Apollo™

Energy Systems

Alkaline Fuel Cells for Mobile and Stationary Applications

Graz University of Technology:
Martin Cifrain, Karl Kordesch, Josef Gsellmann, Viktor Hacker

Apollo Energy Systems, Inc.:
Robert R. Aronsson

Fuel Cell Conference, Nov. 12-14, 2001, Ft. Lauderdale, FL

Common Demands on Fuel Cells

high total efficiency

reliability in daily use
- during fast startup
- during operation
- during long periods of shutdown

many different fuels usable

simplicity of the whole system

ease of maintenance

high power density (kW per liter, for small units)

high specific power (kW per lb, for mobile applications)

low price

Advantages of the AFC

- low cost electrodes
- simple way of stack construction
- higher voltages
- sufficient lifetime for electric vehicles
- low sensitivity to misuse
- low sensitivity to impurities like CO or NH_3
- not sensitive to long periodes of shutdown
- fast startup when used in hybride mode

K. Kordeschs Austin A 40 (1970)

Fuel Cell:
- H_2 / air
- 90V / 6kW

Battery:
- SLI lead acid
- 84V / 7kWh

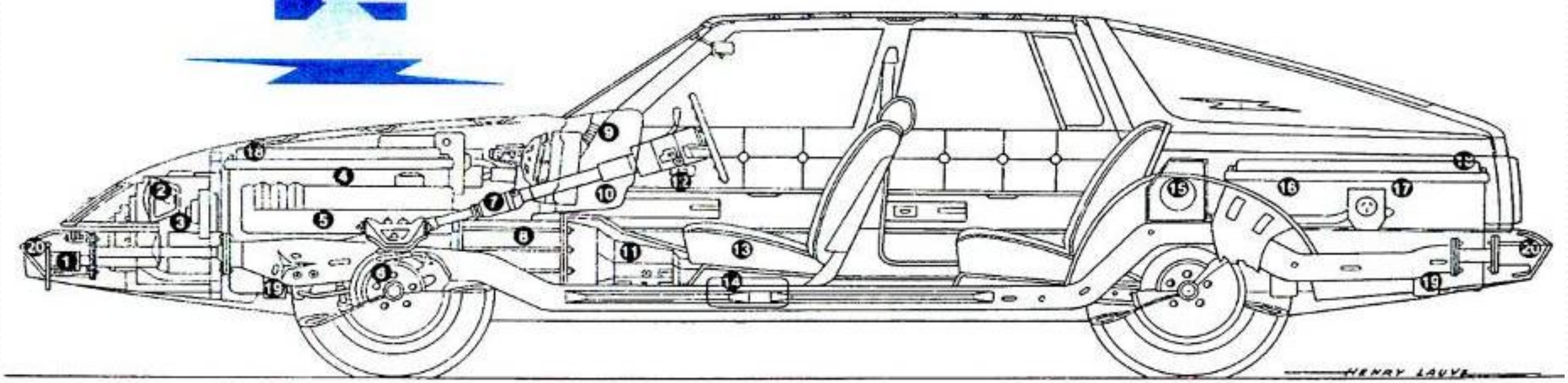
Hybrid weight:
- 1600lb

Max. Speed:
- 50miles/hr

Range:
- 185miles

THE SILVER VOLT

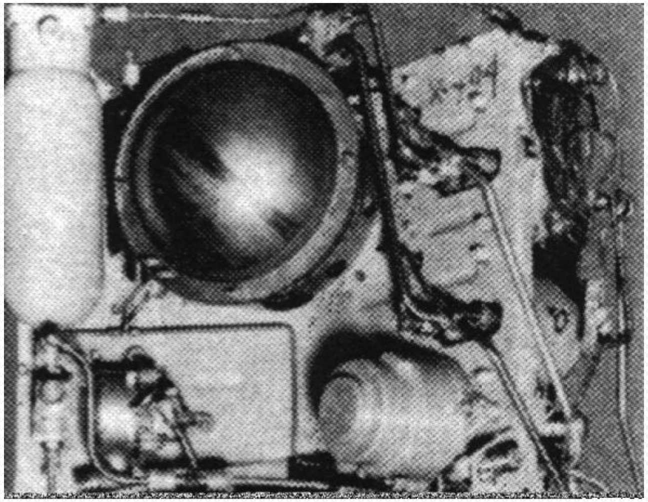
Electric Propulsion System



1. FAST CHARGE RECEPTACLE 400 AMPS
2. DUAL HALOGEN HEAD-LIGHTS
3. CONTROL SYSTEM FOR BATTERY
4. BATTERY, SEALED, FAST CHARGE
5. CONTROLLER FOR ELECTRIC MOTOR
6. POWER BRAKES
7. POWER STEERING
8. ELECTRIC MOTOR 144 KW, 240 VOLTS
9. AIR CONDITIONING
10. AM/FM STEREO RADIO WITH CD PLAYER
11. AUTOMATIC TRANSMISSION
12. POWER WINDOWS
13. POWER SEAT
14. PROPULSION FUEL TANK
15. CHARGER, ON-BOARD, 110/240 VAC
16. PROPULSION FUEL CELL
17. CHARGER RECEPTACLE, 110/240 VAC
18. FUEL CELL COVER
19. COLD-WEATHER HEATER
20. PLASTIC BUMPERS WITH STEEL BACKING

APOLLO ENERGY SYSTEMS, INC.

