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Industrial Ecology for a Sustainable Future

Abstracts from the second ISIE conference

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This document features abstracts from talks and posters presented at the second meeting of the International Society for Industrial Ecology (ISIE). The abstracts clearly reflect the diversity and creativity inherent in industrial ecology.

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Technical Session (T1)

Indicators, Metrics, and Corporate Sustainability Reporting

The E-Equity Index: The Use of Industrial Ecology Principles to Benchmark Sustainable Business Practices for Power Generation Facilities

Jason Makansi, Scott Stallard, Timothy Earney

A flagship coal-fired power station operating in Missouri will be used to illustrate how to apply the E-Equity Index to benchmark, better understand, and make superior investment decisions about, industrial and manufacturing assets. E-Equity Index, based on the principles of industrial ecology, seeks to assess the total value of an industrial enterprise to society, and therefore move the debate about these assets away from simply financial and environmental parameters. The Index can be used to support communications programs about assets, inform the investment decision process, and operate the asset in a more holistic way.

Sustainability Assessment of Eco-ethical Investment Funds: Principles and Method

Thomas Koellner

The fundamental goal of private as well as institutional investors is to maximize the expected rate on return of their investment portfolios. Investors, however, do not only take financial returns into account in their investment choice. They also attempt to balance the expected returns with aspects of liquidity and risk being the constraints of their activities (Steiner and Bruns 2000, pp 50). Recently investors seek to consider ecological and social criteria in their investments beside the financial aspects. Institutional investors such as pension funds, for example, are required to publish their investment strategies with respect to sustainability goals. The supply of investment products – especially mutual funds –, which complies with sustainability criteria, is increasing. In Europe, for example, about 284 different sustainability funds are available (www.sricompass.org, 26.8.2002). Sustainability funds, in this paper, are meant in its broadest sense ranging from eco-efficiency funds to real sustainability funds, which take into account ecological, socio-cultural, ethical and economical aspects at the same time. The green investment alternatives include inter alia large cap stock funds (mix of international companies which are best in their class), pioneer stock funds (only small and medium sized companies like solar energy companies), and bond funds. In order to reach an informed decision, potential investors with sustainability goals need to comparatively assess the variety of funds based on financial as well as non-financial criteria. While approaches and methods for the evaluation of the financial performance exist in rating agencies and banks, the assessment of the non-financial performance (i.e., the ecological and social return) is rather underdeveloped. In consequence, fund managers are not able to set up standards of non-financial performance and thus they are not able to account to investors and their stakeholders for this aspect. The accountability issue is, however, a prerequisite for the investment banking sector playing a serious role in sustainable development. Otherwise, sustainable investment remains a buzzword . In the "green investment market" there is, therefore, a growing need for transparency with respect to ecological and social performance of funds. At the same time, however, the capacity of investors to handle extensive information is limited and thus instruments must be tailored towards the investors needs. Sustainability rating of funds can provide the desired transparency and can complete the existing financial rating. In general very different types of knowledge must be integrated in a sustainability rating. These include knowledge about goals and values, about methodological principles and approaches, and about availability of information. Our objective in this paper is to develop the conceptual framework for a non-financial rating of investment funds as well as to discuss methodological approaches for this rating. The non-financial rating should be designed that it complements the existing financial rating of funds. Clearly sustainability comprises more than ecological aspects, but for the purpose of being focused we do not address economical, social, ethical and cultural aspects of sustainability in the methodological part of our paper.

A Set of Sustainability Indicators for Metallic Raw Material Flows -A Decision Support Approach

Wilhelm Kuckshinrichs, Karl-Ludwig Huettner, Witold-Roger Poganietz

Following the Rio Summit of 1992 many research activities are concerned with sustainability indicators. Considering the production chain of primary and secondary metals, a complex global network of producers and consumers and therefore a multitude of ecological, eco-nomic and social interventions across national boundaries on different scales have to be taken into account. Therefore an holistic indicator set of material flows of metallic raw materials has been developed which considers that its various impacts are embedded in different ecological, economic, social as well as institutional basic conditions. The identified sustain-ability indicators are methodologically differentiated into material flow, sector and product indicators. Additionally, different spatial and temporal dimensions of impacts are considered. The decision support approach takes into account that the development of a holistic indicator set is important in scientific considerations. However, beyond scientific awareness creation, political and economic decision-makers are dependent on specific core indicators suitable to support decision-making. To guarantee the decision support function of the holistic indicator set, three modifications are of central concern. At first the reduction of the holistic indicator set is presented to enable decision-makers dealing with complex issues of contrary eco-nomic and societal protection targets. Secondly, system boundaries of indicators are deter-mined according to different actor levels and decision contexts. Finally, thresholds of indicators are identified whose exceeding justifies societal

call for action. Taken together these steps enable to determine sustainable development orientated recommendations addressing economic and political decision-makers of the material flow of metallic raw materials beyond scientific considerations. The proposed methodology is exemplified by indicator-based studies of the material flow of aluminum and copper.

Evaluation of LEED Green Building Rating Program Using Life Cycle Assessment Methods

Gregory A. Keoleian, Chris W. Scheuer

Commercial buildings account for 15% of U.S. energy consumption and contribute to many other resources and environmental impacts. While efforts to manage these impacts are on-going, comprehensive approaches have been lacking. The U.S. Green Building Council (USGBC) has developed the Leadership in Energy and Environmental Design (LEED), which is a comprehensive green building rating system to evaluate environmental performance from a whole building perspective over a building's life cycle. LEED is a credit-based system. 64 credit points are divided among 5 environmental impact areas (Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality). Since release in 1998 LEED has experienced exponential growth. As of August 2002, there are 1400 member organizations and 515 registered projects. Clearly LEED has been successful as a tool for marketing green buildings. But how comprehensive is a LEED certification? How well balanced are individual credits in a LEED assessment? To date there has been little comprehensive study of the program. This project was sponsored by the National Institute of Standards and Technology (NIST) with the goal of evaluating individual LEED credits utilizing life cycle assessment methods. This project measured changes in life cycle energy consumption and solid waste generation from the simulated implementation of LEED credits on a case study building. The project scope was restricted to analyzing the energy and solid waste impacts of a subset of the LEED credit options from six individual credits (Construction Waste Management, Recycled Materials, Local/Regional Materials, Optimize Energy Performance, Renewable Energy, Green Power). The case study building, is a 7,306 m2, 6-story building completed in 1997. The status quo energy consumption and solid waste generation is 2,300,000 GJ and 8,600 tonnes respectively. The simulated LEED credit changes from the status quo varied from a 1% increase to a 12% reduction per LEED point in total life cycle primary energy burdens. The solid waste impacts varied from a 2% increase to a 7% reduction per LEED point in total life cycle solid waste generation. This paper will present the life cycle inventory for the case study building, a select set of LEED stimulation results, and recommendations for refining LEED. LEED has made substantial contributions to raising the awareness of diverse building impacts as well as sustainable building design strategies. Based on inconsistencies found in our limited analysis, however, we recommend that the LEED credit rating system be analyzed in more detail and recalibrated to address life cycle impacts more accurately. Refinement of LEED should emphasize integration of life cycle oriented measures and standards.

Sustainability Assessment and Reporting for the University of Michigan's Ann Arbor Campus

Sandra I. Rodríguez, Matthew S. Roman, Samantha C. Sturhahn, Elizabeth H. Terry, Jonathan W. Bulkley, Gregory A. Keoleian

This paper presents a framework and set of indicators for assessing the sustainability of the University of Michigan's Ann Arbor campus (U-M AA). This paper also highlights findings presented in a Prototype Sustainability Report, and provides recommendations for institutionalized the reporting process. This research effort was undertaken a part of a Master's Project completed in 2002 by four graduate students at the University of Michigan's School of Natural Resources and Environment. The assessment framework utilizes the "triple bottom line" concept that includes environmental, social and economic spheres of sustainability. Each sphere is divided into categories and further into indicators. Environmental categories ranged from water use to greenhouse gas emissions, social categories from wages to community development and financial categories from revenues to investment policies. A total of fifty indicators were developed, including twenty-five environmental indicators, twenty social indicators, and five economic indicators. Certain indicators are normalized in order to account for the growth of the campus. Geographic boundaries delineate activities that occur within the U-M AA system, including education, research, medical care, housing, food service, recreation, arts and community development. Temporal boundaries define the time period for study as 1990 and 1995 through 2001. Life cycle analysis is used for certain indicators, such as energy use, to measure upstream and downstream impacts, so that a more complete picture of the total impact of activities can be documented. Data gathering and analysis were conducted in close collaboration with over thirty U-M AA departments. The analysis yielded some surprising results. For example, the University of Michigan Transportation Services were responsible for only 1% of the total energy consumption on campus. On-site greenhouse gas emissions increased 19% between 1990 to 2000 compared to 14% for the U.S. as a whole. Over this same period total building square footage increased 20%. Results show both positive and negative trends and provide a baseline for setting short- and long-term goals. This study recommends that the U-M AA institutionalize annual sustainability assessment and reporting in order to enhance its position as a leading educational institution, and to address current environmental, social and economic concerns.

The Spatial Dimension of IE

Mapping Metal Habitats - Development of Site Specific Indicators on Global Scales

Christian Bauer

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Many potential environmental impacts considered in indicator frameworks vary considerably depending on the affected environment on both local and regional scales.

Particularly metals being generally associated with large concentration processes at single sites, are covered insufficiently in generic inventories. Thus the Site-Specific Natural Resources Information System (SARIS) has been developed based on a Geographic Information System to analyze and quantify distinct environmental properties in the vicinity of any producing site considered. SARIS was developed in the framework of a collaborative research programme aiming at the resource orientated analysis of metallic raw material flows. Firstly aluminum and copper were taken as case studies. The spatial database covers all present production sites of ore extraction, refining and smelting. Environmental data for each location were derived from global digital survey data covering land cover, soils, morphology, climate, topography and population density. The main application of this database is the characterisation of environmental safeguard objects which may be affected by the activity of concern on a global scale. Currently land cover data, water availability data and critical loads exceedance rations for acidifying substances are used to assess site-specific interventions such as land use, water consumption or emissions. This site specific environmental impact assessment is used to determine the relevance of potential interventions based on the distribution pattern of production sites in a global framework. In order to address challenges for different groups of stakeholders specific aggregation levels for countries, companies or technologies are chosen. Based on the results indicators can be proposed to measure progress and performance of industrial developments relative to the site specific conditions.

The Strategic Assessment of Value-chain and Environment (SAVE) Methodology: Demonstrated for the Case of Copper

Damien Giurco, Mary Stewart, Jim Petrie

To realize strategic improvements in environmental performance, the minerals industry is beginning to look beyond end of pipe solutions to system-wide improvements along the value chain through the use of tools such as Life Cycle Assessment (LCA). While LCA has an established history in the comparison of products and more recently with processes, there are significant issues which must be addressed for it to be used appropriately as part of a strategic decision making process aimed at improving environmental performance; specifically with respect to where impacts are realized geographically and the scale at which the analysis is undertaken and the level of information detail and indicators it is linked with. Incorporating components of LCA, this paper presents the methodology of "Strategic Assessment of Value-chain and Environment" (SAVE) as a structured approach to assessing environmental performance in the minerals industry at different scales- spanning an initial sustainability assessment of the entire value chain to detailed comparisons between technologies for a single processing step. SAVE begins by characterizing the strategic decision context in terms for key variables to assist in subsequent choice of appropriate tools and indicators for analysis. The variables are: * material (single or multiple) * value chain components (whole value chain or individual component/s) * space (geographic location of value chain components, location of environmental impacts, aggregated either locally, regionally or globally) * time (snapshot of status quo or dynamic model of situation) Second, according to the characteristics of the decision context, appropriate indicators and a corresponding level of information detail is recommended to facilitate the analysis consistent with the uncertainty associated with the desired outcome. Finally, the robustness of the outcome is tested by a re-examination of the initial question at a larger scale to ensure system-wide compatibility of solution and at a more detailed scale to identify key sensitivities for a more detailed analysis. The SAVE methodology is demonstrated here with a case study for the copper value chain where the specific decision context seeks to identify improvements arising from adopting new technologies, increased recycling and linking to clean energy in different world regions. Importantly, it identifies explicitly the geographic location of environmental impacts (including potential carbon credit savings) associated with the explored scenario, as well as which part of the value chain could claim responsibility.

Regional Material Flow Analysis for Environmentally Sustainable Basin Regional Management

Tsuyoshi Fujita, Tohru Morioka, Kazunori Tanji

Industrialization and Urbanization have transformed the regional and local material flow and environmental emissions in the last century. Re-shaping of grown metropolitan regions toward environmental sustainable structures are one of pressing issues particularly in Asian countries, where rapid social change have left environmentally inefficient spatial patterns of infrastructure facilities, land use, and urban activities. Authors show the regional analysis system of material flow and environmental emissions based on regional data base Geographical Information System. Alternative policy options are designed based on the analytical results and their environmental improvement effects are evaluated for CO2 and loss of natural habitats. First, authors established integrated spatial information system of a basin scale, which comprehends land uses, natural vegetations, urban activities, and treatment infrastructures. Second, an preliminary material flow in Muko River Region, with 1.5 million population, was analyzed between 1970s and 1990s, during the period suburban developments changed the regional structures. Several physical indicators such as carbon dioxide emission and solid wastes for landfill are evaluated. Factor analysis showed the infrastructure improved water contamination problems while it increased the emission as CO2 and solid wastes increased during the same period. Thirdly policy options are designed and their improvement effects are evaluated, namely gasification plants, methane regeneration facilities and organic material recycle plans. Finally the policy recommendations are identified for sustainable basin regional management such as recycling infrastructure redevelopments, activity control and land use management.

Urban Consumption, Cash Crops and Human Night Soil: GIS Modeling on the Determinant of Hinterland Agriculture in Early Modern Japan

Kayo Tajima

The concentration of populations in urban centers inevitably creates problems of excessive wastes and pollution. In most examples of urbanization through history, it has been true since urbanization was stimulated by the development of advanced production and market exchange, which accompanied material concentration in urban centers. In contrast, Japan's urbanization was unique because it occurred before industrialization and in an essentially closed economy. Large-scale cities emerged in Japan during the Tokugawa period (1603-1867). Most notably, Edo (present Tokyo) was one of the first few cities in the world that had more than one million people by the beginning of the eighteenth century. Compared to major cities in other cultures (i.e., London or Paris), Edo experienced much fewer environmental problems such as deterioration of drinking water, which caused serious health problems (such as major outbreak of deadly diseases such as cholera and typhoid) through their development. History literatures suggest that the reason they had better sanitary condition is that early-modern Japanese society developed an extensive system to recycle urban waste as fertilizers. Most of the literature suggests that such recycling practices were operated by private services, not through the government. Particularly, ash and human wastes were traded as indispensable resources with positive price. This means that someone came to the households' door to pick up wastes and, rather than being paid for them collecting, paid the household for the resources. This paper sheds lights on the interdependence between hinterland agricultural farm and urban consumption in early modern Japanese society. For farmers in early modern Japan, costs for fertilizers and transportation accounted for a large portion (close to 80% of their sales value) of the cost of their agricultural production. Therefore, proximity to the urban population had twofold advantages for them: less transportation costs for their product, and a better access to the source of fertilizer (human night soil of urban population). In this study, Geographic Information Systems is employed to approximate transportation cost to the urban market along historic road networks, from different places in hinterland villages to the city of Edo. Based on historic information such as prices of goods, agricultural technologies and local history on agricultural productions, this paper analyzes the economic driving forces of the largescale waste recycling system established on the interdependence between the city and hinterland villages. The model bases on Von Thunen approach of bid prices to allow examining the impact of exogenous factors, which determine the types of agricultural land (i.e., types of crops). The exogenous factors in the model include transportation network, infrastructure, land fertility, prices and factor prices of agricultural products.

Multi-Scale Industrial Symbiosis

Marian Chertow

Industrial symbiosis has been previously defined as engaging "traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products" (Chertow, 2000). Yet, the notion of an "ecoindustrial park" has dominated industrial symbiosis analysis, which has unduly restricted the potential of this important concept in space and time and still has not proven to be a practical approach. This paper considers what new insights might be gained from examination of industrial symbiosis at different scales temporally, spatially, and organizationally. It includes the idea that different scales are nested hierarchically, from which new properties can emerge. In the words of ecologist Simon Levin, it investigates "how the signatures of actions at one scale manifest themselves at scales higher and lower." The industrial district at Kalundborg, Denmark has become an archetype of industrial ecology illustrating high levels of inter-firm exchange. A chronological review of this district reveals its forty-year history of evolution as well as very dynamic spatial boundaries of the partners in the Kalundborg industrial ecosystem. Organizationally, there has been a great deal of shifting in ownership and control of various partners, such as the gypsum board company, the power station, and the pharmaceutical plant, but the integrity of the ecosystem has not been disrupted and in some cases has been enhanced. Power stations reveal another aspect of multi-scale analysis. Depending on fuel type, the plants can be seen as contributing to energy independence locally, whereas at the level of a regional or national grid, they lose their local distinction and become symbolic of interdependence. While a constricted notion of scale often leaves an industry with insufficient quantities of by-products for exchange, a broader view can make the opportunity feasible. After building on these examples, the paper considers some emergent properties of industrial ecosystems when considered at multiple scales.

Constructing a Symbiosis with Inspiration from Kalundborg - The Avedøre Project

Stefan Anderberg, Heidi Krüger Troelsen

Avedøre Holme (island or peninsula) is the location of the major power plant in Greater Copenhagen, and a large number of varying industrial activities. 30 industrial companies in this large industrial district have been part of a pilot project under the State Energy Agency (Energistyrelsen) 1998-2001, with the aim of developing industrial symbiosis (inspired by the Kalundborg Symbiosis) between the factories in the area. A consultancy firm made an inventory of possible exchanges and developed proposals for projects. This pilot project showed, as many other cases, that there exists profitable symbiosis opportunities and therefore a local potential to reduce the resource consumption, but it still remains to see to which degree these projects will be realized. In this paper, we present a study about this project focussing particularly on the attitudes of the industrial companies in Avedøre and their participation in the project with particular focus on the geographical context. Why have these projects, with possible and profitable exchanges, not been realized spontaneously earlier? How can such exchanges be encouraged? Although, there do not exist any important differences concerning technological or economic preconditions, Kalundborg might be quite a different case. In Avedøre, there is a much lower degree of communication and limited or no sense of community in the industrial district, something that has also been observed in other similar districts. The industrial district located in small communities in peripheral areas may have better conditions for establishing industrial symbiotic networks than those located in central urban areas. This is connected to the nearness between industry and civil society. Contrary to the Kalundborg symbiosis, Avedøre is a top-down project. The external consultant made first an inventory of the branch pattern, then green accounting to get an overview of resource use, and last interviews with companies to get complementary details. Based on these data, the project proposals have been developed and have then been presented to the industrial companies. The industry has not been part of the process with the result that they often are critical, not very motivated and even resistant to the project ideas.

IE and Management/Operations Research

Options Theory and Sustainability

Jeevan Kumar Duggempudi, Urmila Diwekar

Recently, Cabezas and Faith (2000) presented a new definition of sustainability. This definition and the theory draw heavily on Information Theory and the concept of Fisher Information. Fisher Information is the maximum amount of information that is available from a set of observations, in this case, states of the system. Fisher Information is a function of the variability of the observations such that low variability leads to high Fisher Information and high variability leads to low Fisher Information. In short, Fisher Information is a probabilistic objective defined qualitatively, the criterion states that Fisher Information decreases over time in unsustainable systems, and that Fisher Information does not decrease over time in sustainable systems. Fisher Information provides a basis to include variables from multiple disciplines like ecology, thermodynamics, hydrology, or economics. In their paper entitled "Towards a theory of sustainability systems" Cabezas and Faith developed the beginning steps in this theory using simple ecological models. The aim of this research is to use concepts from economics to enhance this theory further. For this we are using the economic option theory as the basis. Most investment decisions share three important characteristics in varying degrees. First, the investment is partially or completely "irreversible". In other words, the initial cost of investment is at least partially sunk; you cannot recover it all should you change your mind. Second, there is "uncertainty" over the future rewards from the investment. The best you can do is to assess the probabilities of the alternative outcomes that can mean greater or smaller profit (or loss) for your venture. Third, you have some leeway of the "timing" of your investment. You can postpone action to get more information(not with complete certainty). These three characteristics interact to determine the optimal decisions or "options" for investors. A firm with an opportunity is holding an "option" to buy an asset at some future time of its choosing. When a firm makes an irreversible expenditure, it exercises, or "kills", its option to invest. This lost option value is an opportunity cost that must be included as part of the cost of investment. Also, this opportunity cost is highly sensitive to the uncertainty over the future value of the project. Similar to the options theory, irreversibility, uncertainty, and possibility of delay are also important characteristics of sustainability. In this project, we show how optimal decision rules can be obtained to maximize sustainability(Stability of Fisher Information) from methods developed for pricing options in financial markets. We also plan to develop an equivalent approach based on mathematical theory of optimal sequential decisions under uncertainty - stochastic dynamic programming.

Optimizing End-of-Life Economics within the Environmental Constraints of Extended Producer Responsibility

M R Johnson and M H Wang

This paper discusses the development and application of an innovative mathematical model that allows producers and policy makers the ability to evaluate current and proposed legislative requirements with respect to Extended Producer Responsibility (EPR). A growing body of EPR legislation, such as the European Directive on Waste from Electrical and Electronic Equipment (WEEE) and the End-of-Life Vehicle (ELV) Directive, will require manufacturers to take a greater financial responsibility for proper environmental management of their end-of-life products. The developed demanufacturing model addresses both the economical constraints of product demanufacturing and the necessity to achieve specific environmental requirements of sustainability (i.e., recovery rates and pre-treatment of products) mandated within existing EPR legislation. The model was developed and applied with industry collaboration from the automotive sector. This paper will present both the underlying mathematical foundations of the optimization model and its application to an end-of-life vehicle that falls within the environmental constraints of the new ELV Directive. The results of the study provide insight to the future problems and opportunities that will be brought forth by EPR legislation. It will be shown that the optimization model provides a modeling and analysis tool for both manufacturers and policy makers. For manufacturers, the model can be used as a medium to evaluate individual product designs and to optimize the end-of-life economics within the environmental requirements of the new legislation. For policy makers, it allows the ability to evaluate various unseen scenarios such as non-compliance, policy ambiguity, and the possible economic impacts to the various parties within the recycling infrastructure.

A Life Cycle and Cost Analysis for Reverse Logistics: The Case of a Reusable Packaging System

Enrico Cagno, Lorenzo Tardini, Paolo Trucco

Reverse Logistics is a set of resources, structures, and processes directed to manage and organize the return flow of products and materials that move back from the point of consumption to the point of production/distribution. There are different reasons for

goods returning, such as: recapturing goods value, proper goods disposal, recycling, reuse of materials, refurbishing, repair and remanufacturing, etc. The return flow is generally very complex as it involves product manufactures and distributors, private and industrial end-users and public bodies. As matter of fact, today the reserve logistics area is still scarcely developed. The paper presents an integrated environmental and economic analysis to determine the choice between two packaging system solutions (recyclable and not recyclable) and several reverse logistics models. The environmental analysis is based on the Life Cycle Assessment (LCA) methodology by means of SimaPro software. The economic analysis is carried out by implementing a model of differential costs between the different solutions of products and reverse logistics models. The model was verified with a technical, environmental and economical analysis of a reverse logistics system in the case of a reusable packaging. A company that produces elevators is studying a new packaging system to deliver a specific product line in the European market; the new packaging concept is able to reduce waste, pollution and transportation costs significantly. Moreover, the structural characteristics and the materials used make it possible to use the packaging system several times. Thus, an hypothetical reverse logistics system has been drawn, on which a life cycle analysis was carried out to evaluate the real reduction of the various environmental impacts, and at last, a cost model has been developed in order evaluate the potential economic advantage in exploiting the reusable characteristic of new packaging system.

Evaluating Recycling and Disposal Options for Batteries: The AHP Multi-criteria Analysis Approach Compared to a Fuzzy-Sets Methodology

A. Halog, M. Sagisaka, A. Inaba

It is known that electric vehicles (EV) produce almost no pollution on the road and considered to be a technology that almost satisfies the zero emission mandates. In comparison to gasoline-powered cars, these vehicles produce carbon dioxide emission half of that gasoline-powered and almost similar amount in comparison to hybrid electric vehicles over their useful lives. Since most of the emissions in electric vehicles are most likely attributable to production of their very large batteries, environmental consequences of producing and disposing of EV batteries may be significant. For example, lead-acid batteries contain lead, a toxic heavy metal associated with neurological damage in children, high blood pressure in adults, and other undesirable effects in humans and other organisms. Furthermore, recent assessments have raised concerns that emissions generated by recycling batteries used in electric vehicles may create a major environmental impact. This study aims to analyze environmental impacts associated with recycling and disposal management of four electric battery technologies likely to be used in the near future using an abridged life cycle assessment (LCA) which produces easily comprehended information about each life stage of a product. Secondly, it aims to select the most favorable battery technology by considering their manufacturing, political and social viability, environmental impacts and exposure and toxicity potential issues using multi-attribute decision analysis methods. The EVs' batteries considered here are lead acid (PbA), nickel-cadmium (NiCd), nickel-iron (NiFe) and sodium-sulfur (NaS). In this work, we compared potential health and environmental impacts of four battery technologies and focused on recycling and waste disposal life stages, with an emphasis on design factors that could prevent or increase impacts. With regard to the evaluation of battery technologies, since the data used are often contradictory, variable, uncertain and sometimes impossible to validate independently, fuzzy linguistic approach is applied here to address data ambiguity and its results were also compared to the ranking obtained using the well-known analytical hierarchy planning (AHP) approach. The recycling and waste management impacts of electric vehicle batteries are reported and the environmental consequences associated with design factors are emphasized. Based on AHP evaluation, the recycling assessment ranks the batteries studied in the following preferential order: Nickel-metal hydride (NiMH)>Sodium-sulfur (NaS)>Lead-acid (PbA)>Nickel-cadmium (NiCd). In the case of disposal of batteries, NiMH and NaS are of greater concern because of landfill impacts while both NiCd and PbA batteries are considered the most favorable. But due to the toxic characteristics of cadmium and lead metals, it is still recommended that NiCd and PbA batteries should be recycled instead. Almost similar results were also obtained using fuzzy linguistic approach.

Oscillations in Material Supply Chains with Recycling

Klaus-Ole Vogstad, Frank Vidar Melum and Rolf Andre Bohne

A recurring problem for industrial companies is to match their production rate to the rate of final consumer sales. It is well known that the production rate often fluctuates more wildly than the actual consumer demand rate. This phenomenon known as commodity cycles, represent problems in terms of over-capacity, price fluctuation and inefficient inventory management. System dynamic studies show that origin of these cycles is caused by the ordering procedures in the cascaded distribution chain itself. In this paper, we examine a supply chain with a manufacturer, material supplier, recycler and consumer. Increasing the share of recycling increase the dependency in the supply chain in which the oscillations of material stocks can propagate by making the availability of raw material dependent on the level of consumption. The effect on commodity cycles and price fluctuations in the supply chain with recycling is explored by an experimental simulation game involving students and representatives from industry. The supply chain management simulator is based on models of commodity cycles originally developed by Jay W. Forrester to introduce students to supply chain management. The game, played by thousands of students and managers throughout the world, reproduce realistic behavior of oscillations in production and inventory in supply chains. In addition, a system dynamics computer simulation model is developed to analyze how the recycling share and lifetime of the product influence the oscillations in the supply chain.

Material/Substance Flow Analysis

Resource Use and Economic Development: A Dematerialization Analysis for the EU-15 from 1980 to 2000

Helga Weisz, Klaus Hubacek

The paper presents dematerialization analysis of the European Union based on MFA time series data 1980-2000. In the whole body of empirical work on dematerialization only a limited number of studies so far have used MFA-derived indicators From a conceptual point of view MFA should provide a better empirical basis for macro-economic dematerialization studies, mainly for two reasons. MFA-based indicators cover their subject completely and consistently, by applying the law of conservation of mass and allow the calculation of a physical GDP equivalent. Thus we consider them to provide providing a better understanding of dematerialization in relation to long term macroeconomic processes. Although available national MFAs are increasingly available, these accounts still lacked a sufficient degree of comparability. The empirical analysis is based on a revised and updated version of the 2001 estimate (EUROSTAT 2001), which was compiled by the IFF-Social Ecology-Vienna and published by EUROSTAT in the forthcoming study Material Use in the European Union, 1980-2000: Indicators and Analysis (EUROSTAT 2002, forthcoming). With this revision cross country comparability of the EU 15 MFA accounts could be improved substantially. The indicators for material use that were compiled include the following: domestic extraction (DE), direct material input (DMI), domestic material consumption (DMC), and physical trade balance (PTB). The paper will analyze dematerialization in terms of several approaches, among them Environmental Kuznet Curves, IPAT and Physical trade balances. The overall aim is to better understand the driving forces of the observed trends and patterns of material us in the European Union in the past two decades. We will begin our analysis on a highly aggregated level and continue using data on various levels of disaggregation and by increasing statistical rigor. We will address questions such as for how does sectoral shift (a shift of input factors such as labor, capital, energy, and materials to other uses within the economy, e.g. from traditional sectors such as agriculture, and industrial production to services), technical change, or increasing international trade relate to overall material use.

Decoupling Economic Growth from Dissipative Flows

John Holmberg, Sten Karlsson

Decoupling economic growth from environmental impact is an essential element in sustainable development. We cannot expect economic growth to solve the environmental problems automatically. When dematerialization, intensity of use or decoupling are discussed in the literature the focus is put on the intake of materials to society and many different materials are aggregated on a mass basis. Both from an environmental perspective and from a resource perspective it is clear that it is the dissipative use of materials that ought to be the relevant parameter and not the total intake. Sometimes environmental impact is reduced in line with economic development. Such correlation could imply that economic growth automatically leads to reductions in environmental impact. In reality, improvements are generally a consequence of specific environmental policies. So far the industrialized world has been successful in dealing with local problems as safe drinking water and sanitation, also regional problems as sulphur dioxide emissions are improving. In particular, emissions from the production system (factories, chemical plants, etc.) have decreased. Many dissipative flows, especially consumption emissions are, on the other hand, still increasing for many materials. This paper identifies trends for dissipative flows that are relevant for decoupling. The paper also proposes some policy measures. Dissipative flows in the consumption sector can often be traced back to certain specific uses. An example of this is emissions of copper, which predominantly emanate from brake linings and the tap water system. One implication of this might be that an "acupunctural strategy" focusing on the most problematic uses is more efficient than other more general policy measures that have been successful in the past, e.g. sulphur dioxide emission tax.

Dynamic Substance Flow Analysis: Integrating Substance Flow and Stock Models to Analyze the Long Term Consequences of Recycling

Ayman Elshkaki and Ester van der Voet

The extracting, processing, using and waste treatment activities of substances in the economic system are connected to several environmental problems related to the exhaustion of resources and emissions. For sometimes, recycling is believed to be not only a way to minimize the final waste stream but also a way to minimize the extraction of primary materials. However, several questions have been raised of the environmental consequences of recycling itself, for various reasons. Recycling sometimes does not influence the level of primary extraction of the concerned substance. It may have consequences on the demand of other primary materials. Finally, it causes emissions and waste of its own. In light of this, the evaluation of the long term environmental consequences of recycling on a substance level is required. For such analysis, a forecasting model is essential. Applicable substance flow models are mostly static and lack the dynamic behavior of substances in the economic system, therefore these models are not suitable for forecasting purposes. Such dynamics could be provided by substance stock models. Dynamic substance stock models describe one stock over a large number of years on the basis of socio-economic factors and the substance physical and chemical properties. These models provide information on three major flows in the economic system: the inflow of substance into the stock of products-in-se, the emissions flows during use, and the discarded outflow from the stock which is the inflow to the end of life treatment system. Flows and stocks in the economic system interact in different ways. Some of the substance flows are regarded as a result of the developments of the stock such as the waste flows and emissions, which are the stock outflow. Some other flows, such as the flows of substance non-intentional applications and the emission flows and waste streams from other economic activities (extraction, processing, and loops and cycles within the end-of life treatment system), are not linked to the stock, nevertheless, these flows are important for the estimate of the future emissions and

waste streams. Substance stocks can be viewed as dependent on flows: the net results of all inflows and outflows through the years. Until this moment, the substance flow and stock models are operating separately, however, to estimate the future availability of resources and total emissions, both models should be combined. Therefore, our main objective is to establish a methodological framework of a dynamic substance flow-stock model and to evaluate the long term environmental consequences of recycling on the basis of the model.

Data Cube Models for Physical Flow Data

Erik Löfving and Anders Grimvall

Assessment of physical flows play a key role in industrial ecology. Several tools, such as SFA, MFA and I-O analysis, deal directly with such flows. In this paper, we use ideas developed for multidimensional databases and the Data Cube concept to demonstrate how flow data, and calculations involving such data, can be organized in an efficient way. In particular, we show that the most widespread conceptual models for SFA and MFA are merely special cases of a generic Data Cube model. Furthermore, we address the issue of uncertainty measures. So far, flow data have normally been stored in quadratic matrices, such as I-O tables or flow matrices showing the flow between different pairs of cells. This approach has obvious limitations when we consider industrial processes resulting in several different products. However, this short-coming can easily be removed by introducing a commodity dimension, i.e., by considering a three-dimensional data structure in which flow matrices representing different commodities are stored on top of each other. Furthermore, a time dimension can be incorporated to enable storage of flow data from different time periods. The resulting data structure is usually called a Data Cube, and we illustrate how this data structure is related to Data Warehouses and On-Line Analytical Processing (OLAP) techniques used in decision support systems for data processing. One of the main advantages of the Data Cube approach is that it unifies several existing algorithms in industrial ecology and clarifies how they are related to each other. An MFA analysis can be derived from the Data Cube by defining suitable aggregation operations. Furthermore, an SFA analysis can be carried out by using a filtering technique with transmission coefficients. The handling of uncertainty in the analysis of physical flows is often regarded as a matter of error propagation. We show that a Bayesian statistical framework is usually more appropriate. In particular, we show how such a framework can be employed to derive uncertainty bounds for the different aggregated measures that can be formed in a Data Cube.

Dynamic Modeling for Material Flow Analysis in the Resource Cycle of Passenger Vehicles

M.A.Reuter, A. van Schaik

Goods and products are manufactured by using a wide spectrum of different raw materials to meet highest consumer requirements. These complex products have to be recycled at the end of their useful lives to ensure a sustainable society as well as to comply with European Union legislation. Due to the time-varying composition and complexity of these multi-component products, of which the car is an outstanding example, recycling is complicated. The standard texts in industrial ecology generally present a rather simplistic view of metals processing technology and recycling often written by people that do not have detailed knowledge of the metals and material processing industry. Aspects such as rapidly changing product composition (complex "mineralogy"), changing weights, different holdup times in the system of different metals in buildings, cars, consumer products, strongly distributed properties which affect separation and metal recovery etc. make classical material flow analysis far too simplistic. Therefore, in order to describe and optimise these complex resource cycle systems (we have linked all major metals used in car production in an interconnected web defined by the pink block in figure 1), the analysis of the material flows should be based on the statistical distributed and dynamic nature of the various parameters determining the resource cycle system, such as life time, changing design (composition and complexity) of the product, different and changing recycling rates, etc. These time-dependent complex interactions can best be analyzed and optimized by using a dynamic system model (see Figure 1) as will be illustrated in this paper. Using the car as an example, simulations will illustrate the importance of detailed industrial knowledge on the recycling systems to define the behavior of the resource cycle system over time. This produces a meaningful analysis of the changing material flows within the resource cycle to provide e.g. valuable metal inventory and economic insights into the various interconnected metal cycles. The paper also will show how the distributed nature of material flows in car recycling have a significant impact on the process outcomes and model predictions. In addition it is shown how conversion or separation units with variable residence time distributions result in materials spending highly variable times within different stages of the recycling system, which involves a complex network (more complex than is generally presented by the IE fraternity) of interconnected processes and material flows. Furthermore, closing of the material cycle can only be achieved by optimizing the mutual compatibility of the successive processes of mechanical recycling and metallurgical operations within this interconnected resource cycle system based on these time-varying material flows. In summary, this paper will apply the use of a dynamic distributed property model (see population balance modeling in the processing industry) to model recycling systems. This is done in close association with industry to ensure validity of data, statistics, and model predictions.

Industrial Ecology of Information Society - The Weight of Information

Sangwon Suh

Although it is weightless by itself, information requires relevant infrastructures and terminal devices and energy such as networks, PCs, cellular phones and electricity to use it. Therefore, information society inherently relies on underlying industrial production made up of materials and energy. The objective of the this study is to better understand the complex interplay between technology, composition and scale of information sector to estimate the materials and energy terms of information society and to envis-

age a desirable future industrial metabolic structure. Information media to be studies include books, newspapers and printed periodicals, radio and television, fixed telephone, wireless phone and internet. A total of five periods were selected for the time series analysis, each of which characterizes a revolutionary change in ICTs and information environment. They are: 1) 1500's — wood print era, 2) Early 1800's — iron printing and newspaper era, 3) Early 1900's — telecommunication and modern printing era, 4) Mid 1900's — Radio and Television era and 5) 1996, 1997, 1998 — Wireless phone and Internet era. Especially, three consecutive years were chosen for the recent period in order to account for the rapid renewal of information infrastructure and ICT devices. For each period and each information medium, materials and energy intensity and demand on Information and information density are estimated using literatures for the period before mid 1900's and hybrid input-output tables from then. The materials and energy intensity of information is calculated by dividing the materials and energy required to produce and use unit information for each information medium by the total information size carried by the medium (Mbit). It will is also assessed whether introduction of new ICTs displaced traditional ones or created a new demand. This will enable us to estimate the information density of each period through the selected media. Based on the historic data, technology, composition and the volume of final demand on information for the future information society will be envisaged. The material and energy requirements to run such a society is estimated based on previously calculated figures. Finally, key technologies and policy directions that are needed to better close the material cycle for future information society are elucidated. The results shows that the future information society is characterized by higher information density, more efficient technology and higher share by information sectors in industry composition. The technology and composition of future information society will become lighter and more efficient, however, the total growth in scale of the economy will be high enough to cancel out those gains. Possible metabolic structures, including a cascade recycling structure, where leftovers from high-technology market are constantly scavenged by lower-technology market of related products are explored as a solution to close the material cycle of the information society.

Sustainable Consumption

Sustainable Consumption - The Case of Consumer's Choice in Tokyo

Midori Aoyagi-Usui, Nobuo Shirai, Yumiko Miwa

We investigated the factors of determining consumers' choice of so called "environmentally friendly" products - soft drinks in bottles, shampoo in refill, stationary made of recycled materials, energy-efficient home appliances, using questionnaire survey on randomly sampled 3,000 household in Tokyo metropolitan area. Effective 1,213 response was analyzed here. The reasons for consumers choice of each products are: Soft drinks in bottles: 1=Favorite taste, 2=good for health, 3=no use of chemicals, 4=trustworthy manufacture.

Household Energy Use: Generation Matters

Annika Carlsson-Kanyama, Anna-Lisa Linden and Björn Eriksson

Experiences early in life strongly shape values, attitudes and behaviour and serve as reference points ever after. Those who grew up in a society where resources are scarce may behave differently in an affluent society than those who got used to affluence even as children. This hypothesis was tested among 600 households in a major Swedish city who responded to questions about energy related behaviour and environmental attitudes. The households belonged to different generations, or age groups, lived in flats or detached houses and the questions were about energy use in their dwellings. On fourth of the total energy in Sweden is delivered to households for heating and appliances. Household electricity use is increasing. The results show that there are no differences in environmental attitudes between generations. Generally, the concern with climate change is high and both young and old think it is important to conserve energy. However, energy related behaviour differed between age groups. The young people preferred higher temperatures indoors than the old ones, they liked showering better than bathing, they often used electric kettles for heating water because it was faster than other alternatives and they seldom rinsed the plates in warm water before putting them in the dish washer. The old people bathed more often than the young ones, their refrigerators and freezers were older but they valued energy efficiency higher. The old people showed more acceptances for lowering indoor temperature, they put lids on cooking pots more often and they more often aired clothes instead of washing them. All these behaviors impact electricity use and the demand for space heating and hot water. Some behaviour common among the young generation are favorable for energy efficiency, others are not. Scenarios of energy futures should take such differences in behaviour between generations into account. They should also be considered in policymaking, when planning information campaigns and when designing other policy instruments.

Sustainability Tools for Buyer Decision Making

Michael S. Brown, Derek Smith, and Eric Wilmanns

Numerous tools exist for assisting organizations in using the concepts and principles of industrial ecology (IE) to improve their business decision making and help them move along the path towards their sustainability goals. Most of these tools—e.g., life cycle analysis, material flow analysis—require a significant degree of expertise to use and to incorporate into decision making. Moreover, the application of these tools tends to be financially expensive and time consuming limiting use to organizations with significant resources and the luxury of sufficiently long time horizons. Thus, the predominant business users of IE tools are larger manufacturing organizations with sophisticated product development efforts and long product lead times. In contrast, smaller firms, such as mail order companies or retailers, that have a large and diverse range of products, limited product development capacity (if any), or rapid product introduction and phase out rarely use IE tools to improve the environmental profile of their products or

services. IE principles are applicable to these types of firms, but the available tools have little applicability to their needs.

To address this deficiency, we have developed a "Sustainability Toolkit." This paper describes the Toolkit and its application in a mail order firm, Norm Thompson Outfitters, the strengths and weaknesses of the approach, and its potential applications in other settings. The Toolkit is composed of scorecards for product materials, life cycle information that identifies product material pathways towards achieving corporate sustainability goals, and technical information about environmental issues written for staff responsible for product sourcing. The scorecards use a relative scale to rank product materials by sustainability criteria across the material life cycle and indicate for product buyers ways to improve the environmental characteristics of the product in a simple standardized format. Evaluations are based on general life cycle information rather than a specific life cycle assessment for each product material/product. Additional information is available to Norm Thompson's buyers that facilitates existing vendor relationships, which are based on sourcing from available offerings with very limited product development. Improvement in "sustainability" scores for buyers' product lines are used in conjunction with customary personnel evaluation criteria (meeting fiscal and demand expectations, etc.). We discuss the pros and cons of using a tool based on generalized life cycle information rather than specific life cycle assessments.

The paper provides examples from the Toolkit, reviews experiences during the first year of implementation, and evaluates opportunities for improvement. We conclude with a discussion of the applicability of the Toolkit to other types of organizations.

A Cross-National Comparison of Sustainable Consumption Politics and Policy

Maurie J. Cohen

In the decade since the Rio Earth Summit sustainability proponents have come to recognize the policymaking importance of material consumption, especially in the world's most economically advanced countries. Several multinational organizations have played key roles in advancing a case for the realignment of contemporary consumption practices in conjunction with more customary productionist interventions. Induced by this activity within the realm of environmental high politics, as well as by networks of local activists, national governments have begun to initiate research and formulate policy programs to reduce the impacts of environmentally significant consumption. This paper reports on an ongoing comparative project to assess the emergence of policymaking frameworks to facilitate more sustainable consumption in five countries: Norway, France, the Netherlands, the United Kingdom, and the United States. In each national context there is a growing consensus that conventional economic tools for managing the environmental impacts of consumption-ecological taxation, eco-labelling, green advertising—are inadequate and a more expansive, cultural model is emerging to encourage the necessary changes. However, no single approach for achieving these policy objectives is dominant. Rather, sustainable consumption in each country is being pursued quite differently, with policy entrepreneurs seeking to draw on nationally specific political

resources. In addition to reviewing the case studies this paper considers the extent to which a process of social learning is evident and whether the different policy models are amenable to cross-national transfer.

Improving Environmental Systems Analysis: From Simple LCA to Sophisticated Production and Consumption Modeling

Gjalt Huppes, Helias A. Udo de Haes, Sangwon Suh

Hybrid modeling as developed in the context of LCA opens up vistas on more sophisticated modeling. LCA assumes all units of the product analyzed to be equal in their environmental consequences. This assumption, closely linked to the arbitrary unit of function, implies a fully linear system. Also, links with other product systems are cut through allocation. Comparing different technology options for the function thus is made easy. In real life however, we know that function systems are linked, are not linear, have non-linear environmental effects, and are dynamic. By giving up the assumption on the arbitrary unit of function we might come up with a more realistic but also more complex type of modeling. We will describe some options, lifting some of the limitations of current LCA models. Starting point is the now most sophisticated type of LCA, the integrated hybrid analysis, combining process LCA and environmentally extended input-output analysis (IOA) in one consistent framework. The first main step is to make the functional unit part of total consumption, using IOA. The inventory model is kept linear and the modeling type remains that of steady state. The perspective is that many disputes in LCA, as on marginal processes and on allocation, can thus be resolved, ultimately requiring a revision of the ISO standards on LCA. In such a context, it also becomes possible to compare steady state background concentrations, using non-linear models in the environmental part of the systems analysis. Especially if the economy model (inventory in LCA terms) and the environment model are regionalised this is a very sensible addition to LCA. Eg, toxicity discussions as now pertaining to no-effect levels and to shortages of essential elements can then be placed in a better perspective. In order to realize this, modeling, data and software will have to be adapted quite fundamentally. Within this option, we also might avoid the peculiarities of allocation, by just not doing it. In the analysis of outcomes then many other consumption items then will be involved, especially co-products. The basis of comparison might be in terms of value added. An additional step may be to take non-linearities into account in the inventory model. Options relate to introducing diminishing or increasing returns to scale, and to incorporating some market relations. The modeling type then probably shifts from steady state to equilibrium. However, the problems of applied general equilibrium (AGE) modeling drive in forcefully: the world soon becomes too complex for operational modeling by users with a PC. Also, current operational AGE models are too aggregate for rich environmental analysis. Another step is leaving the realm of steady state and equilibrium analysis and going for quasi-dynamic analysis, with a time path specification of technologies and volumes. This option requires a rethinking of the environmental part of the analysis, as there then is not one constant background, eg as background concentration. Ultimately, by incorporating some dynamic elements, further insights can be gained from models, as by endogenising the speed of new technology implementation.

Some options will be investigated. Full dynamic modeling of reality remains impossible: the future is too open for that.

Technical Session (T2)

The Social Dimension/Side of Industrial Ecology

Modeling the Economic Effects of a Material Efficiency Strategy in the Paper Cycle: Application of a Linked Model System

Carsten Nathani

Material efficiency and recycling strategies aiming at changing and reducing material flows in the economy are considered an important part of sustainable development strategies. The extensive realization of these strategies will probably give a strong impetus to technological and structural change in the economy. In this paper a modeling framework for analyzing these changes is presented. It is empirically tested with a case study of the paper cycle. The simulation approach links an economic input-output model with a bottom-up process oriented material flow model. The material flow model covers the interlinkages of processes and activities within a subsystem of the economy with the necessary technological detail. It is calculated in physical units. The more aggregated input-output-model covers interlinkages between the economic sectors more comprehensively and in monetary units. The linkage idea is as follows: The input-output model supplies information on exogenous demand in future projection periods to the material flow model. The latter can be used for simulating different scenarios for meeting this demand, with and without considering recycling and material efficiency measures. Based on these simulation results the variables and parameters of the input-output model are adjusted. The comparison of the results of the adjusted model runs indicate the structural effects related to the material efficiency strategies. The modeling concept was empirically tested with a case study of the paper cycle, for which several possibilities for enhancing material efficiency exist. A material flow model was built, covering the relevant activities from raw materials production to paper production and consumption as well as paper recycling and waste disposal. Three scenarios for the development of the paper cycle to the year 2020 were analyzed, one baseline scenario and two policy scenarios. Latter consider increased paper recycling as well as several possibilities for designing and using paper products in a more material efficient way, including the substitution of information and communication technology for paper products. In order to analyze, how the alternative developments of the paper cycle would affect the economy and especially its sectoral structure, calculations were carried out with the linked model system. The results show moderate effects for the scenario concentrating on increased paper recycling. For the scenario "sustainable paper cycle", in which further measures for efficient production and use of paper products are considered, a strong structural change affecting several economic sectors can be shown. In total the empirical work has proven the modeling concept to be useful insofar as it combines the specific advantages of the two model types. Using a partial analytic material flow model allows for analyzing material efficiency strategies with the necessary detail but within defined system boundaries. The linkage with the input-output model ensures the necessary integration into the overall economic context. Future research issues could be the analysis of further material and product systems as well as a further development of the modeling approach.

Characterization and Classification of By-product and Waste Exchange Relationships

Catherine Zeman and Kathleen Hennings

The goal of establishing eco-industrial relationships and precision manufacturing methods to move our society toward a sustainable industrial and solid waste management enterprise is daunting. Society has tended to look toward engineers, scientists, solid waste management experts, recycling experts, and industrial experts for answers. But, many of these experts have been pointing out that technology alone will not allow us to prevail in this endeavor and that the character and nature of human relationships and human commitment to these changes is equally important. Thus, this proposed presentation reports on a study of eco-industrial exchange relationships in Iowa in an effort to categorize the complexity levels of those relationships and to understand what makes complex relationships — complex and enduring. This presentation will describe the results of in-depth interviews with 25 companies focusing on over 100 by-product, materials exchange relationships. A proposed classification scheme to evaluate the complexity of eco-industrial exchange relationships is presented. This classification scheme is then examined via Pearson's chi square and likelihood ratio tests in order to understand unique characteristics of the proposed eco-industrialization classification levels. Limitations of the study, need for further work, and implications for policy development are also discussed.

A Multi-Agent Model of a Polluting Firm

Clinton Andrews and Robert Axtell

This paper shares the findings of the first year of a three-year research project on agentbased modeling of industrial ecosystems. The objectives of this research are to investigate behavioral and organizational questions associated with environmental regulation of firms, and to test specifically whether a bottom-up approach that highlights principal-agent problems offers new insights and empirical validity. This project investigates key questions in the field of industrial ecology using an agent-based modeling approach. Agent-based computer simulation modeling has matured in recent years to the point that it can provide a safe laboratory for investigating how economic agents interact with one another and their environment, and for exploring alternative organizational structures and contracting arrangements that might reduce adverse impacts on the natural environment. The project includes the following tasks: (1) create an empirical foun-

dation for models by exploiting the New Jersey hazardous chemical Release and Pollution Prevention Report (RPPR) listing environmental release, waste transfer, throughput, and pollution prevention progress information; coupled with in-depth case studies of several respondent firms to document operating histories and organizational parameters; (2) develop a general multi-agent representation of a single-facility industrial firm; (3) derive initial conditions of specific models from the case study evidence, drive the models using exogenous conditions identified in the case studies, and validate the models against outcomes from the case studies; (4) adapt the generic model and selected specific instantiations to the case of the branch plant (vertical relationships within multi-facility firms); and in a more idealized manner, (5) insert the generic model and selected specific instantiations into the supply chain; and (6) insert the generic model and selected specific instantiations into a competitive sector. This paper reports on tasks 1-3. An important result of the project is a suite of empirically validated models that allow research-level "what-if" investigations of the motivations behind corporate behavior. The project adds a new method to the environmental social science toolkit, and develops programming routines that will be useful for agent-based modeling of wide variety of questions in the fields of organizational behavior, public policy, and innovation studies. A specific project result reported in this paper is a clarification of the conditions under which "free lunches" (unexploited eco-efficiency opportunities) occur in small U.S. manufacturing firms. This paper is funded by the USEPA under its STAR grants program on Corporate Environmental Behavior.

Socio-metabolic Regimes, Time-use and the Environment

Marina Fischer-Kowalski

In this paper I seek to inquire what linkages there exist between human lifetime, timeuse and the environment. The first part will explore into these linkages from a theoretical perspective. Point of departure is the presumption that live human time is a major resource (if not even: the major resource) of social systems to provide a certain quality of life to its members, and to effect each other and their environment. This time resource social systems have to take care to reproduce biologically (in the metabolic as well as in the pro-creational sense) and culturally, by supplying meaning and direction. By employing such a dynamic system's perspective instead of the more common view on lifetime and time-use as features of individual persons, I translate demographic structures into time-use potentials of interacting and interdependent social systems, such as the person system, the household system, the community system, the national and beyond the global economy. The available amount and quality of time, and the requirements of its reproduction, constitute major opportunities and constraints of these systems vis-à-vis their environments. Part 2 will analyze the interrelations between sociometabolic regimes and particular regimes of time use and demographic reproduction. Different socio-metabolic regimes (such as foraging, or extensive forms of agriculture, or more intensive forms of pre-industrial agriculture linked to urban centers, or 19th century industrialism …) are associated to particular patterns of time-use. I will discuss this on the basis of relevant literature and illustrate some points with empirical material from case studies in developing countries and from European history. Part 3 will explore into the linkages between time-use and environment for contemporary industrial societies, both on the side of labor, time investment in different kinds of labor, and labor productivity, as on the side of consumption and time-use on consumption activities. Finally, I will seek to pose this as a question of sustainability: what kind of transitions in time-use would we have to conceive of as supportive to sustainability?

Shaping the Past and Future Paths of Industrial Ecology: The Case of Mining Industry in the Murmansk Region of North-Western Russia

Olli Salmi

With some well-known exceptions the core literature of industrial ecology has omitted the historical path dependencies, conditions upon which the institutional and the resulting technical solutions of industrial ecosystems are built. This paper aims to bring forth the discussion of such conditions through a case study of the resource intensive industrial systems in the Murmansk region in North-Western Russia. On the level of planning the Murmansk region has practiced industrial ecology from the 1920s on. Yet this case study and historical data from two of the regions mining communities, Apatity and Kirovsk, reveal that the state and regional decision making system has constrained the implementation of the plans throughout the industrial history of the Murmansk region. Some of the results of this history can be clearly seen in the pollution devastated landscape around the industrial communities of Monchegorsk and Nikel. In spite of the unfortunate previous attempts of establishing an industrial ecosystem, the idea still has strong support in the minds of some of the local experts. Others express concerns of the novel environmental risks such a complex system introduces. So why have the attempts of creating an industrial ecosystem in the Murmansk area failed and still do so? What would be the consequences to the condition of local ecosystems and human life? Or could there be a need for a fundamental change in the design of industrial practices and institutions of natural resource and environmental management? As a response to these questions this article takes a look at the historical events in the local ecosystems and on the different levels of natural resource management of Apatity and Kirovsk. Emphasis is put on events that constitute a significant change either in the industrial system, the local ecosystems, the governance system, or in social conditions. The events again allow for determination of historical path dependencies in relation to the industrial-ecological system. These path dependencies are linked to future paths of the same system, and are constructed on the intersection of the historical causalities and the interviewees understanding of the possible futures.

Sustainable Transportation

Sustainable Consumption of Transportation — Technological Development and Specific Fuel Consumption in the Swedish Car-fleet

John Holmberg and Sten Karlsson

The development and utilization of new efficient techniques are important components in a sustainable development. New efficient techniques are a double-edged sword,

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though. They can be used to decrease the environmental pressure and demand for scarce resources from our consumption, but also lead to increased consumption of goods and services. Within the energy field studies were done already in the 1970ies, showing that a systematic use of best available technology (BAT) could decrease the total energy use despite increased consumption of goods and services. But what has been the actual outcome and why? We have focused the development of technology and consumption pattern within the transportation sector and examined the specific energy use for cars in Sweden since 1975. A database for the Swedish car stock has been developed. With statistical analysis and modeling we have scrutinized the changes within the car stock to reveal how the technological development has been utilized. The stock has changed towards increased weight and frontal area of the cars as well as increased engine power and displacement. Most of this increase has been compensated by increased engine efficiency. Also lower rolling and air resistance coefficients have contributed to lower specific energy use.

An Index of the Ecological Impacts of Water Toxics emitted to Freshwater Ecosystems

Stella Papasavva, Mark A. Beltramo, Steven H. Cadle

We assess the ecological impacts of water toxics emitted to freshwater ecosystems. We have developed a composite Aquatic Toxicity Index (ATI) developed for freshwater for chronic toxicity conditions. The ATI expresses the physical impact of the chemicals to the ecosystem and it provides a ranking system that scales the potency of each chemical with respect to nickel. Nickel was chosen as the numeraire chemical because its ATI value is in the midrange of values of the other chemicals. We also compared the ATI index with measures of Aquatic Eco-Toxicity Potential (AETP) provided by the developers of GaBi and obtained using the European-based impact assessment tool EUSES 1.0, which was based on a more elaborate fate and transport model. The correlation between log (ATI) and log (AETP) is greater than 0.8. Therefore, we believe that our inexpensive approach in terms of computational resources and mathematical modeling may provide a reasonable approach to approximating complex environmental impact assessment for chronic aquatic emissions.

Moving to Cleaner Vehicles: Policies and Programs Promoting China's Sustainable Development of the Automotive Industry

Jimin Zhao

China is still in an early stage in structuring its automobile industry, and it has the opportunity to build the industry from the ground up. Will China attempt to follow the model of the industrialized countries, producing oil-dependent internal combustion vehicles? Or can China instead "leapfrog" to the most advanced cleaner technologies, such as natural gas, electric hybrid vehicles, or fuel cell vehicles? China's decisions on the auto industry will not only affect China's economic development, environmental protection, and energy security, but also have important repercussions for the world in

terms of energy security, economic competitiveness, and climate change. As part of Harvard University's Energy Technology Innovation Project on energy policy and technology development in China, research on clean vehicles is being undertaken in collaboration with China's Ministry of Science and Technology and Chinese researchers and consists of international workshops and in-depth case study interviews with key actors in China and the United States. It aims to analyze the barriers preventing China from developing its technological capability in the automotive sector, and to help the Chinese government design policy mechanisms that can assist the automotive industry in adopting clean vehicle technologies (hybrid and fuel cell) to catch up with or leapfrog the world technology level. Drawn on field research conducted in 2001 and 2002, this paper reviews the dynamic response of China's policies and programs in the automobile industry to the challenges of economic development, environmental protection, and energy security. Four policies and programs for promoting cleaner vehicles are examined: emission standards, unleaded gasoline phase-out, alternative fuel vehicle development, and R&D on advanced electric vehicles. China has moved its policy focus from development only to development with emission controls to development with cleaner vehicle technology. Responding to concerns over serious urban air pollution, national policies and programs have played a major role in implementing this shift. Also, China's commitment to a "green" Olympic Games in Beijing in 2008 provides a niche market and experimental opportunity for clean vehicle development. The desire to "leapfrog" technologically in the auto industry has motivated the government's willingness to invest in clean vehicle R&D. In response to more stringent environmental standards and changing market demand, firms are changing from passive compliance with national standards to active cooperation with government to develop cleaner vehicles. However, significant barriers to cleaner vehicle development remain. These include the lack of systematic and long-term plans for the development of clean vehicles, the absence of incentive policies to encourage the use of clean vehicles, poor R&D capability in conventional vehicle technology, high costs of manufacturing electric, hybrid, and fuel cell vehicles, and insufficient supporting infrastructure. The paper concludes with recommendations on how the national government can aggressively tackle these barriers.

Product Inventory of the Swedish Railway Infrastructure- Implications for Influencing Upstream Environmental Impact

Niclas Svensson and Mats Eklund

The Swedish national railway authority (SNRA) is responsible for building, maintaining and decommissioning of the railway infrastructure in Sweden. This includes management of 10000 kilometers of railway, a turnover of roughly 100 M Euro per year and organizing the product management for about 16 000 different products specific to the railway infrastructure. When approaching an environmental assessment of this large infrastructure organization we have not involved the issue of rail versus car transport (perhaps the most important aspect from an environmental point of view) but rather focused on how to assess the environmental impact resulting from the management of the railway infrastructure. The distribution of environmental impacts between different

life-cycle phases of the railway is dominated by the energy use in the use phase if expressed in energy terms. Since most railways in Sweden are electrified, hydropower and nuclear power dominate the energy mix used for operation of the trains. About 80% of the total energy use are used for operating the trains while the remaining part is dominated by energy use in the production of large amounts of energy-intensive materials and products. If the environmental impact instead was to be expressed in terms of global warming potential, the relative importance of the materials production would increase since the energy sources employed are not only electricity. If improvement regarding the environmental impact related to the materials in the railway infrastructure is to come about which products should the SNRA focus on? SNRA keep about 16000 different products in stock in order to be able to provide products for replacements. However, a new building project uses about 500-600 different products to produce a railway. Our approach has been to screen among the products by combining information about weight, kind of material in each product and the energy intensity of that material in order to find which products that are the most important to focus on in the assessment and further management. The study is based on two case studies of newly built railways. The results reveal that one product group, the different kinds of rails, contributes to around 80% of the total material-related energy use of the railway infrastructure. This is due to that the flow of rails involves a large mass of an energy intensive material, steel. By increasing the number of products under consideration in the product screening to 78, 95% of the material-related energy use was included in the assessment. With this approach it is easy to identify environmental "hot-spots" among the products of the SNRA. The information can give hints to where specific demands to suppliers are appropriate and also indicate where further environmental analysis is needed. We have conducted simplified life cycle assessments of a number of railway products, regarding energy use along different product supply chains. The results indicate that the largest energy use can be found at the upper end of the supply chains. Thus they are the farthest away from the SNRA, which might make it more difficult to influence environmental performance of the product since demands and information have to travel through several different actors along the supply chain.

