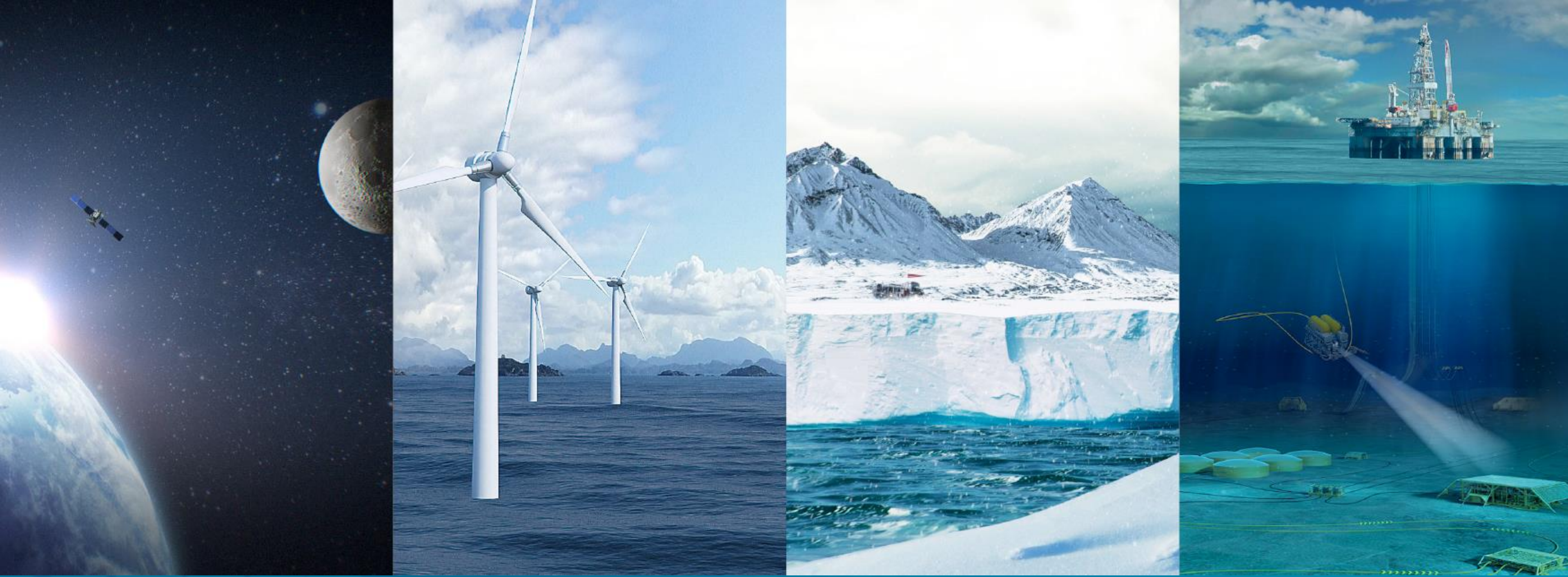


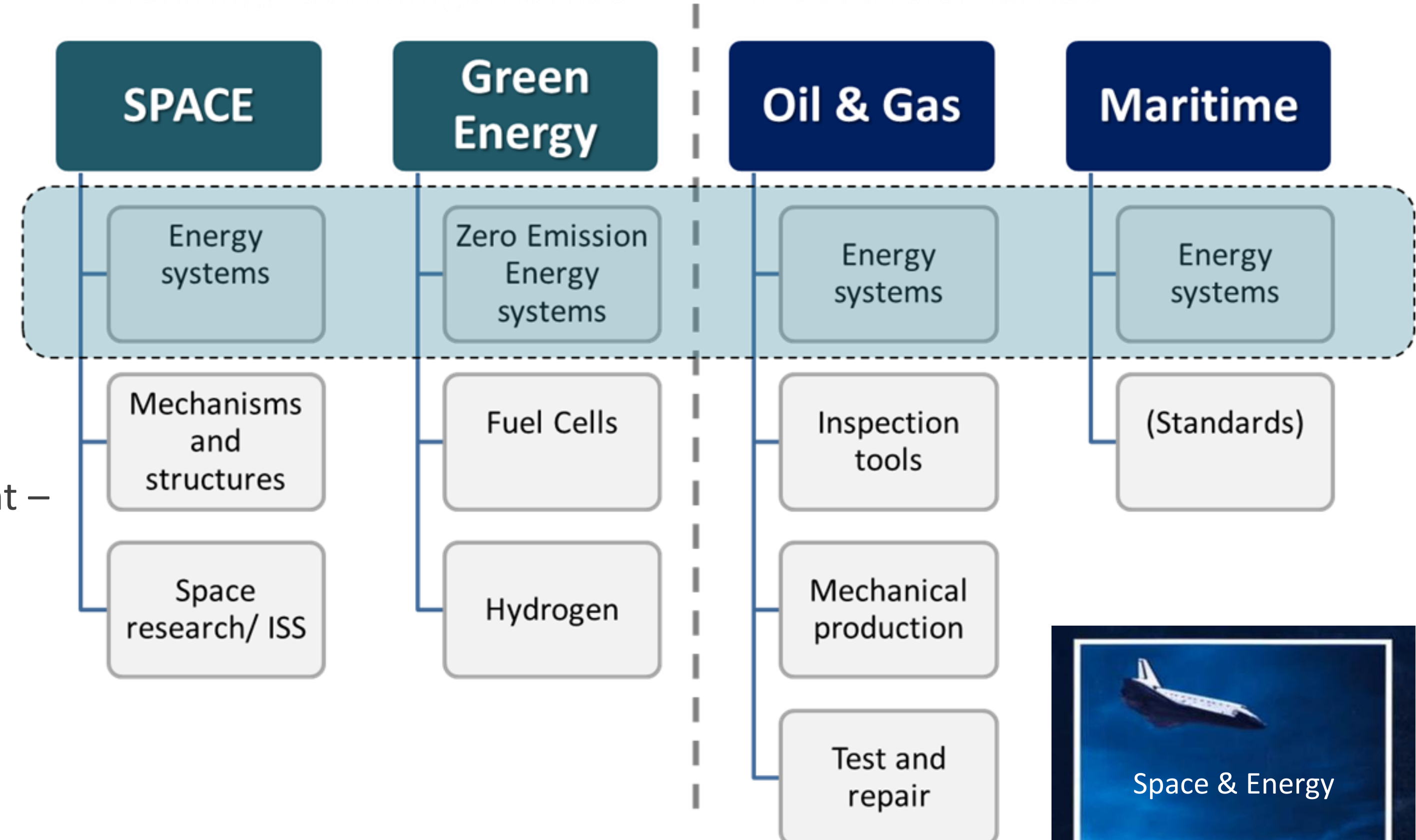
Fuel Cell - What is it and what are the benefits?

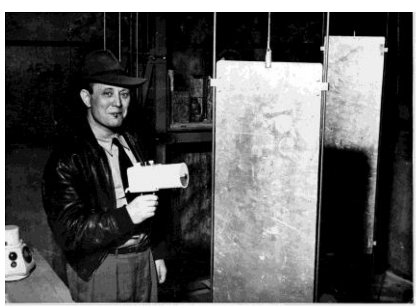
Crina S. ILEA,
10.01.2017 – Energy Lab,
Bergen

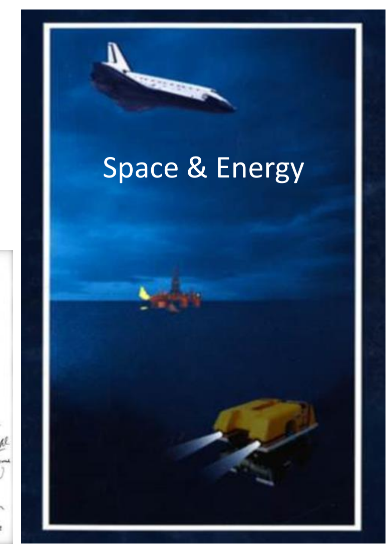
Christian Michelsen Research

cmr Prototech

- CMI
- Founded in 1988
- Two departments:
    - Parts & Services
    - Research & Development
- Prototype development – from idea to product
- Space and energy