The Apollo Fuel Cell Assembly



AFC-Module Data:

weight: 109kg

diameter: 57cm

heigth: 112cm

operation temperature: 200°C

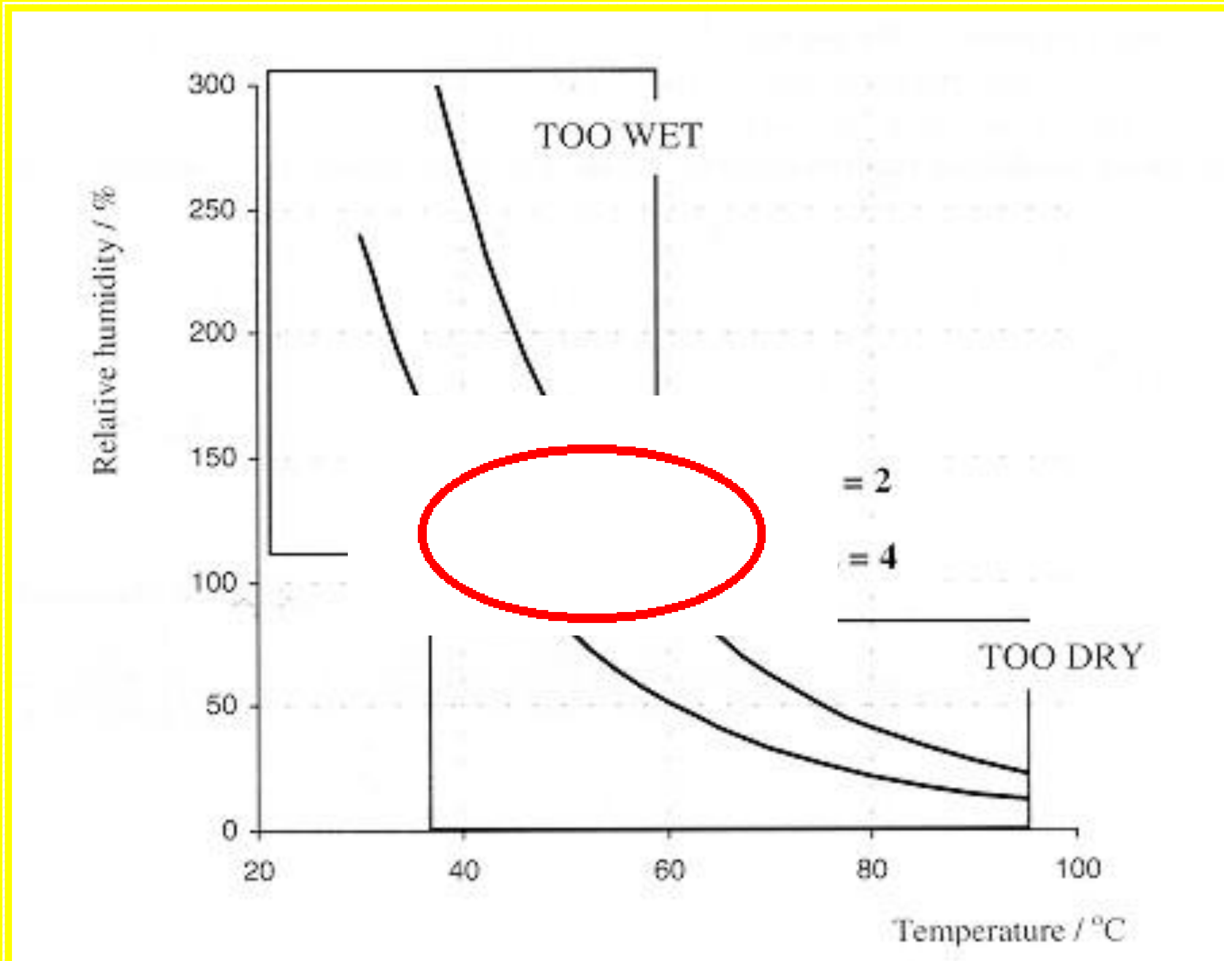
electrolyte pressure: ~3bar

nominal power output: 1.5kW

Advantages of Circulating Liquid Electrolyte

- easy thermal management
- easy water management
- barrier against reactant gas leakage established
- accumulated impurities and carbonate easily removable
- reduction of concentration gradient
- some parasitic currents (in multi cell stacks)

