Electric Vehicles

Battery Electric Vehicles, and

Hybrid Electric Vehicles

Ron Chestnut, EV Addict

August, 2001

Topics of Discussion

- California Air Resources Board
- Pollution and Health
- Zero Emission Vehicles
- Mandates and Free Market
- Hybrid Vehicles

CARB

- Part of mission is ZERO Emission Vehicles
- ZEV Mandate initiated in 1990
- Original goal was 2% in 1998
- Next goal was 10% in 2003
- Current goal is 4% in 2003

- Why Mandates?

Auto Advances

- Safety Glass
- Seat Belts
- Smog Control
- Air Bags
- Rear-view Mirrors
- Low speed impact effects
- Motor not entering cabin on crash

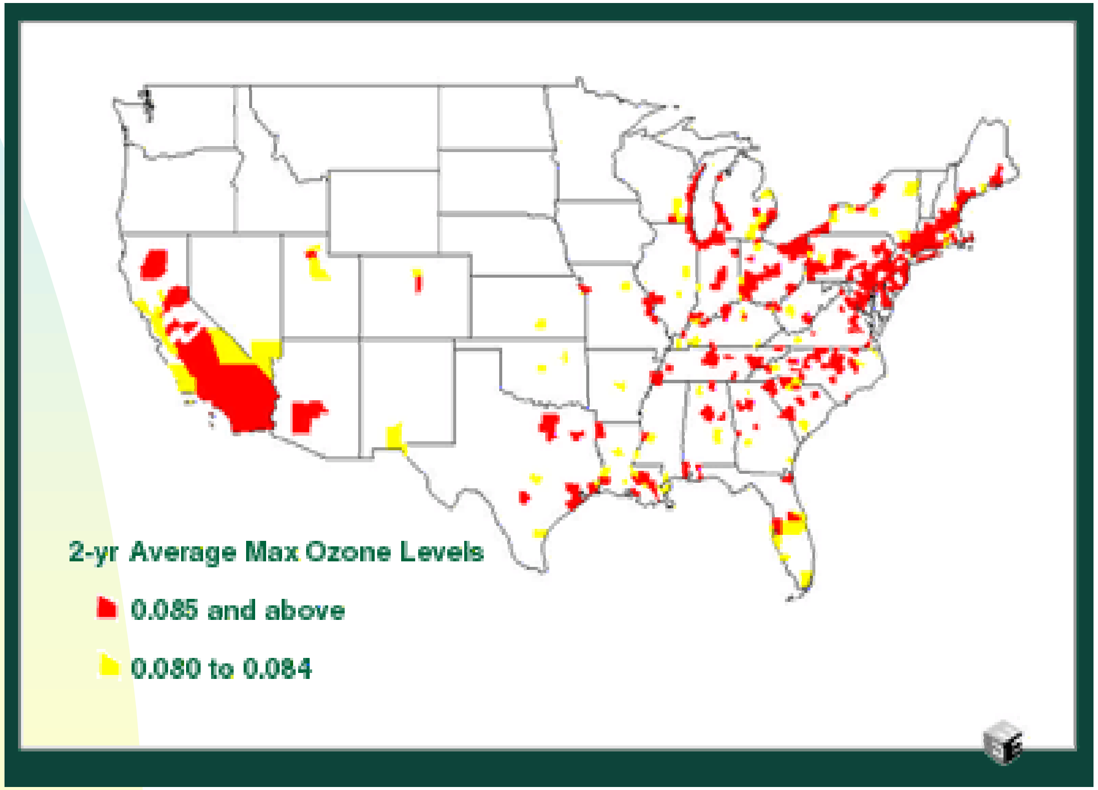
Some Acronyms

- EV - Electric Vehicle
- ZEV - Zero Emission Vehicle
- ICE - Internal Combustion Engine
- LEV - Low Emission Vehicle
- ULEV – Ultra Low Emission Vehicle
- SULEV - Super Ultra Low Emission Vehicle
- CARB - California Air Resources Board

Some Numbers

- One kWh = 3.6 x 10^6 Joules =3410 BTU
- 100 kW = about 135 Horsepower
- 120,000 BTU = about 35 kWh or about 1 Gallon of gas
- EV-1 consumption is about 4.5 miles/kWh or 120 mpg or 2 liters/100 km equivalent

