The Future of the Electric Car

Dr. Ray Ridley

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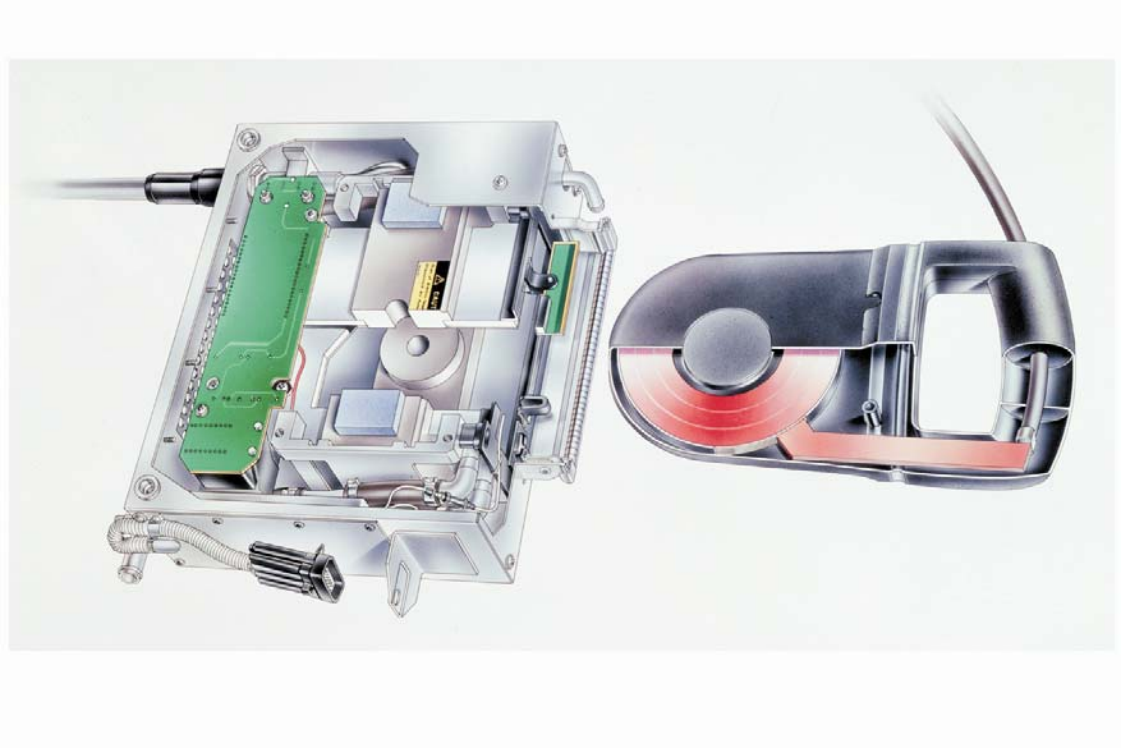
GM's EV1 1998-2004

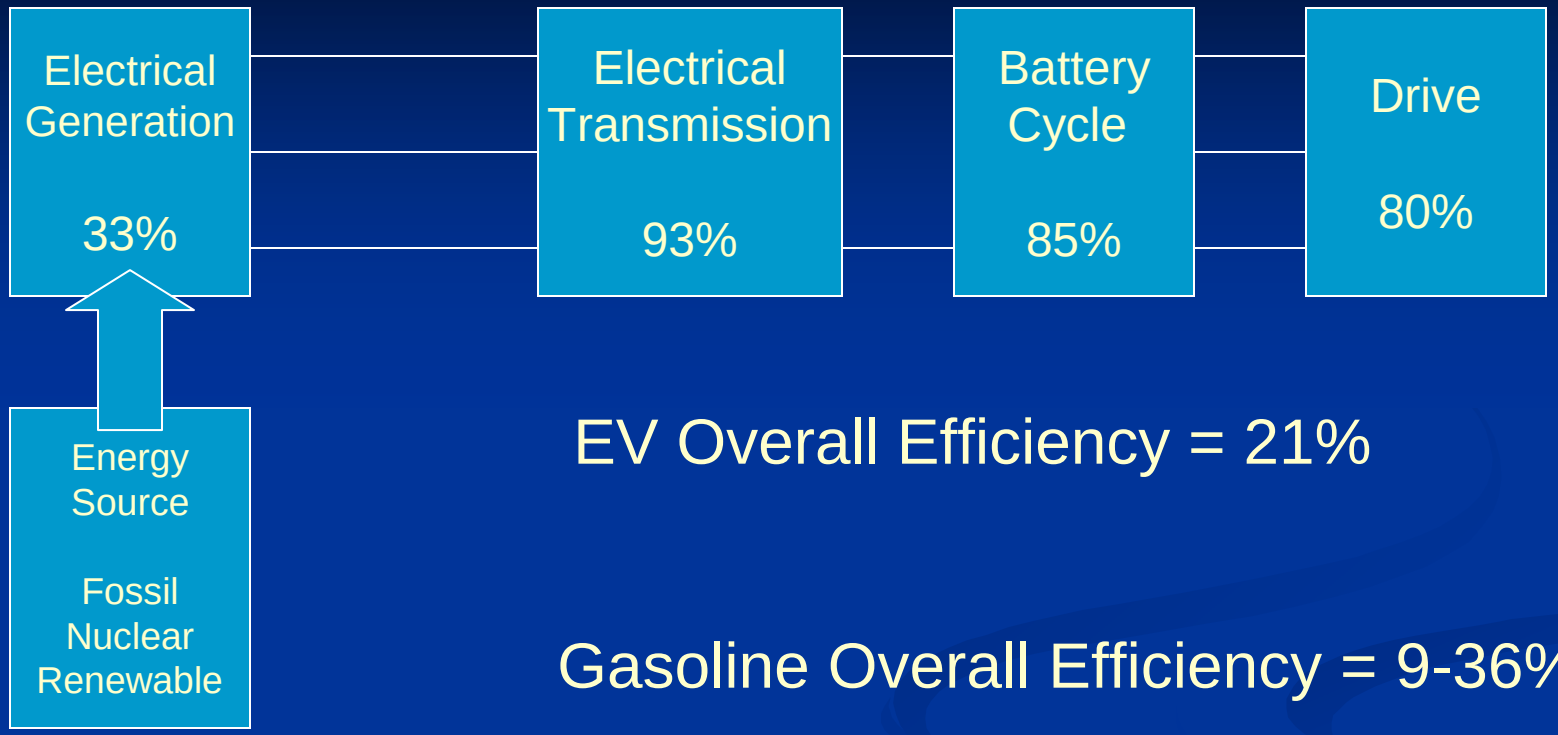
- Collaboration between Hughes and GM
- 50 to 100 mile range – great fun to drive. All owners loved it
- IGBT power system
- Contactless charger
- $1.3bn program to build 1000 in response to CA clean air mandate
- Fixed-term leases

