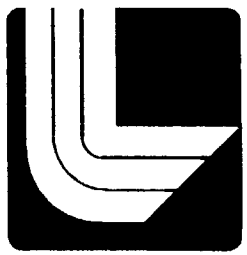
Fuel cells: Status and Technical/Economic Needs

Glenn Rambach
Lawrence Livermore National Laboratory
Livermore, CA 94550



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Technologies Needed for Engineering Design
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Hampton, VA
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Fuel cells

- A combination of material science and electrochemistry
- Convert fuel energy directly into electrical energy
  - No combustion involved
  - Not Carnot limited
  - Can be very efficient
- Made of two electrodes separated by an ion-conductive electrolyte
  - Like a battery
- Produce electricity only when fuel is applied to it
  - Unlike a battery
- Reaction product is water

Fuel cell benefits

- For natural gas at $2.00/MMBTU, and 2.9 Quad/year electrical production from natural gas, at 45% conversion efficiency, for every 1% efficiency increase there would be a $125M/year savings

- For light duty transportation use (with 10% market penetration):
  - Potential displacement of 800,000 barrels/day of petroleum.
  - Potential reduction of 1,000,000 tons/yr of criteria emission.
    - NOx, HC, CO
  - Potential reduction of 60,000,000 tons/yr of CO2.

Fuel cell types

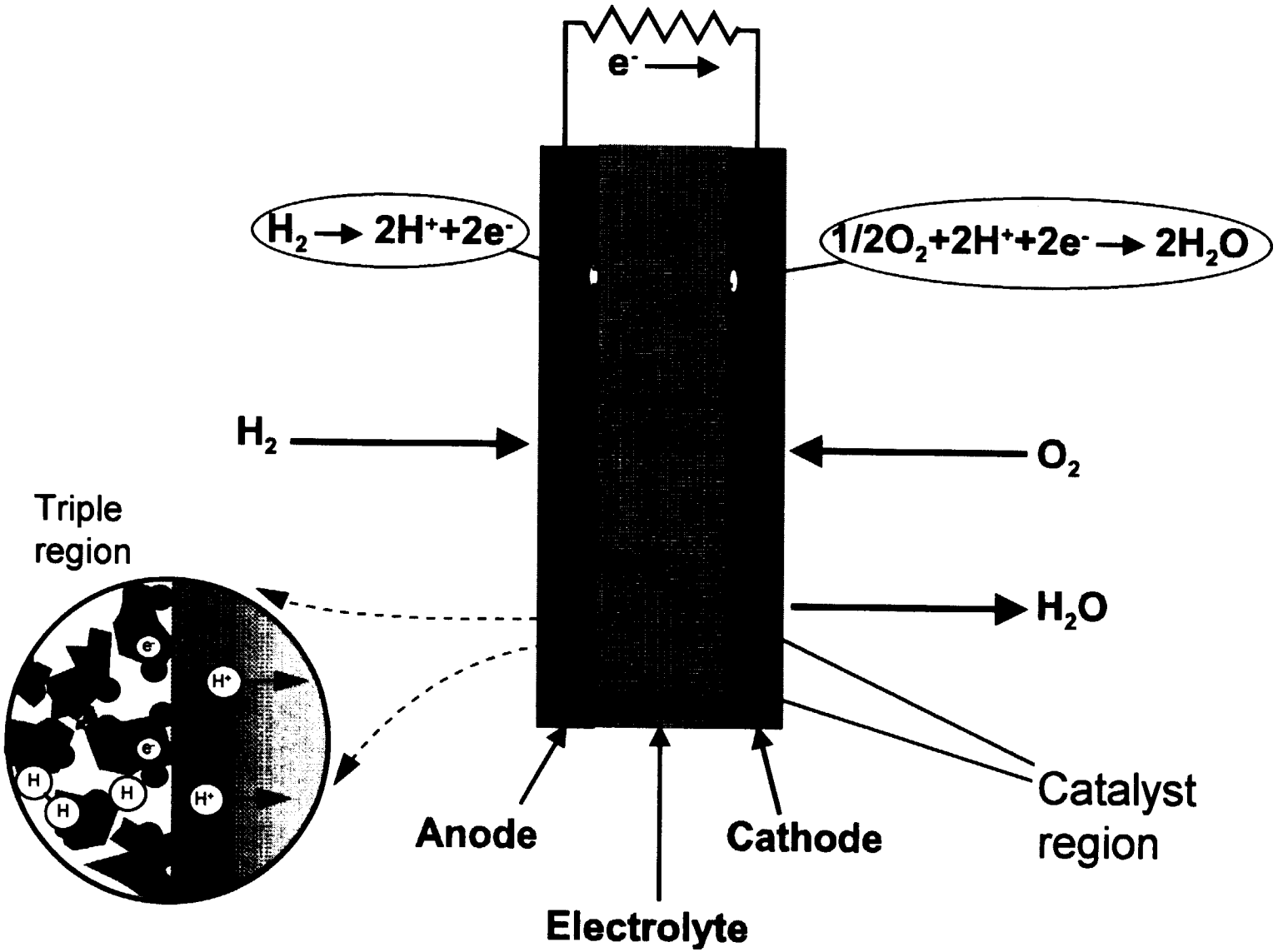
- Proton exchange membrane fuel cell (PEMFC)
  - Solid polymer electrolyte
  - Operating temperature 90C
  - Efficiency to electricity ~ 40 - 45 %
  - High power density
    - Current lead candidate for transportation
  - Requires electrolyte humidification

- Solid oxide fuel cell (SOFC)
  - Operating temperature 700 - 1000C
  - Efficiency to electricity ~ 40 - 50%
  - Potential for the highest power density
  - Potential microelectronics-like manufacture
  - O^{2-} or H^{+} conducting ceramics

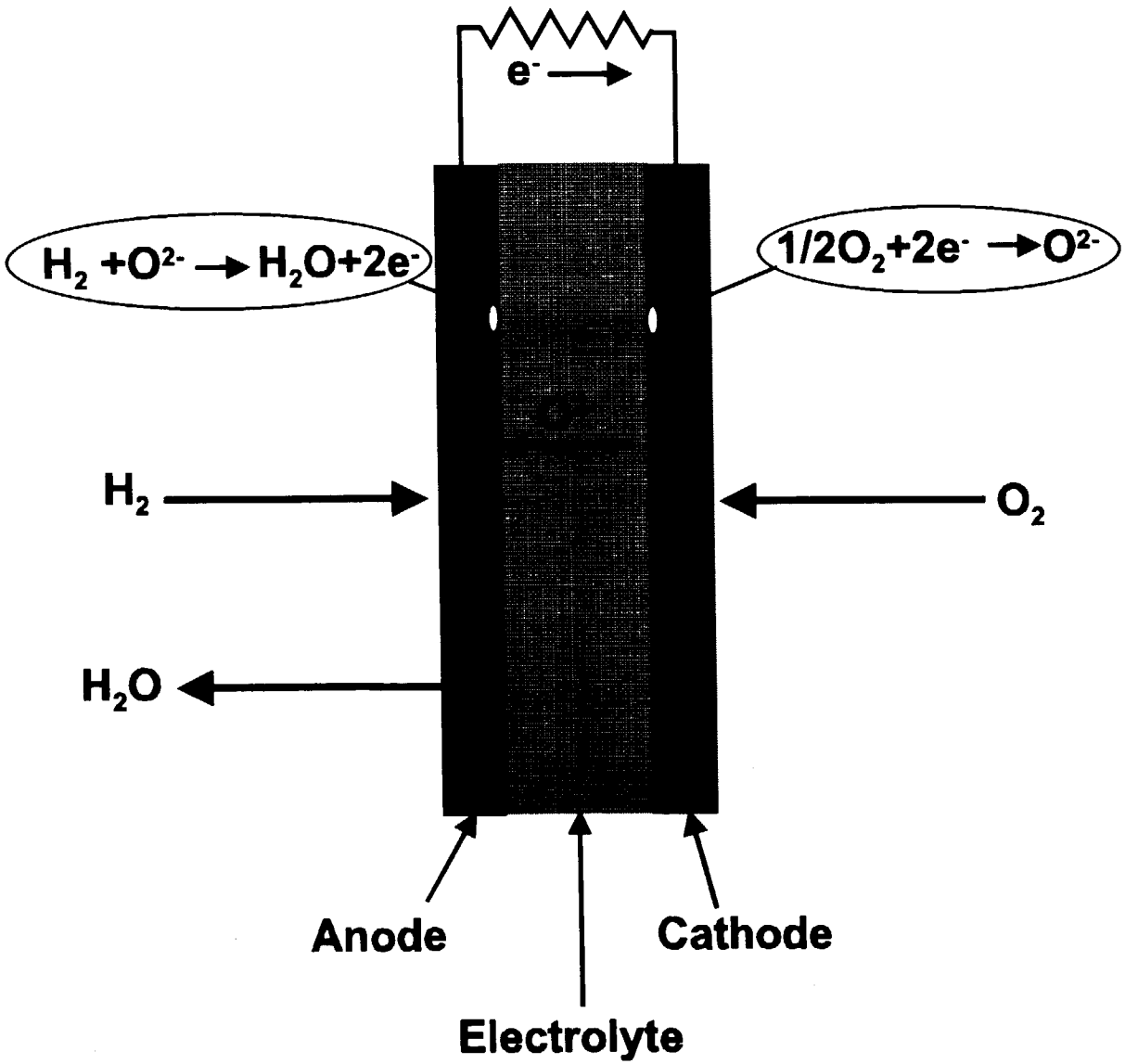
Fuel cell types

- Phosphoric acid fuel cell (PAFC)
  - Operating temperature ~200C
  - Efficiency about 40% to electricity, ~80% with cogeneration
  - Currently commercially available for stationary power
  - Power plant for buses and large vehicles
- Molten carbonate fuel cell (MCFC)
  - Operating temperature ~650C
  - Efficiency about 60% to electricity
  - Near term demonstrations for stationary power
- Alkaline fuel cell (AFC)
  - Used in space program
  - Intolerant of CO2

