1 Fuel Cells

Halina Pawlak Kruczek
PWr 201….

KAPITAŁ LUDZKI
NARODOWA STRATEGIA SPÓJNOŚCI

Politechnika Wrocławska

UNIA EUROPEJSKA
EUROPEJSKI
FUNDUSZ SPOŁECZNY

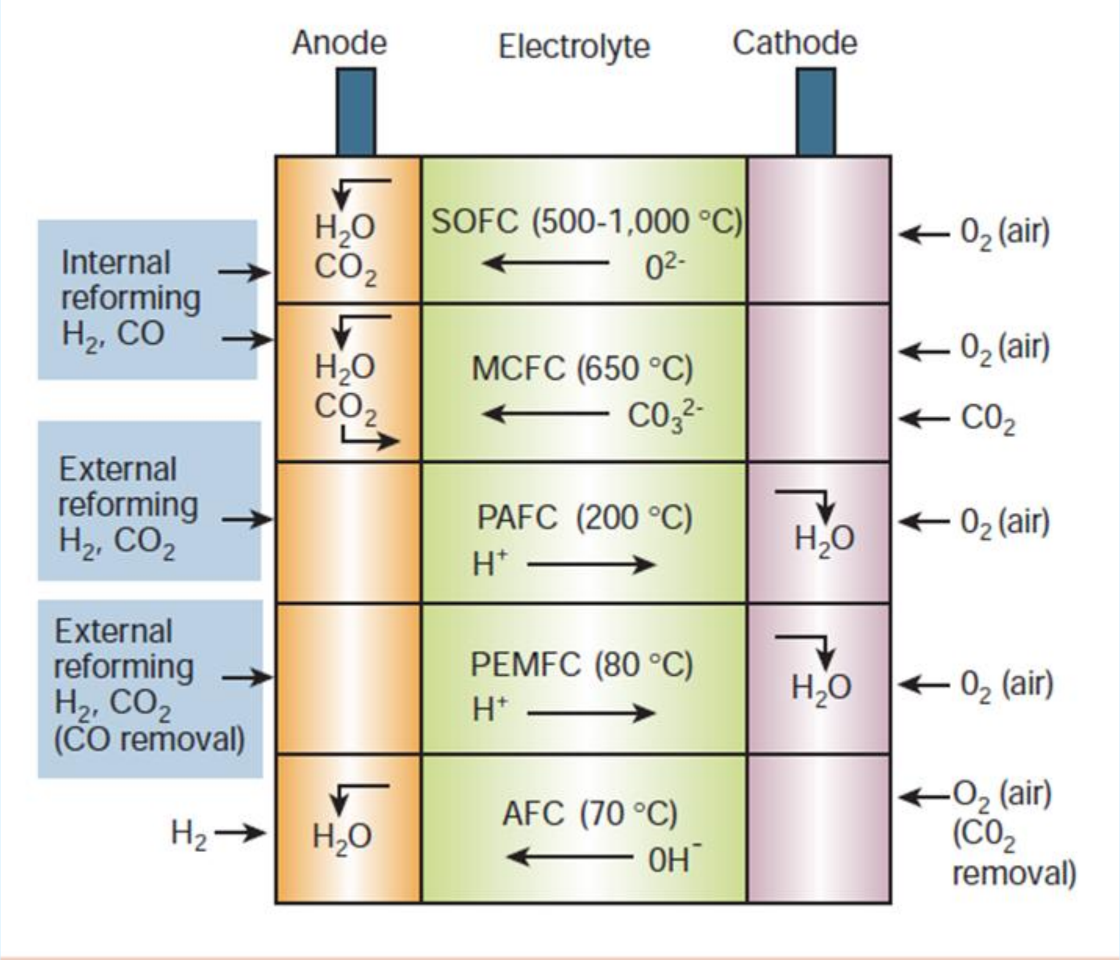
Projekt współfinansowany ze środków Unii Europejskiej w ramach Europejskiego Funduszu Społecznego

WHAT ARE FUEL CELLS

- Fuel cells are electro - chemical devices, constituting a breakthrough in the field of energy sources that can produce electricity and heat directly from a proceeding chemical reaction.