1999 Smog Watch



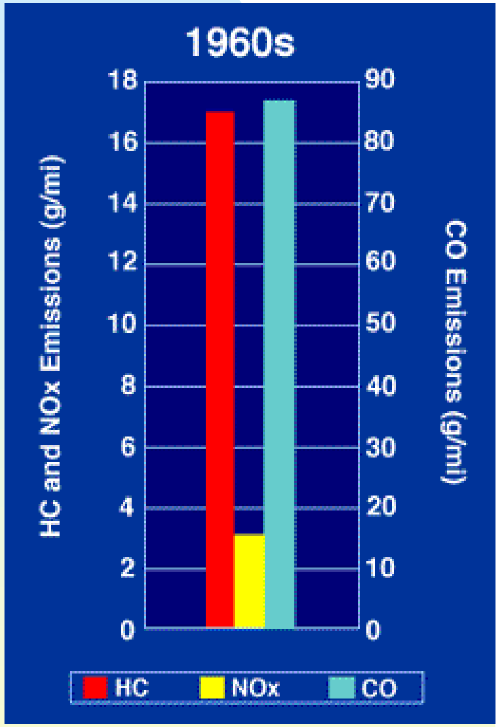
Source: DOE Fuel Cell Presentation

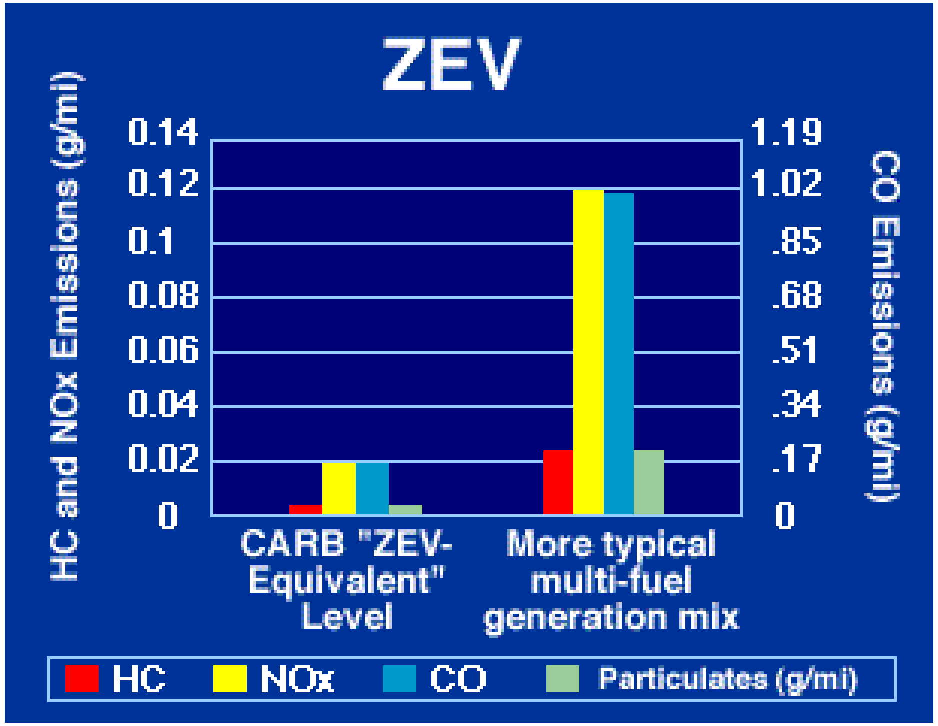
Reactive Organic Gases

1995 Data - ARB Pollution Inventory

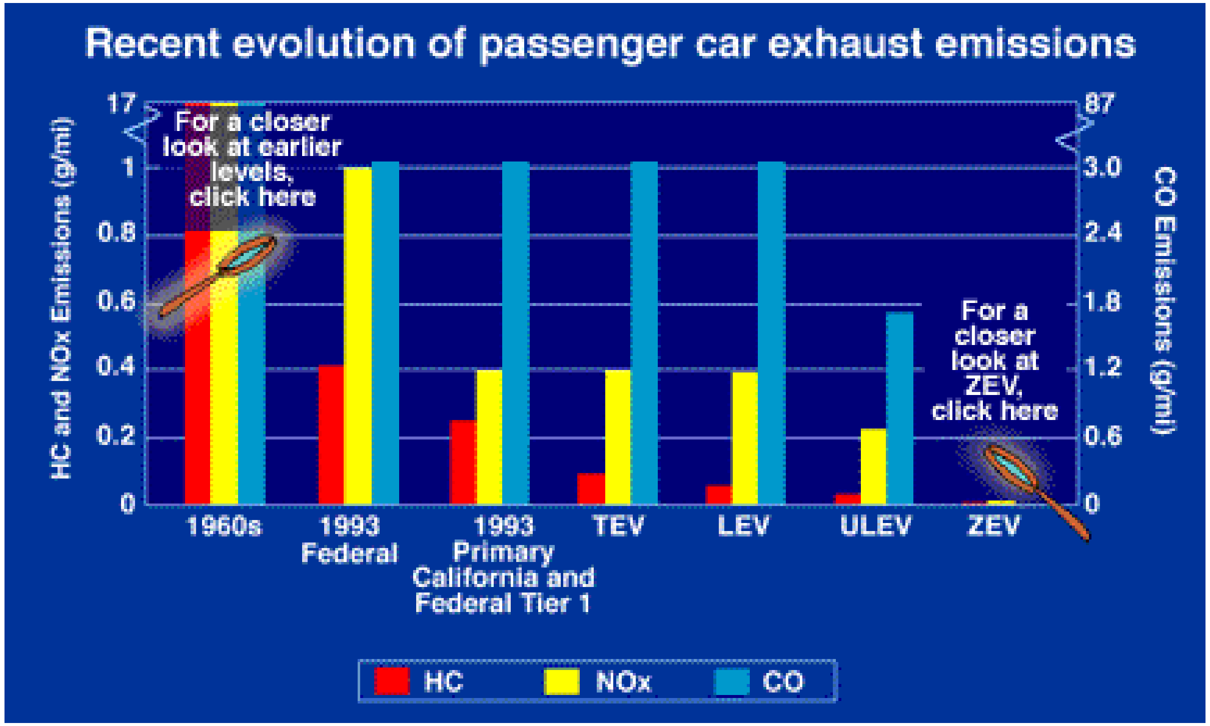
Source	Tons/day	Percent
Stationary	735 (228)	21% (**6%**)
Area-wide	779	22%
Gasoline Vehicles	1588	**47%**
Other Mobile	385	11%
Total	3487	100%
Total Auto	1816	<u>**53%**</u>

1960 and ZEV


1960s
HC and NOx Emissions (g/mi)
18
16
14
12
10
8
6
4
2
0
CO Emissions (g/mi)
90
80
70
60
50
40
30
20
10
0
HC
NOx
CO


ZEV
HC and NOx Emissions (g/mi)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
CO Emissions (g/mi)
1.19
1.02
.85
.68
.51
.34
.17
0
CARB "ZEV-Equivalent" Level
More typical multi-fuel generation mix
HC
NOx
CO
Particulates (g/mi)

CA Pollution Standards



Source: DOE Fuel Cell Presentation

Standards' Data
(grams/mile)

Category	NMOG	CO	Nox	PM	HCHO
Tier I	.31	4.2	.6		
TLEV	.156	4.2	.6	.08	.018
LEV	.090	4.2	.3	.08	.018
ULEV	.055	2.1	.3	.04	.011
SULEV	.010	1.0	.02	.01	.004