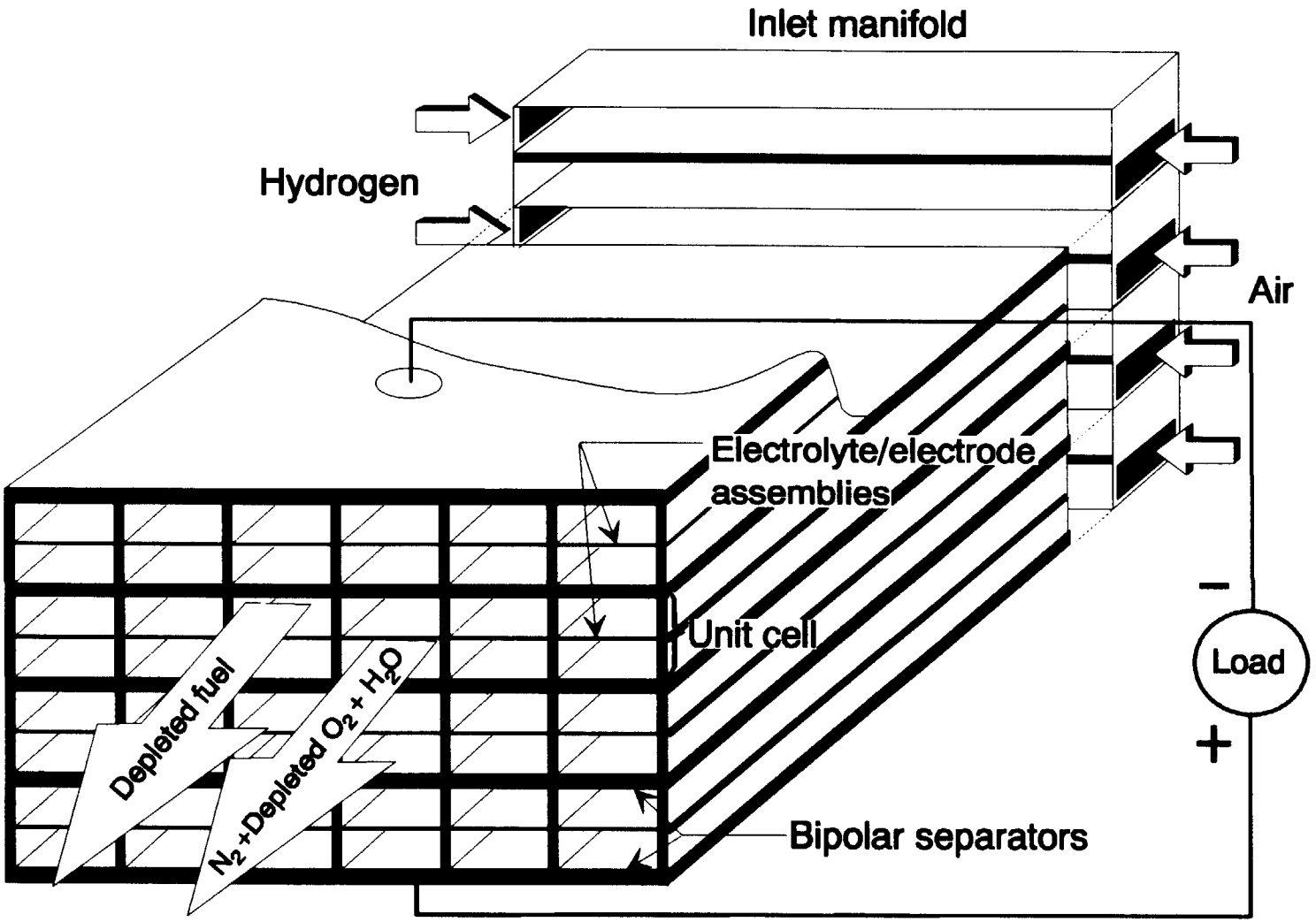
Basic fuel cell mechanism - Proton exchange



Basic fuel cell mechanism - O-ion exchange



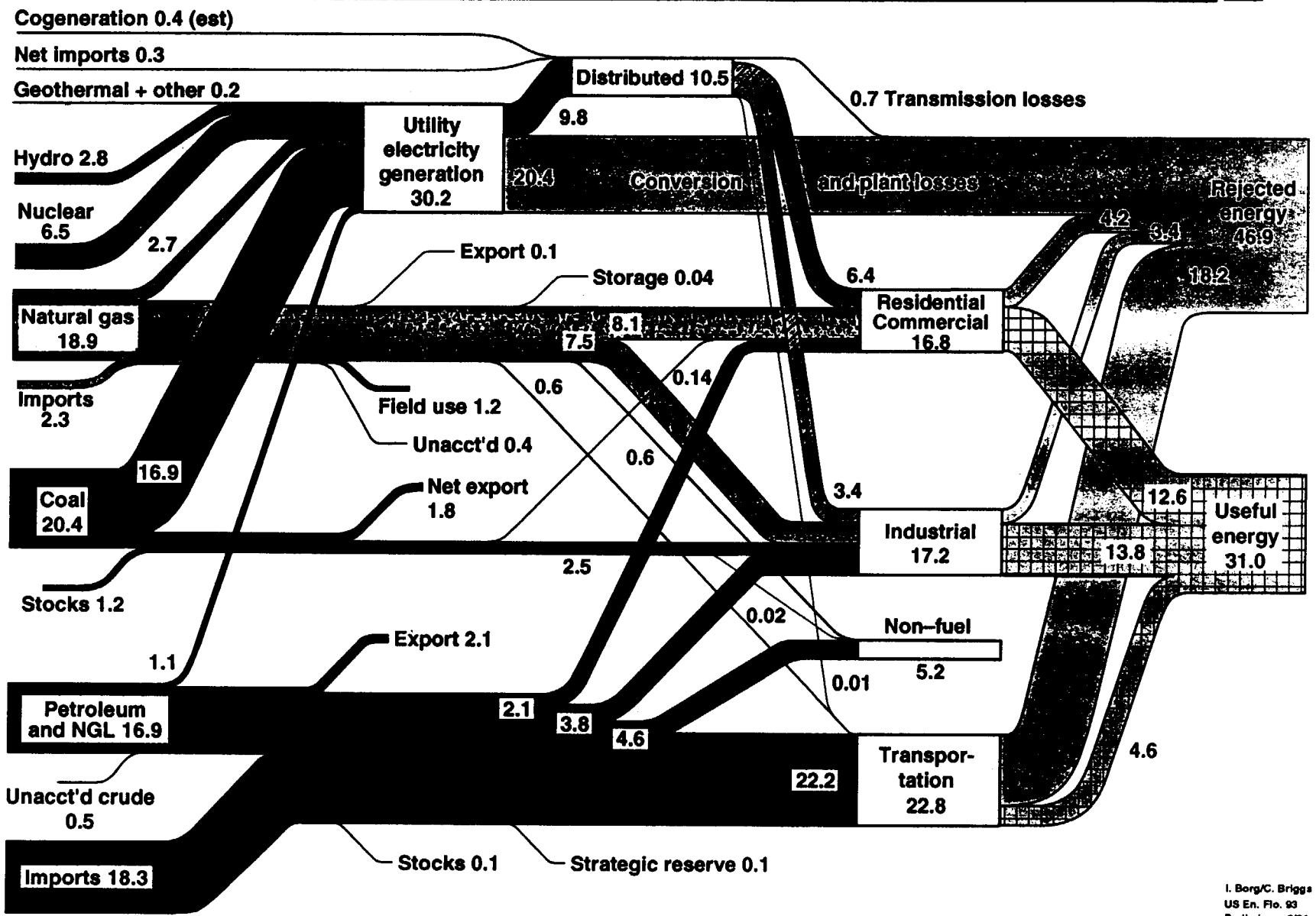
PEM fuel cell stack schematic



Why do we need fuel cells and alternative fuels?