PEM - Humidity vs. Temperature



Sufficient Lifetime for an Electric Vehicle

Given: ➲ Total Range of a vehicle: **125.000 miles**

➲ Medium velocity: **30 miles/hr.**

Therefore, the operating time is **~ 4000 hours**

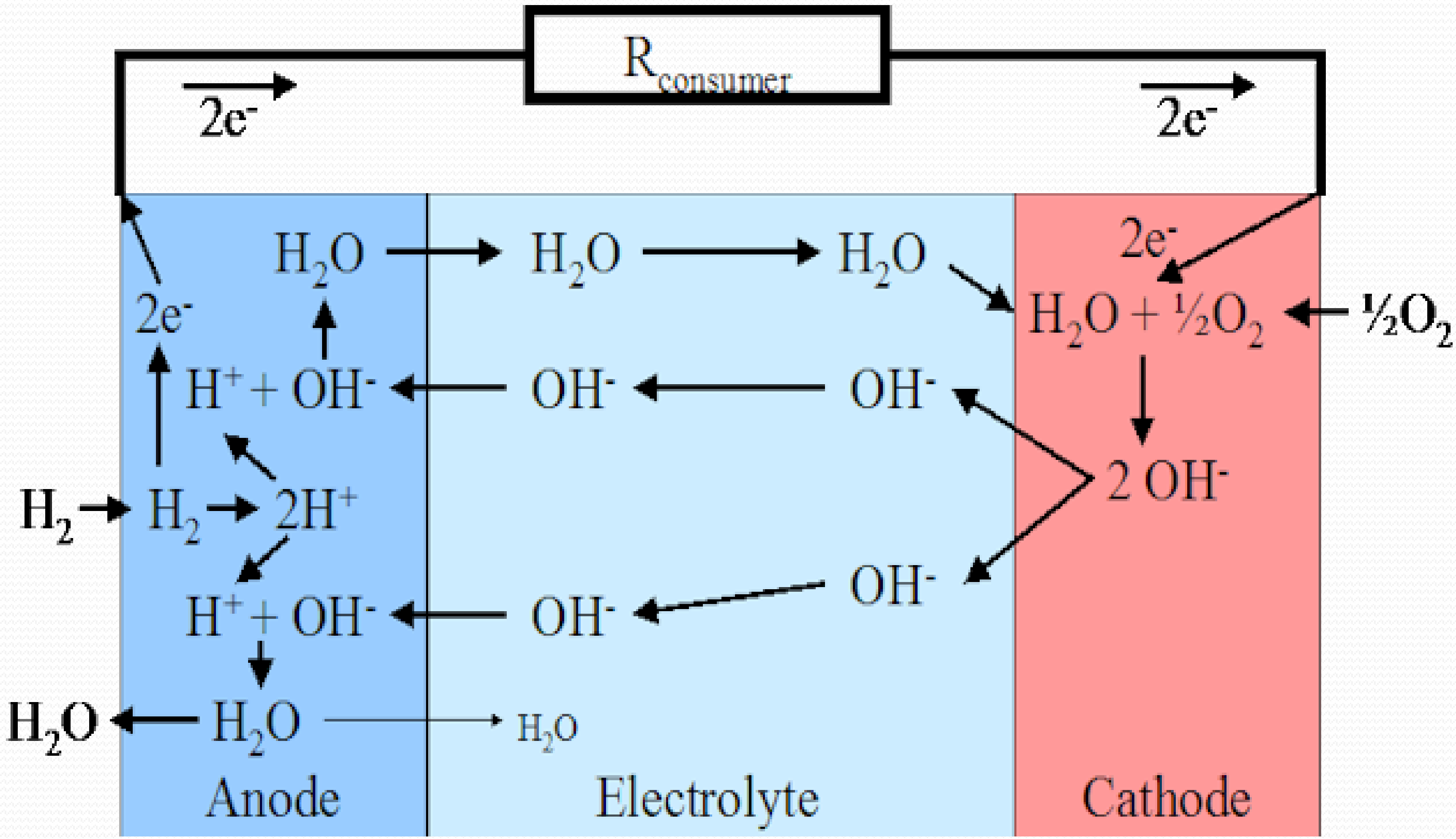
IF: ➲ liquid circulating electrolyte is used

