Energy and Greenhouse Gas Considerations for Various ZEV Alternatives

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Introduction

- AeroVironment (AV) - Founded by Dr. Paul MacCready in 1971.

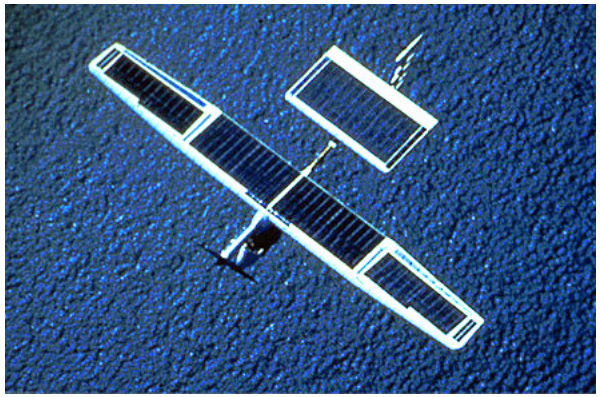
  Inspiration for AeroVironment's involvement in electric vehicles came from our experiences in:

  – Human powered vehicles

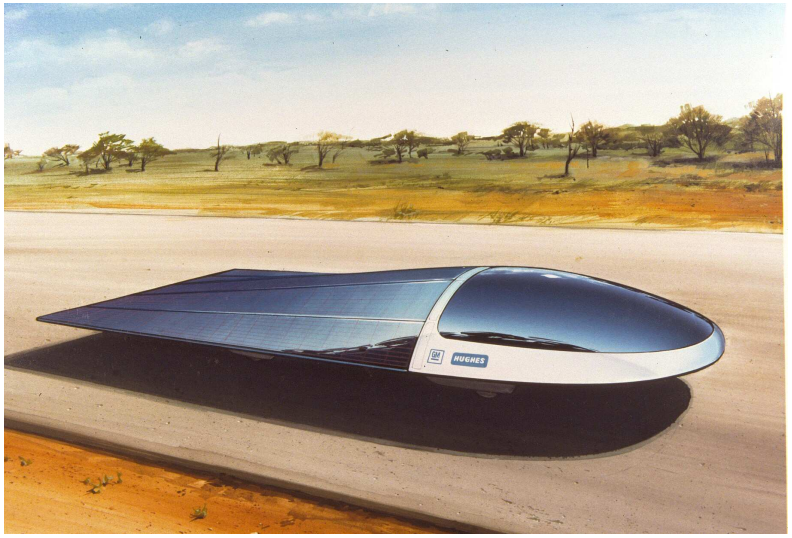
  – Human powered aircraft: Gossamer Condor/Albatross

  – Solar aircraft: Solar Challenger, Pathfinder, Helios

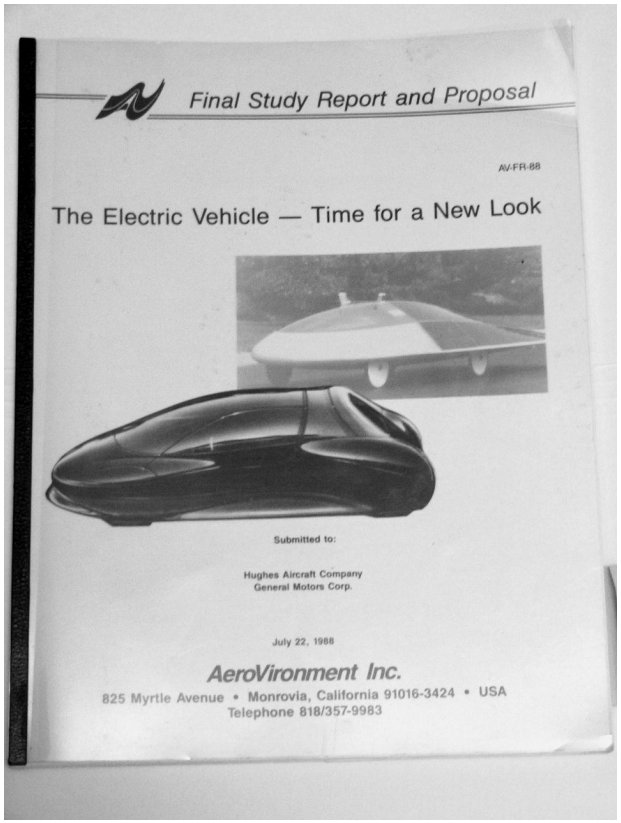
  – AV motto "Do More with less"