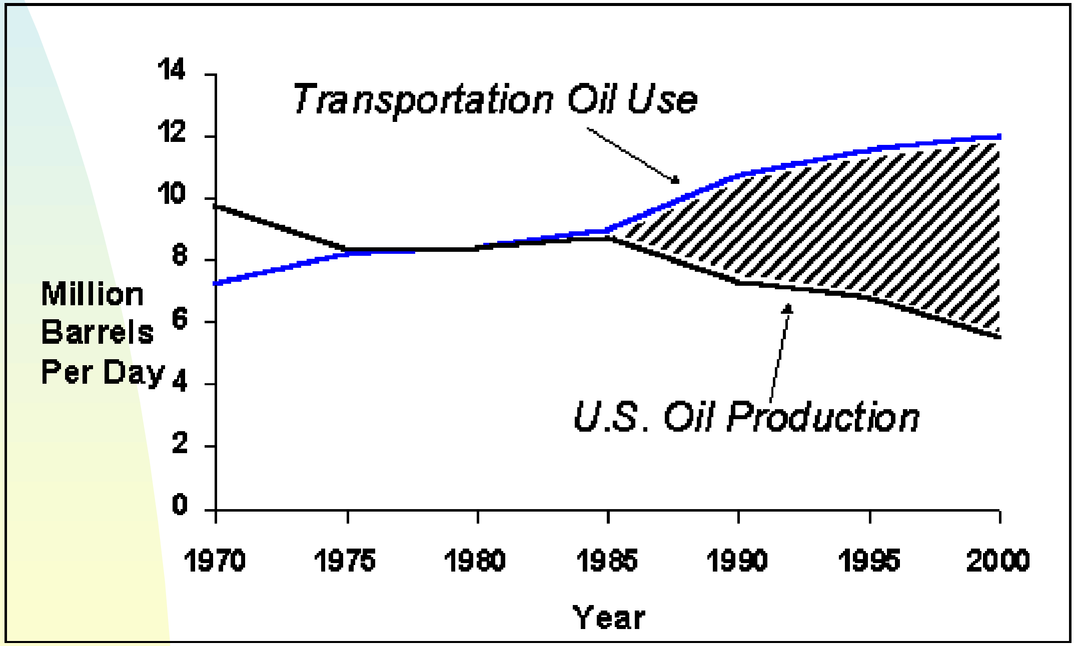
Source: www.dieselnet.com/standards/us/light.html

Fuel Cycle Emissions

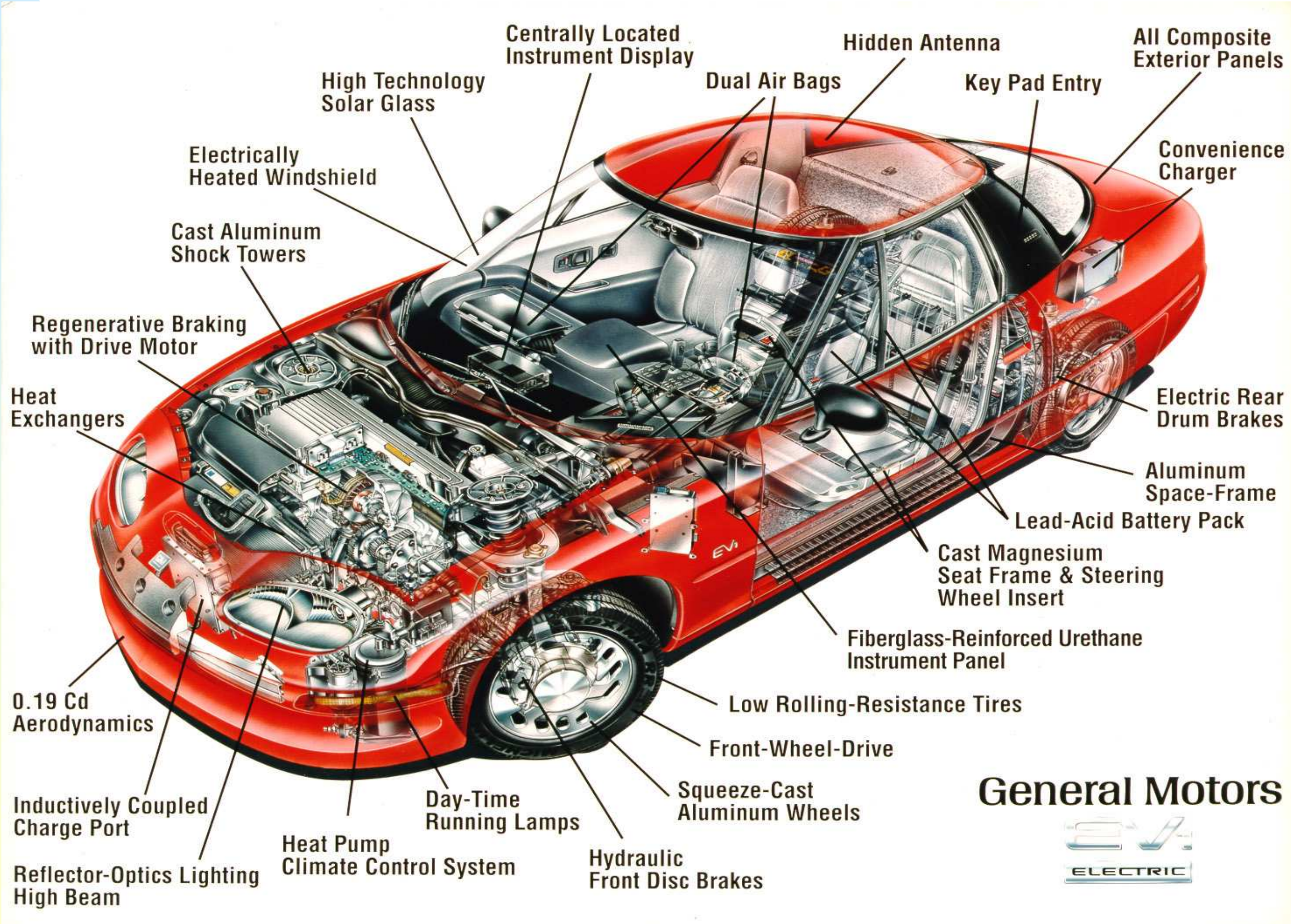
- 5 of the top 7 stationary pollution sources are refineries in the Bay area
- For perfectly functioning ULEV cars, 1/3 of the pollution is upstream
- Gasoline itself is the problem!