➲ electrolyte leaves the cell after shutdown

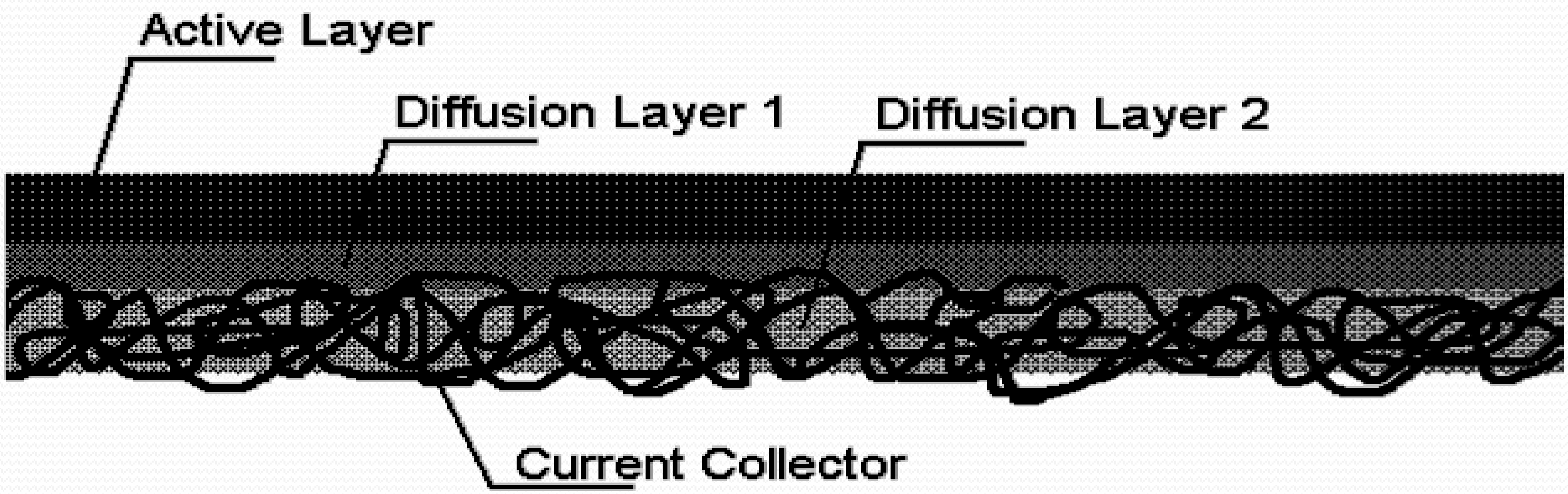
Lifetime of an AFC-electrode: **~ 4000 hours**