A Performance Evaluation of Data and Models Used to Assess the Health Impacts of Transportation Systems in LCA

Thomas E. McKone

This paper addresses the reliability of the tools we use to measure, evaluate, and compare the impacts of transportation systems on human health. In both industrially developed and developing countries, pollutants emissions linked to transportation pose a significant burden on human health. Efforts to characterize the health impacts of transportation systems require three types of information—(1) emissions data, (2) models and data to link emissions quantity to environmental concentrations or burdens, and (3) an approach to relate environmental burdens to impact expressed as disease burden. I will first review the use of Intake Fraction (iF) as an effective tool for expressing source-to-intake relationships for pollutant emissions in Life Cycle Analysis (LCA) for transportation systems. Intake fraction is the fraction of chemical mass emitted into the environment that eventually passes into a member of the population through inhalation, ingestion, or dermal exposure. The iF approach is now widely used in LCA. I will next consider to what extent the reliability of the iF calculation is linked to model uncertainty and data availability. As a case study, I will report on the systematic and ongoing model evaluation process that has been applied to the CalTOX model, which has been broadly used for LCA and iF impact calculations. CalTOX was developed as a set of spreadsheet models and spreadsheet data sets to assist in assessing human exposures from multiple environmental media through multiple pathways. The model has also been widely used in regulatory and educational applications. In science, philosophy and policy, there is continuing disagreement about what it means to validate a model and if model validation is even possible. All models involve aggregation and exclusion. So even when models can be validated for limited situations, there is no such thing as a "valid" model. As a result many have repeated the George Box statement that "all models are wrong, but some models are useful". A useful model may not be "validatible". But through years of use and revision, a model can accumulate confidence among its users. We have found that confidence in model performance only comes about through an appropriate balance among three model attributes-reliability, refutability, and inclusiveness. This balance is difficult because of the competing interactions among these attributes. That is, high reliability can be attained using simple models, but these models may not be sufficiently inclusive. But an inclusive model may become so complex or intractable that it cannot be scientifically refuted. A "useful" model for LCA impacts must establish the balance among these attributes so as to provide input relevant to LCA policies or choices. This requires a model that provides transparency on how relationships among parameters and inputs could alter choices or outcomes.

Impacts of Transportation on the Urban Metabolism

Christopher Kennedy, Halla R. Sahely and Manson Fung

The paper describes the impacts of different transportation modes on the urban metabolism of the Greater Toronto Area and discusses modeling approaches that may be used to understand the ecological / economic constraints on growth of urban regions. A study of the urban metabolism of the Greater Toronto Area (GTA) shows accelerating inputs and outputs relating to transportation (Sahely et al., 2002). Between the study years of 1987 and 1999, per capita transportation energy inputs, i.e., gasoline and diesel fuels, increased, along with a corresponding rise in CO2 emissions. In comparison, per capita inputs of food, electricity and water were relatively stable, while the per capita output of wastewater decreased. Moreover, the total output of solid waste decreased due to the introduction of large-scale recycling. So increases in transportation activity, driven by suburban growth and increased trade, cause the fastest growing environmental stresses impacting the urban system. The environmental impacts of automobile use in the GTA are considerably greater than those relating to public transportation (Kennedy, 2002). A World Bank study in the 1990s found that transportation emissions levels of three major air pollutants in Toronto: nitrogen oxides (27 kg/capita), sulphur dioxide (2.3 kg/capita) and volatile particulates (3.9 kg/capita), were higher than in all other 21 large European and North American cities in the survey. Epidemiological studies suggest that 400 premature deaths per year can be attributed to automobile air pollu-

tion in the City of Toronto alone, although medical understanding of the processes remains poor. At 170 g C /person.km automobiles produce greenhouse gasses at an order of magnitude higher than electric public transportation in Toronto. The relative consumption of land by automobile systems is also high compared to public transit systems. On-going research is aiming to understand the economic drivers of the urban metabolism in the GTA. A macroeconomic model of the region has been developed, using econometric techniques (Fung and Kennedy, 2002). The model is used to simulate greenhouse gas emissions (GHG) from the GTA under different economic conditions. If development continues with current technology, then by 2010, GHG emissions from transportation in the GTA will increase by 22% over 2001 levels. Looking at the urban-region from an ecological perspective, it is of interest to consider what are the constraints on the growth of the city. Before days of widespread automation, limits to body energy were a natural feedback to walking, forming a constraint on urban form (Macoun, 2002). No such biological feedback exists with automation. Urban economists have developed theories of city growth by which residents maximize their utility in a trade-off between transportation costs and the price of land (Mills and Hamilton, 1989; Brueckner, 2001). But perhaps other environmental / economic feedbacks might constrict long-term growth, e.g., costs of extreme weather events due to climate change; health impacts from air pollution; traffic congestion; or long-term economic costs from deferred maintenance of infrastructure. Development of an economically driven urban metabolism models provides a means to explore these issues.

Industrial Ecology Tools – Examples, Practical Experiences, and Critical Evaluation

Ecolabel Certification for Travertine Slabs

Laura Cutaia, Paolo Massacci, Simone Materazzo

The aim of this work is the application of the Ecolabel (Regulation EC 1980/2000) to the production of travertine slabs. The European Commission Decision (2002/272/CE, March 25th 2002) has established ecological criteria for the award of the Eco-label to Hard Floor Coverings (HFC). Such a class of coverings includes hard products for internal/ external flooring, without any relevant structural function. The European Ecolabel scheme (voluntary agreement) has been proposed to stimulate both production and use of goods with a reduced environmental impact. The Ecolabel criteria consider the following aspects:

- reduction of impacts on habitats and associated resources;
- reduction of energy consumption;
- reduction of discharges of toxic or otherwise polluting substances into the environment;
- reduction of use of dangerous substances;
- information that will enable the consumer to use the product in an efficient way which minimizes the whole environmental impact.

The Ecolabel scheme has been applied to the production of travertine slabs (Acque Albule basin, Lazio Region, Italy). Travertine is defined (UNI 8458) as a sedimentary

calcareous rock with a characteristic porous structure, used as building material and ornamental stone. The quarry taken into consideration produces 3000 m3/month of ornamental stone, whose 750 m3/month are shapeless blocks. Besides blocks for saw gangs, the sold products include materials cut to size for wall facings, stairs, inside and outside floors. The first part of this work analyses the energy consumption for the production of plastered, smoothed and polished slabs of travertine. The following parameters are relieved during the manufacturing process: time, voltage and amperage for every operation, in order to analytically evaluate the energy consumption. In accordance with literature data, the global energy consumption has been broken-down in the different phases of the manufacturing process. It turns out that there is a considerable waste of energy for the extraction, in the quarry, and for moving blocks from quarry to the workroom. Reduction of energy consumption is the basis of the HFC Ecolabel criteria, which are analyzed in the second part of this work. HFC split into two categories: natural and processed products. Travertine slabs belong to natural products. Ecolabel scheme for natural products takes into consideration 8 phases: Raw materials extraction, Raw materials selection, Finishing operations, Waste management, Use phase, Fitness for use, Consumer information, Information appearing on the Ecolabel.

Dynamic Frameworks for Industrial Ecology

Sangwon Suh, Gjalt Huppes, René Kleijn, Igor Nikolic, Helias Udo de Haes, Koen Frenken, Klaus-Ole Vogstad, Harry Wilting

Dynamic frameworks that are considered to be relevant to Industrial Ecology studies are compared and evaluated. In order to answer "what if" questions to inform decision makers, industrial ecology needs a dynamic models. Dynamic models that are considered in this study includes dynamic input-output analysis, dynamic computational general equilibrium (CGE) model, system dynamics model and agent based model. Inputoutput analysis and its extensions to dynamic model is basically a comparative static model based on fixed parameters for a period determined possibly non-linear relations. Input-output model covers the regional, national and multi-national system with aggregated manner. The source of dynamics that runs dynamic input-output model is capital formation that is assumed to be proportional to the difference in production volume between two time periods. Later, capacity utilization, time lag in investment planning, endogenised technology innovations, etc. are incorporated in the model. Dynamic CGE model is an extension of CGE model considering temporal variables that affects the equilibrium condition. CGE model assumes that the economy is under an equilibrium state in the base year (benchmark year) and estimates another equilibrium state after an economic shock such as tax reform, major price change assuming that producers and consumers solves complex optimization problems at the same time. System dynamics model is basically a well-defined non-linear differential equation of continuous functions. Executing the model means solving the differential equations based on given conditions. The model results are fully dependent upon the individual functions that are defined at the stage of problem formulation. Various complex mechanisms including price mechanism, demand and supply functions, can be fully described by the system dynamics model given that the model builder exactly knows them. Finally, agent-based model is based on rather new and different paradigm, evolutionary economics, which

focuses more on sub-optimal, path dependence and irreversible change than optimal, reversible change that neo-classical economics emphasized so far. Agent based model defines the behaviour of individual agent of a system, which is complex by itself. However, the result that is emerged from the complex behaviour of individual agents are known to be rather stable. Each models studied show their own strengths as well as weaknesses. Dynamic input-output model suffers from the inherent instability of the model. Furthermore, the sources of dynamics, which is capital investment based on production volume difference, has been questioned as well. However, input-output model is based on a reliable statistics and the variables and assumptions that are involved in the model are rather well-available and transparent. In contrast, dynamic CGE model relies on massive number of parameters extracted from various literatures, which are calculated from often different conditions and assumptions. Most of all, the assumption of inter-temporal optimization by individual agent has long been questioned. Dynamic CGE model can, however, shows a general directions of future change after a significant changes based on well-grounded neo-classical economic theory. Finally, relevance and compatibility of these model with existing industrial ecology tools are studied.

Dynamic Modelling Of Complex Interconnected Metals Cycles

E.V. Verhoef, M.A.Reuter and G.P.J. Dijkema

Industrial ecology places a strong emphasis on the importance of closed material cycles. Challenges for closing the material cycles are to keep the metals at an industrial compatible grade, to cope with the dynamics of the flows and accumulations in the cycles, and to simultaneously minimize damage to the environment and public health. Many of the standard texts of Industrial Ecology give a simplistic view on the complexity of metals processing and recycling, often since the reports originate from non metals-technologists. This paper addresses this complexity, which is best given by Figure 1, that discusses the complex interconnectedness of metals and implicitly therefore of metals processing. Figure 1. Linkages of metals as found in natural resources - map to sustainable recycling of metals. The amount of secondary metals that can be processed relative to fresh raw materials is limited by the amount and type of impurities carried over from end-of-life phase. The continuing development of products, and limited capacity for waste separation lead to waste streams that bring together metals and other elements that are not linked in natural resources. As a consequence, many of these flows are not compatible with any process in the metals production network that was developed for the processing of primary, natural resources. Increased recovery rates may lead to decreasing quality and availability of metals, significant impacts on environment, residue production and losses of metal through these residues. Moreover, higher recovery rates of metals, or changing products compositions - due to the connectedness of metal production, product manufacturing and solid waste management - can significantly change resource use, the material flows and accumulations in the system, and environmental profile (e.g. energy consumption, emissions). Meeting these challenges in policy, waste infrastructure or product development requires an ecological perspective, acknowledging the pattern and the balance of relationships between metal production, product manufacturing, consumption and waste management. Because metal ore, intermediates

and commodities are traded globally, this perspective must be global. Therefore, a detailed dynamic model of six interconnected metal cycles (copper, lead, tin, bismuth, zinc, and silver) is reported, including eight minor elements (antimony, arsenic, nickel, gold, palladium, cadmium, iron and sulfur). This was tested against the discussion of the use of lead-free solder. The Simulink-Mathlab model includes five phases that together represent the life cycles of metals. After mining of the ore, and metal production, the metals are used in the manufacturing of products, which accumulate in the consumption phase. After their consumption, these end up in the solid waste management phase. Here the materials are incinerated, disposed of on landfills or returned to the metal production. In order to capture the global dynamics, the model must account for the complexity of the metal production network, which consists of an interconnected and integrated system that incorporates multiple production/recovery routes for a spectrum of metals. The model has a hierarchical, bottom-up construction from process to integrated material cycles. Literature reports of the individual process steps in the production and waste management of metals were reviewed to obtain input and output data for each process in the network, and develop linear models of the processes. Production and recovery figures of global market were used to calculate the interconnecting flows between the individual processes. Also the extensive industrial experience of the authors assisted in the compilation of useful databases. Dependent on the type of product different delay times were assumed to calculate the accumulation in the consumption phase. As such the model can estimate dynamic system performance as well as individual process performance in different scenarios. The characteristics and the usefulness of the modeling approach are demonstrated on the basis of case studies.

Environmental Performance of a Metals Industry Facility: Industrial Production Chain Analysis

Belmira A. F. Neto, Carolien Kroeze, M.P.J. Pulles, Roberto Frias

In industrial companies the main activity is the conversion of one or several raw materials to specific products, using energy, capital (equipment) and labor. During this manufacturing process, compounds are released into the environment. These so-called emissions (including the production of wastes) have an impact on the state of the environment and might lead to effects. In order to follow the directives from the environmental policy arena, some small and medium size companies are nowadays using, environmental management systems to quantify their environmental performance on an annual basis, in terms of emissions, and production of wastes and the use of resources. Although so far, several tools/procedures integrating the concept of Industrial Ecology are available for assessment of the environmental performance of industrial processes, these methods may not be able to effectively evaluate the impacts associated with decisionmaking at the company level, nor provide opportunities to be more pro active in environmental management. The main reason is that industrial systems are primarily build from the process owner or process operator point of view. Using the available tools, industrial companies aim at keeping the environmental impact of their processes within the limits, set by environmental legislation or even to minimize the impacts in an economically feasible way. This is not a simple task, since the environmental impacts are

complex given the variety of compounds emitted, and the variety of their environmental effects. This study develops an environmental decision support tool, allowing the facility's management to perform "what-if" analyses preparing environmental investment decisions. In focus are the industrial activity, the technology available and the current operational procedure. Although the procedure and algorithms of the tools will be generic, the tool is developed for a company supplying car manufacturers with aluminium die casted products from the Aluminium Die Casting Industrial Sector. The process data used in the study was readily available. A limited chain analysis (industrial process chain analysis) based on the concept of Industrial Ecology is used as a basis for the study. Moreover, the decision support tool will combine relevant parts of life cycle impact assessment, environmental systems management and multi criteria analysis, which are well-developed tools in environmental systems analyses covering ecological aspects of decision making. Improved insight at the process of the facility, zooming its unit process level, will result in a panoramic view, quantifying environmental performance of the industrial process. This quantitative information may make it possible to prioritize environmental management decisions to be made by boarding managers.

Systems Analysis Tools for Promoting Effective Energy / Minerals — Partnerships in Regional Development

Jim Petrie, Lauren Basson, Mary Stewart, and Brett Cohen

This paper explores the role of ESKOM, the world's fifth largest electrical utility, as a catalyst for regional development in Southern Africa, through the formation of partnerships with industry to promote the economic, environmentally responsible and socially acceptable use of energy. There is a need to look at energy provision and energy services in an integrated manner with key drivers for economic development ? both locally and regionally. The minerals sector will remain highly significant to regional economic development in Southern Africa in the medium term, and mining, minerals and metals? projects are both consumers and, in some cases (potential) generators of large amounts of energy (electricity included). It is therefore appropriate to focus on the promotion of partnerships between ESKOM and the minerals sector which seek to improve resource efficiency within the combined energy / minerals envelope, guided by the tenets of Sustainability.

Whilst there has been considerable development of systems analysis tools in recent years to address this sort of ?complex systems? analysis (Life Cycle Assessment, Cleaner Production, and Industrial Ecology arguments for example), there is no effective roadmap available to ESKOM to guide the selection and exploitation of these tools in different contexts. Our previous work developed a Decision Support Framework (DSF) which provides some guidance here, but only within the context of coal-based power generation (i.e. entirely within ESKOM's ?footprint? of operation, and for a selected primary energy source). The DSF employs the tools of Multi Criteria Decision Analysis (MCDA), within which trade-offs between competing objectives are explored. Life Cycle Assessment has been used to generate the set of environmental objectives. Even extending the DSF to cover all aspects of supply-side management, there is still

lacking the necessary tools to analyze a situation in which ESKOM functions as a dynamic network partner with minerals projects (or indeed any resource or manufacturing sector). New models are required for this, which, firstly, seek to characterize such network structures, and secondly, enable the application of the necessary analytic tools to exploit these partnerships and networks for optimal performance. This is the domain of demand-side management. We have taken the view here that demand-side management is not only about developing strategies to meet a projected demand, but more importantly, about developing partnerships with customers to promote the most efficient paths to Sustainability.

This paper explores the development of such a set of network analysis tools, and their incorporation within the DSF. To do so, we make use of process modeling tools from chemical engineering, including those used in energy integration studies. In particular, consideration is given to the choice of attributes needed to characterize partnership linkages and network integrity (e.g. security of supply of electricity), the efficiency of material transformations within any node of the network (as a function of energy consumption), and the impact that this has on the viability of other linkages (e.g. due to reduced availability of raw materials). We discuss how these perspectives help shape the form of objectives to be considered by MCDA. Some discussion is offered too on the trade-off between foreground and background system impacts (particularly where electricity is generated remotely to the minerals? development hub) and how this might inform regional development.

Using a Baseline Sustainability Footprint Analysis for a Commercial Operation

William A. Stough

Before business owners can make informed decisions on how best to invest in sustainable development opportunities, a baseline analysis of their business's current sustainability footprint is essential. This project illustrates an approach developed using the Triple Bottom Line and The Natural Step System Conditions as the philosophical basis to provide a process that creates a baseline sustainability assessment. The initial investigation used four major assessment areas to document the existing footprint: 1. Resource Use; 2. Resource Management; 3. Ecological Impact; and 4. Social Impact. These items were selected to provide a wide profile of the operations and to give the owner a representative analysis consistent with the widely accepted Triple Bottom Line definition of sustainability being used by the business community. Baseline information collected in each of the major heading areas was converted into business metrics that related directly to the operational impact of sales and/or the environment. The final metrics developed were used by the owner to judge where capital improvement investments would have the most positive effect on the business and the environment. The baseline analysis was used as a benchmark for future building or purchasing decisions and for new operations. Use of the tool helped the owner make informed decisions that promoted investments that improved profit margins and progress toward more sustainable operations.

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Material/Substance Flow Analysis

Elemental Cycles: A Status Report on Human or Natural Dominance

Robert J. Klee and Thomas E. Graedel

The modern technological society mobilizes and uses a very large number of materials. These substances are derived from rocks, sediments, and other natural repositories, and most undergo transformation prior to use. A large fraction of the materials is eventually returned to the environment. Natural processes do the same, but not necessarily with the same suite of materials. For purposes of better understanding industrial development and potential environmental impact, it is important to know, even approximately, the elemental cycles of all materials potentially useful for modern technology. In this article we review and summarize cycle information for the first ninety-two elements in the periodic table. Mobilization calculations, presented for seventy-seven elements, demonstrate that human activities likely dominate or strongly perturb the cycles of most of the elements other than the alkalis, alkali earths, and halogens. We propose that this pattern is ultimately related to the aqueous solubilities of the predominant chemical forms of the elements as they occur in nature: human action dominates the cycles of the elements whose usual forms are highly insoluble, nature those that are highly soluble. Examples of the utility of anthropogenically-dominated cycle determinations for resource supply analyses, environmental impact assessment, and public policy are presented and discussed. If the rapid rise in the use of materials by the technological society in the 20th Century continues into the next century, anthropogenic dominance of the periodic table will only increase.

Recycling in Industrial and Ecological Systems: A Comparison

Stephen H. Levine

Material recycling is one of the major concerns of Industrial Ecology, and the belief that industrial systems may have much to learn from ecological systems in this regard is reflected by the very name of the field. Allenby and Graedel (1995, p. 262) note that there exists a "hierarchy of preference in recycling industrial products. Recycling should generally be accomplished as high up the chain as possible." Reuse of the product is of course the preferred course, followed by recycling of subassemblies and then by recycling of components. As Allenby and Graedel note (p. 261), "Usually the least desirable of the alternatives.... is removal of the product followed by the recovery of the separate materials in it (or perhaps some of the embedded energy, if the product is best incinerated) and the injection of the materials or energy back into the industrial flow stream." Given this hierarchy, then, it is interesting to note that natural systems utilize "the least desirable of the alternatives" almost to the complete exclusion of the alternatives higher "up the chain." Rarely does recycling in nature capture any functionality. This is true not only in those material transitions generally recognized as recycling, such as carried out by detritivores, but also in those transitions more analogous to production activities, that is, predation interactions. Historically, recycling in industrial systems has often been located in specialized industries, such as junk yards and scrap metal dealers. In contrast, recycling in ecological systems is carried out by every species at every trophic level. The digestive processes of herbivores and carnivores are not essentially different than those of detritivores. In all cases the ingested biomass is broken down to a set of basic chemical components, and the major part of it used for its embedded energy. Production in ecosystems is not, as in industrial systems, a cooperative effort of multiple firms in multiple industries located in successive production stages. Rather, every individual fully produces itself. And, at least if it is an animal, to do so it must carry out, through digestion, all of its own recycling activities. This presentation will elaborate on this comparison of recycling in industrial and ecological systems as well as address the following questions. What are the characteristics of industrial and ecological systems that lead to these difference? What do these differences tell us about the possibilities for recycling in industrial systems? Is there anything useful to be learned from ecological systems regarding recycling in industrial systems?

Origin and Destination of Waste: Accounting and Analysis of Waste Flows by Means of Physical Input-output Tables

Ilmo Mäenpää, Jukka Muukkonen

Physical input-output tables (PIOT) represent, in the form of exact and detailed balances, the flows of materials from nature to an economy and through the production and consumption chains of the economy back to nature. The explicit representation of waste flows in terms of PIOT indicates unambiguously the share of waste out of the total material flows in the different parts of the economy as well as the share of recovered waste out of the material inputs. Besides, the process of compiling the PIOT enables us to check and complete the often deficient and disconnected sources of data on waste. For example, the commodity and fuel statistics of Industrial Statistics include data on the supply and use of many types of recovered waste better than the databases on actual waste. On the other hand, the balance method helps to estimate the generation of waste where direct data on waste are completely lacking: inputs that do not end up as parts of produced products, are not combusted or are not stored have to be discarded as waste. In this paper, the principles of designing waste flows for the Finnish PIOT of 1999 will be outlined, the share of waste in the total material flows of different branches of economy will be shown, and separate waste balances of the economy will be presented. Finally, the information value of the approach for the material efficiency improving policy in general and for the waste policy in particular will be discussed.

Materials Flow Analysis of Organic Pollutants and Suspended Solids in the Tamsui River and Kaoping Stream Valleys in Taiwan

T.Y. Hsiao, Iddo K. Wernick, Y.H. Yu, L. T. Lu, N. W. Kuo

We present a study of the materials flows of pollutants measured in units of Biological Oxygen Demand (BOD5) and Suspended Solids (SS) into the Tamsui and Kaoping river

systems that drain into estuaries at the northern and southern coast of Taiwan. Material flow analysis (MFA) is applied to analyze the BOD5 and SS in the economic system of the two valleys with different human development patterns using an independent data set covering the period 1992-2000. We calculate the generated flow of pollutants based on unit loading factors associated with the predominant human economic activity in each watershed. An independent calculation is made of the measured pollutant flows based on data collected at monitoring stations along each river system. We compare the predicted generation of these pollutants with flow data measured at monitoring stations along each river system to estimate the Self Purification Capacity (SPC) of each river system which is defined as the system's ability to assimilate and decompose the pollutants under investigation. Our results show that BOD5 generation in the agricultural region exceeds that in the urban region by about 85%. Nonetheless, the lower SPC of the urban watershed results in estuarine releases of BOD5 more than a factor of six higher in the northern estuary. The amount of SS reaching the ocean in the south of the island exceeds the amount reaching the northern estuary as expected based on more intense land disturbance in the southern watershed. Trend analysis over the years 1992-2000 reveals mixed results for the future capacity of these river systems to meet the defined criteria for sustainability. We suggest several objectives for managing of materials flows to both estuaries to improve the prospects for sustained environmental quality in each of these critical regions.

Weighing the Materials: The Impact of the Kilograms

Ester van der Voet, Lauran van Oers & Igor Nikolic

In many countries, material flows are being accounted. A standard methodology was issued recently by Eurostat to set up an account of all material flows in and out national economies, thus providing insight in the material basis of societies. These accounts and the derived indicators are based on the weight of the materials in kg. Although none dispute the value of these accounts as a database, there is an ongoing discussion on the value of the mass based indicators. What is the meaning of the kilograms? In this paper, we try to give one possible answer to this question. We combine mass flow data for the Netherlands with environmental impact data from standard LCA databases. In this way we hope to add a dimension to the mass flow accounts which enables to prioritize between materials. A dematerialization policy thus can be based not only on the weight of materials, but also on a notion of their impacts on the environment. Several analyses and representations of the combined databases are made, each shedding a different light on questions and answers around dematerialization.

Flexibility of Industrial Material Flow Networks

Andreas Moeller, Tobias Viere

In recent years material flow networks have been used by several enterprises in order to obtain material and energy flow transparency, ecobalances, and eco efficiency indicators. For example MohnMedia, a subsidiary of the Bertelsmann group, annually accom-

plishes such material flow analyses. At present the material flow models include about 5 hierarchical net-work levels, 179 process specifications, 6127 materials and altogether 121564 material and energy flows. The results of the material flow analysis constitute a foundation not only of corporate sustainability reporting (e.g. input / output balances, process balances, and environmental performance indicators) but also of the corporate material and energy flow management in general. Some criticize the size of such material flow networks, the degree of transparency in the models, and the extent of the resulting data. They conclude that material flow networks are too complex and their application too time-consuming to make meaningful contributions to industrial ecology in enterprises. A closer examination of the problem shows that these appreciations result from the organizational context in which the material flow analysis is implemented: Due to the complexity of the material flow analysis the model creator is separated from the model user. In general decision theory approves the organizational disconnection of model creator and model user, although this ignores one important phenomena of modeling. Modeling cannot solely be characterized as generation of relevant data for decisions. It is rather a learning process. Therefore the mentioned organizational structures of industrial material flow management results in a dilemma. The learning process is confined to the model creator whereas the decision maker relies on the originators information almost blindly. Even though this dilemma cannot be solved completely it can be eased by interlocking model building and model utilization. Thus we suggest that the modeling expert does not only provide data but also an adaptable model which enables the model user to experience the consequences of different decision possibilities himself. In this way decision makers become part of the model-related learning process and the material flow network loses its "black-box-character". Obviously the complexity of the material flow models has to be reduced in return, since it cannot be expected that the decision maker knows all construction details of the model. This implies two basic changes in material flow software which both lead to more flexibility: The calculation of the material flow network needs to be separated from the model building tool. This measure enables the user to work with a software he is used to (e.g. a typical spreadsheet tool) to perform material flow experiments. Furthermore experiment supporting features of the model building tool itself have to be enhanced. The possibility to choose between several specifications in the same process is one example of such features. Our approach tends to overcome the undesirable disconnection of model creation and decision making in industrial material flow management. It proves the necessity to raise flexibility of material flow networks. In this manner material flow networks become an important tool of industrial ecology.

Sustainable Consumption

Pollution Embodied in Import and Export and its Relevance for the Environmental Profile of Norwegian Households

Edgar Hertwich, Kristin Erlandsen, Jørgen Aasness, Knut Sørensen, Klaus Hubacek

The environmental profile of households is commonly assessed by combining con-

sumer expenditure surveys (CES) with environmentally extended input-output analysis. The pollution intensities are calculated only for domestically produced products using information from the national accounts, such as the National Accounting Matrices including Environmental Accounts (NAMEA). Import is either neglected or treated as having the same pollution intensity as domestic production. The question is whether this can lead to serious oversights or distortions in household environmental profiles. This is likely to be the case if a country has a high degree of economic specialization and imports many products it does not produce itself. Both of that is true for Norway. We present an exploratory investigation of the role of imports combining assessments of the Norwegian pollution intensity with that of selected trading partners, including China, Japan, and the United States. We investigate key greenhouse gases and acidifying compounds. Our analysis shows that using Norwegian pollution intensities for imported products indeed leads to errors in household environmental profiles. National differences are even more important when selecting between alternative products, i.e. when trying to chart a way towards more sustainable household consumption. We present recommendations of how to reduce environmental pollution associated with private consumption.

Sustainable Consumption Analysis using Dynamic IO LCA and Consumer Choice Theory

Gregory A. Norris, Jeff Amlin

Consumption choices related to transportation and habitation are inter-linked and are projected to remain of major environmental importance in North America and globally. They are both aspects of "final demand" rather than intermediate demand within industry. They are therefore priority areas for sustainable consumption analysis and policies. Furthermore, industrializing countries around the globe are showing signs of replicating similar patterns in personal vehicle use and land use development. Thus, it is vitally important that sustainable consumption methods identify consumer-acceptable measures and opportunities to reverse these trends. Macro-based "consumer choice" models work at the level of populations, and attempt to explain or predict market shares for different alternatives as a function of first cost, life cycle cost, other product attributes, as well as economic/demographic population characteristics. Regression analysis is used to estimate parameters in models that forecast new purchase market share responses to product prices and other characteristics. These models implicitly capture the influence of realities such as variability in preferences and prices among consumers, limited/imperfect information, non-rational information processing, and the influence of non-price factors in consumer choice. We apply a multinomial probit framework to estimate new vehicle purchase market shares for different levels of efficiency, as well as modal choice, in response to various policy options directed at influencing consumer transportation demand in directions that will reduce CO2 emissions. We evaluate the impacts of these consumer responses within a closed-loop dynamic economic IO LCA model, with an endogenous (and disaggregated) household sector, dynamic labor markets with migration, dynamic capital investment for both growth and replacement, and regional economic competition. Conclusions from the analysis will be drawn

on two fronts: (1) policy-relevant findings related to reducing the impacts of transportation and housing in North America; and (2) methodology-related findings for the fields of LCA, Industrial Ecology, and the emerging "field" of sustainable consumption analysis.

Lifetime-involved Substance Flow Analysis of Durable Goods: A Case Study of Brominated Flame Retardants in TV Sets in Japan

Tomohiro Tasaki, Masahiro Osako, and Shin-ichi Sakai

Durable goods are different from the other consumer goods in terms of length of lifetime. Measures such as reduction and substitution of toxic substances in new durable goods affect characteristics of the waste products in a long time due to this property. On the other hand, in order to implement recycling of resources or appropriate disposal of toxic substances in waste durable goods at this time, we have to consider substances used in durable goods which were shipped in the past. Therefore, lifetime-involved substance flow analysis of durable goods is required, and we should plan measures of durable goods combining new product measures with waste product measures appropriately, based on the result of the analysis. Conducting the analysis, analysis of lifetime of durable goods is first required and second development of prediction model of numbers of waste durable goods is required. Moreover, we have to investigate weight of components in durable goods in the past and contents of target substances in components, and then substance flows can be clarified. In this paper, we conducted lifetime-involved substance flow analysis of durable goods for an example case of brominated flame retardants in TV sets in Japan. Our subject substances are brominated flame retardants (BFRs), polybrominated diphenyl ethers (PBDEs) and tetra brominated bis-phenol A (TBBA), and related compounds, Sb and polychrolinated dibenzo dioxins and furans (PBDDs/DFs), in 5 size categories of waste TV sets. As results, the beginning of BFRs in rear and front covers of TV sets were from FY 1987 to 1990 and from FY1993 to 1996, respectively, and TBBA is currently used as the substitute for PBDEs, to some extent. The amounts of waste T-Br were predicted to increase until at least FY 2020 due to jumboizing of TV sets. Non-BFRs substitution for BFRs until 2006 would reduce accumulated amounts of waste PBDEs from FY 1995 to FY 2020 by 33,000 tons. However, the amount of waste Br would peak in FY 2009. Waste covers of TV sets should therefore be treated and disposed appropriately at least then regardless of substitution measures. Finally, we will state future issues of substance flow analysis of durable goods.

Dietary Habit Change Impact on Biomass Utilization and Energy Consumption: Energy Flow Analysis of Japan's Food System

Jian Zuo, Toru Matsumoto

Rapid economic development in postwar Japan was accompanied by a number of remarkable changes in people's dietary habit, in particular, increased caloric intake, meat, and fast food consumption rising. These changes have been associated with a series of

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changes in food consumption and production patterns: an increase in imported food and animal feed, development of the food service industry, a rise in the consumption of more processed and luxury food, increases in the distance food is transported, and a change in the food distribution system. Quite simply, the change in dietary habit has altered the structure of material cycles related to dietary life, which has had an increased impact on the environment and natural resources. In this paper, biological energy flow and direct energy consumption of Japan's food system was quantified and analyzed to explore the dietary habit impact on material cycles and environment. A model for biological energy analysis of Japan's food system was developed to discuss the relation of dietary habit and biomass resource utilization. Changes in net primary production (NPP) consumption, energy loss, and effectiveness of the systems are analyzed for the years 1962, 1965, 1970, 1975, 1980, 1985, 1990, 1995 and 1997. From 1962 to 1997, the total NPP inflow into Japan's food system rose 101 percent from 525×1012 kcal/yr to 1,054×1012 kcal/yr while, the total energy loss of the food system increased 112 percent from 461×1012 kcal/yr to 977×1012 kcal/yr. As a result, the total efficiency for the system transferring biological energy from NPP of plants to intake of food decreased by 36 percent. Per capita, the NPP consumption for dietary purposes increased 50 percent from 15.140 kcal/day to 22.918 kcal/day from 1962 to 1997, while the energy loss increased 60 percent from 13,549 kcal/day to 21,224 kcal/day. With increased food and animal feed imports, the overseas quotient of NPP increased from 27 to 67 percent, and the overseas quotient of energy loss increased from 29 to 60 percent. It is estimated that 66×1012kcal of NPP consumption could be avoided in one year if waste in the food consumption process is decreased by 20 percent, also 38×1012kcal of NPP could be saved one year if 20 percent of the dietary energy intake of livestock food is replaced by plant food products. The energy consumed by a person in order to cover his/her food demand was 4,320×103kcal/person/year in 1994, of which 33 percent in the production process, 29 percent in the household's consumption process, 11 percent in the transportation process and 10 percent in the food processing process. Overall energy consumption on a national level reached 54×1013 kcal, which is equivalent to 15.5% of the total annual energy consumption in Japan. The energy volume used in the food processing and distribution industry and its consumption process (food services & households) along with associated domestic automobile transportation has increased in general due to the changes in eating habits, the total energy consumption per capita increased by 2.5 times from 1,077 to 2,676x103 kcal in a thirty year period between 1965 and 1995 while, changes in which households, food services, food processing, distribution and automobile transportation have increased respectively by 2.5 times, 3.1 times, 1.5 times, 9.3 times and 3.9 times.

Sustainable Consumption at City Level: Evaluating and Changing The Household Metabolism In Five European Cities

Henri C. Moll and Klaas Jan Noorman

We address the issue of sustainable consumption at the city level. Environmental loading associated with production and consumption activities is steadily increasing. In many aspects cities are the economic, social-cultural and political heart of society. For a majority of the population the city is the place were they live, work and build up a social

network. Cities play a leading role in a broad regional and national setting. While the issue of sustainable development clearly has a global dimension it is also generally accepted that there exists a strong mutual relationship between the global and local level. Cities and their urban surroundings are therefore regarded as relevant systems for the operationalisation of sustainable development. Our main focus is on consumption, however this is not considered separately from other processes, both upstream (production of consumer goods) and downstream (waste collection/processing) in the production-consumption chain. At the city level individual consumers and household activities play an important role as far as sustainable development strategies are concerned. We used the total (direct and indirect) energy requirements for households as a proxy for environmental pressure related to household consumption in five European cities (Fredrikstad, Stockholm, Guilford, Padova and Groningen). The direct energy requirement refers to the energy that is literally consumed by households (natural gas for heating and hot water production, electricity and motor fuels). The indirect energy requirement refers to the energy embodied in consumer items. Accounting for the indirect energy requirement brings in the production and distribution activities in the production-consumption chain. We use the calculated household energy budgets in the five cities to derive different sets of change options for more sustainable consumption patterns in these cities. Such change options can be operationalised both through direct steering of household behaviour and through indirect steering via other actors in the integral production-consumption chain (producers, retail, distributors etc.), by influencing the conditions under which consumption takes place (including purchase, use and disposal of consumer items), or by investing in more sustainable physical and institutional infrastructure in cites. The research presented is part of the ToolSust project (The involvement of stakeholders to develop and implement tools for sustainable households in the city of tomorrow). The EU Program finances ToolSust within its Fifth Scientific Framework Programme.

Technical Session (T3)

Policy Cases

Telecommuting and Air Pollution

Erasmia Kitou, Arpad Horvath

Telecommuting, or telework, was introduced in the 1970s as a way to reduce traffic congestion and air pollution. As information technologies and telecommunications further developed, telework assumed yet another role and became a popular instrument not only for its potential to reduce employee travel and thus reduce greenhouse gases and air pollution in general, but also for satisfying employee needs, increasing productivity, and helping companies gain a competitive advantage. The number of teleworkers (regular or occasional) is estimated by some to be as much as 20% of the U.S. work force. Over the years, telework's initial role as a potential solution to air pollution problems was overshadowed by other benefits, and its effectiveness as an environmental solution had not been fully assessed. While one of the major benefits anticipated when implementing a telework program is the reduction of transportation-related environmental impacts by eliminating travel on telework days, research has shown that there may be a number of parameters that could counteract these benefits. Telecommuting's impacts must be assessed in the light of new phenomena that seem to occur on a daily basis and define today's reality. The changes in preferred modes of transportation and in commuting patterns, infrastructural changes in both the home and the office, the introduction of information technologies in the daily lives of the employees, and urban sprawl are some of the phenomena that interact with telework and influence how it will develop in the next decade. Managing to understand the existing obstacles and to efficiently overcome them while maximizing the environmental benefits gained is a complex task requiring the simultaneous analysis of all parameters - both transportation and nontransportation related – as well as the comparison between former and current practices. Our research attempts to answer some of these questions and map the interactions between these phenomena and telework by assessing both the direct and the indirect environmental effects of the various components and parameters of telecommuting programs. We present a model that quantifies not just the transportation, but the electronic and electrical, heating, cooling, lighting, and land use implications of telework. Included are personal and public transportation modes, and space use in the company and the home office. The ultimate goal is to identify the critical variables that lead to the successful implementation of telework programs, making them better than traditional commute-to-work practices, ensuring the continuation of their smooth integration into modern societies. We demonstrate that telecommuting programs differ in their environmental efficiency based on the pollutant quantified, location, and the individual travel and space use patterns. Monte Carlo simulation is used to perform a sensitivity analysis of all of telework's parameters. Sensitivity analysis helps identify not only the variables that are driving the success of telework programs, but also the variables that are critical in improving each component and need to be explored in greater depth.

Application of Industrial Ecology to Identifying Pollution Prevention Strategies: Successes and Barriers to Success

Marta A. Panero, Susan E. Boehme, Charles W. Powers and Rashik Shaikh

Application of industrial ecology to identifying pollution prevention strategies: successes and barriers to success The New York Academy of Sciences has undertaken a study to identify pollution prevention (P2) strategies for contaminants entering the NY/ NJ Harbor. This study uses the tools of industrial ecology, mass balance and economic analyses to identify P2 strategies that will have the greatest environmental impact and that are economically feasible. Our first study under this program focused on the flows of mercury through the regional economy and identified key leverage points as mercury moves from one medium to another during the life cycle of various products and services. The research has been structured so as to identify levers of intervention for pollution prevention and abatement. The industrial ecology approach successfully identified the cumulative effect of small and dispersed sources, which represent a large proportion of mercury releases to the environment in the region. Traditional sampling strategies have not captured these sources. Together with risk assessments, these analyses are important to the policy determination process. The benefits of using a system's approach to the analysis of contaminants as well as examples of how this first study is being used by regional entities will be described. The second contaminant chosen under our program is Cadmium. While this work is still underway and these conclusions are tentative, the mass balance analysis suggests that cadmium releases to the Harbor have continued to decrease over the last 30 years. By tracking individual processes and products, however, we have identified Nickel-Cadmium batteries as a potential major target for pollution prevention actions to mitigate potential future source of cadmium to the Harbor (albeit indirectly through landfill leachate and combustion in WTE facilities). More immediately, this work revealed the low recycling rates for batteries in the NY/NJ region. As this study has moved forward on other contaminants in this region, issues related to data availability have become a much greater concern. Applying the industrial ecology approach to the case of mercury flows in the region was successful because this issue was topical and therefore a lot of data was available. However, application of this approach to other contaminants may be compromised by limited data. Furthermore, national material flows data collection efforts are now being curtailed, and input-output tables expressed in monetary units do not lend themselves to mass flow analyses. Nevertheless, this approach may be supplemented by local and regional data collection efforts, and examples of various cases will be presented. A sustained commitment to statistical and information data gathering efforts on material flows is essential to the success of the industrial ecology methodology. The kind of data that would improve the application of the IE approach to our case study will also be discussed.

Industrial Ecology- New Strategies for Developing Economies

Ramesh Ramaswamy

Industrial ecology offers exciting prospects of the development of a more holistic approach to the preparation of environment management plans for developing countries. Instead of framing environment management plans based on a strategy if just limiting harmful emissions from industrial activity, it may be more appropriate to develop plans based on an analysis of the flow of materials in the region, which would optimize use of resources. Through this, it may be easier to dovetail environment management plans with the development strategy of the region. This could result in much better results and greater community involvement in the programmes. To illustrate concepts, five case studies from India (which I have either carried out or been involved in) have been showcased in this paper. Each case study highlights some specific aspect of the applications of industrial ecology concepts in planning development. Given below is a very brief outline of each of the case studies presented. 1. The case study of the flow of materials in Tirupur, a town in the South of India, which is a major center for the manufacture and export of cotton knitted garments, highlights the use of a resource flow analysis in identifying wasted resources and detecting opportunities that such wasted resources present. 2. The case of Seshasayee Paper & Board limited (a paper manufacturer in the South of India) could serve as a possible corporate planning model for other business houses. The company has planned its business activities in such a way that it maximizes waste utilization. This could also serve as an example of a possible Ago-industrial eco system 3. An analysis of the Foundry cluster in Haora, near Calcutta presented an interesting example by which the study of two different subsystems in the region (metallurgical subsystem and the coal subsystem) provided an interesting direction for Research to replace Coke in the Cast Iron foundries, with coke oven gases. 4. The study of the tanning industry in Tamil Nadu from the viewpoint of Industrial Ecology led to a redefinition of the problem and hence to totally new strategy options for the sustainable development of the industry 5. An analysis of the Damodar Valley region in West Bengal and Bihar (a mineral rich region in the east of India and a major coal producing area) provided possible approaches to analyzing the Industrial Metabolism of large area with a mix of activities and material flows. The study pointed to new policy initiatives required to solve the environmental problems of the region The underlying theme of these cases is that all of them have aimed to find new strategies based on the principles of Industrial Ecology to combat traditional problems.

The Importance of Strategic Decisions in Sustainable Development

Ronald Wennersten and Nils Brandt

Industrial ecology is more and more accepted as an important concept in attacking many problems related to Sustainable Development. The environmental question in has turned from having a focus on emissions and point sources to products and services This has made the environmental issue in many ways more difficult to grasp than earlier. We now have a stronger focus on patters of consumption and transports, all based on a discus-

sion of changing life style. One implication of this has been that the market today has a more important role in the transition to a sustainable society. The result is a much bigger responsibility and demand on the individual consumer and producer. But what is the role of politicians and scientists in this perspective? Is the role of politicians only to form the border conditions for the development in the form of legislation, or is their role more to outline the visions for a sustainable society? What would then be the role of scientist in forming such a vision? The development of politics based on a common acceptance of the market economy as the general regulator for economic development, has made the discussion of political strategies for a sustainable development somewhat disreputable. The future should be directed through the many choices of individuals. In this article we will discuss the need for political strategies and public investments in the development of a sustainable society. We will also discuss the role of scientists in this process. Where are the borders between science and politics in designing a strategy for sustainability? Our basis for this discussion has been formed in a co operation our institute is involved in. During a longer period our institute has been involved as advisors in a regional developing program for sustainability in Stockholm. From our experiences in this work we can see that the politicians have big problems in important areas as traffic and energy. Most of the important changes in the area of traffic and energy will be related to changes in the individual life style, as changing transport patters, commuting, using warm water etc. There is no legislation that could solve this problem. It is very much a matter of attitudes and behaviors. The politicians have large problems in orienting in this world with environmental alarms from scientists and political opinions. Our paper will discuss these experiences and suggest some possible roads to a situation where visions can be formulated in a democratic process which citizens, scientists and politicians take part in.

Environmental Systems Analysis of Sector Politics

Rebecka Engström, Annika Carlsson Kanyama and Göran Finnveden

In a four-year research programme, with start during spring 2003, we are going to perform an environmental systems analysis of two sectors in Sweden: the agriculture and the energy sector. Through the analysis we want to describe not only the direct environmental impacts from the sectors, but also the indirect, that are caused by different actors up- and downstream as a result of decisions made in the sectors. The comprehensive picture we get in this way is essential to avoid sub-optimisation and to find resource effective solutions. Today there is no established methodology on environmental systems analysis of sectors. Thus we have to study different methods and their applicability for use in sector analysis. In Sweden an environmental systems analysis has earlier been made of the defense sector and in this case was used environmentally extended input-output analysis, with data from the System of Economic and Environmental Accounts. Another option can be to use LCA data from the different groups of products that come from the sectors. Strategic Environmental Assessments have been suggested as a tool for assessing environmental impacts of policies, plans and programmes. The role of SEA in evaluating sector policies and the possibilities of combining LCA, SEA and environmentally extended IOA needs further attention. In the presentation we will discuss possible approaches for evaluating environmental impacts

of sectors and sector policies and present some preliminary results for the agriculture sector with special focus on food products.

Technological Change and the Environment: Rethinking the Porter Hypothesis

Shunsuke Managi, James J. Opaluch, Di Jin and Thomas A. Grigalunas

Society faces important tradeoffs between economic production and environmental quality in the design and implementation of environmental controls. In carrying out this task on behalf of the public, government agencies must evaluate the technical feasibility, economic viability and, in a broad sense, the social desirability of new regulations which define implicit or explicit tradeoffs between environmental quality and production. Technological progress can plays a key role in the resolving environmental problems while maintaining a high standard of living. However, the extent of its contribution depends on how well environmental policies are designed and implemented. Successful environmental policies can encourage technological innovation, while poorly designed regulations can constrain and discourage innovation. This paper contributes to the literature on productivity change in several ways. First, we apply a nonparametric deterministic technologies technique to the Gulf of Mexico offshore oil and gas industry to measure various components of total factor productivity within a joint production model, which considers both market and environmental outputs. This contributes to our understanding of the impact that environment controls have had on various components of total factor productivity in this industry, and thereby the potential for technological change to maintain productivity in the face of increasingly stringent environmental regulations. We analyzed the contribution of technological change and efficiency change in Total Factor Productivity (TFP) both for oil & gas production sector and for environmental technologies sector. We developed a model to differentiate TFP into technological innovations, learning-by-doing and diffusion. This is important for providing an improved understanding of the process of technological change, and could contribute to design of effective policy. Next we apply two sets of models to test the Porter hypothesis. We apply Almon distributed lag models and Granger causality tests, to provide insights into the dynamic relationship between the stringency of environmental regulations and productivity, and thereby test the Porter hypothesis. We recast the Porter hypothesis to test whether environmental regulations enhance joint productivity of environmental and market outputs, in addition to testing the standard Porter hypothesis which applies to productivity of market outputs only. The direction of causality between environmental regulations and productivity change could go in either (or both) direction. Environmental technologies can clearly affect industry productivity. But causality could go in the other direction, since technical innovations could lead federal agencies to develop tougher environmental regulations that capitalize on these new technologies. Our results support the recast version of Porter hypothesis, which examine productivity of joint production of market and environmental outputs. But we find no evidence for the standard formulation of the Porter hypothesis that increased stringency of environmental regulations lead to increased productivity of market outputs. This finding could be due in part to the command-and-control design of environmental regulations in offshore oil and gas, which historically has not provided much latitude for innovation in achieving environmental goals. Flexible environmental regulations are required to provide incentives for innovation, which could result in a net positive effect on productivity.

Sustainable Transportation

Analysis of Materials Use in PEM Fuel Cell Vehicles

Joyce Cooper

A model for the estimation of power requirements and material use for the PEM fuel cell, batteries, and motor of hybrid vehicles is presented. The model uses vehicle characteristics (mass, shape, size, speed goals, etc.) and fuel cell design and performance data to estimate fuel cell, battery, and motor power requirements. Power requirements are then used to estimate material needs for the fuel cell (membranes, catalysts, bipolar plates, etc.) and other components (batteries, motors, glider enhancements) based on PNGV goals and 50 platforms that represent 95% of today's U.S. production. Material use for a variety of fleets is then estimated based on fuel cell vehicle market penetration scenarios. The analysis covers tradeoffs between fluorinated and non-fluorinated membranes; platinum and non-platinum-based catalysts; graphite, metallic, and composite bipolar plates; and different levels of fuel contamination.

Life Cycle Inventory of a Future Fuel Cell Vehicle

Marc Melaina

Fuel cell technology holds great promise for reducing environmental impacts from vehicles. Many of these reductions will occur across the fuel cycle, but changes within the vehicle life cycle must also be taken into account. Life cycle analyses have been carried out for a wide range of conventional and advanced vehicles, but few studies have examined fuel cell vehicles from a life cycle perspective. This is partly because fuel cell vehicles are still being developed, and significant uncertainties surround future vehicle configurations. Acknowledging that these uncertainties exist, and allowing for some speculation on future vehicle configurations and materials, it is possible to construct a theoretical inventory for a future fuel cell vehicle. The present paper extends the analysis methodology from an existing life cycle inventory study to assess a likely future fuel cell vehicle. An advanced vehicle design is assumed, resulting in an aluminum and magnesium intensive body. A theoretical hybrid electric fuel cell drivetrain is substituted for the conventional internal combustion engine drivetrain. Vehicle parameters are based upon the Ford P2000 prototype fuel cell vehicle. The component substitution methodology is explained in detail. Uncertainties surrounding the modeling of components unique to fuel cell systems are discussed. Energy and greenhouse gas emissions are calculated across the vehicle life cycle and comparisons are made between a high fuel economy conventional vehicle, an advanced hybrid electric diesel vehicle, and the advanced hybrid electric, direct hydrogen fuel cell vehicle. A

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discussion of results includes reflections upon how alternative future fuel cell vehicle configurations may influence energy and material intensities across the vehicle life cycle.

Recycling Proton Exchange Membrane (PEM) Fuel Cell Systems

Stella Papasavva, Rob Privette, Angie Coyle, Renato Legati, Larry Frisch., Richard Paul

In 1999, the Society of Automotive Engineers established a Committee for Fuel Cell Standards. The Committee is organized in subcommittees that address issues such as Safety, Performance, Terminology and Recycling. The mission of the Recycling Subcommittee was to develop a preferred practice document, SAE J2594, that incorporates existing recycling practices and identifies technical, economic, and environmental sustainability issues and applies them to proton exchange membrane (PEM) fuel cell (FC) systems. Recyclability should be considered early in the product engineering design/development process in order to enhance its potential of reuse or recycling at the end of its lifetime. The focus of this presentation is to provide a quick overview of the conclusions of the SAE J2594 preferred practice document. The boundary of the system studied includes: Fuel Supply and Storage, Fuel Processor, the Proton Exchange Membrane (PEM) Fuel Cell Stack, and Balance of Plant.

Towards a Sustainable Personal Transport Sector: Assessing the Potential of Cellulosic-Derived Ethanol

Heather L. MacLean, Michael Griffin, Satish Joshi, Lester B. Lave

An attractive fuel for moderate to large-scale use in the personal transportation sector is ethanol produced domestically from cellulosic feedstocks. Although cars and light trucks offer many benefits, they are far from sustainable. Throughout their entire life cycles, huge amounts of nonrenewable resources are consumed and tons of pollutants and greenhouse gases are discharged, resulting in considerable impacts on human and ecological health, and ultimately, our economy. Considering the more than 700 million vehicles worldwide, it is critical to find affordable, profitable, and safe solutions to these problems that lessen environmental impacts. Driven by these concerns and by pressure from regulators and consumers for a more sustainable system, automotive manufacturers and fuel providers will have to make radical changes in their product offerings. This paper focuses on improving the sustainability of the fuel production and combustion components of the life cycle. Our paper starts with an overview of the current situation; none of the fuels being used in the sector are sustainable. Next, we discuss two primary fuel candidates whose production and use could move the sector toward sustainability; cellulosic-derived ethanol and renewable hydrogen. In the remainder of the paper we focus on ethanol since it could be used in internal combustion engines, transported through our existing infrastructure (with modifications), provided at conventional style refuelling stations, and has a near-term time frame. Displacing gasoline currently used in the light-duty fleet with a domestically produced, cellulosederived fuel has the potential to offer huge gains on the path to a sustainable personal transport sector. We evaluate the desirability of the cellulosic ethanol industry and associated transportation sector. For example, based on preliminary calculations, we find that the U.S. and Canada could replace the 130 billion gallons of gasoline used in their light-duty fleets each year with domestically produced cellulosic ethanol. Assuming the use of a dedicated energy crop feedstock, we calculate that 80 to 240 million hectares of land would be required. The calculation assumes cellulosic biomass yields ranging from 9 to 22 metric tons of biomass/ha and ethanol yields of 88 to 110 gallons/ metric ton. Utilizing a life cycle approach, we detail selected regulatory, technical, environmental, economic, and social conditions under which the production and use of this fuel would be attractive. The results of the research provide insights for informed decision-making regarding long-term feasibility and R&D priorities, information necessary to make an efficient transition to more profitable and sustainable economies.

The Environmental Impacts of Cruise Ships: A Preliminary Use Phase Life-Cycle Inventory and Regulatory Analysis

Cathy Polityka Juilette Commoy Jonathan W. Bulkley

The cruise ship industry is large and rapidly expanding. In 1994, cruise ships carried 4.8 million passengers. In 1998, more than 223 cruise ships worldwide carried an estimated 9.5 million passengers. From 2001 through 2005, major cruise ship companies plan to add 39 new ships to the North American fleet. Mega-ships, ships with 2,000 or more lower berths, will account for 69% of the increased capacity. The average cruise ship in 2005 will have a capacity that is twice the size of the average ship currently sailing in the North American market. The size of the cruise ship industry correlates to the current and future environmental burdens of the industry. These burdens include the discharges of wastes into the coastal waters, air and noise pollution, plus the impact on ecologically sensitive areas from the increasing volume of cruise ships and passengers. The negative environmental impacts of cruise ships are significant for two main reasons. First, the cruiseship industry is not subject to the same environmental standards as land-based industries. In addition, where regulation exists, there is little effective enforcement of the regulations. Second, the environmental impacts of the cruise ship industry are further intensified by the concentration of vessels in environmentally sensitive areas. This paper will focus upon three major tasks. First, it will provide an introduction to the identification of the various cruise ship waste streams. These waste streams include for example, oil pollution, sewage or black water, non-sewage or gray water, hazardous wastes, solid wastes, air pollution, and ballast water. Second, it will identify and discuss the existing regulations for each of these waste streams. A discussion will be included on the adverse environmental impacts arising from the dual problem of lack of regulations and the lack of effective enforcement of the regulations in place. Third, a preliminary life-cycle inventory analysis on the use phase of the cruise ship will be utilized to couple the information developed on the volume and characteristics of various waste streams coming from cruise ship operations together with the analysis of the current regulatory framework. The resulting information will be helpful in identifying where regulatory gaps need to be addressed as well as identifying waste streams that need more effective control in order to reduce environmental burdens arising from the cruise ship industry. It is anticipated that new and promising technologies will be evaluated through the framework of the use phase life-cycle approach to assess their potential effectiveness and potential for application to reduce environmental burdens for the cruise ship industry. The purpose of this research effort is to encourage the utilization of more effective regulations and waste elimination techniques to attain more sustainable cruise ship operations. These new operations will lead to a sustainable form of travel that will address environmental issues of various stakeholders, the cruise industry included.

Mobility Contribution Metric

Thomas A. Cors, Esq., Joseph Burns, Brian Knight

Mobility technology is beginning to shift from the internal combustion engine to a variety of technologies including modifications to the internal combustion engine such as direct injection, development of hybrid electric vehicles, developing ultra-clean diesel engines, as well as deploying fuel cells. Today there is no comprehensive, multivariate metric that measures the contribution of different powertrain technologies to an overarching goal of sustainable mobility. Corporate Average fuel Economy (CAFE) as a regulatory standard ignores critical energy, economic and environmental indicators that must be measured if a meaningful metric is to be achieved. A mobility contribution metric is proposed that is capable of evaluating various transportation technologies by a common yardstick by incorporating disparate measures from other leading studies into a composite score. Existing and emerging powertrain technologies are be evaluated to the goal of sustainable mobility, defined as the highest degree of personal mobility at the lowest societal cost. Personal mobility could include factors such as safety, interior space, low fuel costs, acceleration, and affordability. Societal costs could include energy dependence, environmental impact, sprawl and congestion. Any analysis must be from production of energy to consumption of that energy, or 'well to wheel' to fully appreciate impacts of different powertrains. This metric incorporates the entire energy pathway from existing well-to-wheel analyses. It is capable of evaluating technologies on as many factors as desired to allow for a complete evaluation of any transportation technology. Also the metric allows for the greatest policy concerns and interventions to have more effect on the final analysis. This report will offer insight on the methodology and will show the full potential of this new evaluation process. Developing a metric that accounts for as many factors as desired allows policy makers, manufacturers, and consumers to analyze the systems impact of new power technologies.

Sustainable Manufacturing

Seeking Sustainability; Why Only for Some?

J.C. Powell and M. Peters

It is an obvious fact that some organizations strive for sustainability whilst others do not even consider it. Given a level playing field what makes the difference? This paper

will describe two research projects; firstly a survey based study on why some UK organizations seek to adopt of green energy initiatives; and secondly a case study of how the authors endeavoured to improve the sustainability of an industrial site. The first study consists of in depth interviews with a range of organizations, including local and regional government, and industries, that either have, or have not introduced green energy initiatives such as the purchase of green energy, wind turbines, fuel cell CHP. Some potential barriers such as the long pay-back time, or, more recently the new electricity trading arrangements (NETA) can be identified, but there is a need to find out why these constraints influence some decision makers more than others. What makes one organization welcome the challenge of renewable energy whilst others hardly consider it? The second study overlaps with the first but takes the questions further. Why does one specific organization have an enthusiasm for sustainability, what are the opportunities, and how far are they prepared to go to become sustainable. Is it a question of money or good public relations or a sense of doing 'their bit' for the environment? The 'best' methods of improving sustainability will be identified and quantified. The paper will explore the drivers that lead this organization towards sustainability and will compare them with those revealed in the 'green energy' study. Lessons from both studies will be identified and recommendations for other organizations will be made.

Efficiency, Eco-efficiency and the Environment

Timothy Gutowski and Jeffrey Dahmus

Efficiency, Eco-efficiency and the Environment Timothy Gutowski and Jeffrey Dahmus Massachusetts Institute of Technology, Cambridge, MA Eco-efficiency is a form of conservation in which the material or property conserved produces some environmental load. Eco-efficiency, "e", is then usually written in terms of the goods and services produced per unit of environmental load. Examples include cars produced per unit of CO2 emitted and computers produced per unit of water used. Normalizing units of goods and services by environmental load assigns responsibility and allows for differentiation between producers. Note also that when the IPAT equation is written for a particular good or service, "1/e" is identical to "T". Eco-efficiency is popular among companies as a method to demonstrate social responsibility. Many companies, especially large international ones, now produce environmental or social responsibility reports. Such reports present company performance, based on internal audits, in terms of eco-efficiency measurements. These reports have become so popular that a recent book provides guidelines to help companies write effective reports [Ref. 1]. Another recent book, written by a pair of former CEOs, provides numerous examples as well as guidance on how to increase eco-efficiency [Ref. 2]. In a recent international study of environmentally benign manufacturing [Ref. 3], win-win environmental initiatives, usually in the form of eco-efficiency, were very popular among companies and often served as "role model" projects for promoting eco-efficiency throughout the firm. Still another report, this one from the OCED [Ref. 4], is generally positive about the potential benefits of eco-efficiency at many levels in society. In this presentation we will report preliminary results from a study of the real effects of eco-efficiency on the environment. As we try to identify green engineering principles, it is extremely important to understand the effectiveness of eco-efficiency. It is also important that we identify clear simple guide-

lines for engineers to follow in order to contribute positively to the environment. Here we will report observations based largely from historical data for efficiency trends, primarily in terms of energy and materials usage in the production of materials and products. These trends, which cover the last century and more, clearly demonstrate very active efficiency activities within industry, many of which could be labeled eco-efficiency. This of course is good. However, improvements in efficiency often show a strong positive correlation with increased production. (There are however some important exceptions). The end result is that the environmental load increases. We address the issue of causality, that is the cause and effect relationship between efficiency and production, by arguments based upon the motivational structures for the winners and the losers. Each time a resource is reduced some players win and some lose. Their behavior can be explained by their instinct to survive and simple economic theory. Our results put strong qualifications on the real benefits of eco-efficiency for the environment. The results can be stated simply as follows. If the resource target of eco-efficiency has economic value then it is likely that the old pattern of increased efficiency and increased production will emerge. On the other hand, if the resource target of ecoefficiency does not have economic value, then engaging in this kind of activity is questionable for the firm. However, two possibilities exist for other potential gains. These include; 1) longer term cost savings, for example due to avoided contingency costs for future cleanups, lower labor costs, or perhaps a lower price for capital, and 2) new value creation, for example it is often claimed that these kinds of activities help with the recruitment and retention of talent, or in the creation of brand name identity. The demonstration that these last two items might contribute positively to the firm is an area of active research. Yet, even if these benefits accrue it is not clear whether or not they will be followed by increased production. The underlying question here is if society will ever have enough. To answer this the real value proposition most likely lies outside the firm, where values can be created by society; for example, by the creation of pollution trading permits, taxes on the use of materials and energy, and take back laws as well as potential buy backs of resources. Nevertheless, our conclusion is that improving ecoefficiency is better than the alternative. It performs important social roles of building skills, motivating engineers, assigning responsibility, and helping increase the profile of the environment. However, as a means of protecting the environment, it is likely to fall very short of what is required without the necessary external value proposition.