- The U. S. spends $1B/week to import oil (>30% of the trade deficit).
  - We are expected to import $80-100B/year in oil by 2010.
- Imports account for half of our oil supply.
- If 20% of the U.S. vehicle fleet were powered by fuel cells there would be:
  - An offset of 1,100,000 barrels of oil per day.
  - A reduction of 2,000,000 tons/year of regulated air pollutants.
- Fueling fuel cells with hydrogen from reformed natural gas results in more than 90% reduction in regulated emissions, and a 70% reduction in CO_2, a greenhouse gas.
- Fueling fuel cells with hydrogen from renewables (wind, solar, geothermal, hydro) results in total elimination of all emissions.
- Fuel cells will be commercialized.
  - They will improve America's economic competitiveness.
  - The regions where they are produced will benefit economically.

U.S. Energy Flow – 1993
Net Primary Resource Consumption 84 Quads



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Other: wood, waste, photovoltaic, solar

Federal and State Issues

- California Air Resources Board (CARB) has mandated that 2% (1998) and 10% (2003) of all cars sold in California be zero emitting vehicles (ZEV).
- At least 14 other states are planning to adopt the California mandate.
- Fuel cell vehicles are the only choice to satisfy ZEV *and*:
  - Provide traditional driving range.
  - Provide traditional vehicle performance.
  - Permit traditional refueling times.
  - Provide a power plant with a lifetime which equals that of the vehicle.

Federal and State Issues

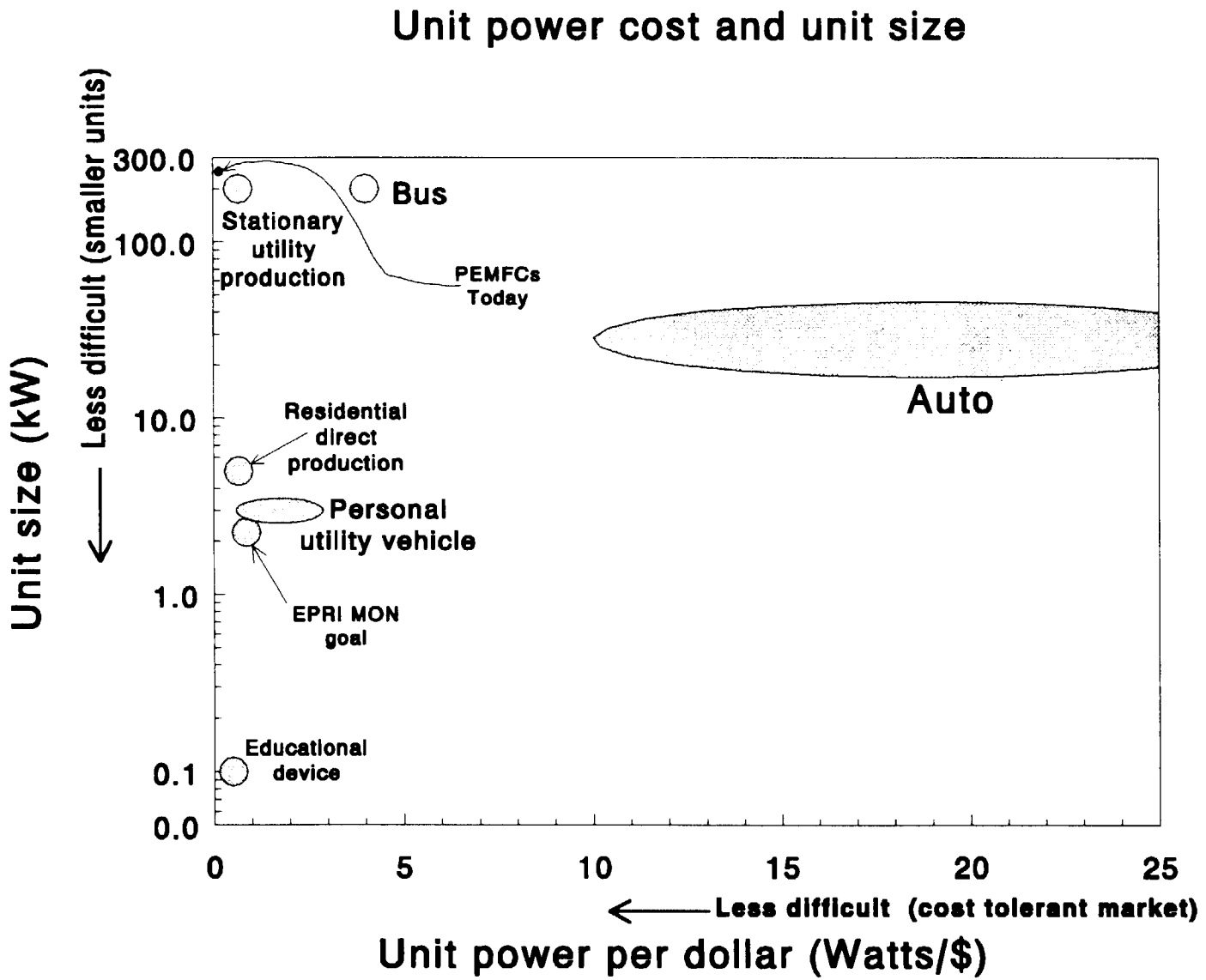
- The Clinton/Gore Administration established PNGV on Sept. 29, 1993.
  - (Partnership for a New Generation of Vehicles)
  - Consortium of the Big Three (USCAR)
  - PEM fuel cells are a key component of the PNGV future.
  - The current administration recognizes the need for fuel cells for transportation and utility uses.
  - The Federal Government is fostering industry/government alliances and opportunities for new business.
    - DOE
    - DOT
    - DOC
    - DOD
    - ARPA

- DOE, DOT and ARPA have current programs supporting fuel cells and hydrogen for future transportation.

Key fuel cell power system issues

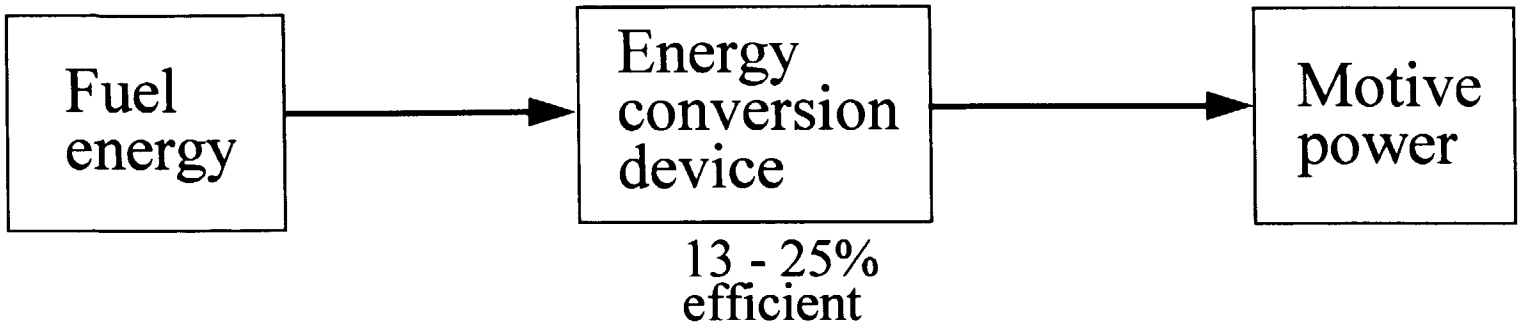
	Cost/kW	Specific power	Power density
Fuel cells today	$3000-15000/kW	.15 - .3 kW/kg	.1 - .3 kW/l
Internal combustion engines	$10 - 50/kW	.5 - 1.0 kW/kg	.3 - .5 kW/l