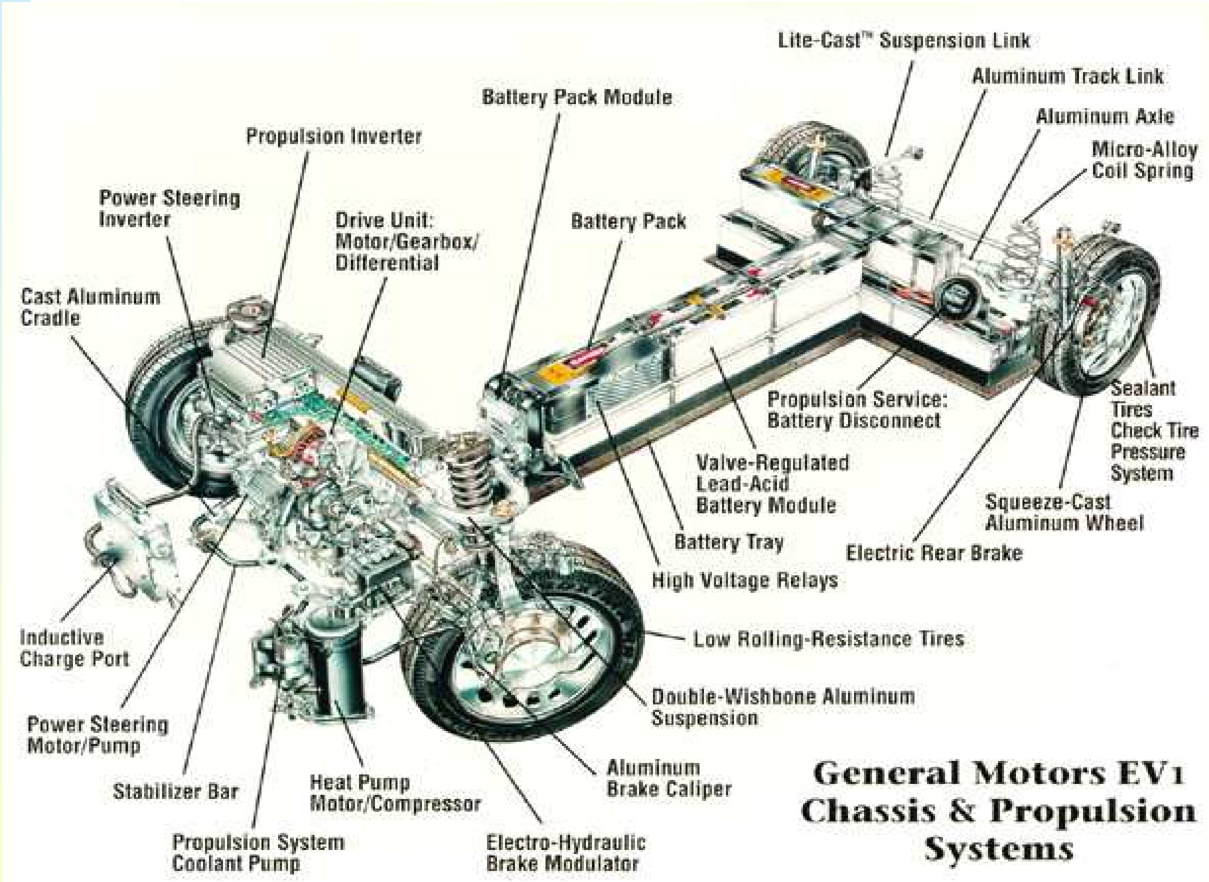
Gasoline Supply

U.S. Has Growing Dependence on Imported Oil



Source: DOE Fuel Cell Presentation


Centrally Located Instrument Display
Hidden Antenna
All Composite Exterior Panels
High Technology Solar Glass
Dual Air Bags
Key Pad Entry
Electrically Heated Windshield
Convenience Charger
Cast Aluminum Shock Towers
Regenerative Braking with Drive Motor
Heat Exchangers
Electric Rear Drum Brakes
Aluminum Space-Frame
Lead-Acid Battery Pack
Cast Magnesium Seat Frame & Steering Wheel Insert
Fiberglass-Reinforced Urethane Instrument Panel
Low Rolling-Resistance Tires
Front-Wheel-Drive
0.19 Cd Aerodynamics
Inductively Coupled Charge Port
Day-Time Running Lamps
Squeeze-Cast Aluminum Wheels
Heat Pump Climate Control System
Hydraulic Front Disc Brakes
Reflector-Optics Lighting High Beam
General Motors
ELECTRIC


Lite-Cast™ Suspension Link
Aluminum Track Link
Aluminum Axle
Micro-Alloy Coil Spring
Battery Pack Module
Propulsion Inverter
Power Steering Inverter
Drive Unit: Motor/Gearbox/ Differential
Battery Pack
Cast Aluminum Cradle
Sealant Tires Check Tire Pressure System
Propulsion Service: Battery Disconnect
Valve-Regulated Lead-Acid Battery Module
Squeeze-Cast Aluminum Wheel
Battery Tray
Electric Rear Brake
High Voltage Relays
Inductive Charge Port
Low Rolling-Resistance Tires
Double-Wishbone Aluminum Suspension
Power Steering Motor/Pump
Aluminum Brake Caliper
Stabilizer Bar
Heat Pump Motor/Compressor
Propulsion System Coolant Pump
Electro-Hydraulic Brake Modulator
General Motors EV1 Chassis & Propulsion Systems

A few other EVs

Ford Ranger

Toyota RAV4

EV Production

Manufacturer	Model	Range (miles)	# on road
Chrysler	EPIC Minivan	97	97
Toyota	RAV4	142	486
Nissan	Altra Wagon	120	37
Honda	EV+ 4 Seater	125	330
Ford	Ranger Truck	94	308
GM	EV1 Sport Car	152	500
GM	S-10 Truck	99	76

Source: CARB 2000 Preliminary Report

City Electric Vehicles (CEV)

Ford Th!nk City

Nissan Hyper-mini

Speed < 60 mph

Range about 50 miles

Neighborhood EVs (NEV)