AeroVironment Builds and Races GM Sunraycer, 1987



AV Creates the GM Impact, Jan 1990



Proposal for Impact development
July 1988

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

Roger Smith, GM Chairman at Impact Introduction

- Jan 3, 1990, Los Angeles

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

1990 - 1996 GM Brings EV1 to Market

EVs in Daily Use by Fleets and Public; Enthusiastic Acceptance by Drivers

100,000-mile RAV4 EVs in 2003

Popular EV parking at LAX

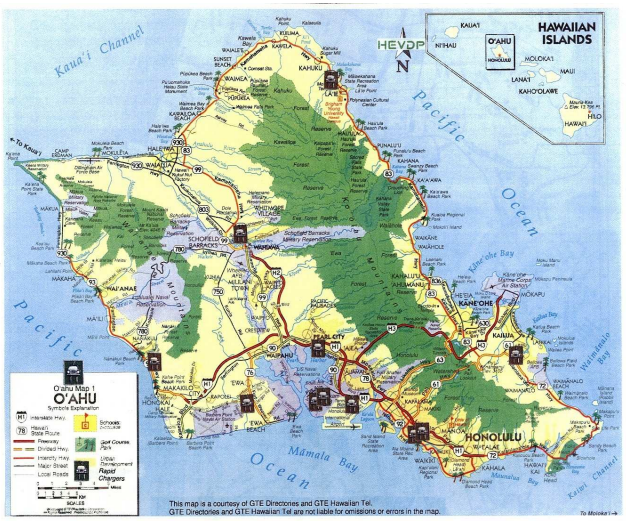
EV Rallies

EV Club Meetings

AeroVironment EV-Related Activities after GM Impact

- Consulted with GM on EV1 development
- Partner in GM/DOE Hybrid Vehicle Program
- Fast Chargers for EVs
- Charger electric bicycle (with GT Bicycles)
- Battery Cycler Product Line
- EV Fast Charging System
- Fast charging for electric lift trucks and airport ground service equipment
- Electric, solar, and hydrogen powered unmanned airplanes

PosiCharge Fast Charger for On-Road Electric Vehicles



Fast charging network in Hawaii

60 kW production unit
120 kW prototype

Posicharge Fast Charging for Lift Trucks

- Posicharge has more than 50% of fast charge market share
- ~6000 charge ports to date

Posicharge installation
at SYSCO Food Services, Inc.

Posicharge Fast Charging for Airport Ground Service Vehicles

Airports:

Houston
DFW
Orange County
Ontario
LAX
San Diego
Burbank
Sacramento
San Francisco
Seattle
Salt Lake City
Phoenix
Chicago
Atlanta
Boston
La Guardia
JFK
Newark
Dulles
Denver
Orlando
Hong Kong
Macau
Toronto
Heathrow

Airlines:

American
Delta
Continental
US Airways
Southwest
ASA
Skywest
FedEx
Southwest

ABC150 Battery Cycler

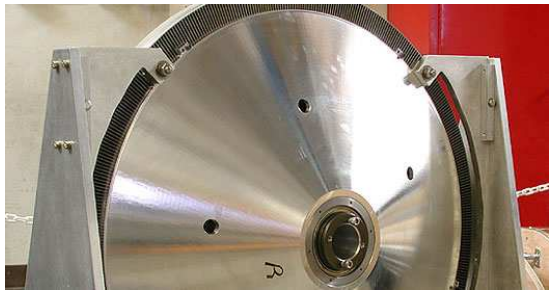
- Bi-directional DC souce and sink, up to 445 V, 530A.
  - Developed in early 1990's to support EV and HEV battery and vehicle testing
  - Flexible current/voltage/power modes, scripted standard drive cycle testing
- Systems in use at 70 locations -- automakers, battery companies, component manufacturers, fuel cell companies, aerospace, and research labs

Hydrogen Unmanned Aircraft

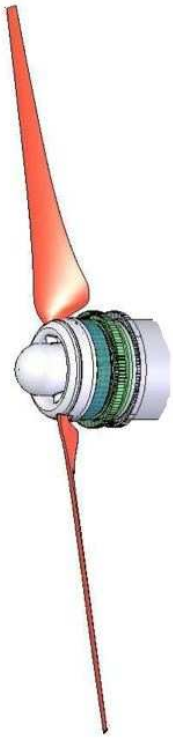
- AV is developing the Global Observer - a high altitude liquid hydrogen powered unmanned aircraft
- A 50-ft scale model was flown in 2005 with liquid hydrogen and a fuel cell powerplant
- Hydrogen has ~ 3x the specific energy of hydrocarbon fuels; enables greater endurance for aircraft, where fuel weight is significant fraction of total weight
- Multi-day duration at 65,000 ft