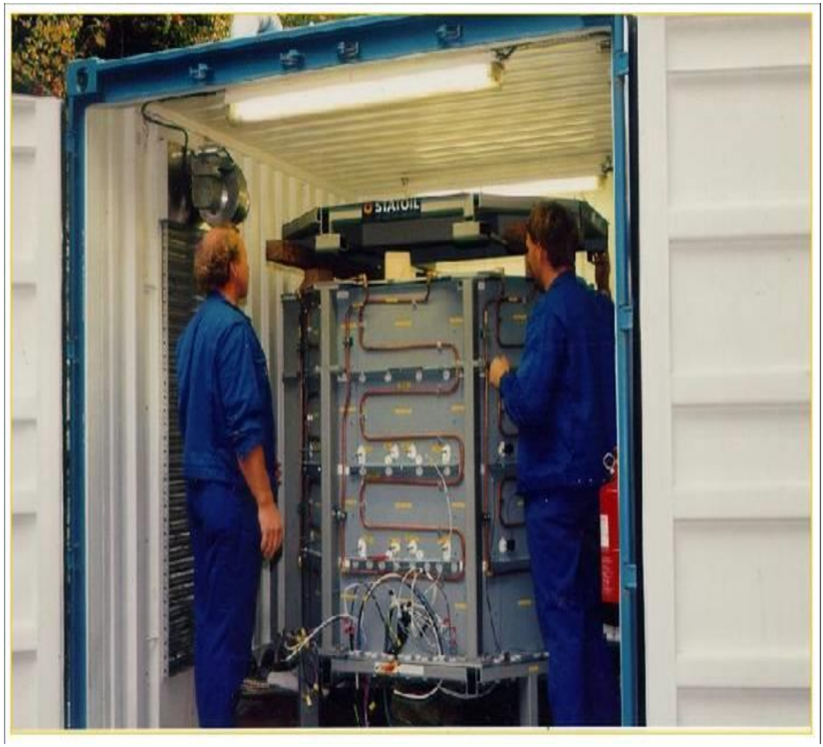






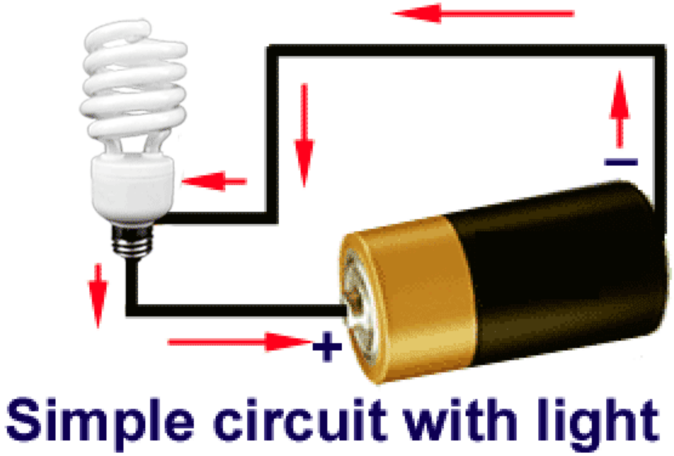
Prototech fuel cell experience

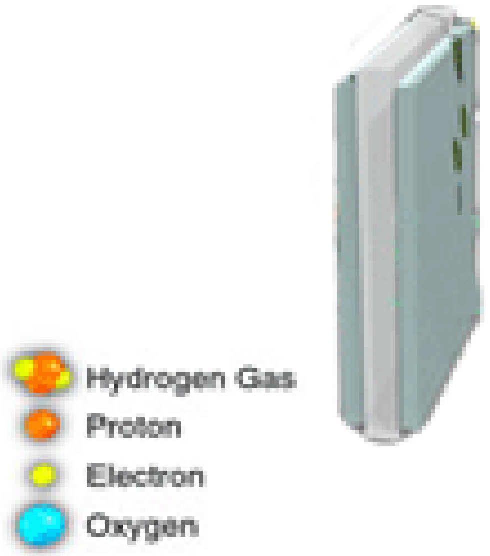
- **Fuel cell activities at Prototech started in 1991 with the Statoil funded Mjøllner project (30 M$ total 1991-1997).**
- **The 10 kW class Mjøllner plant tested in 1997 was the first known complete planar SOFC system in fuelled with natural gas.**
- **Prototech has participated in a large number of fuel cell and hydrogen research projects and has an experienced group of researchers and engineers.**



10 kW class Mjøllner SOFC plant tested in 1997

Battery vs. Fuel Cell





- have 2 ends -- a + terminal
  -- a – terminal
- connect the two terminals with wire → a circuit
- e^- flow through wire → electricity is produced.

1801
Humphry Davy demonstrates the principle of what became fuel cells.

1839
William Grove invents the 'gas battery', the first fuel cell.

1889
Charles Langer and Ludwig Mond develop Grove's invention and name the fuel cell.

1950s
General Electric invents the proton exchange membrane fuel cell.

1959
Francis Bacon demonstrates a 5 kW alkaline fuel cell.

1960s
NASA first uses fuel cells in space missions.

1970s
The oil crisis prompts the development of alternative energy technologies including PAFC.

1980s
US Navy uses fuel cells in submarines.

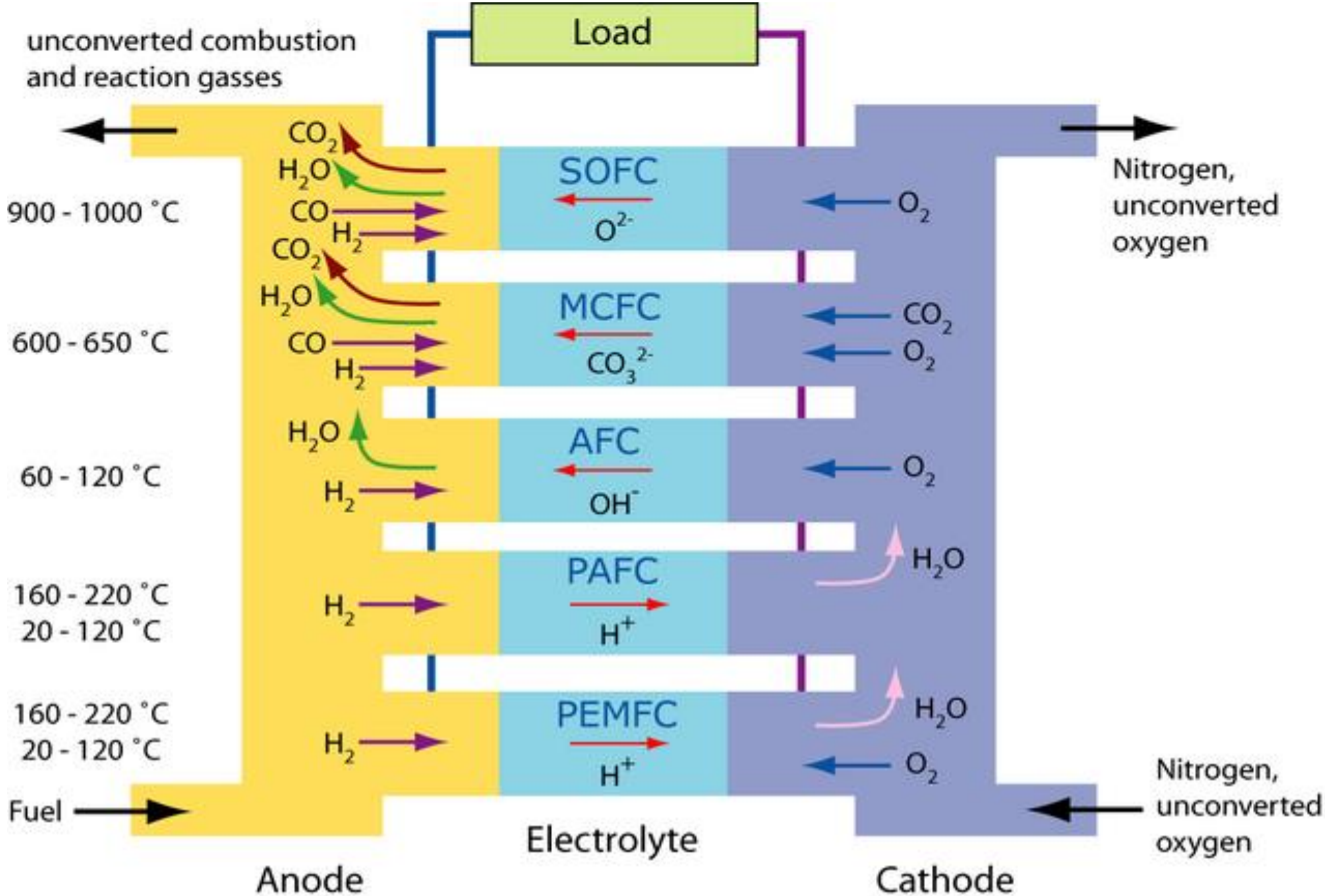
1990s
Large stationary fuel cells are developed for commercial and industrial locations.

2007
Fuel cells begin to be sold commercially as APU and for stationary backup power.

2008
Honda begins leasing the FCX Clarity fuel cell electric vehicle.

2009
Residential fuel cell micro-CHP units become commercially available in Japan. Also thousands of portable fuel cell battery chargers are sold.

Different types of Fuel Cells



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Low temperature fuel cells (AFC, PAFC, PEMFC):

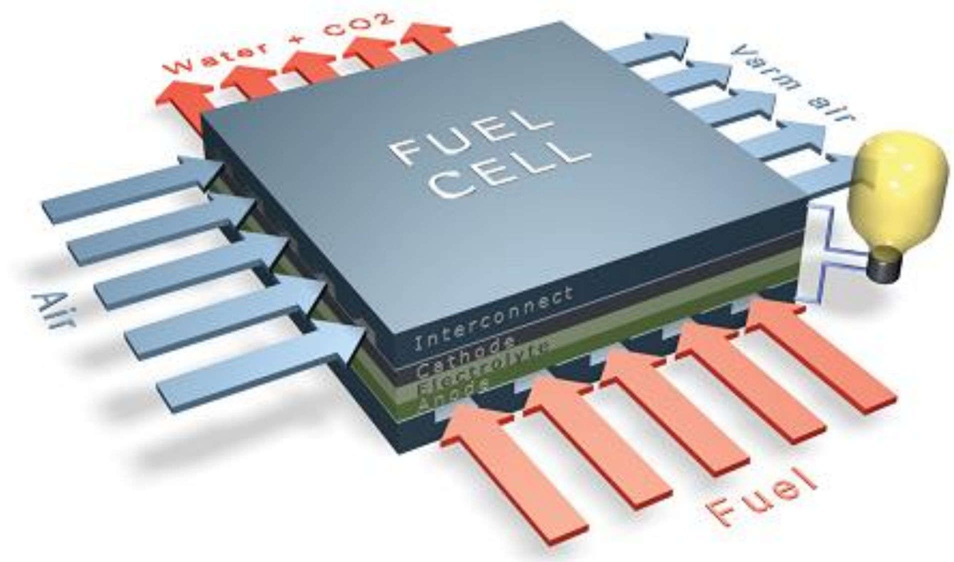
- Lower electrical efficiencies (up to 40%) when using natural gas a primary fuel
- Often use expensive precious metals (e.g. Pt) to improve performance
- Can be rapidly thermally cycled making them better suited to transportation applications
- Require a relatively pure supply of H_2 as a fuel →a separate process is required to convert other fuels to hydrogen
- Generally has a large size and weight, corrosive cell components

High Temperature Fuel Cells (SOFC)

- Operate at higher temperature (reduces need for expensive precious metals)