Speed < 25 mph   Range about 25 miles

EV Pollution

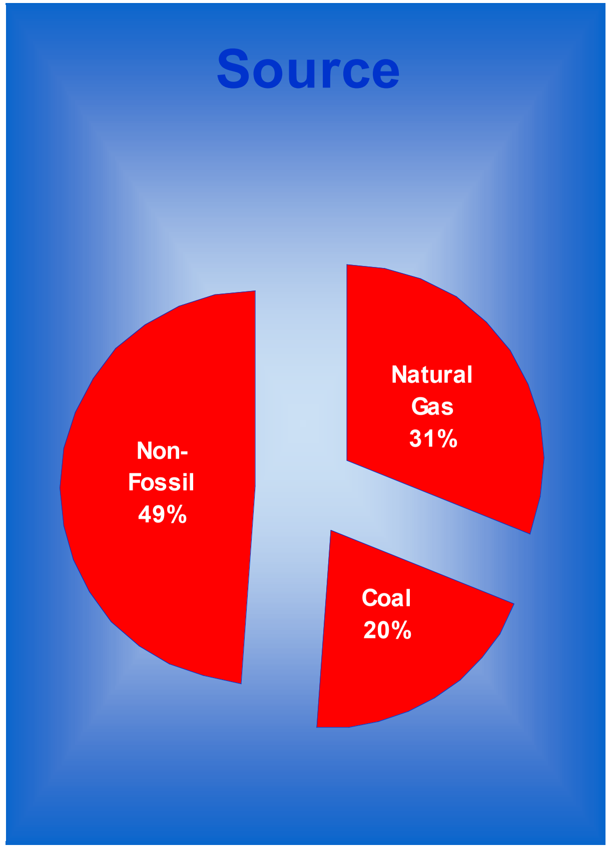
Pollutant	grams/mile	% of ICE
Total organic gases	.011	0.5%
Reactive organic gases	.002	0.13%
Carbon monoxide	.015	0.08%
Nitrogen oxides	.028	1.14%
Sulfur oxides	.0032	4.9%
Total particulates	.0025	2.6%
Particulates < 10 microns	.0020	2.6%

From: Pollution data/Total miles driven/Total power generated 1996 / 1997 P. Karn, EV Driver

These numbers are an approximation and most probably low, maybe up to a factor of two.

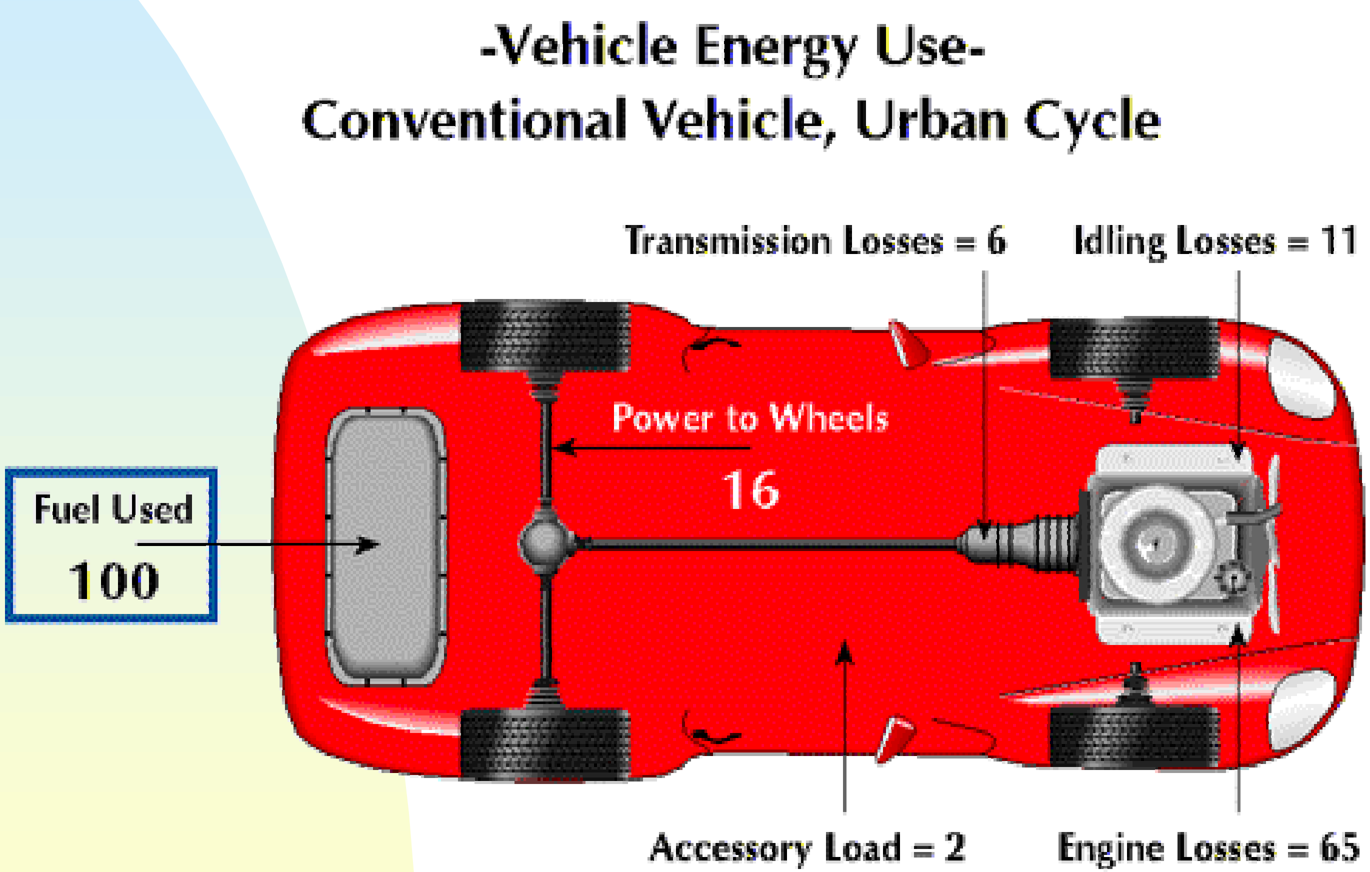
Electric Production Mix

- Old Fossil plants efficiency about 33%
- New plants will be combined-cycle gas plants, about 50-60% efficient
- Oil to refined gas efficiency is about 80%



Non-fossil is 22% hydro, 15% nuclear, 12% geothermal, solar, wind, and biomass.

ICE Efficiency



Efficiency Comparison

- Oil to Refined Gas - 80%
- Tank to Wheels 16%
- Energy Efficiency 13%

- Power Plant to Plug - 33%
- Battery to Wheels 80%
- Energy Efficiency 26%

EV Driver Enthusiasm

- Minimal Maintenance
- 1-2 cents per mile operating cost
- Quick and fast
- Wonderful support teams
- Pride in not polluting
- The wave of the future

Auto Maker Reluctance

- First Wave will be least profitable
- Final Configuration not yet clear
- Disruptive Technology Innovation

- Too expensive!?
- Range an issue?

