Hydrogen from Cracked Ammonia for Alkaline FUEL CELL-Rechargeable Battery Hybrids and ICE Vehicles

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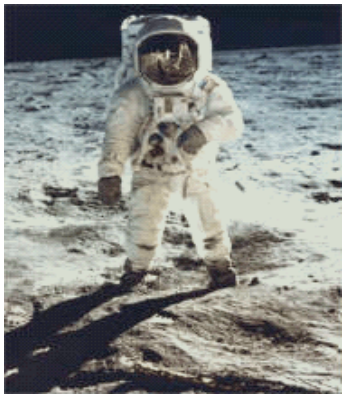
Apollo™
Energy Systems



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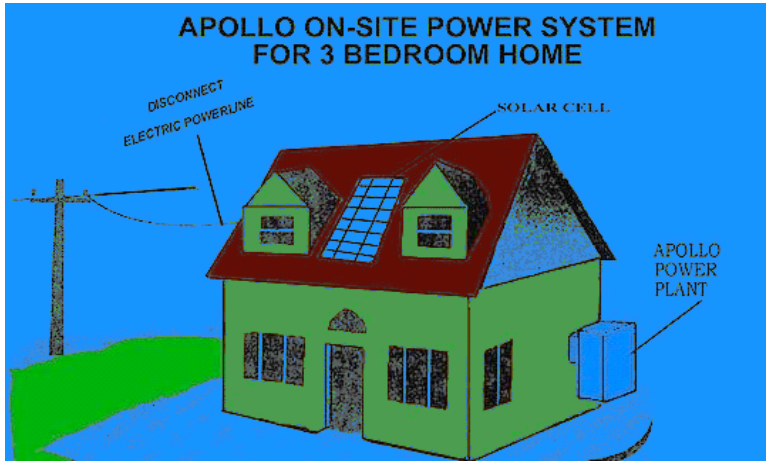
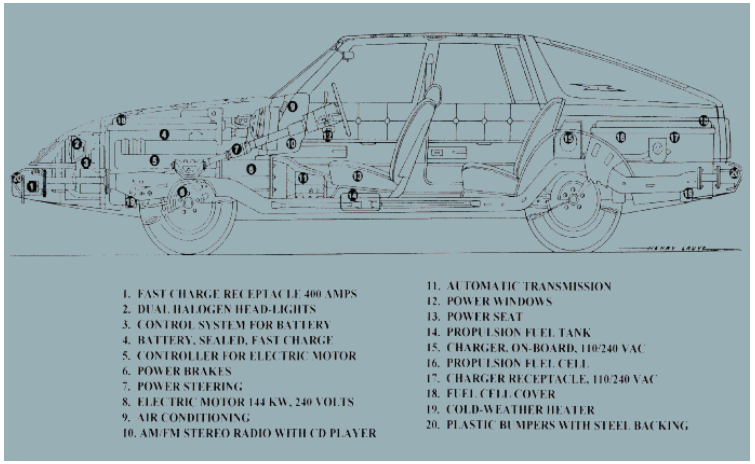