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Toward a Sustainable Plastics Supply

Pedro Rios, Julie Ann Stuart, Ed Grant

In current practice, the plastics supply chain is almost entirely geared toward consumption and disposal. The alarming rate of production, consumption, and disposal of plastics, a non-renewable petrochemical resource, constitutes a serious challenge to the sustainability of contemporary manufacturing. Even though most thermoplastics are recoverable and reusable, nearly 95 percent of all plastic produced is simply used and landfilled. To a great extent, this situation exists as a consequence of the plastics manufacturing supply chain, which has developed without regard to the principles of industrial ecology. In order to use industrial ecology principles effectively in the plastics supply problem, one must expand the concept of a plastics manufacturing supply chain to encompass the entire materials life cycle. Annual flows through the plastics supply chain to the sink include nearly 3 billion pounds of high-value engineering plastics from end-of-life electronics(*). Furthermore, housings of electronic products are increasingly composed of engineering plastics rather than metals. Since current efforts to recover plastics from electronics are extremely limited, models and technology are urgently needed to increase the efficacy of plastics recycling. In this paper, we present new enabling technologies for materials analysis and evaluate three different recycling process designs with potential value-added links to manufacturing. The first scenario represents a typical process flow for recycling end-of-life electronics, which begins with manual disassembly to remove regulated hazards and separate some materials of value, followed by shredding. Automated processes separate ferrous metals, non-ferrous metals, glass and plastics. This approach confronts processors with the problem that its plastics output is mixed and thereby offers little value as a raw material for manufacturing uses such as molding. In the second and third scenarios, we add precise spectrochemical plastics identification and separation steps to test the effectiveness of these measures as a means of adding value to the plastics recycling stream. Our study focuses on the three dominant resin types found in end-of-life electronics equipment: ABS, ABS/PC, and HIPS. We further identify and separate PVC to because it has a disproportionate negative value as a contaminant. To evaluate the three scenarios, we have undertaken a new program of reverse production planning research, applying largescale modeling technology to a supply stream that consists of end-of-life personal computers and televisions. This study explicitly simulates different electronics return rates. Results characterize the three scenarios described above on the basis of (1) weight percentage of each type of plastic separated per product, (2) each type of plastic recycled per 8-hour recycling shift, and (3) recycling costs per kg of plastic recycled. We find that metrics (1) and (3) are the ones that will be most important to those who seek to recover value from end-of-life electronics. Metrics (2) and (3) are needed to forecast the supply of recycled plastics at various grades for manufacturing new goods. Our results suggest that resin identification at the point of disassembly offers a means both to improve the economics of plastic materials recovery and provide a certification of recovered product purity that will build confidence in the marketplace. (*)P. S. Dillon and E. N. Aqua, "Recycling Market Development for Engineering Thermoplastics from Used Electronic Equipment," Chelsea Center for Recycling and Economic Development, University of Massachusetts, Chelsea, Massachusetts, Technical Report 20, March 2000.

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Comparative Life Cycle Assessment of Portland Cement Manufacture from Contaminated Sediments vs. Conventional Materials

Thomas P. Seager, Kevin Gardner, Jennifer Dalton, Mindy Weimer

Sedimentary benthic materials may be dredged from rivers, estuaries, harbors, and other natural waterways to either enhance navigation, remove contaminants, or both. Both the dredging process and management of the dredged materials are contentious issues, especially when contamination is present. The most economical alternative is ordinarily to dispose of dredged materials in the ocean. However, passage of the Clean Water Act (CWA) and the Marine Protection, Research and Sanctuaries Act (MPRSA) have greatly restricted ocean disposal in the United. The closure of traditional ocean dumping sites, limitations by the CWA and MPRSA on new dumping sites and a shortage of suitable upland disposal sites have caused a crisis for contaminated sediment management programs. Therefore, there is increased interest in beneficial reuse of dredged materials. Development of cost-effective, environmentally sound dredged material management alternatives is a critical opportunity for industrial ecology to inform management decisions that can have far-reaching economic, environmental and ecological consequences. This research quantifies the life-cycle ramifications of using contaminated sediments as an alternative mineral feedstock in manufacture of Portland cement. The chemical compositions typical of sediments and conventional raw materials are similar, allowing partial substitution of dredged material. Laboratory results suggest that cement can be manufactured from contaminated sediment samples without jeopardizing structural characteristics. Consequently, this application may have several environmental and economic advantages over current permissible disposal practices such as landfilling. The high temperatures attained in cement kilns effectively destroy organic pollutants (e.g., PCB's). Metals, with the notable exception of mercury, are retained in the cement product and become largely immobilized in concrete products. Therefore, pollutants of concern may be destroyed or effectively sequestered from the environment. However, the process is expected to work best in wet-process plants, which are less energy efficient that dry-process, and chloride fouling of the kiln is expected to require more frequent maintenance. Nevertheless, increased energy requirements in processing may be partially offset by transportation savings, while increased maintenance costs are offset by savings in landfill tipping fees and reduced raw material costs. This research is expected to inform sediment management decisions. It has the potential to foster less expensive remediation of contaminated sites and more sustainable production of Portland cement and concrete products.

Rapid Enumeration of Bacteria in A Model Metalworking Fluid for Sustainable Metal Fabrication

Shu-Chi Chang, Alexa Rihana, Cyndee L. Gruden, and Peter Adriaens

Currently, the U.S. annual metalworking fluids (MWFs) consumption is estimated to exceed 770 million gallons based on an expected annual increase at 5.3 %. MWFs account for 12-17% cost of the whole metal production processes in a typical automotive company and could account for 48% for more rigorous metal fabrication processes in a machining plant. Biofouling of MWFs due to biodegradation of major components results in serious wear and corrosion of machining tools, health threatening endotoxin release and consequently, more frequent discharging to wastewater treatment. Therefore, monitoring microbial growth level and following by biocide addition or filtration actuation in MWFs systems is a common practice for metalworking processes. Currently, most end users still rely on dip-slide estimation methods to monitor the microbial loads in MWFs system. This method takes 18 to 36 hours for incubation only and poses biases on slow-growing and aggregated bacteria, and also viable-but-not-culturable bacteria; and, therefore, cannot provide real-time data for the field practition ners to make informed decisions.

Here we describe a novel method to quantify total bacteria directly in a typical semisynthetic MWF by epifluorescent microscopy (EPM) and flow cytometry (FCM) with nucleic acid dyes. Mycobacteria are relevant target microorganisms in metalworking fluids (MWFs), due to their recent recovery from industrial systems and their potential implication in respiratory illness. Whereas a number of detection technologies are available to monitor microbial contamination in MWF, no methods have been developed for the detection of Mycobacteria in these matrices. We report here a novel method for detecting Mycobacterium parafortuitum in a semi-synthetic MWF with nonspecific nucleic acid dyes using flow cytometry (FCM). Following disaggregation of bacteria through (probe) sonication, the emulsion was destabilized using isopropanol (IPA) to minimize the nonspecific binding of the fluorescent dye to MWF components. The quantitative results show good correlation with direct counts using epifluorescent microscopy (EFM) within the range of 2.31x10⁴ to 2.31x10⁷ cells/ml. The time required to complete FCM and EFM enumeration was 10 and 300 seconds per sample, respectively. These results lend support to the applicability of FCM, a multi-parametric data acquisition technique, for microbial detection in these complex fluids.

Life Cycle Assessment that Leads to Improved Environmentally Conscious Manufacturing of Automobiles

Qiong Zhang, James R. Mihelcic, John C. Crittenden, David R.Shonnard

Our group has recently published research that evaluated four risk assessment methods in order to improve our understanding about the required complexity required for transport and exposure assessment. We have applied our approach to a variety of

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environmentally conscious manufacturing decisions that include: selection of chemicals, selection of chemical reaction pathways, plant-level optimization of manufacturing equipment, and evaluation of U.S. Toxicity Release Inventory (TRI) data. In this study, we apply our risk assessment methods and a detailed chemical fate and transport model we recently developed for large regional scales (the model is called CHEMGL) to output we obtained from the economic input-output life cycle assessment (EIO-LCA) model. This was done to investigate sustainability issues associated with the production of motor vehicles and passenger car bodies. The EIO-LCA converts economic activity to environmental releases and also identifies individual releases associated with a product's complete supply chain. Previous researchers have weighted environmental releases obtained from the EIO-LCA to relative toxicity and determined that the overall toxicity ratio from the total supply chain associated with automobile production was approximately ten times larger than that reported by the "motor vehicles and passenger car bodies" sector alone. However, that previous work did not consider chemical fate and our previous studies have clearly shown that a detailed estimation of chemical fate is required to perform environmental risk analysis for emissions of chemicals that have different physical chemical properties. This is especially important for automobile manufacturing where over 350 chemicals, of varying chemical properties, are released. Our ultimate goal is to provide automotive decision makers (and other industrial sectors) with critical information associated with automobile manufacturing that can not only be used to identify the chemicals most toxic to humans and aquatic life, but also identify persistent and bioaccumulative chemicals of concern. This information can then be used to minimize the environmental impact associated with manufacturing processes.

Material/Substance Flow Analysis

Material and Economic Flows in the Global Production Chain for High-purity Silicon

Eric Williams, Miriam Heller

Material and economic flows in the global production chain for high-purity silicon, microchips, optical fiber, and solar cells are analyzed in order to identify shifts in economic structure relevant to environmental issues. The production chain yielding silicon wafers from quartz uses 160 times the energy required for typical silicon, indicating that purification to semiconductor grade materials is energy intensive. Results suggest that the economic and environmental weight of high-tech manufacturing and specialized material sectors will increase significantly relative to extractive and primary commodity sectors, perhaps reaching a similar environmental scale within a few decades. Though further study is needed, the forecasts suggest that a re-prioritization of analysis and policy to address these new industries is in order. The Materials Flows Analysis at the global sector level is then followed up by a life cycle assessment for a high-tech product: a 32MB memory chip. Results indicate that the weight of fossil fuels and chemicals consumed in manufacture and use of one 2-gram chip total at least 1.7 kilograms. Due to its extremely low-entropy, organized structure, the materials intensity of a microchip is orders of magnitude higher than that of "traditional" goods. Future analysis of semiconductor and other low entropy high-tech goods needs to include the use of secondary materials, especially for purification.

Material Flow Analysis with Time-Dependent Stocks and Flows : A Case Study from the UK Iron and Steel Sector

Jennifer Davis, James Ley, Roland Geyer, Roland Clift, Tim Jackson and Michael Sansom

This paper explores the practical difficulties inherent in and the information obtainable from carrying out a Material Flow Analysis (MFA) of a major material in the industrial ecology : steel. Throughout the world, steel is established as a multiply recyclable material, with relatively high recovery rates compared to most other materials. However, the paths along which steel moves through the economy are complex; this was one of the observations (in the work of Frosch in particular) which led to the development of the concept of industrial ecology. Quantifying and predicting the flows of steel through different uses is notoriously difficult. The problems arise in part from the fact that steel is liable to contamination by a wide range of other substances, leading to complex (and not universal) systems for classifying scrap steel. However, further problems arise from the fact that different uses for steel have a very wide range of service lives, ranging from weeks (e.g. cans and packaging) through years (e.g. cars and appliances) to decades (e.g. buildings). Therefore the significance of stocks in the economy range from slight to dominant. For uses where the stocks are significant, estimation of future scrap arisings depends on knowledge of both the quantity and age of the existing stock and the distribution of service lives. This paper sets out an approach to MFA for materials with significant stock-in-use, using steel in the UK economy as a case-study. Historical data for quantities of steel going into use have been compiled in the form of a time series, disaggregated into different groups of goods. The data compilation illustrates the practical difficulties encountered in obtaining sufficiently complete data, particularly for this kind of material for which a short-term mass balance cannot be formulated because of the significance of stock changes. Data gaps are identified, together with approaches for obtaining estimates for missing data. Estimates for the service life of steel in different product groups are used to estimate future scrap arisings, using a new approach based on the theory of residence time distributions in chemical processing operations. The inferred scrap arisings are compared to data on actual scrap consumption to estimate accumulation/leakage of steel scrap in the UK. The analysis serves to identify sectors which should be targetted for increased scrap recovery. The modelling approach is also used to investigate how sensitive scrap arisings will be to changes in stock. The steel construction sector is analyzed in more detail, as one in which service lives are long and variable. One corollary is that records to indicate scrap quality may not be available so that materials and components may be unnecessarily "downcycled" or recycled rather than re-used. The implications, including the potential economic and environmental benefits, of improved record-keeping are discussed.

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Input Output model of Japanese Material Flow for Metals

Shinsuke Murakami, Tsuyoshi Adachi, and Gento Mogi

Recently, Japan has been trying to shift from conventional economic system of the mass production, mass consumption, and mass disposal to JUNKANGATA-SHAKAI (recycling-oriented economic system.) Japan has been poor in natural resource enough to consider recycling seriously. In addition, it has experienced the shortage of not only natural resources but also of the space for final disposal site these days. Therefore, Japanese government set the transition to the JUNKANGATA-SHAKAI as their political target so as to avoid making these problems more serious. Even though this Japanese word, JUNKANGATA-SHAKAI, is translated as recycling-oriented economic system, they suggest the implementation of three "R"s, which includes not only Recycling but also Reduction of waste, and Reuse. These three "R"s obviously work well with some materials. However, for certain materials, recycling already has its long history so that further promotion of the three "R"s may be difficult. Even in the case of less recycled materials, if its material flow being complex and interact with others', all three "R" s do not necessarily works well simultaneously. In order to solve to these problems, material flow analysis should play huge roles. As examples of materials with matured recycling and complex flows, metal materials are chosen. Gold, silver, copper, lead, zinc, aluminum, nickel, chrome, tungsten, cobalt, molybdenum, manganese, antimony, platinum, palladium, titanium, magnesium, and tin are described in the model. The availability of data prevented to include other metal materials. The material flows of these eighteen minerals are described from ores to final wastes, including recycling and reuse. Since our primal concern is only on metal materials, other materials inputted inside the flow are not counted. The model takes the form of Physical Input Output Table. However, it is slightly different from conventional ones. In the metal material flow, there are so many activities, which produces more than one output from one input, like as recycling and smelting. Then, dividing the flow into smelting, manufacturing, and recycling and combining refinery and recycling as "extraction," we modeled the flow with following two tables, namely "Extraction Table" and "Manufacturing Table." Outputs of "Extraction Table" enter the "Manufacturing Table" as its inputs. With some static analysis with this model, our conclusions are as follows. Firstly, simultaneous promotion of all three "R"s is difficult in the case of the metal materials. In addition, even only for recycling, it is difficult to practice simultaneously among many different materials, when horizontal recycling cannot be applied.

Meso-scale MFA for Filling the Gap Between MFA in Nation-wideeconomy and MFA in Micro-economy - Sectoral Decomposition and Spatial Decomposition

Yuichi Moriguchi, Hidefumi Imura, Hiroki Tanikawa

Material flow analysis/accounting (MFA) is one of the key players of Industrial Ecology studies. MFA has been typically applied in a macro economic level to quantify total inflows and outflows for sustaining a country. On the other hand, microscopic analyses of material flows associated with products, within a firm, and among firms in an industrial estate are incorporated into other IE research such as Life Cycle Assessment, corporate environmental accounting and industrial symbiosis studies. Although the same principle of physical accounting for material flows is employed, studies in these two extremes look very differently and there exists a considerable gap between them. One promising method for filling this gap is to capture overall pictures of inter-sectoral material flows by decomposing macroscopic material flows in a nation-wide level and/ or by aggregating microscopic flows from a firm level. As an example of such approach, multi-dimensional physical Input-Output tables were designed and empirical tables for typical resource categories were compiled. Another potentially promising approach in meso-scale MFA may be exploited in capturing material flows associated with a specific geographical component such as a region or a municipality. Quantification of interspatial material flows among these components, intra-spatial material flows within a component, as well as material accumulation in a component shows us various interesting pictures. They are, for example, mutual inter-dependency between urban and rural areas, transportation of raw materials, products and wastes, as well as intensive accumulation of materials in infrastructures. Moreover, understanding of a whole picture of metabolism will be essential for sustainable management of regional resources As empirical examples of this approach, several case studies for analyses of actual material flows/stocks around different geographical components in Japan are presented. Some studies try to capture the embodiments of environmental burdens, which are hidden behind the actual flows. In addition, the possibility to integrate inter-sectoral flow analysis and inter-spatial flow analysis using a framework of multi-regional Input-Output tables will be discussed.

The Stocks and Flows of Nitrogen and Phosphorus in Finland

Riina Antikainen

The strong influence of human activities on the natural cycle of nitrogen (N) and phosphorus (P) has lead to many environmental problems, e.g., eutrophication, acidification and pollution of ground water. In the Netherlands, for example, agriculture has been identified as clearly the most important factor affecting the nitrogen cycle (Olsthoorn & Fong 1998, Nutrient Cycling in Agroecosystems 52: 269-276). In Finland, the share of agricultural land of the total area is 8%, whereas in the Netherlands it is 53%. Finland is mostly covered by forestry land (68% of the total area).

In Finland, a project called AESOPUS (Analysis of Nutrient Cycles in Ecological and Socio-economic Systems for Policy Purposes) was started in 2001. The aim of the project is to identify and quantify the stocks and flows of N and P within and between different sub-systems (forests, agricultural land, fresh waters, industry, energy production and transportation, consumption, waste management and wastewater treatment) in Finland. Inputs and outputs of nutrients in foreign trade, emissions to sea and air and deposition are also analyzed. The method used is substance flow analysis (SFA). The most important data sources are official Finnish statistics and literature sources.

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In this research contribution proposed to the ISIE 2003 conference, tentative results from the period 1995-1999 are presented. Although the share of forestry land is high in Finland, the in-put of N from agriculture to the industrial system was twice (53 000 t a-1, on average) the N input from the forest system (27 000 t a-1). The input of P from agriculture was three-fold (9 700 t a-1) compared to the forest system (3 100 t a-1). However, if peat production is included in the forest system, the picture is different. The amount of N in peat was ca. 70 000 t a-1 and the amount of P 3 000 t a-1. In addition to peat, other elements of the energy production and transportation system were of high significance. Coal was the largest source of imported nitrogen (import of fertilizers and their raw-materials excluded). Ca. 112 000 tonnes of N were annually deposited in Finland (sea areas excluded), while the emissions of N accounted for about 124 000 t a-1, originating mostly from energy production. For comparison, the input of N in synthetic fertilizers to the agricultural system was ca. 180 000 t a-1. More phosphorus was exported from Finland than imported, because the only apatite mine in Western Europe is situated in Finland. However, less than 1% of the total phosphate production in the world takes place in Finland.

Later, historical and future changes in nutrient flows will also be studied. A macro-economic analysis will be used to study the influence of policy interventions and the impacts of consumer preferences on the nutrient flows.

Materials Flow Analysis (MFA) based Indicators of Sustainable Development

Iddo Wernick, Amy Cassara, Don Rogich

Data on materials flow form a critical subset of the information necessary for national level indicators of sustainable development. Working with partners in the federal government, the World Resources Institute is developing a database on material flows in the United States using a uniform and consistent format for handling commodity data across material sectors. The MFA database formalizes the flow characteristics for individual commodities and establishes relationships among flows. Already established MFA based indicators include the Total Material Requirement (TMR) for materials inputs and Total Domestic Output for outputs. The database will allow for generating a fixed set of indicators as well as the opportunity for creating new indicators of national environmental and economic performance based on structured MFA data.

Input-Output Analysis in LCA and MFA

Industrial Ecology of Portuguese Glass Products based on Hybrid Input-Output Analysis

Paulo Ferrão, Jorge Nhambiu, Sangwon Suh

Life Cycle CO2 for Portuguese glass products is analyzed making use of integrated

hybrid Life Cycle Assessment (LCA), and a software for the hybrid LCA is constructed. Detailed process analyses for the product system of Portuguese glass products manufacturing is performed and extended with existing process-specific database. Compiled process-specific, foreground system is inter-linked with the Portuguese national economic system using information on cut-offs. The cut-offs for the glass bottle manufacturing processes are directly linked to the input-output table, while those for existing databases are estimated using relevant columns of Portuguese and other countries? input-output table. Detailed Portuguese input-output table with energy and fossil fuel oriented CO2 emissions information is constructed using a comprehensive energy use statistics and a set of emission factors. Based on the hybrid product system that is linked with its embedding Portuguese economic system, a number of scenarios are developed to evaluate different options of glass recycling in Portugal. The results show that the direct fuel use by the bottle manufacturing is the most important sources of the CO2 emission, while there are a few important contributors from the upstream inputs as well. Especially, the hybrid input-output analysis elucidates the role of capital, which is generally not accounted for in Life Cycle Assessment (LCA), and, further, create a better platform to develop and evaluate different scenarios by providing the interdependence between the detailed product system and the national industrial system.

Hybrid Life Cycle Assessment of Natural Gas Based Fuel Chains and End use in Transportation

Anders Hammer Strømman, Marte Kjølberg Halvorsen, Edgar Hertwich

Emissions from the transportation sector are a persistent concern. The need to reduce local air pollution as well as the emissions of greenhouse gases has given an incentive to study and develop alternate fuel chains and car power trains. Investing in new technology and infrastructure is costly, and it is therefore important that a holistic assessment of these technologies is performed if an environmental justification for their introduction shall be valid. Avoiding problem shifting of environmental impacts from one impact category to another or to other steps in the value chain is crucial. The life cycle assessment framework offers the possibility to investigate this. We use the hybrid inventory model to establish a more complete inventory by including economic flows as well as mass and energy flows. In this paper we assess a set of alternate automotive fuels, based on natural gas, and their corresponding car power trains are assessed using hybrid life cycle analysis. We investigate several fuel chains that begin with the production and refining of natural gas in Norway and include the transportation of the fuel to central Europe. We established inventory data and assessed Fuel Chains for Liquid Natural Gas, Methanol and Hydrogen. For car power trains, we base our analysis mainly on literature data.

An Empirical Analysis of Hazardous and Other Wastes Embodied in the 1995 Japanese Economy

Shigemi Kagawa, Seiji Hashimoto, Rokuta Inaba and Yuichi Moriguchi

The present paper investigates sectoral differences in the generation of hazardous wastes and other wastes embodied in the 1995 Japanese economy. The important features of the present study are (1) a waste generation matrix (69 industrial wastes) for 1995 showing the final and intermediate disposal quantity for each industrial waste jointly generated by the unit production of each industry, was constructed from industrial waste data collected by each local government; and (2) the 1995 waste generation matrix was applied to competitive and non-competitive imports input-output model (92 sectors), which enabled us to determine the major economic driving forces of the embodied waste generation (intensities) from the viewpoint of domestic waste balance. More concretely, the 69 industrial wastes were categorized into 12 types of hazardous wastes (incineration ash containing toxic substances, organic sludge containing toxic substances, inorganic sludge containing toxic substances, waste oil containing toxic substances, acid waste fluid containing toxic substances, alkaline waste fluid containing toxic substances, waste plastics containing toxic substances, waste paper containing toxic substances, wood chips containing toxic substances, slag containing toxic substances, waste particles containing toxic substances, and infectious medical wastes) and other wastes. The primary findings of the present study are as follows: (1) For the final waste disposal intensities embodied in the unit production of each sector, the top five sectors were non-ferrous metal ores (6,783 kg/million yen), miscellaneous ceramic, stone and clay products (2,636 kg/million yen), non-ferrous metals (2,337 kg/million yen), cement and cement products (1,320 kg/million yen), and water supply (725 kg/million yen). (2) Considering the embodied final waste disposal intensity per unit of the embodied waste generation intensity, the values for water supply, pulp and paper, processed paper products, timber and wood products, printing and publishing, and chemical fertilizer were found to comprise less than 10% of the final waste disposal intensity. The contribution of these sectors to the reduction in the final disposal quantity was significant. (3)F or the embodied generation intensities of hazardous wastes, the top five sectors were industrial organic chemicals (13.5 kg/million yen; primarily waste oil containing toxic substances), steel products (10.2 kg/million yen; primarily waste plastics containing toxic substances), resins (7.8 kg/million yen; primarily waste oil containing toxic substances), steels (5.3 kg/million yen; primarily waste particles containing toxic substances), and medical services and health and hygiene (4.3 kg/million yen; primarily infectious medi-The major economic driving forces of embodied waste generation were cal wastes). (4) household consumption expenditure (32% of total waste generation 323,261 (thousand tons)), domestic private capital formation (28%), and domestic public capital formation (17%), while the major economic driving forces of the embodied hazardous waste generation were government consumption expenditure (32% of total hazardous waste generation 367 (thousand tons)) and household consumption expenditure (24%).

Environmental Impact and Economic Cost of Acceptance of Waste in Construction Industry: Analysis by Dynamic Extension of Waste Input-Output Analysis

Kazuyo Yokoyama

Construction industry uses the large amounts of resources for production and consumes the large amounts of landfill for disposal. On the other hand, the industry has played an important role as a receptor and recycler of much waste. The accumulation of capital goods means the accumulation of waste. Therefore, it is necessary to consider about material flow from demolished durables which waste materials injected to. Waste Input-Output table (WIO)(Nakamura(2000)) as an analytical representation of the interdependence between goods production, waste emission, and waste management. However, a static model like WIO is unsuitable for the analysis of durables with several years of life. In this study, I show a dynamic extension of WIO and evaluate the effects on the economy and environment which durables bring about. This model mainly follows Waste Input-Output model. The difference from Static WIO is consideration of capital accumulation. The conventional fixed capital matrix is considered only about production sectors. However, to accumulate commodities means that the wastes constituting goods are also accumulated. Therefore, it is necessary to extend the conventional fixed capital matrix, and to create an extended fixed capital matrix K tilde. The extended fixed capital matrix is defined as K tilde:=[K0t,Kzt]. K0t refers to the accumulation of capital goods to industrial section; Kzt refers to the accumulation of waste material to industrial section at t period. Next, waste conversion matrix T is defined. T:=[T0,Tz]. T0t refers to the proportion of waste generated from demolished durables. Tzt refers to the share of wastes generated from waste material injected to durables. In case where goods designed by DFE or Eco-design spread, T0 will change. The progress of sorting technology makes Tz high. Waste generated from each industry W0t is as follows. W0t=beta Xt+T B delta {t-1,t} [Xt-Xt-1]+T B delta {t-2,t} [Xt-1-Xt-2]+... delta refers to lifetime matrix, and B refers to fixed capital coefficient. We consider three scenarios. In the first scenario, I consider the complete sorting of wastes. In the next scenario, sorting of construction wastes is considered. This case the sorting option is held refers to complete sorting of waste generated from capital stock. In the last scenario, extension of usage life of building is considered. The results are as follows. Considering carbon dioxide emission, under every scenario, the increasing effect was seen. Control scenario assumes construction wastes are all landfilled. Landfill activity doesn't make carbon dioxide emission. Thus sorting or recovery option makes carbon dioxide emission activity larger. Next, considering the effect of employment, extension of usage life makes employment decrease. This is mainly because extension of usage life makes final demand smaller. Last, considering effects of landfill, complete recovery makes landfill decrease. In conclusion, we can say that if we use waste material which recovery is difficult, landfill consumption will be bigger than before. Now we can not go on recycling without construction industry, and the product goods from this industry will be discarded in future. Therefore we must reconsider recycling of one time.

Input-Output Analysis for Environmental Effect of Newly Developing Steel Recycling Technology

Kenichi Nakajima, Yohji Uchiyama, Kohmei Halada

Corresponding to the increase in a used scrap, the process that consumes used scraps for sheet steel production with severe concentration restrictions of impurities attracts attention. In this study Environmental effect of newly recycling technology is evaluated by LCA. Pig iron, processing scrap, and the used scrap are carried into the object system from the outside of a system boundary. And an object system is not the closed loop recycling like an aluminum beverage can but open loop recycling in which many industries participate, not only steel industry but a car production, a construction, a shipbuilding, etc. If a setup of the functional unit that produces constant production service of sheet steel and bar steel is performed, the amount used, such as a scrap, is unfixable. Allocation of environmental loads to pig iron and the scrap or the extension of a system has big influence on the result of LCA. In general, a method of applying the direct and indirect environmental load calculated in consideration of the cooperation between industries as environmental load of a material or a product is established as application to LCA of an I/O table. It can be considered that this is the "Extension of a system by a material" based on the relation not only in a single industrial system but a country or a global level. "Extension of a system by a material" is a method that has been already proposed. This is an expansion of a system performed by allocating the value reflecting a system to a material. By using I-O table this method gives a boundary defined by the I-O table, i.e., an I-O boundary. Based on this method, it can correspond about pig iron by allocating a direct and indirect environmental load of a system that produces pig iron per unit to pig iron per unit. However conventional I-O method cannot estimate environmental load of processing scrap. It is asked for an input coefficient matrix being non-negative in case of a calculation by using an I-O table. In order to fill the condition, scrap and by-product sections are necessary to be deleted from the input coefficient matrix because these are described with Stone method in the conventional input table. Then, in this research, it was considered that waste and a by-product were products, and it made it possible to treat it on a par with other sections as an independent section. Although it was predicted by setting up I-O boundary compared with the result at the time of assuming non-open loop recycling that environmental load becomes high, it was shown that there is still sufficient effect. As the result of the analysis, it was predicted that the environmental effect of energy consumption and CO2 emission is 19.8GJ per used scrap 1t and 2.93t per used scrap 1t.

Decision Analytic Extension of Waste Input-Output Model Based on Linear Programming

Yasushi Kondo and Shinichiro Nakamura

We elsewhere developed a new tool of hybrid LCA termed waste input-output (WIO) (JIE 6-1, 2003) that extends the environmental IO model of Leontief (1972) with respect to waste flows, and provides a general framework for LCA of waste management and

recycling. The WIO, however, like the conventional IO model, excludes the possibility of choice of technologies from among possible alternatives to meet certain objectives such as the minimization of the emission of particular substances. We propose a decision analytic extension of the WIO based on the method of linear programming (LP). The WIO is extended by allowing for the presence of alternative technologies and allocation (or matching) patterns of waste to waste treatment, the "optimal" combination of which is determined by searching for the extremum of a given objective function subject to a given set of constraints. The resulting model termed WIO-LP enables one to make decisions on waste management policies including secondary resources and recycling that is optimal with regard to a given policy objective and consistent with given physical, economic, and institutional constraints. A decision analytic extension of the LCA was originally done, among others, by Azapagic and Clift (1995) within the framework of process modeling. This paper is concerned with the extension within the framework of WIO. We applied the WIO-LP model to Japanese waste management by use of the Japanese WIO table for 1995. Two policy objectives were considered: minimization of the volume of landfill consumption and the minimization of CO2 emission. Alternative sets of technologies are considered with regard to incineration, the treatment of garbage, and the treatment of waste plastics. Incineration methods are distinguished by size, utilization of waste heat, and the treatment of residue. Three treatment methods are available for garbage: landfilling, biogasification with the use of gas for power generation, and incineration. As for waste plastics, three methods are available: incineration, landfilling, and the injection into blast furnace in the steel industry as a reduction material. The other recovered materials can be recycled as substitutes for virgin materials. It is found that the consumption of landfill volume could be reduced up to 27.9% by a proper combination of the alternatives. This is achieved, among others, by the biogasification of all garbage, by the use of waste plastics as reduction material up to the capacity of the steel industry with the remaining plastics directed to incineration with heat recovery, and by the shredding of small appliances. The emission of CO2 is also reduced by 4.4%. On the other hand, the maximum rate of reduction in CO2 emission is found to be 5.3%. The associated allocation pattern of waste to treatment methods is considerably different from that of landfill minimization; garbage is no longer biogasified but incinerated, and plastics are no-longer incinerated but landfilled. This reduction in emission is realized at the cost of increase in landfill consumption by 5.2%. There is thus a sort of trade-off relationship between the volume of landfill consumption and the emission of CO2.

Technical Session (T4)

Sustainable Consumption

Ecological Impacts of Urban Household Consumption in China

Jingru Liu, Jianxin Yang, Rusong Wang

China has about 120 million urban households. Due to the fast economic growth and dramatic social change in the past twenty years, the urban household consumption

patterns have changed a lot, which are playing an important role in the future Chinese production and consumption system. To identify both the direct and indirect ecological impacts caused by changes of consumption behavior and to explore driving forces behind them are the main targets of this study. The direct ecological impact of household consumption means the household metabolism flows, which may include water use, energy consumption and waste released to land, water and air. The indirect ecological impact means the impacts in the life cycle of goods and services consumed by household. Based on the life cycle inventory model and input-output table of China, the indirect ecological impacts, including energy use, water use, CO2 and NOx emissions, SSP and dust within the whole life time, associated with food consumption (corn and meat), housing (including water and energy), house appliances (washing machine, TV set and refrigerator) are calculated by one Chinese household in one year. Results show that during the past two decades, the direct and indirect ecological impacts from Chinese urban household consumption increased. Moreover the indirect impacts increase faster than direct impacts. In 1981, one person used 39.39MJ of electricity, 47.6 t of water and discharged 47.6t of wastewater, dumped 163 kg of solid waste. By the 1999, these figure increase by 95.3%, 49.5%, 49.5% and 62.95% respectively. In 1981, from the life cycle point of view, the total energy requirement, water use, wastewater and solid waste is 10476 MJ, 914.55t, 720t, 91t. By 1999, these figure increase by 100.3%, 52.6%, 52.6% and 84.5% respectively. The growth of total consumption amount and change of consumption structure are the key factors on the change of ecological impacts from Chinese urban household. Further, the economic growth and the increase of household income can be recognized as the driving forces of ecological impacts. With households income increase, they consume more goods with significant environmental impacts. The income and the consumption level of China's households will further increase in the next decades. So the task is obvious to reduce the ecological impact of each aspect of household consumption.

The Dynamic Changes of Phosphorous Flow in a Swedish City, 1870-2000

Tina Schmid

The flow of nutrients can visualize changes, which occur over time in a city and its hinterland, in particular regarding the lifestyle of its inhabitants. Consumption of food is one of the most tangible activities and alters in different time periods, areas and cultures. The interest in human consumption stretches from the shift in habits to the shift in the larger impact that lifestyle has, in particular on the environment. For the activity to nourish (Baccini&Brunner, 1991), the system changes its extension throughout the historical frame, far beyond local or regional borders. Material-flow analysis is applied to quantify and qualify the changing fluxes within a system and for a range of activities. In recent decades, the environmental discussions on resource management and overload of nutrients in, for instance, surface water, has paid more attention to the nutrients nitrogen and phosphorus. With this method, the sensitivity of phosphorus flows for different processes can be tested for and dynamic changes detected. The evolution from a local closed loop of nutrients towards an open linear flow is of great interest in urban environmental research. The city of Linköping, situated in the Southeast of Swe-

den, is studied, concerning the flow of phosphorus for the consumption and production of food from 1870 until today. This study will show how the flow of phosphorus changed during this period of time and how the different parts of the anthroposphere contributed to the flow. It considers the interrelation of city and hinterland as well as the sanitary technical development in the city and its influence on the flow of phosphorus.

Effects of the Information Technology Revolution on the Energy Embodied in Consumption

Eric Williams and Takuro Hatanaka

The Information Technology revolution affects both the scale and structure of consumption and its embodied environmental impacts. At the macro-level, IT contributes to economic growth, which in turn contributes to rising incomes and reduced consumer prices, which drives increased consumption. We estimate the scale effect of IT on embodied energy associated with consumption by combining macro-economic results on contribution of IT to growth, trends in consumer prices indices, consumer expenditure surveys, and economic input-output life cycle assessment. The results are also specialized to consider how much energy use is induced through the spending savings realized from using business-to-consumer e-commerce. Another level of effect is driven by change in the structure of consumption. One expects that a transition to a "knowledge economy" should also be associated with an increased degree of spending on and use of knowledge goods (such as software). This issue is considered from two perspectives. Trends in consumer expenditures are analyzed to determine the extent to which the structure of consumption is actually evolving towards an increased role for knowledge goods. Also, time use indicates how lifestyle changes affect the use of automobiles and residences in particular.

Industrial Ecology at NSF and EPA

Research Opportunities in Green Engineering: Bridging Design, Manufacturing, and the Extended Enterprise

Delcie Durham, Jan Twomey

Product realization and the manufacturing enterprise will require that engineers and business leaders employ a systems approach to incorporate new technologies and organizational paradigms in addressing issues such as sustainability. Improved performance, higher volumes or mass customization, faster response times, and lower costs have been the driving forces for advancements in design methodologies and manufacturing engineering over the past two decades. On the immediate horizon is concern for materials flow, environmental impact of process and product, human resource deployment, and convergence of the bio-, nano- and information technologies.

Total life cycle management, virtual product realization, and environmentally benign

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design and manufacturing are concepts of green engineering that require a systems approach. Quality-driven organizations will rely on the full scope of information technology tools to enhance the knowledge-base for future product development. Extending beyond today's lean manufacturing, design for XXX, and the flexible manufacturing enterprise and associated supply-chain, systems will require the integration of simulation and modeling tools, some already developed, others still needed. The problem is ours to address.

This talk will include a discussion of ongoing and new activities in the Division of Design, Manufacture and Industrial Innovation at the National Science Foundation., to foster and support basic research for the problem just described.

Industrial Ecology at Us Environmental Protection Agency

Barbara Karn, Diana Bauer, Derry Allen, Suzanne Giannini-Spohn, Angie Leith, Irene Purdy, Walter Schoepf, John Sparks, Larry Weinstock, Steve Young

While there is no single office of US EPA devoted to Industrial Ecology, EPA has many programs that use industrial ecology approaches to protect the environment and human health. This paper will describe both general IE activities and some specific IE programs at EPA in more detail. General types of Industrial Ecology programs include LCA, supply chain management, material flow analysis, product stewardship, eco-industrial parks, DfE, full cost accounting, information and knowledge flows, and pollution prevention technologies. Specific projects to be discussed include LCAccess and LCA research, SCM in the auto industry, National Academy and WRI studies of Materials Flow Analysis, Electronics Extended Product Responsibility, New Jersey by-product synergy/eco-industrial development, Packaging DfE, and Technology for a Sustainable Environment research. This paper also describes lessons learned from initial attempts to apply industrial ecology thinking within a public agency and identifies some potential next steps.

'Cool' Life-Styles Key to the Re-birth of Green Products —UNEP Activities to Promote Sustainable Consumption Using Life-Cycle Approaches

Bas de Leeuw, Guido Sonnemann, Inhee Chung

Psychologists and human behaviorists are being enlisted by the United Nations Environment Programme (UNEP) in a pioneering new activity to save the planet. Experts believe that the traditional messages from governments and green groups, urging the public to adopt environmentally-friendly life-styles and purchasing habits, need to be overhauled. There is concern that many of these messages are too 'guilt-laden' and disapproving and instead of 'turning people on' to the environment are switching them off.

Klaus Toepfer, Executive Director of UNEP states: "Messages from governments,

exhorting people to drive their cars less or admonishing them for buying products that cause environmental damage, appear not to be working. People are simply not listening. Making people feel guilty about their life-styles and purchasing habits, is achieving only limited success". Indeed studies indicate that only five per cent of the public in Northern countries, are embracing so-called sustainable life-styles and sustainable consumerism. "So we need to look again at how we enlist the public to reduce pollution and live in ways that cause minimal environmental damage. We need to make sustainable life-styles fashionable and 'cool' as young people might say. We also need to make it clear that there are real, personal, benefits to living in harmony with the planet, " he said.

The turning to social scientists and behaviorists is being carried out under UNEP's Sustainable Consumption Programme and the UNEP/SETAC Life Cycle Initiative which is looking at a wide range of issues, from labelling to eco-friendly product design, to deliver more environment-friendly consumption.

The World Summit on Sustainable Development (WSSD) held in Johannesburg in August/September, 2002, has resulted in a call to all stakeholders to develop a 10-year framework of programmes to change unsustainable consumption and production patterns, in support of national and regional initiatives. The use of science-based approaches, such as life-cycle analysis, was encouraged. This decision has confirmed UNEP's ongoing efforts to strengthen its Cleaner Production and Sustainable Consumption programmes and to develop an integrated approach, starting with selected human needs (such as clothing, shelter, leisure, food), using life-cycle thinking. Life-cycle thinking can suggest opportunities for adopting new products or services and contribute to formulating sustainable consumption and production policies.

In Vienna, on 22 November 2002, life-cycle approaches to sustainable consumption were discussed at the occasion of a first scientific workshop organised by the International Institute for Applied Systems Analysis (IIASA), the Japanese Institute of Advanced Industrial Science and Technology (AIST) and the United Nations Environment Programme (UNEP). As a follow-up, a next workshop was held in Paris on 3-4 March 2003, organised jointly by UNEP and AIST. It built upon UNEP's work so far and identified both what policy makers in this area need and what researchers have to offer. In an informal brainstorming format, researchers and policy makers discussed the potential use of life-cycle based policy instruments, priority questions to address and research to be carried out. A report is given about the results of these and related expert workshops/ meetings.

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Industrial Ecology Tools- Which Tool for Which Purpose

A Systems-Based, Economic and Environmental Process Planning Model for the Recycling of Plastics from End-of-Life Electronic Equipment

Eric Masanet, Arpad Horvath

With the emergence of such regulatory drivers as the European Union's WEEE Directive and takeback legislation, electronics manufacturers are being held accountable for the collection, processing and recycling of their products at the end-of-life stage. As a result, many electronics manufacturers have turned to Design for Recycling (DFR) as a proactive means of minimizing recycling costs by incorporating end-of-life considerations into product design decisions. When it comes to engineering thermoplastics which represent an increasingly dominant mass fraction in electronics equipment - product designers have typically employed DFR by following a set of "best practice" design guidelines aimed at improving the economics of plastics recycling, such as using snap-fits instead of threaded fasteners, avoiding metal inserts and paints and minimizing the number of different polymers contained in a single product. It has been shown, however, that design is only one factor in the economics of plastics recycling and that the type recycling technologies which are employed (such as manual versus mechanical disassembly and manual versus automatic polymer sorting), the logistics network, the intended disposition path (closed-loop or open-loop recycling) and the product mix in the end-of-life batch can often impact the economics of plastics recycling in ways that can be independent of DFR product attributes. The current presentation describes a simulation model that is being developed to investigate how different takeback scenarios affect the recylability of a given product design in terms of cost and environmental impacts (energy consumption, global warming potential, air pollution and solid waste generation). Specifically, this model investigates how different disassembly and sorting process technologies, transportation modes, logistic networks for collection and processing, batch mixing effects and end-of-life disposition targets affect the cost and environmental impact of recycling a proposed product design in terms of the following key plastics design variables: selected polymer(s), selected polymer/color combination(s), fastener type(s), metals content and use of paints or coatings. The simulation is based on the unit process modeling approach, in which discrete process models have been developed to capture the economic cost and environmental impacts for each potential process in a takeback system.

Roadmap for a Sustainable Development of Information and Communications Technologies

Mario Dopmke, Kerstin Lahser, Mario Tobias, Uwe Weigmann

Motivated by Germany's ongoing transition from a production-based society to an information-based society, it became obvious – on the one hand – that the implementation of ICT in society poses certain problems with respect to sustainable development - and on the other hand - that ICT applications and their integration into business processes also offer enormous potential for shaping sustainable development. In order to use this potential a dialogue takes place between the business world, the scientific community and policy makers to produce "paths of innovation" for technological, economic and social developments. Priority fields of action and within each one focus topic are defined. The focus topics are: mobile communication, displays and public procurement. Within the focus topics the status quo is analyzed, statements describing current trends in their respective areas are formulated, visions for more sustainability of the ICT sector in the future are developed and strategies ("paths") how to realize these are suggested. The roadmap is a contribution toward early coordination of the medium and long-term developments in the ICT sector with the needs and demands articulated by politics and society. In addition to ecological challenges and paths of innovation, the roadmap should spell out concrete objectives and actions. For the implementation phase, commitments governed by time horizons will be sought from all parties involved. An iteration process consisting of discussion and practical testing has the purpose of continuously refining the objectives defined within the roadmap and taking on board new developments – so that at the end of the project, a well-coordinated roadmap emerges which enjoys wide acceptance. For creating these roadmaps companies like IBM, HP, Siemens, Sony, Deutsche Telekom, SAP, LG.Philips etc. took a big interest from the very beginning. To disseminate the results of the project in the German ICT-industry, the German Association for Information Technology, Telecommunications and New Media (BITKOM) plays a very important and active role. BITKOM represents 1,300 companies, 700 of which are direct members, producers of ITC hardware, office machinery and terminal equipment, telecommunications network infrastructure as well as suppliers of software, services, new media and content. The first draft of a roadmap for the focus topics (mobile communication, displays and public procurement) was discussed with a wider public in May 2002. Now the work in the project is more concentrated on general action plans for the different aims in the roadmap and on special action plans for single companies and other actors concerned. Up to now the results are very promising that a roadmap for sustainable development of ICT is a useful tool. The fast-moving nature of the ICT sector, however, requires continual review, revision and further development of the roadmap beyond the conclusion of the project itself. Therefore, a further goal of the project is to investigate different possibilities of institutionalising the roadmapping process in order to assure its continued development.

The Additional Value of the Industrial Ecology Perspective to Current Integrated Assessment Tools with Cases of PVC and the Hydrogen Economy

René Kleijn & Ester van der Voet

Since environmental policy measures may have many impacts that are linked to each other in both physical and socio-economic respect, the need for tools for assess this variety of impacts is growing. In this paper the main aim is to describe the need for the development of a methodology to identify, categorize and quantify the environmental co-benefits and co-damage of environmental policies. Currently Integrated Assessment models like IMAGE and RAINS are used in a policy context to calculate the possible effects of environmental policy measures with regard to climate change and acidification respectively. These Integrated Assessment models have a strong focus on the processes and material flows in the environment. The effects of environmental policy measures are translated in changes in socio-economic variables like economic growth and changes in production volumes of different economic sectors. Furthermore, detailed information on the dynamic relations between important sectors are often in added in a so-called "drivers module" e.g. for a model like IMAGE this drivers module is used to describe the complex dynamic relations between different processes in the energy sector. This driver module produces greenhouse gas emissions as an output. Because of the focus on processes in the environment and on the drivers these models lack a more comprehensive picture of the interconnections of material flows in society: one of the main objects of study in Industrial Ecology. In this paper it will be shown that using an Industrial Ecology systems perspective can provide crucial additional information to current Integrated Assessment models. This will be done using two cases. The first case is chosen from the realm of the chlorine industry: policy measures related to PVC. The PVC case is used to show the need for a systems perspective when evaluating the effects of environmental policy measures. If PVC is banned from certain applications alter native materials will be used with environmental effects of their own. Furthermore, the production of PVC is linked to other parts of the chlorine industry via the use of HCl in the oxychlorination process. A strong reduction in the production of PVC would have to result in either large solid waste flows or changes in production processes. Furthermore, PVC is linked to chemical waste treatment and, via the production of chlorine, to the production and use of caustic. Next to this relatively simple case a more complex case will consider a transition from the current fossil fuels based economy to a hydrogen economy. This case is chosen because it refers to an economy wide transition and therefore can be used as a test of the boundaries of applicability of the methodology. Furthermore, focusing on large-scale transitions fits well with the current national environmental policy.

Material/Substance Flow Analysis

Scenarios for Future Copper Use

Amit Kapur

Mining, refining, recycling, and the end of life dispersal of copper can potentially pose significant environmental concerns at either global or regional or local scale. Futuristic scenarios for copper use were developed to analyze possible interactions among resource availability, technological change, and waste management system & practices to address sustainable management of copper. The scenario model was developed based upon the generic Intergovernmental Panel on Climate Change framework for greenhouse gas emissions scenarios. A set of three scenarios - 'Trend World', 'Tech World', and 'Green World', are proposed and sub-hypotheses within each scenario are based upon three time scales – short term (10yrs), medium term (25yrs) and long term (50yrs). The name of each scenario refers to the dominant driving force influencing the future. The 'Trend World' scenario is a business as usual scenario, where the system in the future represents a picture of things continuing to happen in the same way as they are happening now. The 'Tech World' scenario assumes that rate and direction of technological innovation and change and economic viability determines the future material flows of copper. In the third scenario, 'Green World' changes in environmental consciousness, policy and regulation radically shape the future world as being more green and dematerialized. For each of the scenarios, the effect of technological change, environmental regulation, emergence of alternative substitutes for copper products and changes in waste management systems & practices are also evaluated. Technological change in the copper industry and the possibility of new alternative substitutes for copper were determined through an 'expert opinion' study. Using the scenario model and incorporating results from the Stocks and Flows Project at Yale University and expert opinion study, plausible trends of the copper industry, its usage and end of life management were explored globally for seven regions – Africa, Asia, Eastern Europe and Former Soviet Union, Latin America and Caribbean, North America, Oceania, and Western Europe. Developing Countries of the East emerge as potentially significant to influence the global copper cycle. Technological barriers, lack of enforcement of environmental policies and economic incentives appear to be the stumbling blocks towards management of copper in an environmentally friendly way. There exits a tremendous potential globally to enhance reuse and recovery of secondary copper, emanating in significant quantities as 'waste streams' in various forms from societal in-use stocks built up during the latter half of the twentieth century. Stakeholders in developed countries display significantly better maturity and responsibility on environmental consciousness and action. Near complete copper recycling is limited by economic viability and stabilization cum convergence of copper intensity of use levels. Sets of possible policy directions are presented for the North and the South to embark upon a common and uncertain journey towards sustainability.

Cross-Scale Analysis of the Contemporary Copper and Zinc Cycles

T.E. Graedel

Cross-Scale Analysis of the Contemporary Copper and Zinc Cycles T.E. Graedel Center for Industrial Ecology, School of Forestry and Environmental Studies Yale University New Haven, CT 06511 ABSTRACT A traditional definition of industrial ecology is that it is the study of the interactions between technology and the environment. The interactions have almost always been addressed at either very small spatial levels (e.g., the factory) or very large spatial levels (e.g., the planet). These approaches strongly resemble the tendencies in biological ecology to restrict one's studies to a single restricted temporal and spatial level, say to this season's vernal pools or half-hectare ecosystems or landscapes, thus avoiding the challenges of studying (in Princeton ecologist Simon Levin's words) "how the signatures of actions at one level manifest themselves at levels higher and lower". Similar arguments apply to cross-scale research, in which results for a phenomenon measured by one scale are compared with those measured by another. This challenge has been addressed for metals cycles by comprehensively characterizing the multilevel cycles of copper and zinc, and then comparing different features of the cycles by utilizing the tools of exploratory data analysis. The analysis is performed at three discrete spatial levels - country (more than 50 countries or country groups that comprise essentially all anthropogenic stocks and flows), nine world regions, and the planet as a whole. The anthropogenic metal cycles are structured with six major flows: the rate of extraction of the metal in ore, the rate of fabrication and manufacture, the rate of usage, the rate of addition to stock, the rate of flow to waste management, and the rate of flow to landfill. In addition, four other parameters of particular interest are computed: the overall balance between imports and exports, the fabrication transformation ratio (i.e., the ratio between copper in elemental form in products to that in alloy form), the nutrient ratio (i.e., the ratio of "experienced nutrients" [copper from recycled scrap] to virgin nutrients [copper from ore]) and the recycling ratio (i.e., the ratio between the rate of recycling and the total rate of discard). Results will be presented for distributions of country-level stocks and flows, correlations of fabrication with rates of extraction, additions to stock, and the statistical distributions of metal cycle parameters.

Assessing the Policy Implications of a Copper Substance Flow Analysis

R. Lifset, R.B. Gordon, T.E. Graedel and Amit Kapur

The Stocks and Flows (STAF) project at the Yale University Center for Industrial Ecology is conducting a series of global substance flow analyses (SFAs) on copper, zinc, silver, nickel and other substances. A comprehensive multilevel contemporary cycle for stocks and flows of copper has recently been completed. This paper scopes and discusses the policy implications of the analysis of the copper cycle. Among the areas addressed are production rates in relation to resource reserves over time; externalities in extraction and their relationship to resource availability; the characterization of metals as nonrenewable resources; the role of SFA in illuminating "leakage" to the environment in materials cycles; comparative national patterns in the production, use, recovery and loss of copper; the potential use of SFA forecasting models for recycling and waste management; and the targeting of life cycle stages for additional empirical investigation. With quantitative SFA output now in hand, the goal is to both to derive specific policy implications from the copper SFA and to ask more generally to what degree the outputs of SFA modeling inform policy analysis, using the copper results for purposes of illustration. Our aim in this work is to better understand where the SFA could be refined, elaborated or combined with other forms of analysis to make it more useful to the decision-maker.

Input-Output Analysis in LCA and MFA

Testing Dematerialization and 'International' Pollution Coefficients

Eleni Papathanasopoulou and Tim Jackson

This research paper is motivated by the need to assess whether dematerialization occurs in post-industrialized economies. The definition of dematerialization is clearly distinguished between a production versus a consumption perspective. This is paramount to the analysis as the forces which underlie each outcome differ. From the production perspective, economic structural change (towards environmentally benign industries) and technological improvement is fundamental to perceived changes. The consumption perspective requires consumption patterns changes (towards environmentally benign consumption) and a decrease in imports to be present for dematerialization to occur. To address the occurrence of dematerialization in an industrial economy, the first part of the paper maps material and energy flows for the UK over a 30 year period. A multi-regional input-output framework is used to allocate primary and intermediary flows to each sector of the UK economy. The outcome of this sectoral divide is to highlight those commodities dependent on large quantities of natural resources. Changes in the inter-industry technical coefficients, which require lower levels of material for a given output, reflects a positive trend in decreasing material use. The change in these coefficients, as well as structural changes, are assessed over the time series. However, the reliance on technical coefficient to substantiate the possibility of dematerialization confines the analysis to natural resources demanded from the production side. In this case, final demand is split between domestic demand and export demand. To overcome the omission of imports, consumption encapsulated in the final demand vector is complemented by the level of imports required to satisfy demand. Focussing on domestic final users demand for materials incorporates the amount of domestic material, as well as imported material, required (but excludes exports). The change in the level of consumption of material demanded from domestic production and imported consumption are compared over the 30 year period. A decrease in the materials required would represent a positive trend in obtaining dematerialization. The difference in level of commodities demanded by producers and consumers results in a trade balance. Comparing the quantity of material used for domestic production (final domestic demand and export) and domestic consumption (final domestic demand and imports) tests whether the assump-

tion of dematerialization for service dominated economies can be validated. It also facilitates the apportioning of responsibility for environmental degradation to producers and consumers. This is relevant when policies aimed at reducing material requirements between producers and consumers are being considered. Findings from the first part of the paper are then used to test the sensitivity of 'international' pollution coefficients in assessing the environmental impact of increased trade activities (specifically imports). Identifying the total proportion of materials demanded by domestic consumers allows a more detailed analysis of the environmental impacts caused by post-industrial consumption trends. The flexibility of the multi-regional input-output model is essential when assessing trade activities among a number of heterogenic economies. Realising that the demand for homogenous commodities in different economic settings leads to varying degrees of environmental impacts, questions whether the blanket use of 'international' polluting coefficients for trading partners is acceptable. Sensitivity analysis is undertaken to test the magnitude of divergence by considering structurally different economies at different stages of development. Responsibility for trade policies, when there is increased reliance on imports, is essential in an interdependent world. Insight into the commodities demanded from various trading partners, and their ability to deal with environmental damage, inspires the need to initiate trade policies that are direction safe and distribute the benefits of trade more equitably.

Can a Local Currency Harmonize Environment and Economy? Inputoutput Analysis of Environmental Effects by Means of a Local Currency in US

Noboru Yoshida, Iwan Azis

As typical symbolized as submission of the final report of the Council for the Promotion of Decentralization Reform, in October 2002, de-centralization has been accelerated in Japan. Various economic instruments associated with industrial ecology were recently implemented at local government levels, such as state landfill taxes, a packaging tax, a highway tax specific for large diesel automobile, etc. In the process of de-regulation on de-centralization, local economic instruments have started to play an important role to lead industrial ecology at local level. As if in accordance with the above movement, more than 100 of, various kinds of local currencies have given birth in Japan. It is known that their strengthening power in local circulation of goods and services can give great contribution on loop closing. Although these currencies are not treated as actually currency in Japan so far now, these original and distinctive features are also highlighted from the environmental point of view. A local currency named Ithaca Hour was launched in 1991 in Ithaca, New York state in the U.S., and it is now known as one of the local currencies that have long history and largest amount of circulation. Against the above background, this research attempts to analyze quantitative effect of a local currency on local and global environment, through increasing multiplier in the local economy where the local currency is implemented. Ithaca Hour is tradable to dollar currency and it covers the county-wide circulation area. Firstly, yearly regional purchase ratios are extracted for the year of 1995-98 using Tompkins County social accounting and Input-Output data. Number of goods and services are also extracted from old editions of Ithaca Hour

directory. Then we construct the county Input-Output table aggregated into 80 sectors, which represent goods and services treated using the local currency, and other sectors that have given relatively great change in regional purchase ratios for total local demand. Some elastic relationships are observed quantitatively between changes in regional purchase ratios and in numbers of goods and services of the local currency. Secondly, we estimate future trend of input structure, where changes in substitution of goods and services for intermediate demand are taken into consideration, based on 95 and 98 I-O tables. The estimated input structure indicates increasing carbon dioxide emission attributed to the outer region both directly and indirectly. Then reduced emission of carbon dioxide is calculated against the increased regional purchasing ratios by 1% in agriculture, service and retail sectors due to the assumption of increased circulation of local currency. Finally several scenarios are assumed corresponding to the degree of future diversity of goods and services in trades by the local currency. The analysis suggests that variety of trading goods and services bring about eco-efficient local economy due to increased regional purchasing ratios. Furthermore, policy mix of economic instruments are discussed for environmental local taxation, bonds, subsidy systems.

Scenario Evaluation Using Integrated Product and Process Input-Output Material Flow Analysis

Reid Bailey, Bert Bras, Janet Allen

Material flows are important factors in the environmental impact of industry. Hence, many tools have been developed to model systems of industrial material flows. Lacking in most of these tools is the ability to consider both the direct and indirect flows involved in a material flow system. In linear flow systems, this deficiency is not critical. In closed-loop material flow systems (such as those associated with industrial ecosystems), however, indirect flows are important contributors to system behavior. Inputoutput (I-O) flow analysis is one tool that does model both direct and indirect flows. Despite its strengths, I-O material flow analysis is not easily applied to systems with multiple types of material flows. In this paper, a method for applying I-O flow analysis to two types of flows ? product and process ? in a single system is demonstrated. Furthermore, the usefulness of I-O flow analysis to evaluate scenarios with both environs and flow metrics is explored. Environs trace the flow of materials through a system (e.g., tracing the percent of an inflow that exits a system through a specific outflow) while flow metrics characterize a system's behavior (e.g., modeling the percent of flows in a systems that are cycled). Throughout this paper, the production, use, and recycling of tufted carpet by Interface, Inc., is used as a case study. I-O flow analysis is successfully applied to both the product and process flows associated with carpet production and used to identify areas to focus design efforts through the evaluation of multiple scenarios. Results indicate that, while the amount of material cycling is increased by recycling tufted nylon carpet, the net virgin inputs also increases with recycling due to the large amount of material needed to produce raw nylon from post-consumer carpet. Furthermore, environs and flow metrics are used to determine that efforts to make the materials in tufted carpet easier to separate after use lead to greater material flow efficiency improvements than do efforts to increase the amount of carpet diverted from landfills. More important than these specific results, however, is that I-O flow analysis is shown to be a useful tool for evaluating material flow scenarios for a specific product and its manufacturing processes.

Technical Session (T5)

Industrial Ecology in a Global Context

Real Problems for Applying Industrial Ecology Concepts

Ana María Ruz, Iván Urzúa, Italo Serey

In the Parque Industrial Escuadrón located at Concepción, Santiago of Chile, are installed 45 companies. These international and national corporations are fish food producers, wood producers, chemicals, storage, canned fish food and paper pulp producers. Eighteen of the companies are organized through the Asociación Gremial Parque Escuadrón. Based on concepts of cleaner production and industrial ecology the project developed by the Chilean Corporation of Technical Research identified opportunities of utilizing materials and energy resources efficiently. The principal difficulties identified on the project Parque Industrial Escuadrón are the following: 1) The concepts related to the industrial ecology are not present at the initial project. So the economical advantages for the cluster and the social environmental advantages for the region are not recognized. 2) The environmental projects developed for environmental professionals do not take account of economical context of companies, where they make their decisions. The professionals work from their reductionists' points of view. 3) There are not relation between all the companies, only a group is associated. 4) The companies associated do not have upgraded relations on economical and social aspects covered. 5) The companies must prioritize their basic investments, by example, pavements, public lighting and sewing systems. 6) The building company that sold the locations is driven by their own economical short terms perspectives. The companies operational costs are not evaluated. 7) The selection of companies that developed different functions, as in a natural ecosystem, it is not possible in a previous defined industrial park. The idea must be conceptualized from the beginning. Three initiatives were recommended in the Parque Industrial Escuadrón for getting the advantages of industrial ecology: a local biomass energy plant, a central waste management plant and individuals interchanges of products, waste and energy between companies. Different organizations are called to diffuse economical and environmental advantages that could be gotten by applying the industrial ecology concepts to the design and construction of industrial parks. Some of them are universities and international organizations by diffusing success cases. The local authorities with the urban regulators plans, must take care of social, economical and environmental benefits that are on an hierarchical level over the companies.

How Prepared are Nigerian Manufacturing Companies for Sustainable Practices?

Ishaq Oladapo Adeleke

Innovative products and processes are portrayed as sustainable business practices. The few developmental organizations at the forefront of such initiatives in some developing countries can only do a little to help. While economic, environmental and social benefits of waste reduction and pollution prevention are widely being reported in the developed economies, and most recently in the transiting economies, how manufacturing sectors in the developing countries can go about adopting and adapting sustainable practices seem inconceivable to many. Proponents of sustainable development hint that the strategy could catalyze the developing countries' developmental goal. The globalization issue, perhaps, raises doubt on this possibility in developing countries. Factors which are often cited as obstacles to sustainable practices are those related to know-how, risk assessment, capital, and environmental policies. Source reduction pilot projects and hands-on training by development agencies and bodies in some developing countries seem sector-specific. This study attempts to set a pace for a sustainable manufacturing mindset in developing countries. Efforts of manufacturing sectors in managing wastes, and in monitoring and abating hazardous wastes from manufacturing plants are investigated. The influence of some relevant stakeholders are also addressed. The research obtain some facts about practices in Nigerian manufacturing companies and report on how they prepare grounds for sustainable implementations. Strategies for building sustainable culture and practices were recommended.