- In 1839 British physicist William R. Grove demonstrated that during the electrochemical reaction involving hydrogen and oxygen electricity is produced. Such a cell has no moving parts, operates without noise, and its only waste substance is water. However, basing on this phenomenon fuel cells for over a century were just a laboratory curiosity.

https://www.youtube.com/watch?v=R15R54oZAdA
Fuel cells and hydrogen production



Fuel cells a

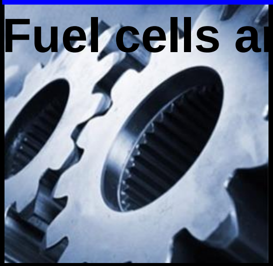


Table 2 Summary of future R&D requirements for fuel-cell materials

Application	Size (kW)	Fuel cell	Fuel	Critical materials issues
Power systems for portable electronic devices	0.001–0.05	PEMFC DMFC	H_2 CH_3OH	Membranes exhibiting less permeability to CH_3OH, H_2O
		SOFC	CH_3OH	Novel PEN structures
Micro-CHP	1–10	PEMFC	CH_4 LPG	CO-tolerant anodes, novel membranes, bipolar plates
		SOFC	CH_4 LPG	More robust thick-film PENs operating at 500–700 °C
APU, UPS, remote locations, scooters	1–10	SOFC	LPG Petrol	More robust thick-film PENs operating at 500–700 °C; rapid start-up
Distributed CHP	50–250	PEMFC	CH_4	CO-tolerant anodes, novel membranes, bipolar plates
		MCFC	CH_4	Better thermal cycling characteristics
		SOFC	CH_4	Cheaper fabrication processes; redox-resistant anodes
City buses	200	PEMFC	H_2	Cheaper components
Large power units	10^3–10^4	SOFC/GT	CH_4	Cheaper fabrication processes for tubular SOFC system

Abbreviations: UPS, uninterruptible power systems; LPG, liquid petroleum gas; GT, gas turbine. Other abbreviations defined in the text.

FUEL CELLS

- Fuel cells only in the sixties of this century lightweight and compact (though expensive) NASA began installing a spacecraft to supply them with electricity.
- Today, this technology is promising environmentally clean, efficient and quiet, trying to take advantage of the many new land uses, including to power mobile phones, portable computers, houses and flats, and electric engines.
- Experts estimate that replacing traditional methods of generating electricity from coal by fuel cells should reduce carbon dioxide emissions by 40% - 60%, while emissions of nitrogen oxides by 50% -90%. Principle of working fuel cell is base on the electrochemical reaction.
- Fuel cells produce electricity by Electrochemical reactions.

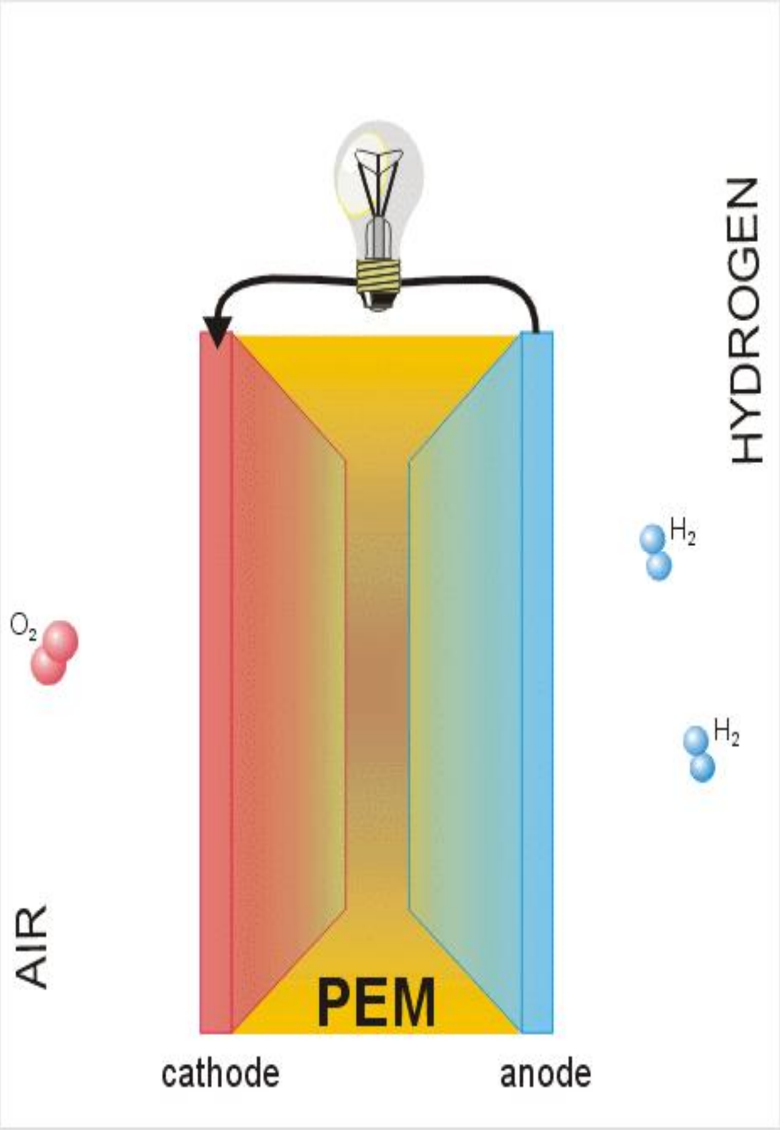
FUEL CELLS

- The rapid development of fuel cells resulted in the demand for highly efficient and clean energy sources in the era of rapidly depleting fossil fuel sources.