EV1 Charging System



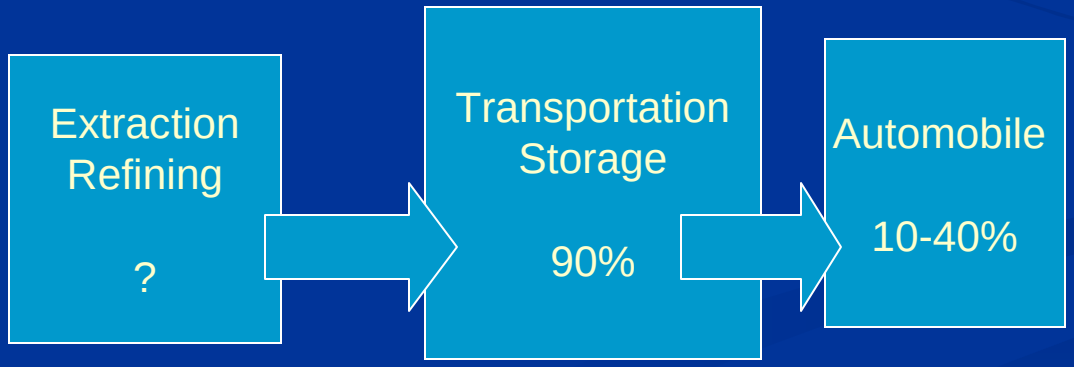
- Split transformer design
- All about marketing safety image
- Amazing power electronics achievement
- The wrong way to do it – far too complex and costly
- Charging stations were difficult to maintain and unreliable