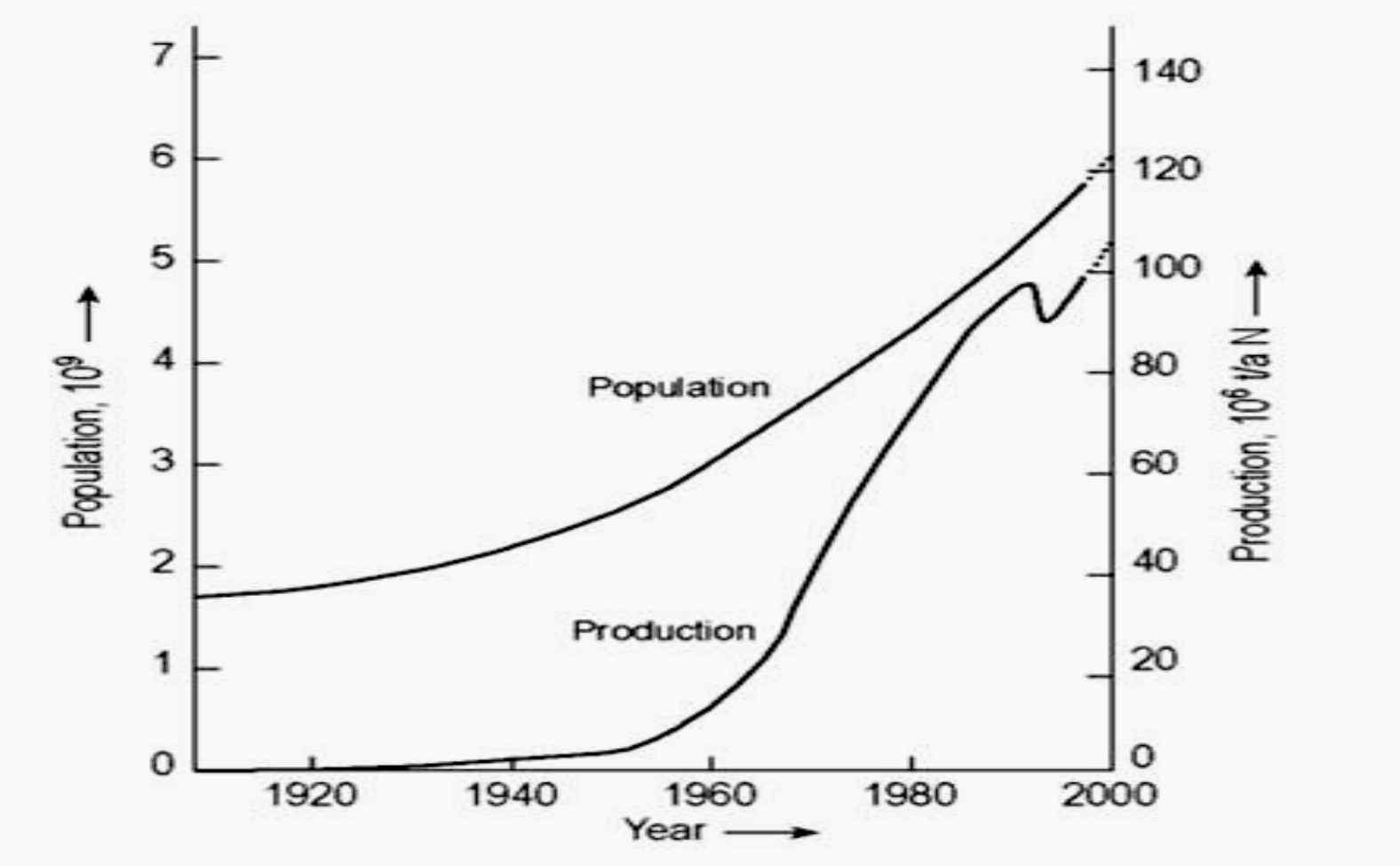
Objectives

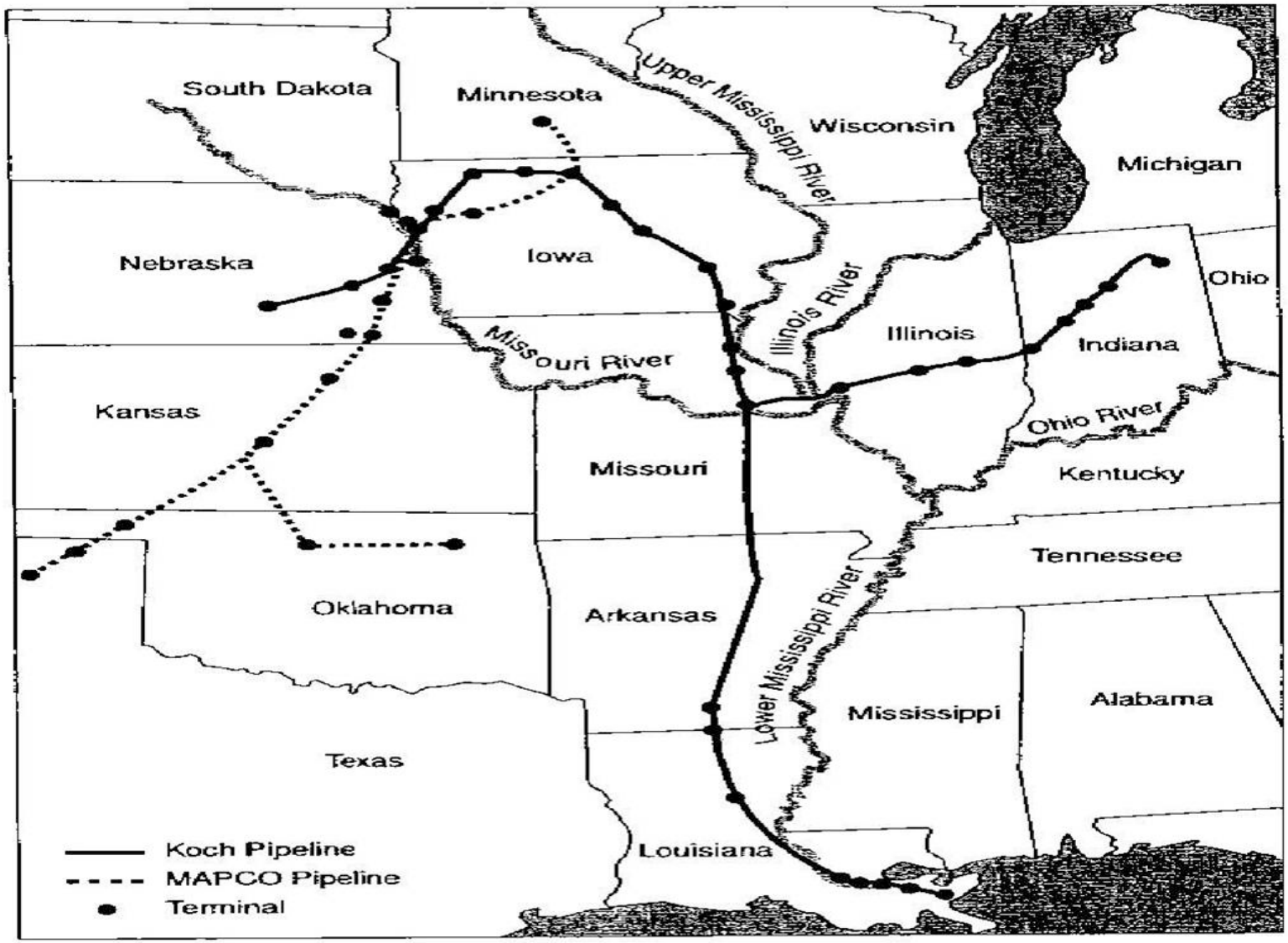
- Design of an Alkaline Fuel Cell System with circulating Electrolyte for vehicles in intermittent duty service and small units for uninterruptable hybrid power supplies.
- Development of low cost Ammonia Cracker
- Optimisation of System Performance & Life
- Cost Reductions for accessories, especially:
- Catalyst reduction, use of non-Pt catalyst

PROBLEMS

- New Energy Technologies like Fuel Cells and Fuel Cell Hybrids need Hydrogen
- The Handling and Storage of Hydrogen is questionable, dangerous and expensive
- Ammonia as Global Hydrogen Carrier may solve the Storage and Distribution Situation
- What other H_2 Carriers are to consider ?
- Are renewable Energy Sources available?