Ironless Motors

- Motors without iron can have much higher efficiency
  - Initial applications in aircraft
  - Potential EV / HEV applications for power generation and traction drives



50 kW prototype ironless motor for Airship Propulsion
Efficiency ~97%

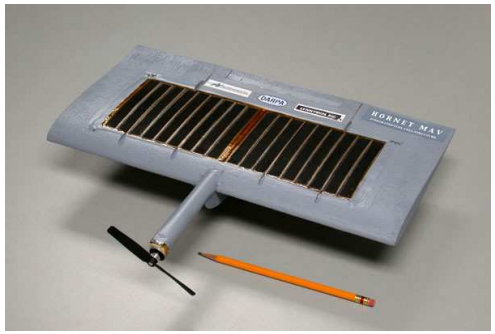


Ironless motor motor for Global Observer.
Efficiency ~96%

Electric Airplanes

Helios - solar powered,
Altitude world record holder
96,863 feet

Raven



Hornet: first fuel cell
powered aircraft, 2003

Wasp, 16” span
9 oz, 45-60 min
endurance

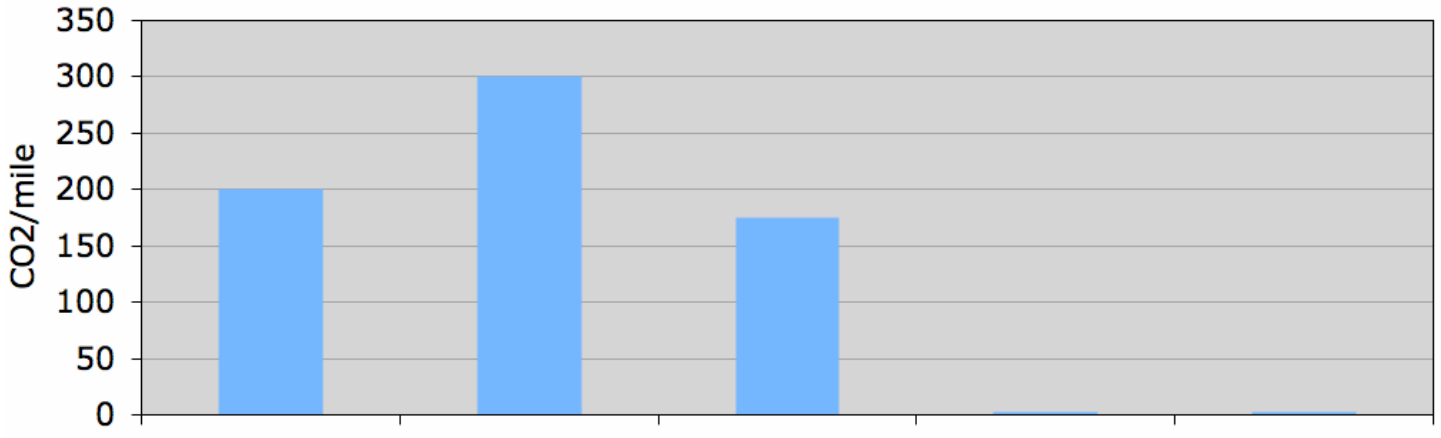
Architectural Wind Energy

- AV developing architectural wind products for integration on buildings

Considerations when Comparing ZEV options

How Do We Account for the Environmental Footprint of Vehicle Alternatives?

- Is it enough to say that an option is green just because it can be fueled with renewable energy? It matters how much renewable energy it takes!
- How to factor in the opportunity cost of using renewable energy?



Both show zero greenhouse gas per mile when powered by renewable electricity -- but do both have the same environmental footprint? This graph gives no indication as to how much renewable electricity each option uses.

Hydrogen

- Hydrogen is an energy carrier made from other sources of energy - principally natural gas and electricity
- Natural gas and electricity work well directly in vehicles
- There needs to be a compelling reason to go through the trouble of converting natural gas or electricity to hydrogen to use in a vehicle, rather than using these energy sources directly in vehicles

Reduction of Greenhouse Gasses - Compared to What?