NO MORE LIFETIME THAN 4000 OPERATION HOURS IS NECESSARY FOR MOBILE APPLICATIONS

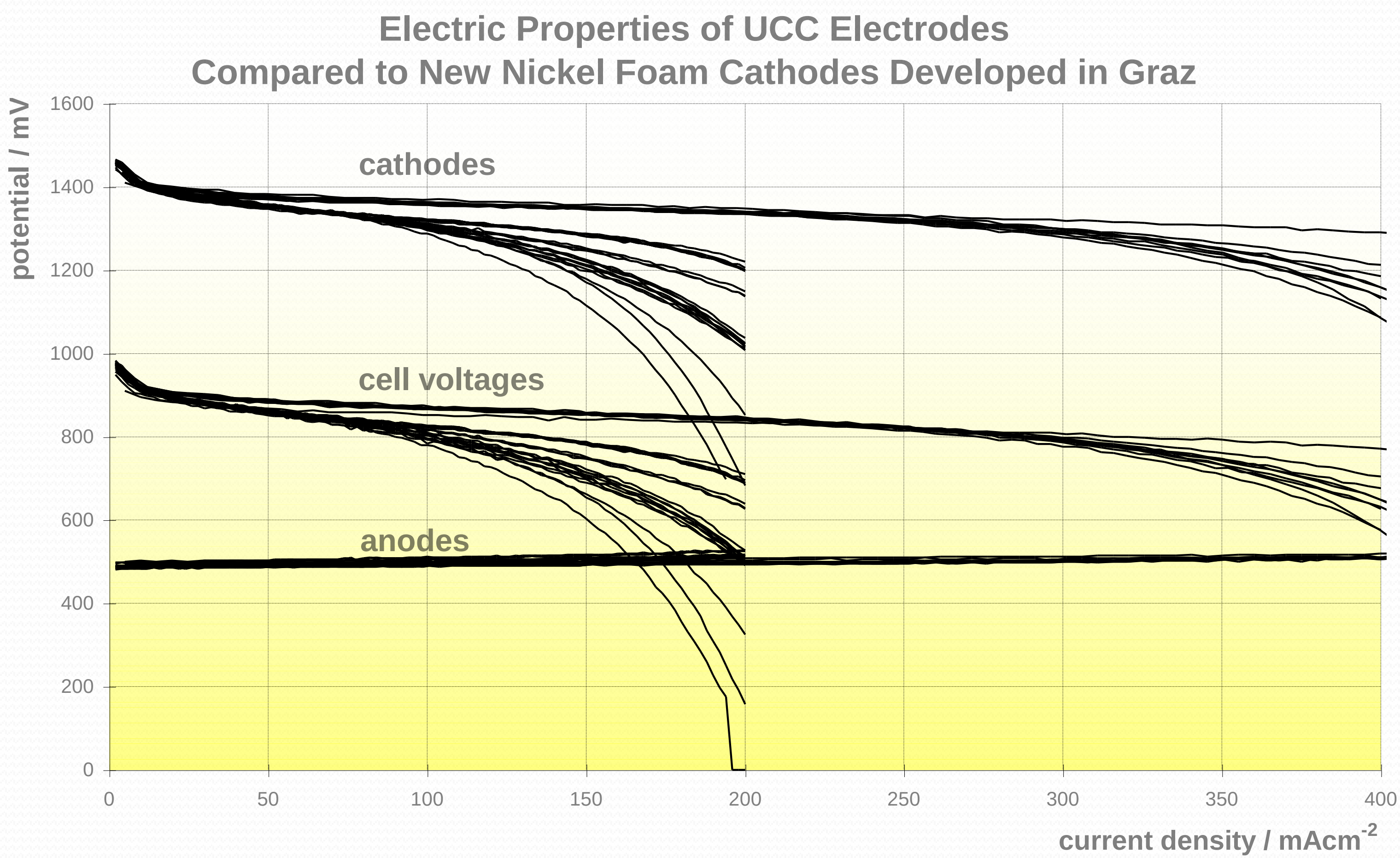
Electrochemical Reactions



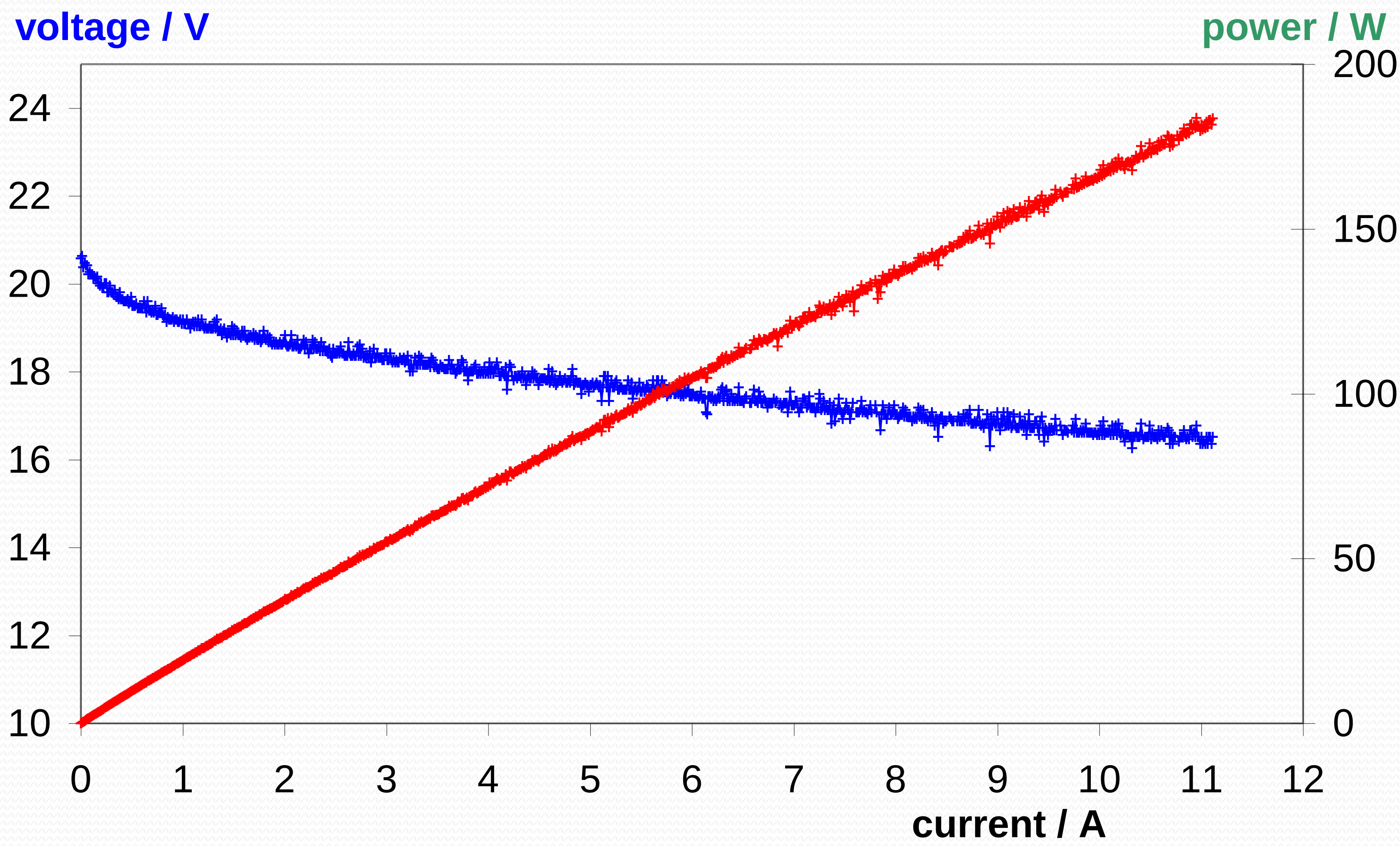
Carbon-based
Gas Diffusion Electrode



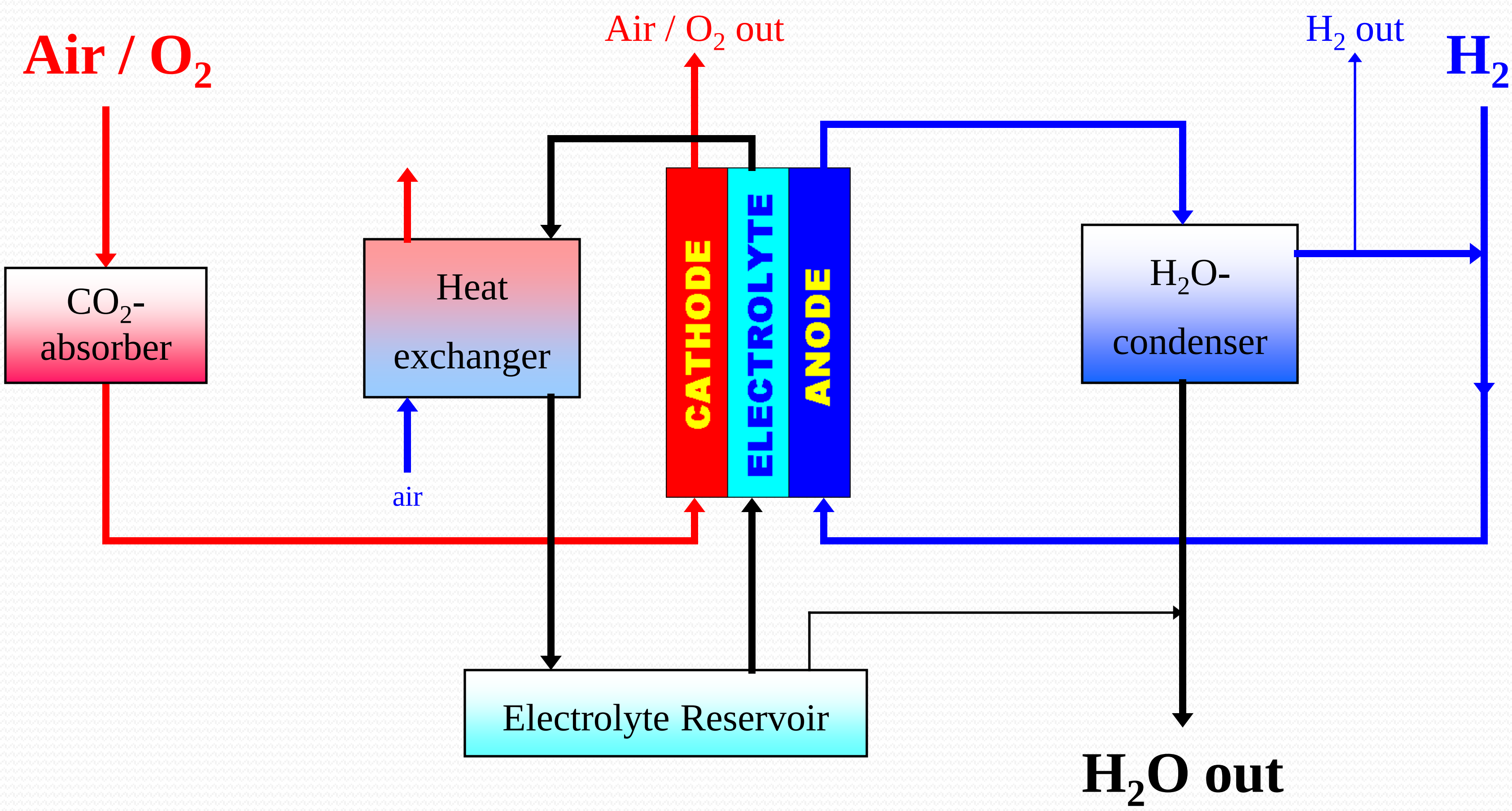