The Global Production and Use of Metals in Relation to Sustainable Development

Donald G. Rogich

This paper examines global production and use trends for ferrous, nonferrous and heavy metals over a thirty-year time period, 1970-2000, to assess how these trends can inform us about the use of metals in relation to sustainable development. In addition to production and consumption, intensity of use and recycling are examined, along with estimates of the magnitude of hidden flows and emissions to the environment. Changes in global equity, as reflected by the intensity of use of metals, are examined to assess how this has changed during the thirty-year period.

An Integrated Assessment of Indicators for Socio-economic Development and Materials -and Energy Use for the region of Southeast Asia

Heinz Schandl and Clemens M. Grunbuhel

Our presentation contributes to the theme of 'Industrial Ecology in a global context'. We focus on the region of Southeast Asia, which is currently experiencing rapid socioeconomic transition. Change occurs at all levels of the economy as well as in the social structure. On one hand, Southeast Asian societies are gradually becoming a vital element of global trade and transport networks, which enlarges economic opportunities.

On the other hand, these changes result in pressures upon the environment such as rising levels of resource utilization, increasing per capita consumption and ever growing emissions and wastes originating both from production and consumption processes. We describe and analyze these changes in terms of material- and energy flows and standard economic and social indicators for four Southeast Asian economies, namely Thailand, the Philippines, Laos and Vietnam. The Material- and Energy Flow Accounting (MEFA) methodology applied to the case studies has been developed in the last decade and has been applied to industrial economies, such as the United States, Japan and the EU. Adapting this framework for 'transition' economies requires taking into account the dominant share of subsistence activities in these countries, which are not monitored by official statistics and requires adapting the methodology to the specific geomorphologic conditions. In spite of applying specific methodological solutions for the regional context, the accounting is compatible with the international standards reached in the MEFA methodology. Hence, the results for Southeast Asian economies are directly comparable to case studies in industrial countries. Since the MEFA framework is compatible with the System of National Accounts (SNA) the indicators from the MEFA framework will be cross-interpreted with standard economic indicators to ask how socio-economic development is reflected in environmental pressures. The results show to what extent these countries depend on local resources and what role they play in international trade. We show, inasmuch economic growth is directly related to resource use and emissions. We ask whether these countries follow a path of 'dirty industrialization ' by expanding their industrial sector using material- and energy intensive technologies or whether they follow a new trajectory. The first question will be tackled within an environmental Kuznets curve framework for the relation of national income (GDP) and environmental pressures. The second question deals with possible sustainability strategies, which avoid the historical path taken by today's industrialized countries and related effects on the environmental performance of these economies. A physical trade balance portrays whether these countries are "extractive economies," i.e. macro-economies selling their natural resources without gaining added value through processing. The value density of imports and exports will enable us to review the position of Southeast Asian countries in the world economy. Finally, using headline indicators for the quantity and quality of materials and energy use and comparing them to figures for industrial countries will enables us to discuss the potential future environmental pressures from this world region.

World Systems Theory And Societal Metabolism: Two Complementing Concepts For Explaining Global Trade

Nina Eisenmenger and Stefan Giljum

Since the 1990s the concept of societal metabolism obtains broad acceptance within the scientific community for framing analyses of society-nature interactions. The analytical tool used to operationalize the concept, material flow accounts, calculates the biophysical exchange relationships of a socioeconomic system with the natural system, mostly a nation state. In the light of growing globalization of the economic system, material flow accounts are confronted with the need of assessing international biophysical flows between socioeconomic systems in an appropriate way. The world systems

theory is a social theory that deals with the mutual interaction between nations and the resulting dynamics and options of socioeconomic development. The theory describes the historical development of the world system and the political and economic driving forces as well as the emerging consequences. The article asks in a first step whether the world systems theory provides a conceptual frame within which international material flows can be better described. On the one hand, the two concepts show parallel approaches, most importantly their systemic view. On the other hand, the two approaches complement each other, as empirical work of world systems theory mostly deals with economic and political dimensions of exchange relationships whereas the concept of societal metabolism describes the biophysical dimension of these interactions. In a second step a look at empirical data on material flows of several developing and industrialized countries will draw a biophysical picture of international trade and the role of different countries within the world system. Economic processes described by the world systems theory like unequal trade, capital accumulation, or the establishment of a division of labor with core-countries and peripheries can thereby be amended by a biophysical description of these processes.

Implementation Status of Environmental Management Systems

Richard Almgren

Environmental management systems (e.g., ISO 14001) are not always implemented in organisations to their full potential. The language in the guiding document (the standard) gives one message and the reality another. To explore the extent to which environmental management systems do not cover the full spectrum of environmental impacts and to consider which measures need to be implemented to overcome such discrepancies this study is being carried out. Focus in the study is aimed at environmental impacts from products along the life-cycle and to what extent its environmental impacts have been included in the environmental management system. Furthermore, the study points out action to be taken to improve the implementation practices. The study will be presented in the form of a gap analysis, which means that an ideal picture of an environmental management system will be introduced and then compared with the current practices. Examples of aspects to be considered are the following: Is the system in question well structured and does it include all environmental aspects in relation to extraction of natural resources, processes and products; Does the system encourage objectives and targets to be reached, including encouraging innovation, decreased environmental impacts, economic benefits; Are the systems widely used in all major countries, sizes of organisations and sectors; Does the implementation respond to incentives, such as market benefits, less intrusive environmental legislation, lower fees for authority actions; Do the systems give rise to recognition and commitments to environmental improvements; and, Are the systems implemented in a harmonized way worldwide. One component of the study is a series of interviews with leading people in the environmental management area in some twenty countries, which gives a pretty good overview of the current implementation practices. The countries chosen cover about 70 percent of all implemented environmental management systems worldwide (June 2002). The presentation will focus on the implementation status with respect to the mentioned issues. So far it can be concluded that: Implementation practices vary; the whole ISO 14000 family is not fully used; and there are ways of improving the implementation practices significantly.

Sustainable Cities and Regional Metabolism

Material Flow Analysis as a Tool for Sustainable Management of the Built Environment

Susanne Kytzia

Infrastructure construction is frequently discussed in regional sustainable development because it causes extensive movements of material. Yet, in industrial countries the process of construction is almost completed. The focus has shifted to management of the built environment. Decision-making in this field is supported by information on environmental burdens, costs and benefits. Economically Extended Material Flux Analysis (EE-MFA) can provide such information. It is an analytic tool that extends a civil engineering approach, Material Flow Analysis (MFA), by economic Input-Output-Analysis (IOA). Study objects are economic sub-systems, which are described as process networks linked by material and financial flows. MFA investigates pathways of selected materials whereas IOA assesses a region's economic structure. In studies on the built environment, EE-MFA is apt to incorporate models of material and capital stocks. Material flow models focus on the material composition of the built environment, its vintage structure and technical needs for maintenance, repair and overhaul (MRO). In addition, IOA analyses the economic value of the built environment and rates of depreciation and obsolescence. By combing both analytic tools, an EE-MFA provides a comprehensive model for regional sustainable development. This method is applied to evaluate a regional resource management system for roads and buildings in a Swiss region in 1990. The empirical study shows that 1) Material stocks in buildings and roads are still growing and could become important construction material supplies in future. Yet, capital stocks are declining. 2) Utilization of buildings, roads and railways accounts for almost 70-80% of the total regional energy demand. New technical solutions bring about significant efficiency gains (by factor 4 to 10). 3) Expenditures for usage and MRO of both processes exceed expenditures for new construction. 4) An integrated resource management system of both buildings and transport infrastructures it favorable. It encourages a cascade use of materials aiming at closed material cycles because roads and railways are homogeneous material stocks with high change rates. This is complementary to buildings, which represent a heterogeneous material stock with low change rates. As MRO and usage consumes more resources than today's construction activities, we argue that we can afford to increase construction activities in order to reduce resource consumption in utilization. Boundary conditions should be an increase in recycling and the implementation of energy efficient technologies. Yet, implementing this strategy would cause a major intervention in the regional economy because it suggests prevailing further growth in the settlement area and replacing the existing building stock. Such intervention is not a matter of "economic incentives for ecological improvement." It includes fundamental decisions in regional development, which have major economic and social implications. To encourage discussion on such issues and prepare long-term oriented regional development, we have to develop new concepts in regional planning. In this context, an EE-MFA could be used in participatory approaches to accompany regional decision-making.

Urban Infrastructure and Sustainability in a Changing Environment

Matthias Ruth and Paul Kirshen

Much of the infrastructure in use today was designed and constructed decades if not centuries ago. Many of these infrastructure systems are vulnerable to a variety of anthropogenic or natural disruptions even though their functioning is vital to the creation and maintenance of quality of life in a region. Moreover, concepts and designs have persisted even as technologies have changed. Yet the demands and technologies of the future may require infrastructures-both material facilities and human institutionsthat are radically different from those of the present. Dealing appropriately with immediate infrastructure vulnerabilities and infrastructure evolution requires a combination of effective short-term crisis management and anticipatory, strategic thinking and planning. Both the "material nature" and institutional issues surrounding urban infrastructure in a changing environment pose formidable challenges to efforts by industrial ecologists to improve the sustainability of urban areas. This presentation describes the results of a collaborative study carried out over the course of more than three years by a group of scientists from engineering, policy analysis, geography and public health, together with a local planning agency and over 200 stakeholders from the public, private and non-profit sectors in metropolitan Boston. The research was conducted as part of the CLIMB project, which explores Climate's Long-term Impacts on Metro Boston. Special focus was given to vulnerabilities and dynamics of urban infrastructures for energy, communication, transportation, water run-off, and water quality, as well as the interrelatedness of these systems, and implications for public health. Computerbased scenarios are presented for potential future infrastructure dynamics under a variety of assumptions about changes in technology, infrastructure investment, and local climates. The presentation concludes with a set of strategies for environmental investment and policy making that are currently considered for metro Boston, and many of which are highly relevant to, and directly applicable in other locations.

Estimation of Future Material Balance in Urban Civil Infrastructures and Buildings

Hiroki Tanikawa, Seiji Hashimoto, Yuichi Moriguchi

The quantification of material needed to support our way of life is the first step toward achieving a sustainable society having a proper eco-balance. Material Flow Analysis (MFA) is an effective method by which to quantify and evaluate such materials. As to material balance in Japan, the total material input is 2.0 billion tons (1995), 1.1 billion tons of which have been designated for construction and infrastructure. Approximately one-billion tons of materials are accumulated as structure or infrastructure every year. Such construction materials are stocked as structures in some years, but overage and unnecessary structures cause the new material flow to become waste. In the near future, a huge overage stock that was built during a period of rapid growth will cause the new material flow to become waste. In the future, the materials balance may change as a result of (1) the increase in waste generation due to the increase in overage structure, and (2) the decrease in civil engineering projects, such as road construction, that use the greatest share of recycled material in the construction industry. In order to avoid becoming a recycling-dependent society, we should focus on "upstream" countermea-

sures, which are more important for the long-term, rather than "downstream" countermeasures, which are effective in the short-term. In this study, MFA is applied to a city, and the change in the material flow for the near future is estimated. The following analyses are performed in the present study: (1) Estimation of material stock accumulated in every urban civil infrastructure according to resources type and the number of years the stock has been held. The bottom-up approach is applied to every structure using the GIS (geographical information system). (2) The renewal schedule is set according to the attributes of each structure. To estimate the material flow for the near future, we set some scenarios in consideration of new technologies, such as long-life structure, low energy consumption buildings, skeleton-infill method. Further, we examine scenarios to know "how much" and "when" is good for installing structures based on the new technology to realize proper material balance. Kitakyushu City (Fukuoka Pref., Kyushu Island in Japan) was selected for a case study since good quality spatial data are available for this city.

Sustainable City Quarters: Material Flows, Local Consumption, and Regional Development – Results from two Case Studies of Brownfield Development in Germany

Uwe R. Fritsche

The sustainability of local and regional developments on the level of two new innercity neighborhoods (city quarters) in the German cities of Neuruppin (North-East Germany), and Freiburg (South-West Germany), was quantitatively analyzed with respect to ecological and economic impacts. Social indicators were included as well in a semiqualitative way. The analysis started from the demand side (addressing e.g., construction materials for buildings, energy use for heating, local transport, products like food and textiles), tracked the life-cycles associated with the supply of products used locally, and then identified the environmental, and regional economic impacts along process chains. The combination of material-flow analysis with bottom-up economic data for local and regional added value is a valid tool to operationalize the concept of a material-flow economy for the local and regional level. Based on this analysis, the linkages between the ecological and economic impacts of various local and regional activities and strategies to achieve a more sustainable neighborhood are determined, and "win-win" options identified. The research developed tools to "measure" the impact of local actions (and scenarios for future options) on local, regional, and global material flows, and economic indicators. The work on the real-world examples of local activities considers their full life-cycle impacts, and differentiates between local, regional and national/global impacts. The linking of local economic impacts with regional effects uses a process-chain ("bottom-up") approach. The material flows are linked to the economic activities on the local/regional scale. The explicit consideration of local/regional actors and stakeholders relies on the micro-economic analysis, and the indicators developed to "measure" sustainability were derived in a participatory process with local citizens. The quantitative linkage of ecological and economic effects using material flow analysis allows first steps in the direction of a material-flow economy on the local and regional scale. More information is given on the project website www.oeko.de/service/ cities/. This work was sponsored by the German Ministry for Education, Science and Research (BMBF) under the programme "Regional sustainability".

Design of an Energy Conscious Waste Management Systems based on Unified City-Rural Area Metabolic Development

R. Noda, M. Kawasima, T. Shirota, S. Aoyagi, T. Ikefuji and M. Horio

The waste management systems in Japan can be radically innovated if sewage works accept garbage wastes for their biogasification and if municipal and industrial wastes are thermochemically gasified after wet garbages as well as halogen rich wastes are separated. By introducing gasified gas into large scale power stations or distributed small scale stations the waste energies so far not utilized can be effectively converted to electricity which may amount 20% of the present thermal power generation in Japan. Detailed case studies including sewerage systems and regional mass flow analysis also supported the potential of the present proposals.

A Collaboration Platform to Evaluate Energy, Mobility and Building Technologies For a Sustainable Urban Ecosystem

Steven Kraines, David Wallace

We present developments on the implementation of a multidisciplinary, interactive computer modeling "collaboration platform" (hereafter "platform") for coordinating widely distributed research efforts and disciplinary expertise to evaluate alternative options for a more sustainable urban ecosystem. Our platform uses the distributed model integration infrastructure DOME (distributed object based modeling environment) to integrate independently developed simulation models and databases. The platform provides a "city template" that can be filled out with specific databases that represent the region for the study of urban sustainability. The platform can then be used to model and evaluate large-scale holistic, integrated technology systems, including life-cycle impacts, in order to determine the impacts and tradeoffs of energy, mobility, and building technology options for sustainable urban development as well as to explore the performance of technology systems in specific urban sustainability projects through the use of systems of models. Our work follows three major lines of activities: 1. Development of a platform infrastructure that enables connection and integration of simulation models and databases via the Internet by sharing models directly from the modeler's own computers, the same way that web pages are shared by web servers. Tasks include theoretical development of the software integration architecture, user-friendly graphic interfaces, and advanced system analysis and optimization algorithms. 2. Simulation model and database development, including construction of a software tool for characterizing urban land-use based on a geographic information system database, physical and costing models for different technologies to be evaluated, and an Input-Output analysis based software tool that assesses the total cost and environmental impacts of different technology choices taking into account the whole industrial ecology. 3. Integration of the simulation models and databases for particular case studies that assess tradeoffs between technology options for making urban regions more sustainable in order to prototype the overall platform design. A multi-objective evolutionary optimization algorithm is used to discover integrated technology solutions that perform particularly well for the targeted urban ecosystem. We present findings from two case studies:

1. Development of models for the study of municipal waste disposal options including prediction models for household and small business waste production, waste collection models, and models of disposal technologies for combustibles, plastics, and kitchen waste. We use an integrated framework based on these models to study combustible waste disposal in Tokyo in order to assess the potentials for increased resource recovery. 2. Development of a set of models for cascading energy use in integrated cogeneration systems for energy supply to buildings in order to increase energy efficiency and reduce pollution emissions. The top of the energy cascade is a solid oxide fuel cell (SOFC) system that produces high temperature exhaust and electricity with overall efficiencies approaching 95% (45% electricity, 50% heat). The high temperature exhaust is cascaded to a micro gas-turbine to convert the heat to more electricity. The remaining heat can be used directly in winter. For summer we are studying the use of a double-stage absorption chiller to transform the heat produced by the SOFC into cooling for the building.

Sustainable Manufacturing

Comparative Life Cycle Assessment of Direct Metal Deposition with Traditional Die and Mold Manufacturing

William Ross Morrow and Steven J. Skerlos

The use of dies and molds has become a key element of fast, reliable, and cost-effective manufacturing. Currently, combinations of casting, forging, machining, HSM (High Speed Machining), EDM (Electric Discharge Machining), grinding, and various finishing procedures, as well as heat and surface treatments, may be required to produce a single die or mold. Hence, die and mold manufacturing is time consuming and expensive, and leads to significant amounts of energy consumption, resource use, and environmental emissions. Alternatively, state-of-the-art direct metal freeform manufacturing processes present an opportunity to manufacture dies and molds with a short design cycle, and with less energy consumption, emissions, and primary material waste during mold manufacture. Direct metal deposition (DMD) is a solid freeform fabrication technique that integrates five common technologies: lasers, computer-aided design (CAD), computer-aided manufacturing (CAM), sensors, and powder metal delivery through co-axial nozzles along with the laser beam. The resulting process can create parts by focusing an industrial laser onto a metallic workpiece to create a molten pool of metal. By controlling the deposition and cooling with high accuracy and precision, functional dies and molds can be made additively rather than through subtractive processes. The goal of this research is to better understand the potential environmental benefits, along with potentially negative environmental impacts, for the DMD process in the application of die and mold manufacture by performing a life cycle comparative assessment against current die and mold manufacturing processes. While DMD can produce functionally identical dies and molds when compared with traditional manufacturing processes, it also can produce functionally improved parts. These new technical capabilities have a significant impact on the assessment of environmental impact of DMD technology in die and mold manufacturing. For example, an H13 tool steel die with copper heat sinks and conformal cooling channel produced by DMD can reduce the in-process cycle time for an injection mold by 10-40%. This means that injection

molding processes can have improved productivity, leading to increased output, or fewer machines and overhead taken over the whole manufacturing operation. When these parts wear during their use-phase, DMD material deposition allows for a nondestructive repair of dies and molds, which extends the functional lifetime even over engineering changes. Moreover, at the "final end-of-life" the molds themselves can be returned to the material input stream by reforming them into powder. While these characteristics of DMD are environmentally beneficial, it is clear that heterogeneous material fabrication (e.g., copper heat sinks embedded within an H13 steel substrate) may lead to dies and molds functionally, economically, or environmentally incompatible with current recycling techniques. Furthermore, introducing new techniques for die and mold manufacture could also lead to shifts in behavior that change the overall impact profile for the industry. Building from the ISO 14000 standard, a streamlined methodology was developed for a comparative assessment of die and mold manufacture through alternative processes. An initial case study was developed through which manufacturing processes could be assessed independently of the use and disposal stages, where many of the differentiating capabilities occur. The case study was extended to consider the full capabilities of DMD to improve die and mold manufacture/use, as well as potential disposal and recycling issues associated with the use of the technology. For all assessments, material and energy inventories and the corresponding impact profiles were generated across those activities that differentiate the DMD-influenced die or mold life cycle from traditional techniques. Process costs were estimated for the entire life cycle, including activities that are not changed by DMD production of dies and molds.

Toxics in Vehicles: Lead

Jeff Gearhart, Charles Griffith, Dean Menke

Automotive applications of lead comprise 76% of annual U.S. lead consumption and the emissions from lead production are inextricably linked to the automotive life cycle. Environmental releases of lead take place at various life-cycle stages of the automobile: from raw materials extraction and processing; from the fabrication of lead-containing parts in the vehicle manufacturing and assembly stage; during vehicle use, the wear of lead-containing parts like brake pads and the replacement and subsequent disposal of these parts (including the lead-acid battery); and finally through vehicle disposal, from processes such as shredding, non-ferrous metal separation, electric arc furnaces (EAFs) that melt lead-contaminated steel, and from secondary lead smelting (battery recycling). Lead is used in a variety of automotive applications. The lead-acid battery in every automobile weighs approximately 15 kg (contributing to about 1 percent of the weight of the vehicle), 11 kg of which is lead and lead compounds. The mass of lead in other automotive applications is considerably smaller, approximately 2 kg per vehicle total, but still significant when considering the amount of lead in the entire vehicle fleet now on the road. It is estimated that the current North American vehicle fleet contains more then 3 million metric tons of lead. Most lead-acid batteries are currently recycled: it is the lead contained in other automotive applications that often remains un-recovered at the end of the vehicle's useful life, and is allowed to enter the environment, where it can cause adverse human health and environmental effects. The paper calls for a proactive approach to design lead out of products and manufacturing processes. In fact, in recognition of the health hazards posed by lead, industry leaders are taking steps to reduce or eliminate the amount of lead in their products. For example, automobile manufacturers are phasing out some applications of lead, such as lead-based electrocoat primers or terne metal fuel tanks—but other, more pervasive, applications remain. By documenting the interrelationships between the automotive uses of lead and lead emissions, and examining lead-free alternatives to lead containing components, this report seeks to encourage further research and development of alternatives to all applications of lead. Finally, the report will review global policy approaches to address lead and other toxic materials contained in vehicles.

Product Process and Structure: Redesigning the Industrial Ecology Of the Automobile

R. J. Orsato and P. E.Wells

Sustainable transportation (consumption) cannot be separated from the physical processes by which products are made (production) and the capital structure of the businesses operating in the sector. As we will argue, the interdependencies between the dominant capital structure and modes of competition between industrial organisations have led them to unsustainable practices. Over-production, product obsolescence and hyper-mobility of capital currently undermine both the economic and the ecological sustainability not only of individual firms but also entire industrial sectors. Nowhere has this been more apparent than in the automotive industry—a sector epitomizing the dilemmas of sustainability. This is why we use our extensive experience of the sector not only to present an analysis of the main causes of the unsustainability of the industry but also an alternative for its development. Theoretically the analysis of the sector is informed by an approximation of ecological modernization theory within the perspective of industrial ecology. On more empirical grounds we propose the concept of Micro Factory Retailing - a radically different business model to manufacture, distribute, retail, service and recycle vehicles-as a viable alternative to creating a sustainable automobile industry.

Management of Sustainable Development Innovation: Integration of TRIZ and QFD Under the Framework of Soft Systems Methodology (SSM)

Fouzia Baki and Michael H. Wang

New product development is a key factor to the successful product strategy and thus, one of the most important components of a firm's competitiveness. Most of the literature on innovation management in product development has studies from both organizational and inter-organizational perspectives, only a few studies have discuss about supporting tools, methodologies, and infrastructure for innovation. First, this paper introduces the concept of sustainable development innovation (SDI). Next, a systematic methodology for developing and managing sustainable development innovation in organizations is presented. The method presented in this paper will be useful to any organization that designs and produces consumer products. The framework for the methodology is based on the soft-systems methodology (SSM) approach and theory. Soft systems methodology has been recommended as a tool for scientifically evaluating complex environments. Two supporting tools: Quality Function Deployment (QFD) and Theory of Innovative Problem Solving (TRIZ) are used within this framework. Each of these methodologies has its place in the product development process. The authors use these tools within the larger SSM framework to provide a synergy that makes them suitable and valuable for innovation management.

Remanufacturing: Trendsetting Economic and Ecologic Benefits in a Global Review

Rolf Steinhilper

Throughout the entire product life cycle chain—from the first part supplier to the last material recycler-an impressing variety of parties and technologies play their individual —often conflicting—roles. Remanufacturing—the principle to manufacture "like new"-products from used products, is attracting the attention of scientists and executives, worldwide. It offers multiple economic and ecologic benefits: - From an environmentally conscious citizen's viewpoint, the main reason for supporting remanufacturing will certainly be their appreciation for recycling as a key principle of "making peace with nature" and securing a sustainable future. - A business strategist finds that remanufacturing rewards the world of manufacturing with new business opportunities in the after sales service market enabling one to offer their customers new solutions with a minimum total cost of ownership. - The waste manager will be delighted how remanufacturing can serve to turn around their costly disposal processes into product loops creating profits. - The innovative manufacturing engineer will identify the five steps of remanufacturing, from disassembly, cleaning, inspection via parts reconditioning until reassembly and final testing, as an expansion of familiar technologies by new challenges especially in the first steps. - Any maintenance expert will point out, that remanufacturing is the most effective way to perform servicing and repairing tasks to both the worker's and customer's satisfaction. - Politicians and government officials, whether on federal, state or regional levels, will agree that remanufacturing is a unique strategy for new business development and creating jobs in their surrounding communities. - Economists will honour remanufacturing enterprises as members of the esteemed community of "hidden champions" of industry, playing an important role for today's and future industries' survival. - The environmentally responsible industrial professional at once will recognize that remanufacturing is the key link in an integrated green technology chain to perform his new "cradle to grave"-product and recycling responsibilities successfully. - For the consumer, remanufacturing is not just the most ecologic but also the most economic way of having access to state-of-the-art technology products at affordable prices but always the quality of new products. - Success and also risk assessment analysts will describe remanufacturing as an approach to successfully repeat, replay (and to an interesting extent even replace) those manufacturing technologies, which so far only created a product's first life cycle. Remanufacturing offers a product many life cycles - it is the enabling technology for "cradle to cradle" product loops. - Scientists will plainly state, that remanufacturing is the most efficient and effective way to save resources, whether energy or materials, of any form of recycling. -Finally, one doesn't need to belong to the small party of idealists to esteem

remanufacturing not just as a principle for the "rebirth" of a product, but also as the birth of an idea how to give new breath to the ideals of a sustainable future for our planet and civilizations. Observations and outlooks from these perspectives will be presented, using examples from a wide range of industries (mechanical, automotive, electric, electronic) and on an international scale.

Incorporating Degradation and Obsolescence Factors in Predicting Returns of End-of-Life Products

Andre Kasmara, Sun Dong Min, Shinobu Matsuoka, Masaaki Muraki

Efforts to realize the ideal of a sustainable production system through remanufacturing have been facing complexities in handling the return of End-of-Life (EOL) products to the production system. This generates the needs for predicting returns of products in addition to conventional necessities of forecasting demands. Knowledge of EOL product returns can lead to enhancing the effectiveness of closed-loop supply chain, production and disassembly planning. Moreover, information of returns as well as the actual life of products provides guidance for designing the optimal characteristics of parts selection, product introduction time as well as generating the optimal strategy for recovery of EOL products. We recognize two main factors that determine the end of product life, namely degradation factor and obsolescence factor. Degradation refers to the product reaching the end of its life due to reasons related to physical and reliability degradation without any influence of newer generation product or series. However, the timing of EOL product occurrence is not determined only by physical or reliability considerations. It is also determined by obsolescence, which counts the dynamic of product innovation and stimulates EOL due to functional obsolescence relative to the newer, innovative products introduced to the market. Our emphasis on the significance of obsolescence factor answers the challenge to enhance remanufacturing activities and performance within the current environment of rapid product innovation in the manufacturing industry. As industry is gradually moving toward remanufacturing from conventional material recycling activities, we respond to the increasing needs for more specific and accurate information of EOL products for each respective product generation/series and the associated parts to be remanufactured. This study aims to provide a reliable method for predicting returns of EOL products per generation/series by incorporating both degradation and obsolescence factors. We adapt the product innovation concept of technology diffusion and substitution theory to analyze the pressure on consumers to switch their old product to the newer generation one. We extend the diffusion/substitution sales forecasting model to recognize repeat purchases and product switching so as to provide some indication of EOL products due to degradation and obsolescence factors. Upon the considerations of both factors in the model, we expect to generate forecasts of EOL product returns for each respective generation/series of product that adequately accommodate product innovation reasons in addition to physical and reliability degradation considerations.

Managing Energy and Greenhouse Gases

Formulation of Goals and Assessment Of Goal Achievement for the Global Cycling of Carbon

A. Grimvall, E. Löfving

There is overwhelming scientific evidence that the modern society has strongly influenced the global carbon cycle and caused an unprecedented increase in the concentration of atmospheric carbon dioxide. Also, it is generally accepted that the combustion of fossil fuels is the main cause of this change. However, the uncertainty in the formulation of goals for the cycling of carbon is considerable, and the same holds for the assessment of goal achievement. In this paper, we examined this uncertainty on three levels: (i) the formulation of interim targets, (ii) the establishment of guidelines for assessing whether or not the interim targets have been achieved, and (iii) the imprecision of raw data used in the assessment. Global and national environmental goals for the cycling of carbon are normally expressed as emission targets. It is uncertain how these goals can be transformed to goals for atmospheric CO2-levels or climate change. We reviewed some attempts to estimate what emission reductions that would be necessary to stabilize the atmospheric CO2-level at about 450 ppmv, and we found that the results obtained varied strongly with the paradigm or scientific approach that was employed. A data-based mechanistic modeling approach indicated that annual emissions of about 7 Gigatons per year would result in such a stabilization. More complex hypothetico-deductive approaches indicated that a reduction to 2.5 Gigatons per year would be necessary. International conventions, such as the Kyoto protocol, put great demands on guidelines for calculating national CO2 emissions. Our analysis focused on the fact that consumption in one country can cause emissions in other countries. In particular, we showed that the growing import/export of electrical energy in northern Europe makes it increasingly difficult to assign CO2 emissions to nations. Also, we showed that steadystate calculations of the environmental impact of substituting fossil fuels for biomass can overlook significant temporary increases and decreases in CO2 emissions. The imprecision of raw data is normally a minor source of uncertainty. However, closer examination of official statistics on CO2 emissions revealed that existing data regarding production, trade and consumption of fuels are not fully consistent. In particular, we found that the assignment of emissions to specific years can be uncertain.

Incorporating Dynamic Feedback Relationships Between Material And Energy Flows, Vintage Effects And Regional Heterogeneity: Implications For Managing Greenhouse Gas Emissions.

Brynhildur Davidsdottir

Carbon emissions from the combustion of fossil fuels and biomass and methane emissions from biomass decay in landfills are two notable anthropogenic contributions to changed atmospheric concentrations of greenhouse gases. As one of the most energy intensive industries in the US manufacturing sector and a processor of large amounts of biomass, the US paper industry can play a significant role in reducing greenhouse gas emissions. The US paper industry purchases large amounts of fossil fuels, yet at

the same time over 55% of its energy needs is produced directly as a byproduct to chemical pulping of virgin fibers. To maintain or increase this level of selfgeneration is only easily feasible if the industry continues using virgin fibers. A substantial increase in the use of recycled fibers necessitates a larger proportion of purchased energy, albeit generally as a proportion of a smaller total since waste-fiber pulping it not as energy intensive. If the industry recycles a substantial amount of waste-fibers it delays methane generation from landfills, but an increase in the amount of fibers deposited into landfills will facilitate methane generation. In light of the relationship between materials and energy flows, and between carbon dioxide and methane emissions, the investment/ management choices of which fibers, or what type of energy to use, are closely intertwined - and thus the question how to control greenhouse gases necessitates the simultaneous analysis of material and energy flows. In addition, since the industry is a mature capital-intensive industry it faces considerable "capital inertia" which greatly influences technological change and thus investment/management decisions. To examine historical and potential future energy and fiber use, as well as carbon and methane emissions by the US paper industry, a model is developed of that industry for eight geographic regions within the USA. The model simultaneously incorporates investment decisions, material and energy flows, as well as incorporates directly the vintage structure of the capital stock – capturing the impact of capital inertia. A perpetual inventory model quantifies changes in the capital stock. Each vintage or age-class of installed capital is specified by age-specific retirement rates, fiber, and energy intensities. Two types of technical change are incorporated: change embodied in the capital stock of newly installed capacity and change occurring after installation. Carbon emissions from fuel use and methane emissions (using the EMCON methane generation model) from wastepaper discarded in landfills are calculated. The engineering and econometrics-based vintage model of the US paper industry is used to simulate carbon and methane emissions between 2000 and 2020 under the assumption that no new policies affecting the industry are introduced. Results demonstrate that carbon emissions vary considerably between regions within the US mainly due to differences in growth rates, output mix, energy and fiber mix, as well as differing factors that influence the choice of which-and how much-materials and energy to use. Those results have important implications for the management of greenhouse gases, which are discussed.

Cost and Ecological Impact Analysis Of An Integrated Energy System for Supplying Heating, Cooling, and Power Requirements to Buildings

Celine Weber, Steven Kraines, Michihisa Koyama

We present results of an analysis of the ecological impact and costs of an integrated energy system for providing an office building with heating, cooling, and power requirements. The integrated energy system that we have studied is comprised of a solid oxide fuel cell system (SOFC), a micro gas-turbine, and an absorption-chiller. These technologies are believed to potentially support increased ecological sustainability in urban regions. SOFCs in particular are considered to be promising future technologies because of their low pollution emissions and their suitability for use as a decentralized power source. In particular, they can be designed so as to best meet the energy requirements of a given building. However, besides providing the desired electricity, they also generate a lot of heat (approximately 45% of the energy input comes out as electricity, 50% as usable heat, and 5% as heat losses). While in the winter and in cold regions, this heat is useful for providing hot water and heating, for a region such as Tokyo in the summer, production of heat will almost always exceed the available demands. We have studied a system that cascades the high temperature exhaust gas of the SOFC to a micro gas-turbine for additional electricity generation and then to an absorption-chiller in order to provide cooling for the summer. In order to assess the effectiveness of the energy system from an ecological point of view, we consider three aspects: - the pollutant emissions of the devices throughout their life cycle (construction, use, and recycling or demolition) - the costs of the devices throughout their life cycle - the efficiency of the system. For the first two aspects, a simple life cycle assessment is performed. For the third aspect, an exergetic efficiency calculation is made. The exergetic analysis not only allows us to evaluate the efficiency of the system as a whole but also of the devices independently, thus indicating on which elements efforts should be concentrated to design a system that is more efficient and thereby more environmentally friendly. This system is a first prototype of a comprehensive integrated modeling platform to study the effectiveness of energy system technologies. More technology device options will be integrated in order to compare different combinations of technologies. Initial evaluations for a single building in Tokyo show that a SOFC connected to a gasturbine (SOFC/GT) is more efficient than the grid in Japan even when only electricity demand is considered: the power from the grid in Japan generates 110 gC/kWh, while the SOFC/GT combination only generates 80 gC/kWh. Adding the benefits of cogeneration of heat in the winter further increases the benefits of the SOFC/GT combination. For the summer period, we can increase the efficiency of the cogeneration system by replacing conventional reciprocating chillers with an absorption-chiller that can take advantage of the heat of the SOFC/GT combination. Further analyses will show the optimal balance between capacities of SOFC, GT, absorption chiller, heat pumps, and reciprocating chillers from cost, environment, and efficiency perspectives.

Sustainability of Advanced Silicon Solar Cell Technologies

E.A. Alsema and M.J. de Wild-Scholten

Photovoltaic solar energy is widely viewed as an energy supply technology which can contribute to a sustainable energy supply in the future. At the same time, however, it has to be recognized that present production technologies for solar cell modules have some disadvantage, such as a relatively high energy consumption. This implies that solar cell systems of the present generation have only a limited capability of mitigating greenhouse gas emissions (Alsema, 2000). Newer production technologies, which are currently under development, should lead to an improvement of this situation. A study was done to investigate the environmental aspects of advanced production technologies for production of "solar-grade" silicon feedstock, new methods for producing thin silicon "sheets" and novel cell processing techniques. Also the aspects of building integration are considered. In our paper we will present results on the expected improvement of the environmental profile of photovoltaic systems in the next 10-15 years. Also problems regarding data quality and impact allocation will be discussed.

Measuring the "Efficiency Gap" between Average and Best Practice Energy Use

Gale Boyd

A common distinguishing feature between parametric/statistical models and engineering economics models is that engineering models explicitly represent best practice technologies while the parametric/statistical models are typically based on average practice. Measures of energy intensity based on average practice are of little use in managing energy use or for corporate goal setting. In the context of company or plant level indicators, it is more useful to have a measure of energy intensity capable of representing where a company or plant lies within a distribution of performance. In other words is the performance close (or far) from the industry best practice. This paper presents a parametric/statistical approach that can be used to measure best practice, thereby providing a measure of the difference, or "efficiency gap" at a plant, company or overall industry level. The approach requires plant level or similar micro-data and applies a stochastic frontier regression analysis to energy intensity. Stochastic frontier regression analysis separates the energy intensity into three components, systematic effects, inefficiency, and statistical (random) error. Standard linear regression analysis only includes systematic effects and random error. As in standard regression, the stochastic frontier regression requires that a linear model of systematic effects on energy intensity is specified. Variables in the model could include economic decision variables like energy prices and capital costs, or structural variables like plant size, location (climate), utilization, technology, etc. The stochastic frontier regression analysis assumes there are two types of error terms. The first is the random "noise" error term. The second error term has a one sided distribution and represents inefficiency, i.e. the degree of departure from best practice energy intensity. Various assumptions can be made regarding the distribution of this inefficiency component. It can be distributed as an exponential, truncated normal, or Gamma distribution. The flexibility of the Gamma distribution makes this assumption highly desirable, but difficult to estimate. A recently developed method of simulated maximum likelihood (Greene September 30, 2000) makes this estimator feasible. The paper presents specific examples of this method, as it was implemented for the EPA Energy Star® industrial program (Boyd and Hicks 2002). Greene, W. H. (September 30, 2000). Simulated Likelihood Estimation of the Normal-Gamma Stochastic Frontier Function. New York University Economics department working paper. Boyd, G. and T. Hicks (2002). Benchmarking Plant Productivity. Earth Technologies Forum, Washington, D.C.

Life-cycle Assessment (LCA) of Global Impacts from Electricity Generation Technologies

Sergio Pacca, Arpad Horvath

The increasing demand for electricity calls for comparisons between the various generation technologies in terms of their global impacts. No analysis of greenhouse gas emissions from power plants is complete without a comprehensive Life-cycle Assessment (LCA). The LCA presented herein focuses on comparable hydroelectric, solar, wind, coal, and natural gas power plants, and aggregates emissions from construction, burning of fuels, flooded biomass decay in the hydroelectric plant's reservoir, and loss of net ecosystem production (NEP). Land use by these plants is also assessed. In addition to their spatial distribution, the temporal scale of such emissions is of interest for decision-makers due to the fate of different greenhouse gases in the atmosphere, the timing of their release, and the urgency to respond to climate change. By combining process-based and input-output analysis-based LCA with the global warming potentials of greenhouse gases, the global warming effect (GWE) of the studied technologies over four planning periods (10, 20, 30 and 40 years after construction) are calculated. The results indicate that a wind farm and a hydroelectric plant in an arid zone (such as the Glen Canyon Dam on the Colorado River) appear to have lower GWE than the other power plants. The type of ecosystem displaced by the reservoir and the period of analysis is fundamental to the assessment of the alternatives. After 20 years of operation, the upgrade of the Glen Canyon hydropower plant (in 1984) increased the power capacity by 39%, and resulted in a mere 1% of the CO2 emissions in comparison with the initial construction effects. No additional emissions from the reservoir occurred, making a periodic upgrade an important action in the life-cycle of power plants. Technological changes such as the anticipated increased efficiency of wind and solar energy conversion and lower manufacturing impacts are also discussed.

Life Cycle Assessment and Management

Life Cycle Inventory for Semiconductor Manufacturing

Cynthia Folsom Murphy, Jean-Philippe Laurent, David T. Allen, Jennifer L. Schuppe

The University of Texas is working in conjunction with International SEMATECH and its member companies to develop generic, parametric life cycle inventory modules for wafer fabrication in the semiconductor manufacturing industry. While there is growing interest within the industry, there is also resistance to engaging in life cycle activities, in large part due to lack of adequate data on material, energy, and emissions (inventory). Progress is hampered by lack of an appropriate structure, and standards for collecting data. The structure of existing databases does not account for the need to manage data on a unit operations basis. In addition there are no standard system boundaries and collecting. Many of the chemicals used for wafer fabrication are not adequately represented in available databases, and the data do not account for the significant variability in usage rates that exists within the industry. A structure for performing mass and energy balance analyses that will facilitate process-based LCA and management of data at the unit operation-level is presented along with two approaches that are being used to develop inventories within this framework. The first is to collect detailed data for a single unit operation (wafer cleans) and use this information to generated modules. The second methodology is to collect data for individual products at each process step, to group by unit operations, and to identify and quantify the critical parameters. These data are then used to create generic, parametric modules.

Printed Scholarly Books and E-book Reading Devices: A Comparative Life Cycle Assessment of Two Book Options

Greg Kozak, Gregory A. Keoleian

Books have endured because they are remarkably well engineered; they are easy to use, portable, relatively cost-effective, and they require no instructions or manuals for their use. Despite their utility, however, conventional books published on paper have numerous limitations. Traditional, print-based books can be extremely costly to produce, store, ship, and sell. Less evident, however, are the environmental burdens associated with the infrastructure and activities necessary to produce and deliver the conventional book. With the advantage of being able to store thousands of pages of text and graphics in a single portable device, dedicated electronic reading devices (e-readers), on the other hand, are gaining in popularity. This paper presents the findings of a life-cycle assessment (LCA) of two different book options - electronic and print. The purpose of this study is two-fold: (1) to investigate the life cycle environmental aspects of e-publishing of scholarly books and e-book reading devices (i.e. e-readers); and (2) to apply the life cycle models to a variety of scholarly e-book applications and compare LCA results for traditional print based counterparts. This study compared the life-cycle burdens and impacts of a college student reading 40 scholarly books and the equivalent amount of digitized information (53.6-MB) using a dedicated e-book reading device. By comparing these two book options, this study provides industry, consumers, and policy makers with valuable information necessary to make environmentally informed decisions regarding e-book technologies. E-reader critics have rightfully argued that e-readers are not conducive to long sessions of reading text from a screen, lack the tactile appeal and "atmosphere" of conventional books, and are inconvenient in the sense that they represent yet another device that the user must purchase and learn to use. However, from an environmental standpoint, it is difficult to argue against the integration of e-readers into a school's curriculum, especially if the original user chooses to retain rather than resell the book or if the utility of owning the book expires (i.e. the book is discarded). The most notable observations gleaned from this study are as follows:

- Environmental burdens associated with electronic book storage (i.e. server storage) are small when compared to the physical storage of books (i.e. book-store).
- E-readers eliminate personal transportation-related burdens since they allow for instant accessibility to digitized texts (i.e. anywhere there is Internet access).
- E-readers are more compact and are less material intensive than the equivalent number of printed books.
- Although the most significant contributor to the e-reader's LCA results, electricity generation for e-reader use had less of an environmental impact than did paper production for the conventional book system.

The intention of this study is not discourage the use of the printed book. Rather, this paper provides industry, consumers, and policy makers with a better understanding of the potential environmental impacts associated with traditional and electronic book

systems. Further, this study also provides another case study examining the relationship between information technology and the environment that can contribute to product design improvements and the development of more sustainable technologies.

Comparative Life Cycle Analysis of a Petroleum- and Bio-Based Metalworking Fluid

Julie B. Zimmerman, Kim F. Hayes, Steven J. Skerlos

The metalworking industry is one of the largest in the United States. Integral to this industry are metalworking fluids (MWFs) that serve as coolants, lubricants, and corrosion inhibitors. In Y2000, over 2 billion gallons of MWFs were sold in the U.S. The primary components of typical MWFs include water, oil, and emulsifiers, with up to eight additional additives providing supplemental performance characteristics such biostability, extreme pressure lubrication, and chelation. MWF formulations have traditionally been based on a petroleum feedstock, raising concerns about environmental degradation and toxic substance release to the environment throughout the life cycle. Moreover, there are increasing concerns regarding the mounting costs as well as the diplomatic and military support necessary to sustain the current level of domestic petroleum consumption. These undesirable characteristics have led to increased research and development of bio-based MWFs. A bio-based feedstock offers a renewable MWF formulation base with superior potential for biodegradation at end of life and improved machining performance. These properties have increased interest in bio-based feedstocks as a way of meeting the increasingly stringent MWF disposal limits currently being considered by federal governments and the international community. However, economic obstacles currently exist since vegetable oils are considerably more expensive to produce than petroleum oils. This establishes a trade off between environmental benefits and economic cost. To evaluate the environmental and economic impacts of a feedstock shift from petroleum- to bio-based MWFs, a comparative, streamlined life cycle assessment (LCA) was performed. The in-use MWF fluid lifetime was found to be a key parameter which determines the relative impact of bio-based versus petroleum feedstocks, since the MWF lifetime determines the gross environmental and cost impacts at each life cycle stage (i.e., production, transportation, use, and end-of-life). Production impacts for mineral and vegetable oil, as well as the selected petroleum and vegetable derived emulsifiers, were determined using data from publicly available databases and the literature. The impacts associated with the use phase (process energy, emissions, and cost) were evaluated from primary sources including laboratory experiments, field measurements, and data provided by suppliers. The energy, emissions and costs of three end of life scenarios (reuse, incineration, and disposal) were also evaluated for both formulations. To streamline the assessment, MWF formulations were developed with identical secondary additives in equal quantities. Under the assumption that additive functionality is unaffected by feedstock, the life cycle model (LCM) was able to elucidate the key differences between petroleum- and bio-based feedstocks for MWFs. The LCM was analyzed for sensitivity to specific system decisions including oil production strategies, fluid lifetime, and end of life options. The model also permitted an explicit evaluation of the significance of uncertainties, data gaps, and situational variability on specific system conclusions.

Life Cycle Assessment and National Energy Usage

Julian Allwood

Life Cycle Assessment is securely established, widely applied and well researched. As a tool it offers important insight into product design choices and has had impact in directing effort in reducing the impact of particular products. Nevertheless, applications of LCA are inevitably selective in the effects included within the system boundary and in particular the impact of energy in distribution is often reported to be very small. In contrast, national energy consumption figures indicate that freight transport is responsible for around 10% of all energy use. This paper seeks to explore this discrepancy between product level analysis and national analysis. A large set of published LCA figures are aggregated and compared with national energy statistics. The comparison is used to assess whether LCA may be misleading in consistently underpredicting impact in some areas of energy usage. The analysis is intended to underline the need for caution in the use of LCA. In particular LCA may not generally capture effects related to the scale and organization of production systems.

Financial Systems Analysis of Gasification, Incineration and Landfilling of Waste

Getachew Assefa, Ola Eriksson & Bjorn Frostell

Catalytic combustion - as a part of an energy conversion chain - is a promising technology that is presently studied at KTH in Stockholm. In this particular application, the catalytic combustion is used as the final step in a waste-to-energy system including gasification and combustion. Instead of using a normal gas turbine flame combustion, a catalytic combustion is used. Following promising experimental results, a systems analysis was performed with the aim to assess the ecological and financial performance of different waste-to-energy chains. In the study, a life-cycle assessment approach previously developed for systems analysis of waste management, the socalled ORWARE model was used. The following different treatment scenarios were studied: (1) Gasification with catalytic combustion, (2) Gasification with flame combustion, (3) Incineration with energy recovery and (4) Landfilling with gas collection. In the study, compensatory district heating was produced by combustion of biofuel. The power used for running the processes in the scenarios was supplied by the waste-to-energy technologies themselves while compensatory power was assumed to be produced from natural gas. The emissions from the system studied were classified and characterized into the following environmental impact categories: Global Warming Potential, Acidification Potential, Eutrophication Potential and finally Formation of Photochemical Oxidants. Gasification with energy recovery in a combi cycle using catalytic combustion in the gas turbine (scenario 1) was found to be the most competitive technology from primarily an environmental point of view. It was also obvious that a decreased use of landfilling in favor of an increased energy recovery from waste is positive from all considered impact categories. A comparison of the catalytic combustion and the flame combustion showed that catalytic combustion is favorable, mostly thanks to its very low emissions of NOX. This was since the

gasification process studied was identical between the two alternatives; only the combustion technology in the gas turbine was different. Here, catalytic combustion allows a much lower reaction temperature which results in a lower production of NOX. The financial costs were, however, found to be slightly higher for catalytic combustion than for incineration with energy recovery. This means that ecological performance has to be valued financially in order to clearly justify the introduction of this technology instead of traditional waste incineration with energy recovery.

Integration of Design for environment and Environmental Management Systems

Jonas Ammenberg, Erik Sundin

Standardized environmental management systems (EMSs) are quite commonly used today. It is the authors' experience that many companies, authorities and individuals regard a certification according to ISO 14001 as a guarantee for good environmental performance. For example, the Swedish government has chosen the number of ISO 14001 certificates and EMAS registrations as an indicator for sustainable development. Moreover, some important European countries offer regulatory relief if companies have an ISO 14001 certificate or are EMAS registered and US authorities consider easing regulatory burdens for companies using EMSs. The overall objective of ISO 14001 is "to support environmental protection and prevention of pollution in balance with socioeconomic needs";. But are standardised EMSs really leading to improved environmental performance and reduced environmental impacts? This certainly depends on to what extent these systems are leading to changes in important flows of material and energy, which in turn is closely connected to influence on companies' product development. The adaptation of products for the environment is commonly conducted by different Design for Environment (DFE) methodologies. Consequently, it appears vital to investigate the connection between EMSs and the concepts of DFE. This paper presents the concept of product oriented environmental management systems (POEMSs). A POEMS is an EMS with a special focus on the continuous improvement of the company's product's eco-efficiency (ecological and economic) along the life cycle, through the systematic integration of eco-design in the company's strategies and practices. In addition, based on interviews with Swedish external environmental auditors, it is presented how these auditors interpret and apply the central requirements of ISO 14001 concerning products and product development. Thereby, it is illuminated to what extent Swedish manufacturers incorporate DFE principles into their EMSs. Based on the results, it can be concluded that there are many motives to integrate the concepts of EMS and DFE. Firstly, DFE-thinking might enrich EMSs by contributing with a life-cycle perspective, helping the organization to identify the most important flows of material and energy to focus on. Secondly, EMSs might remove the common pilot project character of DFE activities, thereby making them more permanent. Thirdly, an integration of EMSs and DFE concepts could lead to successful co-operation both internally and externally, i.e., lead to a co-operation between environmental managers and staff responsible for product development and lead to concerted environmental efforts within a supply chain, i.e. to a better life cycle management. Concerning the roles of auditors, it can be concluded that their requirements and experiences vary to great extent. While some auditors consider it as mandatory for a manufacturing company to incorporate products and product development into their EMS, others approve EMSs where the link between EMS.

Technical Session (T6)

Eco-Industrial Parks and Networks

Industry And Infrastructure Co-Evolution: Transition Management In Rotterdam-Rijnmond

G.P.J. Dijkema, M.P.C. Weijnen

The energy infrastructure and industrial cluster in Rotterdam-Rijnmond co-evolved into their present state over more than half a century. Their dynamics can be characterized as 'discrete event driven' and 'slow': heavy process-industry installations as well as cogeneration facilities, pipelines and other energy infrastructure typically are one-off installations that are designed-and-built in 2-5 years depending on the size and complexity of the project, whilst having a typical operating lifespan of some 20-30 years or beyond. During its lifespan, an infrastructure or industrial plant may be revamped, modified or extended when economic conditions favor the adoption of new technology or require optimization of its performance. Final closure of any installation, industry or infrastructure, affects other companies in the cluster, as well as the viability of the entire energy infrastructure. These dynamics are driven by competition, regulation and stakeholder involvement. Whilst the diversity and scale of the energy infrastructure and industry available in Rotterdam-Rijnmond greatly expand the scope for sustainable development, the exploitation of synergies between infrastructure and industry also creates interdependencies. In addition, the technologies and systems employed by the companies operating in Rotterdam are state-of-the art: large-scale, technologically advanced and complex. It may thus be seen that any transition towards a 'Sustainable Rijnmond area' through the adoption of novel energy infrastructure or infrastructure redesign will involve co-evolution of and redesign in the industrial cluster. The ' focus of our research is to elucidate and visualize the scope for a transition towards a sustainable Rijnmond, which will involve planning and management of regional energy infrastructure and industry co-evolution. Based on process system engineering, system dynamics, industrial economics and stakeholder analysis, methods are developed to enable sound predictions of the scope and impact of energy infrastructure development on industry structure and systems content. A major question is "does energy infrastructure development lead to industrial system development, or is it another extreme that prevails: industrial development leads, energy infrastructure follows." Throughout the world, Regional Development Agencies (RDAs) have the responsibility to foster the development on the industrial zones under their 'jurisdiction'. Whilst in infrastructure development their span-of-influence often is large, and public funding is rather common, both RDA's and Governments depend on decisions by individual companies for the development of their regions industry. Thus, in a Greenfield situation infrastructure must be developed such that it provides maximum attractiveness for prospective companies, in a Brownfield situation the policy of an RDA an other governmental bodies must both accommodate and influence companies already present as well as new entrants. In Rotterdam-Rijnmond various initiatives have been launched to realize 'Brownfield-rejuvenation' and to initiate green or sustainable Greenfield development. In the paper and in the presentation, results from a number of case studies on both type of initiatives will be presented, modeled and analyzed and conclusions drawn. These comprise, amongst others, fostering infrastructure development for fine and specialty chemicals production—'green chemistry' and industrial and infrastructure development around the production and use of hydrogen.

Establishment of an Eco-industrial Park for Material Recovery of End-of-Life Electronics in Conjunction with a Methane Producing Landfill

Cynthia Folsom Murphy, J. D. Porter, Garland Luedecke, and Mike Hanratty

The US Department of Commerce's Economic Development Administration had funded the development of a Master Plan for an Eco-industrial Park in Central Texas. This park will focus on material recovery of end-of-life electronics and attempt to co-locate and consequently collapse the supply chain involved in recycling of electronic components, plastics, glass, and metal. The tenants are slated to include a computer recycling operation, materials separation (especially engineering thermoplastics), a plastics compounder, and at least two operations that manufacture products using recovered materials either on-par (injection molding) or through innovative use of high-mix materials. The park is to be constructed on a 100-acre site at a landfill owned by Texas Disposal Systems that handles a significant portion of the solid waste along the Austin-San Antonio corridor. This landfill, which is already operating in a very environmentally conscious manner is expected to begin producing methane within the next year. Most of the operations in recovery of electronics materials have extremely high energy demands (grinding and/or melting) that could be in part met by the use of locally generated power from methane. Co-location with a landfill will facilitate some of the reverse logistics problems associated with product recycling and provide an outlet for materials that the landfill owner does not wish to place in the landfill. In addition, one of the most significant challenges facing computer recycling operations elsewhere in the country, is disposal of cardboard and other paper products. Texas Disposal Systems has well established cardboard recovery and composting systems. The primary benefits of collapsing of the supply chain through co-location are expected to be reduced transportation costs and environmental load as well as improved communication and material flow efficiencies.

The North Texas By-Product Synergy Program: A Case Study of an Effective Regional Eco-Industrial Network

Jeff Stovall

In this paper, a current case study of an eco-industrial network will be presented - the By-Product Synergy (BPS) program facilitated by Trinity Consultants (Trinity). The BPS program is a growing network of companies in the North Texas region that seeks to create "synergies" between one member's by-product and another member's input

material. The BPS program in North Texas began with nine charter members in 1999 as a spin-off of the Business Council for Sustainable Development's Tampico, Mexico demonstration project. Trinity assumed sponsorship of the BPS program in 2001, and the BPS program has since grown to include over 40 companies throughout the North Texas region. Example industries represented include pulp and paper, cement, power generation, tire manufacturing, fiberglass, synthetic graphite, steel, and metals recycling. This paper will provide an overview of the methodology utilized to create synergies for the BPS program. The process begins with the collection of technical data through interviews, information forms, and site visits. These data are then input into a custom-built database, which generates potential synergy matches. In addition, potential synergies are identified by Trinity or from open discussion among BPS member companies at bimonthly meetings. Once a potential synergy is identified, an investigative process to determine its feasibility is initiated. Each investigative process yields expertise, which is stored in the database for future reference. If the investigative process reveals that a synergy is feasible from all angles - economical, regulatory, logistical, and technical the synergy is implemented. In addition to discussing the synergy process, this paper will detail the specific technical aspects of several synergies investigated in the BPS program. For example, a synergy involving paper mill by-products as a replacements for agricultural lime in mine reclamation has under gone extensive testing to develop the right mixture of by-products that will create an effective liming material. Another synergy, spent caustic from a natural gas fractionater as a paper mill input chemical, has required detailed investigation in several areas: chemical viability, process feasibility, storage, handling, and transportation logistics, and regulatory acceptability. Other example synergies include: by-product graphite as a carbon source for steel manufacture, latex paint sludge as an input for a brick manufacturer, synthetic gypsum (flue gas desulfurization gypsum) as a replacement for natural gypsum, and spent sand from a foundry as a silica source for glassmaking. Finally, this paper will discuss the results of the BPS program, including the financial savings and revenue generated, the amount of material diverted from disposal, and the amount of virgin input material displaced. In summary, the BPS program blends a diverse group of companies to create both environmental and economic wins, and it provides a practical example of an effective industrial ecological network that can be emulated and even optimized in other regions of the world.

Industrial Symbiosis in the Island Context: Case Studies in the Caribbean

Peter J. Deschenes

Some may interpret the closure of a large alumina refinery in St. Croix as a permanent blow to the island's economy. A large amount of machinery stands unused, old processing structures obstruct valuable port facilities, and environmental contamination problems scare off potential tenants from the site. However, under the optic of ecoindustrial development, a wealth of opportunity exists for new industry on the site. A giant pile of red mud, the residue of the refining process, has the potential to be processed into useful material. Buildings on the central part of the campus can be renovated and made available to research and manufacturing operations, many of which could benefit from existing roads and the port facility. Large buildings formerly used to house stockpiles of bauxite and alumina could be used for storage of solid waste from the island. This material could be processed to recover resources such as paper, metals, and energy on site. Liquid storage tanks might be converted to house fish in an aquaculture operation, and port space may potentially attract cruise ship tourists to a recreation area. A power plant on site has already been re-fired to provide electricity and steam for current and future industrial applications in and around an industrial park centered in the old refinery. All of these possibilities exist in the unlikely setting of a small island traditionally known as a tourist destination and a waypoint for sailors. Consideration of a number of characteristics of St. Croix and other islands suggests that they are not such an unlikely setting for using industrial symbiosis to promote environmentally sustainable development. The inability to import power and potential volatility of fuel supplies requires local power generation and creates the impetus to develop local fuel sources and energy cascading between users to increase energy use efficiency. Scarcity or limited supply of resources increases the need to close loops of resource use within the island system. Limited outlets for emissions, small land areas, and dependence on coastal ecosystems set forth the need to reduce emissions into the natural environment and to focus on the reuse of energy and resources from existing waste streams. In addition, isolation from continental sources of resources can make imported resources, such as food, paper, and metal, more expensive for consumers and more valued for the additional embodied energy they possess as a result of the distance they must travel. All of these factors combine to create the island context within which industrial symbiosis is a valuable tool for addressing the immediate challenges of sustainability.

Why Participate in Eco-industrial Networks? Case Study of Puerto Rico's Pharmaceutical Manufacturing Cluster

Ashton Weslynne

Eco-industrial development has been of two types - 1- new parks where participants match each others' projected input/output flows, and 2- existing industrial networks where new participants are brought in to complement existing flows. New developments aim at finding participants willing to locate there as a result of ideology or perceived benefits from the material/energy flows. Within the latter network, existing members typically function in a paradigm that precludes seeing the potential benefits of cooperation with neighboring companies. In order to overcome this obstacle, new relationships need to be built that facilitate the sharing of information and engage firms in cooperative behavior. The industrial ecosystems in Kalundborg and Styria evolved in this manner over several decades. Factors attributed to the willingness of private firms to participate in these regions include face-to-face interactions among managers and realization that cost-savings could be accrued by locally sourcing by-products as inputs. Understanding how to create interaction, information sharing and concept buy-in among existing members of an industrial network would therefore be useful to ecoindustrial developers. Economic clusters, regional agglomerations of firms producing similar goods or services, show great potential for utilizing existing relationships to facilitate eco-industrial activity. Research being performed in the pharmaceutical manufacturing cluster in Puerto Rico indicates that there is a high level of firm interaction through industry associations and public-private partnerships. However, the cluster

faces increasing natural resource constraints, such as limited local hazardous waste disposal options and groundwater contamination and over-extraction. These features suggest an opportunity to jointly tackle environment-based problems. Past research has explored specific areas in which cooperative, eco-industrial solutions to resource problems may provide economic and environmental benefits to the cluster (Ashton and Chertow, 2002). This paper analyzes the variables that may influence a cluster member's willingness to participate in an eco-industrial network. These variables include parent company policies, relative importance of environmental costs, and level of activity with others in the cluster. These findings may assist eco-industrial developers in devising strategies that increase the willingness of firms in an existing network to participate in industrial symbiosis activities.

Sustainable Cities and Regional Metabolism

Material Flux Analysis And Agent Analysis As A Basis For Transition Towards Improved Regional Wood Flows: The Case of Appenzell Ausserrhoden, Switzerland

Claudia R. Binder, Daniel Lang, Arnim Wiek, Roland W. Scholz

This paper discusses material flux analysis and agent analysis as tools for supporting a transition towards an improved regional wood management in Appenzell Ausserrhoden (AR), a small Swiss canton (i.e., state) with 93 square miles located in the Pre-Alps of Switzerland. We present a wood-flow analysis for forests, wood processing industries and consumption in AR, accounting for different wooden goods. We find, that the forest is currently significantly underutilized despite of considerable imports of wood and energy to this small region. The wood resources, however, would be sufficient to satisfy the total current wood demand of the population in AR and to export wood to more densely populated regions. To achieve this, consumer wood demand and supply by forest owners have to be aligned to each other. The agent analysis shows that there are three main barriers for an increased use of regional wood resources: a) low wood prices lead to revenues from forest management that are negative. b) not certified wood quality leads that foreign certified wood is preferred over local wood. c) state and canton subsidies have not been coordinated and earmarked to overcome these issues. Based on the wood flow analysis and the agent analysis we will depict the regulation mechanisms, which are relevant for managing regional wood flows. In addition, results of an ongoing consensus and strategy building process on the basis of wood flow analysis and agent network analysis will be presented. We conclude that wood flow analysis combined with agent network analysis are useful tools for supporting a transition management process towards improved regional wood flows.