Development of ammonia production and world population





Ammonia shipped by Pipelines in the USA

Ammonia, NH_3

- Heating Values:
  Lower: 18.6 MJ/kg , Upper: 22.5 MJ/kg
- Storage as Liquid:
  Pressure: 8.6 bar at 20 ^{o} C
  Density: 0.61 kg / cm^3 (11.3 MJ / Liter)
- 1 Liter NH3 (lq) stores 1290 Liter H_2 (gas)
- 1 Mol Hydrogen corresponds to 22 Liter
- 22 Liter Hydrogen can produce 54 Ahrs.

Gas Station selling small Propane Tanks

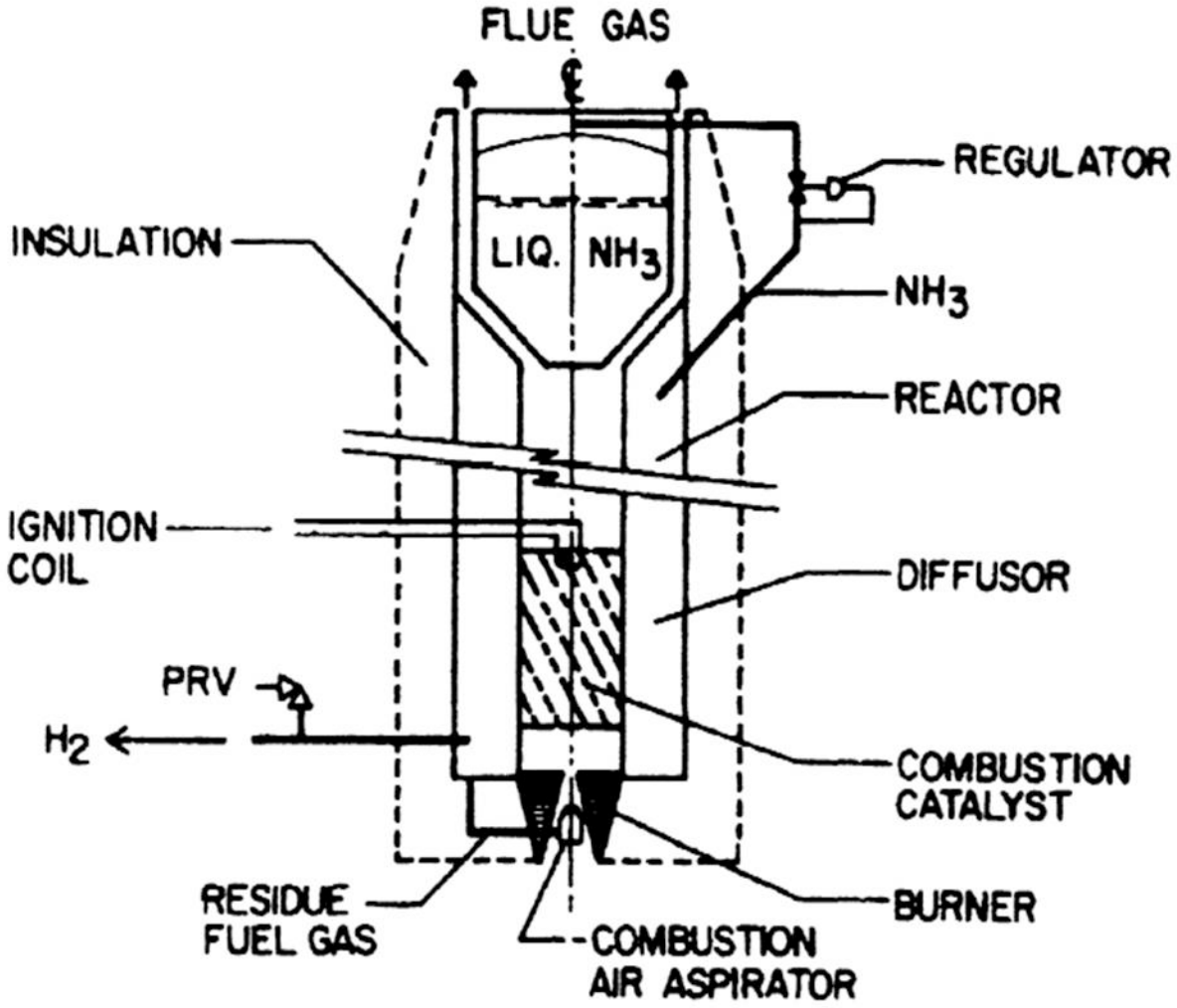
Advantages of Ammonia

- Simple Storage as Liquid
- High Storage Density at low Pressure
- Does not burn easily, No CO_2 No NO_x
- Easy and efficient to Crack (reform)
- Great Experience in Industry and Farming
- Biologically completely safe (e.g. spilling)
- Poisoning by Inhalation completely reversible
- Lower Cost than Hydrogen or Methanol

Reforming Ammonia is endothermic

- 1 kW NH_3 plus Heat produces 1.15 kW H_2
- Residual NH_3 after reforming: 100 to 300 ppm, suitable for alkaline Fuel Cells, can be cleaned by adsorption to 1 or 4 ppm for PEM Fuel Cells
- Adsorption cleaning uses only 3 % of energy and is a simple and low-cost process