- Operates with a number of different hydrocarbon fuels

- Combined with heat recovery technologies
→ total system efficiency up to 85%



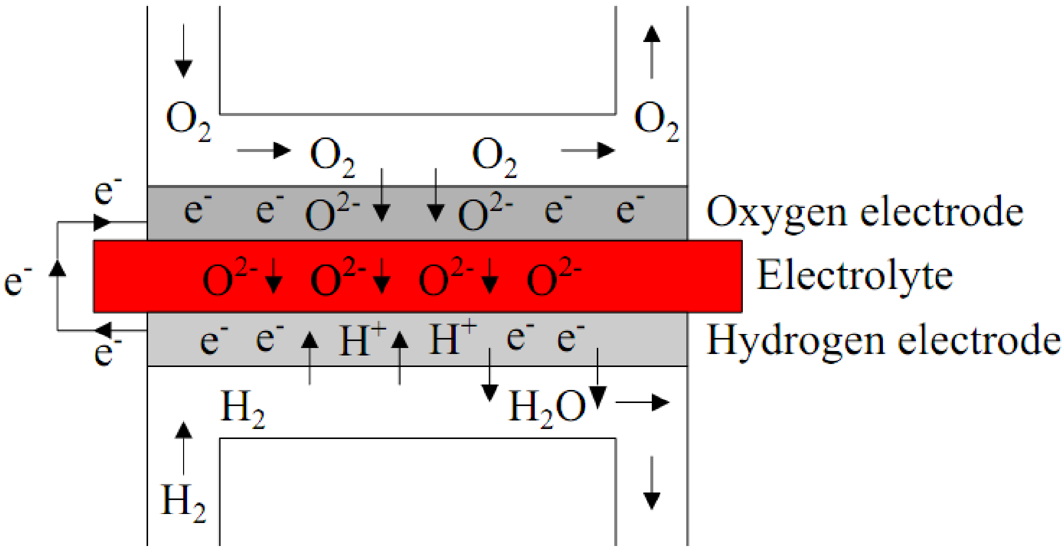
- Clean, reliable, near 0 – emissions

- Noise pollution associated with power generation eliminated

- Combined together into stacks can provide large amounts of electric power

- They promise to be extremely useful in large, high-power applications such as full scale industrial stations and large-scale electricity-generating stations

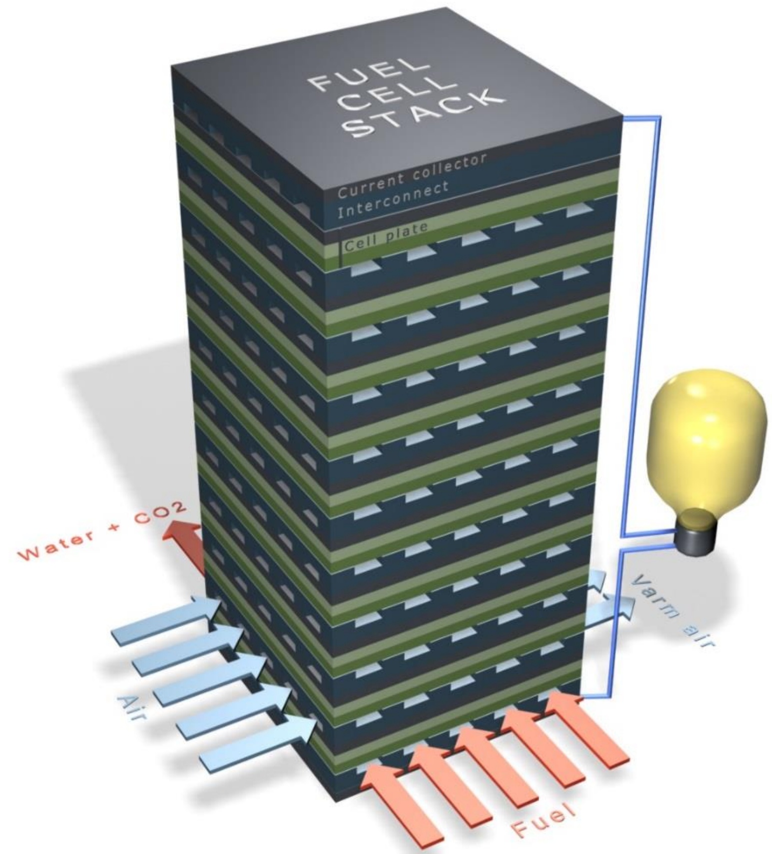
SOFC – How it works



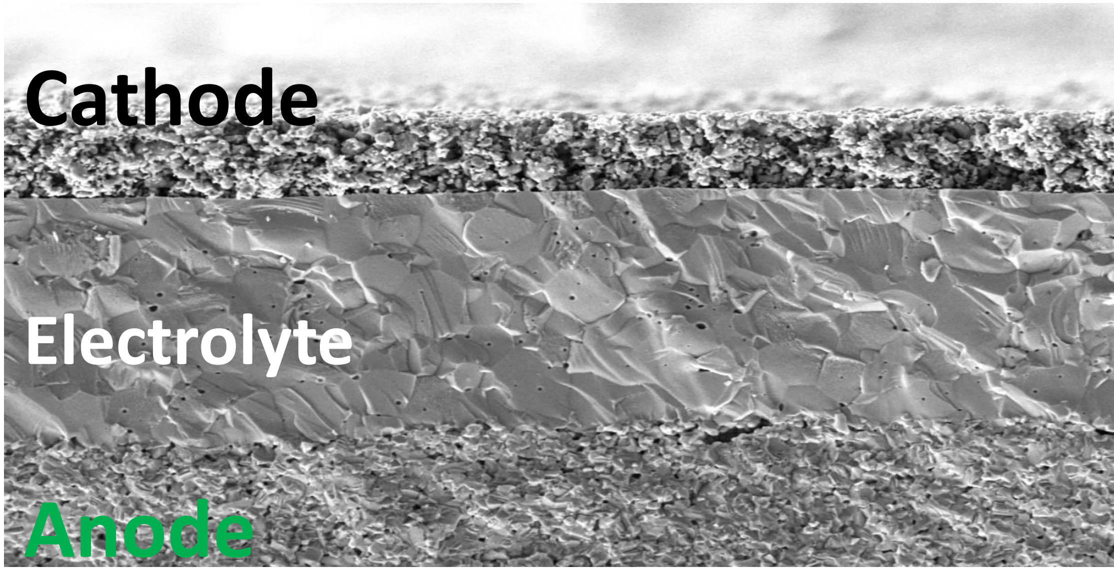
$$H_2 \rightarrow 2H^+ + 2e^-$$

$$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$$

$$2H^+ + O^{2-} \rightarrow H_2O$$



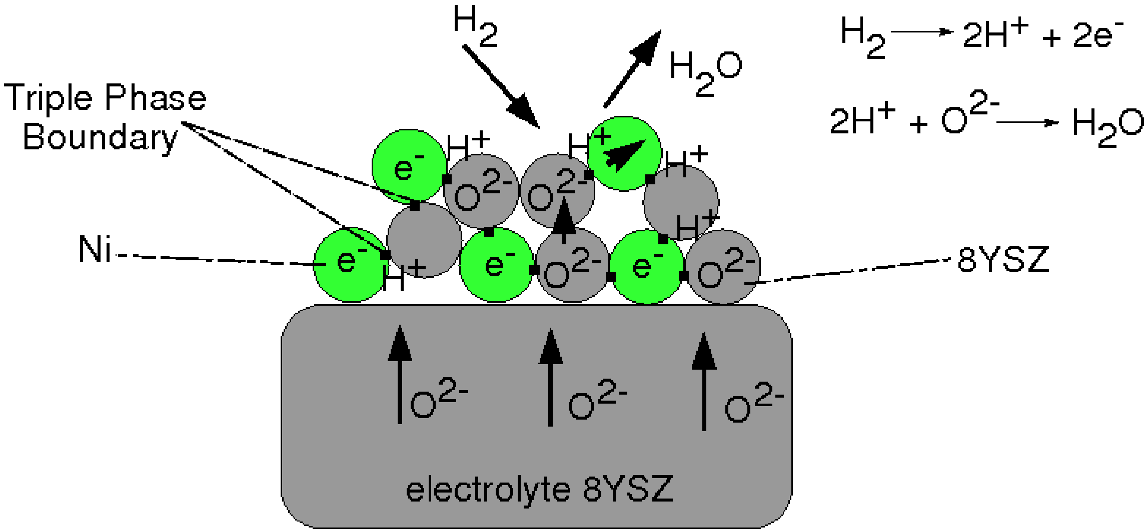
Triple Phase Boundary (TPB) Mechanism



- interface established: reactants, electrolyte and catalyst = **TPB**

- e^- , O^{2-} and fuel gas present in the electrochemically active area

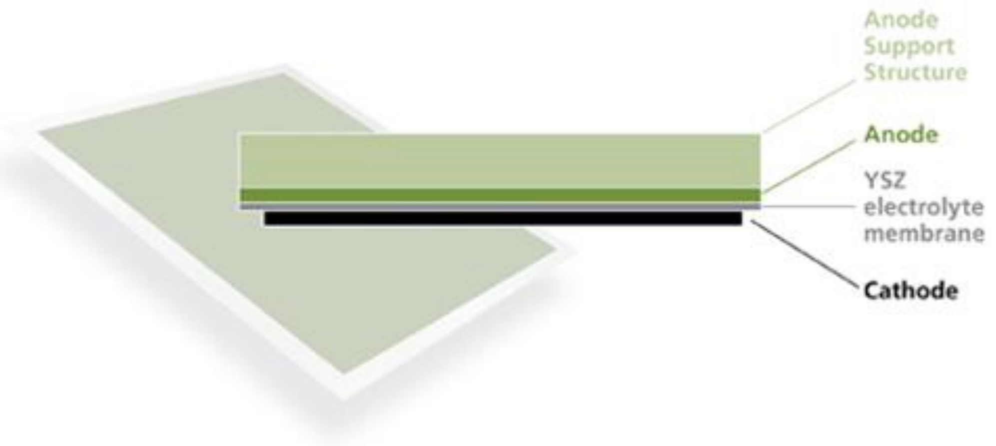
- O^{2-} ion gives up $2e^-$ and with H_2 forms a H_2O molecule; e^- are conducted by a metallic current collector towards the outside electrical circuit.