The Magnitude and Spatial Distribution of In-use Copper and Zinc Stocks in Sydney Metro

D. van Beers, T. E. Graedel, W. Caldicott

As one of the largest urban and industrialized cities in the south Pacific, Sydney Metro possesses large reservoirs of in-use copper and zinc. As the aging stock of copper and

zinc-bearing products reaches the end of its useful life, each metal will gradually become available for re-use, should that prove technologically and economically desirable. In order to consider mining a resource from any reservoir, natural or otherwise, three pieces of information are required: (1) How much of the resource is present; (2) in what form; and (3) at which locations? Once this quantitative and qualitative information is known, the costs of recovery and processing can be examined. These costs can be compared to the anticipated market price, and a decision on whether or not to proceed can thus be made. Locating and quantifying virgin resources are common practices in resource geology, but doing so for the "experienced resources" in cities is new intellectual territory. The paper aims to address the following hypothesis: is it desirable and feasible to regard large urban conurbations as major future sources of materials, bearing in mind that the increasing occurrence of large urban areas has lead to higher concentrations of in-use resources in constrained geographical areas? A model, using Geographic Information System (GIS) software, has been developed to spatially assess contemporary stocks and predict future stocks of copper and zinc in selected uses in Sydney Metro. Copper and zinc have been selected as case-study materials because they have depletion times of less than 100 years at low contemporary prices. In order to demonstrate the analytical opportunities offered by the GIS model, six sample areas were selected for a detailed assessment: two each from Inner Sydney, Outer Sydney, and Sydney Surrounds. We estimate the stocks of copper and zinc using a bottom-up approach for the following applications: building and construction, infrastructure, transportation, business durables, and consumer durables. Sydney Metro is a mega-city with about 4 million inhabitants. Its economy contributes almost 70% of New South Wales' Gross State Product and its population growth rate of Sydney is about 1.4% per annum. This numerical and spatial growth has been accompanied by industrial growth, resulting in increasing inflows of resources (such as copper and zinc) from local and distant sources. These inflows will eventually result in increasing outflows of discard material. Ready availability of data required to successfully conduct an Australian casestudy makes this region particularly attractive.

Urban Cybernetics as a platform for Industrial Ecology

Declan Commons

A technological response to societies non-optimal resource use is presented as involving a comprehensive revision of how substance's flow through settlements. This is undertaken with a view to upgrading to a new infrastructure that manages substance flows at an efficient rate, measuring and recording all through-put activity and making this data widely available. Ultimately this system is conceived as an infrastructure of substance transportation and near-immediate information feedback illustrating the relationship between human behavior and substance flows using communication technology. The physical attributes of such an infrastructure, and the opportunities it's intelligent and communicative properties provide for public policy to influence production and consumption cultures, are discussed with concern for broadening industrial ecology theory and practice. An infrastructure network such as this is proposed in the light of existing and emergent knowledge and technologies. The revised infrastructure channels themselves are to be designed and calculated in the light of the latest thinking which moves away from predict and provide to demand side management. These chan-
nels employ technologies to measure and process data on substance production, consumption and waste per producer/user (whether citizen - group, building - area etc.) in real-time continuity. In turn the communicative infrastructure makes this feedback data widely available, to be collated or divided as the interested party requires. While this system will primarily allow analysis of present resource efficiency problems, it is shown that industrial ecology applications will emerge as relevant solutions. It follows that public sector institutions and policies will morph and adapt to this new tool. As such, integral to the regime which implements this infrastructure will be a dynamic configuration of resource regulation and taxation, flexible and sensitive to feedback data, using this to inform policy and legislation, recognise exchange opportunities and reward compliant behavior. The technical usefulness of the data, the potential benefits of regulatory compliance and an emerging 'connectedness' (the combined result of physical infrastructure connection, related communications and mutually beneficial exchanges) may give way to a new social recognition of our relationship to our common pool of resources. In turn this awareness is expected to become a dynamic element in utilizing feedback data for informed decision making at every level.

GIS Based Regional Material Flow Analysis and Environmental Impact Assessment Caused by Long Term Urban Developments

El-Lithy Khaled, Tsuyoshi Fujita, Tohru Morioka

Urbanization and population growth constitute the major driving force of environmental impacts. Urbanization, in particular, results in considerable changes in land use/land covers (LUCC) and life environment. This factor is particularly important in the environmental improvement and development process in the regional scale. Authors present a pilot study for analyzing urbanization growth patterns and environmental impacts related to urbanization, population and economic growth in MUKO River Basin Region, a west part of Kansai Metropolitan Region, Japan, based on a comparative analysis between 1975s and 1995s. Since 1970s, the Region have been faced with pressed by development pressures of population growth, industrial developments and continuous residential developments, which resulted in rapid increasing of material and energy flows as well as transportation fluxes. Environmental impact elements brought by several regional driving forces and regional management policies are identified by 1km grid data of urban activities and environmental emissions with their spatial patterns. Several key factors for policy recommendations are found for future economic development planning, natural resources allocation, and environmental and ecosystem management in the Basin Region. First, authors established an integrated GIS data base system for MUKO River Basin Region. The system is obtained by utilizing comprehensive various categories and types of regional data such as land use/ land covers, population allocation, and natural vegetation and other related data. Social activity data of urban activities such as industrial activities and commercial sales and other socioeconomic data are also converted into 1km grid data as well as transportation trip generation related to suburbanization activities growth in the region. The data have been made for time-series comparative analysis between the 1975s and 1995s. Secondly, environmental impacts and their changes for three decades are evaluated, and regression models for the analysis are established for data calculation and simulation process in the region. Spatial patterns of environmental indicators defined such as the loss of natural land covers, contaminated effluents into river water, generation of solid wastes and carbon dioxide emissions. Thirdly, the relationship between driving forces for the Region and environmental impacts is analyzed by decomposing aggregated environmental impacts into several elements attributable to each driving force. Environmental impact elements attributable to management policies such as Planned Unit Developments, and the development of regional transportation networks are identified. Finally the results of this study guide to draw the policies to direct the development plans and strategies for growth management, environmental natural resources activity control and land use management.

Application of Industrial Ecology Principles for Reducing Regional Metabolism.

Krrishnamohan Kanduri, Peter Daniels

This paper describes an attempt to apply industrial ecology (IE) principles such as byproduct exchange to a region as opposed to industries, with a view to reduce regional metabolic flows such as the consumption of energy and resources, and generation of wastes. The study is undertaken for a local government area in South East Queensland, Australia. Such a study is unique and pioneering in Australia. The sustainability of a region is dependent on the use of energy and resources and the capacity for assimilation of waste emissions (solid, liquid and gaseous) by the region's natural environment. Usually, in the absence of ecological modernization, increased industrial and economic activity of the region increases the metabolism of the region and deteriorates the environmental quality. Traditional environmental management options such as end-ofpipe treatment and preventive technologies such as cleaner production (CP) while found to be effective at individual industry level, are not effective for optimizing the metabolism of an entire region. In other words, cleaner production at a regional level is likely to be best managed by the application of IE principles. In order to investigate options for IE strategies for reducing the regional metabolism, the first step has been to identify the various 'activities' or 'sectors' such as industrial, residential, local government, service sectors (e.g., tourism), with in the region. In order to determine the regional metabolism, materials and energy flow analysis (MEFA)was performed generally for each of above mentioned sector, but with greater focus on the industrial sector. The MEFA quantified and tracked the flows of some of the major materials (used in bulk and which were perceived to have environmental impact) and energy fluxes through various sectors. The combined (for all sectors) energy and material flux is considered as the metabolism of the region. After the regional metabolism was determined, IE options such as byproduct exchange were explored by identifying potential by-product synergies within each sector and also between sectors.. The study has opportunities and constraints, which will also be discussed in the paper.

Direct and Indirect Energy Use of Households in Stockholm: Expenditures Versus Energy

Annika Carlson-Kanyama, Rebecka Karlsson

The study present results from a European project, ToolSust, in which direct and indi-

rect energy use of household consumption is quantified The focus is on households in Stockholm and how their spending contributes to energy use. A Dutch energy analyses programme, EAP, was modified to portray Swedish conditions, and analyses of more than 300 consumer goods were performed. These data were matched with information about family expenditure patterns from 1996. Six households were analyzed, Swedish average, Stockholm City average and four households from Stockholm City. The results show that it is possible to portray households' total energy use, even the indirect one, with the help of the EAP programme and Swedish statistics. Further, indirect energy use may account for more than half of households total energy use and therefore it needs to be considered in policy making. The total primary energy use for the average households varied from 240 to 260 GJ during 1996. Heating, food and transportation were large contributors. The energy efficiency of total household spending varied from 8.8 MJ per Euro 13 MJ per Euro. Information about the energy efficiency on spending is valuable but cannot be presented and used without considering basic needs and quality of life. The total energy use per person varied from 50 to 350 GJ per year, a difference of factor seven. The analyses of energy efficiency of spending, MJ per SEK, indicate important opportunities for less energy demanding spending patterns, but those with low incomes have fewer opportunities than those with high incomes. The energy profiles for different households show that the individual ones may differ a lot from the average picture. There is a need for individual household advice about how to find more energy efficient spending patterns. Large cuts in household energy use means substantial changes in both energy intensity of goods and services and expenditure profiles. Expenditure levels should also be questioned.

Design for Environment

Integrated Green & Quality Function Deployment (IGQFD)

Enrico Cagno, Lorenzo Tardini, Paolo Trucco

Using the simplified LCA model called the 'Matrix Approach' together with Enhanced QFD, a new product development and improvement methodology termed 'Integrated Green and Quality Function Deployment' (IGQFD) is proposed. The focus on quality and eco-efficiency needs results in greater and more interactive integration of these areas, so reducing arbitrary assumptions in a coherent product strategy. The most innovative aspects are essentially the introduction in the product development process of two new design tools and the restructuring and completion of the operational design phases. In particular, the lack of effective integration of quality and eco-efficiency in GQFD II is overcome in IGQFD by means of the 'Green and Quality House' (GQH). Based on the 'House of Quality' (HOQ) found in traditional QFD, this tool allows not only the parallelism of requirements (quality and eco-efficiency) in product development, but also continual integration of objectives. Actually the inclusion of environmental issues in the product development process is a desirable company decision; in that most of the environmental impact attributable to a product or a product system is determined in the concept definition and design phases. However, this decision must offer the company the chance to reduce foreseeable impacts effectively without compromising product quality and performance. GOFD II considers quality, eco-efficiency and cost demands throughout the entire product development process, integrating Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) in QFD. The second innovative tool is the 'Concept Selection Matrix' (CSM) which during the selection phase identifies the Best Concept, i.e. the design alternative which best combines the needs of the stakeholders, the direction in which the company wishes to move, and the influence the latter believes it can assert on the customer through promotion. Some improvements in comparison with traditional methods enhance the role of CSM, which becomes not only a tool to assess product concept, but also a means of identifying and defining new design alternatives. To verify usability and highlight the strengths and weaknesses, the methodology has been applied in a case study of the design of a engine oil filter.

123 Examples of Best Practice for Greening of Products

Richard Almgren

The greening of products is a rapidly developing area within industry and business. Actually, one of the business community's key contributions to future environmental policies will be the development of environmentally sound products and the introduction of these products to the market. Over the past few years, business has focused on finding the best pathway to designing and marketing environmentally sound products and continues to view this as an ongoing challenge. The study has been worked out to give an impression of the current practices within industry, when it comes to product development where environmental considerations have played a major role. Most of the examples of best practice originate from the Swedish market, but also from other countries within the European Union (EU). A synthesis of in total 123 examples of best practice of environmentally improved products will be presented. It is interesting to note that more than half of the examples given originate from SMEs (small and mediumsized enterprises). The study shall be seen with the background within the EU to implement a new policy, referred to as the Integrated Product Policy (IPP). Thus, the European Commission issued a Green Paper (Green Paper on Integrated Product Policy, Commission of the European Commission, 2001) in early 2001. The next step, a White Paper, is expected to be released within the next few years. The Swedish government also issued a communication on the topic in 2000 (A Strategy for an Environmentally-Sound Product Policy - Swedish guidelines for an integrated product policy (IPP), Government Communication 1999/2000:114). The background for the shift in focus from policy makers' point of view is the fact that the environmental agenda has shifted, from a focus on the emissions of pollutants from large industrial facilities to issues such as the environmental impact of products with a large number of wide-spread minor sources. Furthermore, the climate change issue has grown in importance. Environmental impacts from products are obviously too diverse and evolving too rapidly to be dealt with via traditional policy instruments. Furthermore, these impacts from each single product are not generally perceived to be serious enough to legitimatize enforcement of strict environmental regulation. What is of special interest from a research point of view is the notion that the concept has the potential of transferring traditional environmental policies into market-oriented systems. Since the knowledge of carrying through such a new strategy is limited a lot of research must take place beforehand. The concept is still being developed and so far only a few studies have been published. The purpose of this study is to provide a number of examples of products that reflect systematic improvements from an environmental perspective. The examples in the study cover a variety of products:

Consumer products 20 examples; Business-to-business products 56 ;Housing and office premises 10; Transportation services 9; Energy supply 6; Waste handling 14; Other services 8; Total 123.

It can be concluded that

•Environment plays an increasingly important role in industry when it comes to product development;

•The importance covers all kinds of sectors and is wide-spread from SME's to MNE's; •The knowledge on environmental impacts from products is still limited and consequently the way of dealing with it.

Sustainable Product Development: Design for the Environment at Herman Miller

Gabe Wing

The integration of sustainability criteria into new product development at Herman Miller was a corporate strategy driven by senior management. This signaled to all levels of the organization that sustainable product design was being embraced and was to become one of the cornerstones of Herman Miller's corporate culture. The newly organized DfE (Design for Environment) team developed an environmental rating tool for new products; created a materials database; and established training procedures. All of these activities helped to operationalize this new process at Herman Miller. The DfE tool for assessing product design was developed in conjunction with McDonough Braungart Design Chemistry (MBDC), a design firm dedicated to revolutionizing the design of products and services worldwide. The database allows designers and engineers to select eco-intelligent materials when creating new products. The DfE principles have been widely accepted by product development teams due to the training sessions, which stress the importance of DfE principles as a design requirement. The combined efforts described above have all been critical to the successful integration of sustainability criteria into the new product development process at Herman Miller.

Network Analysis and Sustainability in Waste Management: Assessing Highest Resource Recovery Through Combinations of Open and Closed Loop Recycling

Mary Stewart, Brett Cohen and Jim Petrie

In this paper we demonstrate the development of a generic approach to the optimization of integrated open- and closed-loop recycling systems. Both forward and reverse flows are accounted for explicitly. In this context we strive to maximize resource efficiency; resource efficiency is articulated relative to indicators of the environmental, social and economic performance of the network as a whole. The objective of the optimization is to determine an optimal network structure for open and closed loop waste management systems. We demonstrate the effectiveness of the approach using a number of case studies. For example, all feasible network structures which deliver highest resource value in wood waste management are identified and presented. This case study incorporates both closed loop recycling of timber products back into the same product, or into additional products; and open loop recycling through energy from waste technologies and other end-of-life wood waste options such as the production of mulch. In this case study we demonstrate that different network configurations arise when emphasis is placed on either environmental, or economic performance - and thus develop a pareto optimal surface for the network. Selection of a preferred operating point is discussed. A number of policy decision scenarios are presented. Conclusions on the potential of the modeling methodology developed to support strategic planning for integrated open- and closed-loop recycling networks are presented. Specific comments on the development of appropriate indicators to assess the performance of these networks are included.

Analysis of Situational End-of-Life Factors to Promote Robust Design Strategies for Product Asset Recovery and Energy Conservation

Aaron Hula, Karim Hazma, Kiumars Jalali, Kazuhiro Saitou, Steven J. Skerlos

The bulk of recyclable and reusable materials comprising disposed household products are not reclaimed. Recovering target materials and components through disassembly has the potential to reduce the life-cycle environmental impact of such products, provide inspiration for innovative new eco-friendly products, and create a profitable enterprise for the parties involved. However, situational factors and uncertainty can significantly influence disassembly decisions. For example, it is well known that product structure, materials, locations of recycling facilities, and legislative and cultural context have a major impact on the economic and environmental benefits of material recovery. In extreme situations, disassembly may be neither economically nor environmentally worthwhile. The intent of this research is to provide specific information about the financial and energy impact of disassembly at the design stage to facilitate trade-offs between recycling and cost under variable situations. Specifically, this research re-visits the life cycle of a coffee maker to analyze the economic and energy use implications of EOL decisions made under variable situational conditions. The analysis is made possible by a computer model that can determine 1) optimal disassembly strategies (i.e., it produces preferred linear disassembly sequences and end-of-life (EOL) fates of disassembled components), and 2) a sensitivity analysis of variables embedded within the model. Disassembly strategies are analyzed using a two-step approach. First, a novel multi-objective genetic algorithm (GA) is utilized to create a tradeoff frontier (Pareto set) of the best disassembly strategies in terms of both energy use and profit. A second evaluation technique is used to enumerate targeted disassembly strategies within a focused region of the Pareto set. The specific situational factors that influence the resulting disassembly sequences and EOL fates are then isolated quantitatively. The analysis presented here focuses on answering three questions: 1) What, if anything, needs to be done to create a viable disassembly infrastructure network in a given geographic, economic, and cultural scenario? 2) How might the appropriate disassembly strategies differ under varied situational factors? 3) Is it possible, or desirable, to design products that have a predetermined disassembly sequence and end of life fate which would be robust to the variation of situational factors in the intended markets? These questions are specifically addressed for situations present in Aachen, Germany and Ann Arbor, USA. The situational factors investigated include distances in the end-of-life transportation network, labor costs, material prices, and legislative constraints. Uncertainty in these factors, and the life cycle assessment model, are treated explicitly. Ultimately, this project will investigate the interplay of disassembly decision making, situational factors, engineering design, and policy initiatives to determine how they can be used to encourage economically beneficial EOL strategies that minimize life cycle environmental impact. With the life cycle model, optimization methodology, and disassembly analysis techniques developed herein, it is possible to better understand the economic, logistical, and political drivers required to create market incentives for the design of environmentally preferable products.

Design for Environment: A Case Study of Novel Technology to Capture, Recover and Re-use Hazardous Air Pollutants

Amit Kaldate, Hamidreza Emamipour, Mark Rood, Deborah Thurston

Objectives: Environmentally conscious design is increasingly being recognized as a central issue in development of new products and manufacturing processes. Traditional pollution control and prevention efforts were concerned primarily with regulatory compliance, with little attention paid to the sustainability of these processes themselves. Industrial ecology has shown promise as a new paradigm by allowing designers to employ a set of tools to better utilize resources and reduce environmental impacts. Designers of such sustainable systems are expected to consider impacts which often lie beyond their formal fields of expertise, achieve regulatory compliance, while at the same time create improvements in technical, economic and environmental performance. This paper illustrates an application of such integrative efforts for design of a new air pollution control and recovery technology. The need to focus more closely on the cost-effectiveness of pollutant recovery is emphasized through integration of economic analysis into bench-scale and pilot-scale experimental design.

Managing Energy and Greenhouse Gases

Life-Cycle Based Greenhouse Gas Emissions Inventory of Canadian Wastewater Treatment Facilities

Halla R. Sahely, Heather L. MacLean, Hugh D. Monteith, David M. Bagley

Increased concern about the potential impacts of global change has brought to the forefront the importance of accurate accounting of greenhouse gases (GHG) emissions resulting from all sectors of countries' economies, so as to further our scientific understanding of the responsible processes and of global change, as well as in support of scientific and policy-based decision making. Before we can make progress in GHG emissions abatement, we need to know the current inventory of emissions, but more importantly, we need to know how much each of our current activities contributes to inventories on a life cycle basis and what are the priority components of these activities that we

must change to reduce environmental burdens. In the past, disregard for this type of life-cycle approach has led to sub-optimal decisions with respect to environmental and human health. Therefore, an approach that considers the inputs and outputs associated with the full life cycle is crucial for allocating GHG emissions to a product or service and for measuring progress in emissions abatement. Global climate change policies should be intricately tied to life cycle based emissions inventories. This paper proposes a framework for developing life-cycle based GHG emissions inventories. The current work focuses on the wastewater treatment sector, considered one of the larger minor sources of GHGs. This paper is a preliminary study of the extent of greenhouse gas emissions from Canadian municipal wastewater treatment plants using the life-cycle based framework. The current inventory differs from traditional approaches because it estimates not only onsite emissions due to the biological processes used and fossil fuels consumed onsite for energy and heat, but also accounts for emissions upstream of treatment plants, specifically from electricity generation. Using the life cycle approach framework, estimates were generated using real-world data from all ten Canadian provinces coupled with engineering calculations. The total on-site emission rate of carbon dioxide from Canadian municipal wastewater treatment facilities in 2000 was estimated at 702,900 tonnes/yr. Only on an assumption of undetected leaks of methane from the anaerobic digestion process can any estimate of emissions of this GHG be computed. This quantity came to approximately 1,600 tonnes/yr, assuming a 5 % leak from the digestion and gas collection and delivery system. Once upstream energy emissions are included, the estimated carbon dioxide equivalent emissions from wastewater treatment increases to 1,048,500 tonnes/yr. Studies of GHG emissions from wastewater treatment have traditionally focused on methane emissions assuming that methane is released from anaerobic processes. However, the methane emissions levels reported in this study are considerably lower than those reported in other studies. In addition, this study estimates carbon dioxide emissions using engineering calculations and mass balances while other studies do not due to differences in boundary definition. These differences will be discussed in more depth. It is clear that considering upstream emissions can alter estimates significantly and shift the focus away from a simple accounting procedure to a greater understanding of which inputs or outputs to the process are contributing most to greenhouse gas emissions. This type of inventory framework could also be coupled with other assessment tools to aid in identifying new technologies or strategies which can best accomplish abatement goals.

Ecological Cumulative Exergy Consumption Analysis, An Approach for Including Ecological Products and Services.

Jorge L. Hau, Bhavik R. Bakshi

Exergy analysis is a popular method for analyzing and improving the efficiency of chemical and thermal processes. Its extensions such as, cumulative exergy consumption analysis (CEC), expand the analysis boundary to consider the life cycle scale by including processes starting from natural resources to the desired products. A common shortcoming of most economic, thermodynamic, life cycle assessment and other existing approaches for decision making is that they ignore the contribution of ecological products and services. Such approaches that take nature for granted continue to cause significant deterioration in the ability of ecosystems to provide goods and services that are essential for every human activity. Furthermore, accounting for nature's contribution is essential for determining the sustainability of industrial activity. Emergy analysis is a thermodynamic approach developed by systems ecologists that does consider ecological products and services. However, it is much less popular than exergy-based methods, and has not been used much outside a relatively small community. This work identifies the challenges and presents an approach for expanding exergy analysis to include the contribution of ecological products and services. The resulting expanded or ecological cumulative exergy consumption (ECEC) accounts for the exergy consumed in both, creating the necessary ecological inputs, and in making the industrial products. Practical challenges in obtaining ECEC are identified. Expanding exergy analysis to include ecological inputs results in novel insight into the relationship between cumulative exergy and emergy. ECEC is shown to be equivalent to emergy for the same allocation method and analysis boundary, and if global energy inputs are represented in solar equivalents. Consequently, some data and aspects of emergy analysis may be used for ECEC analysis. ECEC analysis is applied to the life cycle of synthetic ammonia. Synthetic ammonia manufacturing is a much popular process that has been studied for many decades. This case study illustrates how the approach works and serves to identify potentials and challenges for integration with economic analysis and Life Cycle Impact Assessment. Results don't discard the possibility of encountering trade-offs between economic and ecological indicators. In such a case, decision making will depend on factors defined by the particular situation and valuation of the analysts and designers. The main contribution of this approach is made clear with this case study. References Hau, Jorge L. and Bhavik R. Bakshi "Expanding Exergy Analysis to Account for Ecological Inputs" Technical Report, Department of Chemical Engineering, Ohio State University, Columbus, OH 43210.

Energy Consumption of Wired and Wireless Communications Networks

H. Scott Matthews, Woon Sien Loh, Hui Min Chong

There has been rapid growth in the popularity of mobile phone use in the US. According to the Cellular Telecommunications and Internet Association (CTIA) semi-annual Wireless Industry Survey, the US has seen a steady increase in the number of subscribers, wireless minutes of use, cumulative capital investments, total number of cell sites and total service revenue. Further, a 2002 report from the Yankee Group stated that 3% of US households have completely replaced landlines with wireless phones. As the size of the cellular network grows, it is important to analyze the energy impacts and implications of its growth, compared with the 'traditional' Public Switching Telephone Network. This paper investigates the energy consumption of the telecommunications network in the United States. The scope of the study covers the 'voice' network, including both the Public Switching Telephone Network (PSTN) and the Mobile cellular network. Using results from a previous study, the estimated total electricity consumption of the telecommunications network in the US was found to be about 25 TWh/year, about 0.6% of the US total electricity consumption. This paper also analyzes the breakdown of the energy consumption between the PSTN and the Mobile network, and found the Mobile network to be more energy efficient in terms of energy used per subscriber connection. One important consideration when making such comparisons is the allocation of core communications network services to wired and wireless networks. This is because wireless networks are only wireless at the endpoints. They still depend heavily on a wired core network to provide service. These results on the energy consumption of voice communications networks are compared to previous work done by the authors on energy implications of data networks. The manufacture of the network equipment is also considered to give a partial life cycle assessment of the energy consumption.

A Source Generation Comparison of Electricity Consumption in US Production Sectors

H. Scott Matthews, Iavor Kostov, Jonathan Mayes

When considering the life cycle implications of a product or process, effects tend to be dominated by energy (specifically electricity)-related impacts. Important implications from electricity occur in the form of air pollution, fuel use, and global warming. Thus it is important to have good measures of electricity implications. However, most current analyses of electricity in the United States use fairly aggregate measures of electricity generation. In the case of input-output based models, the scope is the total US electricity sector. When such a large perspective is taken, a great deal of detail is lost at the plant or state level. For example, in this case, all sectors consuming electricity are assumed to use 'US average electricity which is largely fossil-source-fueled, and about 40% coal. However certain sectors, based on either their geographical location or other factors, buy electricity with very different generation parameters. An aluminum factory in the Pacific Northwest may have more than 20% hydroelectric power. Towards this end, we have used a hybrid approach that combines Department of Commerce facility location data by state with electricity generation mix data from the Department of Energy. The result is a sector-by-sector accounting of the generation mix as opposed to a single national value. We assume that interstate purchases of electricity and on-site generation are negligible. This data can then be used to derive a much more accurate picture of the effects of electricity. There are relevant public policy concerns with such data, such as determining which sectors would be most sensitive to energy taxes, carbon taxes, etc. When the sector-level electricity generation detail are combined back into an input-output based life cycle model, specifically EIO-LCA (available at www.eiolca.net), an estimate of the total electricity (by generation source) needed across the supply chain to produce a particular product or service can be estimated - but with full sector-level generation mix detail. Of course, the more diverse the supply chain, the more the electricity mix of that product trends towards the US average. However there are some specific interesting cases where vastly different effects are found. In addition to desegregating the generation across sectors, additional work has begun to fully desegregate the electric services sector into the transmission and distribution components (which are generally at the construction phase). This paper reports on the progress and research results of this project and shows how they can be used to better inform decisions in the policy arena.

Transport of Coal by Rail vs. Transmission for Electricity Generation: Application of Hybrid LCA Comparative Analysis

Joule Bergerson, Lester Lave, Chris Hendrickson, Scott Mathews, Alex Farrell

A variety of fuels and technologies are available for electricity generation. The life cycle environmental implications and costs are needed to make informed decisions about both dispatch of current power plants and the choice of fuels and technologies for new plants. Here, we exercise a hybrid LCA comparative analysis framework to examine an important issue: should coal be transported to a generator near the load or should the generation plant be located near the mine and the electricity shipped to the customer? In this example, the costs and environmental and health implications of shipping coal versus power from the PRB to Texas are examined. Hundreds of billions of ton-miles are generated by shipping coal to generating plants each year. This transport requires large amounts of energy, generates pollution emissions, and results in the death of an alarming number people each year at rail crossings. A significant portion (30%) of coal mined in the US is mined in the Powder River Basin (PRB), WY. In 2001, 330 million tons of PRB coal was shipped to 27 states. Texas receives 50 million of those tons per year. The cost of coal at the mouth of a PRB mine is approximately \$5/ton whereas by the time it is shipped to Texas the cost is approximately \$25/ton. This implies that the cost of shipping the coal by rail constitutes the majority of the cost of the coal. In addition, current rail capacity is not unlimited and therefore, a major increase in unit trains would require new capacity. However, shipping the energy in the form of electricity has its own cost, health and environmental implications. These include land use, noise, visual impacts, as well as resource consumption from building and maintaining the transmission lines. Life cycle analysis is used to assess the environmental impacts associated with every stage of the production of electricity, from extracting ore to final disposal of unwanted residuals. A framework is created in this paper using a hybrid approach to LCA. This method combines the benefits associated with the EIOLCA (Economic Input-Output Life Cycle Analysis) method as well as the traditional SETAC/EPA approach. The cost and environmental impact data available at a national, aggregated level (by industrial sector) are used in conjunction with a product analysis of more specific electricity generation scenarios.

Resilience and Leveraging Consortia as a Survival Strategy for Japan's Electric Power Industry Amidst Megacompetition in an IT Driven Global Economy

Chihiro Watanabe

The dramatic surge in information technology (IT) around the world and an evolving global economy are subjecting firms to megacompetition. This is particularly the case in Japan's electric power industry. Japan's power rate is one of the highest one in the world, therefore Japan's industry lost its price competitiveness in world market resulting in stagnation of production which leads to stagnation in the power demand. In addition, increasing trends in customer's preference and the variety of participants in the power supply race have put electric power companies at the mercy of customers

with alternative supply sources. Given that in addition to power demand continues to stagnate due to low or negative economic growth, customer shift to rival suppliers increases, and uncertainty with respect to energy security as well as power generation and distribution systems safety increases, a dramatic conversion of existing strategies would be indispensable for electric power companies. First, a conversion from a high demand elasticity dependent supply structure to a resilient structure is required. While the former aims at constructing a high demand elasticity supply structure based on the myth of high demand growth of demand, the latter aims at maintaining profit while minimizing the elasticities of factors with high uncertainty such as energy resources and costly capital investment liked to fluctuating power demand. Second, a conversion from the indigenous oriented supply system to consortia type supply system is required. Contrary to the former system which looks for self sufficiency, the latter depends on network externalities by tightly connected to the effective utilization of spillover technologies from external industries. This paper will demonstrate the significance of resilience and leveraging consortia structure as a survival strategy for Japan's electric power industry amidst megacompetition in an IT driven global economy. In order to do this, an empirical analysis using Japan's nine leading electric power industries over the last quarter century is conducted.

Life Cycle Assessment and Management

Simulation Framework for Life Cycle Assessment of the Built Environment

Robert Ries

The evaluation of the construction and operation of buildings and infrastructure from an environmental perspective is an important part of the sustainable development process. The available software targeted toward the building industry has been limited in that it does not specifically simulate operational effects, does not include uncertainty analysis, and uses spatially and temporally insensitive impact assessment methods. In an integrated environment, a life cycle assessment (LCA) application can exchange data with energy, heating, ventilation and air conditioning, and lighting simulation modules to determine the impacts from the building's operation. Evaluating uncertainty in a LCA has been acknowledged as an important aspect of the analysis. Data regarding construction, operation and maintenance processes, properties of substances, ambient concentration limits, and manufacturing processes of functionally equivalent systems or materials are all variable and uncertain. Lastly, environmental assessment of the built environment has generally used spatially and temporally insensitive evaluation methods. Aggregated mass emission values in a life cycle inventory do not consider the temporal distribution nor the characteristics of the context, resulting in a loss of information regarding their emission rate and location. Therefore, the impact evaluation methods that use such inventories cannot include these aspects. Although modeling spatial and temporal emission distributions in the context of an LCA can be data intensive, judgements regarding the intensity, duration, and spatial distribution of emission releases should be considered in impact analysis. In order to enable a more comprehensive evaluation of environmental impact of the built environment life cycle, appropriate methods and models implemented in computational design and evaluation tool is re-

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quired. A prototypical computational tool for life cycle environmental impact assessment has been developed as a part of an integrated building design and simulation framework consisting of a graphical user interface, a shared building representation, distributed analysis tools, and databases. The LCA is based on a representation of the processes, contexts, and emissions that occur in the life cycle of buildings and an impact assessment model. The impact assessment models implemented to date are a regional fate and transport model based on a level three Mackay fugacity model and a tropospheric ozone model. The integrated simulation framework allows the environmental model to evaluate operational effects such as heating, cooling, and lighting in the analysis. A recursive Monte Carlo sampling scheme is used to assess the effects of uncertain parameters, which are represented through probability distributions, standard deviations, and mean values. The temporal and spatial distribution of emissions can be evaluated with the environmental model through the representation of processes, contexts, and emissions. Considering the importance of the entire life cycle of buildings to overall environmental impact, the data collection and processing requirements, and the multi-disciplinary nature of the evaluations involved in the LCA of buildings, an integrated computational framework is one way to provide meaningful decision support.

Implementing Life Cycle Management for Production Chains using Life-Cycle-Images: A Method for Stepwise Modeling

Manuel Gottschick

One effective approach to a sustainable economy is the integrated optimization of all life cycle stages. These optimisations need to overcome classical company boundaries and have to take into account the supply chain, companies' collaborators and clients (Margni/Jolliet/Payet 2001). Effective Life-Cycle Management (LCM) has to combine methods like LCA, LCIA, LCC with business management tools (Weidema 2000) and has to be brought into practice in business decision making (Haes et al. 2002). In the project "Sustainable Metal Economy in Hamburg" (EKOS/von Gleich 2000; 2001) several short case studies have been applied. For example, we showed that the used metal beads from surface blasting are not waste but constitute a valuable resource for producing metal foams. Another focus was the reduction of cooling lubricants in metal processing with several partners. A further case study was to analyse Life Cycle Impacts and optimization strategies for the product design and product use of forklifters (Gottschick 2000). The important finding with respect to the focus of this paper is the relevance of "soft" strategies to overcome doubts and impediments of the companies. The strongest impediments found are the reservations against using waste as a raw material (metal beads), against the new technology, because of assumed restrictions in flexibility (cooling lubricants), and against the change from "selling products" to "selling services" (forklifters). To reduce these impediments and to optimize the whole Life Cycle, we found it necessary to create cooperations between all companies involved (Gottschick/Jepsen 2000; Gleich/Gottschick/Jepsen 2001). We found that cooperations can support the development from a plain "how to save money attitude" to sustainable thinking. In this process, four different phases can be distinguished: 1. Initiation; 2. Establishing; 3. Realisation of cost savings; 4. Chance of broader scope. The last step is quite important: after reaching the primary objective, a stage of disorientation occurs.

This is the critical point where either the cooperation ends or the perspective is extended to further environmental and social matters. This last step can be achieved if the cooperation is coordinated by means of an overall concept which can be formed by a sufficient illustration of LCA results and which is inspired by the creation of Guiding Images. Guiding Images have been proven to be a powerful tool to orientate and coordinate the cooperation of new partners (Dierkes 1992). Based on the results of LCA and LCC, Life Cycle Images may be built in analogy with the different stages of cooperation as shown above. To support the learning process, a stepwise streamlining LCA (respectively MFA) procedure was developed combined with LCC and an account of social effects. The main emphasis was placed on the illustration of LCA results and the visualisation of Guiding Images. Rough estimations and high aggregation are followed by cooperation specific steps of widening breadth of impacts (also social and economic effects), scale, aggregation and quantification, quality, and specificity of data.

Environmental assessment of re-use strategies - the case of concrete from the Swedish building sector

Liselott Roth, Mats Eklund

Buildings can be seen as a reservoir, a stock, of materials that after having served its purpose can be re-used in different applications. The dominant part of the waste from the building sector in Sweden originates from demolition of buildings. Due to structural changes in where people want to stay, a large number of dwellings are being demolished long before their technical lifetime has expired. The average multi-family dwelling that is demolished in Sweden at present is about 40 years old and some are less than 30 years. This average lifetime of buildings have dropped rapidly in Sweden during the last 20 years. This development changes the relation between the distribution of environmental impacts for the different life-cycle stages of a building. It is often stated that 85 to 95% of the environmental impact of a building (Europe and North America) can be attributed to the use of energy during the use phase of the building. However, such calculations depend on the expected lifetime of the buildings, which are often 50 to 60 years. If the building's lifetime decrease, the relative importance of the environmental impact from the materials used in the building phase and the end-of-life strategies increase. The stock of concrete in Swedish buildings is roughly 500 000 kilotons. About half of that amount consist of concrete framing in multi-family dwellings. One estimate suggests that 1 600 kilotons can be attributed to empty dwellings that probably will be demolished within a few years. In Swedish common practice today, the concrete from demolished buildings is crushed and either landfilled or used for landscaping locally. There are examples of other uses, mainly in small scale where the quality of the concrete material is conserved to different extents, for instance substitution of new concrete in new buildings. This has been studied in two case studies where concrete from deconstructed buildings was used for construction of new buildings. In one case, precast concrete elements were deconstructed, transported and incorporated in a new building 40 kilometres away. In the other case, in-situ cast concrete houses were deconstructed by sawing and used in the frame of a new building after being transported 65 kilometres. Other examples of re-use alternatives for crushed concrete are; (i) as ballast material for the production of new concrete, (ii) substitute for crushed rock in road structures or (iii) substituting moraine in the sub-base of road constructions. In such applications the

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crushed concrete substitutes materials with lower energy intensity and thus the environmental benefit will be less than in cases where the waste concrete substitute new concrete. This presentation contains a quantitative environmental assessment of different kinds of re-use of concrete using a primary energy indicator. The assessment is mainly based on what the re-used concrete substitutes in its new application.

Material Selection for First Use and Downcycling: A Case Study

Elizabeth Wright, Warren Mellor, Roland Clift, and Gary Stevens

One of the main drivers for the development of industrial ecology in Europe has been "take-back" legislation which places the responsibility on manufacturers to recover and recycle materials and products. This requires companies to introduce unfamiliar considerations into their material selection and procurement policies. To inform such decisions, a novel system analysis tool has been developed: CHAMP - CHAin management of Materials and Products. CHAMP combines elements of process synthesis and flowsheet analysis with elements of life cycle assessment, to enable the user to explore the technical, economic and environmental consequences of selecting alternative materials and introducing different strategies for material recovery and re-use. The CHAMP methodology has been presented before (including a presentation at the First Conference of the International Society for Industrial Ecology). This contribution will present a case study in which it is applied to a problem of current practical concern: selection of a polymer to form the interlayer in toughened glass automobile windshields and windows. Glass represents some 4% of the average weight of a vehicle. Driven largely by the EU End-of-Life Vehicles (ELV) Directive, commercial processes have been developed to crush and separate the glass and polymer interlayer, but currently only the glass is recycled. The case study compares alternative polymers for the interlayer, with possible recycling scenarios to investigate how recovery affects material selection. The material currently used for this purpose is a polyvinyl butyral (PVB) polymer. Two alternative materials are polyvinyl chloride (PVC) and ethylene vinyl acetate (EVA). Of these materials, it is technically possible to recycle PVB but no markets for the material have been identified, but it can be used as a fuel. Both PVC and EVA can be "downcycled" into other uses in the form of flexible sheeting used, for example, as floor coverings or in furniture. CHAMP is used initially to analyse the supply chains leading up to first use of the virgin polymers, in a conventional Life Cycle Assessment. The analysis is then extended to consider several "lives", including downcycling into use as soft covering after the first use as windshield interlayer. The environmental impacts, economic costs and technical performance criteria associated with each option are evaluated, to identify the Pareto-optimal options. The results show how significant is the relatively simple recyclability of PVC - an important consideration in the debate over the acceptability of this material - and show how this analysis can lead to re-evaluation of material selection.

Cascade Link of Fluoro-Nitric Acid between the Semiconductor and Steel Industries

Masahiko Hirao, Yuki Kuwauchi, Hiroshi Uesugi, Masashi Fujiwara, Tomohiro Suginaka

Fluoro-nitric acid is used as a washing agent both in the semiconductor and steel industries. It is discharged as by-product from individual industries after the waste-water treatment by neutralization which produces a large amount of inorganic sludge. In the semiconductor factory, the highly purified and highly concentrated fluoro-nitric acid is used to wash manufacturing equipment, while the relatively lower grade acid is used in the steel industry as a pickling solution for stainless steel sheets. Therefore, it is possible to recover the used acid in the semiconductor industry and reuse it in the steel industry. To realize this cascade link system, they first carried out experiments to find the effect of impurities on the surface property of stainless steel sheet. Then a new system to recover recyclable acid was installed in a semiconductor factory and an acid control system was developed in a stainless steel factory. We performed life cycle assessment (LCA) of this cascade link system using the system boundary expansion method. Inventory data were collected from the industries and the case in which used acid is treated in each individual factory is considered as a base case. The results of LCA showed that the cascade use of a 10 ton of by-product acid reduces energy consumption by 4.0 tons as a crude oil conversion value, reduces CO2 emissions by 4.3 tons, and reduces sludge generation by 24.8 tons. We found that this cascade link of by-product acid is an example of good practice for the inter-industrial network.

Integrated Economic and Environmental Assessment of Supply Loops for Mobile Phones

Roland Geyer, Grant A. Kirkman, Tim Jackson, Roland Clift

End-of-life management of mobile phones is under growing scrutiny from stakeholders with environmental concerns and increasingly subject to take-back legislation like the European WEEE directive. At the same time, as the mobile phone markets in all industrialized countries mature, second hand markets and recycling networks develop. These self-sustaining secondary industries result from economic opportunities to recover value from handsets that are no longer used by their owners. The recovery of end-of-life handsets can therefore be motivated by different economic and environmental drivers, which are not necessarily in alignment. There is thus increasing need for an integrated approach to end-of-life management since environmentally motivated product take-back needs to be profitable in the long term and economically driven take-back is coming under increasing pressure to demonstrate its environmental benefits. The three basic options to recover environmental and economic value from end-of-life products are refurbishment of the entire product, reuse of its components or recycling of its materials. In each option circular supply chains are created which we will call supply loops. It is generally agreed that the three recovery strategies form a natural hierarchy since closing the loop higher up in the chain of value creation is assumed to increase both environmental and economic benefits. Plausible though it may sound, this claim needs to be substantiated by a quantitative assessment based on a life cycle approach with

appropriate system boundaries. This paper presents such an assessment for the case of end-of-life mobile phones. The case is based on experiences from current and previous take-back schemes in the UK and data from component suppliers, handset manufacturers, network providers, retailers, end-of-life collectors and re-processors have been collected and analyzed. In the analysis we pay special attention to the operational, technological and market conditions, to which the different supply loop options are exposed. These conditions can form constraints, which dramatically impact the economic and environmental performance of the three recovery strategies. We show that the three recovery strategies face different constraints with different levels of impact, which affects the comparative economic and environmental advantage of the supply loop options. Our models also illustrate how these constraints can turn the economic and environmental performance measures into non-linear functions of the decision variables. This can result in non-intuitive optimal decisions for the individual supply loops and change the alignment of their economic and environmental incentives. This is an important observation since many assessments of product recovery strategies are based on linear models, which are unable to capture these effects.

Technical Session (T7)

Eco-Industrial Parks and Networks

The Kwinana Industrial Area: An Evolving Example of an Ecoindustrial Park

Rene Van Berkel

The Kwinana Industrial Area is Western Australia's primary area of industrial development. It was established in the early 1950s and is now home to 25 core processing industries (including e.g. oil, alumina and nickel refineries, pigment, ceramics, fertilizer and chemical plants), 4 major infrastructure and utility providers, and support industries (including many small to medium sized enterprises providing specialized services). The area represents a unique blend of connecting heavy, support and infrastructure projects - a 2001 survey identified 106 synergies between 26 industries, up from 27 synergies between 13 industries in 1990). The Kwinana Industrial Area provides an example of the triple bottom line benefits from co-location of diverse industries. It is a major source of revenue for the State and Australian economies (equal to 22% of the Western Australian manufacturing sector's total factor income), employment and community development, and has achieved significant environmental improvements. The industry body is now actively pursuing further regional synergies, in four key environmental impact areas: non-process waste; process inorganic residues; energy and greenhouse gas emissions; and water use. A new water reuse system is now being constructed which will enable treated sewerage water to be used as substitute process water by some of the most water intensive industries in the area, in turn freeing up mains water for domestic consumption in the drought affected Perth Metropolitan area.

The Development of Industrial Symbiosis Networks - Experiences and Lessons from Regional UK Projects

Murat Mirata, Dr Colin Pritchard, Steve Harris

The paper describes experiences from a number of regional Industrial Symbiosis projects in the UK that have become part of the recently established 'National Industrial Symbiosis Programme'. Methods used in implementing the projects are discussed along with their effectiveness in catalysing the development of networks with desired functional characteristics. Experience from the UK projects confirm that conditions have developed to support the introduction of the Industrial Symbiosis (IS) concept into business strategy. This is partly attributable to the fact that concepts that include supplementary elements to IS thinking, such as TQM, supply chain management, environmental management systems and concurrent engineering, have been gaining increasing importance in the board rooms. In other words, companies are better prepared to look beyond their own boundaries in search of environmental and business improvement potentials. In our opinion, however, pressure from recent environmental policy elements of national and local administration is at least equally important in providing the impetus for IS programmes to evolve. More specifically, the landfill tax, climate change levy, and numerous environmental programmes (such as waste minimization) aid the facilitation of IS and acceptance of the concept by the business community. The paper describes practical experience gained from a number of regional projects and the importance to move beyond the waste = food concept, to include other examples of 'inter-company co-operation' that improve business and environmental performance. It also suggests that since the business environment appears to be more receptive to concepts such as IS, there is an increasing need to pay attention to the desired attributes of emerging IS networks, and how their acquirement can best be facilitated.

By-Product Synergy: Lessons from Six Years of Regional Collaboratives

Andrew Mangan, Gordon Forward

1. Background In September 1998, Andrew Mangan, then-Executive Director of the Business Council for Sustainable Development-Gulf of Mexico (BCSD-GM), joined with four Business Council member companies (Conoco, Grupo IMSA, Texas Industries, Hatch Associates) in establishing a for-profit venture dedicated to commercializing the By-Product Synergy concept, which had been pioneered by the BCSD-GM in Texas and field tested in Tampico, Mexico during 1996-1997. By-Product Synergy (BPS) is defined as "The synergy among diverse industries, agriculture, and communities resulting in profitable conversion of by-products and wastes to resources promoting sustainability." The process involves creating a forum where process knowledgeable experts can explore reuse opportunities with company engineers. As one BPS participant put it, "BPS establishes a culture of possibilities." For the next two years, Applied Sustainability LLC developed its By-Product Synergy process, refined it and sold it to more than 60 companies across North America. Andy Mangan served as president of the company. As its projects came on-line, Applied Sustainability became an increasingly sophisticated search engine for synergies and a marketer of appropriate technolo-

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gies. In January 2001, with growing demands on its limited resources, Applied Sustainability's board of directors decided to wind down operations and seek partners willing to apply the resources necessary to turn this catalytic startup into a fully developed, profitable business. In its years of development and operation, Applied Sustainability launched seven projects, finished four of these, and learned much about the potential for profitable collaboration across industries. Mangan has since developed BPS projects in the New Jersey/Delaware/Pennsylvania region with CH2MHILL, in Texas with the Dow Chemical Company, and in Kansas City with the Elements, the Sustainable Consulting Division of BNIM Architects. 2. The Process One way companies have sought to optimize operations is through recycling by-products. However, these activities have been usually confined to recycling within the plant or process. Waste exchanges were set up in an effort to offer wastes or unwanted by-products to a broader audience. But these efforts had limited success. Unlike waste exchanges, BPS recognizes that the acceptance of one company's waste as a feedstock for another takes more than simply announcing its availability. Rather, it is a relationship-building process between individuals in companies. Success is predicated on the establishment of a high degree of trust that the waste or by-product stream can be delivered reliably and within manageable specifications of quality and quantity. To these ends, the BPS process is an information collection and facilitation process, bringing information and people together from a diverse set of industries to reveal and discuss their feedstock needs and the by-products they produce. In the initial stages of the BPS process, participating company engineers and operations staffs are exposed to the production processes, raw material needs, and waste streams of one another's businesses and industries. Through extensive coordinated and facilitated collaboration, these participating companies discover ways of integration that cut pollution and reduce material costs, improve internal processes and boost bottom lines. My company's waste problem becomes our companies' synergy search. As the year-long BPS process proceeds, participant relationships are formed through due diligence processes, brainstorming and teaming. Barriers begin to fall, opening new opportunities to convert by-products into raw materials for processes in other industry sectors. This collaborative approach appeals to government regulators because it enlists industry's abilities in addressing tough waste and pollution issues. In return, regulators have shown a willingness to consider regulatory flexibility for reuse options that can be shown to produce higher environmental results.

Eco-Industrial Parks and the Zero-Waste Philosophy: Potentials and Limits

Helmut Rechberger

Eco-industrial parks have been assigned a central role in the concept of industrial ecology. The idea is to establish a cluster of different production factories and services that are sharing resources and are reusing or utilizing each other's wastes creating a socalled industrial food web. Wastes of a production process becoming the feedstock of another production process is seen as a crucial means to reduce overall waste generation and to realize the inherent metaphor of industrial ecology, namely, to produce no or little waste as the biosphere does. A famous example has become the eco-industrial park of the city of Kalundborg, Denmark. There, materials (fly ash, sulfur, sludges, and yeast slurry) and energy (steam, heat) are exchanged between firms and factories within a radius of ca. 3 km. Concerning food webs there is a fundamental difference between energy and materials. Energy shows different qualities (exergy content) but is not "contaminated" or "toxic". Therefore it is relatively straightforward to establish an eco-industrial park with regard to efficient energy use. Power-heat coupling is a long practiced technology to reduce energy loss (correctly spoken exergy loss) via waste heat. For example, in Austria nearly all power stations deliver heat to a district heating network, to industrial processes such as paper mills, fabric producers, production processes of the chemical industry, to public indoor swimming pools, greenhouses, etc. There are no fundamental obstacles to create "energy food webs" helping to reduce waste of exergy. For unmixed wastes, having homogeneous and known composition, recycling and reuse is already well established (e.g. new scrap). These cases are excluded here. The reuse of "complex" wastes as feedstock, replacing primary resources, is much a much higher challenge. Knowledge about the chemical composition of the wastes is indispensable. Many wastes are not appropriate to be used as a secondary resource without prior treatment. One example is the use of fly ashes for cement production. Fly ashes from coal combustion and especially from energetic waste recovery (municipal solid waste, sewage sludge, mixed plastics) may contain substantial amounts of heavy metals. The fly ash replaces only a small amount of primary aggregates for cement production but may alter the chemical composition of the cement significantly. Another example is the production of bricks, roof tiles, and park benches from mixed plastic wastes. Even if there is a market for these products this is merely a postponement of a proper treatment solution for the "new" product than resource conservation. The list for negative examples (e.g., waste oil mixed into the feeding stuff of a chicken farm) could be extended arbitrarily. Hence, industrial food webs are not positive per se. Also recycling and so-called "down-cycling" is not a goal since 100% recycling and consequently zero-waste are not feasible when only limited energy resources can be employed. However, two main goals of any eco-industrial park have to be protection of human health and the environment as well as resource conservation. Industrial food webs may be a means to achieve these goals but in certain cases other options may be more goal-oriented. In order to check whether a certain waste reuse is favorable material flow analysis (MFA) and statistical entropy analysis (SEA) have to be applied. The paper discusses the difference between means and goals and exemplifies the application of MFA and SEA to detect non-favorable solutions and to support the design of eco-industrial parks.

Managing Sustainable Revitalization of Urban Industrial Sites

Korenromp, RHJ

Managing sustainable revitalization of urban industrial sites Within the boundaries of European cities, there are many smaller industrial sites surrounded by residential areas. These sites, especially those that are older, are associated with a multitude of problems: out-dated infrastructure, production processes and non-compliance with current environmental regulations. The consequence of this is that the well-heeled companies leave for new sites and the inner city becomes run down. City planners respond to this but in many cases and for different reasons, local authorities are not able to make a transition to sustainability. Traditional approaches cannot provide the primary solution to envi-

ronmental and spatial problems in urban areas. After all, for a vital, economically robust, habitable city, it is important that residents are able to live agreeably in a clean, healthy and safe environment as well as work, shop and pursue leisure activities there. The inner city industrial sites are potentially outstanding at providing balanced employment of medium sized and large business, crafts and small industries. Scientific objectives This project focuses on the management and decision making process in the revitalization of urban industrial sites and optimizing and sustaining the socio-economic and environmental impact of the sites. The main objectives of this project are to provide a management guide and practical tools to create a new partnership with industry and the public, based on awareness, transparency and openness to dialogue in order to improve and maintain optimum sustainability, in both environmental and socio-economic terms. Working approach Local authorities in five cities from five countries are assisted in the revitalizing process of urban industrial sites by executing case studies. For these case studies existing economic and environmental models as well as decision making tools are improved and developed to work together in one toolkit. This toolkit will be tested in the MASURIN project. The results and knowledge developed in MASURIN will be disseminated in international Working Conferences, which will be held in different countries. Finally the project aims at realizing national and international networks of cities dealing with the issue of the sustainable (re)vitalization of urban industrial sites. MASURIN project organization The MASURIN project involves 8 European research institutes, lead by TNO from The Netherlands. The 5 cities that collaborate on the project are Utrecht (The Netherlands), Amiens (France), Venice (Italy), Grenland (Norway) and Bytom (Poland).

Education

Industrial Ecology in Higher Education: Evolution and Implications

Kristan Cockerill

The phrase "industrial ecology" is becoming prevalent in higher education. Internet searches of universities throughout the world reveal a plethora of references to industrial ecology as a general concept, a reading topic, a course topic, and of course, part of a journal title and a society name. While industrial ecology has become a fairly common reference in various types of literature, its inclusive nature makes it difficult to define much like the concept it strives to support - sustainability. Hence, while there seems to be general agreement that education dedicated to industrial ecology is important, there is not agreement on the specific direction this should take. Industrial ecology is being introduced in disciplines ranging from engineering to business to public health. A review of more than 1000 universities found numerous programs offering students degrees and/or research opportunities with an industrial ecology focus. These programs, however, are incredibly diverse and take several different approaches to teaching industrial ecology. A simplified delineation of these approaches shows that programs tend to fall into one of three categories: 1) Those that focus on developing innovative technology/models; 2) Those that emphasize quantifying processes and identifying "best" technologies and/or best uses for technology/models; 3) Those that cover societal factors (economic, behavioral, paradigmatic) to highlight the human aspects inherent in industrial ecology efforts. While industrial ecology is featured in diverse disciplines, the primary focus remains on efforts in the first two categories with significantly less attention granted to the third category. The ideal approach to developing education with real-world applicability is likely some combination of these three. However, in designing a formal curriculum, it is not feasible (nor necessarily desirable) to cover all three in depth. This project proposes communication as the key to ensuring that the benefits from all three types of programs can accrue and contribute to enhancing the general concept of industrial ecology and its role in efforts to achieve sustainable societies.

Integrating Industrial Ecology in Undergraduate Curriculum

James Eflin

After a full decade of the growth and maturing of Industrial Ecology, its focus continues to sharpen and its values penetrate into the lexicon of many disciplines. Despite its incorporation in the thinking of many scientists, engineers, policy makers, and designers, industrial ecology remains largely unknown outside the engineering and technical science disciplines. As with other new paradigms, industrial ecology represents a new way of thinking and one that can be most powerful when widely adopted across societies. The successful adoption of the industrial ecology paradigm will require its promotion through formal education as well as in popular literature. In formal education, the needs are stratified, including very technical applications for advanced (graduate) programs as well as more simplistic presentations for undergraduate curriculum (ranging from introductory to upper-level programs). The power of industrial ecology is revealed in the "ah-ha" reactions as the metaphor is grasped for the first time by people who never conceived its systems linkages before; it grows as a means by which to conceive a re-ordering of society's priorities through closed-loop thinking. Important for undergraduate education is the prospect of advancing closed-loop thinking as a core concept in the curriculum, alongside more conventional elements that promote environmental literacy and sustainability in higher education. This paper will explore the literature that reports on how industrial ecology has been incorporated in education, paying particular attention to its use in undergraduate curriculum. Discussion will focus on how industrial ecology might be incorporated in both upper-level and introductorylevel undergraduate courses and will provide useful examples of in-class exercises, focused reading assignments, and integrative projects whose goals are to promote the adoption of the industrial ecology paradigm.

Considerations in Learning IE Concepts - An Industrial Perspective

Ann Dougherty, Kim Lenti

During 1998-99, a group of academics, professionals and students from the American Institute of Chemical Engineers, Chicago Section met in Chicago and designed a waste trading game, for use at a chapter dinner meeting. Over the course of a year of monthly discussions, short white papers and posters for nine industries were developed from US Department of Energy and industry publications. The data gathered summarized process schematics, materials, energy and environmental emissions flows. This paper describes the design team discussions, how the goals of the game shifted over time,

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and what has been learned from the play of the game. The original goal of the waste trading (or materials cascade) game, was to make the most money. Through discussions with the design team, that goal was expanded to three goals: 1) Make the most money, 2) End with the least amount of waste, and 3) Trade with the greatest number of industrial partners. Each of these goals affects the outcome of the game. The game has been played with various participants, including students, professors and industry professionals, and the same set of industries consistently "win". What are the drivers for these industries in their trading and what do their materials offer their trading partners? A brief review of the literature on materials cascades, including the most useful data generally available for industry use, will be presented. Based on insights from the waste trading game, three suggestions for "next steps" in the development of industrial ecology education of industry partners in North America are presented. Current beneficial uses of industrial by-products in the central midwest U.S. will also be outlined.

"Sustainable Transportation" University Technology Course

John Hannon Martin

A course on "Sustainable Transportation" has been developed and offered for three years at two different institutions (Program on Sustainable Development and Appropriate Technology, Appalachian State University and the Environmentally Conscious Manufacturing Institute at North Carolina Agricultural and Technical State University. The class outline, goals, objectives/activities, and evaluations will be presented, as well as selected overviews of paper/projects. In the first year over a dozen alternatively fueled vehicles were developed (i.e. solar powered bicycles, boats, gocarts, motorcycles, charging stations for electric cars; Biodiesel/ethanol/methanol tractors, buses and cars). Students were challenged to redesign the campus over a future twenty year Plan for Sustainability. This experience led to the national competition "Bus Rapid Transit and the American Community" where ASU won the academic "Most Innovative Award" for the "Solar Goose- a Road/Rail Vehicle". This has been followed by a plan to redevelop the state ferry system to provide and use sustainable energy systems. NCA&TSU is introducing alternative fuels into the Aggie Motorsports Program and with the Triad Electric Vehicle Association are providing technical/educational support for state high school's EVChallenge and middle school's Solar Sprint programs. Plans for an alternative shuttle to the present bus service, alternative powered farm vehicles, and a multimode fueling station have been proposed. Resources such as the Biodiesel Development Board, Ethanol Boards, FormulaSun, World Solar Challenge, Clean Cities, Sustainable Energy Associations, Interactive International Business Proposals, and key websites will be shared.

Environmental Management

Thinking Outside the Box of Extended Producer Responsibility: A Looser View of Product Recovery

Christine Meisner Rosen, Charles White

The purpose of this paper is to critique the current paradigm that underpins most current research and theory on product recovery, reverse manufacturing, and other aspects of end-of-life (EOL) product management in the computer industry. The existing literature on product management in the computer industry has been deeply influenced by the principle of extended producer responsibility (EPR) as well as the key role played by original equipment manufacturers (OEMs) like IBM and Hewlett Packard in the organization of the industry. The EPR principle holds that improvements in the environmental performance of industrial systems can be driven by laws, norms, and market structures that give primary manufacturers cradle to grave responsibility for minimizing the environmental impacts of their product. Industrial ecologists who have studied product recovery in the computer industry have tended to adopt an EPR stance, analyzing recovery loops from the perspective of the OEM. Their models depict a tight loop in which the OEM not only controls the forward manufacture of products but also the takeback, reuse, and reverse manufacture of them at EOL. We call this OEM centered model the "tight loop" model, because it describes a relatively constricted closed loop in which an OEM takes back all its products for reuse and refurbishment or to be remanufactured into new products. It meshes smoothly with the simple depictions of the closed loop economy at the heart of the EPR principle in which all the materials that go into a product are endlessly recycled at EOL and used to produce new copies of that product. The problem with this tight loop model is that it is an ideal that does not conform to the whole reality of how product recovery is managed in the computer industry. Our paper will present an alternative model, based on field research, in which coordination of recovery occurs within a number of dispersed, web-like reverse supply chains characterized by transactions between atomistic actors with little or no central oversite by OEMs, as well as within OEM controlled tight loops. We call this a "loose loop" system of product recovery. In contrast to the idealized tight loop system where loop closure takes place within a given product market under the control of an OEM, closure in the loose loop recovery system occurs on a variety of different temporal and spatial scales that allow product assets to be redeployed in other product markets and manufacturing sectors. The flow of products into the reverse supply chain is heterogeneous and comes from many sources rather than a single OEM. Firms engaged in different stages of recovery often do not know or communicate directly with the manufacturers of the products they recover. Loose loop systems of recovery present a variety of logistical and management problems that are not present in tight loops. They also challenge the logic of the EPR principle, which assumes that it is better for the environment for product recovery to be managed by a single producer. We provide an overview of the unique management and environmental challenges and questions raised by the loose loop model.