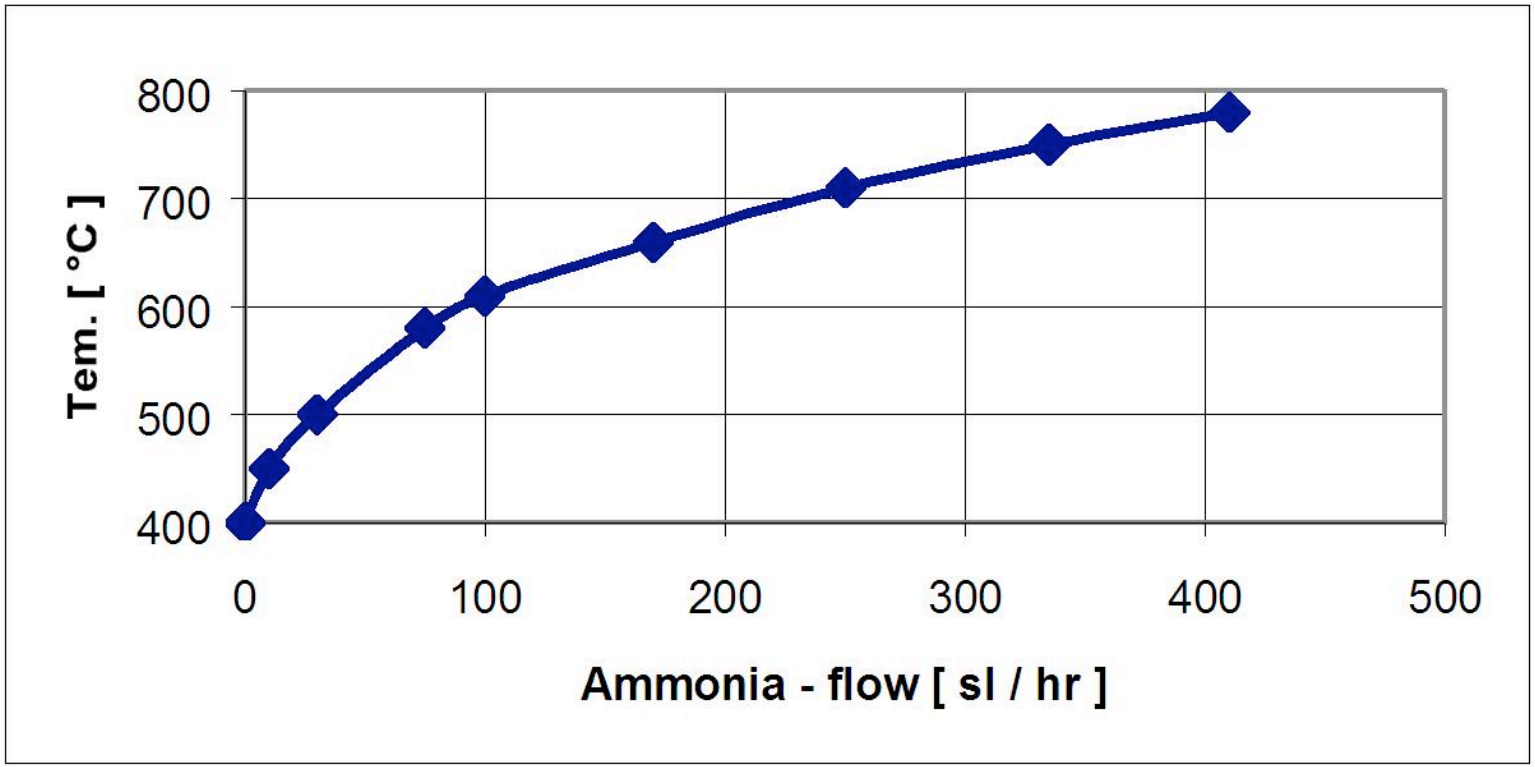
Temperature of reforming determines catalyst type, efficiency and cracker construction cost