Market entry challenges for fuel cells

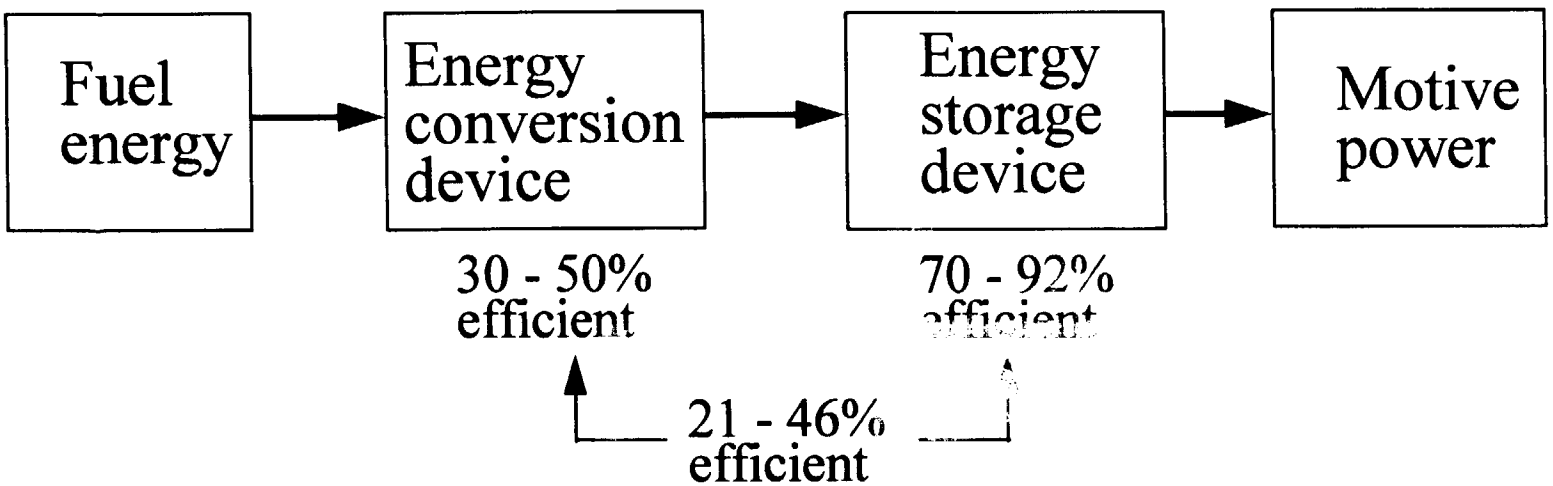


Vehicle drive options

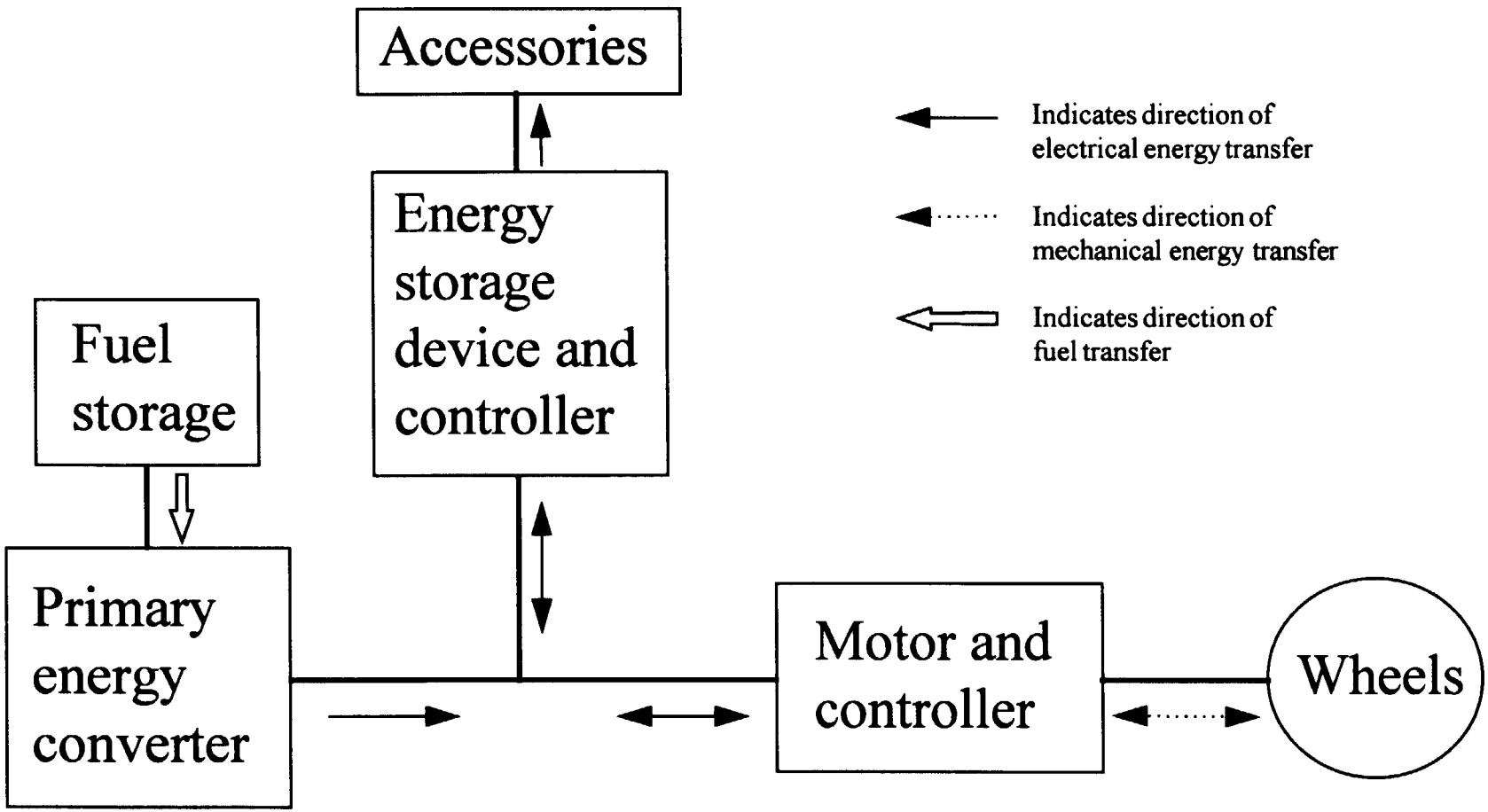
Direct drive vehicle



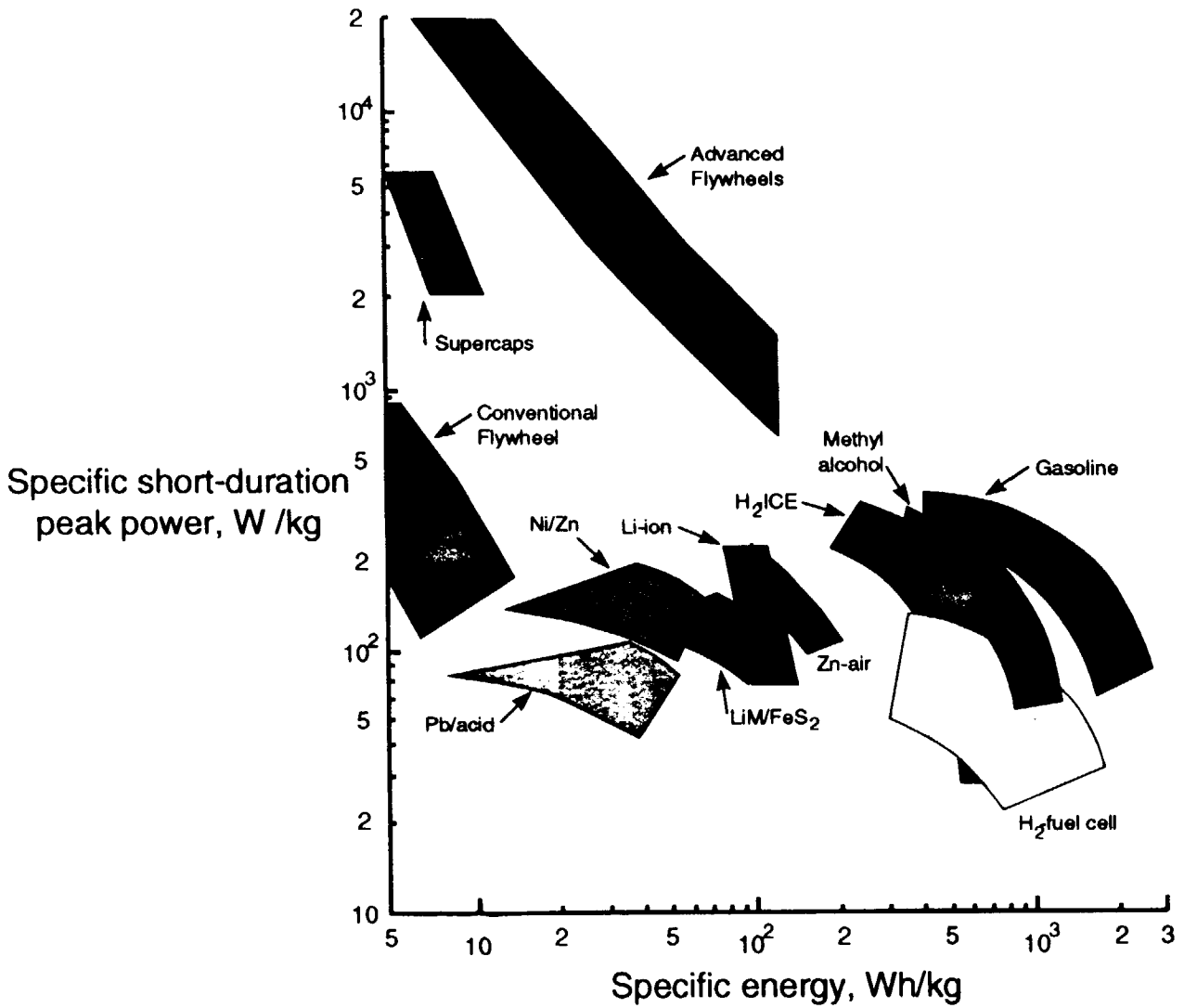
Hybrid electric drive vehicle



Series hybrid drivetrain schematic