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Approaches to the Study Of Corporate Environmental Management

Jayadi Kamrasyid, William Pan

Studies in the area of corporate environmental management are conducted from four basic approaches. First, ecological economics approach focuses on the value of ecosystem functions and ecosystem services. Second, environmental regulation approach addresses the issue of how properly designed environmental standard can trigger innovation. Third, resource-based approached concerns with the core competency of corporations and the constraints imposed by the biophysical environment. And fourth, an institutional approach focuses on organizational context and the process by which organizations contribute to sustainability. The vision of ecological economic approach is that the ecosystem plays a fundamental role in supporting life on earth at all hierarchical scales: from the life support system such as global material cycles to ecological services of producing renewable resources. In the perspective of environmental regulation, the new paradigm addresses the issue of the environment-competitiveness relationship. The resource-based approach, in the meantime, addresses that the performance of the corporation depends primarily on their core competency and the ability to manage resources and capability to gain competitive advantage. Lastly, the institutional approach concerns with how the vision of ecological sustainability are generated and accepted by employees, management and stakeholders of corporations. The result of this explorative study suggests that there is a need to develop an integrative model utilizing a system framework to study ecologically sustainable organization.

Localisation, Production Technology and Sustainability

Julian Allwood

Work on sustainability in production to date has largely concerned the optimisation of existing processes, particularly in energy conversion and in the extraction of raw materials. To achieve a step change in the impact of production systems, there is a need to explore alternative structures. This paper examines the potential for distributed smallscale or 'localized' production as a valuable alternative. Identification of sectors which might show benefit from localisation requires examination of two key questions: In what sectors would localised production offer significantly improved environmental and social performance? What production technology is required to make this economically attractive? The paper mainly addresses the first of these questions by examining existing data and analysis related to the main material types sent to landfill in the UK. The choice of an appropriate scale for production systems depends on the interaction of many forces: the balance of fixed and direct costs; energy consumption in production and distribution; the destination of products at end-of-life; the potential of different material classes for re-use or re-constitution; the nature of the offering made by producer to consumer including the balance of product and service, quality, risk and traceability; job design; political and legal influences. For each of these forces, some basic data is presented, and existing work is reviewed in an attempt to identify materials, products and sectors where a change of production scale would offer improved sustainability. Some practical case studies of successful scale changes are given. For sectors where scale change looks attractive, careful research is required to identify key technological limitations which make scale change economically unattractive at present and to search

for potential solutions. The paper concludes by attempting to anticipate the characteristics of such solutions and gives some recent examples of innovations which may facilitate new approaches.

Combined Environmental and Economic Life Cycle Evaluation of a Company

M. Margni, F. Della Croce, O. Jolliet

In recent years, producer's responsibility has, therefore, clearly moved from production site responsibility to an overall, or "extended" producer liability for materials production, manufacturing, transport, use, and disposal of its products. If life cycle assessment of products is well known and applied, the means of identifying the overall environmental effects of companies is poorly defined. Therefore, firms often employ inhouse methods based on qualitative criteria and mainly consider on-site emissions during manufacturing, without looking at life cycle burdens. This is the cause of some errors in the identification and evaluation of environmental priorities; errors that may reduce the effectiveness of the Environmental Management System (EMS) and induce an inefficient use of economic resources. In response to this lack, this presentation aims to present a systematic tool to identify the significant environmental impacts of a company and its products, whilst relating this with the cost saving potential. The approach aims in particular to combine environmental and cost assessment in a quantitative and reliable scientific way. The analysis, based on a life cycle perspective, considers not only the site of the company but also the subcontractors and the environmental impact of the suppliers. The method is based on a synergy between Life Cycle Assessment and Ecodesign, applied to the overall activity of the company. It takes into account the following stages: (1) Problem and functions definition, according to the overall activity of the company; (2) Inventory data collection and determination of primary energy consumption and CO2 emissions; (3) Screening of the impacts of toxic emissions (4) Cost analysis based on the same system definition and collected inventory data; (5) Detailed analysis, with benchmarking to national standards and to similar sectors, on the key points identified in the first calculation; (6) Determination of indirect impacts of services based on Input/Output analysis, combined with the process approach. The method is applied to four case studies: a service company (bank) and a mechanical industry (microtechnics) a University (EPFL) and a public transportation company. Significant direct and indirect impacts are discussed in detail, enabling to identify the relevant aspects in an environmental-financial interface. The presented examples clearly showed that the reductions of impacts have to be considered outside the classical company boundaries and extended not only to the supply chain, but also to companies' collaborators and customers.

Integration of Design for Environment and Environmental Management Systems

Jonas Ammenberg and Erik Sundin

Standardized environmental management systems (EMSs) are quite commonly used

today. It is the authors' experience that many companies, authorities and individuals regard a certification according to ISO 14001 as a guarantee for good environmental performance. For example, the Swedish government has chosen the number of ISO 14001 certificates and EMAS registrations as an indicator for sustainable development. Moreover, some important European countries offer regulatory relief if companies have an ISO 14001 certificate or are EMAS registered and US authorities consider easing regulatory burdens for companies using EMSs. The overall objective of ISO 14001 is "to support environmental protection and prevention of pollution in balance with socioeconomic needs". But are standardised EMSs really leading to improved environmental performance and reduced environmental impacts? This certainly depends on to what extent these systems are leading to changes in important flows of material and energy, which in turn is closely connected to influence on companies' product development. The adaptation of products for the environment is commonly conducted by different Design for Environment (DFE) methodologies. Consequently, it appears vital to investigate the connection between EMSs and the concepts of DFE. This paper presents the concept of product oriented environmental management systems (POEMSs). A POEMS is an EMS with a special focus on the continuous improvement of the company's product's eco-efficiency (ecological and economic) along the life cycle, through the systematic integration of eco-design in the company's strategies and practices. In addition, based on interviews with Swedish external environmental auditors, it is presented how these auditors interpret and apply the central requirements of ISO 14001 concerning products and product development. Thereby, it is illuminated to what extent Swedish manufacturers incorporate DFE principles into their EMSs. Based on the results, it can be concluded that there are many motives to integrate the concepts of EMS and DFE. Firstly, DFE-thinking might enrich EMSs by contributing with a life-cycle perspective, helping the organization to identify the most important flows of material and energy to focus on. Secondly, EMSs might remove the common pilot project character of DFE activities, thereby making them more permanent. Thirdly, an integration of EMSs and DFE concepts could lead to successful co-operation both internally and externally, i.e. lead to a co-operation between environmental managers and staff responsible for product development and lead to concerted environmental efforts within a supply chain, i.e. to a better life cycle management. Concerning the roles of auditors, it can be concluded that their requirements and experiences vary to great extent. While some auditors consider it as mandatory for a manufacturing company to incorporate products and product development into their EMS, others approve EMSs where the link between EMS.

Lead In Electronics: An Industrial Ecology Case Study

Julie M. Schoenung, Oladele Ogunseitan, Jean-Daniel M.Saphores, Andrew A. Shapiro

Lead (Pb) is one of the most toxic and widely distributed metals in human societies. Indeed, exposure to lead is known to cause neurological, reproductive, renal, and hematological disorders. Children are especially at risk because early exposure to Pb adversely affects cognitive development. Therefore, Pb is no longer used as a gasoline additive or in paint sold in the United States, and a comprehensive battery-recycling program has been implemented. The focus is now starting to shift to Pb used in electronics and electrical equipment. A key problem with Pb in electronics is its use as a solder material, although Pb in CRTs has also attracted the attention of decision-makers. Devices such as computers, printers, cell phones, PDAs, and fax machines, as well as large electrical appliances such as televisions, VCRs, refrigerators and dishwashers all contain lead-tin solders. These solders are used primarily for interconnecting and packaging electronic components and assemblies, such as on printed circuit (or wiring) boards. In the United States alone, approximately 10,900 tons of refined Pb was used for soldering in 1998. With the decreasing lifespan and increased use of both consumer electronics and large appliances, there has been a substantial growth in Pb-containing waste electrical and electronic equipment ("WEEE" or "e-waste"). In 1998, e-waste represented approximately 4% of the municipal waste stream. This volume, which is expected to increase by 3% to 5% annually, could double in the next 12 to 15 years. This implies that the amount of Pb contained in municipal waste could dramatically increase and thus threaten increasingly valuable groundwater resources or become air-borne if incinerated. Compounding the problem are consumer attitudes toward disposal of obsolete electronics. According to the Institute for Local Self-Reliance, approximately 75% of obsolete electronics are currently being stored until there is an agreement on how best to manage them. In this paper, we review and discuss the economic, scientific, and environmental issues pertinent to the presence of Pb in e-waste. Our discussion is organized along two lines of inquiry: the growing amount of e-waste and its potential toxicity. We first review new and proposed legislation in Europe, Japan, and the United States currently motivating changes both in the selection of materials for electronic devices and in the selection of appropriate disposal and recycling methods. We then use lead-based solders as an example for evaluating trade-offs between engineering requirements; toxicity, public health and environmental impact; and waste management considerations in the ultimate materials selection decision. Results of various life cycle assessment studies are also presented along with a brief discussion on policy options. We conclude that, although there is no natural link in the US between the quantity and toxicity of e-waste, both need to be addressed when developing long-term legislation.

Biomaterials and Biocomplexity

Biocommodity Engineering: Evaluating Environmental Impacts.

Amy E. Landis, Thomas L. Theis, Heriberto Cabezas, John Glaser

The transition to a sustainable society will involve a decrease in reliance on fossil fuels accompanied by a shift to renewable raw materials such as agricultural feedstocks for commodity goods. Products derived from biomass, often termed biocommodities, are the most logical and promising replacements for petrochemical goods. As society becomes increasingly reliant on bio-based feedstocks, it is important to critically examine the implications associated with such production. Industrial ecology tools such as Economic Input Output (EIO) methods, Life Cycle Assessment (LCA), and energy consumption and CO2 emissions analyses can be used to assess the sustainability of biobased renewable raw materials. This presentation addresses some of the issues in conducting comparative LCA research, including use of databases, discrepancies between modeling tools, and the lack of inclusion of certain impacts into traditional LCAs. With respect to the latter, certain environmental impacts of biotechnology has not been in-

corporated into these traditional methods. This presentation will also address the development of a consistent scientific methodology to determine the environmental impacts of renewable plant-derived products through a hybrid of existing tools. The evaluation of environmental impacts of renewable raw materials is explored through case studies of biopolymer production. Traditional methodologies for assessing impacts are modified to incorporate the diverse environmental impacts of crops genetically modified for biopolymer production.

Biobased Industrial Products: A Sustainable Industry Begins to Emerge?

Bruce E. Dale, Seungdo Kim

Biobased industrial products are fuels, chemicals, materials and other industrial goods derived from plant raw materials. A new industry based on plant matter is beginning to emerge. This biobased products industry has the potential to replace unsustainable, highly polluting, petroleum-derived products with a new generation of materials that is much more sustainable and environmentally benign. However, it will require careful analysis and planning so that the potential of biobased products to enhance the environment and move our society along more sustainable paths is actually realized. In other words, the promise of the biobased products industry may be realized or not, depending largely on what we do now--as the industry is emerging. Our group is working under U.S. Department of Energy contracts with two industrial leaders, Cargill-Dow Polymers and DuPont Biobased Materials, to provide life cycle analysis support for their new polymer platforms, lactic acid and 1, 3 propanediol, respectively. Both of these products are currently based on fermentation of corn starch, but both organizations also wish to move toward lignocellulosic materials such as corn stover as a source of fermentable sugars as technology emerges. Life cycle issues are significantly different for industrial products based on starch or lignocellulose, and also depend strongly on whether the lignocellulosic material is a crop residue such as corn stover or rice straw, an annual plant, a perennial grass such as switchgrass or a leguminous perennial such as alfalfa. Our presentation will describe our interactions with Cargill-Dow and DuPont, compare and contrast the use of starch and/or lignocellulose as raw materials for biobased products and will outline some of the features of this emerging industry with respect to its likely environmental and social impacts, including probable impacts on the production of food and feed. We also treat the soil and water quality issues connected with the choice of plant raw materials (residues, annuals, perennials and legumes) as feedstocks for industrial products. Our analysis to date indicates that careful, thoughtful development of the biobased products industry can significantly enhance the sustainability of our current carbon-based economies. Somewhat surprisingly, it also appears that large-scale production of fuels and chemicals from lignocellulosic materials will actually increase food and feed supplies, rather than decreasing food resources.

Raw Material, Energy and Greenhouse Gas Profiles of Polyhydroxyalkanoate (PHA) Derived from Corn Grain

Seungdo Kim, Bruce E. Dale

Cradle to gate analysis is implemented to review the environmental performances of a biobased polymer, Polyhydroxyalkanoate (PHA), especially focusing on raw material uses, energy requirements and potential global warming impact. The system boundaries include corn production, dextrose production in corn wet milling and PHA resin production. Corn production data from only the US Corn Belt states - Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin, are taken into account. Other processes are assumed to occur in any place in the United States. Raw material uses are presented as crude oil, natural gas and coal. Energy requirements are defined as a cumulative energy that includes the energy use during the fuel life cycle and the energy delivered to the final use. Nitrous oxide (N2O) emissions from agricultural soils and carbon sequestration due to increasing soil organic matter (SOM) are included in the analysis of greenhouse gas emissions. Changes of SOM are simulated by the CEN-TURY model, and nitrous oxide emissions from soils are simulated by the DAYCENT model, a daily time-step version of CENTURY model. Both models can take the regional effects due to soil texture, climate condition and so forth into account. Two counties from each state are selected to simulate N2O emission and carbon sequestration. The selection of counties is based on their corn production and the soil data availability. The average value over these two counties in each state is taken as a state average value. The environmental performances of PHA are compared to those of its counterpart polymers (petroleum based polymers): high-density polyethylene (HDPE) and lowdensity polyethylene (LDPE). The inventory data for those petroleum based polymers are obtained from the data reported by the Association of Plastics Manufacturers in Europe (APME). In the comparison, these data from APME are modified to reflect the US situation. The electricity power grid data in these reports is changed to the average US power grid so that the environmental parameters associated with electricity use reflect the US situation. Furthermore it is assumed that the technologies used in producing these petroleum based polymers in Europe are similar to those in the United States.

Methods of Defining the Sustainability of Biobased Materials

Robert P. Anex

The successful conversion to a sustainable raw material base is undoubtedly one of the most important challenges facing society in the 21st century. As part of this endeavor a joint government-industry working group has already set targets for substantial increases in the use of biomass-derived feedstock in the fuel and chemical industries by 2050. Benefits expected from bio-based materials include: superior material performance; decreased dependence on imported petroleum products; economic benefits from new markets and employment opportunities; and ecological benefits from the sustainable use of renewable materials. However, the use of bio-based materials on a large industrial scale will present a variety of complex economic, social, and environmental tradeoffs compared to the use of petroleum-based alternatives. The widespread use of bio-based materials will likely require massive changes in agricultural practice and land

use with concomitant impacts on soil erosion, water use, biodiversity, and social practices and institutions. The potential changes associated with a widespread shift to biobased materials are multifaceted and complex and require new assessment techniques. The identification and assessment of impacts are complicated by the likelihood of interaction effects within and between natural and social systems. Yet the potential for interaction effects makes the task of identifying and assessing particular broad trajectories of change all the more important. This paper will present a framework for assessing the impacts and sustainability of bio-based material use within the complex technologicalagricultural-natural-social system. The framework will be the result of an international consensus conference on the topic to be held at the University of Oklahoma in the Spring of 2003. The paper begins by defining potential bio-based products in terms of feedstocks used, processing technology and final uses (including products that would be replaced). These data are presented as a matrix of the many possible combinations of feedstocks, processing methods and uses, and allows classes of bio-based materials to be identified. The paper will also summarize the current state-of-practice of bio-based material assessment techniques (e.g., LCA) and sustainability indicators. The paper will conclude by presenting a consensus framework for assessing the impacts and sustainability of bio-based material use from an Industrial Ecology perspective.

Environmental Implications of Substituting Bio-Based Products for Traditional Lubricants in Industrial Applications

Shelie Miller, Thomas L. Theis, Ronald Reich, Michael Wang

In the wake of increased concern over the use of non-renewable sources, substitutes have been proposed for fuels, plastics and other synthetic materials, however, there has been relatively little development in the way of sustainable alternatives for petroleum-based lubricants. As is the debate with many bio-based products, it is important to differentiate between what is renewable and what is sustainable. The term "biobased" can easily acquire an environmentally friendly connotation, however, due to the nature of current farming practices and their inherent environmental impacts, this is not always the case. It therefore becomes essential to take a holistic approach when discussing issues of sustainability, in order to determine the most desirable alternative. This research examines the feasibility and environmental implications of using vegetable-based lubricants in major industrial processes such as aluminum rolling. Technical and financial considerations are discussed, as well as an introduction to the environmental aspects of processing these products. A life-cycle approach is required to determine environmental impacts, not only during application, but also during farming and processing of the raw material. This research seeks to address whether a transition to bio-based lubricants is truly environmentally beneficial, investigating the amount of petroleum required to produce the vegetable-based lubricant, the effectiveness of bioproducts as lubricants and the respective VOC emissions from both petroleum and vegetable-based lubricants. This research is supported by the National Science Foundation's IGERT and PREMISE programs.

Modeling the Biocomplexity of Alternative Materials to Achieve More Sustainable Infrastructure Systems

Vanessa Smith, Jon Dettling, Richard Chandler, Alissa Kendall, Gregory Keoleian

Concrete use in infrastructure such as roadways, bridges and pipes causes huge material flows between natural and human systems. Global concrete construction exceeds 12 billion tons per year and contributes to significant challenges in sustainability performance as measured by environmental, economic and social indicators. Critical issues include substantial greenhouse gas emissions, major land disturbances, air pollution, and roadway-related traffic congestion and vehicle damage. Alternative materials are being developed to improve the functional performance of concrete infrastructure systems, Engineered Cementitious Composites (ECC) are especially promising materials for these applications. ECC formulations can be designed through microstructure tailoring of input materials including cement (fly ash, bottom ash, CSA cement - calcium sulfoaluminate), matrix (foundry sand, shredded plastic - office machine waste), and fiber (virgin, recycled polymer, textile waste cuttings, natural fibers - banana, sisal, etc.) elements. Strain capacities up to 500-600 times greater than normal concrete have been achieved, giving aluminum-like properties. Currently, decisions about formulating and applying ECC are guided strictly by functional performance and capital costs. Broader environmental, social and economic issues related to life cycle impacts of infrastructure systems have gone unrecognized. The goal of the present study is to enhance infrastructure sustainability and investment decisions by determining the full costs and benefits of ECC application in a particular infrastructure system, a bridge deck. The method presented here uses life cycle analysis to evaluate environmental, economic and social indicators for a bridge containing conventional steel-reinforced concrete joints, and a bridge containing Engineered Cementitious Composites (ECC) link slabs. A life cycle inventory (LCI) model and a life cycle cost (LCC) model were created to evaluate the environmental, economic and social indicators for a bridge with either conventional steel-reinforced concrete joints or with ECC link slabs. The LCI and LCC models are closely linked, and are based on a bridge with a 60-year total service life. It is assumed that the application of ECC in bridge deck link slabs will double the bridge deck service life and reduce maintenance frequency. A broad system scope is applied, including construction and maintenance processes, construction-related traffic congestion, and endof-life management in addition to materials production and distribution. Our results indicate that the ECC bridge deck system has significant advantages in both economic and environmental performance. Even though ECC is twice as energy intensive and two to three times more expensive per cubic meter compared to conventional steel reinforced concrete (1% steel by volume), the ECC system results in a 36% reduction in total energy use and carbon dioxide emissions compared with the conventional system. Savings in other air and water emission categories ranges from 20 to 50%. The ECC system results in a monetary savings of \$130,000 (14%) in agency costs, and \$330,000 (27%) in social costs over the conventional system. Construction processes and related traffic congestion contribute significantly to total life cycle costs and impacts. Materials production is also a major contributor to environmental impacts, suggesting potential benefits from further incorporation of alternative materials than can extend infrastructure service life. This research was initiated as part of the new National Science Foundation Materials Use: Science, Engineering, & Society (MUSES) Biocomplexity Program.

Waste Management

Life-Cycle-Based Solid Waste Management

P. Ozge Kaplan, Eric Solano, Robert D. Dumas, Kenneth W. Harrison, S. Ranji Ranjithan, Morton A. Barlaz, E. Downey Brill

The development of integrated solid waste management (ISWM) strategies that are efficient with respect to both cost and environmental performance is a complex task. There are numerous interrelations among the different unit operations in the solid waste system; e.g., collection, recycling, combustion, disposal, and large numbers of design parameters that affect estimates of cost and environmental emissions. The objective of this study was to develop and demonstrate an ISWM model to assist in the identification of alternative SWM strategies that meet cost, energy, and environmental emissions objectives. The modeled system includes over 40 unit processes for collection, transfer, separation, treatment (e.g., combustion, composting), and disposal of waste as well as remanufacturing facilities for processing recycled material. Waste composition and generation rates are defined for three types of sectors: single family, multifamily and commercial. The mass flow of each item through all possible combinations of unit processes is represented in a linear programming model using a unique modeling approach. Cost, energy consumption and environmental emissions associated with waste processing at each unit process are computed in a set of specially implemented unit process models. A life-cycle approach is used to compute energy consumption and emissions of numerous pollutants, including CO, fossil- and biomass-derived CO2, NOx, SOx, particulate matter, and CH4. The model is flexible to allow representation of site-specific issues, including recycling and composting targets, mass flow restrictions, and targets for the values of cost, energy and each emission. The model was applied in a hypothetical case study. Several SWM scenarios were studied, including the variation in energy and environmental emissions among alternate SWM strategies; the effect of mandated waste diversion (through recycling and other beneficial uses of waste such as combustion to recover energy) on environmental releases and cost; the tradeoff between cost and the level of waste diversion; and the tradeoff between cost and greenhouse gas emissions. In addition, the flexibility of the model is illustrated by the identification of alternate SWM strategies that meet approximately the same objectives using distinctly different combinations of unit processes. Use of the model illustrates the potential impact of solid waste management policies and regulations on global environmental emissions. Recently, the model was extended to enable consideration of uncertainty in input parameters. Monte Carlo simulation with Latin Hypercube Sampling was integrated within the ISWM model to estimate the uncertainty in cost and emissions for a specific SWM strategy. For each realization, the cost and LCI coefficients are computed. These are then combined with the mass flows of waste items corresponding to an SWM strategy to estimate its cost and emissions. After repeating this procedure for all realizations, the resultant cost and emissions values are used to form output cumulative distribution functions. The extended capability of the ISWM decision support tool was again illustrated using a hypothetical case study of a typical municipality. Results show that by considering uncertainty, increased expenditure may not necessarily result in reduced environmental emissions and that some SWM alternatives are more robust although their expected performances are similar.

Recycling C&D waste in Copenhagen - An Impact Analysis

Rolf André Bohne, Hilde Nøsen Opoku

For the world to reach sustainability, society must reduce its use of non-renewable resources with factor X. Industrial Ecology (IE) is one of many ways of moving society towards sustainability. The field has, however, not comprehensively looked at a major contributor to the resource depletion process; the Architecture, Engineering and Construction (AEC) industry. Within the society, the AEC industry uses 40% of the energy, creates 40% of all waste and uses 40% of the resources. In addition to this, the AEC industry makes use of a grand portion of the transportation capacity (transportation consumes 30% of the energy) as well as building the transportation infrastructure. It is therefore important to get more knowledge of how the society deals with the metabolism within the AEC- and transport industry in order to move these industries towards sustainability. A success story on C&D waste recycling is found in the Danish capital Copenhagen. Here they have reached 98% recycling and energy recovery, leaving only 2% for deposition in landfills (mainly asbestos and other non recyclable fractions). This paper describes and analyses the composition and implementation process for this recycling system from an industrial ecology perspective. The method used is impact analysis for program evaluation from the field of policy analysis.

Strategy Assessment for Municipal Solid Waste Management in China

Jian Zuo, Toru Matsumoto

In China, in light of the rapid economic development in recent years, and with the increase in urban population and expansion of the consumption activities of residents, municipal solid waste (MSW) has rapidly increased in the amount generated and has also remarkably changed in quality. Under the system that municipal solid waste is generally collected without classification, these changes have made municipal solid waste disposal more difficult. This paper aimed to characterize MSW and examine problems existing in MSW management systems in China; forecasts demands for MSW disposal in technology, disposal capacity and expenditure, and carry out strategic environmental assessment (SEA) to several MSW disposal plans. MSW characteristics including generation rates, composition and heating values were respectively analyzed at three levels of the whole nation, provinces and major cities. Determining factors of MSW generation were made by multiple regression analysis and models of MSW collection rates were developed for the nation, a major city and for Shanghai. In addition, a concept model of MSW characteristic change was developed for major cities based on a cluster analysis. As a result, per capita waste generation rate in China is decided by climate condition, economic or consumption level and household fuel by multiple regression analysis. The total generation rate of China has been increasing rapidly during the past twenty years because of urban population and per capita waste discharge increase, now per capita waste collection increase is slowing down and increase in total

collection rate will mainly caused by urban population increase in the near future. There is geographic difference in per capita waste collection rate by analysis at province level; it is usually higher in colder northern area because coal is still used as family fuel. Major cities generally show cut in per capita generation rate at the primary phase of economic development because of popularization of gas using in family, then show increase with continues economic development. Share of organic materials and calorific value of waste in Chin's major cities keep increasing. Existing MSW management systems need to improve their resource waste recovery systems, to anticipate strategies for waste electric appliance disposal, and to resolve the difficulties in collecting waste collection charges. Beijing was chosen for the case study for the prediction of demands for MSW disposal facilities and relevant building investment under different technique conditions. Needs for the new MSW disposal facilities and requisite investment for the new facilities in the next 20 years from 2001 to 2020 in Beijing were estimated in twelve scenarios combined with two cases of future MSW collection amount, three cases of disposal patterns and two cases of facility scales. It is estimated that Beijing will require 1,620 to 4,580 million Yuan of capital investment to build 8 to 22 new facilities, providing capability to dispose of the 37 to 50 million tons of municipal solid waste exceeding the disposal capacity of existing facilities in the next 20 years. Strategic environmental assessment was carried out for the different disposal scenario of Beijing by using index of CO2 emission, energy consumption, landfilled residual and chemical waste, residual resource and occupied space.

Utilization of Municipal Solid Waste and Wastewater for Reduction of Carbon Dioxide Emission in Tokyo

Keisuke Hanaki, Toshiya Aramaki

This study demonstrates the potential reduction of carbon dioxide emission from Tokyo by utilizing biomass contained in solid waste and wastewater and heat from wastewater and solid waste incineration. Possible systems compared to demonstrate the potential carbon dioxide emission were: electricity generation using biological methane gas from kitchen solid waste or wastewater, heat recovery from solid waste incineration plants or wastewater using district heating and cooling system. Theoretical potential of energy recovery from the above systems were compared. This calculation was based on calorific value of solid waste, organic content of wastewater and wastewater temperature, and some other parameters in methane production process. The possible energy recoveries through biogas from solid waste and wastewater sludge are 0.6 and 0.1 GJ/person-year, respectively. The possible energy recoveries from heat of solid waste incineration and wastewater are 3.1 and 1.9 GJ/person-year, respectively. These values are up to 10% of energy consumption of residential, commercial and office sector. However, actual energy recovery is smaller than this amount due to energy conversion or other practical limitations. Feasibility and more realistic potential were evaluated. Methane production process from kitchen waste can be implemented at biogas plants to which kitchen waste is collected or at sewage treatment plant to which kitchen waste flows in through kitchen disposer equipment. The former can reduce more carbon dioxide than the latter, but collection system needs to be implemented. The latter case was simulated by using the data of all wastewater treatment plant of Tokyo 23 ward area. The results show that the advantage of the latter system depends on increase of energy consumption in wastewater treatment process due to the increase of organic loading. Electricity generation efficiency is also important factor for the advantages. Introduction of high-rate innovative technology is needed. Heat recovery from incineration plant is evaluated in combination with introduction of cogeneration system. Geographical information system of all building use in Tokyo was used to evaluate the electricity saving effect of the building throughout Tokyo. Cogeneration for multiple building in district scale was also assumed. Effect of carbon dioxide emission by saving electricity consumption in Tokyo depends on carbon intensity of the replaced electricity. Two ways of calculation are possible in this regard. The first way is to assume that the replaced electricity has average carbon intensity in this region. The second way is to assume that electricity generated from fossil fuel is replaced. These two ways of calculation result in significantly different reduction effect of carbon dioxide emission. About 8% of carbon dioxide can be saved when assuming the replacement of fossil fuel electricity, whereas the saving is only 2% when assuming the replacement of average electricity. These calculations demonstrate that the utilization of solid waste and wastewater has potential of reduction of carbon dioxide to some extent although the amount is not large.

Issues Associated with Recovery of Resources from Waste Products using Energy from Waste Technologies: Stakeholder Perspectives

Matthew Warnken, Brett Cohen

Recent legislation and public concerns in Australia and internationally have focussed on the recovery of resources which would otherwise be consigned to landfill (with attention being paid to ensuring realisation of highest resource value), as well as to the production of energy from renewable sources. One suite of technologies which is potentially beneficial in both of these areas is that of Energy from Waste (EfW). EfW recovers the inherent energy value from waste streams which would otherwise be lost to landfill. Energy from waste is, however, a highly emotive issue owing to historical associations with polluting incinerators. As such different stakeholder groups voice significantly different opinions of the benefits and disadvantages of such technology options. A recent national project undertaken by the EfW division of the Waste Management Association of Australia (WMMA) with federal funding through the Australian Greenhouse Office aimed at providing a framework whereby stakeholders could engage proactively in the debate regarding EfW to ensure that optimum environmental, economic and social goals were realised. This framework was termed the Sustainability Guide for Energy from Waste Projects. As part of this project a series of 18 stakeholder workshops were run around metropolitan and regional Australia with the aim of identifying the perceived issues and benefits associated with EfW projects. In this paper we discuss significant issues and themes identified through these workshops, and discuss these within the context of how to assess the sustainability of EfW projects. We also provide insight as to how stakeholder concerns differ as a function of both geographic location (and hence local industry and available resources), and the interest groups which stakeholders represent. Reference is made to how criteria identified relate to recent successful and unsuccessful EfW projects within Australia.
Metal Mobilization: Phytomining as a Competitor for Anthropogenic Production

Ermelinda Harper, Thomas Graedel

Several elements, including copper, zinc, molybdenum, and boron, are essential micronutrients for natural organisms. These elements are also central to modern technology, forming high-strength steels, engineering alloys, and integrated circuits. Although both the organismal and technological uses are common knowledge, their relative magnitudes are not. Focusing on the plant community, we have utilized information on uptake of metals by plants and of global plant biomass to estimate micronutrient metal stocks and flows related to plants. For several metals, we find that the global mobilization by plants may meet or exceed that of modern technology. The results suggest new perspectives in the study of metals cycling. Investigations at the city level have the potential to provide a more detailed understanding of variations in the stocks and flows of micronutrients in plant tissue on a spatial scale.

Technical Session (T8)

Quo Vadis IE

Merging Emerging Ideas: "Science of Sustainability" (Industrial Ecology) and Science and Technology for Sustainability

Barbara Karn, Robert Correll, Diana Bauer, David Cash, and Twig Johnson

Sustainability is too important an issue for the science and engineering community to ignore. Physical and biological scientists, social scientists, and engineers each need to bring their distinct expertise to this problem. The Industrial Ecology ("Science of Sustainability") research community is one among several grappling with the role of science and technology in building a societal capacity for sustainability. One key complementary group is the Network for Science and Technology for Sustainability. This group grew out of discussions at the 2000 Friibergh Workshop on Sustainability Science and a Forum piece published in Science in 2001. Since then, the group has held workshops around the world and crafted an initiative on Science and Technology for Sustainability for the World Summit on Sustainable Development held in Johannesburg in 2002. The Network organizes itself around a set of key research questions focused on dynamic nature-society interactions at different scales complementary to the multi-scale application of the materials flow tools of Industrial Ecology. A collaboration between the Network and the Industrial Ecology research communities will enable progress towards a sustainability science and engineering metadiscipline which will, in turn, enable the coexistence of human society with the natural systems of the planet across time and space. More than any other science, sustainability science and engineering will be focused on the dynamics of changing systems, particularly those involving nonlinear transformations and evolution. It will involve recognizing and controlling change in a manner that maintains a healthy diversity and quality of life on the planet. Possible

steps for interaction and collaboration between the Industrial Ecology and Science and Technology for Sustainability research communities include joint research programs, demonstration projects, and virtual collaborations.

Towards a Research Agenda for Sustainable Resource Management

Stefan Bringezu

Environmental policy as well as research often focus on specifically defined problems which leads to narrow scope of analysis, and contributes to shift the problems between issues, regions and over time. Although this seems to be part of an inherent dilemma of human knowledge, any progress towards sustainable development of society in general, requires a wider perspective which minimizes the risks of problem shifting, contributes more to an insight into and a change of the underlying causes, and also elucidates feasible ways into future. This contribution will exemplify those problems and outlinethe basis for a future research agenda on sustainable resource management (SRM). For that purpose, the background of actual EU policy towards SRM will be given as well as recent developments towards scientific networking, internationally and especially in Europe. The proposed research agenda which is expected to foster international cooperation of researchers and institutions shall provide answers to the following tasks and questions: (1) Integrated analysis of the materials and energy metabolism and land use of society: Which are the driving forces and patterns of development? (2) Integrated future scenarios: How can a sustainable metabolism and land use of society and economy look like? (3) Which technologies will play a major role in the future with respect to direct and indirect resource use? Which tools for integrated assessment can be used in practice? (4) Which information, data bases and indicators are required to assess the performance of the economy and support monitoring and planning of effective measures for long-term sustainability? (5) Which strategies, instruments and institutions can effectively contribute to SRM at various levels (international, national, regional, local) in industry and policy?

Practical Challenges for Industrial Ecology

John Ehrenfeld

The development of "industrial ecology" has largely followed an academic pathway based on the distribution of membership in the International Society for Industrial Ecology. Papers at this meeting are, with few exceptions, offered by researchers in universities, companies, and independent research organizations. This community generally knows what constitutes industrial ecology although a strong dialogue about its bounds continues. On the other hand, a number of practices, such as the Natural Step, ecodesign/DfE, or Biomimicry, have evolved without explicit cross-reference to the field but based on similar principles. Many of these have been picked up both at strategic and operational levels in firms, government agencies and NGOs, but with no obvious tie to industrial ecology. In another pattern, technical areas central to industrial ecology such as LCA and MFA have co-evolved with industrial ecology along with the estab-

lishment of institutional supporting activities such as SETAC. If industrial ecology is to push out of the Academy into a robust professional field of practice such as classical engineering or interdisciplinary fields such as risk analysis, it seems probable that formal and informal ties need to be made to these arenas of activity. A model of organizational change will be presented as a framework for building a strategy. The presentation will offer a few suggestions about possibilities, but is designed primarily as a vehicle for eliciting discussion from the audience.

Managing Energy and Greenhouse Gases

The Transition From Fossil Fuelled to a Renewable Power Supply in a Deregulated Electricity Market

Klaus-Ole Vogstad

This paper investigates the trade-offs between long-term and short-term effects of en ergy planning within the context of a deregulated power market. The purpose is to find efficient policies that can aid the transition from a fossil fuelled to a renewable based power supply. Our case study is on the Nordpool power market. The model focuses on the main feedback loops that influence the long-term development for new capacity, namely the unit commitment (operational characteristics), capacity acquisition, technological progress and eventually resource depletion. On a daily basis, the electricity generation are determined by the operational costs. In the longer term, investment costs determine the investment of new capacity, and finally technological progress and resource depletion influence and are influenced by price and costs of electricity. These feedback loops are shown in the causal loop diagram below. The simulation model is implemented as a system dynamics model and the technologies considered are: nuclear, coal, natural gas, gas with CO2 sequestration, hydropower, wind power and biomass. The results show that substituting from coal to gas reduces CO2-emissions in the short run, but increase CO2-emissions in the long run when effects on investment decisions and technology progress are taken into consideration. The explanation for this is that the substitution effect on existing coal plants is quite limited, due to their low marginal costs of operation. In the long term, gas power also substitute investments in renewables and stimulate demand growth by suppressing electricity prices. The results demonstrate the importance of including both long-term and short-term effects when making long-term energy policies.

Integrated CO2 Emission Computer Program—NICE III

Hiroshi Yagita, Baoren Wei, Mitsuo Kobayashi, Atsushi Inaba, Masayuki Sagisaka

NICE model (NIRE CO2 Emission Model for NICE I or National Integrated CO2 Emission model for NICE II) was developed in AIST Japan. NICE model has been used to calculate the CO2 emission and to investigate the CO2 emission reduction strategies in Japan. NICE III computer program is currently underdevelopment that targets to be applicable to the different economic structures in other countries. NICE model is based on the estimation of economic development in a country. From the baseline statistic data, NICE model further calculates the energy demand and CO2 emission. Many parameters in NICE model have scenario choices (High, middle, low and data assigned by a user); a user will be able to evaluate CO2 mitigation options by changing those scenario choices. The main difficulty in NICE III development is that the structure of economic sectors is different from country to country and even from time to time. Therefore, in NICE III package, basic variables, energy demand variables, energy supply variables and CO2 variables are defined. Basic variables are used to calculate energy demands in sectors and electricity supply. GDP and Population Size are examples of basic variables. Sometime, energy demand in one sector can be used as a variable to calculate the energy demand in another sector. In this case the energy demand in this sector is not only an energy demand variable, but also a basic variable. NICE III package allows doing so. An economic sector might need some types of energy, such as, electricity, coal, gas and solar energy, etc. the amount of one-type energy required by a sector is defined as one energy demand variable in this sector. In this part, nine types of energy have been defined as default energy types, and users are allowed defining some other types of energy. It is free for a user to choose any name and number of electricity sources in NICE III package. The CO2 emission in NICE III package is calculated by the amount of electricity supplied and the amount of energies used multiplied by the corresponding coefficients. In NICE III package, the basic variables are completely in an open structure. There is no basic variable originally except one variable "Year" that will be created when a user creates a new project. The user has full freedom to choose variables and set relationship between variables. Users can define any variable they want by inputting equations or the data of the variables. Therefore, a user can build tailored CO2 emission models using one series of basic variables for a country and using another series of basic variables to build CO2 emission model for another country with NICE III package. NICE III package will be flexible enough to fit the conditions in different countries to calculate CO2 emission and evaluate its reduction strategies. In this open structure of the program, there is also enough room to upgrade for the future such as introducing optimization approach or connecting to LCA tools.

A Complete Decomposition Model of Korean Energy Flows

Yujeong Kim, HeoEunnyeong

This study analyzes energy consumption in Korea from 1981 to 2001, using a complete decomposition model. The methodology we used divides the total change of energy consumption of manufacturing into economic activities, composition of industry activities, energy intensity and fuel substitution. The subdivisions of manufacturing include food and textiles, wood and paper product & printing, chemicals and petroleum, nonmetallic mineral products, basic metal industry, machinery & equipment and the types of energy used in this study include petroleum, coal, electricity and town gas. This study also discusses whether dematerialization (deenergization) has occurred in Korea. Empirical analysis reveals that: 1. Change of energy consumption in all subdivisions of manufacturing depended mainly on the economic activity effect. 2. The structural effect was very small compared to other effects. 3. The intensity effect decreased from 1981 to 2001 except 1999. This result shows that energy use efficiency in Korea was improved from 1981 to 2001 concluding that dematerialization occurred during this period. The main reason of intensity effect on manufacturing is the change of energy.

intensity on chemicals and petroleum industries. 4. According to the analysis performed by types of energy, substitution effect was larger than structural effect and intensity effect.

Input-Output Analysis in LCA and MFA

Deriving a New Measure of Corporate Environmental Performance Based on Human Health Impacts

Dinah A. Koehler, Deborah Bennett, Gregory Norris, John D. Spengler

To date there is no consensus on the definition of acceptable corporate environmental performance, much less on what constitutes firm-level sustainability. The World Business Council for Sustainable Development has proposed eco-efficiency to evaluate a firm's sustainability. However, focusing on physical emissions quantities, such as kilograms of toxic chemical releases per unit output, current analysis of corporate environmental reports will underestimate the environmental and public health impacts. We propose a more comprehensive environmental performance measure based upon the social cost of toxic emissions to aid in ranking sectors and firms in terms of a measure more closely tied to expected impacts of concern. Following the damage function approach to estimate and valuate human health impacts of toxic chemical emissions, our cancer risk estimates are drawn from CalTOX, a multimedia multipathway fate and exposure model. We employ Economic Input-Output Life Cycle Assessment to analyze the total environmental burden of industry supply chains. We find that industry ranking by toxicity weighted 1998 chemical emissions is significantly different from ranking by emissions per unit output using Spearman's rank correlation coefficient and Analysis of Covariance. For the majority of industries the total supply chain social impacts far outweigh those associated with an industry sector's direct 1998 releases and should thus be considered when evaluating corporate sustainability. Results of this analysis will inform the financial services industry (FSI) engaged in socially responsible investment (SRI), corporate managers interested in demonstrating the value of pollution reduction, and policy makers engaged in social cost-benefit analysis of policy initiatives.

Expansion of I/O Based Embodied Environmental Burden from a Mass Basis to an Impact Basis

Keisuke Nansai, Yuichi Moriguchi

This study proposed a method of calculating embodied environmental burden intensity considering site-specific characteristics around sources. Embodied environmental burden intensity can be calculated from an input-output table; it yields coefficients which indicate the amount of direct and indirect environmental burden induced by unit production activity of a sector in the input-output table. For instance, the embodied carbon dioxide (CO2) emission intensity is often used as inventory data for life cycle assessment (LCA), which gives a clear definition of the system boundary of a life cycle. In terms of air pollutants, for instance, the embodied nitrogen oxides (NOx) emission intensity can be calculated and applied to inventory data just as with CO2. In the case of emission of air pollutants, e.g. NOx, however, the embodied emission intensity that is expressed as an emission quantity is insufficient for assessing the impact of emissions on human health and others. It is important to include not only the emission amount, but also conditions around the emission site, such as a population and a meteorological condition, in the embodied emission intensity. This must be done to maintain advantages of embodied emission intensity based on an input-output table while expanding it into a coefficient suitable for impact assessment of LCA. This work used a geographic information system (GIS) to obtain information on conditions around emission sources; then, that information was combined with the corresponding sector in the Japanese input-output table. This process enabled us to visualize direct and indirect pollutant emissions along with production activity of a sector in the input-output table, and evaluate the "actually-probable" impact of the emission from the sector in consideration of both the emission amount and the exposure condition reflecting neighboring population distribution. We calculated embodied emission intensity evaluated as an impact; then, we analyzed differences between it and the embodied emission intensity based on a mass.

Climate Change Damage Assessment Using an Input-Output Approach

Thomas Gloria

A shift in focus on the repercussions of climate change is afoot. Policymakers are shifting their focus from emissions inventory activities and prioritization of reduction opportunities to estimation of damage and mitigation efforts. This shift in policy perspective will have a profound effect on how Industrial Ecologists should provide insight and viewpoints on this global issue. Similar to Natural Resource Damage Assessments (NRDAs), the authors propose a method, climate change damage assessment (CCDAs), to estimate the monetary cost of restoring injuries to human and natural resources due to climate change. Damages to human and natural resources are evaluated by identifying the functions or 'services' provided by the resources, determining the baseline level of the services provided by the injured resource(s), and quantifying the reduction in service levels as a result of climate change. Specifically, two areas using methods of input output economics are presented. The first is an examination of the appropriateness of a general comparative static input output method that combines the technosphere, ecosphere, and valuesphere, to examine long range planning issues. The second is an examination of sequential interindustry methods to analyze unforeseen, but highly impactive unscheduled events that result in either short duration interruptions or major shifts in environment with repercussions of the very long term, such as

floods, droughts, and saltwater intrusion into aquifers.

Life Cycle Assessment and Management

Life Cycle Assessment for Australian Grains

Venky Narayanaswamy, Jim Altham, Rene Van Berkel, Murray McGregor

Growing consumer interest in the provenance of food, including the environmental burden caused by farming, processing and food manufacturing, and mounting concerns

on the environmental impacts of large scale monoculture farming, encouraged Curtin University of Technology (Western Australia) and the Australian Grains Research and Development Corporation to start a two-year exploratory study into the applicability of Life Cycle Assessment (LCA) to improve the environmental and economic performance of the Australian grains industry. LCA is emerging as the internationally preferred approach for assessing and managing the environmental performance of products and services. Despite its growing acceptance, in particular for manufactured products, application of LCA for food products is hampered by both methodological issues in particular in the farming stage, such as consideration of location specific land based impacts, seasonal variation and nutrient cycling, as well as lack of crop specific data. The grains LCA project includes two lines of investigation. Firstly, three case study LCAs are being executed to assess the relative contributions of farming, farming supplies, food processing and consumption to the total life cycle environmental impacts. The three case studies are wheat to bread, canola to cooking oil and barley to beer. The core environmental impacts covered in these three case studies are resource energy consumption, global warming, human toxicity, eco-toxicity and euthrophication, while land based impacts are being covered in a qualitative manner (in particular dryland salinity and biodiversity loss). Secondly, the impact of regional and seasonal variations in farming on the total lifecycle environmental burden will be assessed. It is planned that this will lead to a simplified method to compile a transparent environmental profile for grain commodities, on the basis of standard production records and agricultural statistics.

Application of the LCA Approach to the Environmental Management System Implementation of a Fruit-Juice Production Plant: The Italian GESAMB Project

Michele Galatola, Eliana Russo

The results presented in this paper are part of the outputs coming from the GESAMB national research project that ENEA (the Italian National Agency for New Technologies, Energy and the Environment) is carrying out in the Southern part of Italy. The main aim of the project is the implementation of an integrated certification (Quality-Environment-Safety) within industries working in the agro-industrial area. We are running the project looking at different sectors, like dairies and cheese making, farming, manufacture of alcoholic beverages and soft drinks, restaurants and hotels, fish farms, manufacturing of food products, and fruit juice production. The agro-industrial sector has been chosen as it represents a widespread area of business in Italy, especially in the southern part of the country. Most of the enterprises are small or medium size, and their annual turnover is about 12% of the National Gross Production, just behind the mechanical and textile industries. Notwithstanding this, there only 2 companies that have the EMAS registration and 19 got the ISO 14001 certification in the agro-industrial sector. Anyway, the Italian market is showing an ever-increasing interest towards the environmental friendliness of all those product somehow related to food consumption. Indeed it is often stated in market surveys results that consumers recognize a strong relation between product environmental performance and its quality. In this paper we report the outputs of a Life Cycle Assessment that has been carried out on a fruit juice production plant located in the Basilicata Region. The management of this plant is trying to get an ISO14001 certification as a first step, moving then to a European EMAS

registration. In this second case is of key importance the knowledge and, whenever possible, the management of the indirect environmental impact, that means of all the impact that are not under the direct control of the plant management. The methodology used and the definition of system boundaries is discussed, together with the main outputs of the study. These results are being used in order to better plan the Environmental Management Program, and to define reasonable objectives and targets for the production process management. This study is confirming the central role played by LCA within the contest of sustainable development, especially taking in consideration the local action required by Agenda 21 and all the other local environmental policy approaches. We don't know yet if this plant will get the EMAS registration, but the implementation of an EMS and the LCA is helping the management to have a clearer and more systemic view of their functional role within the production system.

Life Cycle Assessment of Cane Sugar Production on the Island Of Mauritius

T. Ramjeawon

It is well accepted at the international level that the small island of Mauritius is a model for economic and social development for democratic and multicultural developing countries. In less than three decades, Mauritius has changed from a poor developing country with uncontrolled population growth, high infant mortality, and declining or stagnant growth per capita income, to a rapidly industrializing country. Mauritius is the sixth most densely populated country in the world, and it has one of the lowest cropland per capita ratios. Since more than 90% cropland is devoted to sugar cane, Mauritius must import most of its food. Combined with lack of mineral and fossil fuel resources, this makes Mauritius extremely dependent on imports and the sustainable use of its limited natural resource base is imperative. Small islands like Mauritius, provide a special case in development, largely due to special characteristics of their natural, economic and social environment. Understanding and implementing strategies for sustainable development become critical issues for islanders. Sugar cane has been grown for more than three centuries in Mauritius and until recently its economy relied entirely on sugar exports. Although sugar cane still dominates agriculture in Mauritius, occupying about 90% of total land under cultivation, and sugar still remains the backbone of the economy, the contribution of that industry to total export earnings is now only about 28%, representing about 11% of GDP. However, from a socio-economic point of view, the sugar industry is a highly important crop in Mauritius. The industry is presently facing serious difficulties and needs a major urgent restructuring due to the erosion of preferential access on our traditional exports markets for sugar and new challenges imposed by the trade liberalization process. The long-term viability of the Mauritian Sugar Industry depends on the ability to cut down on production costs. Government has established a sugar sector strategic plan and the reform process implies more centralization, cost reduction, enhanced productivity, manpower rightsizing, and optimal use of cane-sugar resources. The following targets have been proposed for the year 2010: - Ensure export market commitments are fulfilled (500,000 tons) - R e duce cost of production from 18 cents/lb to 14 cents/lb -Reduce number of sugar factories from 14 to 7 - Reduce sugar harvest time and in-factory processing to a strict minimum -Generate as much electricity from renewable sources, in particular from bagasse -

Ensure irrigation water in the dry regions of the country -Effect a substantial reduction of the labour force -Ensure a more efficient and judicious use of land and water resources Government agricultural policies will have enormous effects on agriculture production systems and their subsequent environmental impacts. Life Cycle Assessment(LCA) uses a scientific approach to help in finding ways to make the production chain sustainable and in assessing the overall impact of these policies. The primary goal of this study was to carry out a LCA of sugar production on the island . The figure below is a simplified representation of the sugar production and supply chain, showing the inputs and outputs. At each step opportunities exist for optimizing the input of resources and reducing the generation of wastes and emissions.

POSTER ABSTRACTS

Adoption of Sustainable Business Practice in Developing Countries: A Survey of Nigeria Industrial Businesses

Ishaq Oladapo Adeleke*

Innovative products and processes have been portrayed as sustainable business practices. Few developmental organizations are noted to be at the forefront of such sustainability initiatives in some developing countries. While real and potential benefits (economic, environmental and social) of such adopted initiatives are reported in the developed economies and most recently in the transiting economies, how Africa countries can adopt and adapt sustainable business practice seems indeterminable. Proponents of pollution prevention often suggest that the strategy could catalyze or leapfrog the developing countries in the developmental race. The globalization issue raises more doubt about on this possibility in developing countries. Variously cited obstacles to innovative practices like Cleaner production, Eco-efficiency, Design for Environment and similar strategies have been those related to know-how, risk assessment, capital, business management practices, and environmental policy, among others. Source reduction Pilot projects and hands-on training in some developing countries seem not targeted at long-term sustainable development. In order to set a pace for most businesses in developing countries like Africa, more fundamental and core issues need to be addressed. This research obtains some facts on industrial practices and capacity of businesses in Nigeria and how such practices prepare grounds for sustainable implementations. Critical success factors to sustainability in developing world are addressed.

Direct Detection of Pathogenic Bacteria in a Semisynthetic Metalworking Fluid by Flow Cytometry for Sustainable Metalworking Processes

Shu-Chi Chang, Sarah E. Bahrman, Anna I Khijniak, Cyndee L. Gruden, Alexa Rihana, and Peter Adriaens*

Metalworking fluid (MWF) is a central and vital lubrication technology for the metal fabrication processes of multiple industrial sectors, including aerospace, automobile, electronics, and defense, with U.S. consumption exceeding 600 million gallons in 1998. Most of the main components of MWFs are high volume products, exceeding million gallons production per year, which poses high tension on sustainable utilization of those finite resources on the Earth. The service time of a MWF depends not only on its chemical integrity but also on its microbial content. With the occurrence of a recent incident in a machining plant linked to non-tuberculosis mycobacterium (NTM) resulting in significant downtime of processes because of workers' medical leave, it is evident that MWFs has to be discharged and the whole system has to be cleaned once if contaminated with highly infectious and persistent pathogens. Therefore, pathogenic bacteria detection became a critical and essential role for the sustainability of metal-

working processes.

Here we describe a novel application to detect and quantify an NTM in a typical semisynthetic MWF by flow cytometry (FCM). An immunological method is successfully defined by employing a *Mycobacteria*-specific polyclonal primary antibody and a fluorochrome-conjugated secondary antibody with proper treatment of the samples. A detection limit down to 100 cells/ml of this NTM in a pure culture and 1000 cells/ml in a mixed microbial community in this MWF is achievable. The total assay time is less than 3 hours, which is much less than a typical fluorescent *in situ* hybridization (FISH) method by employing either deoxyribonucleic acid (DNA) or peptide nucleic acid (PNA) probes but with comparable sensitivity and specificity. Further, an accurate viable count of this NTM in a mixed community is also consistently achievable by utilizing propidium iodide and a non-specific nucleic acid dye. Since this probe is universal for all tested *Mycobacteria*, which tend to have longer generation time during growth, usually 7 to 8 hours for rapidly growing *Mycobacteria* and longer for other slowly growing *Mycobacteria*, this method can provide a relatively accurate snapshot of the cell density of *Mycobacteria*.

Combining this success of applying a relatively rapid and reliable immunological detection technique in MWFs and the commercial availability of the antibodies for major pathogens, detection of specific pathogenic bacteria in MWFs becomes feasible and economical. This application will help the metalworking processes be maintained in a sustainable manner and reserve the raw material resources involved in the production of MWFs.

From the Cow to the Kitchen Table - Opportunities for Reducing the Environmental Impact of Milk Transports in Denmark

Birgitte Pedersen and Stefan Anderberg*

Transports are fundamental in modern society and they have been constantly increasing with the societal development. In the most advanced regions, the environmental impact of many activities have been stabilized or reduced, but this is not the case for transports that have become the great-unsolved environmental problem. This paper is based on a master thesis, which has evaluated the transportation of milk from producer to consumer in Denmark via a method inspired by life cycle assessment. The aims have been to identify in which parts of the system where the potential for reducing the environmental impact is largest, and investigate the importance consumer behavior. The study has mainly focused on reduced transport as a way to reduce the environmental impact, and CO2 emissions have been used as indicator for such impacts. The milk transport system has three links: 1) from the farm to the diary, 2) from the dairy to the shop, and 3) from the shop to the consumer. As a complement to the systems analysis, a small qualitative survey of consumer habits regarding shopping and choice of transport, based on a focus group interview, has been performed. The analysis shows that the third link, from the shop to the home, is by far the most important part, If car transport is used, this step accounts for 70-95% (dependent on differing assumptions) of the emitted CO2. However, it is also this link that seems most possible to influence. While industrial transports are already very efficient, the consumer is able to reduce the emissions considerably; he can use a bike or public transport, or make fewer trips or going shopping in connection with other activities. Home delivery service can also be an alternative that may reduce transport impacts, but it is not widely available. The group interview indicates that consumers are not entirely negative to alternatives such as using the bike more frequently or having groceries delivered, but with lack of time and long distances he does not generally see an alternative to the car. In the final discussion, the limitations and prospects of the methods used are addressed. For understanding a system involving behavior, it is desirable to combine quantitative and qualitative methods. The major problem with just following a limited quantity of one type product is that the importance of freight transport tends to become underestimated, and it is more difficult to identify opportunities for increasing the efficiency. Tools for assessing products may not be appropriate for the study of sectors.

Life Cycle Assessment of Thermal Treatment Technologies - An Environmental and Financial Systems Analysis of Gasification, Incineration and Landfilling of Waste

Getachew Assefa*, Ola Eriksson & Bjorn Frostell

Catalytic combustion - as a part of an energy conversion chain - is a promising technology that is presently studied at KTH in Stockholm. In this particular application, the catalytic combustion is used as the final step in a waste-to-energy system including gasification and combustion. Instead of using a normal gas turbine flame combustion, a catalytic combustion is used. Following promising experimental results, a systems analysis was performed with the aim to assess the ecological and financial performance of different waste-to-energy chains. In the study, a life-cycle assessment approach previously developed for systems analysis of waste management, the so-called ORWARE model was used. The following different treatment scenarios were studied: (1) Gasification with catalytic combustion, (2) Gasification with flame combustion, (3) Incineration with energy recovery and (4) Landfilling with gas collection. In the study, compensatory district heating was produced by combustion of biofuel. The power used for running the processes in the scenarios was supplied by the waste-to-energy technologies themselves while compensatory power was assumed to be produced from natural gas. The emissions from the system studied were classified and characterized into the following environmental impact categories: Global Warming Potential, Acidification Potential, Eutrophication Potential and finally Formation of Photochemical Oxidants. Gasification with energy recovery in a combi cycle using catalytic combustion in the gas turbine (scenario 1) was found to be the most competitive technology from primarily an environmental point of view. It was also obvious that a decreased use of landfilling in favor of an increased energy recovery from waste is positive from all considered impact categories. A comparison of the catalytic combustion and the flame combustion showed that catalytic combustion is favorable, mostly thanks to its very low emissions of NOX. This was since the gasification process studied was identical between the two alternatives; only the combustion technology in the gas turbine was different. Here, catalytic combustion allows a much lower reaction temperature which results in a lower production of NOX. The financial costs were, however, found to be slightly higher for catalytic

combustion than for incineration with energy recovery. This means that ecological performance has to be valued financially in order to clearly justify the introduction of this technology instead of traditional waste incineration with energy recovery.

Comparing Material Cycling in Natural and Industrial Systems

Reid Bailey*

Material flows represent one of the strongest links between natural and industrial systems. With increasing environmental problems, understanding material flows in industrial systems and their relationship to natural systems has never been more crucial, yet at the same time more difficult due to their complexity. Qualitatively, the current dominant perspective urges industrial systems to be designed to be similar to natural ecosystems due to the perceived ability of natural ecosystems to cycle materials efficiently. To better understand this perspective quantitatively, an approach from ecology (namely, input-output flow analysis) is applied to determine if a common set of characteristics is shared by all ecosystems and if this set of characteristics can be used to distinguish natural and industrial systems. Such information is crucial in (1) clarifying the qualittive system level environmental goal of designing industry to be more like nature, (2) understanding the environmental performance of industries, and (3) designing alternatives to current material flows in industrial systems. In this paper, material cycling in six industrial systems is compared to seven different types of natural ecosystems using inputoutput flow analysis. The results show that the general trend is for natural systems to cycle materials more effectively than industrial systems. Several key exceptions to this trend are identified and used to explore the role of closed loop material cycling in industrial systems.

Quantitative Comparisons of Downcycling and Closed-Loop Recycling

Reid Bailey*, Janet Allen, Bert Bras

Downcycling has long been recognized as being less effective than closed-loop recycling from a material flow perspective. The differences between downcycling and recycling, however, have not been quantified and explored in depth. In this paper, inputoutput flow analysis is used to quantify the differences and the similarities between downcycling and closed-loop recycling. Input-output flow analysis is an appropriate tool because it considers both direct and indirect material flows in a system; in a system with closed loops, indirect flows play a particularly important role. More specifically, two metrics from flow analysis, Path Length, which measures how many processes a unit of material flows through on average before exiting a system, and Cycling Index, which measures the percentage of flows in a system that are cycled are useful for comparing downcycled closed-loop recycled flows. Results from this research matching expectations include that closed-loop recycling is more effective at cycling materials and at keeping them in the system longer than downcycling. The more interesting result is that as the number of processes in each downcycling and closed-loop recycling systems increases, the behaviors of the two types of systems converge. Material stays in the downcycled system just as long as it does in the recycling system (i.e., the path

lengths of the two types of systems converge), while the amount of material that is cycled approaches zero (i.e., the cycling index approaches zero) in both types of systems. The practical implications of the results are that downcycling systems should be extended to include as many processes as possible while the number of processes through which material flows in a closed-loop recycling system should be minimized.

Inclusion of Sustainable Development Principles in Product Development: Challenges and Opportunities

Fouzia Baki* and Michael H. Wang

The concept of sustainable development has become a part of our common usage in the media, within government policy and in corporate mission statements. Although there is a global consensus on the need for sustainability, the means of achieving the core values and principles of sustainable development remains a challenge. The Western world has for many years been characterized by an enormous throughput of resources and energy. It represents 20% of world population and uses 80% of the material and energy resources annually extracted and exploited. This means that a tremendous amount of material 'capital' has already been invested in the developed countries. Vast amounts of natural resources have been taken from sources in the developing world. The countries that have made the resources accessible for extraction and distribution were presented with unsustainable natural conditions and the associated wastes, emissions and pollution. In the area of cleaner production, preventative, proactive and process-integrated approaches have a preference over those that are curative, reactive and end-of-pipe. It is well established that product development should integrate consumer and waste management problems, as well as issues regarding working conditions and current and anticipated problems associated with resource availability. The objective of this paper is to find out how traditional product development procedure can be reorganized to incorporate sustainable development principles i.e., the product development procedure should consider 'prevention' as a starting point, and moves to integrated product development that achieves reduced impacts across the whole product life cycle. The scope of this paper is limited to extended producer responsibility (EPR), remanufacturing, recycling and material selection. This paper is based on the current practice of well-known companies. This article provides a list of suggestions to make the challenging path to changing product development process to foster sustainable development and technical innovation simultaneously and successfully.