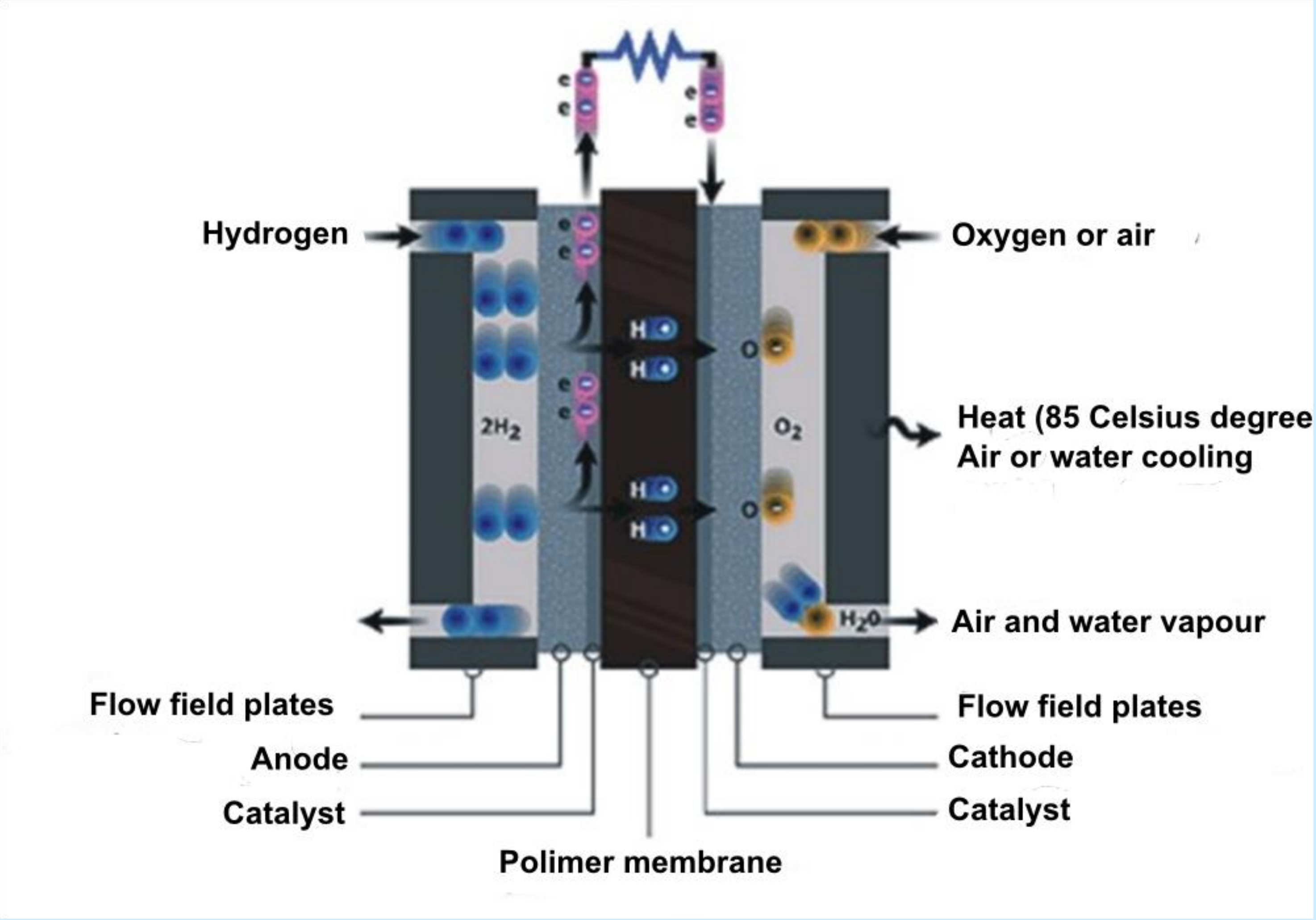
- Hydrogen and other fuels that are high hydrocarbon fuel for fuel cells can be obtained by using alternative energy sources such as solar, wind, and from biological sources, eg bacteria of the genus clostridium obtaining hydrogen from biological waste. Research on obtaining hydrogen aim to become independent of the population partly or entirely from fossil fuels

Fuel cells operating principle and construction

- Fuel cells are electrochemical devices that produce useful energy (electricity, heat) in a chemical reaction of hydrogen with oxygen. Water is a byproduct of this reaction.