Electrolyte Supported SOFC

- Thickness: 160 - 200 microns
- Operates at >800ºC
- Stable and requires relatively simple fabrication using existing ceramic manufacturing techniques
- a lower power density compared to Anode Supported SOFCs

Anode supported SOFC



- Thickness 260 - 280 microns thick
- Operates at < 780ºC
- much higher power density compared to electrolyte supported fuel cells

Nanopowders for SOFC

– increase in ion conductivity of the electrolyte;

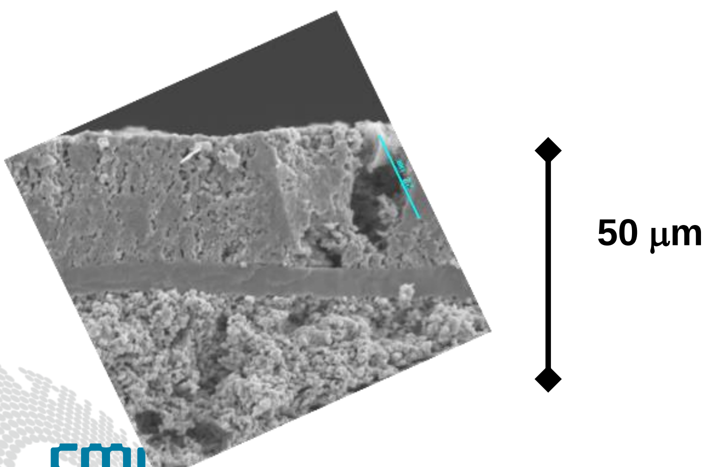
– increase catalytic capacity of the cathode and anode;

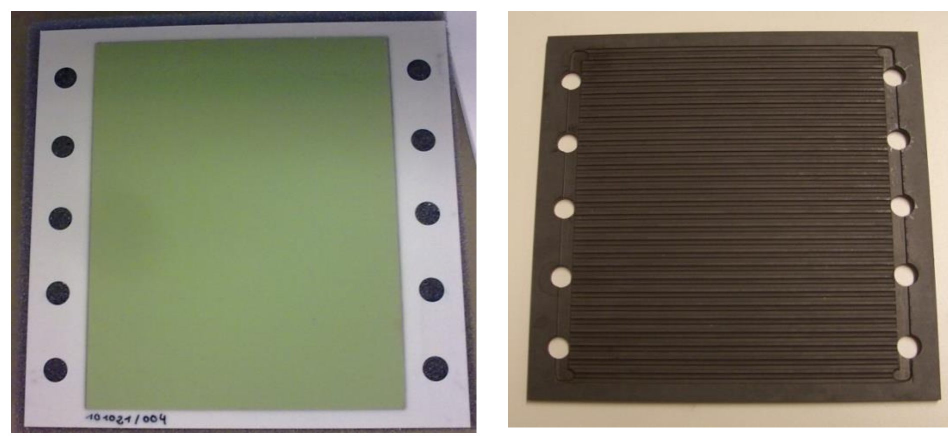
– reduction of the losses at TPB;

– decrease of sintering temperature;

– doping elements are distributed homogeneously;

– enhanced mechanical properties under temperature change and gas passage through the electrodes;





SOFC cell and interconnect

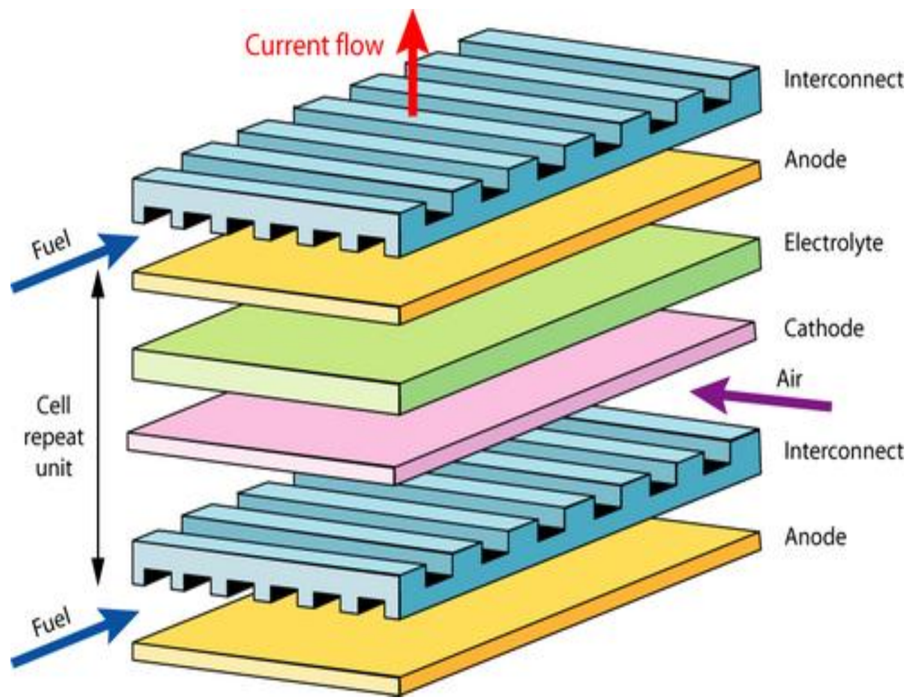
Materials developed for fuel-cell applications

Interconnect
- Metals (Fe-Cr alloys)
- Ceramics (e.g., $LaCrO_3$)

Electrolyte
- Yttria-stabilized zirconia
- Samarium doped ceria
- Gadolinium doped ceria

Cathode
- Doped $Sr\text{-}LaMnO_3$
- $La_{1-x}Sr_xCo_{1-y}Fe_yO_3$
- Cermets

Anode
- Cermets (e.g., Ni-YSZ, Ni-SDC)
- Ceria-copper



Cell Stacking

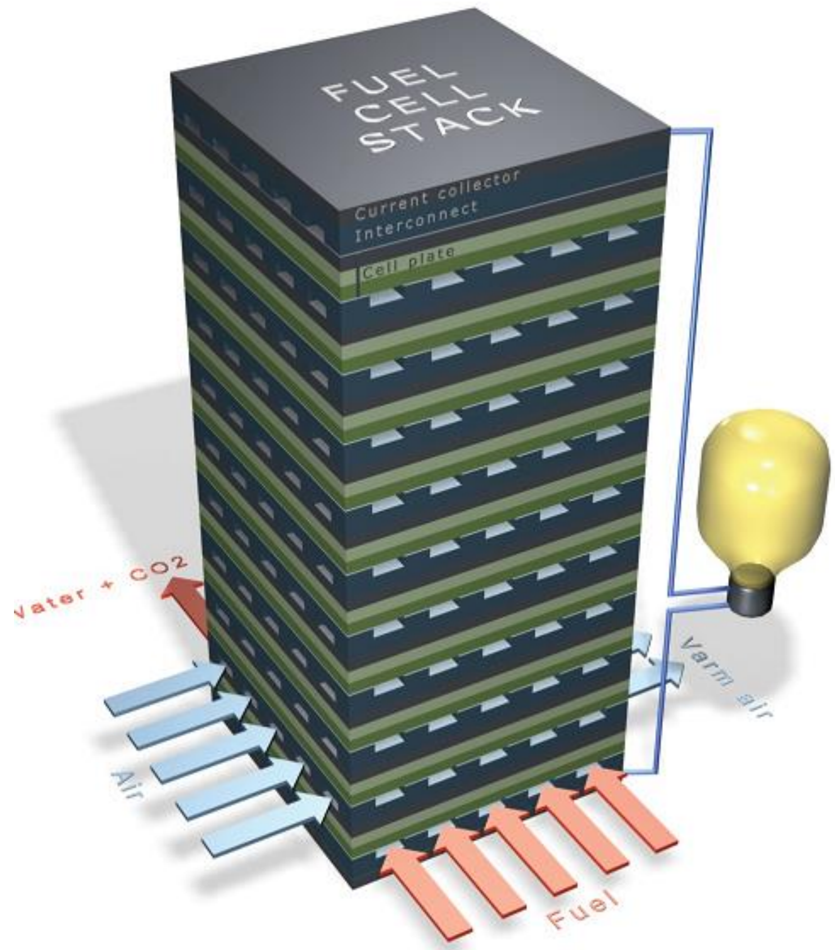
Individual fuel cells must be combined to produce appreciable voltage levels and so are joined by interconnects

Because of the configuration of a
flat plate cell, the **interconnect** becomes a separator plate with two functions:

1) provide an electrical series connection between adjacent cells, specifically for flat plate cells

2) to provide a gas barrier that separates the fuel and oxidant of adjacent cells

All interconnects must be an electrical conductor and impermeable to gases



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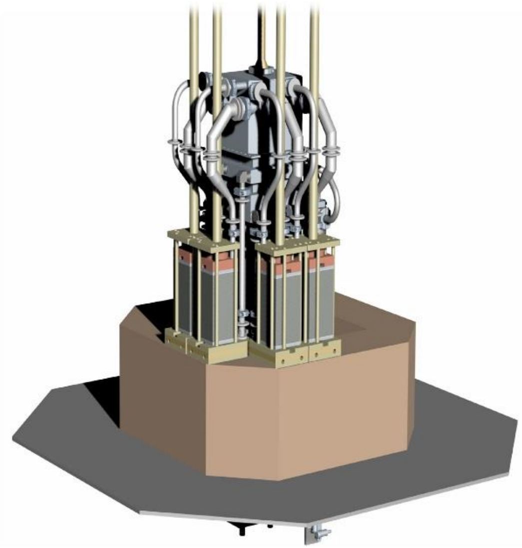
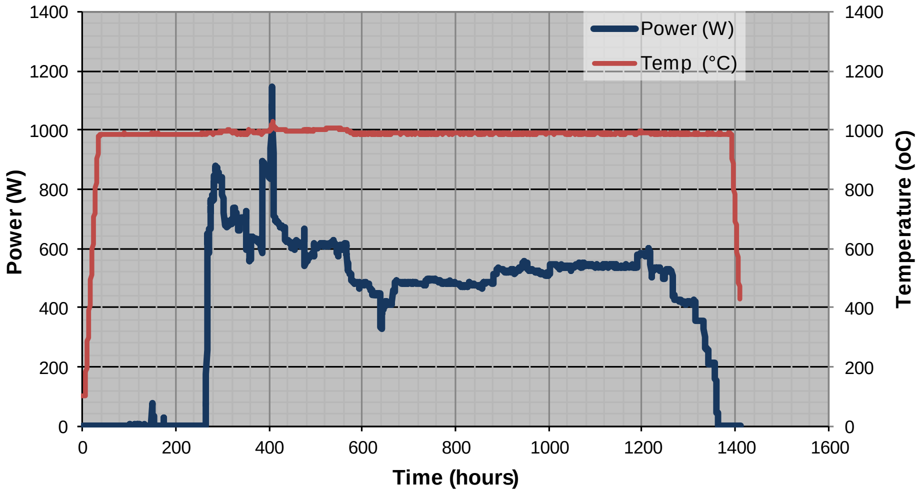
Attractive markets