Assessment of the Pollution Prevention Potential of MSW Gasification for Integrated Solid Waste Management Using Life-Cycle Analysis

Morton A. Barlaz*, H. Christopher Frey and Minsheng Li

The objectives of this study were to develop a novel assessment methodology for evaluation of the risks and potential pay-offs of new technologies that avoid pollutant production and to demonstrate the methodology via a case study. Gasification of munici-

pal solid waste (MSW) blended with coal is a promising new approach that was selected for study. Refuse derived fuel (RDF) produced from MSW and coal serve as the raw materials in an integrated gasification combined cycle (IGCC) system for the production of syngas, which is subsequently converted to methanol and electricity. In addition, recyclables are recovered from the MSW during RDF production. This approach has the potential to convey benefits in the areas of avoided chemical production, with additional benefits to electric power generation, production of transportation fuels and avoidance of pollution associated with alternate MSW treatment methodologies. Process models have been developed in Microsoft Excel and ASPEN Plus to simulate an IGCC polygeneration system. The process simulation models calculate the mass and energy balances of each major process area of the IGCC system, taking into account interactions among different components of the system. A life-cycle inventory (LCI) of the complete processing of MSW and coal into useful products has been completed. As part of a multi-scale modeling approach, inputs to the LCI pertaining to the IGCC system were characterized based upon outputs of the more detailed process simulation models. The benefits of the production of useful products from MSW and coal were quantified by an offset analysis in which the avoided emissions associated with production of the same products from virgin materials was subtracted from the overall emissions inventory to complete the LCI. In addition, a case study was conducted to compare the environmental burdens associated with MSW processing via the IGCC system and conventional mass burn combustion. In all cases, MSW gasification resulted in lower emissions than a mass burn facility. Opportunities to optimize the IGCC system taking into account environmental burdens were evaluated based upon sensitivity analysis of the process simulation models coupled with quantification of the LCI for ranges of values of selected design variables. The benefits of a multi-scale approach to process simulation and LCI modeling are discussed.

Historical Perspectives on Copper Usage in North America, a Residence Time Analysis

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Quantifying the stocks and flows of materials throughout the technological cycle can inform resource policy, environmental science and waste management. If carried out over multiple years for one substance this type of analysis can characterize the stock and age distribution of products in use and estimate the flow of product discards using residence times. The major motivation for looking at historical inventories of substance stocks and flows is to understand how and in what proportion materials are used, how they may dissipate into the environment, and how they partition into certain reservoirs (e.g., landfills), which can ultimately lead to assessing the feasibility of mining landfills for recovery of valuable materials. It can also provide a basis for forecasting models for waste management. This paper investigates the quantity of copper that has been mined, smelted, fabricated, and used in North America in the 20th Century. Successive mass balance calculations determine the flow of copper from ore to metal, from metal to products in use, and thence into waste deposits or re-use. The quantity of copper waste from societal stocks is a function of the inflow of new products and their residence times. In a one-year scenario (1994), we compare estimates of Cu entering the waste

system using our residence time model, with published waste generation rates and Cu concentration. Furthermore, in the residence time model we allocate copper products to the six waste categories. Preliminary results of the quantity of copper used in North America over the last century (1900-2002) suggest that approximately 166 Tg of copper (131 Tg of refined copper and another 35 Tg of old copper scrap) entered the economy, of which 69 Tg were discarded; 40 Tg were collected for recycling; 29 Tg were landfilled; and by difference, 97 Tg were added to the in-use stock. Furthermore, in the production of copper metal during the 20th century (1900-2000), about 25 Tg of copper in the form of tailings and slag were generated. Assuming today's collection and recycling rates for copper in post consumer waste, an additional 11Tg of copper will be added to waste reservoirs by 2020. The residence time model shows an exponential trend in copper waste sent to landfills from 1950 (210 Gg Cu) to 2020 (1900 Gg Cu). This trend may intensify in the future because of the rapidly increasing rate of electronic equipment use and correspondingly shorter residence times, and the absence of an efficient collection and processing infrastructure for retired electronics.

Construction of a Recycling System Knowledge Production and Distribution of Power – The Case of Copenhagen

Rolf André Bohne* and Elin Mathiassen

During the late 1970's and early 1980's, Danish authorities registered an increase of toxic pollutants in their groundwater reservoirs. Investigations isolated leakage from legal and illegal landfills as the main course of the problem, and it became evident that a reorganization of the national waste treatment scheme was necessary. An end to the practice of depositing waste in landfills by means of a general ban was the solution chosen. The shift further involved isolating the construction and demolition waste stream, as it turned out to constitute about half the waste being deposited as well as the main part of the non-combustible waste. To implement the new waste treatment regime, authorities involved central stakeholders in "Koordineringsgruppe for genbruk af BAaffald" (KGB) and "Genanvendelse, Rådgivning og Udvikling" (GRU) which were established to facilitate communication and knowledge transfer. These were later demobilized. The new system has reached a waste distribution that at first glance looks successful, with a 93% reuse of materials, 6% as energy recovery and only 1% for deposition, but there are indications of sub- optimalisation and lock-ins. In this paper we investigate the development of the knowledgebase for the problem definition and the solution chosen. How did it become evident that a reorganization of the national waste treatment scheme was necessary, and by which processes did the option to ban landfills come to stand out? Who was involved, and what power did they exercise? By aid of Actor-Network Theory we take a closer look at the role of knowledge, how it is produced and coupled to decision-making, and consequently what new patterns of power and compliance are created. This is combined with an institutions perspective, shedding light on the effectiveness of the communication process involved. The use of the knowledge and the structural arrangements developed for instance in KGB and GRU might both have lead to the present system's perceived good performance as well as lock-ins that preempt a further development and refinement.

International Comparison of Material Resource Use - The Development of Total Material Requirement, Direct Material Inputs and Hidden Flows and the Structure of TMR

Stefan Bringezu*, Stefan Moll, Helmut Schütz, Sören Steger

We will compare resource use with respect to Total Material Requirement (TMR) and Direct Material Input (DMI) for all countries studied so far. The data basis comprises about 10 and 25 countries, resp., and the European Union (EU-15). The dynamics of TMR as well as of the main components will be analysed in relation to economic growth in order to show whether there is a decoupling (relative or absolute) from GDP and a change of the metabolic structure in the course of economic development. DMI/cap so far only decoupled from GDP/cap in relative terms, i.e. in most of the high-income countries it reached a rather constant level but showed no absolute decline yet. TMR/cap was absolutely reduced only in three high income countries which in these cases were due to political influence. These cases will be considered in more detail in order to elucidate the preconditions of an absolute dematerialization. We will analyse the dynamics of the structure and composition of TMR over time and in the course of economic development. Changes in TMR were more influenced by hidden flows (HF) than by DMI. In general, the economic development of industrial countries was accompanied by a shift from domestic to foreign resource extraction. Different relations can be discovered for the share of biomass, fossil fuel resources, construction resources and metals and industrial minerals.

Measuring Corporate Sustainability

David Burdick*, P.E.

Section III of the Plan of Implementation from the Johannesburg's World Summit on Sustainable Development 2002 calls for the development of a 10-year plan to accelerate the shift towards sustainable consumption and production within the carrying capacity of ecosystems. It further delineates the need to identify specific tools for measure its progress, emphasizing the use of collaborative partnerships with private and public stakeholders. A necessary component of sustainable development and living within earth's carrying capacity is to insure that, at a minimum, the sum impacts from all human actions fall within earth's bio-services to provide, power and sequester these activities. Although it is possible to determine a sustainable and equitable maximum amount of earth's resources per individual (the ecological footprint concept), devising a means to assign these limits to the businesses that create these goods and services has is not vet been fully developed. Calculating a corporation's share of ecological resources requires additional assumptions and calculations beyond conventional ecological foot printing. This includes determining land, air, water and ocean equivalencies for a variety of industrial products and processes and finding a means to equitably allocate the amount of these biophysical resources to a specific corporation. This paper offers a preliminary method to estimate an individual organization's level of sustainability. It gives a corporation tools to establish its ecologically sustainable goal in simple and easily understood terms, to prioritize its efforts, and to gain a marketing advantage in developing sustainable products. Public disclosure of this information benchmarks the organization's efforts, shows leadership and lends credibility to its commitment towards sustainability.

Decision Support Tools for Sustainable Product and Process Chain Management

Jun-Ki Choi*

Products create environmental impacts across many media. These impacts are propagated to each component and material through out the supply chain. Sustainable product development (SPD) involves the life cycle of a product and shared responsibility for the life-cycle environmental impacts of the product. Decisions that support SPD activities need to consider product information from a much broader perspective than is used for typical product decision-making. Collecting the necessary data for analysis within and across these functions and across geographical distributed suppliers is challenging. There are significant information-related challenges attendant to integrating environmental and product development assessments over the life cycle. It requires input from various staff functions, material, environmental, product design, manufacturing, engineering, and marketing amongst others. Further these inputs must be integrated through the entire supply chain. Presently, however, little theory exists to explain what occurs in supply chains and in their management. A major part of supply chain management (SCM) is concerned with the sharing of responsibility for various aspects of performance such as: lead time, transaction cost, product quality, effective communication among suppliers, manufacturers, distributor and retailers. Environmental supply chain management (ESCM) defines its scope to the end user and beyond, to reuse, recycling, and disposal. However, environmental matters have not traditionally been highly valued in supply chain management. In order to analyze environmental impact over the ESCM, effective tools and methodologies should be integrated into ESCM. A large number of tools have been developed in order to aid public or private sector environmental management strategies and operations. Each methodology has its own specific characteristics and is more or less suited to address particular environment-related issues. The choice of the methodologies and tools depends on, the scope of the decision problem, its definition in space and time, the availability of data on environmental impacts, and the uncertainty associated with the estimation of the costs and benefits. It is crucial to use the most appropriate tools for specific problem solving. Generally, no single tool can depict all sorts of problem shifting. Failure of using appropriate combination of tools for supporting decision-making can result in the use of an incomplete or inappropriate analysis, and finally come up with the wrong conclusion. Life Cycle Assessment (LCA), a technique for gathering data and improving the environmental performance of a product, is a candidate for ESCM integration. However, LCA applies to a specific product and there are practical problems related to data, time, expense, and expertise requirements to conduct an LCA. Therefore, research is required to adapt LCA for integration with ESCM. The aim of this research is to develop LCAtype tools to link material flows analyses with ESCM in order to stimulate innovations in products, processes, and management techniques to the scope of ESCM. A system

level tool needs to be developed to frame a comparative environmental analysis of products capable of performing broadly equivalent functions. The results will be mapped with data confidence indicators. This mapping will provide a means to understand the environmental impacts and material flows associated with supply decisions.

The Case of Hsinchu Science-based Eco-Industrial Park

Bruce Kuo-Hui Chung* and Shiann-Far Kung

According to the Kalundborg experience, a close mental distance or trust-based communication at senior levels is important to implement the eco-industrial development. Beyond the material and energy flows, information flow should be the vital role in the initiation of the eco-industrial development as well. How do we know the role of information flow to initiate an eco-industrial science parks? This paper could be a good example to interpret this role and its barriers and opportunities toward the eco-industrial science park.

Hsinchu Science-based Industrial Park(HSIP), one of the most successful science parks in the world, has played a paradoxical role in Taiwan's economic development and environmental protection. It was regarded as the most important components to promote the economic development, however, people even treated it as an image of low pollution in early days. In terms of the interviews to executants of the environment, safety and health (ESH) departments in HSIP on 2000, this paper examines their attitudes and relationship toward eco-industrial science park. With sampling companies of IC industries as 'anchor tenants'; from six major industries in the HSIP with qualitative and quantitative filters, we revealed HSIP's information network. The leading production plants in HSIP are also the anchor tenants. Small plants are highly dependent on the anchor tenants. Messages, information and knowledge handled by different scale plants are tightly exchanged via informal ESH information network. As a science park, HSIP should make use of this character and advantage to implement an eco-industrial science park.

Multiobjective Decision-Making in Environmental Design: Facilitating Objective Valuation

John M. Clayton*, F. Michael Saunders

Most industrial design problems are inherently multiobjective in nature. Designers must select design solutions for implementation based on performance in multiple objectives, combined with an assessment of relative importance, or valuation, of these objectives. At least implicitly, combination of objectives and valuation usually consists of the dot product of an objective vector and an objective weight vector that is chosen to reflect relative objective importance. Environmental objectives included in such problems are often incommensurate; valuation of these objectives, analysis of how changes in valuation impact solution preference, or valuation analysis, can be helpful, particularly when multiple points of view on valuation must be resolved. Many automated design search algorithms are built to solve single-objective problems. These algorithms re-

quire objective valuation to be specified a priori, reducing multiobjective problems to single-objective renditions prior to searching for solutions. This requirement complicates valuation analysis, since design search must be repeated for each new valuation scheme. When solution models are large, repetition of search can be time-prohibitive. Pareto searches identify improved design solutions without requiring a priori valuation. A Pareto search generates multiple discrete solutions and compares solutions based on domination; a dominant solution is superior in all objectives simultaneously. A Pareto set contains all solutions that are not dominated by any other solutions uncovered during search. Among solutions in a Pareto set, improvement in any one objective requires degradation in at least one other. Pareto set solutions are thus the best solutions identifiable from a search without specifying valuation. Designers may apply any valuation to a Pareto set and immediately identify the preferred solutions corresponding to that valuation without repeating the search. Design search and valuation are thus decoupled; decisions on valuation are postponed until after design search, where they can be addressed explicitly with a clarified understanding of design implications. Pareto design approaches are potentially applicable at any design scope and level of detail where there are multiple competing objectives. This work demonstrates the approach at a detailed level, focusing on environmentally conscious design of a pulp bleach plant. A mathematically complex bleach plant model is used to simulate design solutions. Objectives of production cost and chlorinated organics formation (to be decreased) and product quality (to be increased) are obtained from model results. A Niched Pareto Genetic Algorithm (NPGA) searches for dominant solutions within design parameter bounds. An NPGA is chosen because it is generally applicable to wide ranges of complex model structures. In two- and three-objective design problems, Pareto sets are shown to form and improve as search progresses. Valuation analysis is subsequently and independently applicable to these sets. Results demonstrate that design search and valuation can be effectively decoupled via Pareto design approaches, facilitating valuation analysis. Because NPGAs are broadly applicable across many model types, these algorithms are also shown to be promising candidates for use in Pareto searches at any scope and detail of environmentally conscious design, up to and including design problems in Industrial Ecology.

Bioregional Development: An analysis of the Environmental Implications of Local "Closed Loop" Graphics Paper Recycling

Antony. S. Hart, Roland Clift*

The BioRegional Development Group (BDG) has been pioneering work with the paper production and waste paper recycling industries to develop a new approach to sustainable paper production, use and recycling in the UK. A key aspect of this work has been the development of a 'Local Paper for London' (LPfL) production/supply/recycle system. The LPfL project is entirely focussed on the recycling and remanufacture of uncoated woodfree printing and writing paper (uwf P+W paper). There are a number of reasons for this focus on uwf P+W paper, which is in fact one product from what is commonly termed the 'graphics paper' sector: This paper grade is of high quality and because of its fibre and whiteness characteristics it is highly recyclable. Despite these qualities, and coupled with the fact that its use in a city setting is highly focussed

within offices and commercial consumers, current recycling rates for this grade are low. When this grade is made from virgin pulp, a high proportion of the wood pulp furnish is derived from hardwood tree species. Compared to softwood forest systems such as conifer and spruce (where pulpwood is extracted for use generally in lower grade papers and packaging materials), the environmental and ecological impacts associated with the use of hardwoods for pulp production are in many respects higher. Such impacts result from biodiversity issues associated with the extraction of timber from old growth forest systems or from fast-growing eucalyptus plantations. Other high impacts associated with virgin uwf P+W paper can be seen in the higher transportation requirements to the UK for hardwood pulps, (typically from Nth. and Sth. America, Northern Europe, Southeast Asia and Iberia) compared to softwood pulp imports (typically from Scandinavia, Nth America or Central Europe.) The broad aim of the 'Local Paper for London' concept is to adopt a bioregional production strategy that makes use of locally available recycled material, offsets demand for imported virgin materials, encourages the development of local industry and works to reduce local waste disposal impacts. A 100% LPfL recycled 'printing and writing' grade paper is currently made from locally recycled waste graphics paper. This system has been running as a pilot project for 2 years. The LPfL cycle works as follows: Locally arising post-consumer graphics waste paper from the 'urban forest' is collected and routed back to a local de-inking plant and recycled paper manufacturer. The development of a 'closed-loop' cycle is promoted amongst commercial paper consumers, waste paper collectors, sorters and distributors, the papermaking company and local paper merchants. Such a production system has the potential to close ' as tightly as possible' the raw material supply loop for graphics paper production around an urban consumption area. The author's core work has been to conduct a complete life cycle assessment of the Local Paper for London 100% recycled production cycle and to assess possible improvement strategies that could be applied to the current loosely connected pilot LPfL cycle in order to improve the environmental credentials of the cycle. To achieve these novel research objectives, primary LCA data has been developed for the current 'Base-Case' LPfL cycle. Having described the 'Base-Case' scenario, a number of improvement assessment strategies have been developed that could be practically developed at the city-scale in order to 'close the loop' further on the LPfL cycle. Research has also focussed on comparative analysis of the LPfL cycle with the associated environmental burdens of conventional production and supply strategies, which currently exist in the UK for uwf P+W graphics paper. Existing LCA studies into waste paper recycling underline the fact that high environmental burdens in current recycling models are associated with energy consumption in the production phase and from energy and air emission impacts associated with transportation in the collection, sorting and redistribution phases. The Local Paper for London project and the associated comparative LCA pragmatically seek to address these issues. The LCA shows that the focussed recycling of waste graphics paper from commercial premises can improve the case for recycling this grade of waste paper over virgin paper production and over incineration for energy of waste papers. As the research work highlights, the use of degraded waste paper as a dedicated feedstock for incineration for energy certainly has a role to play in sustainable urban waste management strategy, but the LCA highlights the fact that waste graphics paper represents a valuable fibre resource and, if separated efficiently, the best practicable environmental option is to utilise this fibre for the production of the same paper grade. This thesis reports on the findings of the Local Paper for London LCA and demonstrates

how, via improvement assessment strategies, the Local Paper for London LCA has the potential to help direct waste paper recycling strategy at a city scale. This research explains that in order to tightly 'close the loop' the steps in the LPfL cycle should become more firmly integrated. Local Authorities, commercial waste paper collectors, the papermaker and a renewable energy company have an opportunity to work together and develop a paper cycle that could work effectively on an economic, environmental and social scale. At the heart of this integrated approach lies the development of a PAPER-MERF (PAPER – Materials and Energy Recycling Facility). At the PAPER-MERF, waste papers, primarily from the commercial sector are sorted and the resultant recycled fractions can be used to re-make Local Paper for London, produce renewable energy to supply the papermaking operation and provide the raw material for a fibre-based coproduct. Additional advantages could be realised via the development of satellite recycling industries around the PAPER-MERF who are involved in the recycling of other waste streams that emerge from commercial premises. Significant traffic impact reductions could be achieved by the development of a collection vehicle fleet that is capable of collecting a variety of recyclates (including waste office papers, toner cartridges, computer equipment, drinks cans and furniture etc) and returning them to the PAPER-MERF Eco-Industrial Park for distribution to the respective recycled manufacturing companies. The Local Paper for London LCA also incorporates qualitative assessment methodology, primarily in the form of results from social research questionnaires from 130 trial consumers of the Local Paper for London 100% post consumer waste recycled paper product.

Evaluating Sustainability at the Communal Level Using a Multi-Regional Environmentally Extended Input-Output Model - with a Case Study of Vevey in Switzerland

Tourane Corbière-Nicollier*, Sangwon Suh

The research is based on the municipality of Vevey in Switzerland. Vevey owes its development to its convenient geographical situation, near Leman Lake. This causes profitable economic and cultural exchanges and foreigners highly contribute to the towns life. Vevey is an urban area, counting 15364 citizens of which 39% foreigners. Economical activities are oriented toward services, tourism is a key sector. The other economic sectors, I and II, are quasi-inexistent with less than 10% of the economical activity. In Switzerland, local communities are encouraged to apply the sustainable development principles. The Town of Vevey is implementing a local Agenda 21 with a large participation of citizens and local groups. Administration departments, firms and inhabitants are involved in the project. Citizens are invited to meet within working groups and to discuss possible projects and actions in such domains as waste, transport, sustainable consumption and local participatory democracy. Project background In Vevey, an essential question for city planning and management is: local Agenda 21 offers many possibilities for actions, how to establish priorities in a coherent way? How to follow and evaluate actions objectively? A simple and consistent framework for evaluation, adapted to the local context and to multi-objective projects, is needed. Objectives of the project The aim is :

- to develop a methodology to determine the socio-economic and environmental impacts of various alternatives,

- to set development priorities considering multiple development objectives like economic activity increase, employment level increase, environmental impact reduction,

- to differentiate long-term and short-term effects as well as local and national scales,

- to have a tool that is usable for local projects and understandable by local authorities.

The methodology will be applied to diverse alternatives in Vevey which will be presented at the conference.

Methodology :The research is based on the extended Leontief Input/Output system. A localised multi-regional input-output table for Vevey has been compiled on the basis of partial survey methods assuming complete market homogeneity. Further the table has been extended with environmental variables. Each options can be assessed with the extended input-output table.The assessment focus on three (or four) development objectives of Vevey. Then the influence of each option on the development objectives can be evaluated using multi-criteria decision making models.

Conclusions: The strengths of this approach are :

The possibility of decoupling the different geographical levels.

The fact that the same methodology is usable for assessing socio-economical and environmental impacts. The evaluation of different objectives with the same consistent framework is an asset. Clearly, the final decision lies in a political weighting of the different impact categories. Does the locality wants to stimulate the local economy or to increase energy efficiency?

LCAccess: An On-Line Directory for Global Life Cycle Assessment Information and Data

Mary Ann Curran* Timothy J. Skone

Evaluating environmental impacts holistically from raw material acquisition, through manufacture, use and disposal using a life cycle perspective is gradually being viewed by environmental managers and decision-makers as an important element in achieving environmental sustainability. However, the lack of readily-available, quality data can hamper the incorporation of life cycle considerations into the environmental decisionmaking process. A major barrier to using life cycle assessment tools is the difficulty in obtaining viable data for completing the analysis, called the life cycle inventory (LCI). LCAccess is a U.S. Environmental Protection Agency sponsored website intended to help overcome this barrier and promote the use of life cycle assessments in business decision-making by facilitating access to data sources that are useful in developing an LCI. LCAccess serves as a central source for life cycle assessment information. The main goal of the website is to promote the use of life cycle thinking in decision-making by facilitating access to resources and data sources useful in developing a life cycle inventory. It accomplishes this goal by providing information on EPA's role in life cycle assessment, the benefits of life cycle assessment, what is life cycle assessment, a brief overview of how to conduct a life cycle assessment, how to find data sources (through

the LCI Global Directory), available resources (i.e., documents, software tools, other related links), on-going efforts in the field (e.g., EPA, other US efforts, international efforts), and upcoming events (i.e. conferences and workshops). While LCAccess does not itself contain data, it is a searchable global directory to potential data sources. From the results of a key word search on an industry sector, data profiles on individual data sources are generated to give the user an idea of what each data source contains. To find the LCAccess web-site go to: http://www.epa.gov/ORD/NRMRL/lcaccess. LCAccess is currently soliciting organizations that have completed life cycle assessment studies to provide their data sources for reference in LCAccess. Inquiries should be directed to the development manager, Mr. Tim Skone (703/318-4604) and/or the EPA Sponsor, Ms. Mary Ann Curran (513/569-7782).

Life Cycle Assessment of Food and Beverage Packaging as a Tool for Policy Definition: the Portuguese Case Study

Paulo Ferrão*, Paulo Ribeiro, Paulo Silva

Packaging is a fundamental element of almost every product system in contemporaneous society. Acknowledging this fact, the European Union has created a legal framework to extend the producer responsibility over packaging residues, and this constitutes an opportunity to promote Industrial Ecology policies and infrastructures. In this context, a Life Cycle Assessment of the most important Portuguese food and beverage packages was conducted in order to support the formulation of environmental preferable recommendations to encourage innovation, technological development and the definition of sustainable policies in Portugal. The paper considers different economic sectors, such as: bottled water, soft drinks, beers, wines, dairy products, alimentary fats, fruits and vegetables, confectionery and frozen products. The packaging considered includes six materials: aluminium, steel, wood, plastic, paper/board and glass. The results of the LCA have identified the production stage of the packaging system as the principal cause for the major environmental impacts. Within the production stage, primary packaging was almost every time the one with more liabilities. The analysis of the major drivers for different environmental impact categories, contributed to identify ecoefficiency opportunities at the level of life-cycle management. The results show that increasing recycling rates and reducing weight in the primary package are environmentally efficient. It is also demonstrated that well organized systems for returnable packaging and one-way packaging systems with high recycling rates are equivalent alternatives for glass products in a sustainable packaging policy. The results obtained demonstrate that public policies on packaging are location dependent and shouldn't be identical for all packaging materials. For example, in Portugal, within the beverage sector, PET needs to increase about forty times its current recycling rate to obtain a 50% reduction on the environmental impact in Greenhouse gas emissions (using a PET chemical recycling process), while the one-way glass would only have to double its current recycling rate to reach a reduction of the same order of magnitude. The main conclusions refer that an Industrial Ecology framework is very relevant to support environmental policies on packaging management by ranking alternative end-of-life managing systems, taking into consideration the local culture, available technical and organizational infrastructures and the legal framework.

Infrastructure for the Industrial Ecology of the Automobile: the Portuguese Case Study

Paulo Ferrão* and José Amaral

Europe is facing a challenge to establish new infrastructures for the Industrial Ecology of the automobile, as a consequence of the EU directive 2000/53/EC on end of life vehicles (ELV). This legislative text addresses ELV as a waste-management problem to be faced on the basis of financial extended producer responsibility and stipulates minimum reuse and recovery rates for end-of-life vehicles. The task of creating an economically robust recycling infrastructure, involves a significant effort to develop systems and procedures that will have to meet requirements established by the ELV directive. This paper presents the results of a model developed to simulate the dynamics of the ELV recycling infrastructure. Besides the dismantler and shredder operations, the model considers emergent automotive shredder residue (ASR) separation and recovery technologies. This allows for an assessment of the overall economic costs and the recycling/recovery rates associated to the ELV recycling infrastructure. Two main strategies for ELV recycling are analyzed in order to reach the recycling targets established by the EU directive. The first strategy aims to reduce the amount of ASR by more intensive dismantling of ELV components, under financial incentives for pre-established parts or materials used in vehicles. The second strategy consists in upgrading the technologies available for processing the light and heavy fraction of the automotive shredder residue by developing separation technologies and finding recycling possibilities for the products gained from the separation. This paper makes use of a system dynamics model, applied to the Portuguese ELV processing infrastructure, to evaluate how current and future practices under both strategies mentioned above, depend:

•On different policies at the recycled materials market level, and on the vehicle composition, as determined by different design strategies;

•On exogenous factors, such as the prices of recycled metals and recycled plastics, is discussed; It is clear that nowadays only metals recycling has proved to be economically feasible and, as a consequence, the significant value of plastics content suggests the need to build a more effective plastics recycling infrastructure, and this is the emphasis on both strategies previously defined. This is particularly important taking into consideration that the plastics content in vehicles has been increasing. The results show that the first strategy may provide the required recycling targets as fixed by the EU directive and the costs are quantified as a function of technological and economical parameters such as the labor cost and the vehicle composition. When the second strategy is considered, the recycling rates achieved vary with the ASR separation and recovery technology. Technologies such as RESHMENT, TAKUMA, EBARA and VW Sicon may prove recycling rates in the interval of 81 % to 95 %, thus allowing for the fulfillment of the targets established for the EU directive, and the cost of these solutions depend on the synergies established with other end-of-life products streams.

Indicators Used to Plan an Environmental Strategy to Convert a Cluster into an Eco-Industrial Park

Gabarrell*, X; Sendra, C.; Vicent, T.

The indicators of each company, combined with other tools, can be used to plan the strategy to convert the cluster into an Eco-Industrial Park or to reflect the environmental situation. Some parameters like material, water and energy consume, waste generation, production and others were quantified using the material flows. The indicators were calculated using these parameters. The system is situated in Barcelona's metropolitan area, and it's formed by 39 companies. Each companies is treated as a cluster's subsystem. Information comes from inquiries (Industrial Activities File) made by CEA to each company, in year 2000. Indicators are calculated with data from Completed Data Matrix. The indicators, for each subsystem, are quantified with these new data. In table 1 (not shown), there are some of these indicators and the results of assembled data. These indicators could be used for:

- Detecting subsystems with stronger environmental impact, raw material depletion, waste generation. Although, a high value of an indicator doesn't mean a critical environmental situation - - Give numeric value about the system's and subsystem's evolution. This evolution or comparison can be:

a) Time: analyzing the same system a long the time

b) Spatial: analyzing different systems in the same period of time

c) Scaling: analyzing comparing systems of different sizes ex. clusters, regions, sectors.

- Indicators and other environmental tools can be used together to plan an strategy to convert a Cluster into an Eco-Industrial Park:

a) Detect critical points of consume or waste generation. An small improvement in this point can represent a big benefits.

b) Evaluate the continuous cluster's improvement after applying the strategy. Studying the Inputs and Outputs decrease and the Throughputs flows increase.

With this methodology, the relations among flows and environmental impact are not direct, because many flows have multiple and complex effects on the environment. So it is difficult to identify and quantify environmental impacts of each flow. But it is evident, that higher the flow, higher the impact.

Table 1 (not shown)- Cluster Indicators. Annual values (2000)

The Industrial Ecology of an Italian "Tourist Farm": EMAS Application within the GESAMB Project

Michele Galatola*, Stefano Canese, Eliana Russo

The results presented in this paper are part of the outputs coming from the GESAMB national research project that ENEA (the Italian National Agency for New Technologies, Energy and the Environment) is carrying out in the Southern part of Italy. The

main aim of the project is the implementation of an integrated certification (Quality-Environment-Safety) within industries working in the agro-industrial area. We are running the project looking at different sectors, like dairies and cheese making, farming, manufacture of alcoholic beverages and soft drinks, restaurants and hotels, fish farms, manufacturing of food products, and fruit juice production. The agro-industrial sector has been chosen as it represents a widespread area of business in Italy, especially in the southern part of the country. Most of the enterprises are small or medium size, and their annual turnover is about 12% of the National Gross Production, just behind the mechanical and textile industries. Notwithstanding this, there only 2 companies that have the EMAS registration and 19 got the ISO 14001 certification in the agro-industrial sector. Anyway, the Italian market is showing an ever-increasing interest towards the environmental friendliness of all those product somehow related to food consumption. Indeed it is often stated in market surveys results that consumers recognize a strong relation between product environmental performance and its quality. In this paper we report the preliminary results of a study we are carrying out in a 'tourist farm' located in the Basilicata Region. This is not a typical case study, as in this kind of enterprise we can find a deep integration of different aspects connected to the several activities run daily within the farm. There are six main production areas: (i) growing of cereals and other crops, (ii) farming, (iii) production and preserving of meat, (iv) operation of dairies and cheese making, (v) restaurant and (vi) provision of short-stay accommodation. This complex net of activities and potential impacts makes really tricky and scientifically interesting the implementation of an integrated management system (Quality-Environment-Safety) that could then be registered according to the European EMAS scheme (Environmental MAnagement and Audit Scheme). In some aspects this 'tourist farm' represents a simple industrial district with the same problems and opportunities for closing some material and energy cycles. The methodology used and the identification of the significant environmental aspects is discussed, together with the working approaches experimented in this project. As far as we know in Europe there is no experience of such integration for those 'tourist farm' within the framework of the EMAS scheme. The outputs of our project will be used in order to plan and implement the Environmental Management Program of the farm, and to define reasonable objectives and targets. We don't know yet if this farm will get the EMAS registration, but the implementation of an EMS and the LCA is helping the management to have a clearer and more systemic view of all the relations existing between their own activities and between the farm and the rest of the world.

Material Flow Analysis for Spain (1980-2000)

Silvia Cañellas, Ana Gonzalez-Martinez*, Ignasi Puig, Daniela Russi, Christina Sendra, Amalia Sojo

Intensity of material and energy use can be a good indicator to assess the extent to which a country is unsustainable, or, in other words, the hypothesis that due to such factors as technological progress, the amount of matter and energy that are used per unit of output could be increasing or decreasing. In those cases where the trend is decreasing, the phenomenon has been referred to as "dematerialization." Such a notion has also been referred to as "industrial metabolism." Materials flow analyses are those

that examine the dematerialization in the world's economies. Although the level of sustainability lays in a large extent on qualitative properties, the quantitative scale of the societal metabolism may give some indication on potential environmental impact of an economy. This paper conducts a materials flow analysis for Spain - in absolute and relative numbers - by measuring its throughput in material terms. Eurostat methodology is used here in order to assure comparability with other similar analyses conducted for different countries in Europe. The analysis has been carried out in three sectors: energy, biomass and minerals for the period 1980-2000. The Spanish economy has experienced strong growth in the last twenty years, characterized by 1) cycles of recession, stagnation and recuperation, 2) structural change (due to an increasing predominance of the service sector), and 3) an increasing use of natural resources. Our analysis reveals that materials use has sharply increased over the period under examination. For instance, the material requirement of the Spanish economy -expressed by Domestic Material Consumption (DMC) from 1980 to 2000 increased by 78%, surpassing GDP growth and population rate although a structural change in the economy was taking place at the same time, conferring more and more importance to the services sector. Domestic Extraction (DE) and Domestic Material Consumption (DMC) followed a similar path. Domestic Extraction is dominated by mineral/ores sector (65% share) while Domestic Extraction of energy sources has been decreasing. On the other hand, mineral/ores account for most of the exports. In terms of intensity, material consumption has increased from 9 ton/person in 1980 to 15.5 ton/person in 2000. In addition, imports have considerably increased, mainly in the energy sector. 5/6 of imports have been composed by oil and oil products. In addition, fossil fuels were the most utilized energy sources in Spain during the period under examination. Based on this analysis, we conclude that the Spanish economy is not undergoing dematerialization and furthermore, it is becoming increasingly dependent on international trade. In other words, it is using natural resources from other economic systems to increase its welfare.

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Eco-Parks for Eco-Development: Part 2

Marsha Gorden

"Industrial ecosystems have the potential of changing today's industrial development paradigm" [Côté, R. *JIE* 1(3): 9-11.] These prescient words are demonstrated today at innovative industrial parks around the world where park management encourages the entry of sustainably minded businesses. One example, the Burnside Industrial Park in Nova Scotia, Canada also includes an Eco-Efficiency Centre formed through a partnership between Dalhousie University and Nova Scotia Power that provides environmental management support for its businesses. In this park, 12% of the more than 1300 businesses provide services to "reuse, refinish, refurbish, repair, rent, remanufacture and recycle" the region's discards and byproducts [Côté, R. *JIE* 3(2-3) 11-12.]

This is the model to support a region's recycling needs, whether based on landfill regu-

lations or business expediency. Now, several cities and towns in the Commonwealth of Massachusetts, USA are examining these waste and byproduct concepts as they plan for new economic development. Faced with a new statewide Solid Waste Management Plan (SWMP) calling for a 70% reduction in waste generation by 2010, these communities are searching for new solutions.

The City of New Bedford, a former international whaling capital and now a major fish port and seafood processing center, has a unique approach. There, the New Bedford Area Chamber of Commerce, struck by the continuing industrial need for landfill space, is leading an effort to develop a virtual eco-industrial park. With support from state and local funds, the Chamber has organized a new program, Sustainable Greater New Bedford. It includes members of the local business, government, academic, marine and agricultural communities in an effort to minimize landfill disposal and develop sustainable development strategies for job creation.

The first year of funding brought evaluations of the solid wastes generated by the two largest, local manufacturing sectors: seafood and rubber. Fish wastes of approximately 80 million pounds generated annually with 85% going to landfill and the remaining 15% to wastewater treatment became the target for analysis. Advanced Marine Technologies (AMT), a small manufacturer of nutraceuticals from the fresh fish waste with an innovative process for its byproduct can manufacture a high-grade organic fertilizer. Increasing its Organic Gem sales would simultaneously increase the removal of fish wastes from both the landfill and the wastewater treatment plant. A typical fish processor would save approximately \$115,000 annually in disposal fees alone. SGNB's business support to AMT which includes establishing a "New Bedford Profile", helping to develop their business plan, granting them a Chamber Award for Sustainability and providing assistance with alternate financing will lead to expanded sales. They now process about 7% of the total fish waste and anticipate reaching 90% by the end of the decade.SGNB is presently evaluating locally generated scrap rubber to serve as an input to asphalt for 18 parking lots at the local University campus. This concept will now require an additional source of scrap - perhaps from used tires — as the previously generated scrap manufacturing waste of almost 1000 metric tons per year is decreasing to approximately 100 mt per year with product changes. Industrial ecology plus added rubber testing can help determine a new resource solution.

Environmental Impact Analysis of Engineering Materials by Analytic Hierarchy Process

D. Weng, L. Shi, T. Graedel*

It was synchronously considered for assessing the environmental impacts of engineering materials with service performance. In this paper an analytic hierarchy process was introduced for the environmental impact analysis. The environmental burden was quantitatively evaluated for three engineering materials such as carbon steel, aluminium alloy and high-density polyethylene (HDPE). By a normalized treatment of the data, a dimensionless eco-indicator could be used for the demonstration of the environmental impact analysis. We will show the eco-indicators from carbon steel, aluminium alloy and high density polyethylene. It was shown from the dimensionless eco-indicators that the aluminium alloy had the largest environmental burden in the three engineering. Relatively, carbon steel and HDPE demonstrated nearly similar environmental impact.

Rapid Enumeration of Bacteria for Microbial Stabilization in Metalworking Fluids

Shu-Chi Chang, Alexa Rihana*, Cyndee L. Gruden*, Steven J. Skerlos, and Peter Adriaens

Currently, in the United States, the annual metalworking fluids (MWFs) consumption is estimated to exceed 770 million gallons based on an expected annual increase of 5.3 %. MWFs account for 12-17% of the cost of metal production processes in a typical automotive company and could account for 48% for more rigorous metal fabrication processes in a machining plant. Biofouling of MWFs due to biodegradation of major components results in serious wear and corrosion of machining tools, health threatening endotoxin release and, consequently, more frequent discharging to wastewater treatment. Therefore, monitoring microbial growth levels and limits for the purpose of actuation (filtration, biocide dosing, etc) in MWFs systems is a common practice for metalworking processes. Currently, most end users still rely on off-line growth function methods to monitor the microbial loads in MWFs systems. The methods are slow and pose biases on slow-growing aggregated and viable-but-not-culturable bacteria; and, therefore, do not provide accurate data for the field practitioners to make informed decisions. To address these shortcomings, we have developed a novel rapid screening method to quantify total bacteria directly in a typical semi-synthetic MWF by direct counts using epifluorescent microscopy (EPM) and flow cytometry (FCM) with nucleic acid dyes. Three nucleic acid dyes, acridine orange (AO), SYTO®, and PicoGreen® were tested. Exo-polysaccharides produced by bacteria can cause the cells to form sticky aggregates in liquids, and matrix complexity of MWF can cause optical problems for both EPM and FCM. Thus, pretreatment was required prior to quantitative detection involving 45 seconds sonication and addition of equal volume of 1,1-dimethyl formamide. By employing PicoGreen® with 15 minutes incubation, the FCM method detection limit (MDL) is 10,000 cell/ml, exceeding a typical bacterial total direct count in an uncomplicated matrix such as buffered saline. FCM analysis reduces the assay time by 50% and more than 97% in comparison to EPM count in MWFs and the commonly employed dip-slide method, respectively. The development of sensitive and near-online monitoring methods for microbial growth in large volume industrial liquids will allow the process manager to respond in a timely manner to stabilize microbial growth using a range of actuation technologies. Future emphasis in the proposed detection technology development is to couple data output to control algorithms and microfiltration unit design. Ultimately, by reducing system downtime and MWFs discharge, substantial economic saving and more sustainable metalworking process could be realized considering the estimated cost and consumption volume of MWFs in manufacturing processes.

Life-Cycle Analysis in the Context of General Equilibrium Economic Growth: The Case of Advanced Vehicles, Fuels, and Infrastructure

Donald A. Hanson*, Anant Vyas, Marc Melaina, John A. "Skip" Laitner

Within the field of industrial ecology, this paper is related to a number of areas of interest including transportation assessments, life-cycle analysis, energy and greenhouse gas management, material flows, and the relationship to economic models such as input-output models and general equilibrium models. The last topic deals more with methodology. This paper is divided about half into the methodology of embedding LCA questions within economic models and half with application results for advanced vehicles and the associated fuels and infrastructures. The dynamic general equilibrium model used is the All Modular Industry Growth Assessment Model (AMIGA) maintained at Argonne National Laboratory. This model has a 200 sector input-output table embedded in it. However, unlike most input-output tables, material flows in physical units are included in the supply-demand balance equations and the cost and price equations. The paper describes how we consistently are able to map from economic variables to physical variables and back to economic variables. Production processes are specified for each physical material or energy output. The motor vehicle module within AMIGA is a stock-flow model. Vehicle sales by type of vehicle and size are driven by economic variables and are added to the on-road stocks. Retirement and scrapping rates are based on vehicle age and type. The advance vehicles that can be considered one-by-one or in combination are advanced gasoline and diesel ICE, hybrid vehicles, CNG vehicles, and fuel cell vehicles. These are analyzed by scenarios. Learning functions are included depending on experience and scale economies. For each scenario, direct and indirect energy consumption is calculated as well direct and indirect greenhouse gas emissions and criteria air pollutants. Other real resource utilization (labor, capital, imported fuels and materials) is also reported. There is substitution among goods and services in the economy due to price and income changes. The well-being of consumers under the scenarios is measured by a consumer surplus concept called equivalent variation in the economics literature. Sector outputs and overall production of goods and services (i.e., GDP) are also reported. Production processes of special interest are vehicle production, fuel production, and construction of transportation related infrastructures. For the LCA results, a number of physical and economic indices are reported. The model also gives a unique perspective on inter-temporal differences among the scenarios. This work is being supported by the U.S EPA Office of Atmospheric Programs and the Pew Climate Center.

Six Indicators of Material Cycles: Application to a Single Class of Product

Seiji Hashimoto* and Yuichi Moriguchi

Recycling is important in developing a sustainable society. In Japan, The Basic Law for Establishing the Recycling-based Society was instituted in 2000, with the aim of attaining a 'recycling-based society', in which "the consumption of natural resources will be

restrained and the environmental load will be reduced as far as possible", by promoting recycling (material cycling) of by-products and used products. The first essential step toward promoting material cycling is to understand the current state of material cycles in a society. In addition, an important factor in promoting material cycling is the establishment of the indicators that will enable objective measurement of the effectiveness of policies and actions. We categorized the forms of material cycles that we should document, and proposed 6 indicators for describing material cycles: Direct Material Input (DMI), Use Rate of Recovered Used Products (URRUP), Material Use Efficiency (MUE), Product Use Time (PUT), Recovery Rate of Used Product (RRUP), and Domestic Processed Output (DPO) (Hashimoto and Moriguchi, 2002). The indicators that we proposed aim at describing material cycles of a resource or of the sum of multiple resources without being specific for an industry or a product. In this paper, we examined the applicability of the indicators to a single class of products. We used 6 types of drink containers as examples. We draw the following conclusions: 1) Life-cycle inventory (LCI) analysis can be used in applying the indicators to a single class of product. In the application to a product, some adjustments are needed and the indicators have the characteristics, as described below; 2) In case of a product, Total Material Input (TMI) and Total Processed Output (TPO) are more appropriate expressions for DMI and DPO, respectively; 3) We introduced MUE in order to avoid defining by-products (in other words, avoiding co-product allocation); however, the application of the indicators to a product inevitably involves the allocations in co-production of multiple products and co-treatment of multiple wastes. Therefore, calculated MUE describes the material use efficiency after such allocation; 4) For example, the rate of use of cullet (waste glass) that is currently used describes recycling rate of glass material. On the other hand, URRUP calculated by using LCI includes raw materials for glass production and other raw materials for glass bottle production; therefore, we can take broader view of the state of recycling related to a glass bottle from material input side. By using LCI analysis, we can also study more complicated products that consist of various materials such as cars and buildings.

The Role of Champions in Establishing Eco Industrial Parks . Focus: Komsomolske, Ukraine

Anne K. Hewes

During the past twenty years, Industrial Ecology has emerged in response to a global call for sustainable development to counteract environmental pollution from industrial wastes. In particular, there has emerged a form of industrial structure that creates organizational arrangements between firms called Eco Industrial Parks (EIPs). EIPs encourage inter-firm exchanges of waste by-products at industrial sites, thus reducing the release of wastes to the environment. The focus of my dissertation research is on the individuals who champion industrial-environmental interaction through the creation of Eco Industrial Parks. My definition of a "champion" includes individuals who have been involved in planning EIPs that I define as successful. I define a successful EIP as inter-firm cooperation among co-located companies that have entered into a formal agreement to coordinate production activities to exchange waste materials as part of the rou-

tine of daily business. By my definition, a champion, is not only associated with a successful EIP but is actively promoting Eco Industrial Parks at new locations. The premier EIP is located in Kalundborg, Denmark. Known there as an Industrial Symbiosis, it serves as the model for other EIPs, such as that in Londonderry, New Hampshire. Based on the above definition, my research characterizes Kalundborg and Londonderry as successful EIPs and the two champions I am targeting were instrumental in these EIPs' success. In addition to those efforts, the champions participating in this research are currently implementing EIPs in Devens, Massachusetts, and Cherkassy and Komsomolske in the Ukraine.

The champions have developed social relationships required to create inter-firm exchanges that encourage economic benefits, environmental protection, and a sense of community. The poster proposed for the ISIE Conference will focus on the project in Komsomolske, Ukraine, which I visited in April 2003 with Valdemar Christensen. Komsomolske is an example of the energy cascades from power plants that have been in practice in the former Soviet Union since the 1920's. Today in Komsomolske the power plant provides wastes that are used in district heating and fly ash in construction. However, an infrastructure is available to link a green house, a dairy, and a recycling project that manufactures plastic tubes. I was a participant-observer in meetings with Mayors, Oblast (County) Environmental Commissioners, university representatives, and business owners. I noted that the champion encouraged project participants to consider feasibility studies to establish a negotiating basis for exchange of waste inputs (a tactic used successfully in Kalundborg). Of interest, was the champion's ability to both facilitate discussions and listen to the concerns of the participants. Currently, pockets of political instability and a lack of market economy mentality highlight the many challenges that Ukraine faces as it embraces industrial symbiosis.

The data collection was based on a variety of qualitative research tools including observing, journaling, and interviewing. The emphasis of this research is on collecting empirical data from the champions as they initiate new EIPs so that their voices may reveal the strategies and mechanisms behind the EIP process.

A Plan for Japanese Forestry Reconstruction as Energy-Material Coproduction Industry

M. Horio*, S. Aoyagi and R. Noda

The Japanese forestry condition is thoroughly reviewed and its potential for CO2 reduction is evaluated. To realize its massive utilization first the social diagnostics of the present depression of Japanese forestry is conducted. With this economic analysis, second, a set of countermeasures to reduce the cost of forest utilization is proposed. Finally, the potential of applying our new regional revival program is evaluated for all the major areas of our country.

Technical and Legitimation Uncertainty in Industrial Ecology Analyses of a Chemical Controversy

Jeff Howard

Proponents of any program for sustainable design confront two interrelated forms of uncertainty: "technical uncertainty" about the functioning of ecosystems and how they interact with technological systems; and "legitimation uncertainty" about how to advance the design program itself in the social world of economic institutions, social values, and political ideologies. The two types of uncertainty are inextricably intertwined. The character of this interaction constitutes a central dimension of both the sociopolitical shaping of technical design and, reciprocally, the technical shaping of social decisionmaking. This paper sketches the technocratic form of interaction displayed in Industrial Ecology analyses of an ongoing controversy over industrial use of chlorine and the human health and environmental impacts of chlorinated organic chemicals. The empirical reductionism evident in the Industrial Ecology analyses is strongly shaped by their alignment with the prevailing risk-based regulatory paradigm and the political-economic commitments on which that paradigm rests. One consequence is that the analyses are unable to effectively engage the controversy as a whole, which is driven in large part by precaution-based proposals for a chlorine phase-out. Another consequence is that the analyses do not reflect the sensibilities necessary for Intelligent Trial and Error in technological design.

Application Of Information Management To Improve Material Accounting Techniques

Ju-Pin Hung*, Graham Low, Stephen Moore

There are a number of tools or techniques that have been developed to assess and provide information to manage material flows in the last two decades, including; Life Cycle Assessment, Substance Flux Analysis, Material Input Per Service Unit, Sustainable Process Index, Ecological Footprint, and Total Material Requirements of a Nation. These techniques are all based on the same principle - tracing materials and energy flows through the human economy, however at different scales. To analyze a national economy in detail, every technique is equally important. Each technique has its own characteristics. It is unlikely that material flow in a region can be fully assessed by just one tool. Up to date each technique is worked out by use of spreadsheets, except LCA. Each technique can only be undertaken separately; meanwhile tremendous amounts of data are required and hundreds of processes need to be assessed. This traditional approach has low data integrity. With little cross linkage of the existing methods and little uniformity in data structure, it makes integration of these tools difficult. To overcome this problem, an information system could be utilized to integrate a wide variety of data being collected from the established databases within different material accounting techniques so that materials flows in an industrial economy can be tracked and measured and managed more effectively and efficiently. In an efficient manner, a database can relatively easily answer each question that users may want to ask about the data. Due

to standardizing the data at all stages of data processing, it is able to integrate the wide variety of data being collected from different material accounting tools. This is how the material accounting techniques can be integrated into a comprehensive technique. The Relational Database Management System (RDMS) can be used as a main tool for establishment of a database model. The methodology used in each material accounting technique can be transformed into a relational database model. Within the relational database model, each piece of data is categorized in accordance with the same standard that can help to simplify the complexity in data processing, and also can help to reduce the difficulty of data sharing collected from different techniques. Based on the same structure, each technique is more easily compared. Finally, a holistic database model can be developed by grouping the same characters used in the individual model. This information management application will enhance the data supply provisions of each of the material accounting techniques. The most significant advantage of this approach is material accounting control can be undertaken in either micro or macro scale of an industrial economy. This new approach leads to the development of an improved technique that provides better answers to material flow control questions.

Computerization of Life Cycle Assessment

H.T. Wang, D.Q. Xiao1, G. Huppes*, R. Heijungs

Life Cycle Assessment (LCA) is the most important quantitative analytical tool to assess the environmental impacts of a product during its entire life cycle. On the other hand, LCA method has many obvious weaknesses, such as complex method, time- and cost-consuming, uncertainties of data and results, which have prevented it from being applied to more products. All these weaknesses are due to the heavy load of collecting inventory data and the data processing, in which information technologies should be introduced to deal with it, namely the computerization of LCA. The computerization of LCA comprises three phases, i.e. the generation of inventory data, storage and retrieve of inventory data, and LCA analysis. The computerization of inventory generation aims to derive inventory data constantly and automatically from the actual production. A comprehensive method based on LCA, Enterprise Resource Planning (ERP) and accounting rules is conceptually discussed in this paper. As far as the computerization of storage and retrieve of inventory data is concerned, there are some LCI databases available around the world. In this paper, a Chinese LCI database is briefly introduced. And the Chinese LCA software under way in Sichuan University is introduced too.

Life Cycle Environmental Impacts of Telecommunication Networks and Telemonitoring System

Yves Loerincik, Christophe Matas and Olivier Jolliet*

In collaboration with the Centre for Competence in Urbistic (CREM), the city of Martigny, in Switzerland, set up a system for the monitoring of the resources like gas, electricity, water and central heating. The system measures various consumptions at different points within the network. This enable the industrial services to better understand the con-

sumption pattern and thus to improve the management. Nevertheless, the question was asked whether the environmental benefits of the management improvement overcome the impact of the necessary infrastructure of the monitoring. In this context, a life cycle environmental impact was performed to answer this question. In order to perform a first evaluation and to have the possibility to take into account the services, an Input-Output approach has been used to perform a first screening. The direct impacts are negative and include the necessary infrastructure: computers, electricity consumption, research funding, etc. The indirect impacts are mostly positive: resource management to enhance the efficiency of the network, spare building of a reservoir, possibility to dialog with the customers, etc. The first part of the study was dedicated to the inventory of the equipment, energy and necessary time to set up the system. The second part assesses and quantified the benefits of the monitoring. The ecoindicator 99 coefficients were used to evaluate the environmental impact of the infrastructure versus the avoided impacts resulting from the use of the monitoring. All the ecoindicator 99 coefficients were evaluated for both the necessary infrastructure and the avoided impacts of the monitoring. They are 5 to 20 times higher in the second case. Thus, the first evaluation shows that the monitoring system is highly beneficial for the environment. Nevertheless, more data are needed to decrease the uncertainty linked to the estimation made. Difficulties are encountered in evaluating the indirect effects and in allocating them to the use of the monitoring system.

Input/Output Life Cycle Assessment of Air Transportation

Josef Kaenzig*

Air transportation has become a very important sector with annual growth rates around five percent and two to three percent of anthropogenic CO2 emissions (IPCC 1999). The primary motivation for the present research is that a series of recent input/output based Life cycle assessment (LCA) have shown air transport to be a major contributor to the total environmental burdens of several products and sectors. This study aims to characterize the environmental and economic impact of air transportation using input/output life cycle modeling. It also aims to advance the methodology of input/output LCA. Background Life cycle assessment (LCA) is a quantitative method for comparing product systems in terms of their total system-wide environmental consequences. In the more traditional process-based method LCA, the chain of process is constructed by including only the major inputs of materials and energy. Input/output-based LCA is a newer method of LCA. It makes use of national level economic input/output tables, linked with databases on environmental releases per sector. The US input/output accounts differentiate the production of roughly 490 different commodities by roughly 490 different industries. One such sector is Air Transportation. Input/output models model supply chain process systems more coarsely but more completely than processbased LCA approach. Our research contains a background summary and comparison of how process-based LCA and input/output LCA characterize the environmental impacts of air transport. It characterizes which inputs are included and it describes the unit of function applied in each method. Air transportation has been assessed with input/output LCA and compared to process-based LCA. In this study an input/output method has been developed to assess and to characterize the environmental impor-
tance of a commodity (e.g. air transportation) in the supply chain of another product or service. It can be applied to any of the 490 commodities. Results and conclusions with input/output methods all sectors of the economy can be ranked in terms of total dollars of air transport consumed per year, and per dollar of output. In this study the 490 commodities have also been ranked in terms of the importance of the environmental burdens due to the total use of air transportation in their life cycles. Service sectors do have a very high share of energy use and CO2 emissions due to air transportation because of business related travels. The study identifies key parameters and highlights that aircraft emissions affect the environment in a different way than ground level emissions. One important result is that the environmental impact of short distance flights is significantly higher than that of long distance flights, compared on a per kilometer basis. The research also shows how to achieve a more sustainable air transportation and leads to suggestions on how to improve LCA. The application of the new input/output method developed in this research is not at all limited to the Air Transportation sector. It's a sophisticated and efficient input/output tool for environmental prioritization and management.

Facilitating Policies for Sustainable Industrial Systems – Stock based Indicators for Redistribution of Cadmium to Swedish Arable Soils

Sten Karlsson*, Fredrik Fredrikson, John Holmberg

To facilitate a development towards sustainability, it is of importance to support policy formulation and effectuation with relevant indicators. It is for instance important to indicate the development of the impact of the materials turnover of the industrial system on different environmental compartments. A key compartment is the agricultural soils and a key issue is to restrict their contamination. Heavy metals have historically tended to accumulate in arable soils. Cadmium is one of these metals giving rise to the largest concern. The cadmium is added to soil by redistribution of different limited resource stocks through a variety of flows. This turnover in the industrial system is highly dynamic. In situations like this, to facilitate policies for avoidance of further accumulation, it may be well suited with aggregated and stock-based indicators as a complement to indicating the pressure or the environmental state. A stock based methodology has been developed to derive such aggregated indicators. It is applied to the accumulation of cadmium in Swedish arable soils. Stocks of cadmium are identified. A prospective decomposition is then performed to estimate the potential amount that can end up in arable soils through different flows. The requirements for cadmium abatement to achieve prescribed goals are then determined. These requirements are then compared with the historical and current situation and prospective techniques. The aggregated and stock based methodology adds some import information. The most obvious result is that the fact that the stocks are limited actually matters for future accumulation of cadmium in arable land. It will also help in facilitating priorities between measures on different contributing flows. Further, the stock perspective gives new light to policy measures like for instance recycling. It is also concluded that it is possible to achieve a significantly lower than historical future addition of cadmium in Swedish agricultural soils, even though the addition depends to a large extent on activities and policy measures outside Sweden. There are still large uncertainties in the future deposition from air, especially from small-scale distributed emissions from fuel burning and reemission of deposited cadmium. Measures are necessary to guarantee a continued low addition through phosphorus fertilizers.

Developing an Inspection and Maintenance Policy for High-Emitting Automobiles Using Reliability Analysis of Emission Control Systems

Hyung Chul Kim*, Gregory A. Keoleian, Jonathan W. Bulkley

For the last few decades, automotive exhaust emissions per mile have decreased remarkably due to emission control improvements, which have been driven by increasingly stringent regulations. Despite this recent progress, vehicle emissions such as carbon monoxide (CO), oxides of nitrogen (NOx), and hydrocarbons (HC) remains a significant concern in most urban areas. This can be attributed to driving under conditions that differ from certification tests, increasing vehicle miles traveled and, most of all, the continuing use of old, high-emitting vehicles. The exhaust emissions from properly maintained and driven cars, called "normal-emitters", generally increase gradually with vehicle mileage. On the other hand, emissions from poorly maintained and driven cars, called "high-emitters", often jump incidentally. The emissions per mile from this small fraction of high-emitters are considerably higher than the certification standards and account for almost half of the average real-world emissions (Ross, Goodwin et al. 1995). To reduce the emissions from high-emitters, programs that encourage early scrapping of older vehicles have been implemented. For example, scrap page programs attempted to recruit and scrap high-emitters with some compensation to the vehicle owners. In addition to the scrap page programs, inspection and maintenance (I&M) programs were introduced to reduce the emissions from old, malfunctioning vehicles. However, identifying malfunctioning vehicles efficiently through simple inspection has proven difficult, and thus the repairs are often temporary measures. As a result, the emission reductions were inconsiderable in the I&M programs of such states as Arizona and Colorado (Zhang, Stedman et al. 1996). The type of high-emitter is characterized based on the profile of tailpipe emissions. Each of excessive CO, HC, or NOx emission represents a different type of high-emitter with different causes. The technical causes behind these high-emitters include failures of the oxygen sensor, malfunctioning of the electronic engine control, bad spark plugs, and obstruction of the catalytic converter. The present study shows, however, that it is difficult to pinpoint a basic cause for a particular high-emitter since component failures are closely related with each other. For example, replacing a catalytic converter may result in only temporary emission improvement if repeating misfire degrades the catalyst (Wenzel and Ross 1998). Therefore, a system approach that simultaneously characterizes the reliability of the entire emission control system may be critical for effective inspections and repairs. The objective of this study is to recommend effective I&M strategies through modeling system reliability of emission control systems for an internal combustion gasoline vehicle. First, to understand the basic causes of high-emitter occurrences and dependencies among high-emitter types, a fault tree analysis (FTA) will be conducted for the emission control system. FTA is a deductive process to identify the cause of hazards using cause-and-effect diagram. Second, the real world I&M test results will be analyzed to determine the frequency of each high-emitter type and to describe transitions between normal and various high-emitter types with mileage. Finally, emission reductions that each component repair strategy will achieve after certain mileage will be quantified. Recommendations for improved I&M strategies will be discussed based on the results. In the analysis, emissions accounting for complete automobile life cycles will be considered. These issues will be discussed in connection with accelerated vehicle retirement strategies.

An Input-Output Approach for Tracking the Flow of Resources through an Industrial Ecology

Steven Kraines*

Leontief Input Output tables have been used to supplement more detailed LCA's by essentially providing a dataset that functions as a standardized boundary of interindustrial flows. In this approach, the life cycle inventory of requirements from other industrial sectors for the introduction of a new product are added to the "final demand" vector Y of the IO analysis framework, and the change in the total output X of each industrial sector is calculated from the standard formula X = (I - A)-1 Y, where A is the matrix of direct input coefficients between all industrial sectors and I is the identity matrix. Using IO analysis, one can also assess the effect of a change in the production technology of a certain industry by changing that industrial sector's set of direct input coefficients. For example, a shift in the steel-making sector from coke-intensive integrated steel-making to electricity- intensive recycled steel-making could be expressed by decreasing the direct input of coke into the steel-making sector, and increasing the direct electricity input. The problem here is that generally the total value of inputs to the steel-making sector will generally no longer balance the total value of outputs, depending on the relative prices of coke and electricity. However, we can rebalance the inputs and outputs of all industrial sectors in the IO table by determining the relative changes in commodity prices that accompany the change in the direct input coefficients. This is done by solving the price model: $P = ((I - A) - 1)^2 W$, where W is the vector of external factor inputs into each industry per unit output of that industry (such as labor, water, and other factors not included in the interindustrial system) and P is the vector of prices per unit output of each industrial sector. In this approach, we express the commodity flows of the IO table in units that are specific to each industrial sector, e.g. "kilowatt-hours of electricity" or "the amount of telecommunications services that equals a dollar under the conditions of the original IO table". Consequently, while we can calculate the total outputs of each industrial sector because they all have the same units, we cannot calculate the total inputs to each industrial sector unless we know the relative values of the different products because the units of each input are different. We use the price model to calculate the relative "value" of all of these units. In particular, we can use any type of "currency" we like, such as heavy metals or scarce resources. For example, if we gave the factor inputs as the water used directly by each industrial sector to produce one unit of product, P would be the total amount of water embodied per unit of each industrial product. We present our developments of this IO analysis based approach for studying the flow of resources in an industrial ecology through a specific case study on the use of water as well as the emissions of particulates and air

pollution in steel-making industry of Liaoning Province, China.

How can industrial ecology support regional planning?

Jakub Kronenberg

Industrial ecology (IE) is used principally for the planning of products (using LCA and DfE) and processes (pollution prevention, DfE). IE can also create a basis for strategic planning, both in private and public sectors. It has already been proved that industrial ecology is an adequate tool for regional planning. The most frequently quoted example of how IE works at a regional level is Kalundborg, Denmark. Nevertheless, the "industrial symbiosis" has evolved there spontaneously, without much help from local authorities. It is suggested however that some uses of IE require more involvement from regional authorities and that they should be considered in planning. The aim of the paper is to define specific features of IE that make it an ideal tool for regional planning. It also indicates a set of situations to which IE is particularly applicable.