Properties of new AFC-Electrodes



Properties of Stack Mk III

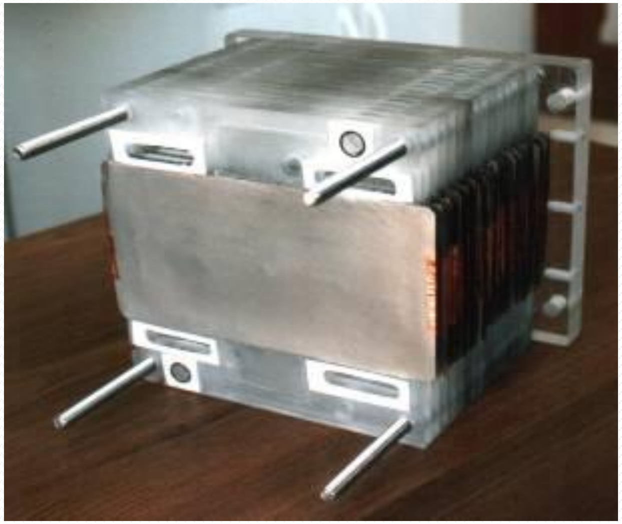


Principle of an AFC-System



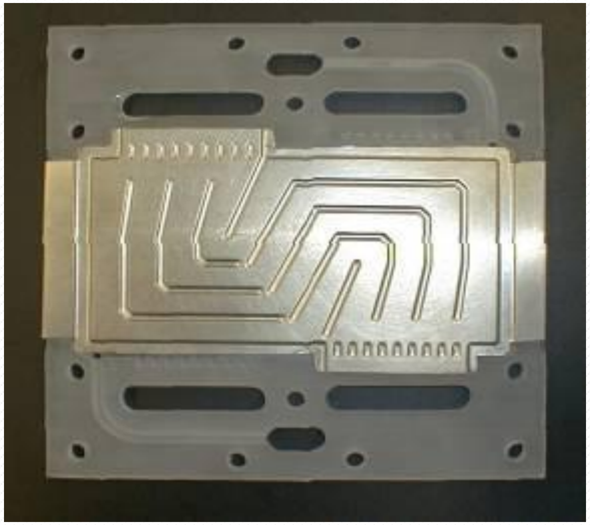
Bipolar and Monopolar Stacks

Stack Mk I



1998
bipolar
15 cells
90 W
24 W/liter