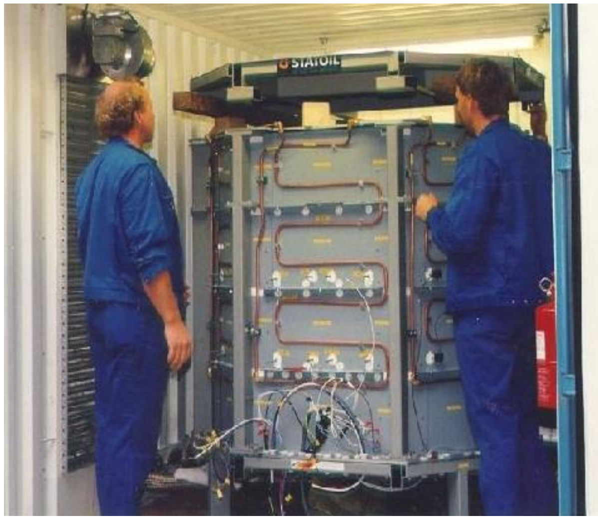
- Continuous operation (> 4000 hrs, few on/off per year)
- High energy prices (remote areas)
- Poor grid

- Small or medium scale power production
- Combined Heat and Power
- In combination with back-up systems
- In combination with hydrogen production

Mjøllner plant (1997)







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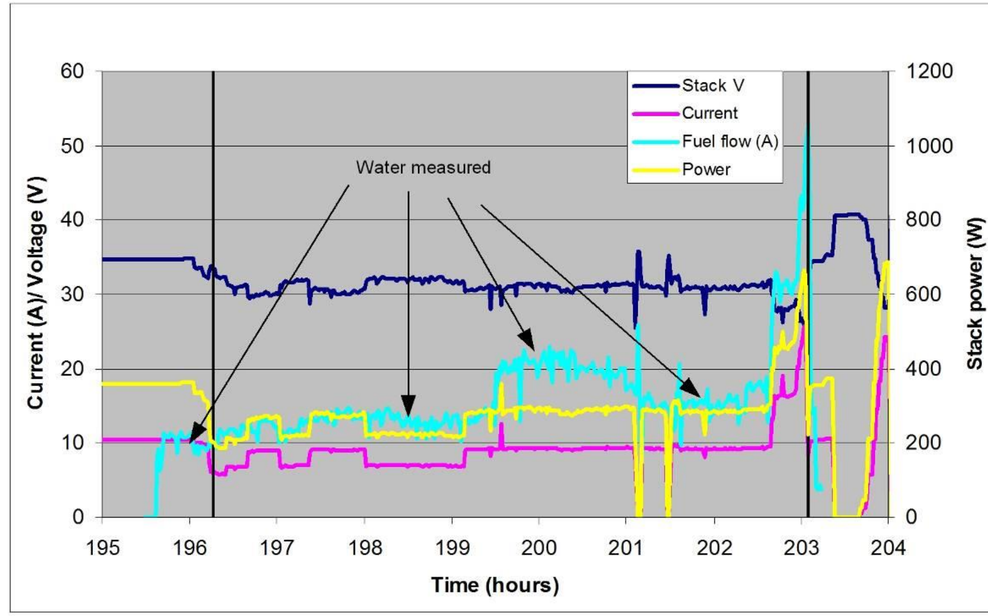
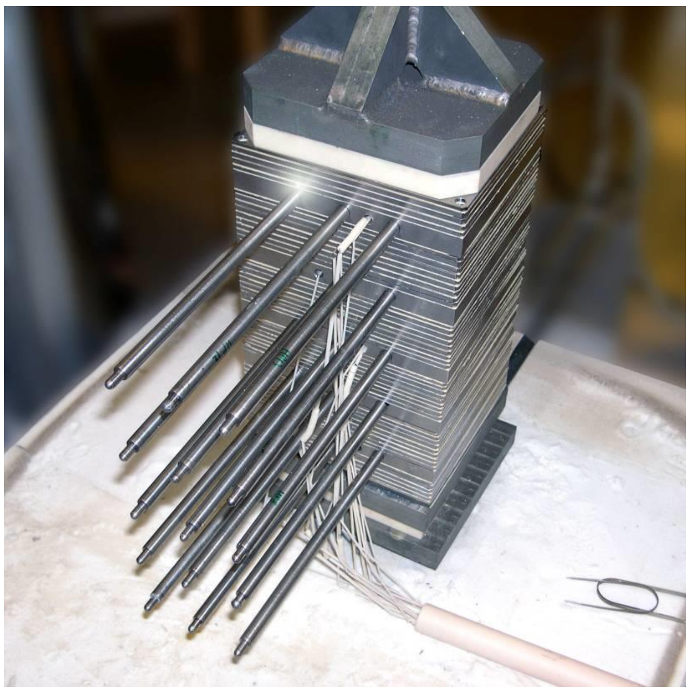
BioCellus (2007)





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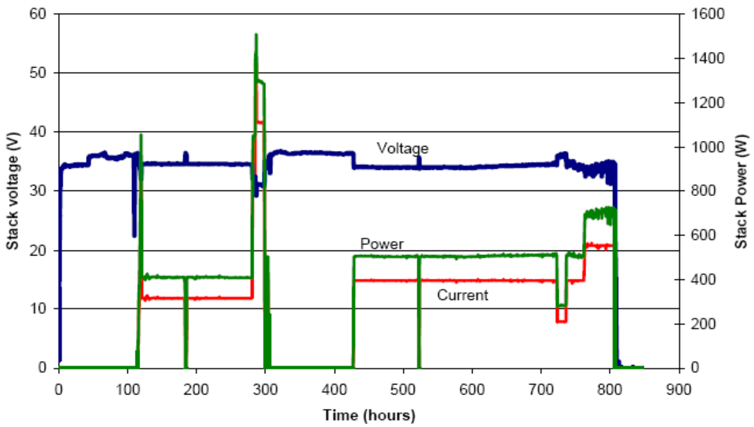
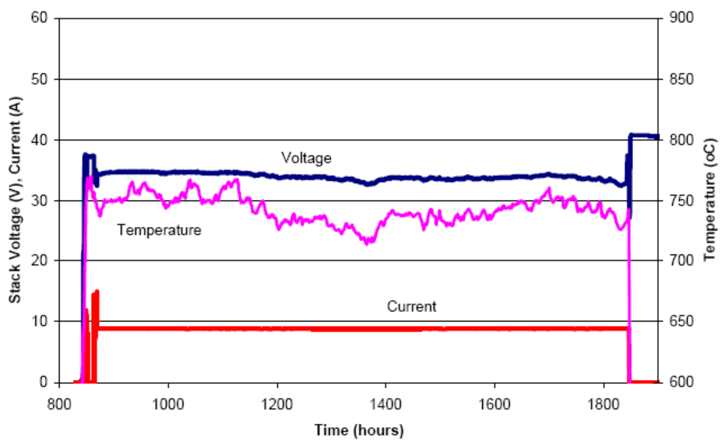
SEVENTH FRAMEWORK PROGRAMME

3 kW CHP (2008)



Stack voltage (V)
Stack Power (W)
Time (hours)
Voltage
Power
Current



Stack Voltage (V), Current (A)
Temperature (oC)
Time (hours)
Voltage
Temperature
Current