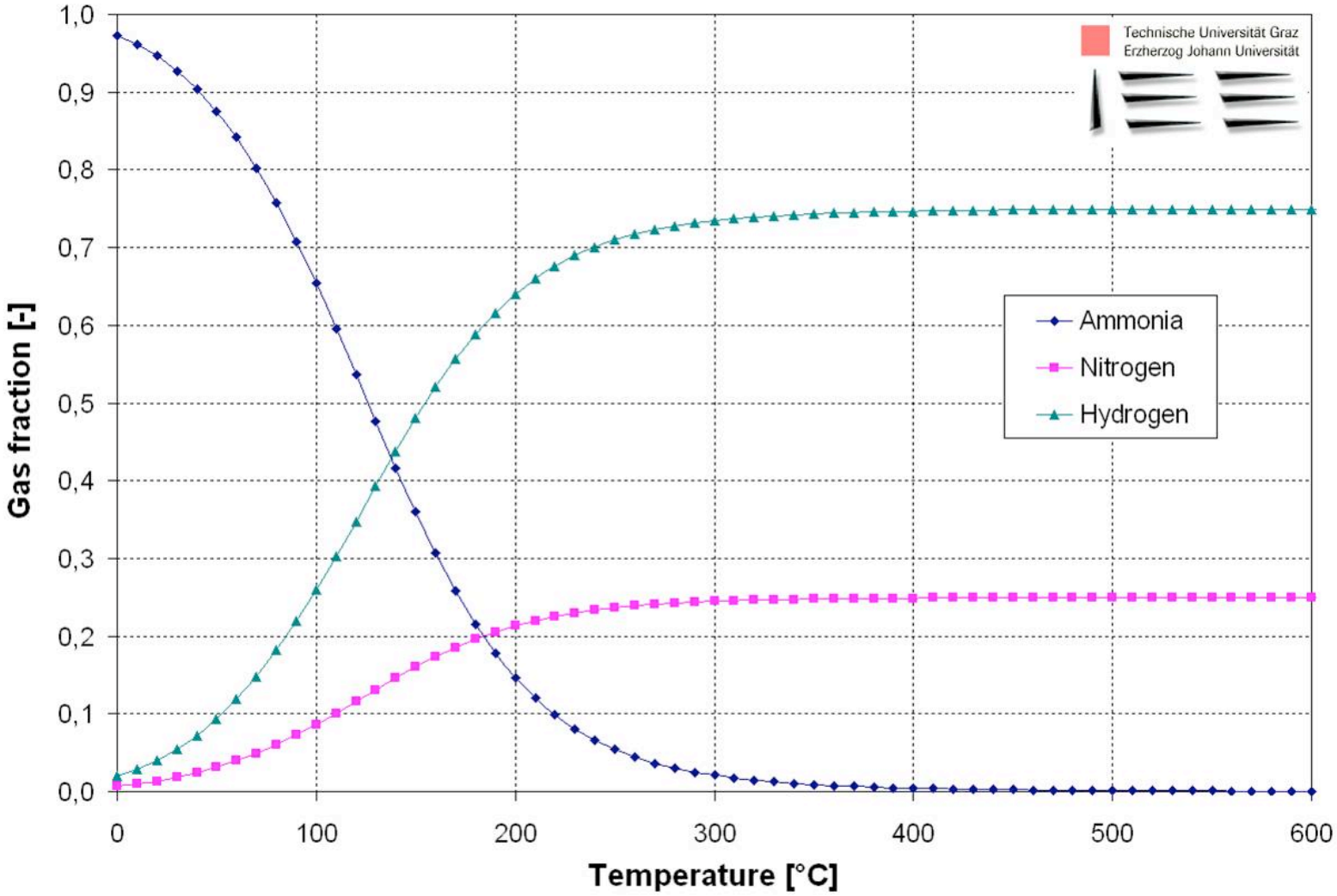


Principle of an Ammonia Cracker

Electrically heated 3 kW Ammonia Cracker

Cracking efficiency (> 99,99 conversion) with Ni-Ru - Catalyst

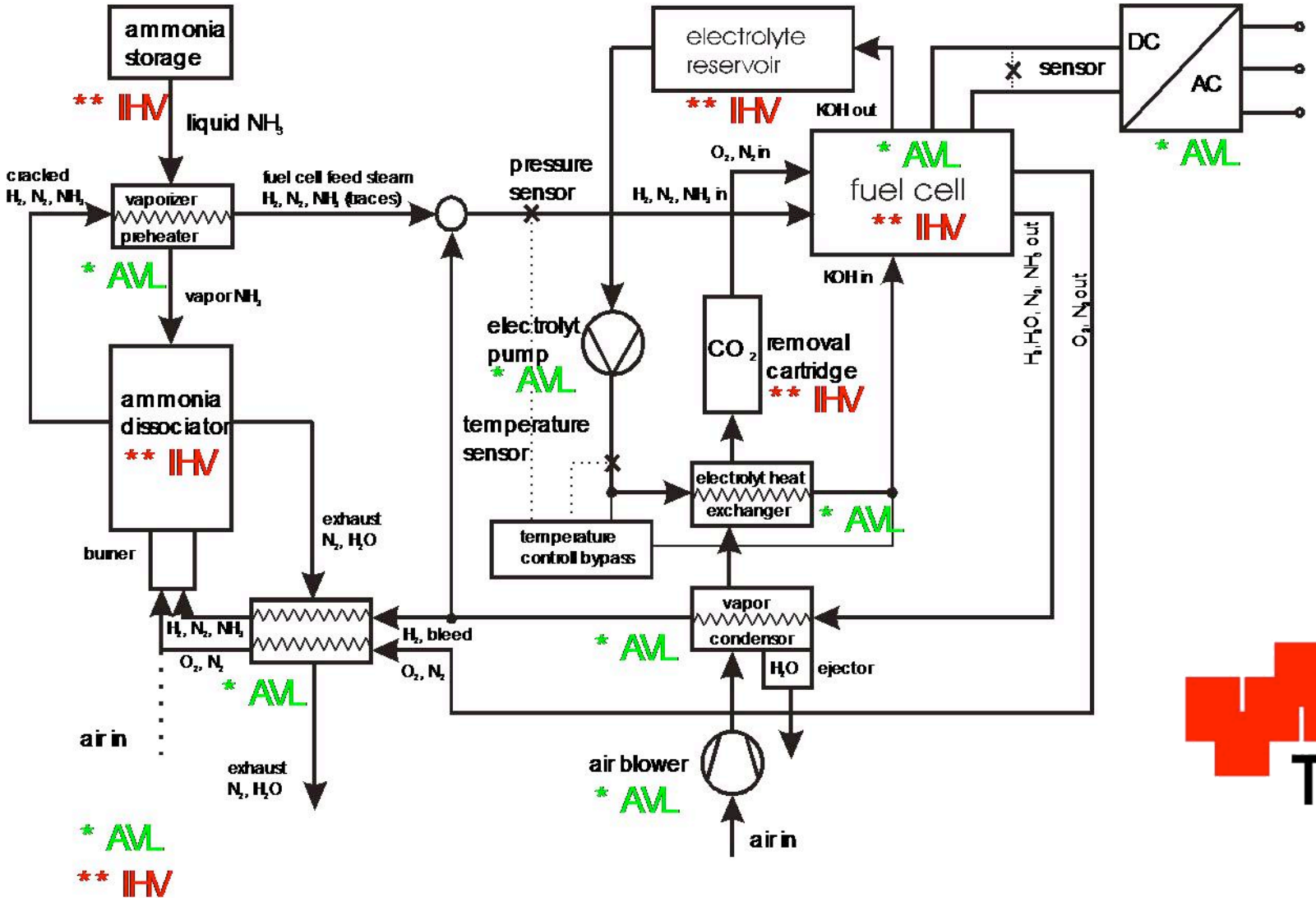




Thermodynamic of the Ammonia Thermal Cracking Process

Properties of the AES System

- ☺ low cost electrodes (carbon-based, plastic-bonded)
- ☺ low cost monopolar stack design, no bipolar plates
- ☺ low cost commercial tools for operating the stack
- ☺ no humidifier, no compressors, no membranes
- ☺ fuel (H_2, pure or reformed) at ambient pressure
- ☺ air at ambient pressure
- ☺ easy startup (hybrid) within minutes
- ☺ simple shutdown
- ☺ self-regulating water and thermal management
- ☺ tolerates 150ppm CO_2 (air: 300ppm)