Electric Vehicle Efficiency

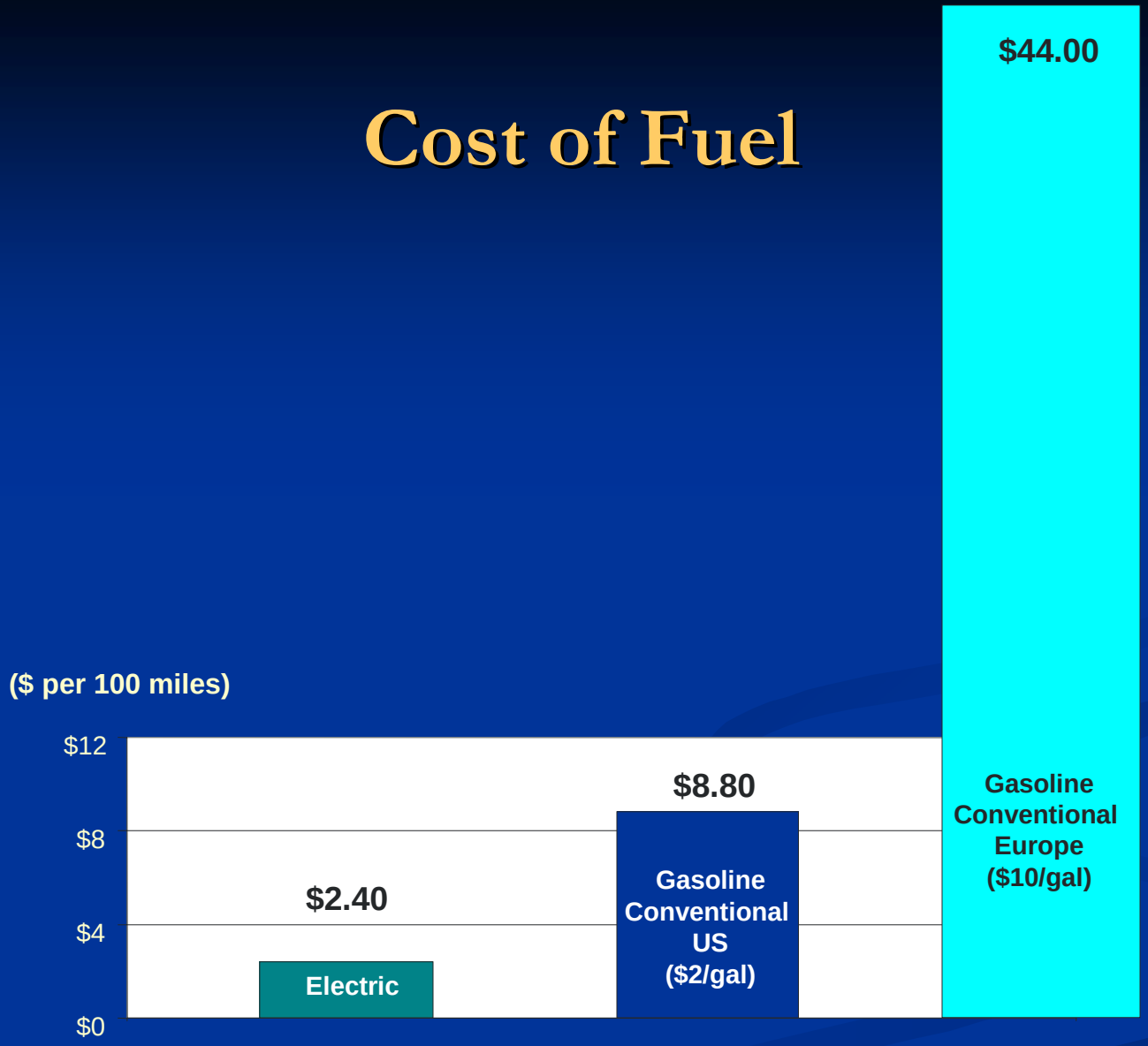


EV Overall Efficiency = 21%

Gasoline Overall Efficiency = 9-36%



Cost of Fuel



What killed the EV1 program?

- Removal of government mandates in 2001
- Poor driving range
- Long charging times
- Infrastructure of chargers
- Lack of funding with no profits in sight for GM
- Modern business mentality
- Low gas prices
- Fuel usage efficiency

The EV1 Funeral

- December 2004

EV1 Contemporaries

Toyota RAV4 EV
out of production

Chevy S10 EV
out of production

Honda EV Plus
out of production

GM EV1
out of production

Ford Ranger EV
out of production

Chrysler EPIC EV
out of production

- Were these programs an engineering failure?
- They were the first step toward miniaturized power electronics and cost-reduced electric propulsion, essential for hybrids and the next generation of electric vehicles
- They were a business failure in the modern context

EV1 Suitability

- Short distance driving
- Commuting to work <50 miles, which enables 75% of US driving needs
- This is what most of us need!

- This viewpoint is counter to popular marketing today . . .