Corporate Foresight

"The telephone has too many shortcomings to be seriously considered as a means of communication. The device has no value to us."

Western Union Internal Memo, 1876

Generic Battery Data

Technology	Energy Density W-hr/kg	Power Density W/kg	Current $/kW-hr	Future $/kW-hr
Lead Acid	35	412	150	100
NiCd	50		300	300
NiMH	80	220	1000	200
Li	183			

Source: www.madkatz.com; hearsay, manufacturers, EE-times.

Hybrids

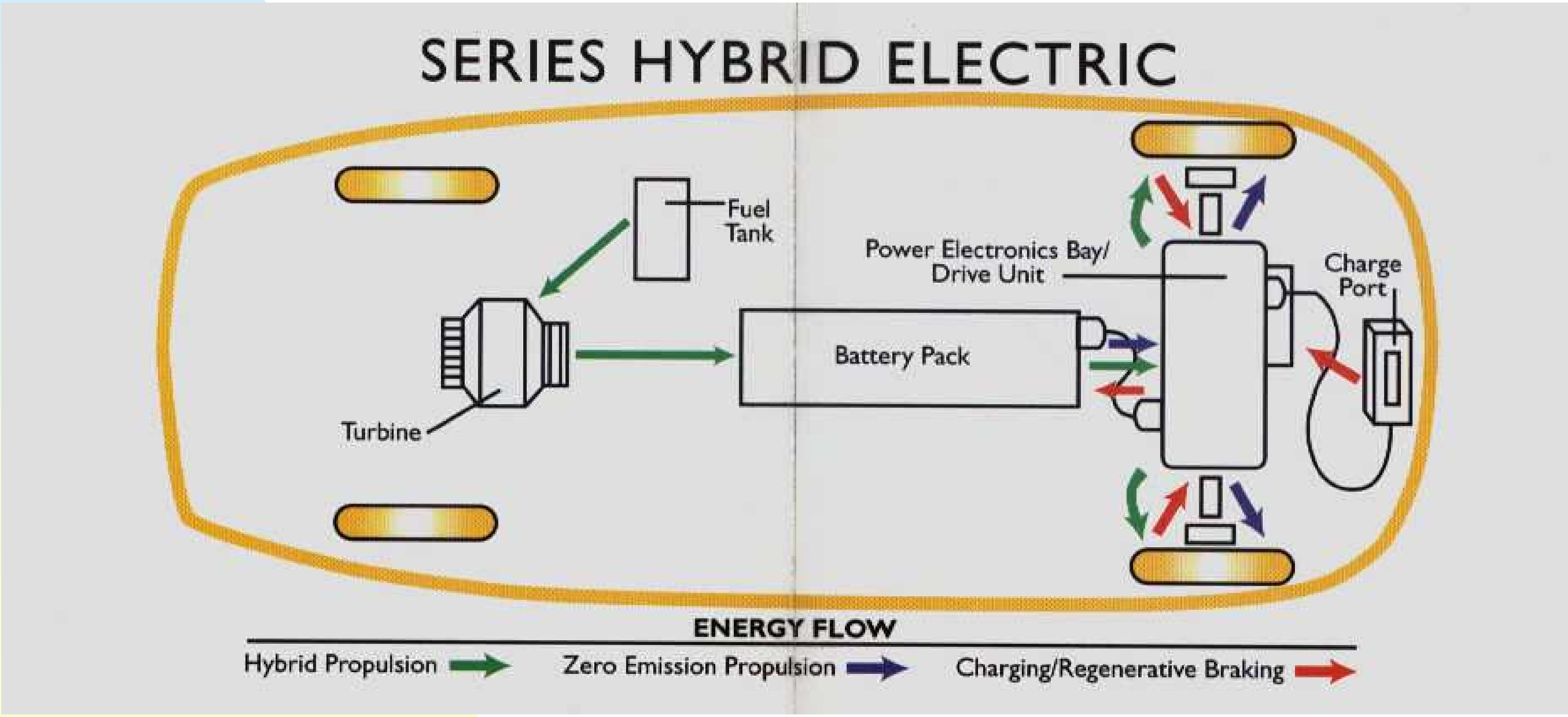
- Electric & Other (ICE, Turbine, …)
- Parallel or Series
- ICE dominant
- Electric dominant
- ZEV Credits