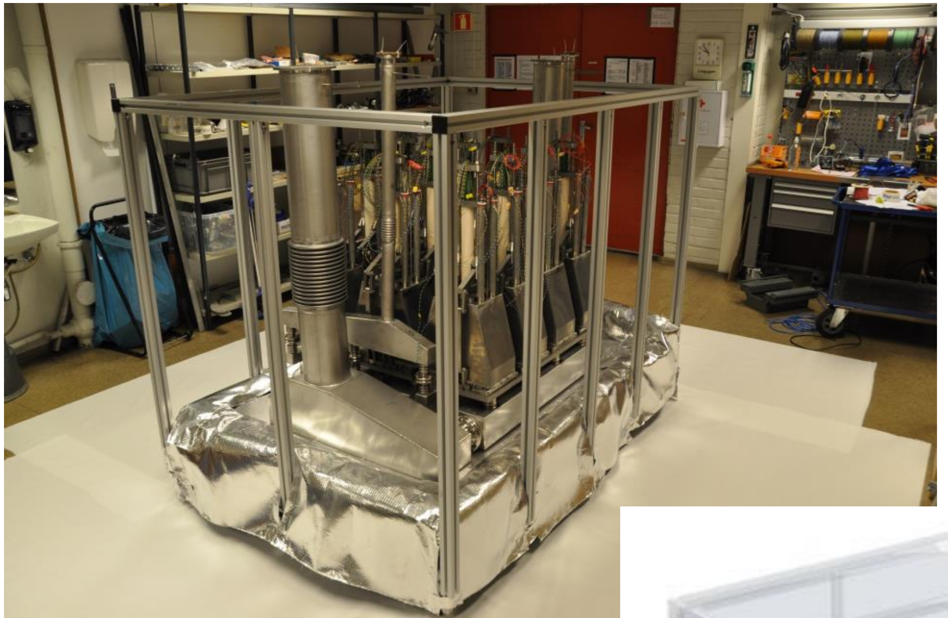
KALD SONE
cmr Prototech
Brenselcelle

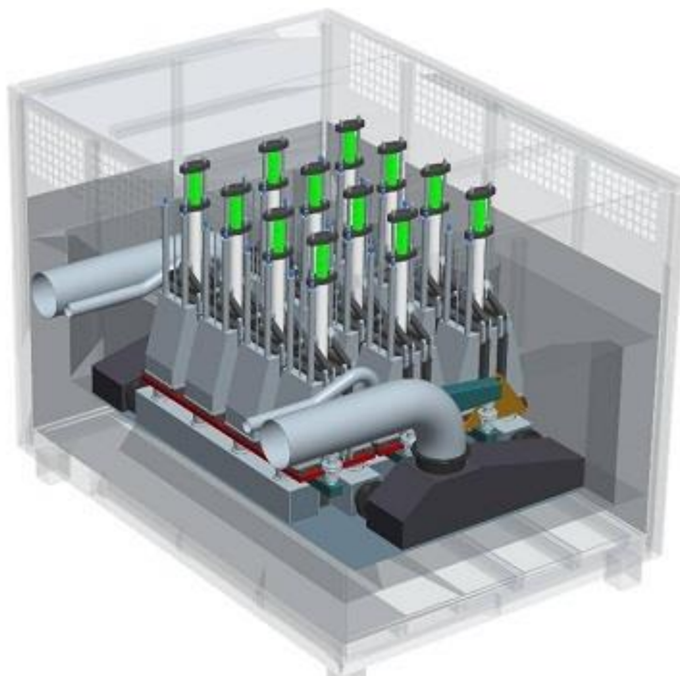
cmr Prototech

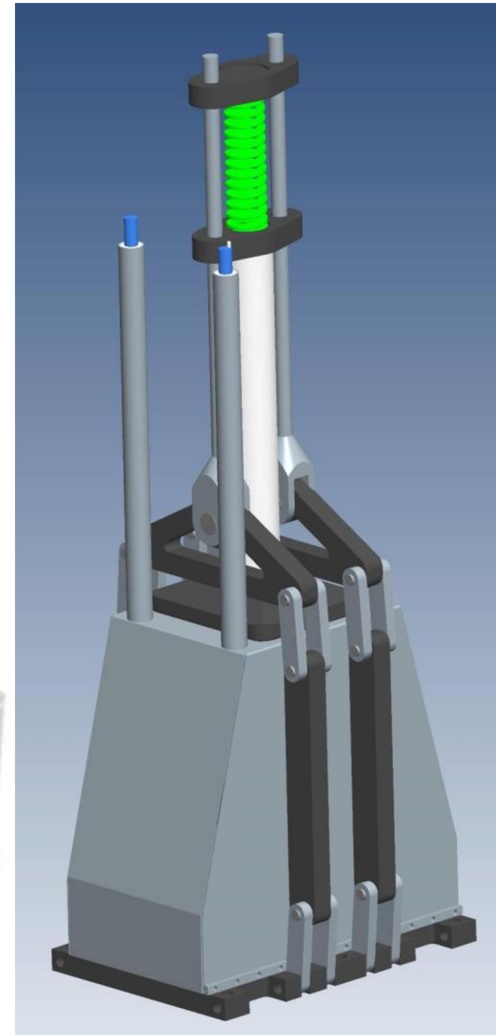
REMKOF (2009)

- Demonstration of a HTPEM-driven ferry boat in Bergen harbour
- 12 kW HTPEM + batteries, H2 in metal hydride tanks

20 kW system - 24 stack SOFC hot box – ZEG Power (2010-2013)







Hydrogen fuelled high speed passenger vessel (2014)

Examine possibility of using H2 as fuel for ships (offshore supply ships, ferries, passenger vessels, etc.)

Used existing high speed passenger vessel as basis for specific case

Next step will be to develop full scale demo

Refueling station must be developed

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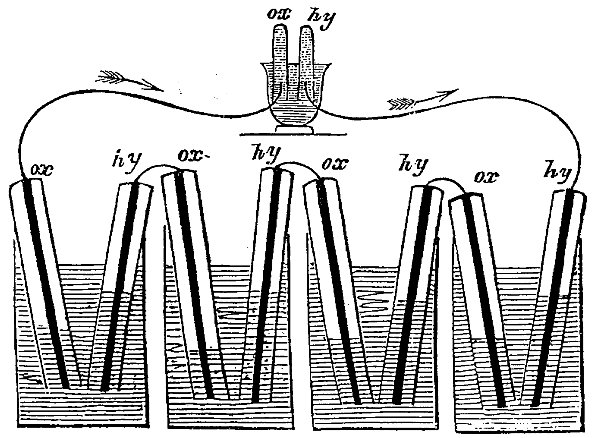
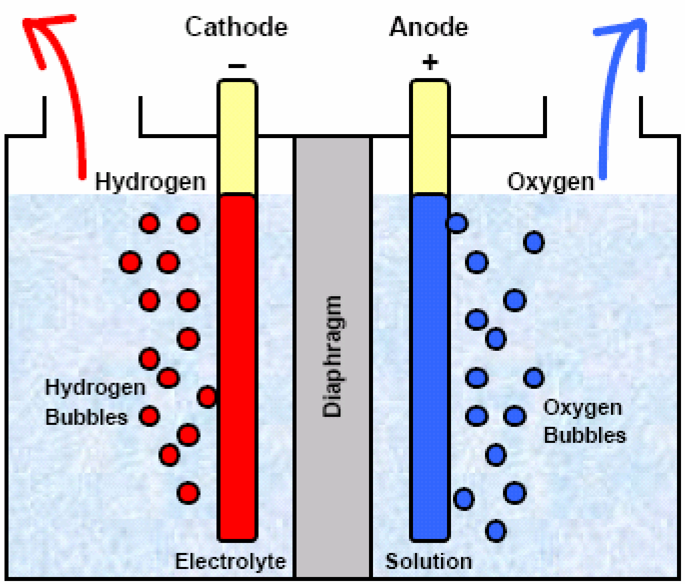
Water Electrolysis – H_2 generation



Grove's experiment of 1842
Figure from Grove's publication of 1842 [3]

By providing energy from a battery, water (H_2O) can be dissociated into the diatomic molecules of hydrogen (H_2) and oxygen (O_2)

$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$



Standard Electrolysis

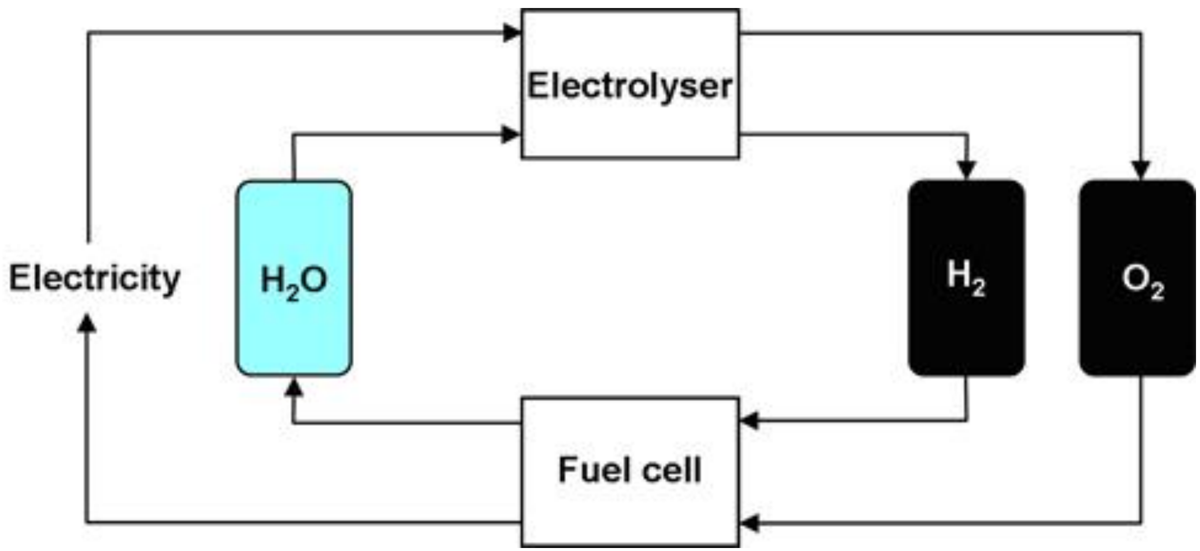
	Energy Density (Mega Joules per kilogram)
Li-ion Battery	0.54
Gasoline	46.9
Hydrogen	120.0

~ 220 times more energy than batteries

~ 2.6 times more energy than gasoline

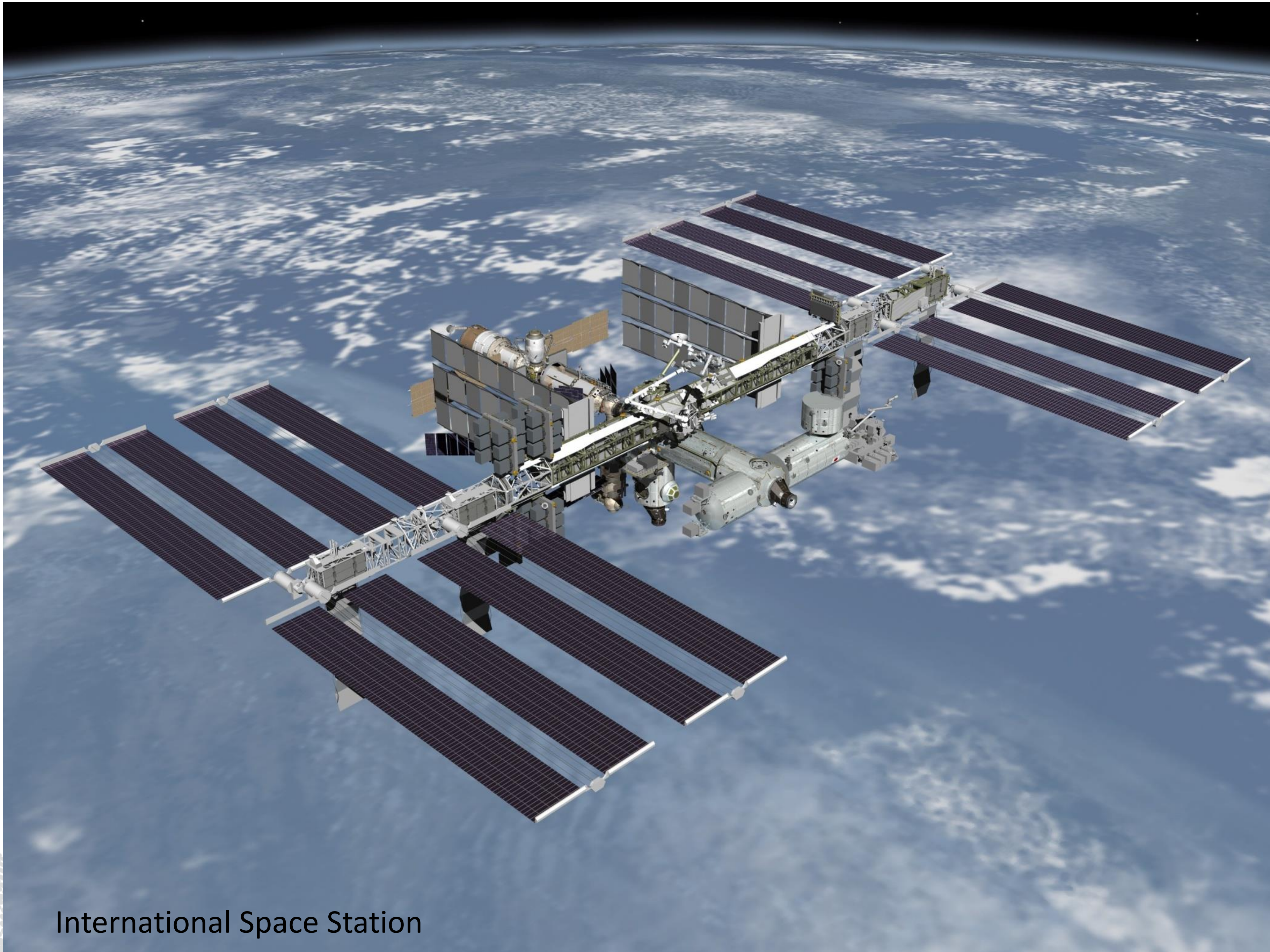
No available source of H_2

Reversible SOFC (2014)