We need Hummers!
www.hummerart.com

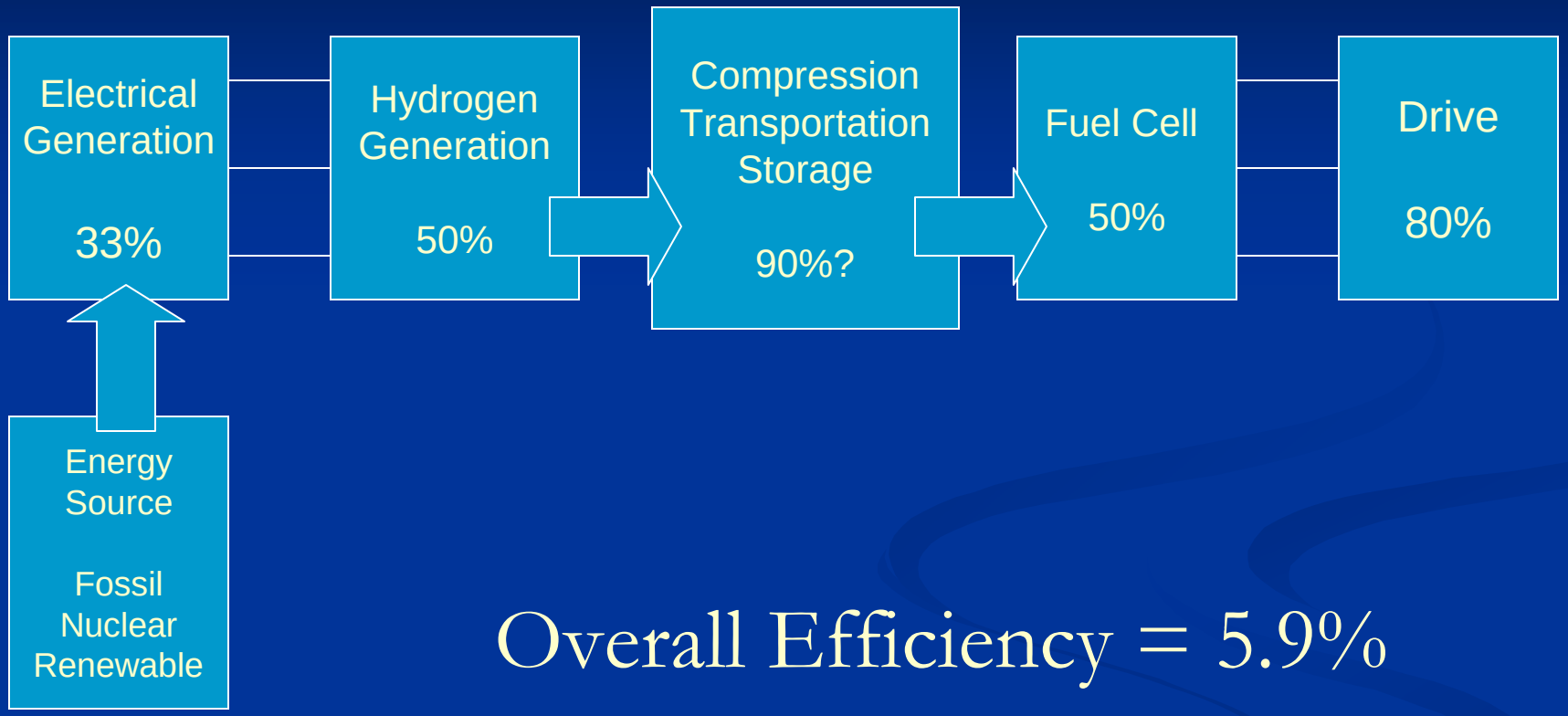
The “Green” Hummer

- Hydrogen powered
- About 50 miles per tank
- No infrastructure to refuel

The Hydrogen Economy

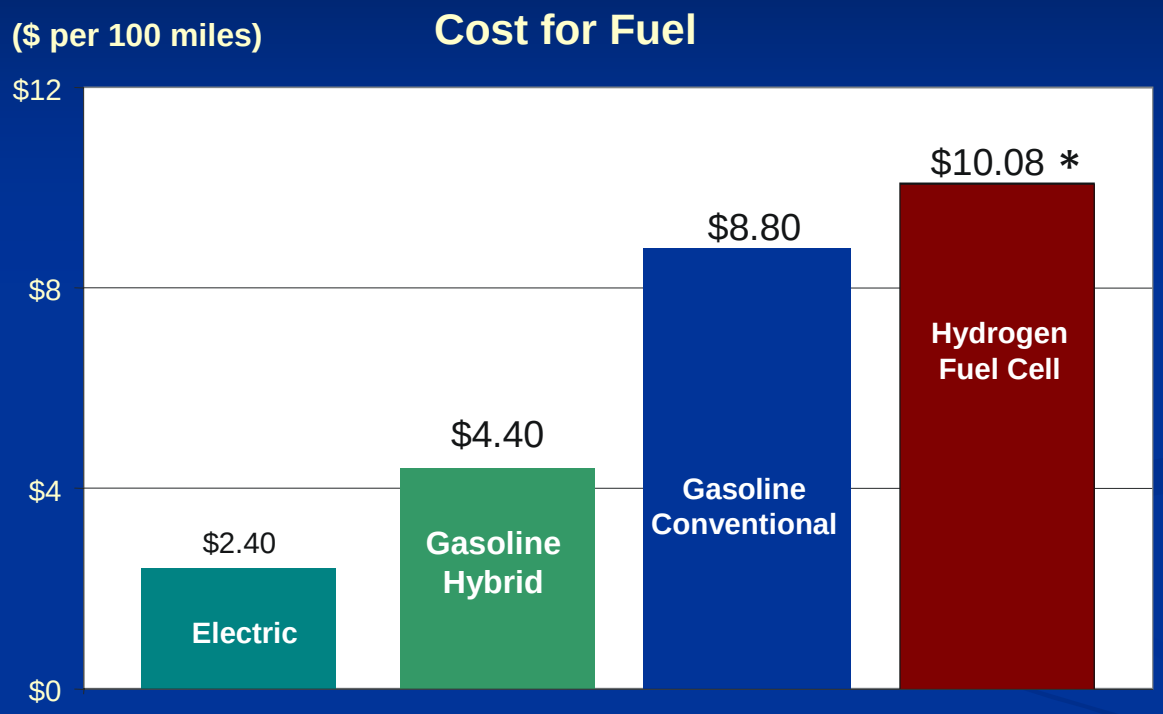
- Beyond the Hummer, does it make sense?