Stack Mk II



2000
bipolar
19 cells
130 W
25 W/liter

Stack Mk III

2001
monopolar
21 cells
290 W
120 W/liter

Fuel Cell running on Ammonia

Anhydrous Ammonia

Ammonia Cracker

Fuel Cell Module II

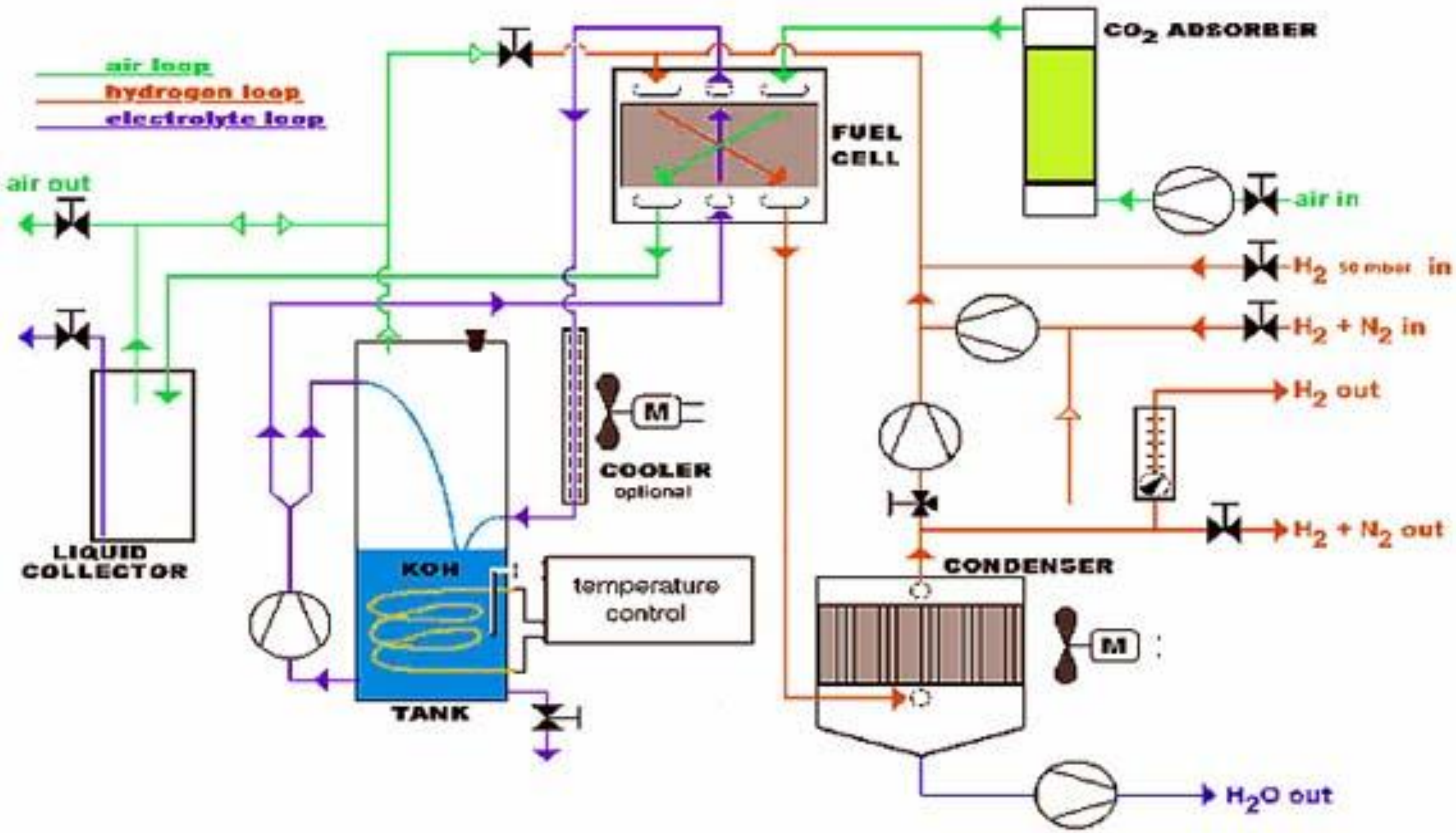
Hybrid battery (lead acid)