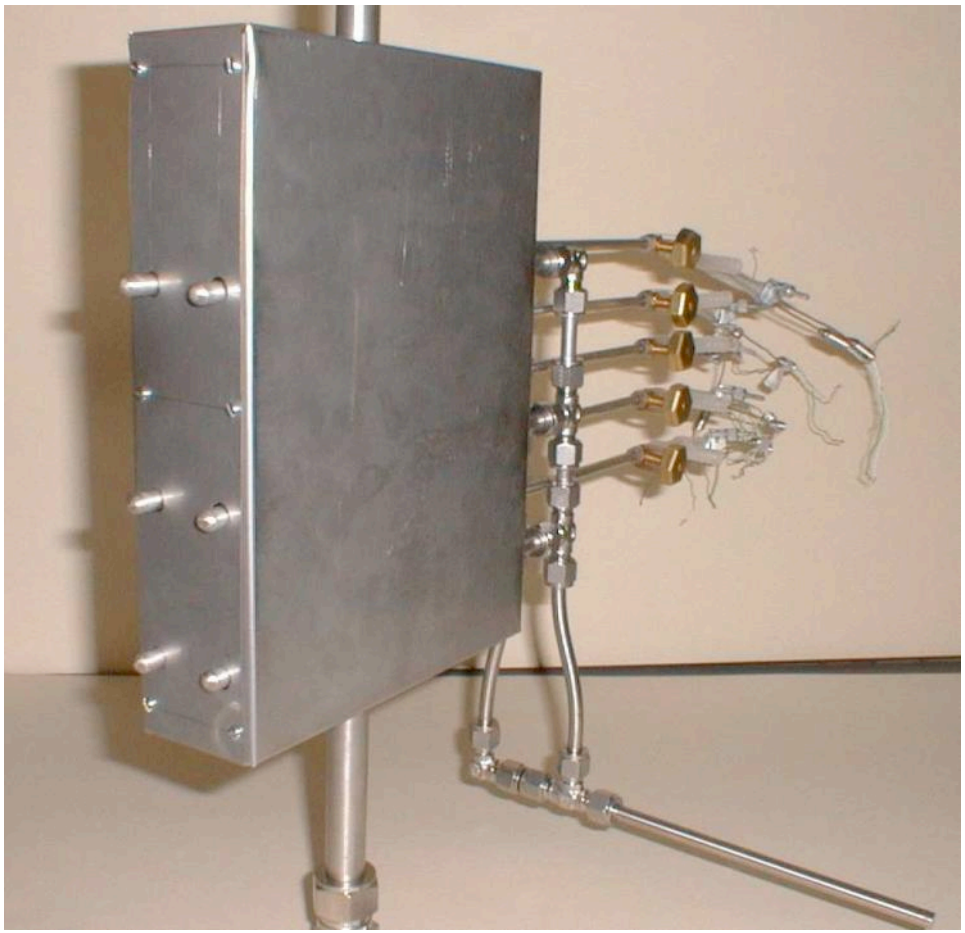


Combination of an AFC and an NH_3-Cracker

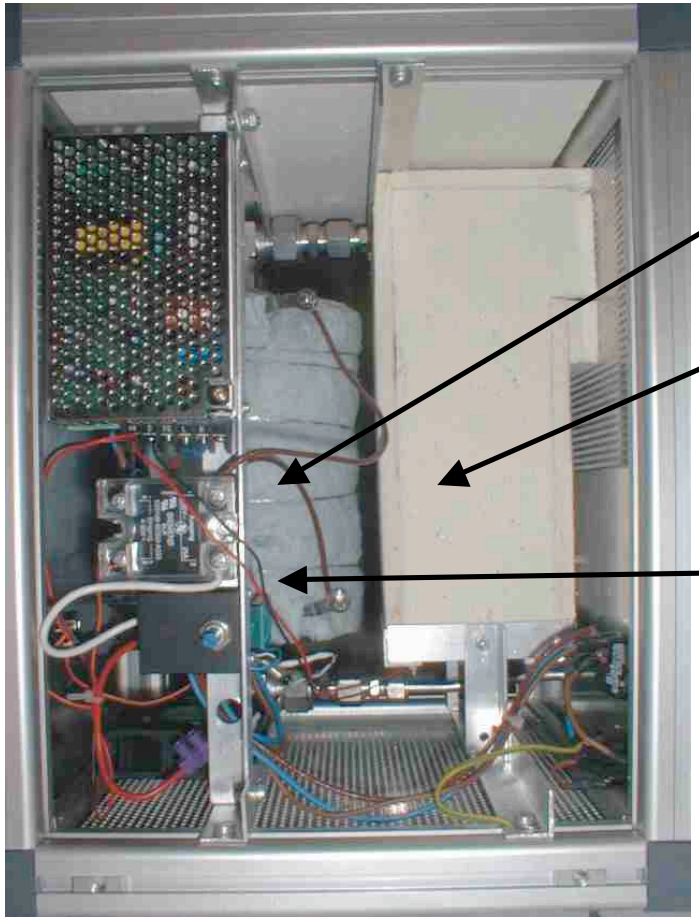
Hybrid AFC running on NH3

Anhydrous Ammonia **Ammonia Cracker** **Fuel Cell Module II** **Hybrid battery (lead acid)** **Electric Motor and Fan**