Hydrogen Efficiency



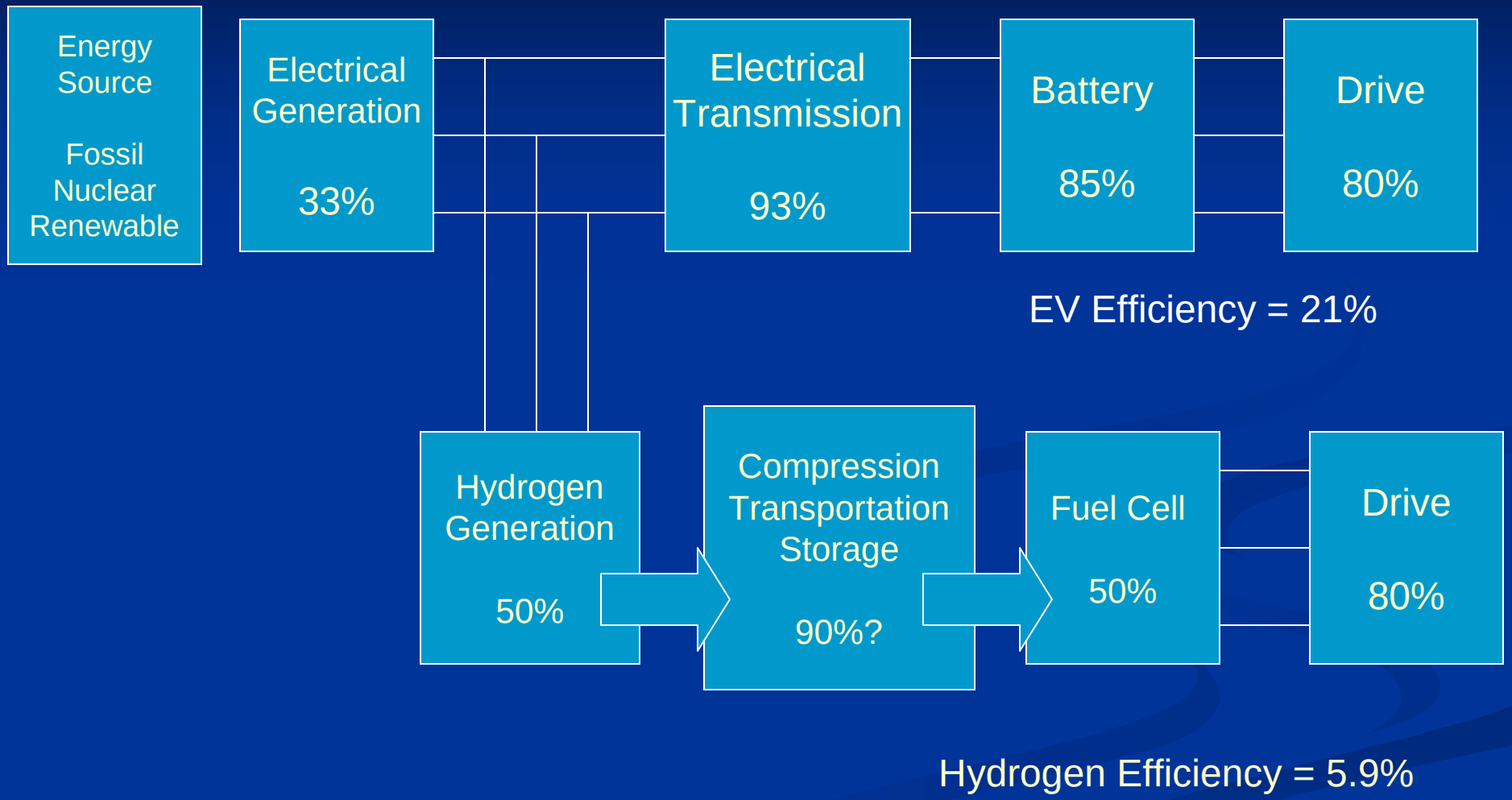
Overall Efficiency = 5.9%

Hydrogen Costs



* Does not include transportation and Infrastructure cost of Hydrogen

Hydrogen vs. Electric Efficiency



Real World Numbers

2003 Toyota RAV4 EV

Electric Vehicle

Possible Tax Incentives

Use your Gas Prices | Switch to Metric units

Fuel Economy

Fuel Type	Electricity
Energy Consumption(city) (kW-hrs/100 miles)	27
Energy Consumption(hwy) (kW-hrs/100 miles)	34
MPG (city)	125
MPG (highway)	100
MPG (combined)	**112**
Annual Fuel Cost	**$362**

Toyota RAV 4 EV

EPA rating:
30 kWh/100 miles

Energy use per mile:

0.30 kWh/mi

Honda FCX FCEV

EPA rating:
50 mi/kg H2

Energy to make H2:
63 kWh/kg (based on Stuart Energy electrolyzer)

Energy use per mile:

1.26 kWh/mi

2003 Honda FCX

Miles per kilogram of hydrogen

51 city | **48** hwy

Annual Fuel Cost: **$1515***

EPA Air Pollution Score	Best 10 (0 – 10)
Range	170 miles
Fuel	Hydrogen
Fuel Cell	Polymer Electrolyte Membrane
Motor	60 kW DC
Energy Storage Device	Ultracapacitor

*Annual fuel cost is estimated assuming 15000 miles of travel per year (55% city and 45% highway) and a fuel cost of $5.05 per kilogram of gaseous hydrogen.