IE requires an integrated approach to overall management of an organisation or a region. It is particularly relevant to long term planning. In many cases, however, immediate benefits occur following the adoption of ecological principles. Industrial metabolism and input-output analyses are a useful way of describing the starting point. They are the most common form of IE application at the level of a region. Quite rarely however, are conclusions and suggestions drawn from these analyses. These conclusions should be used in planning. Although knowing the region's industrial metabolism is crucial to plan its development, the latter is no less important. Planning requires interdisciplinarity. IE is an interdisciplinary concept and thus provides an excellent framework for planning. The natural systems metaphor is particularly supportive of the industrial "learning environment" philosophy which is a crucial context for the planning debate (Meppem, T., Gill, R. 1998. "Planning for sustainability as a learning concept". Ecological Economics, no. 26: 121-137). Systems perspective characteristic to IE is also crucial for successful planning.

IE can and should be used in planning at all levels in industry and government. It should be treated as a set of instruments that support sustainable development strategies. Its potential uses at regional level include among others choosing scenarios for transport network development (rail, intermodal transport etc.), particular types of pollution to combat first, areas where excessive amounts of waste material or waste heat are generated. IE could be used as a basis for corporate environmental plans set up in close cooperation with local authorities. Thus, cooperation and links within region's boundaries would be enforced. All analyses concerning economic development at regional level, including those based on IE, should take a look at the employment impact of plans that are taken into account. IE should also be considered in public procurement where local authorities should use LCA as a decisive criterion. Instruments to be used always depend on the country's level of development and, what is more important, industrialization. Therefore, a distinction has to be made between IE applications in industrialized and in industrializing countries. A number of possible IE applications in both cases is presented.

Industrial Ecology and Regional Sustainable Development in Central and Eastern Europe. The Case of the Voivodship of Lodz, Poland

Jakub Kronenberg*

Economic, social and environmental situation in Central and Eastern Europe has changed drastically since the fall of communism. It is still under transformation and new approaches towards environmental protection are necessary. Taking the example of the Lodz region (2.7 million inhabitants; industrialized: textiles, lignite extraction, energy production), the relevance of industrial ecology (IE) to regional planning is discussed. It is particularly emphasized that IE can stimulate economic transformation and development, partly due to eco-restructuring. The current environmental and economic situation of the region is analyzed. Central and Eastern European economies used to be the most energy and material intensive in the world. The environment was traditionally neglected under the communist regime. After the transformation had begun, environmental investment accounted for 1-1.5% of GDP every year. Most types of pollution have been curbed. It resulted from both the fall of industrial production and the technological modernization. Backcasting is used to prove the wide area of IE applications aiming at improving the state of the environment and economic development, thus raising the quality of life. A scenario for 2010 is elaborated (compared to 2000): 80% reduction of waste sent to landfill, industrial consumption of raw resources 40% lower, 75% of derelict industrial estates restored, CO2 emissions cut by 15%, 33% of artificial components used in industry replaced by biodegradable substitutes etc. The strategy to reach this scenario consists of multiplying selected ideas already adopted and verified abroad and creating new solutions. In order to achieve the aforesaid objectives, a number of activities have been identified that have been taken up by the regional government. These include:

- Analyze the region's industrial metabolism.
- Develop a broad waste-exchange program involving all waste producers from the region.
- Build environmental literacy and awareness, inform citizens on the state of the environment.
- Educate 200 specialists to apply for and manage the EU assistance funds.
- Support private initiatives in the area of industrial ecology.
- Reduce price distortions.
- Implement local tax shift.
- Promote covenants signed by industry and local authorities.
- Improve direct regulatory instruments, reinforce indirect instruments.
- Encourage industrial tourism.

The new approach should principally be based on cooperation and promote innovation. A number of specific instruments is described. Most of the results obtained are general enough to be applicable to the majority of Central and East European industrialized regions. By the time of the presentation the concept will have already been presented to the authorities of the voivodship of Lodz. Their reaction to the concept will be presented during the conference. It is expected that the scenario will raise some interest and probably, at least some of its elements, will have been adopted in the strategic environmental plan of the voivodship. As other examples show, political dialogue is critical to elaborate workable solutions.

Environmental Assessment of Different Waste Management Options of Recovered Waste Wood

Krook*, J, Mårtensson, A, Eklund, M Linköping

At least 360,000 tonnes of recovered waste wood (RWW) is annually generated in Sweden. This waste mainly originates from construction and demolition waste wood (C&DWW) and from industrial waste wood (IWW, mainly wood packaging material such as wood pallets). Most of the RWW is used as an energy source at biofuel plants which reduces the amount of waste that goes to landfill and produces heat thereby establishing an economic outlet for the waste resource. However, RWW contains elevated heavy metal concentrations that lead to increased emissions to the surrounding environment during combustion and landfilling of the generated ashes. This practice makes it impossible to use these ashes as filler material thereby replacing extraction of raw materials and decreasing the need for landfill space. Furthermore, landfilling of the ashes leads to a continuous accumulation of hazardous heavy metals in the economy that poses future environmental and health problems. This paper evaluates the environmental performance of two main strategies for managing RWW generated from the economy. The scope is to address the potential of reducing environmental pollution and resource loss related to heavy metal contamination of RWW. The main difference between the two strategies is the extent of removing contaminated materials from the RWW flow (e.g. industrial preservative treated wood, surface treated wood, and plastic waste) thereby handling these materials separately. In the "dilution strategy", there would be no extended removal of contaminated materials from the RWW flow. Consequently, all RWW (including the heavy metal contaminated materials) would be used as an energy source at biofuel boilers. This strategy mainly represents the management of RWW as it is today. In the "extended sorting strategy", identified contaminated materials are removed from the RWW stream by the waste generators. The unpolluted wood is combusted in biofuel boilers whereas the polluted wood is combusted in municipal waste incinerators (e.g. surface treated wood) or destruction plants (industrial preservative treated wood). It is hypothesised that this strategy can result in decreased heavy metal flows to the surrounding environment and also enable reuse of the ashes generated from the biofuel boilers. The two waste management strategies are evaluated and discussed from a heavy metal pollution perspective and also by applying energy and resource indicators. One major issue when trying to make changes in large technical systems is distribution costs between actors in different societal sectors (i.e. different actors have varying incentives for implementation of a specific strategy). To investigate the possibilities and impediments for the different waste management strategies, economical perspectives will also be included and analysed integrated with the environmental assessment.

Long-run Perspectives of Global Copper Material Flow: The Environmental Impact

Witold-Roger Poganietz, Wilhelm Kuckshinrichs*, and Petra Zapp

Copper as a popular metal is used either as a pure metal or as alloys. However, from the ecological point of view, processing of copper has some drawbacks. For example, emissions of non-caught sulphurous compounds during smelting and converting process. In the longer run, the environmental drawbacks seem to intensify as an increase in demand for copper products can be expected, enforcing growing mining and processing activities. However, at least two trends can counteract these developments: technical progress and increased use of recycled metal. The objective of the study is to discuss whether technical progress and increased use of recycled metal will lead to a reduced (potential) impact of the copper material flow on the environment. The focus of the paper will lie on emissions of sulphurous compounds and carbon dioxide as well as on waste. Discussing the longer run environmental impact different scenarios will be computed. The scenarios will differ regarding demand for cathode copper and supply of recycled copper. The study grounds on a process-based partial equilibrium model, mapping the global material flow of copper. The model depicts each process step of processing copper, beginning with mining of ore, and ending with processing of cathode copper. Additionally, recycling of copper is considered. At each (primary and secondary) process step, commonly used techniques are implemented. Beside the output of coppery products at each process step, emissions of carbon dioxide and sulphurous compounds as well as the amount of waste, assigned to each used technology, are calculated. Furthermore, the model allows for modeling main by-products of copper, i.e., gold, silver, etc. Important auxiliary chains, i.e., generation of energy and processing of sulphuric acid, supplement the main chain. Since the global material flow is under investigation, the world is divided into 14 regions. The allocation of output to technologies as well as the dispersion of technologies to regions is based on economic decisions subject to constraints set by inter alia techniques, capacities, and mass balance. It is assumed, that the driving force of economic decisions is profit maximization. That means, the underlying algorithm, i.e., linear programming, simulates market mechanisms. Thus, the used model permits an integrated analysis of the ecological, technical, geographical, and economic dimension of the material flow of copper inclusive its auxiliary chains. The model supplements approaches like MFA and SFA. Comparable to MFA and SFA, the approach considers both, economic interdependencies between economic agents and the mass balance principle as a core rule. However, additionally the used model allows for modeling the driving forces of underlying economic decisions, i.e., in our case profit maximization.

Review of Life Cycle Assessment Activities in India

Yamini Kurani* and Vinod K. Sharma

LCA is a new concept in India but it is expected to dominate the environmental management in the coming years as government, industries and public all are paying more attention towards betterment of environment. Major studies on LCA conducted in India are on few sectors, namely, waste paper recycling, steel, coir and coal. This article presents the results of a study on waste paper conducted in Mumbai, India. Waste paper cycle was divided into four main life stages-generation, collection, utilization and disposal. A survey of major stakeholders involved in the waste paper cycle namely, informal waste-pickers, buyers, wholesalers and paper manufacturers was carried out to know the socio-economic and environmental impact during each stage. Abridged matrix method was applied for Life Cycle Assessment. The results from the waste paper study indicate that while there is a moderate environmental impact of wastepaper during generation, collection and disposal stages, the utilization stage had a significant impact on the environment, especially during manufacturing in paper factories. Although the study does not use a comprehensive LCA approach, it shows that such simple abridged assessment methods for various products and processes could be helpful in delivering the complex LCA models. Other activities on LCA are related to formation of LCA groups such as Indian Society of Life Cycle Assessment (ISLCA), organisation of various academic events, guidance of students for masters and doctorate thesis on LCA topics etc.

Reducing Dissipative Copper for Sustainable Consumption: A Revelation from Substance Flow Analysis of Copper in Hong Kong

Heng Li* and Albert Koenig

Substance flow analysis (SFA) in the anthroposphere has been proposed in recent years as a useful technique for better understanding of the interactions between human activities and the environment. The argument that sustainable consumption of copper in Hong Kong relies on dissipation reduction is based on a comprehensive accounting of the anthropogenic use and the environmental mobilization of copper materials. In this study, copper was selected as an indicator of substance flows through modern, industrialized society, taking the Hong Kong Special Administrative Region as a model system. Based on data from various statistics, reports, and previous research findings, major copper flux channels in Hong Kong were quantitatively analyzed according to a multitude of processes of external inputs/outputs, internal consumption, recycling, waste generation, dissipation, and disposal. Copper fluxes in different regimes including the atmosphere, hydrosphere, and lithosphere were studied and the interactions/linkages between the different regimes were estimated. A complete copper balance diagram was established to reveal the spatial and temporal flow patterns of the metal in Hong Kong. It was found that the largest annual input of copper (in forms of pure metal or alloys) into the system originated from human activities, accounting for more than 99.5% of the total copper input of 111 kt in 1999. More than 68% of the total copper input were recovered and recycled, with the major part of recycling taking place outside Hong Kong in Mainland China. About 32% of copper were retained in Hong Kong, of which 20% were for civil infrastructure expansion and maintenance, while 11% eventually ended up as waste in landfills. Emissions of copper to the atmosphere, hydrosphere or lithosphere accounted for 5% of the total retained amount, with most copper being discharged via sewage or storm water to ambient marine environment. This portion of dissipated copper gradually found its reservoirs in marine sediments. In light that current recycling practices are neither economically nor technically feasible to copper storage sites as

landfills and sediments, reduction of copper dissipation must be considered in relevant decision making processes in order to achieve sustainable copper consumption.

Material Flow Cost Accounting for Evaluation of Urban Organic Resource Circulation

Toru Matsumoto*, Jian Zuo, Takumi Iwao

A large amount of fossil fuel has been inputted into organic resource circulation system of city now. As for Japanese diet, about one fifth of supplied food is lost as food waste, and a large amount of fossil fuel has been consumed for treatment and disposal of the food waste. This study aims to develop a technique tool for analysis of urban organic resource circulation by using the method of material flow cost accounting originally developed for internal management of enterprise, and examine its applicability by applying this tool for a present assessment in a real city example. As a result, framework for the analysis of material flow cost accounting in cities was developed, and this provides us with a tool which enables the sequencing of material flows from food production process to waste handling process in Fukuoka City's food system in 1997 and the input structure of resultant energy and packaging material to be systematically identified. The flow cost matrix of Fukuoka City's food system in tabular form was created in material unit and currency unit respectively, showing the calculated material cost, system cost and distribution/handling cost for products, packaging and material loss respectively. The results shows: according to the categories of material flow, material loss accounted for a fairly high share of 32% in carbon unit and 40% in currency unit and packaging was 4% in carbon unit and 6% in currency unit among the total cost; according to the categories of flow cost, system cost accounted for 31% of the total cost in carbon unit and 45% of the total cost in currency unit, which was about half of the material cost in carbon conversion and equal to the material cost in currency conversion. Based on these results, the effect of food waste reduction in one process (material center) and the effect of food loss reduction in households, distribution industry and catering industry on resource utilization could be quantified by scenario analysis for relating policy assessment. In addition, by applying this concept to multiple cities and locations it is possible to compare the patterns of expenditure in detail. Material flow cost accounting can also be applied to the study of other areas of policy and management.

Construction of a Visualization and Decision-Making Tool for Co-location of Facilities in Eco-Parks

H. Scott Matthews* and Joseph Marriott

A popular green design or industrial ecology strategy at the regional level is the formation of eco-industrial parks. The basis behind these parks is, amongst other potential high-level development objectives, to co-locate firms that have uses for each others' effluents. But realistically such projects can be viewed as a partnership that tries to minimize the total environmental burden of their activities. A primary problem in efficiently co-locating facilities to maximize effluent reuse is that as additional facilities are sited, each will tend to generated additional effluents that must then be consumed as feedstock by yet another facility. As this simulation proceeds over time, eventually there are no further facilities that can be added to use the generated waste streams. Lack of space for sitting may also be an inevitable result. Another aspect of eco-parks which does not generally receive much attention is the increased burden on local transportation or community networks to handle the influx of residents or commuters. If a wide scope is used and appropriate cross-media assessments are possible, the increased impacts of transportation may exceed benefits from facility/effluent reuse practices. This paper presents an update on work being conducted to formalize the inputs and outputs of common industrial facilities to assist in eco-park planning. For example, a database showing the inputs and output streams needed by breweries for beer production. After such a database is generated, the choice of facility locations can be iterated over many combinations of other new facilities to generate scenarios that would optimize effluent reuse.

Resource Recovery of Industrial Minerals - Synergies between the Alum and Portland Cement Industries

Ray Merrell

The Portland cement industry is the largest consumer of industrial minerals in the forms of limestone, silica, aluminum and iron. By-products of other industrial processes supply many of these key minerals. This paper describes the synergy between the aluminum sulfate (alum) industry and Portland cement industry as an example of sustainable development by recycling extracted natural resources. Both industries use kaolin or bauxite clays high in alumina content as a source of aluminum. The extracted clays are calcined prior to use in cement or distribution to alum manufacturing facilities. In alum production, the calcined clays are digested with sulfuric acid forming aluminum sulfate or alum. The alum is separated from the silica clays by a series of water washes followed by filtration prior to shipment to customers typically by truck or rail. Bulk liquid alum is used in paper manufacturing and as a flocculent in water and wastewater treatment. Mechanical presses dewater the remaining clays for landfill disposal or more likely they are slurried into settling impounds with the water recycled back to the alum process. These solids are referred to in the industry as Alum Process Residues (APR) or Processed Silica (PS). The alum industry typically closed the PS impounds in place after they reached storage capacity by dewatering the impounds, grading the surface and placement of a vegetative cover. This practice continued until the alum facilities ran out of real estate for new impounds, shut down, were prohibited by environmental requirements or more economical alternatives were developed. The alum industry faces legacy issues from these former impounds as sources of acidic leachate containing aluminum, sulfates and trace metals potentially impacting groundwater and surface water run-off. Historically dating back to the 1940's, alum production facilities were often sited adjacent to paper mills where the alum was piped directly to the mill, eliminating transportation costs of this key raw material. This early example of industrial synergy serves as a model for the cement industry, although paper manufacturing technology and the markets has reduced the demand for use of alum as paper mills modifed their processes

for producing acid free paper. The cement industry began experimenting with using PS as a source of industrial minerals in the 1980's as the alum industry started dealing with the environmental consequences of generating nearly half a million tons of PS per year across the country. Through the efforts of a few individuals, the value proposition for using PS was demonstrated to the cement industry by a series of full scale trials in the mid 1990's. The PS proved to be a favorable source of amorphous silica with physical characteristics that were less abrasive to the cement kiln's front-end equipment. This silica quality resulted in less mechanical maintenance and higher kiln throughput while meeting product quality specifications. The material handling and transportation costs are the primary barriers for the beneficial use of PS from ongoing alum production or stored in closed impound reserves around the country. The most economical PS sites are near barge loading facilities or are located within 100 miles from the cement kiln. Rail transportation may be a viable alternative to barges for inland PS sites. The greatest value proposition of optimizing industrial mineral resources is the co-location of new alum facilities adjacent to cement kilns, eliminating the transportation cost factor for the PS. A viable market must exist for the alum, although the lower cost for managing the PS could offset higher transportation costs for the alum product. The greater use of bulk rail to tank truck terminals serving local alum markets could also improve the economics of this co-location model. As the cement industry reaches out further for industrial minerals, this model may become a strategic advantage and mutually beneficial to both industries. Once used in Portland cement, these extracted minerals can be recycled indefinitely in various forms of crushed concrete in construction projects.

A Nation-wide Case Study Towards Environmentally Sustainable Transportation in Japan

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Indicators representing environmental burdens associated with transportation, such as the transportation-related CO2 emission per capita, are relatively modest in Japan compared to other developed countries, thanks to high population density and welldeveloped public transits. Nevertheless, energy consumption and accompanying CO2 emissions from transportation activities have been steadily increasing. In particular, energy consumption by passenger's travel has been growing in spite of the recent economic recession. This seems to be driven mainly by consumer's choice to own largesized passenger cars and by the growth in modal share of private cars. On the other hand, air pollution in metropolitan areas and particularly at roadsides of trunk roads is still not sufficiently improved, mainly because of emissions from heavy-duty diesel trucks for freight transportation. On the basis of such a background, a macroscopic nationwide case study for long-term reduction of air emissions from transportation activities was undertaken. This study was mainly motivated by the preparation process of the OECD Conference on Environmentally Sustainable Transport (EST) in Nagoya, March 2003, hosted by Japanese Ministries, which aims at disseminating the concept of EST to Asian countries. In order to prepare background materials for the Conference, an expert group consisting of national and local governments, universities, and research institutes undertook several studies on the interface of transportation and the environment in Japan and Asia. This paper aims to report scientific basis for these studies, focusing on a study for CO2 emission reduction in Japan. The target of drastic reduction of CO2 emissions was set, and the scenarios to accomplish this target were prepared by applying back-casting approach. A techno-optimistic scenario, a demand management scenario as well as a composite scenario were examined and compared. In order to meet an ultimate target of emission reduction, expected improvements in technological efficiency alone will not be sufficient. Not only modal shift from less efficient modes to more efficient modes but also improvements in occupancy of each transit mode will be necessary. The quantitative assessment in the study is mainly based on a fuel efficiency model reflecting technological improvements, traffic condition, and occupancy, hence the model dealt only with the direct energy consumption for operation. However, for more comprehensive assessment, indirect additional environmental burdens associated with construction and maintenance of infrastructures such as railroads and roadways have to be considered as well, as they may have significant contribution to life-cycle resource demand and environmental impacts, according to existing empirical studies. The life-cycle approach seems to be essential and useful, not only for environmental impact assessment but also for the cost- benefit analysis of the investment in transportation infrastructures. Social dimension will also be further considered, to meet the broader concept of sustainability. For example, the policy to encourage modal shifts should take into account the diversifying transportation demands from rapidly aging society.

Dynamic Allocative Efficiency of Environmental Burdens in the Japanese Economy

Keisuke Nansai*, Shigemi Kagawa and Yuichi Moriguchi

In this paper, we present dynamic programming based on the von Neumann-Leontief type input-output system, to demonstrate dynamic allocative efficiency of the following environmental burdens in the Japanese economy, long-term, beginning in 1995: carbon dioxide (CO2), industrial wastes, nitrogen dioxides (NOx), sulfur dioxides (SOx), suspended particulate matter (SPM). This dynamic programming model determines annual optimal industry activity levels, to maximize total domestic final demand for each vear, factoring in both economic constraints (labor constraint and capital constraint) and environmental constraints (CO2 emission, industrial waste emission, NOx emission, SOx emission, and SPM emission). For example, the environmental constraint for CO2 emission is to reduce levels to 6% below 1990 levels by the first commitment period. This simulation enables us not only to determine optimal economic growth path under economic and environmental constraints but also to estimate sectoral environmental burdens under the attainable economy. In the present simulation, we used a 1995 inputoutput table that describes monetary inter-industry flow of goods and services, and 1995 environmental data that describes physical flow of the 5 above-mentioned environmental burdens. Although our dynamic programming analysis uses only a 1995 input-output table and presumes that the economic structure will not change during the

target period, we found different key sectors that mainly contributed to GDP maximization and environmental burden reduction under some environmental scenarios. In addition, sectoral contributions to total emissions in each scenario were analyzed to evaluate compatibility with economic growth and environmental problems.

Information Flow Based conceptual Framework and Model for Analysis of the Co-evolution of Biosphere and Society, and Development of Novel Control Strategies and Management Options

Igor Nikolic*, Ester van der Voet, Gjalt Huppes and Ruben Huele

Homo Sapiens has co-evolved as a part of the biosphere, forming an integral part of it. With the onset of culture, extremely rapid cultural evolution superseded genetic evolution as the principal driver of variation, adaptation and selection of human society and behavior, causing an evolutionary uncoupling. As culture evolves, the amount and speed of information transferred within it increases. In order to keep the flow manageable, societal interactions are structurally elaborated and formalized in a highly hierarchical complex system. This structural complexity, while providing stability, increases the response time to environmental impacts. The biosphere does not have this extra layer of formalization and elaboration, and directly responds to changes in the environment. Biological evolution is an information refinement process. That means that the genetic information within the organism is sufficiently adapted to the environment it lives in. Differences in environmental factors select which information can exist where. Ecosystems can therefore be understood as complex, adaptive information exchange networks, with short response times. Humans are impacting this network by removing the physical barriers to information spread by international transport, by creating new habitats through urbanization, by homogenizing and simplifying the environment through agriculture, and by adding new types of information into the biosphere through genetic modification, further shortening the biospheres response times. Humanity is creating a new form of environmental problem. This new class of problem can not be solved by defining it only in terms of energy and mass flows, as dealt with by current environmental policy. Unlike mass and energy, living beings are able to move, adapt reproduce and evolve. Evolutionary stress operates on a time scale of small, quickly adapting organisms that is measured in weeks up to a year. Society's internal structural complexity makes it impossible to respond quickly enough to such problems. Furthermore, the impacts presented above are decreasing the response time of the biosphere, which combined with the increased response time of society, in principle creates a system instability. It is the goal of Industrial Ecology to tackle complex environment - society interactions and introduce measures in order to reduce the impact. If it is to be successful, IE must approach the problem of information pollution head on. The only way so solve a problem based on biological information and its evolution is to turn to evolution itself for an answer. A new approach to control and management of biotic pollution, called « Pre-emptive Adaptive Management» (PAM) is suggested. PAM is a bottom up, distributed, adaptive pro-active approach to policy development and environmental control. PAM is based on a unified conceptual framework based on information flows for modeling and analysis of the co-evolution of biosphere and society. The key objective is the development of a novel method of analysis for deriving new strategies for sustainability control, management and policy deeply embedded within Industrial Ecology. Development of PAM is based on theory development, model development and validation, and case implementation. Modeling will be done in an Agent Based Network framework, with a Genetic Algorithm basis. Cases of evolutionary stress and information pollution will be translated into the unified framework. The novel PAM options will be developed as a Genetic Algorithm based Neural Network Controller. The Neural Network dynamically steers the two interacting complex systems and the most fit one is evolved. The Industrial Ecology community can greatly benefit from this approach since it strengthens the biosphere - society analogy and stimulates interdisciplinary thinking by combining neo-Darwinian analysis of the co-evolution of society and biosphere with advanced control theory and policy development.

Combining Input-Output Analysis and Risk Analysis. A Case Study of Increasing Insulation in the US Homes

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To better capture the site-dependency of risks associated with numerous emission sites that are involved in Input-Output (I-O) analysis for the United States, we construct a model framework that combines risk assessment and I-O Life-cycle Assessment (LCA). For the risk calculation step, we utilize the concepts of intake fractions, which simplify the exposure analysis. Because power plants have the tallest stacks, we use their intake fractions of PM2.5 for the lower bound of the uncertainty range. We use the intake fractions of mobile sources as the upper bound since their emissions are at the ground level. We suggest the use of the upper and lower bounds and the central estimates of sector-level emission-weighted intake fractions in I-O analysis to screen important contributors to the total risk. After screening, we use a site-specific dispersion model for the major contributors to refine the intake fraction estimates. In this refining step, we assess the relative effects of the actual stack height at various locations across the United States. We calibrate the intake fractions calculated from the past regression models developed by Levy, et al. (2002) for mobile (ground-level) sources by applying the stack height effects. This allows better estimation of exposure to particulate matter emitted from those important sites. For intake fractions of air toxics, we apply the national average values as found in Bennett, et al. (2000). We apply our analytical framework in a case study of fiberglass insulation. Past literature shows that increasing insulation is beneficial to society not only in terms of direct costs but also in non-energy benefits such as reduced mortality and morbidity. However, impacts from the upstream production of materials required for the energy efficiency programs have never been fully documented or incorporated in costs/benefits calculations. For a comprehensive analysis of health impacts associated with the supply chain, conventional site-specific risk assessment would be difficult because the number of emission sites that need to be modeled would be uncontrollably large. Our model can help LCA practitioners to screen important sources, for which more detail analysis such as site-specific dispersion models can be applied at the refining stage. With our approach, costs/benefits evaluations of energy efficiency programs can account for health risks associated with the supply chain activities, which vary regionally with the source strength, meteorological conditions,

and the receptor distribution.

Applicability Of Integrated Environment-Quality Design Approach To Services the Case Of Lodging Activities

Luigia Petti*, Andrea Raggi

In the industrial ecology perspective, the need of dematerialization of the economies becomes more and more stressed. As a consequence, the relative contribution of the service activities to the overall economic output is expected to increase. This entails a growing focus on service-related aspects and their ability to meet, on the one hand, consumers' requirements and, on the other hand, society's needs. Among the service sectors, one which has been gaining an increasing interest by consumers is tourism. Even though it is well recognized that an increase in tourism-related activities may be burdensome to the environment, no systematic approach seems to have yet been developed for designing tourism activities in order to be more environmentally conscious and, simultaneously, to meet the quality requirements expressed by consumers. In this research work we investigate the main aspects concerning the applicability of existing or newly developed integrated design tools to the above-mentioned service sector with particular focus to the lodging activities. In particular, the well-known QFD design tool is taken into account and its integration with life-cycle-based instruments for environmental assessment is proposed and evaluated with the aim of improving the level of customer satisfaction and compliance of society requirements in the lodging services.

The Logic of the Consumer Economy

Thomas Princen*

On the face of it, consumption is straightforward. It's what all the production is about: making things people need and are willing to purchase. But as soon as one begins to ask what is the consuming for, why do people do it, and what is its contribution to environmental change, things get sticky. One might think there's a huge literature out there answering just these kinds of questions. After all, we know from the IPAT formula that consumption (read Affluence) is one of the Big Three Drivers in environmental change.

There is, in fact, a lot on "consumer culture" and "consumerism," much of which is useful for answering the "why" question. But one is hard-pressed to find work that explicitly connects industrial and economic processes to consuming patterns and then environmental impact. In this paper, I point research in this direction by developing a "logic of the consumer economy." I show that while such a logic may be economically rational, it is not ecologically rational.

A Framework for the Selection and Optimization of Energy Systems for Buildings

Ayat Osman, Robert Ries*

Cogeneration systems for building applications, often called combined heat and power (CHP), offer the potential for a reliable source of energy, high energy efficiency, and reduced environmental impact compared to conventional systems because they present an opportunity to simultaneously satisfy both the electrical and thermal loads of a building. On average, two-thirds of the primary energy consumed by conventional electrical power generation systems is lost to the environment. Cogeneration systems capture the otherwise wasted thermal energy and utilize it for various purposes, such as space and water heating and cooling. In addition, natural gas, which is currently recognized as the major fuel for cogeneration systems, has the advantage of a lower unit carbon, sulfur, and nitrogen content than coal, the principal fuel in conventional central power plants in the United States, resulting in lower environmental impact. The performance of a cogeneration system is affected by the operational mode, the building's load characteristics, and the cogeneration system characteristics. Cogeneration systems can be operated in different modes, such as following the variations in the building's electrical or the building's thermal load over time. Building load characteristics effecting CHP system performance are the thermal and electric peak demand, the thermal temperature and/or pressure requirements, and the daily, seasonal, or annual variations in the load profile. Cogeneration system characteristics include capacity, availability, efficiency, reliability, part-load performance, maintenance requirements, and equipment and installation costs. Other characteristics of the cogeneration systems determine the environmental impact from these systems, such as unit air emissions, land and materials use, water effluents, and solid waste. Since each cogeneration technology and each building type has its unique characteristics, the application of a certain technology will be affected not only by the technical specification of a cogeneration system but also by the building conditions and location. The objective of the current research is to investigate the various components of cogeneration systems for buildings to create a framework for optimizing the selection and operational strategies of these systems, with the primary focus being the lowest environmental impact. The study uses a life cycle assessment framework to evaluate the environmental impact of using natural gas-fired technologies for heating, cooling, and electrical energy generation in buildings. Some of the factors investigated are different environmental impact indicators, economic impacts, effect of various climates on performance, different building types and load characteristics, and different modes of operation. The life cycle assessment framework for cogeneration systems offers more insight on system selection, performance, and applicability of an operational strategy because the life cycle assessment framework can lead to optimizing the environmental impacts from the system, as well as identifying specific opportunities for improvement.

A Basic Analysis of Transport-related Environmental Features and Their Socio-economic Background in Asian Countries

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The one of the causes for automobile related environmental problems in the developed countries is thought to lie in their traffic system characterized by high automobile dependency, which is underpinned by high automobile ownership rate. Meanwhile, in Asian developing countries including the member states of ASEAN, the traffic congestion is growing into a serious problem as a result of extended commute in connection with the rapid expansion of metropolitan area accelerated by significant increase of the urban population from the rural area and inability for the road infrastructures to keep up with the amplified automobile ownership rate due to the improvement of the income. Firstly, this research aimed at constructing the scenario analytical method relative to the cause and effect of the environmental deterioration in the filed of land use and transport planning. The assessment of the environmental improvement method is important in the developing countries where there is a remarkable upward trend in the rate of population growth and in the energy consumption. In this study, we attempted the empirical analysis of the environmental related parameters including energy consumption, global warming, and regional air pollution focusing attention on casual relationship between various socio-economic indices such as population density, urbanization, motorization, and economic development. Targeted countries are South East Asian countries, East Asian countries and Mongolia and India from other part of Asia. The above comparative analysis of socio-economic indices was conducted targeting the capitals of these countries. The analysis result brought about the following findings. -Over-concentration of population in urban area remains remarkable. - The major public transportation is bus and para-transit operated for cheap rate. - Main individual transport of urban area is motorcycle. - Public transportation users are potential private automobile owners. - Foreign capital dependency of automobile industry is noticeable. -The cases of automobile related environmental problems in the metropolitan area are PM, NOX, lead, HC, and CO. - Automobile inspections are often dysfunctional due to foreign element. - The lack of the basic data to be managed by transport and environment section of official organs and that of the maintenance system are growing into crucial problem. In this research, we conducted an investigation and an analysis of each country's environmental policies. These practices such as emission control policy, transportation demand management were originally introduced to the metropolitan area as a main target. Further, we also examined the historical setting and background of these practices as well as stakeholders, effect of its implementation, and outstanding issues.

Designing a Chemical Cluster to Get a Sustainable Production

Cristina Sendra i Sala*, Xavier Gabarrel i Durany i Teresa Vicent i Huguet

Industrial Ecology is an strategy which sharing acknowledgement of engineering and environmental science tries to identify the main environmental problem associated to industrial sector, as the use of energy and raw materials, the waste's generation, the atmospheric emissions, depletion of resources... In this sense, Industrial Ecology is focus on increasing the efficiency of the process, exchanging by-products between industries, applying Clean technologies,...

In this work it will be shown the results Industrial Ecology's application in a industrial cluster of the chemical sector. One of the main tools used in this work is the material flow accounting.

The use of resources and the waste's generation is compared in two different scenarios:

- a) The industries working isolated
- b) The industries as a whole system

Five chemical industries have been analyzed individually and as a group. The started point of this work for each industry was the design of the industry based on the production needed. This part of the study has been done by students of Chemical Engineering degree.

The paper will show the improvement in the environmental behaviour if the system is studied as a whole group. We analyse the advantages, that will suppose to have all the industries in the same place: by-products use, interconnections of services, new opportunities, transport and waste management.

Incubating Sustainable Development: The interplay of Community Development Corporations and Eco-Industrial Parks as a means of generating Economic Development

Ryan Salcido

The mission of a Community Development Corporations (C.D.C) is to advance Economic Development. The purpose of Economic Development is to promote the economic welfare of a community. In accomplishing this, C.D.C assist in the establishment or expansion of industrial, commercial or research facilities with the intent to. (a) Create and preserve employment opportunities for its residents; and (b) Expand the tax base for the community, with the goal to continually enhance the quality of life in its county. But the problem is that most current economic development has negative environmental externalities. Communities, consequently use tax revenues just created by the new business, to combat the environmental degradation caused by the new firm. Thus, this paper argues it should be the mission of Community Development Corporations to foster sustainable economic development. Furthermore, that C.D.C. should base their eco-

nomic development strategy around the creation of Eco-Industrial Parks. These parks promote economic performance while minimizing environmental impact. It is the point of this paper to examine the role of C.D.C business incubators, in creating Eco-Industrial Parks.

Life Cycle and Economic Investigation of Kenaf Reinforced HDPE Shipping Pallets

Thomas P. Seager*, Ed Saliklis

Shipping pallets represent a problematic solid waste problem. Wooden pallets are inexpensive to manufacture but short-lived. They are often damaged during use and are labor-intensive to repair. End-of-life options include energy recovery and mulch production, ensuring that new pallet demand must be met from virgin, albeit renewable, resources. Alternatively, plastic pallets are more expensive to manufacture, but longerlived, easier to recycle, and may be less expensive long-term. However, capturing the economic benefits of plastic pallets requires protection of ownership so that pallets may be reused without being repurchased. Under conditions in which the pallet cannot be recovered and returned, use of plastic pallets is prohibitively expensive. Constructing a pallet that has competitive initial cost, durability, and recyclability requires a material that has the high stiffness and strength to weight ratio of wood, but the durability and remoldability of plastic. This research investigates the potential for a composite of kenaf fibers and post-consumer high-density polyethylene (HDPE) to provide an economical and environmentally superior alternative. Comparative structural and economic data suggest a remoldable HDPE/kenaf pallet may be structurally viable at competitive initial cost (compared to wood), while preliminary life-cycle data suggests that a remoldable product may significantly improve economic and environmental performance. Several critical elements of the product life cycle have yet to be determined: structural response, energy and chemical requirements, and environmental implications (e.g. volatile organic compound release) as a function of remold cycle. Also, the life cycle of kenaf production and availability of post-consumer HDPE will influence the results. To investigate the potential economic viability, a game theory framework will be applied to predict the best strategies of different life cycle players (pallet manufacturers, shippers, and receivers) for managing used or damaged pallets, using estimated costs of manufacture, transport, and remolding. This research is expected to result in design of a prototype HDPE/kenaf pallet, with the potential for pilot scale manufacture and field testing, pending results of the economic and life cycle assessments.

Scenario Construction for Sustainable Agricultural Production

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Sustainability is doubtless a complex subject with many aspects. In agriculture, sustainability contains a large portion of ecological issues, if the environment is damaged you can not sustain your production since it relays on natural systems. The social

as well as economic aspects of sustainability are also important since agriculture often is important in rural areas. Finally there is an agriculture-specific aspect; animals are used for producing food, which brings in ethical considerations on how we treat our animals. Conclusively there is no "triple bottom line" to sustainable agriculture but a "quadruple bottom line". In agriculture there are several conflicting goals between the four sustainability aspects. One example is that in order to minimize the emission of ammonia, the animals should be kept indoors with a slurry manure system. This will interfere with a possible goal to facilitate natural behavior of the animals. The Swedish research programme Food 21 is aiming at a more sustainable Swedish food production. In order to fulfil this objective a synthesis of ongoing research was necessary. The goal was to present solutions for future systems; hence we decided to work with scenario methodology. It offers possibilities of communicating complex results in a comprehensive manner, and at the same time scenarios provides a platform for discussions between researchers from different areas, which is at the heart of the synthesis work. To get credibility both towards our research colleagues and society we needed a strict method to construct the scenarios. First, the method has to be transparent; a receiver of the resulting scenarios must have information about all assumptions and choices made. Second, it should minimize the risk that the scenarios was a result of the researchers view of what was feasible, i.e. be limited by preconceived ideas. We have developed a step-wise method for scenario construction that fulfils the above demands. It builds on dividing the system in single production systems (e.g. milk, wheat), and identifying sustainability goal conflicts. These conflicts are solved by prioritizing between the goals using "Goal visions" which is grouping goals in accordance to what aspect of sustainability they originate from. Thereafter the single production systems are put together to form entire farming systems. These goal visions scenarios are presented on workshops with researchers and people from companies and authorities. The knowledge and insights gained from these workshops are used to reformulate the scenarios and possibly another round of workshops is needed. Finally the scenarios can be evaluated from the four sustainability aspects and communicated as scenarios of how future agriculture could look with different goal visions. By using this method detailed knowledge can be incorporated in the scenario construction. It is our experience that it is necessary to present suggestions of solutions to get interactions with the specialists within different research fields. At the same time the specialist knowledge is indispensable for creating new and better systems. Conclusively, the method offers a feasible way to incorporate specialized knowledge in a broader perspective, and to present complex results in a comprehensible way.

From Regional to Global: Zinc Stocks and Flows Analysis at Multiple Levels

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Substance flow analysis is a useful tool for examining the interactions between the natural environment and the technosphere at many different levels ranging from the macro to the micro. At the global and continental level SFA can provide an indication of intensity of usage trends and a gross snapshot of how materials are used and where

they tend to reside. Data available at the country level can be used to model material flows across the life cycle, and thus provide rough indicators of usage and recycle patterns, which can then be used for guiding national policy on materials management. Country level flows can be aggregated into continental and global cycles, the results of which can show trends in resource management and economics. At the micro scale material flows are directly useful for assessing environmental risks and impacts. This paper examines the zinc technological cycle at country, continental, and global levels. A comprehensive contemporary cycle for stocks and flows of zinc is characterized and presented, incorporating information on extraction, processing, fabrication, use, discard, recycling, and dissipation. The analysis is performed on an annual basis, ca. 1994, at three discrete governmental unit levels -countries or country groups that comprise essentially all anthropogenic zinc stocks and flows, nine world regions, and the planet as a whole. We also examine metrics on the per-capita level within different countries for the defined continents. Inter and intra-continental scale comparisons reveal global and local disparities in material usage, they also provide a gross indication of in-use materials stocks available for future use, which is important for guiding waste management decisions. We present results from SFA studies for zinc conducted for all the continents. A regional material stock and flow (STAF) model developed at Yale was used to track the pathway of zinc in the early 1990s in select countries globally. The collection of multi-level cycles shows that most primary zinc is mined, then exported as concentrate from North and South America, Oceania, and central and Southeast Asia. Europe and Japan import the majority of the metal as concentrate, then smelt and refine it domestically for their fabrication and manufacturing industries. While zinc's residence time can be high for many of its applications in the building and construction sector, since the majority of it is used as an anti-corrosion coating, there are dissipative losses occurring during the lifetime of products and infrastructure containing zinc. This study and others suggest that zinc losses from use over the last century are significant in magnitude and should be thus examined historically.

Energy as an Indicator for Environmental Impact from Materials and Products

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Energy indicators are often used to monitor and illustrate environmental impact. For example, the indicator Embodied Energy (EE) is used frequently for analyses and comparison of environmental impact from different kind of building materials. The EE indicator encompasses all the energy invested, in for example a building component, from a cradle-to-gate perspective. It is supposed to reflect to a certain extent a range of resource and pollution issues connected to the component during its whole life cycle. It is also common practice that when examples of results from Life Cycle Analyses (LCAs) are shown, an energy indicator is chosen that is suggested to represent the environmental impacts occurring in many impact categories. If two indicators are shown, sometimes an energy indicator is combined with an indicator for climate change, often displaying similar results. For several reasons, we feel that there is a need to analyse and discuss how well energy indicators describe the complex nature of environmental impacts from materials and products. Firstly, environmental impacts from energy systems

vary widely with the mix of energy sources and conversion technologies involved. This means that the energy indicator, in terms of its reflection of environmental impact, is strongly site and time specific. Secondly, the types and levels of environmental impacts of a particular energy system and those of a particular material or product may be differing in many respects. This is probably true even in the case of a product for which the energy use and supply involved is well specified. The main component of this analysis is an overview of how environmental impact from different energy systems is distributed over different impact categories developed from a common LCA approach. Different energy systems are included. One of these is the current European Union (EU) energy system. The other systems are hypothetical. Their main energy source is assumed to be (a) fossil energy, (b) nuclear energy, (c) biomass (d) hydropower, (e) wind power, and (f) solar radiation for heating and power production. In addition a hypothetical EU energy system based on renewable energy is included. The environmental impacts from these systems vary largely and hence using the energy indicator as a proxy for the environmental impact from a material or product would consequently be varyingly valid. In addition, we analyse and discuss what types of environmental impacts that are not considered when using the energy indicator. This is performed by using specific products as examples. The environmental impact categories for these products are compared to the ones found in connection with energy conversion and use. In conclusion, our study shows that energy, for example EE, may be used as an indicator for a range of environmental impact categories from a product or material. However, its use is limited due to the large variation in environmental impact from different energy systems and to the lack of correspondence between these impact categories and those of a specific product or material.

Lifetime-involved Substance Flow Analysis of Durable Goods: A Case Study of Brominated Flame Retardants in TV Sets in Japan

Tomohiro Tasaki*, Masahiro Osako, and Shin-ichi Sakai

Durable goods are different from the other consumer goods in terms of length of lifetime. Measures such as reduction and substitution of toxic substances in new durable goods affect characteristics of the waste products in a long time due to this property. On the other hand, in order to implement recycling of resources or appropriate disposal of toxic substances in waste durable goods at this time, we have to consider substances used in durable goods which were shipped in the past. Therefore, lifetime-involved substance flow analysis of durable goods is required, and we should plan measures of durable goods combining new product measures with waste product measures appropriately, based on the result of the analysis. Conducting the analysis, analysis of lifetime of durable goods is first required and second development of prediction model of numbers of waste durable goods is required. Moreover, we have to investigate weight of components in durable goods in the past and contents of target substances in components, and then substance flows can be clarified. In this paper, we conducted lifetime-involved substance flow analysis of durable goods for an example case of brominated flame retardants in TV sets in Japan. Our subject substances are brominated flame retardants (BFRs), polybrominated diphenyl ethers (PBDEs) and tetra brominated bis-phenol A (TBBA), and related compounds, Sb and polychrolinated dibenzo dioxins

and furans (PBDDs/DFs), in 5 size categories of waste TV sets. As results, the beginning of BFRs in rear and front covers of TV sets were from FY 1987 to 1990 and from FY1993 to 1996, respectively, and TBBA is currently used as the substitute for PBDEs, to some extent. The amounts of waste T-Br were predicted to increase until at least FY 2020 due to jumboizing of TV sets. Non-BFRs substitution for BFRs until 2006 would reduce accumulated amounts of waste PBDEs from FY 1995 to FY 2020 by 33,000 tons. However, the amount of waste Br would peak in FY 2009. Waste covers of TV sets should therefore be treated and disposed appropriately at least then regardless of substitution measures. Finally, we will state future issues of substance flow analysis of durable goods.

Composting Toilets vs. Conventional Toilets: A Comparison of Waste Treatment Technologies in an Institutional Setting

Michael Taylor

In the United States there are approximately 16,400 publicly owned wastewater treatment plants that treat a total of 41 billion gallons of wastewater per day. Many of these municipalities are finding it difficult to fund wastewater treatment plants to meet increasingly stringent environmental standards. The U.S. Green Building Council has proposed composting toilets in institutional buildings as a method of reducing the environmental footprint of buildings and reducing the associated on wastewater treatment plants. Composting toilets are waterless and break down human waste product biologically in an aerobic environment. These systems consume no potable water and convey no sewage, but they do require constant ventilation. Energy requirements for continuous ventilation may offset environmental benefits achieved through reduced water consumption.

This study considered the life cycle environmental impacts associated with conventional systems and composting toilets. Manufacturer specifications on ventilation for ten premanufactured composting toilets were compared to conventional bathroom building codes for ventilation rates. The study found that, on average, manufacturers specify less ventilation for composting toilets than is required by law for conventional systems. In addition, several impact categories were used to compare the burdens associated with ventilation, wastewater treatment, and drinking water treatment.

Thermodynamic Methods for Measuring Environmental Sustainability of Industrial Sectors

Nandan U. Ukidwe*, Dr. Bhavik R. Bakshi

Importance of sustainable development is fast gaining acceptance. Economists have realized that preservation of economic, ecological and social capital is necessary for true growth (1). Industry is also increasingly adopting the concept of corporate sustainability because it leads to long-term value creation (2). What is missing is a theoretically rigorous and practically feasible method for measuring sustainability. Such

method must account for economic resources such as labor and capital, ecological resources such as rain and fertile soil and social resources. It must also account for emissions and their impact on human and ecosystem health. As an effort in this direction this presentation proposes a thermodynamic methodology to measure environmental sustainability of industrial processes. Application of thermodynamics is relevant because an integrated economic-ecological system can be considered as a single network of energy flows. For joint analysis of industrial and ecological systems exergy or available energy is a better currency than money because money often fails to appreciate the intrinsic value of "free", nevertheless vital, ecological resources. This methodology focuses on three aspects of environmental sustainability: resource consumption, ecosystem impact and human health impact. The methodology quantifies total resource requirements by taking a life-cycle perspective. Theoretically any product's or processes' life-cycle extends to the three primary sources of energy namely solar radiation, geothermal heat and tidal forces. This includes ecological stages that convert global energy inputs into ecological resources and industrial stages that transform ecological resources into economic resources. State-of-art methods such as EIOLCA (3) do include economic stages in a product's or processes' life cycle but exclude ecological stages. This leads to ignorance of ecosystems' contribution to industrial systems and, consequently, their true worth. Inclusion of ecological life-cycle stages is a challenging task because ecological networks are not well-understood. This prohibits direct extension of input-output analysis. The new methodology overcomes this shortcoming by implementing ecological cumulative exergy consumption analysis or ECEC (4). ECEC extends traditional cumulative exergy consumption analysis to include ecological resources and is especially useful when only partial information about the underlying network is available. Under specific conditions ECEC is shown to be equivalent to emergy. The new methodology has been used to determine total resource requirements of industry sectors. We have considered ecological products such as coal and timber, ecological services such as wind for pollution abatement and impact of emissions on human and ecosystem health. These results have been used to determine environmental sustainability indices for industry sectors. The first half of the presentation will discuss theoretical aspects of the new methodology whereas the second half will concentrate on its applications to US economy. The presentation will conclude with case studies with special emphasis on sustainable transportation.

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Innovation in Response to the Sustainability Challenges in Minerals Processing

Rene Van Berkel

The mining and minerals processing industry are increasingly being challenged by the global quest for sustainable development, and in particular the need to address environmental problems, at the local, regional and global scales, as well as equity considerations regarding the division of minerals wealth between local stakeholders, national economies and shareholders, now and in the future. Technology development and innovation will have to play a profound role in addressing those challenges. Minerals processing, the stage at which ores are being converted into industrial grade metals and minerals, acts as a gatekeeper between the mining project lifecycle and the mineral product lifecycle. Minerals processing enables effective use of mined ores, creates a significant environmental impact from its own operations (energy, chemical consumption, waste and emissions) and can contribute to closing materials cycles through greater reprocessing of recovered materials. This paper provides a summary impression of the debate on mining and sustainability, and its implications for the minerals processing industry. Factor improvements in the ratio of value of product per net environmental impact will have to be achieved through persistent incremental improvement and innovation in current processes ('Cleaner Production and Eco-Efficiency') and vision shaping strategic innovation into break-through technologies ('sustainable innovations'). It is argued that the application of Cleaner Production and Eco-Efficiency in minerals processing so far has been limited to continuous improvement of the pollution control and environmental management functions of mining and minerals processing, thereby leaving opportunities for environment-driven improvements in the operational performance of core operations untapped. Examples from Australian minerals companies illustrate that such opportunities exist, and generate good economic and environmental outcomes. Strategic innovation for sustainable minerals processing appears to be fertile ground for Research and Development, provided such is being undertaken in an integrated and comprehensive manner, allowing strategic analysis to inform and guide engineering and operational research, and vice versa, on the basis of stretch Eco-Efficiency targets.

Benchmarking to Trigger and Sustain Eco-Efficiency in SMEs

Jim Altham, Rene Van Berkel*

abstract: Eco-Efficiency and Industrial Ecology require industry to change behavior towards the environment. Even with demonstrated economic and environmental benefits, and large variations in industrial environmental performance, the behavioural change remains a challenge. Put at its most basic, for programs to be successful it is necessary to attract the entrepreneur's attention, then retain this attention while the technical skills and appropriate business culture is developed. The paper reports on a small business eco-efficiency benchmarking program, that was based on the following widely-held assumptions:

- · What gets measured gets managed
- · Cost savings are the principal driver for improved environmental management
- · Continuous improvement requires an external focus
- · Small businesses face a number of barriers to Eco-Efficiency
- · Small businesses face a number of barriers to benchmarking.

The program applied basic environmental management accounting and benchmarking to the drycleaning sector in Western Australia over a period of two years. Data was collected on a mix of leading and lagging indicators. The indicators included: education and training levels; environmental incidents; energy, water and chemical consumption; and waste generation. Potential cost saving were represented as an increase in net profit. Due to the large fold variations in the physical output of the businesses this research concluded that there is a need to statistically test for the presence of economies of scale, and if necessary, to correct for this to generate realistic targets. Three critical success factors (CSF) for environmental benchmarking emerged:

•The identification of gaps in environmental performance gaps in areas important to the long-term future of the businesses

Providing and/or promoting the drivers to close the performance gaps

• Ensuring entrepreneurs possess the ability and tools to close the performance gap.

The drivers to close the performance gap relate to cost saving, risk management and a license to operate. Participants in the best practice program on average improved their energy efficiency by 6%, chemical efficiency by 30% and reduced hazardous waste generation by 48%. The CSFs of benchmarking link well with the innovative SME model and the successful implementation and sustaining of this model increase the success of Eco-Efficiency programs. This model exposes entrepreneurs to external sources of information and knowledge blended with the opportunity to learn from their peers. This program did attract and retain the attention of entrepreneurs. The results of this research concluded that 'what did get measured, does get managed particularly when there is a local reference point i.e. peer's benchmarks. When this is the case, benchmarking triggered and sustained the uptake of Eco-Efficiency.

Advanced Sustainability Analysis for Industrialised Countries

Vehmas*, Jarmo; Kaivo-oja, Jari; Luukkanen, Jyrki

Advanced Sustainability Analysis for Industrialised Countries In the field of sustainability evaluation there is a need to develop new evaluation tools for the analysis of critical industrial ecology trends. In this paper a new evaluation framework called Advanced Sustainability Analysis (ASA) is presented with an empirical application to major industrialised countries including the U.S., Japan and the European Union. The ASA framework, an evaluation system of environmental information, can be used for explorative data analysis in learning from the past experience, for trend extrapolations, and for scenario analysis of sustainable development policies. The basic leverage point of ASA is postulating the conditions necessary for advancing sustainability. It means that the results shown are not necessarily sufficient for advancing sustainability, nor

do the results tell whether a state of the world is sustainable as such in some absolute term or not, e.g. in the meaning of carrying capacity, ecological footprint, and other measures. ASA reveals change information about sustainability; it studies the direction of change of environmental stress components and rates of change, instead of the absolute state of the human affairs and environment. This feature makes it more pragmatic tool for policy formulation. The ASA framework offers decision-makers a new and advanced tool of policy analysis as well as policy formulation for sustainable development, linked to conventional economic and welfare concepts. The information evaluation system of ASA has its specific syntax or mathematical structure, its peculiar semantics or meaning of its variables and quantities such as environmental stress, welfare, dematerialization, rebound, etc., and its pragmatics; its intrinsic ways of use in scenario analysis and policy formulation. In this sense ASA is not a general analysis tool of sustainability but a tool for emphasis on focused issues. But within the range of its applicability ASA is a theoretically complete decomposition of what can be empirically observed as data. Policy relevant questions, which can be analysed via the ASA approach, include e.g. analysis of different dimensions of sustainability in different historical development processes, analysis of different dimensions of sustainability in future scenarios, analysis of dematerialisation of production and immaterialisation of consumption, analysis of the rebound effects of growth, analysis of structural shifts needed for sustainable development, and analysis of sustainable economic growth. In this paper, these analyses are provided for major industrialised countries, including the U.S., Japan and the European Union. If data is available, the ASA approach can be used at all levels of regional planning. The empirical results presented in this paper indicate that there can be sustainable transition strategies that diminish environmental stress. The ASA approach provides a realistic approach and an empirical method of analysis for the crucial sustainability challenges of the future.

Industrial Ecology of Norwegian Consumption of Paper

Klaus-Ole Vogstad*, Anders Hammer Strømman and Sangwon Suh

Abstract Production, consumption and recycling of paper products consumed by households in Norway are analysed combining linear programming (LP) and the hybrid inputoutput framework. The multiple material flows of paper production, use and end-of-life treatment is modeled as a LP network optimisation problem, in which the material flows of each paper type are decision variables and the total environmental impact is the objective function. Life cycle impact assessment (LCIA) is then applied to each process (i.e. thermomechanical pulping) to quantify its environmental impact. Missing environmental flows are accounted for by linking economic flows of the processes with the Norwegian national input-output table using the hybrid input-output framework. This approach enables us to optimize material flows with respect to environmental impacts for multiple products under various constraints imposed on the production, consumption and recycling of paper. End-of-life options such as recycling vs. incineration are explored as well. Finally, uncertainty of the optimal results are analysed using the Monte Carlo simulation technique. The results show that the hybrid input-output framework provides a useful platform for the questions in industrial ecology by revealing the structure of industrial and economic systems embedded in the broader socio-economic and

natural systems. Combined with LP techniques, such a framework can successfully provide a picture of the optimal metabolic structure of an industrial system.

Introduction of China Experience on Eco-industrial Park

Z. Wang*, R. Wang, J. Liu, M. Wang

The purpose of this poster is to give a brief introduction of China experience on Eco-Industrial Park (EIP). The introduction was given from four perspectives: (1) The origin of EIP in China; (2) A review of these EIPs; (3) Giving a analysis on networking framework of some noted Chinese; EIPs (4) Environment for EIP development in China. The exact time when the concept of EIP came into China is hard to make clear. The practice of EIP, however, has a quite long history. Here provided a viewpoint about two predecessors :one is traditional Chinese enterprise,another is industrial park. Cleaner Production activity provides a groundwork and driving force for the development of EIP after 10 years effort. In China, there are about 25 EIPs publicized in Chinese literatures database and government/enterprise websites, which can be divided into three stages: built-up, planning and potential stage. These EIPs are distributed in 16 provinces, which occupy 48.5% of China provinces, and have been involved in 19 types of industry. After making a inventory of 8 Chinese EIPs, Conclusions on some Characters of Chinese EIPs development were drew: three patterns of EIP development in China; all estates have Large scope or scale; two forces were identified in management; a widely cooperation among company, government and academy. The type of systematic networking framework will be an important key for maintaining viability and collaborative activities with in an eco-industrial development project. In this paper, by analyzing a inventory of eco-industrial sub-systems in 4 noted cases, several characters were found. Generally, in China, these eco-industrial systems are immature and few works are focused on specific sub-systems, except for material and water utilization. There are a lot of traditional companies which have sound designs in usage of by-product and some EIPs can combine environmental benefit with economic benefit successfully, however, economic aspect and Environmental aspect are still not treated as the same importance widely. Three environments for EIP development were discussed. The first is Law environment: A brief framework of laws on resource utilization and environmental protection was given. Until now, no special law or regulation has come into being for regulating the design, planning and assessment behaviors of EIP. On the other hand, establishment of special laws on resource reutilization is in processing, the Law system will be created step by step. The second is Academic environment: There are at least 14 universities and academies involved in this domain, more and more Chinese academic groups are taking part in the research on EIP and IE with wide science backgrounds and topics at different level, moreover, they has a strong connection with practice. The third is research project and international cooperation: Research and practice on EIP is still in the beginning, a big vision has not come into being. Projects on this are quite few and financial support and cooperation with international are demanded greatly. To pursue a prosperity phase of EIP development in China, there are 6 Challenges and 7 Chances to face in the coming age.

Resource Use of the EU 15 1980-2000: Lessons from the Revised Estimate

Helga Weisz*, Christof Amann, Nina Eisenmenger, Fridolin Krausmann

The paper presents and discusses the major results of the revised and updated account "Resource Use of the European Union 1980-2000". In 2001 a first estimate of time series MFAs for the European Union was compiled by the Wuppertal Institute and published by the European Statistical Office (2001). This estimate was revised and updated in 2002 by the IFF-Social Ecology-Vienna (EUROSTAT 2002, forthcoming). The revision aimed at improving cross-country comparability by further developing methodological procedures, in particular biomass accounts. The paper will present the major results of the revision in terms of cross-country comparisons, trend and patterns the main MFA derived indicators (DE, Imports, exports, DMC, DMI, and PTB), and discuss them in terms of data quality, hidden biases achieved and further methodological improvements, international comparability and interpretation of MFA derived indicators.

Partnership between Universities and SMEs in Sustainable Development

Ronald Wennersten* and Nils Brandt

Small and Medium Sized (SME) companies are very important actors in the area of industrial ecology and sustainable development. There are a lot of reasons for this. SMEs involve a lot of people, they live close to the market and the consumers, and there are a lot of innovators and entrepreneurs among people working in SMEs. They however often lack a strategic perspective to issues related to environment and sustainability. A potential solution to this problem would be a more active partnership between SMEs and universities. This paper addresses the potential roles of universities and SMEs in the development of a sustainable society. Several reports and articles have put forward the importance of these actors, but few have dealt with how a fruitful partnership between universities and SMEs really could be developed. Looking at these actors separately, you can see many limitations in the perspective of creating new initiatives in the field of developing sustainable technology, products, and services. Universities are lacking practical experiences concerning market conditions, consumer pressure and the economical realities of SMEs. There are however several important obstacles for building a fruitful partnership between these actors. One important obstacle is the lack of criteria for sustainability in technology and processes, which can be used in practice in the SMEs. Developing such criteria could be one important assignment for universities. The question is how this Gordian knot can be resolved. How can university and SME – companies complete each other and interact in order to develop sustainable solutions in areas of technology, products and services. In this paper we will discuss the total different success criteria at the university and in the SMEs. From the basis of a SWOT analysis for each actor, with reference to sustainable development, we will look at different promising perspectives. As a result of our studies and experiences we have developed a research brokerage where our institute and a network of SMEs take part. In this network we have created a more effective two-way dialogue between teachers and researchers at the institute, and the actors in the SMEs. In order to be sustainable this network has to fit in to the success criteria for both partners. We will here present some ideas and experiences of methods in which could form the basis for a more effective co – evolution between SME and university in the strive for a sustainable society.

Separation of Mixed Color Toner Waste For Reuse

Anahita Ahmadi Williamson*, Brendan H. Williamson, Dr. Thomas Theis, Dr. Susan Powers, Dr. Gregory Campbell

The xerographic industry has seen remarkable advances in speed and quality of image production in the past few decades. This technology is still improving today with many companies competing for the future in copy and print technology. One of the main components in the xerographic process is the marking material, or toner. Toner is dry ink that creates the image on paper during the xerographic process used in most copiers and some large printers. It consists of small particles in the size range of 5-13 micrometers, and is composed of three basic raw materials – polymer, colorant (pigments), and small amounts of additives that help to control the image quality.

A baseline life-cycle inventory (LCI) was performed on a specific black toner used in the xerographic process. The LCI showed that the system is mainly a classical "cradle to grave" model, although recycle streams within the system improve the overall environmental performance. Through recycling initiatives that were implemented recently in the toner manufacturing process, the production of solid waste from the life-cycle has been reduced by 24%. The majority of the solid process waste produced (>90%) is associated with post-toner production processes, and the majority of the air emissions in the system resulted from energy use. Post-production processes combine for nearly 90% of the total energy used in the system, with customer use accounting for more than 50% of the total.

The demand for full color documents, however, has increased dramatically in recent years. Therefore the focus of the industries has shifted to manufacturing large quantities of color toner. Color documents are created using four main colored toners: black, magenta, cyan, and yellow. The colored toner is manufactured the same way as black toner, but the there is a large difference in the recycling loops. Current production and use methods result in a mixture of color toner waste, consisting of the four colors, which cannot be directly recycled back into the manufacturing process.

The purpose of the current research is to develop a method for separation of these four different colored toner particles so they can be recycled into their individual manufacturing processes. Two methods that are being researched are separation by density and separation by charge. The research will include mathematical modeling of the systems along with experimentation to show the feasibility and efficiency of the separation methods. Final results from the LCI, and intermediate results and future work on toner waste separation will be the focus of this presentation.

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