Comparison of energy storage devices



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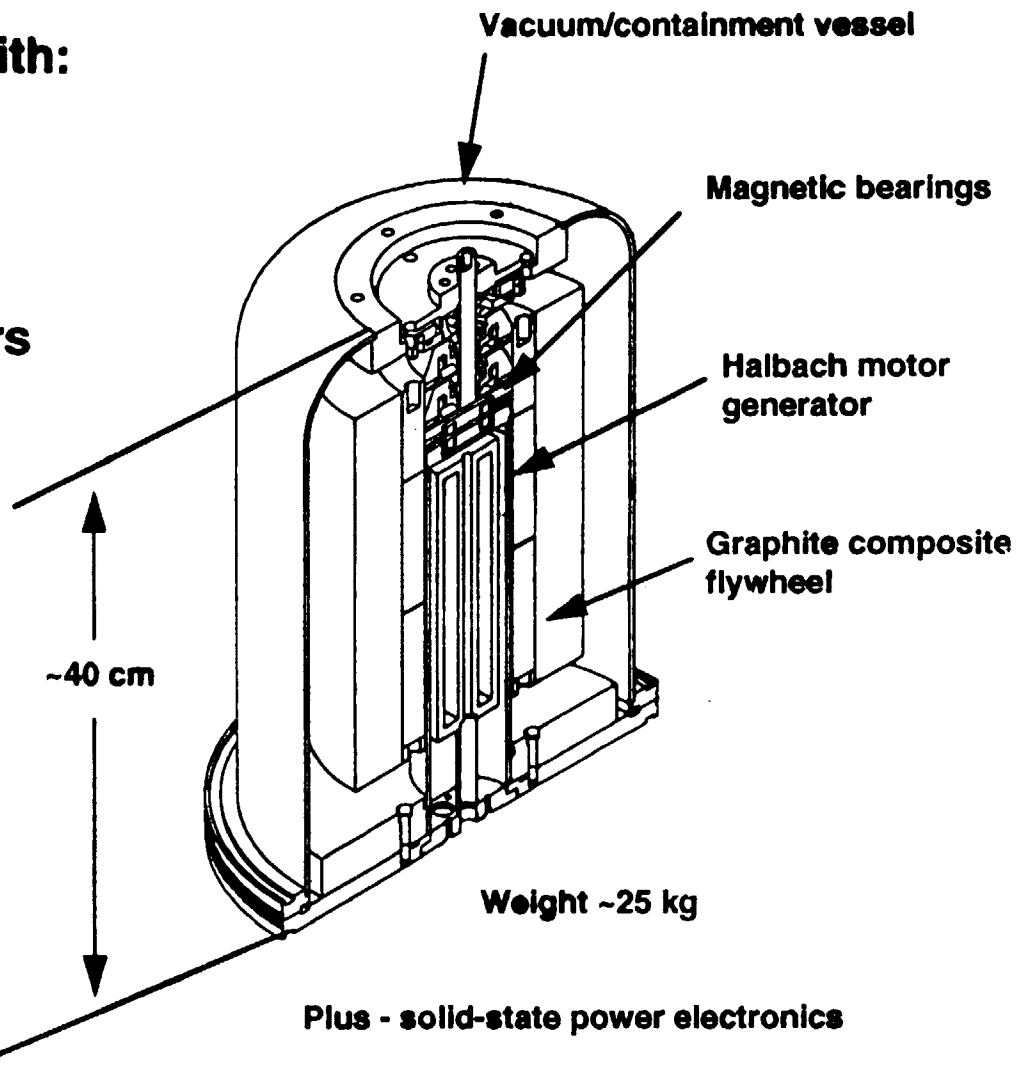
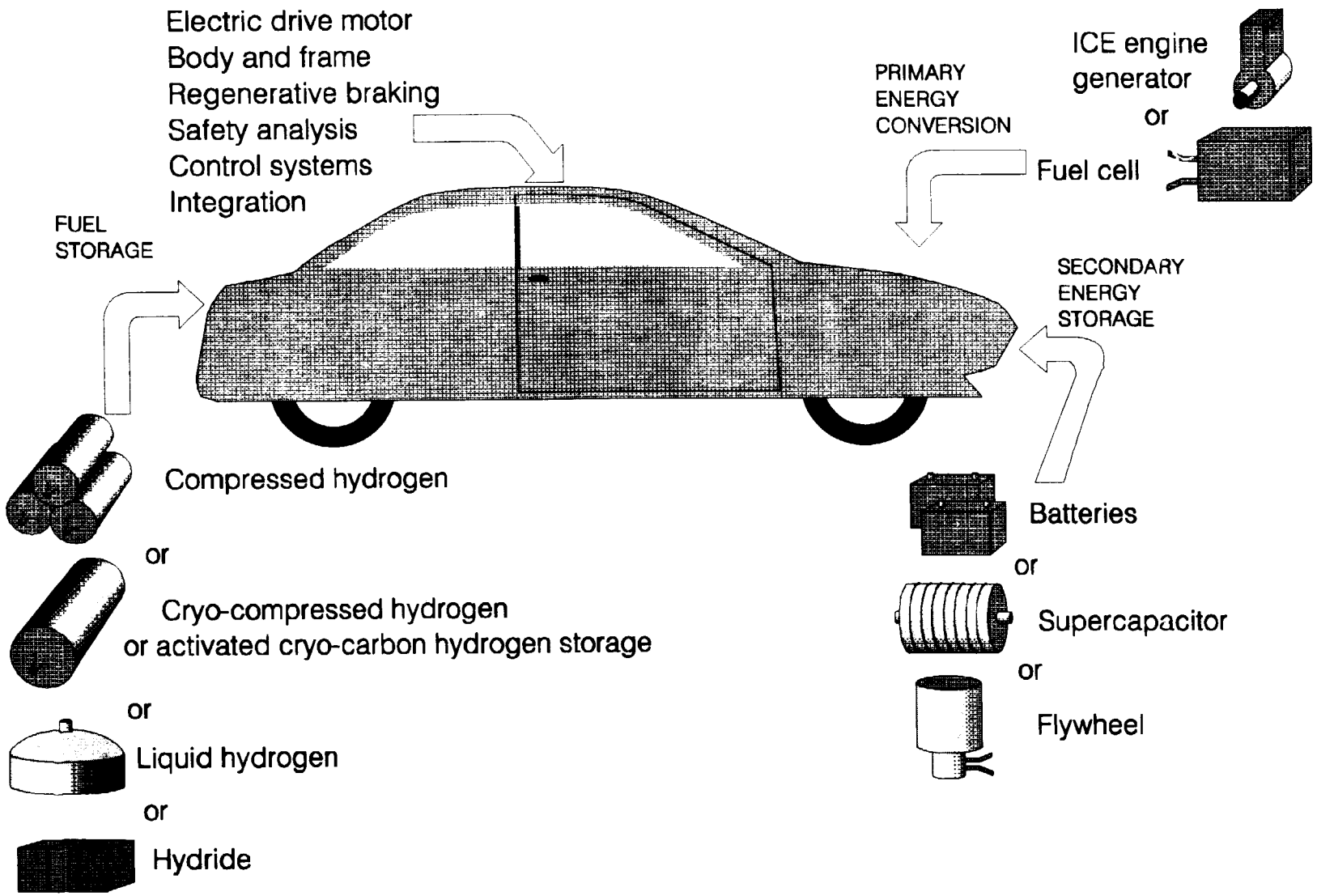
We are developing high performance electromechanical batteries

Modular flywheel energy storage with:

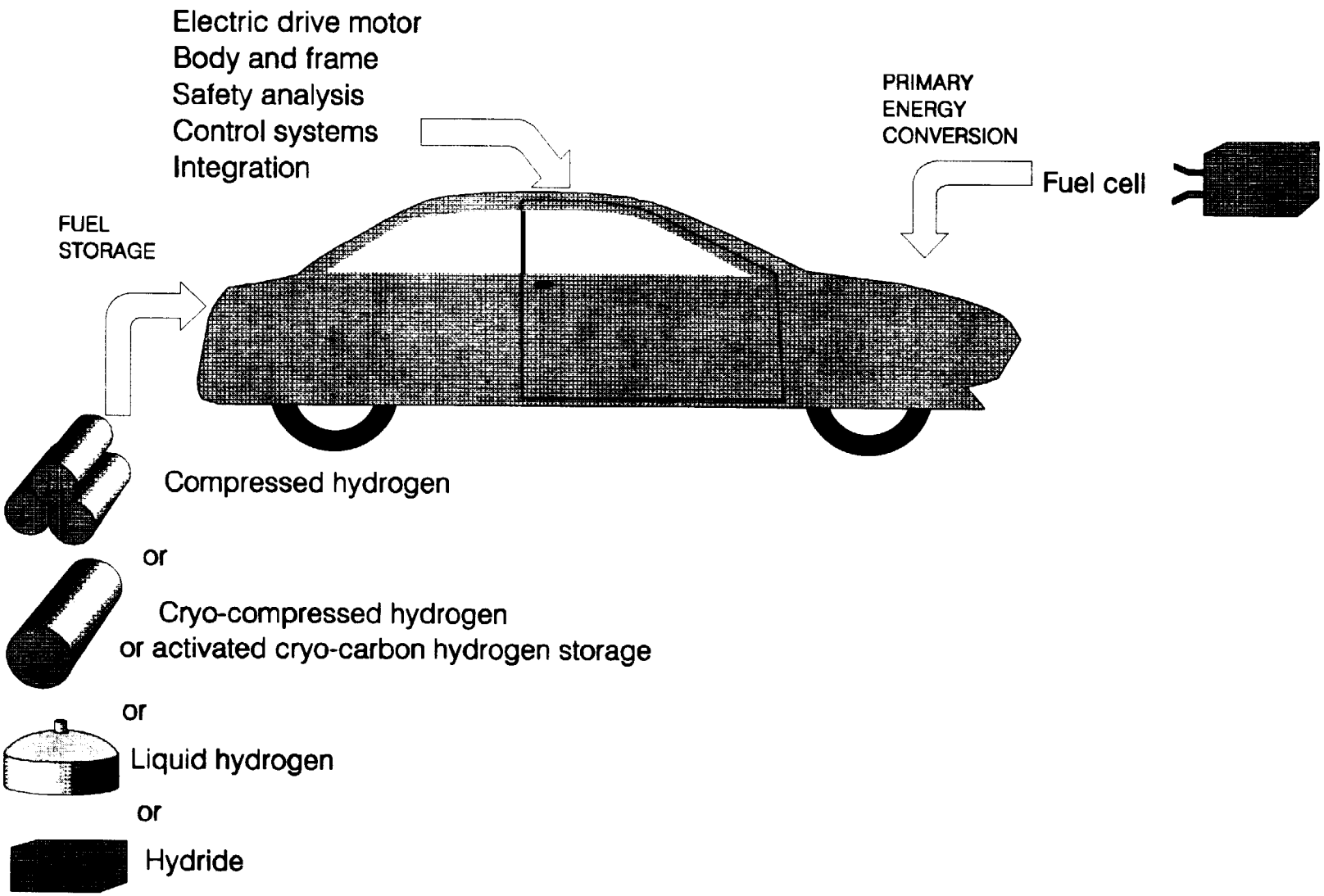
- **High power >140 kW**
- **Stored Energy >1kWh**
- **High storage efficiency: >95%**
- **Long service lifetime: >10 years**
- **No toxic chemicals or scarce materials**



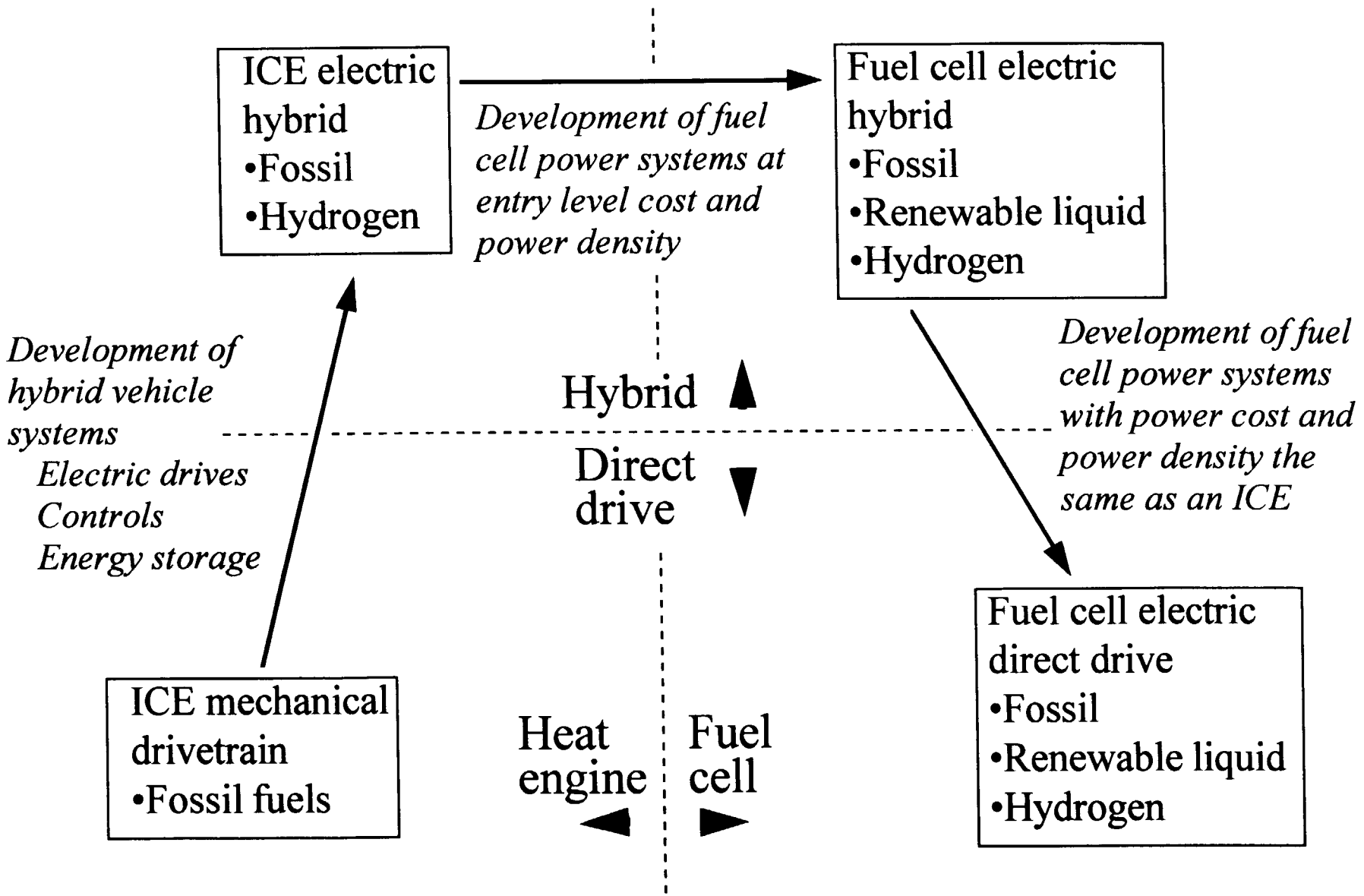
Hydrogen hybrid electric vehicle Components and technologies



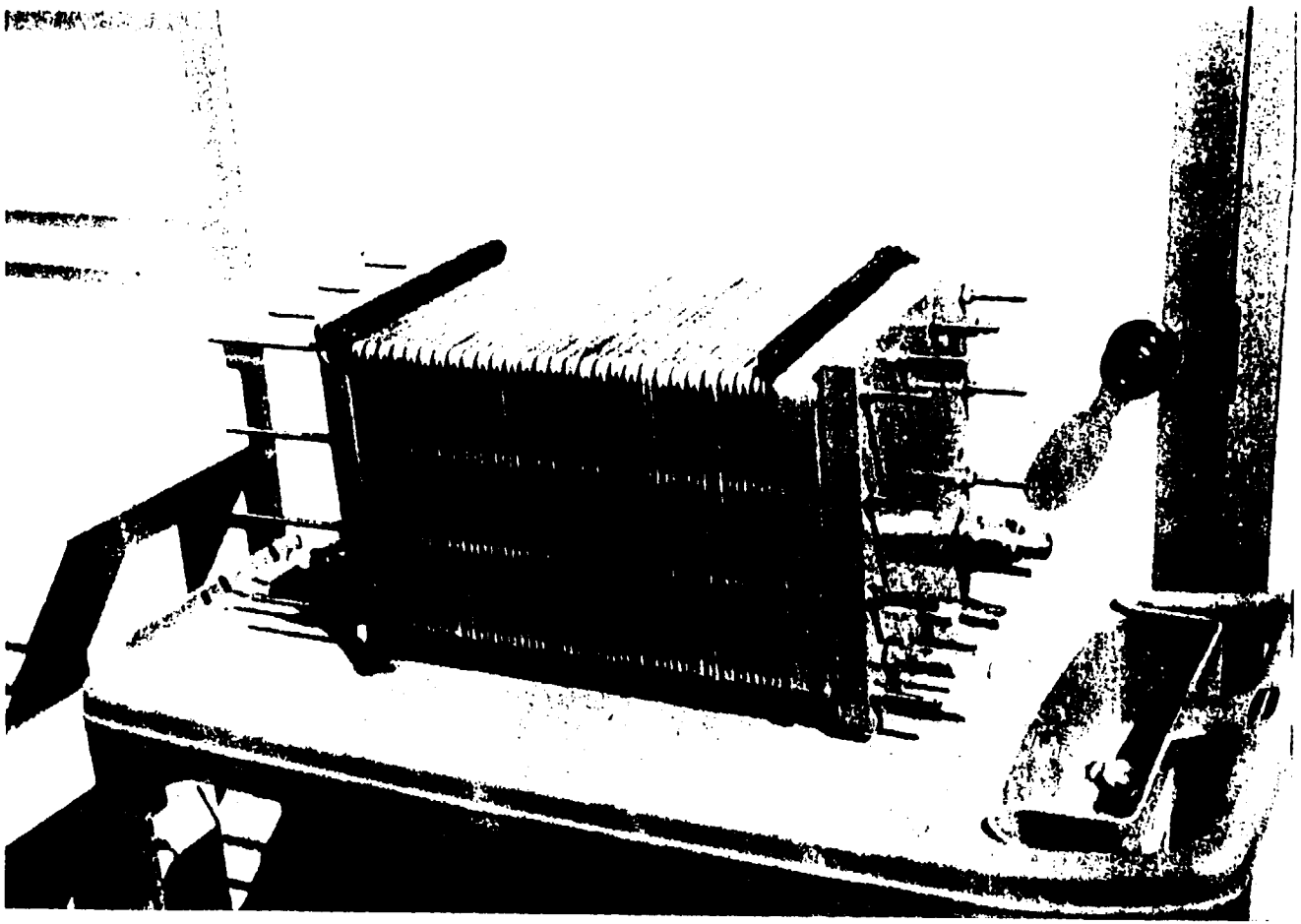
Hydrogen direct drive electric vehicle Components and technologies