The Technical Challenges for Hydrogen

- Increase efficiency by 400% to match EV
- Extreme high volume production of hydrogen
- Where will the energy come from?
- Safe storage at 5-10,000 psi
- Safe fuel dispensing at 5-10,000 psi
- Fuel tank volume
- Reduce fuel cell cost by factor of 10
- Increase fuel cell efficiency
- Transportation and infrastructure
- Remember, hydrogen is not a natural fuel resource – it is an energy storage system

The One Benefit of Hydrogen

- Rapid refueling – equivalent to 3 MW

Hydrogen for Aviation

- The last time it was used, things didn't go well – was hydrogen the problem?

The Cryoplane

- Liquid hydrogen is the only hope of getting enough fuel on board. Even then, fuel tank capacity must be 3.5 times bigger than gasoline tanks for the same energy storage.

The Future Electric Vehicle

- New battery technology
- New car frames and materials
- New economics of world fuel supplies

AC Propulsion's Li-Ion tZero

- 0 – 60 in 3.9 seconds
- Top speed 85 mph
- 300 mile range
- Cost of fuel $4 - 6
- Charging infrastructure already in place (electrical grid)
- Designed by Alan Cocconi

AC Propulsion's Li-Ion tZero

tZero vs Ferrari F355 1/8 mile

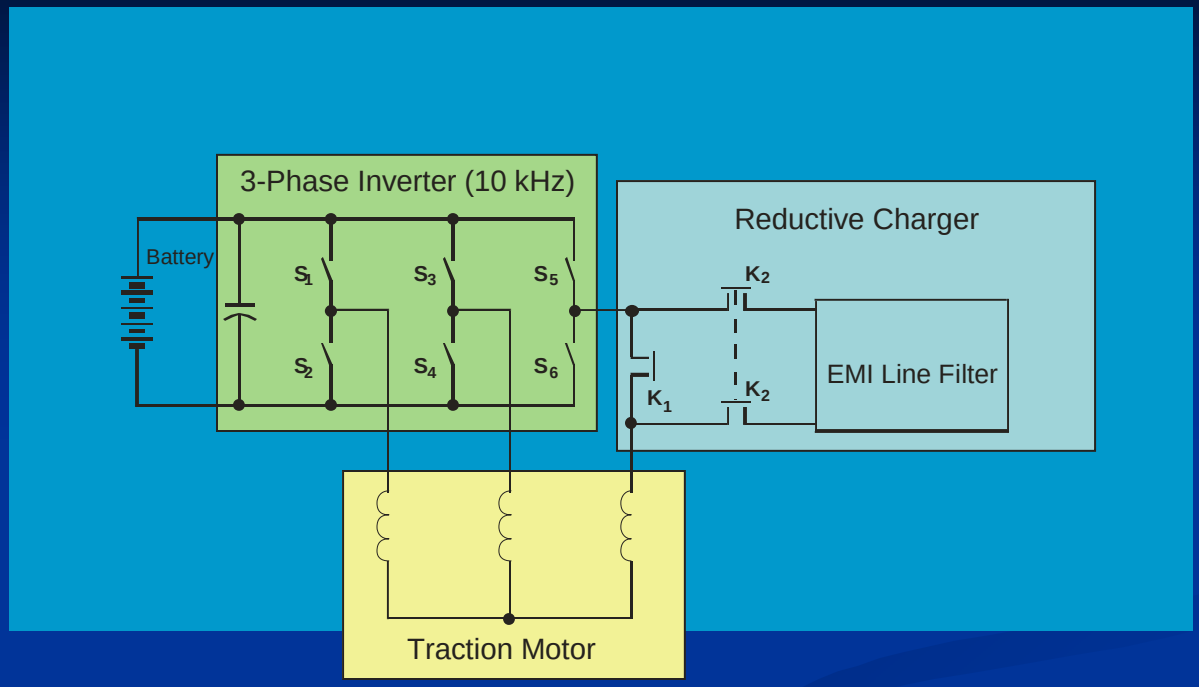
tZero vs Corvette

tZero vs Porche Carrera 4

Li-Ion Batteries

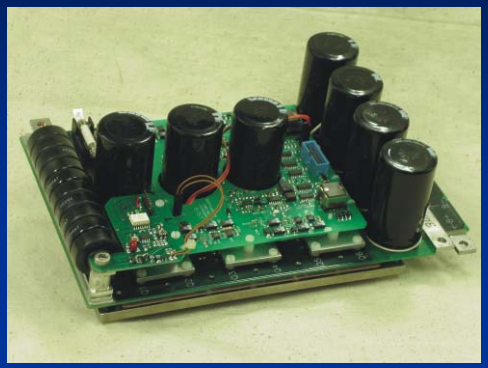
6,800 cells give 330-420 V at 500 A

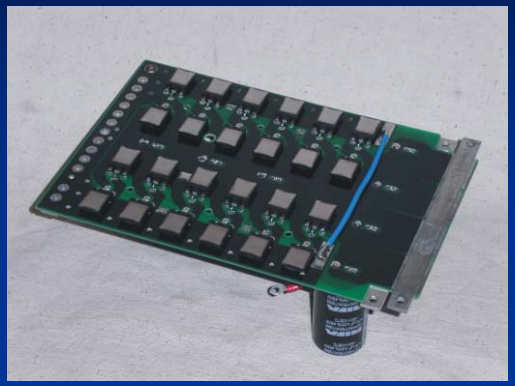
Power Electronics of the tZero