1917 Woods Dualpower

2 Seat Sport Coupe
Gas/Electric Hybrid
4 cylinder engine with electric boost

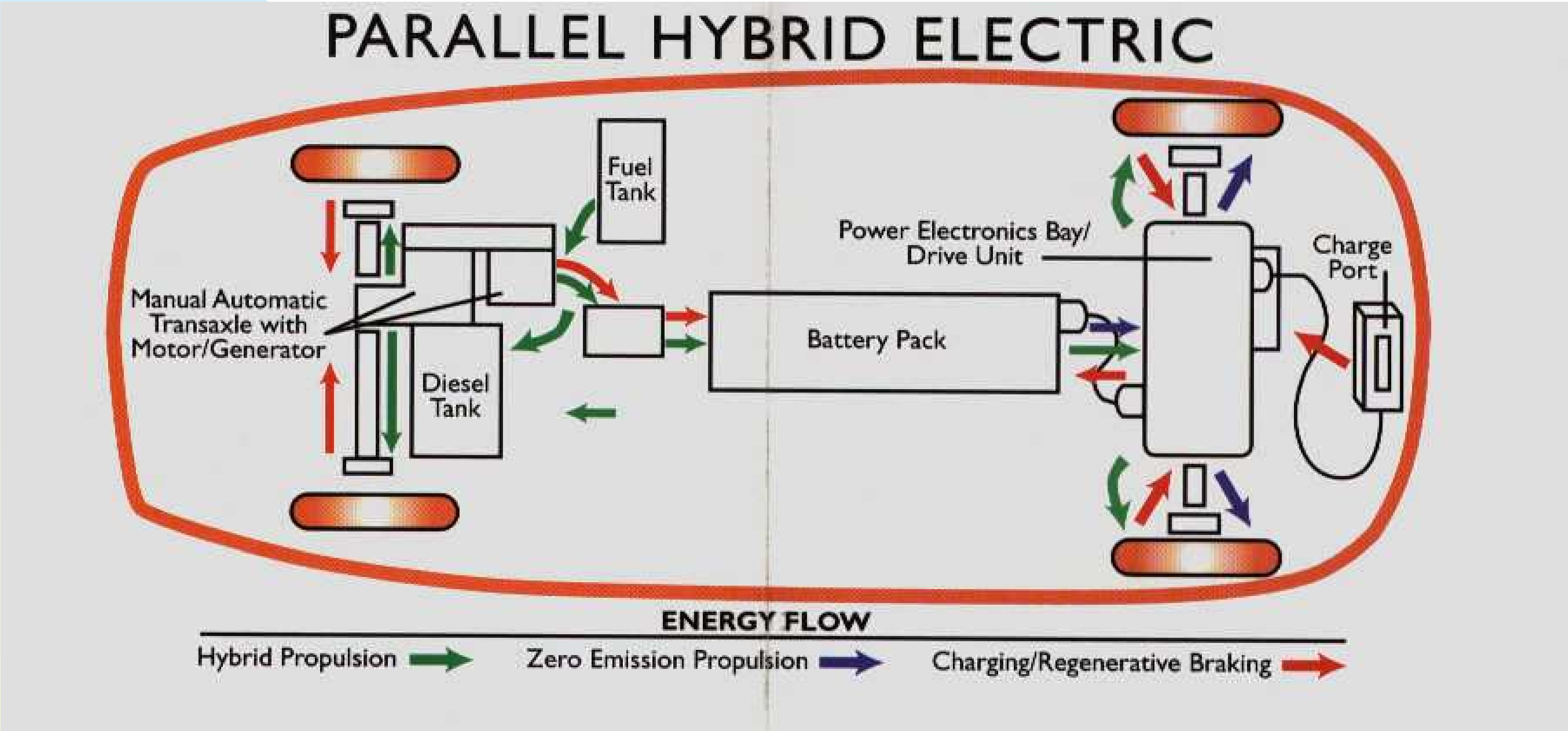
The electric motor/generator is on the end of the crankshaft. It provides electric assist during acceleration and acts as a generator to charge the batteries during braking and when the car is operating under gas power. The car could operate in pure electric mode up to 15 mph. Then the gas engine kicks in and takes over. When you stop, the gas motor shuts off.

Series Hybrid



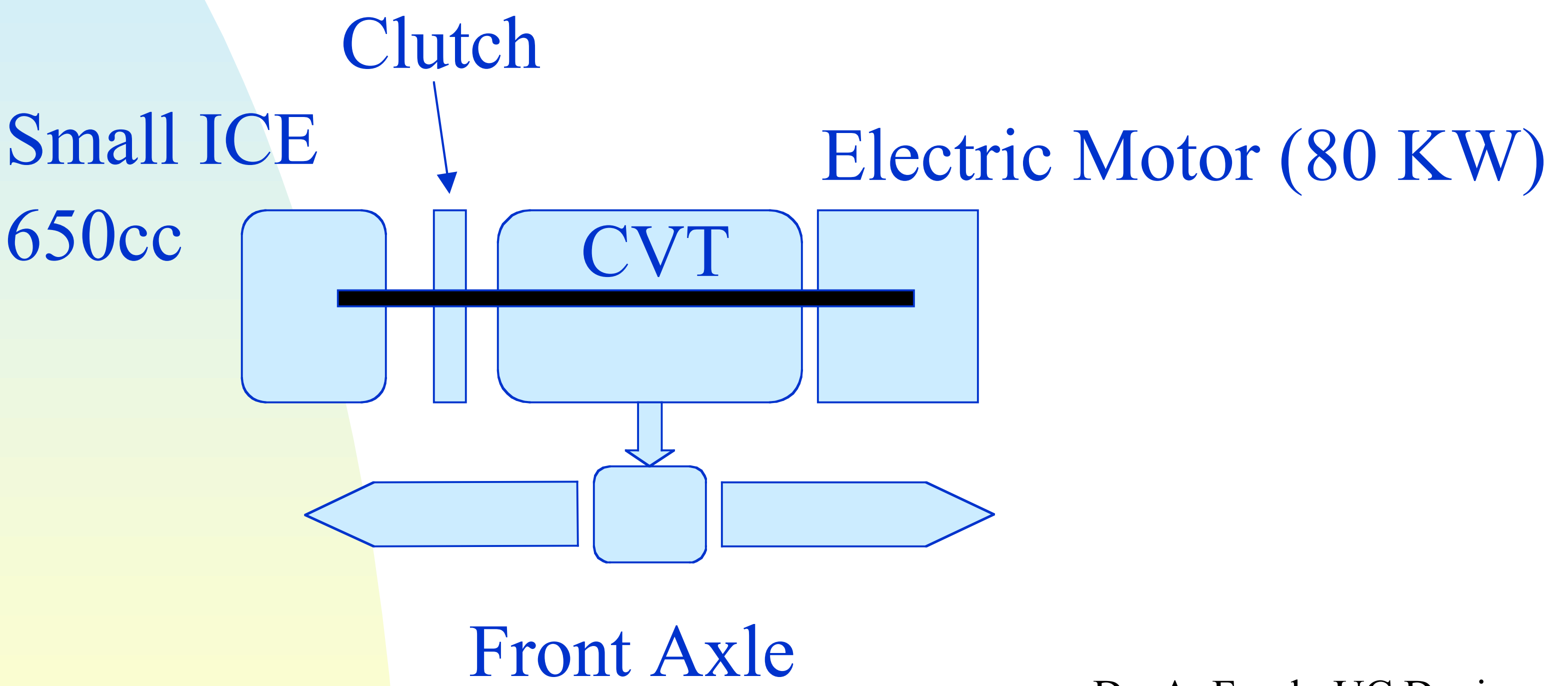
Source: 1998 GM ATV Glossy

Parallel Hybrid



Source: 1998 GM ATV Glossy

Parallel Hybrid (2)



Dr. A. Frank, UC Davis

HEV Classifications

	Parallel	Series
Charge Depleting (Battery Dominant)	Significant ZEV Range Grid charging Limited APU use Simple Efficient APU use	Significant ZEV Range Grid charging Limited APU use Simple Less efficient APU use
Charge Sustaining	Minimal ZEV range No grid charging Constant ICE use	n/a