Evolution to fuel cell vehicles

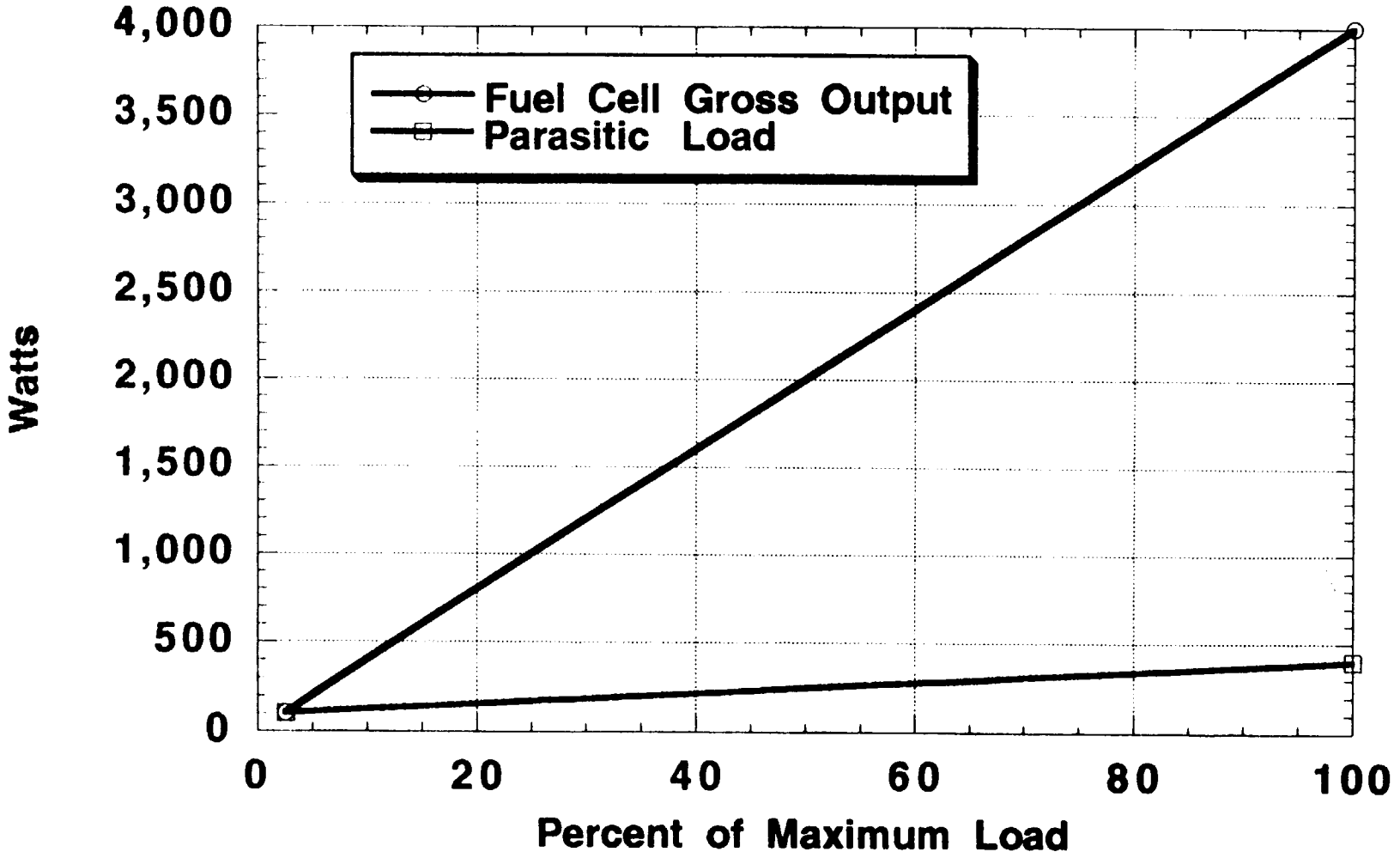


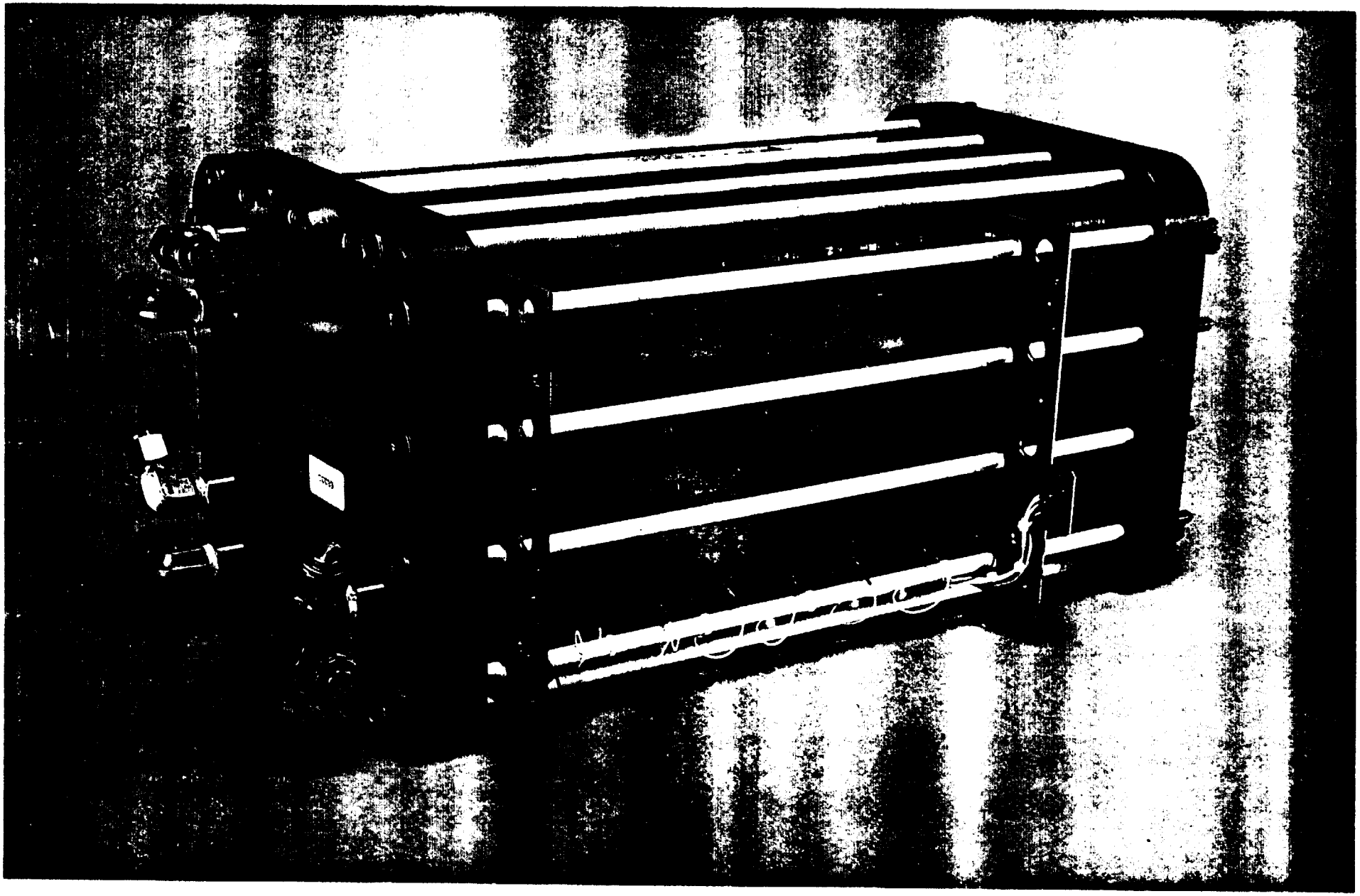
SERC 4.0 kW FUEL CELL STACK



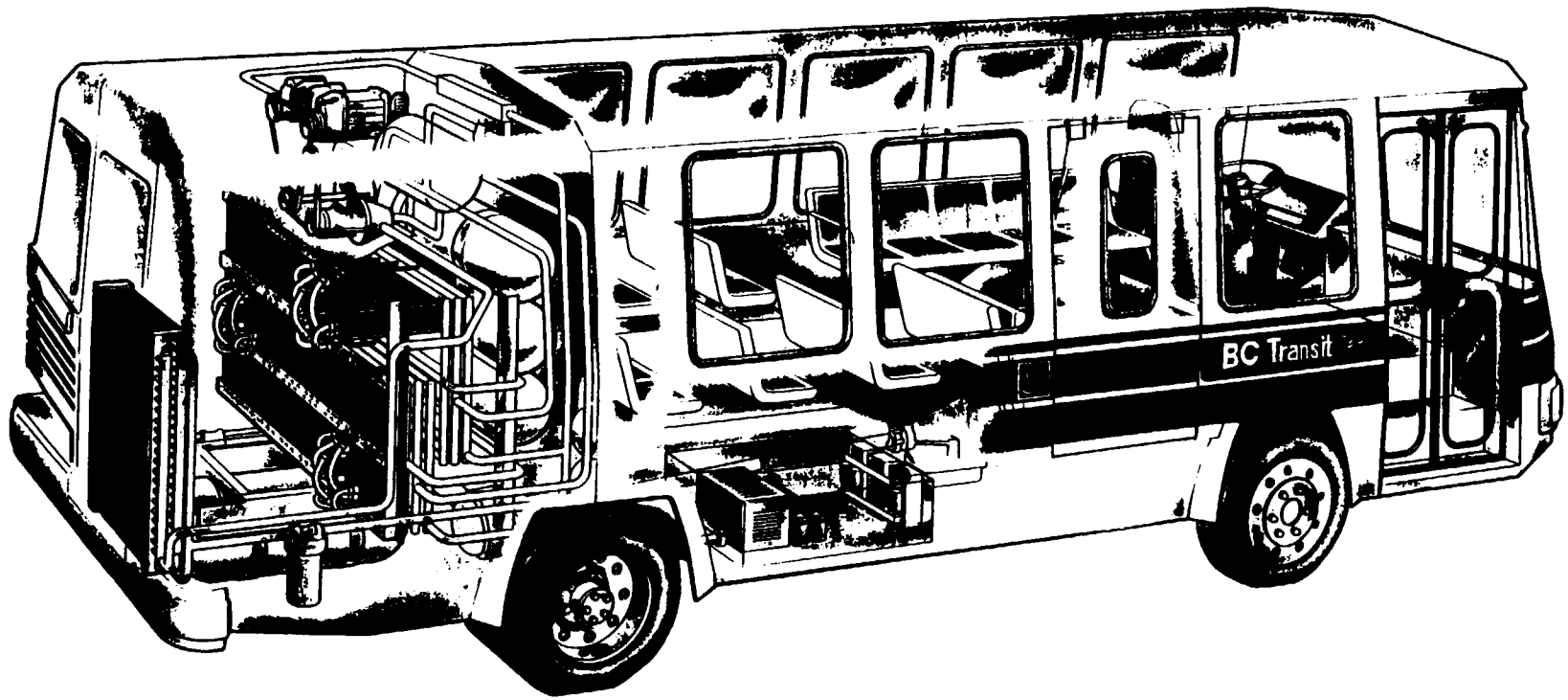
Schatz Energy Research Center Humboldt State University Arcata, CA 95521

Parasitic Load of SERC Fuel Cell





Ballard power Systems 5 kW PEM fuel cell stack - 1993

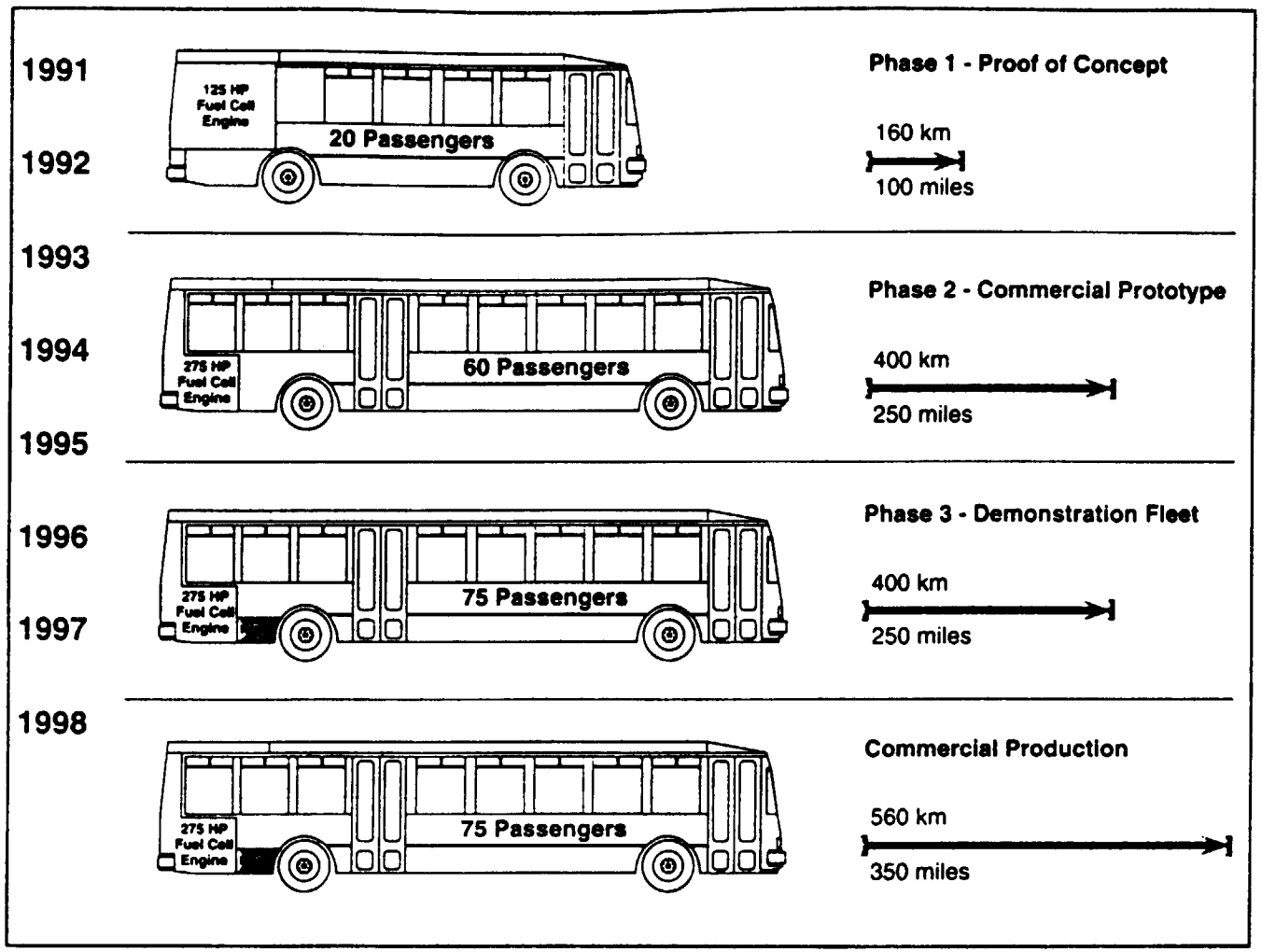


Ballard

PEM Fuel Cell Powered Transit Bus

Zero Emission Vehicle (ZEV)

Ballard Power Systems fuel cell powered bus commercialization plan



What is needed for the United States to compete strongly with Europe, Japan and Canada in the fuel cell market?

- Increased support from all directions to:
  - Reduce manufacturing costs of fuel cell power systems.
  - Increase power density of fuel cell power systems.
  - Perform component, system and end-to-end demonstrations.
  - Provide an assured entry market for fuel cell vehicles (fleets) and other applications.
    - Accelerates cost reduction and performance improvements.
- Consortia to form vertically-integrated businesses to produce fuel cells and associated components and systems at an appropriate rate and an appropriate cost.
- Parallel growth in a cost-effective refueling infrastructure.