- 6-pulse bidirectional inverter/rectifier for unity PFC charging, motor drive, and regenerative braking
- Traction motor acts as boost inductor for 20 kW charging
- If you have an alternate energy source – windmill, solar, geothermal, biomass, etc. – fill up the car yourself!
- Car can run as emergency generator for home use or grid support

Power Electronics of the tZero





Twelve TO-247 IGBTs are paralleled for each power switch

Complete power electronics package with cooling fan

200-hp Traction Motor

- Total weight = 50 lbs
- Efficiency = 90%

Commercial Implementation

- Volvo 3CC concept car with AC Propulsion drive and Li-Ion batteries with a 180-mile range
- Car never made available to the public

The Venturi Fetish

- Custom built for 25 customers
- 200 mile range with AC Propulsion Drive
- 105 mph top speed
- 0-60 mph in 4.5 seconds
- $500,000 price tag (Half the price of the EV1!)

The Narrow-Minded View

Top Ten Auto Show Duds: What Were They Thinking?

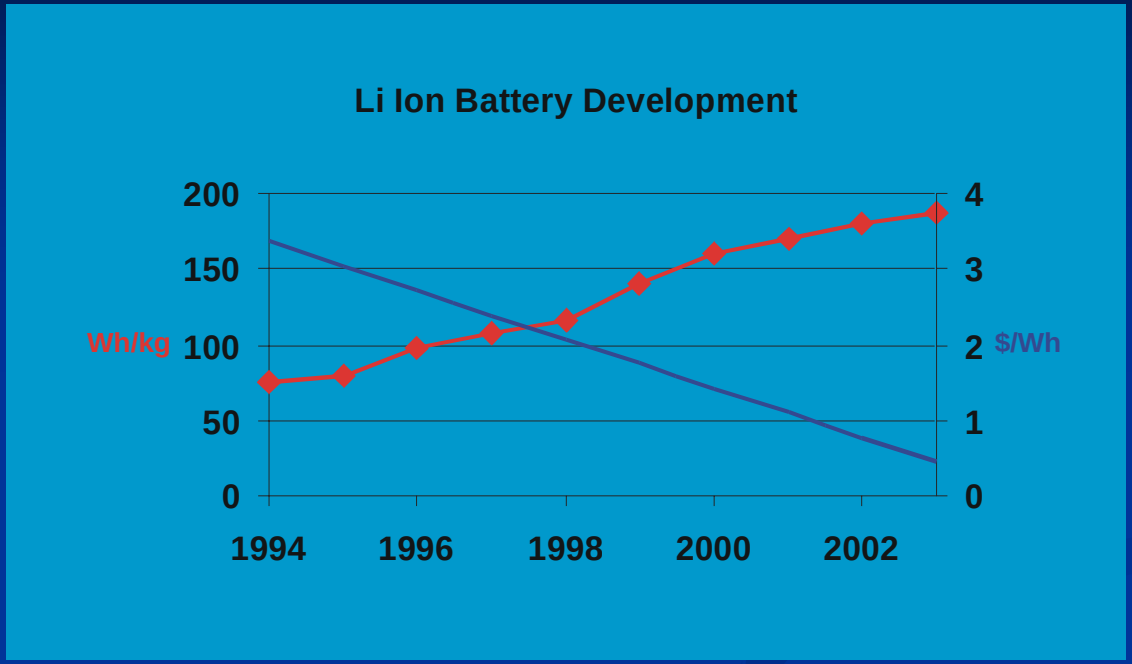
“If you like exorbitantly priced, two-seater vehicles that don't go very far or very fast and must subsequently remain out of commission for hours at a time, the Venturi Fetish just may be the perfect vehicle for you.”

-- Thom Blackett autobytel.com

Charging Rates

- Future EVs, estimate about 1 min/mile charge time at 10 kW
- 10 miles in 1 minute at 100 kW (100 miles in 10 minutes)
- 200 miles in 20 minutes at 100 kW
- Habits must change for this to succeed