Consumers

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)

Detailed Gas and Electrolyte Flow



Advantages of Ammonia

- ☺ Not flammable
- ☺ liquid at very low pressure
- ☺ 1.7 times more H_2 than liquid H_2 (at same volume)
- ☺ low cost (third largest chemical produced worldwide)

  NH_3: 1.17$/kWh Methanol: 3.79$/kWh H_2: 25$/kWh [Kaye, Bloomfield]
- ☺ distribution technology available and in daily use
- ☺ simple cracking (low temperatures if used with AFC)
- ☺ no cleaning of the reformed gas necessary (H_2, N_2)
- ☺ <u>not toxic</u>
- ☺ easy smellable

Literature

K.Kordesch, J.Gsellmann, S.Voss, M.Cifrain, R.Aronson, *Annual Intl. Power Sources Conference*, August 26–28, 1998, Nagoya, Japan, NPC'98 Proceedings pp. 9 – 16; also in *FCT Advanced Fuel Cell Technology*, **Vol.2** No.12 (1998), pp. 2 – 7

K.Kordesch, J.Gsellmann, M.Cifrain, R.Aronson, *1998 Fuel Cell Seminar*, Nov. 16–19, Palm Springs, CA, USA, Abstracts pp.387–390

K.Kordesch, J.Gsellmann, S.Voss, M.Cifrain, R.Aronson, V.Hacker, Ch.Fabjan, T.Hejze, J.Daniel-Ivad, *21st Internat.Power Sources Symposium*, May 10–12, 1999, Brighton, UK, Proceedings (Power Sources **17**), pp. 190 – 197; also in *Journal of Power Sources* **80** (1999) 190 – 197

K.Kordesch, J.Gsellmann, M.Cifrain, et.al., *39th Power Sources Conference*, June 12–15, 2000, Cherry Hill, USA, Proceedings p.108

K.Kordesch, V.Hacker, J.Gsellmann, M.Cifrain, et.al., *Journal of Power Sources* **86** (2000) 162 – 165

K.Kordesch, M.Cifrain, T.Hejze, V.Hacker, U.Bachhiesl, *2000 Fuel Cell Seminar*, Oct. 30 – Nov. 2, 2000, Portland, Oregon, USA, Proceedings pp. 432 – 435

K.Kordesch, J.Gsellmann, M.Cifrain, V.Hacker, et.al.,*2000 Fuel Cell Seminar*, Oct. 30 – Nov. 2, 2000, Portland, Oregon, USA, Proceedings pp. 655 – 658

G.Faleschini, et.al.,*Proc. of the 2000 Fuel Cell Seminar*, Oct 30th-Nov 2nd, Portland, Oregon (USA) pp. 336-339

J.H.Hirschenhofer et.al, *"Fuel Cell Handbook"*, Parsons Corp. for US Department of Energy (DOE), 4th edition, Nov. 1998

K.Kinoshita, *"Electrochemical Oxygen Technology"*, Wiley, Chichester – New York – Toronto 1992

K.V.Kordesch, G.Simader, *"Fuel Cells and Their Applications"*, Wiley, Weinheim – New York – Tokyo 1996

R.Metkemeijer, P.Achard, *Int.J.Hydrogen Energy* **19** (1994) 535

I.W.Kaye, D.P. Bloomfield, *"Portable Ammonia Powered Fuel Cell"*, *Proc. of Conf. Pow. Sources*, Cherry Hill 1998, pp. 408-409