- SB76, the Calif. Hydrogen Highway funding bill requires
  - 30 percent reduction of greenhouse gas emissions relative to comparable emissions from current year vehicles.
- CARB set the greenhouse gas ‘bar’ based on 25.5 mpg, or 444 g/mi CO_2
- CARB selected hydrogen Prius as one of the demo vehicle types to lease
  - 634 g/mi CO_2 with H_2 made with California electricity
  - 287-363 g/mi CO_2 with H_2 made from natural gas
    - CO_2: 13.0 kg/kg for H_2, on-site steam reforming
      11.5 kg/gal for gasoline, full fuel cycle
      (source: Hydrogen Highway Societal Benefits final report)
  - Standard Prius 206 g/mi
  - RAV4EV 134 g/mi
  - Hummer H3: 641 g/mi
- Adding ‘new renewable’ energy doesn’t change the numerical difference between hydrogen vehicle and other alternatives

Fuel Cell Vehicle Uses Four Times as Much Electricity per Mile as EV

56.5 miles/kg H2

65 kWh/kg

1.15 kWh/mi ⟷ 0.3 kWh/mi

30 kWh/100mi

2006 Fuel Cell Vehicles	Honda FCX
Compare Side-by-Side	
Fuel Economy	
City (miles/kg)	62
Highway (miles/kg)	51
Range	190 miles
Vehicle Characteristics[1]	
Vehicle Class	Subcompact
Fuel Type	Hydrogen
Motor	80 kW DC Brushless
Type of Fuel Cell	PEM
Energy Storage Device	Ultra Capacitor 9.2 farad
Availability[2]	Lease only - 50 states

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

Use of 32 kWh per day Solar Energy

32 kWh
28 miles

FCEV

Run your car
Zero CO2

or

8.4 kWh
28 miles

EV or Plug-in HEV

+

23.6 kWh
Run household loads

1. Run ten compact fluorescent light bulbs for 5 hours
2. Provide the daily energy needs of the refrigerator
3. Run the television for 4 hours
4. Run the computer for 4 hours
5. Run the dishes through the dishwasher, including electrically heating the water
6. Run a load of laundry through the washer, including electrically heating the water
7. Dry the load of laundry (gas dryer)
8. Heat water for four showers
9. Run a 3-ton (36000 btu/h) central air conditioner for 5 hours

<u>Run your car AND your house</u>
<u>Negative</u> 10 kg CO2

Fuel Cell Vehicle vs. CNG Hybrid

Start with 3.6 kg natural gas

Reform NG
Into hydrogen

Use NG
Directly in vehicle

1 kg hydrogen

Honda FCX FCV
(EPA size class: subcompact)
3713 lb empty weight
56.5 miles/kg

56.5 miles

3.6 kg natural gas

Bi Fuel Prius II CNG*
EPA size class: midsize
3196 lb empty weight
3.4 kg/100km (combined)
18.3 m/kg natural gas

65.9 miles

* (Holdigaz SA &Gaznat SA Switzerland)

ZEV Data Shortfall

- Dig in and get real data for kg H2/mi, kWh/mile, etc. in both test cycle and real world driving
- CARB has been supporter of hydrogen for years through grants and Cal FCP, yet doesn't have information on H2 consumption - it is a secret (or what information it does has cannot be released to the public)
- CARB has not tested electrolyzer energy consumption
- In the past, CARB tested EVs for range and energy consumption at El Monte lab: SCE and EV America ran independent tests, published data.

Final Thoughts

- Evaluate greenhouse gas emissions per mile based on marginal emissions rates
  - Compare total 'global' greenhouse gas emissions for incremental miles driven with each technology
  - Allocate the same amount of "new renewables" to different options when making comparisons
- Reconsider state policy that places greatest emphasis on hydrogen fuel and use of renewable energy to produce hydrogen
  - Until true zero carbon source of hydrogen is available, use of current energy sources to make hydrogen for transportation will increase greenhouse gas emissions
  - If a zero carbon source of hydrogen becomes available as a vehicle energy source, that does not mean that hydrogen itself needs to be distributed and stored in cars;
    - Hydrogen could instead be used in a powerplant to make electricity for plug-in vehicles, or be used to create synthetic liquid fuels that can be blended into existing hydrocarbon-based fuels
- Set basis for evaluation of new technologies as BACT "Best Available Current Technology", not ACT "Average Current Technology"
  - e.g. is hydrogen vehicle better than current hybrid or electric vehicle?, not is hydrogen vehicle better than current average vehicle?