Li-Ion Battery Performance



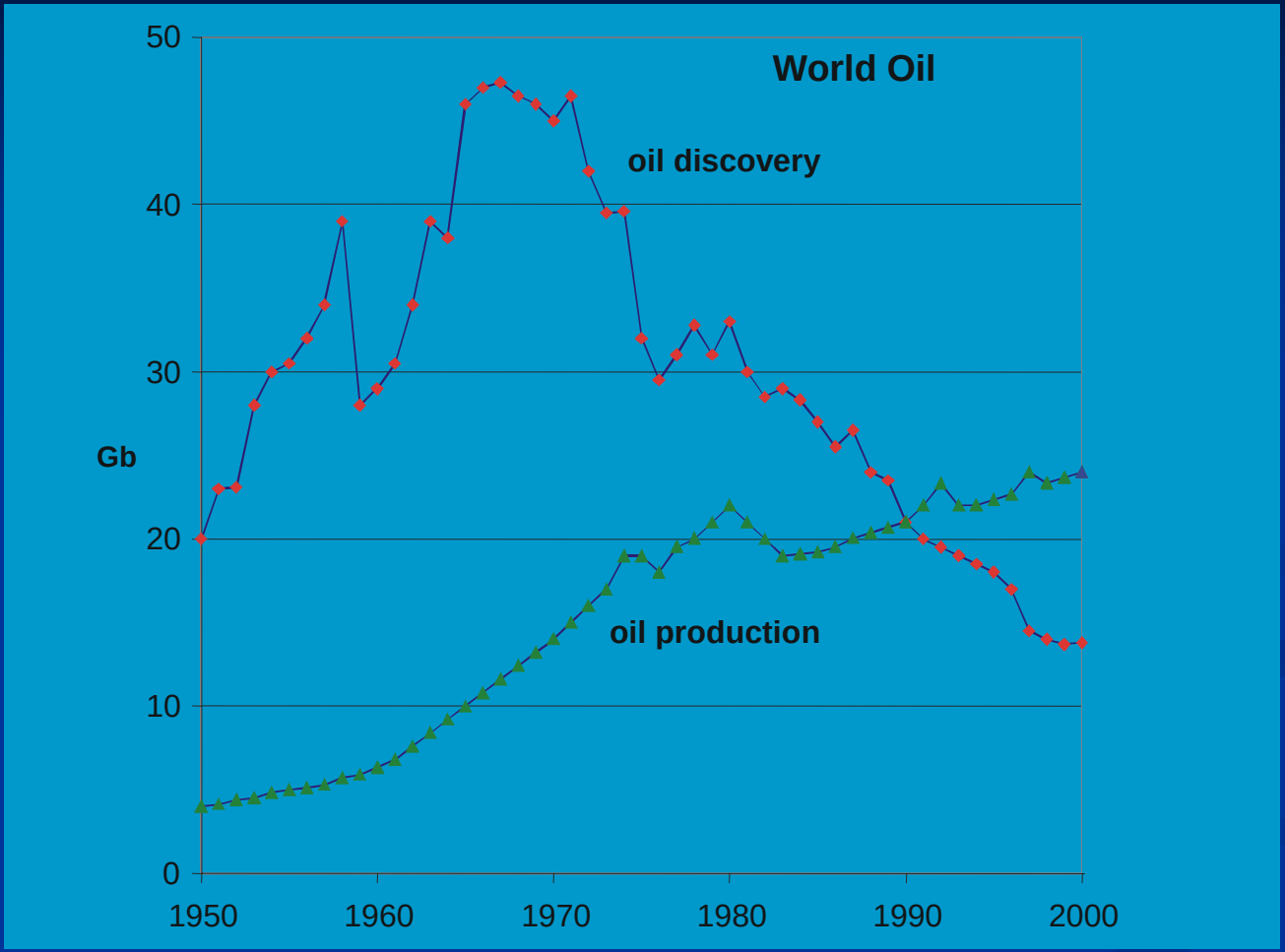
- Batteries for 200 mile range about $18k
- Current fuel cell cost about $1-2000 per kW (100 kW needed, tZero is 150 kW)

What are the Priorities?

- Reduced dependence on oil
- Reduced cost of cars
- Increased short-term and long-term profits for carmakers
- Lower cost of driving
- Uncompromised performance – range, speed, fueling time.

You cannot have it all!

The Oil WILL Run Out



…in our children's lifetime if nothing is done.

New drilling will not make a significant difference.

Hydrogen vs. Electric

Fuel Cells $100k (100 hp)	Batteries $18K (200 mi range)
5.9% Efficiency	21% Efficiency
Storage and Transportation	High Power Outlets
Fuel safety at 5-10 kpsi	Fire safety of Li-Ion
Fuel Tank Size >5x present	Battery Size
Hydrogen fueling stations	High power stations or fill at home
4 times pollution of EV	4 times lower fuel cost
Fast Refueling	Reversible system – battery backup, self-charge from alternate sources, support of electrical grid.
Government funding: $1.2 bn	Government funding: $0

What must be done?

- Technological risks and challenges of hydrogen far exceed those of the EV
- Accelerated hybrid/electric development with emphasis on electric storage and pluggable cars
- Drastic reduction of fuel consumption
- Research into battery technology
- Increased charging capability
- Research into alternative energy
- Re-education of the public about what they want
- Normal market forces of supply and demand will not alter our marketplace in time; legislative intervention is necessary
- There is a HUGE opportunity here for the power electronics industry and the economy – will we take it?

Government involvement?

- Drastically reduce the hydrogen program – redirect the $1.2 bn into electric/hybrid
- Provide incentive innovation – invest in it, reward its success and protect our IP
- Provide long-term incentives for car makers – break the "make the quarter" mentality