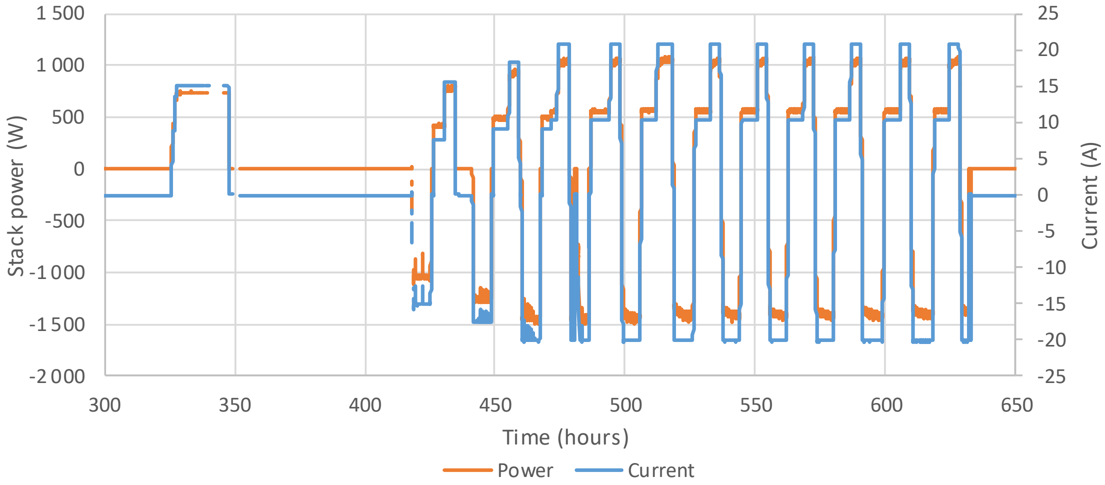


Fuel cell is a battery that runs on gases → generates electricity directly from the chemical energy of its reactants, typically H_2 and O_2, The only by-product is H_2O.
An **electrolyser** works as a fuel cell in reverse: it generates H_2 and O_2 from H_2O using electricity

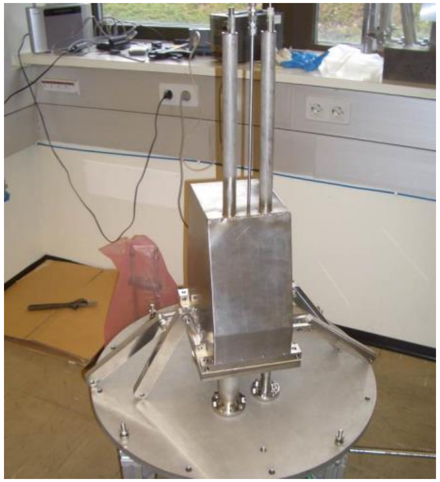
In a **regenerative fuel cell** system these two components act together as a rechargeable battery. When the solar panels of the satellite provide sufficient power, the electrolyser produces H_2 and O_2 which are stored in separate gas tanks. During the eclipse, when the solar panels are inactive, the fuel cell uses the stored gases to generate the required power. The by-product H_2O is stored so that it can be supplied to the electrolyser after the eclipse.

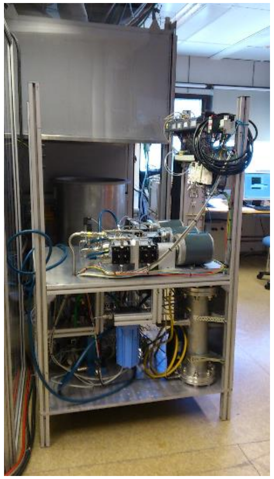


International Space Station



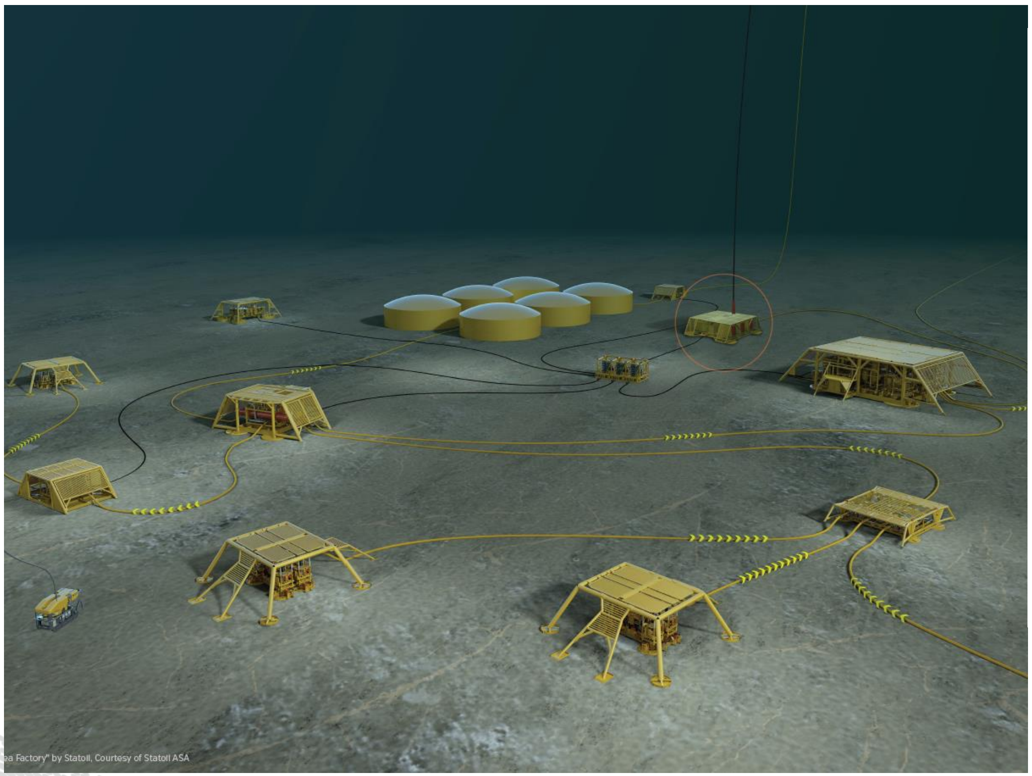
Stack power (W)
Current (A)
Time (hours)
Power
Current
1 500
1 000
500
0
-500
-1 000
-1 500
-2 000
25
20
15
10
5
0
-5
-10
-15
-20
-25
300
350
400
450
500
550
600
650

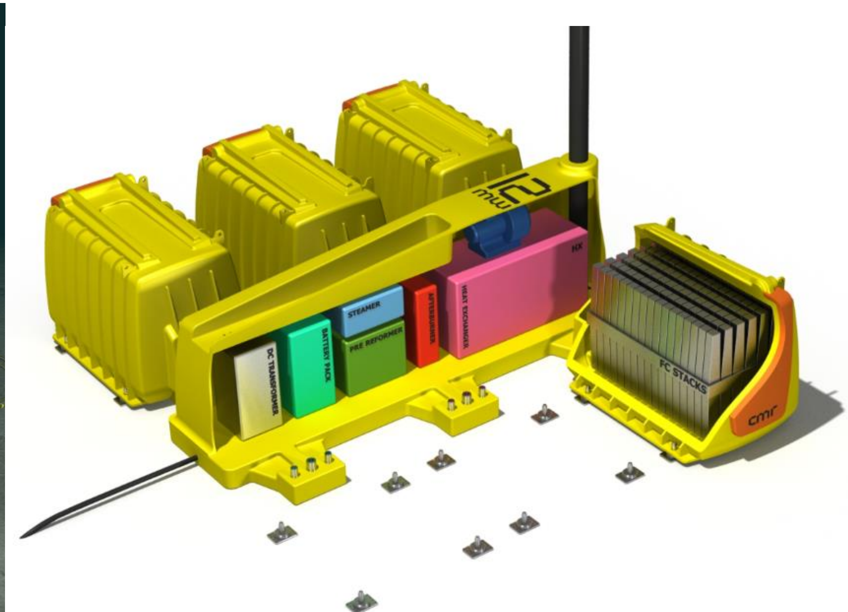




CHEOP – Clean Highly Efficient Offshore Power (2017)

- 16 mNOk JIP-project Statoil and Shell are industry partners
- Develop an optimal fuel-cell stack for offshore use (topside and subsea)





- Module based (2MW)
- 60-85% Power efficiency
- Runs on local NG
- Redundancy reduction
- Low maintenance need
- Few movable parts