Performance Highlights (EV-1 Variations)

	NiMH	Series	Parallel	Fuel Cell
Fuel Economy	N/A	60 mpg	80 mpg	80 mpg
Emissions	ZEV	ULEV	LEV	ULEV
Range (miles)	160 ZEV	350 (40 ZEV)	550 (40 ZEV)	> 300
0-60 time	8.5	9	7	9
Horsepower	137	137	219	137
Weight (lbs)	2,850	2,950	3,200	3,030
Seating	2	4	4	4

Source: 1998 GM ATV Glossy

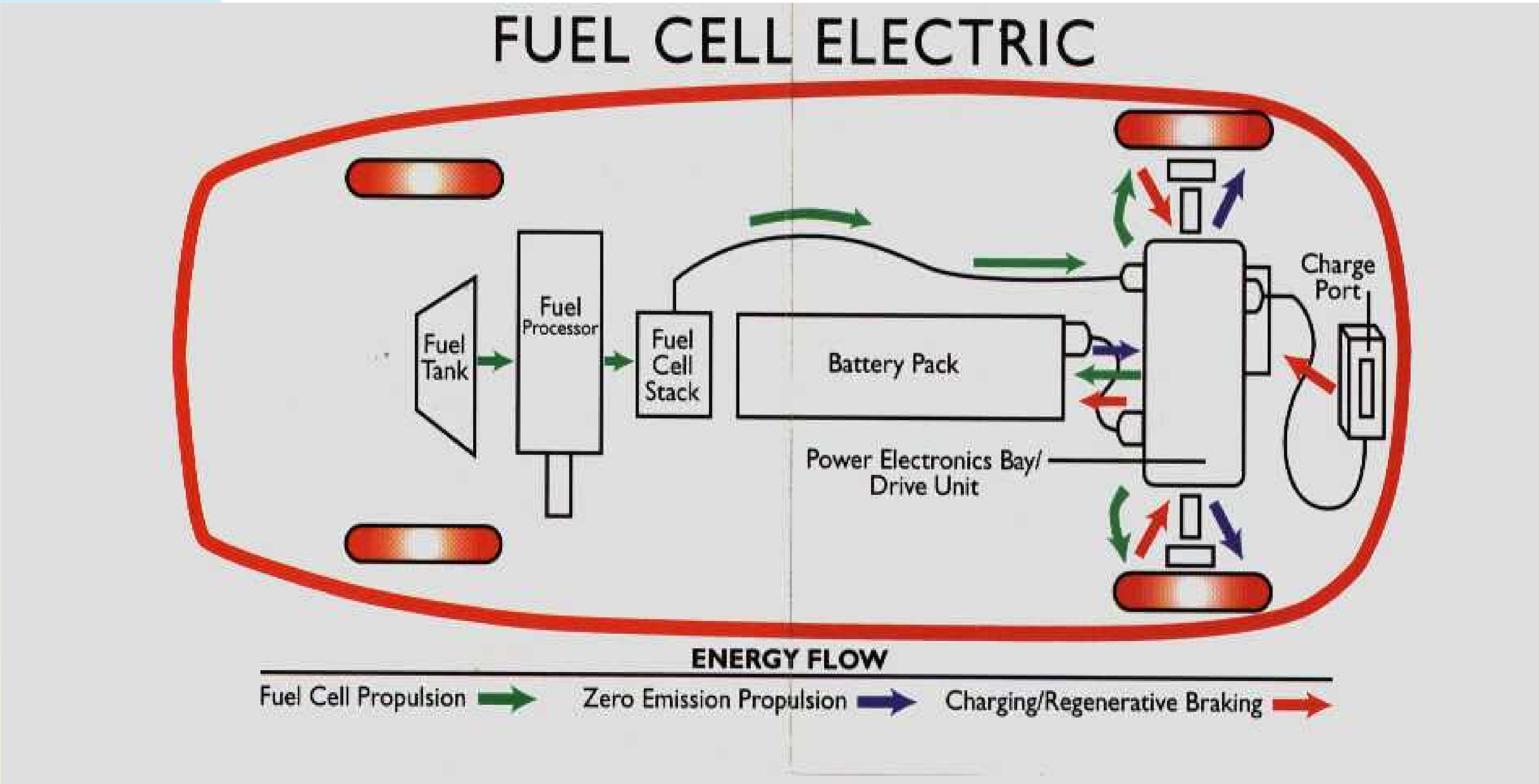
Current Hybrids

Make & Model	Emissions Class	Secondary Energy	Primary Propulsion	Secondary Propulsion
Toyota Prius	SULEV (target)	.18kWh useful energy	Gasoline ICE, (43kW)	Electric Motor (30kW)
Honda Insight	ULEV	.09kWh useful energy	Gasoline ICE (54kW)	Electric (10kW)

Fuel Cells

- Catalysts ionize hydrogen
- Recombination provides energy
- Hydrogen is the best fuel
- Ethanol, Methanol, Gas ???
- Lots of current research
- Many demonstration vehicles
- Promise for maybe 2005?

Fuel Cell Hybrid



Source: 1998 GM ATV Glossy

EV Myths

- Fuel Cells make EVs Obsolete
  EV still the gold standard
- Consumers will not buy EVs
  Real problem is supply
- EVs are too expensive
  Chicken and Egg
- Performance Inadequate
  150 Miles/ 0-60 in 8 seconds

An EV Plan for China

- Develop mass-produced advanced batteries for EVs
- Use these locally instead of old, very dirty ICE vehicles.
- Work with Korea or Japan, providing batteries for cars
- Sell these on the US market

A Stone Age Analogy

The stone age ended because a better technology was discovered, not because people ran out of rocks.

People speak of having 40 or 50 years of fossil fuel (coal & oil) left. Let us not wait until it runs out before we use better technology!

Literature

- Jack Doyle: “Taken For A Ride”
- John Motavalli: “Forward Drive”
- J. Decicco, J. Deluchi:
  “Technology, Energy, and Environment:
  How Far Can Technology Take Us?
- M. Shnayerson: “The Car That Could;
  the Inside Story of General Motors’
  Revolutionary Electric Vehicle”