Cracker IV front and rear view



Prototype II - Components



AMMONIA FOR SILVER VOLT ELECTRIC CAR

WITH 60 kW APOLLO FUEL CELL

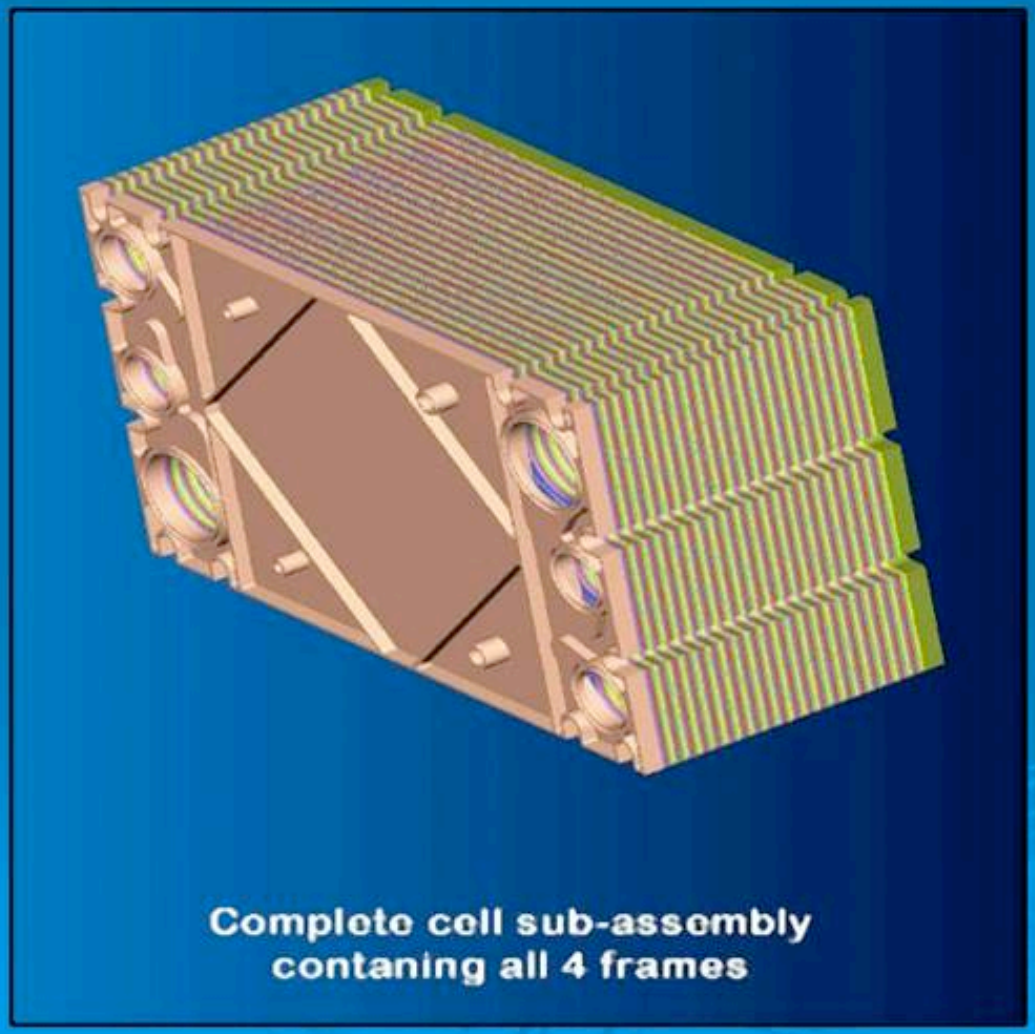
DRIVING RANGE: 240 MILES

AMMONIA: 60.48 kg –80 Liters –21 Gallons

1 –Gallon of Ammonia weighs 5.1 –pounds

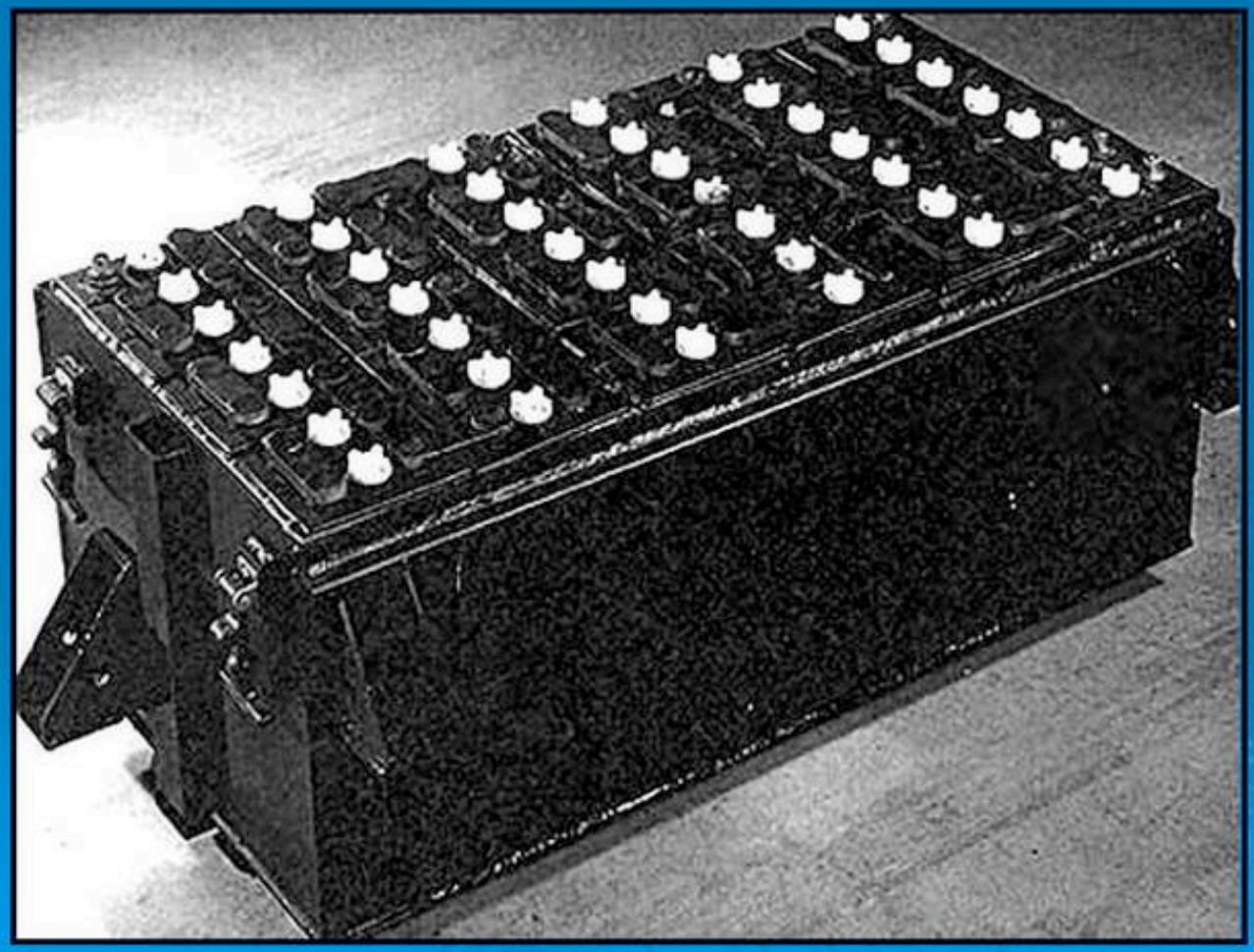
1 –Gallon of Gasoline weighs 6.1 -pounds

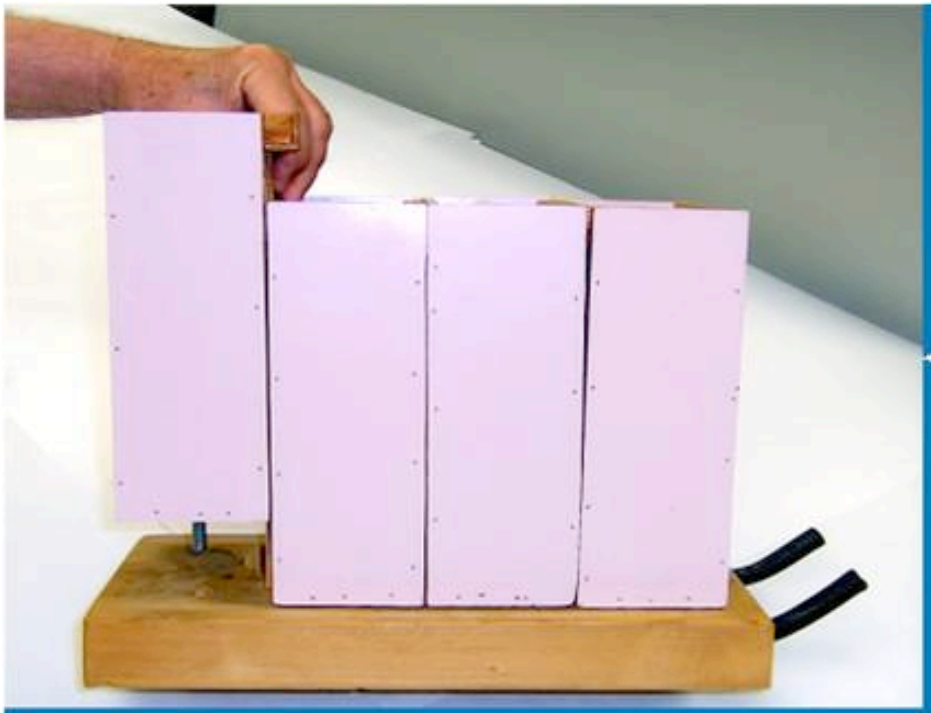