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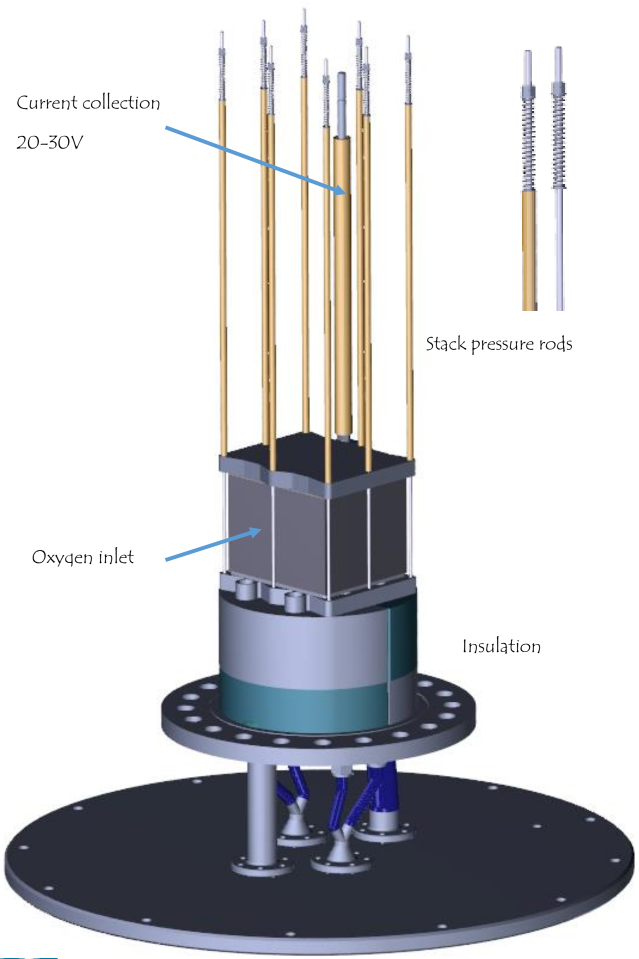
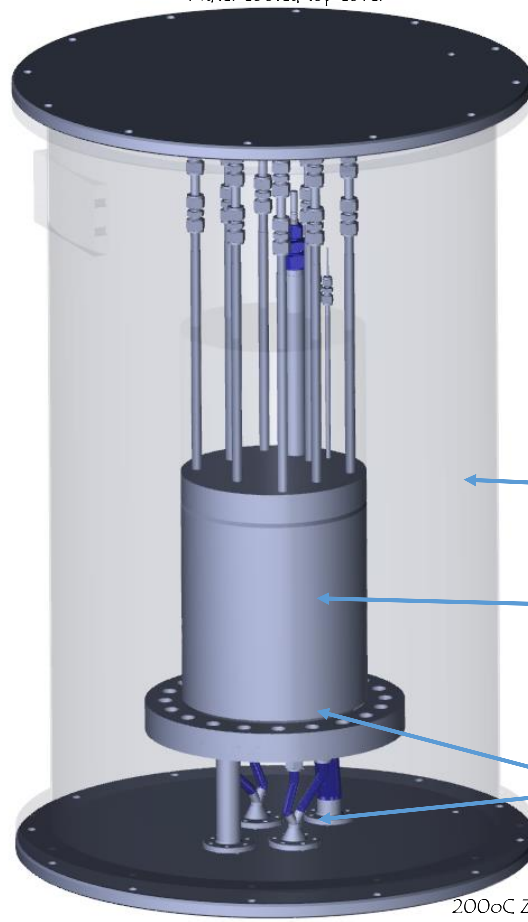
FC Mars (2017)





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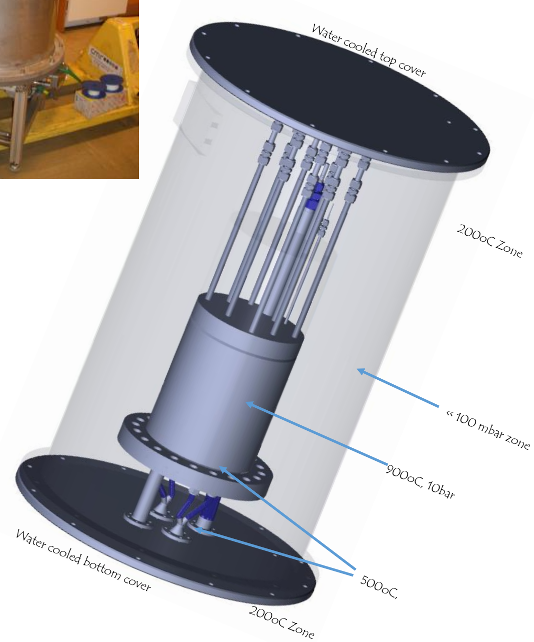

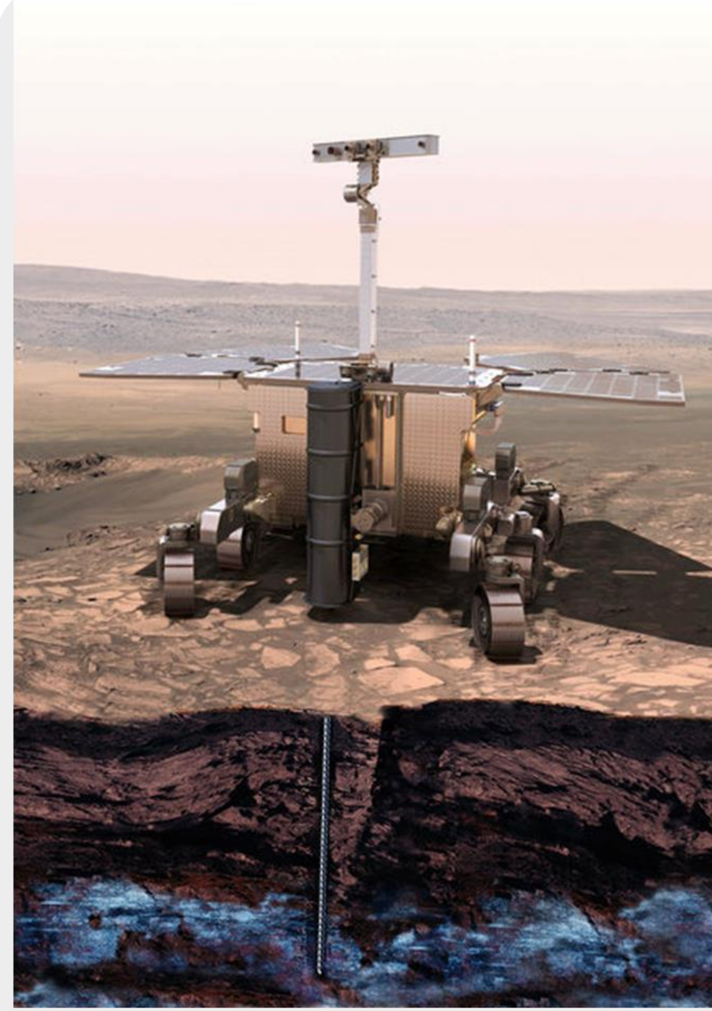

ExoMars rover, 2018, ESA

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More details:

http://prototech.no/home/

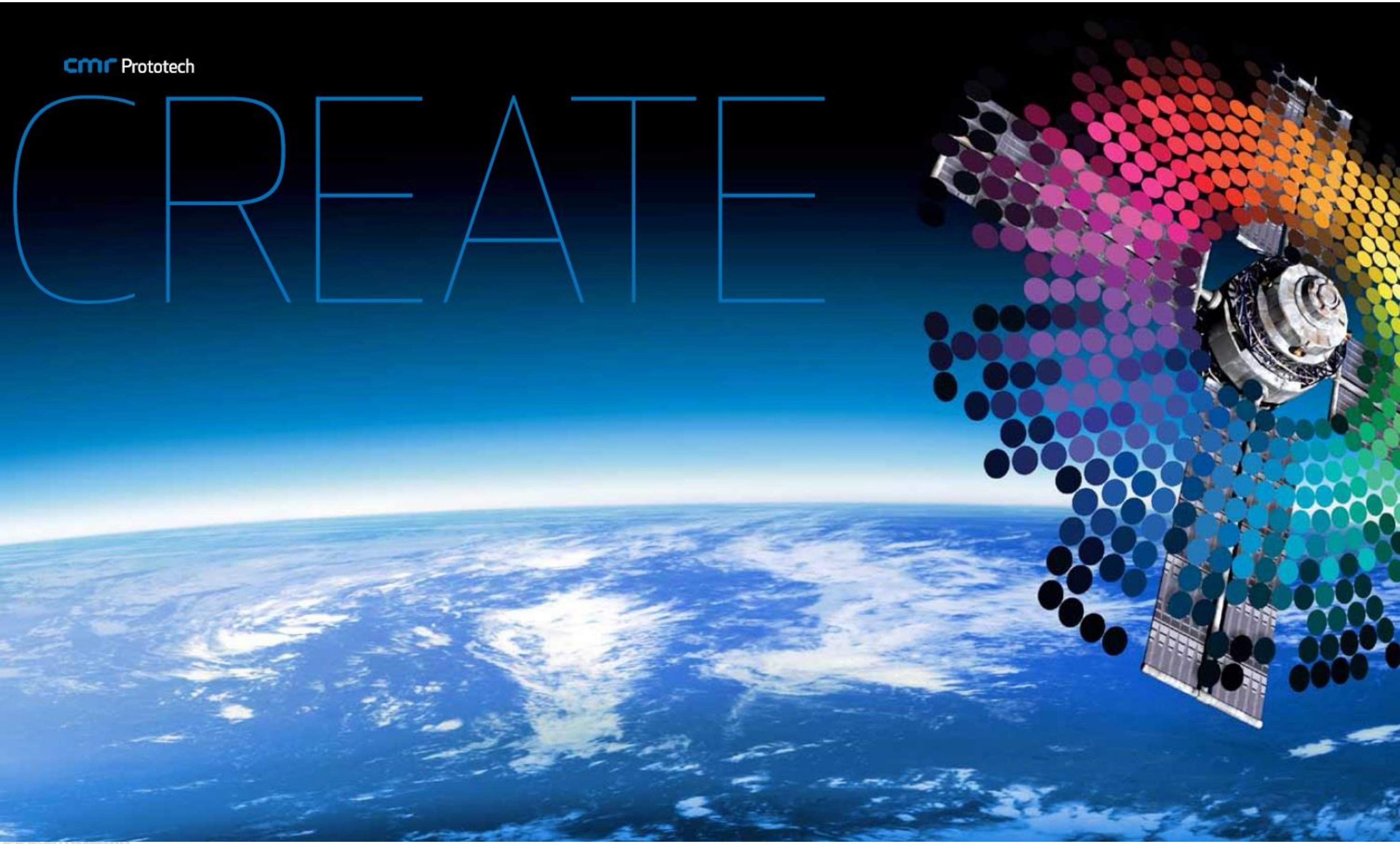
http://prototech.no/projects/

http://prototech.no/projects/10454/clean-highly-efficient-offshore-power-cheop/

http://prototech.no/projects/10568/hydrogen-ferry/

http://prototech.no/projects/10680/green-fish-farm/

Contact: crina@prototech.no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CREATE

Thank you for your attention

crina@prototech.no