APOLLO FUEL CELL STACK



Complete cell sub-assembly
contaning all 4 frames

APOLLO™ LEAD COBALT BATTERY

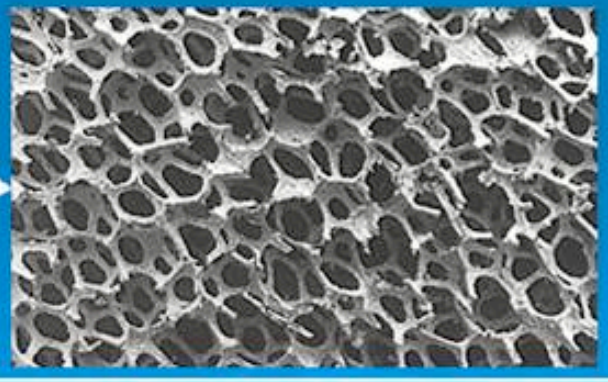




MULTI-CELLUAR
TRI-POLAR BATERY
U.S. PATENT 7,037,620 B2

LEAD FOAM GRID

LEAD FOAM
MAGNIFIED



WEIGHS 16% OF TRI-POLAR LEAD GRID

300% MORE POWER

THE SILVER VOLT REPRESENTS OUR HERITAGE, OVER 25 YEARS OF RESEARCH AND DEDICATION TO ALTERNATIVE POWER