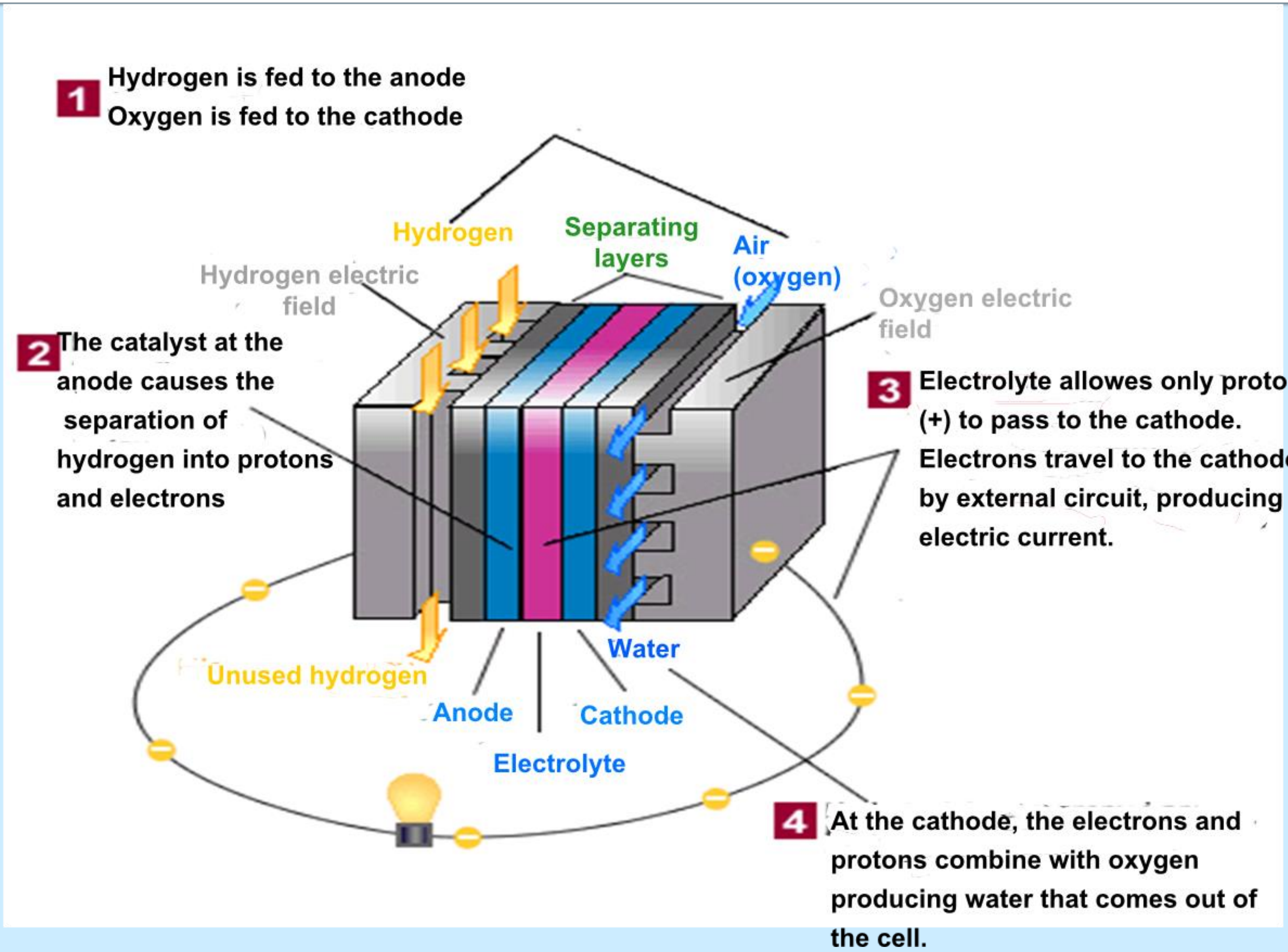
Fuel cell construction



Fuel cells operating principle and construction (9hr 5/03/13)

- A fuel cell is composed of two electrodes: the anode and cathode. The electrodes are separated by an electrolyte present in liquid form or as a solid. The electrolyte allows the flow of cations, but prevents the flow of electrons.
- The chemical reaction occurring in the cell is broken hydrogen proton and electron at the anode, then the combination of reactants at the cathode. Electrochemical processes accompanied by electron flow from the anode to the cathode without an impermeable membrane. As a result of electrochemical reaction of hydrogen and oxygen produced electricity, water and heat.
- Fuel - Hydrogen in pure or mixed with other gases - is fed continuously to the anode and the oxidizer - oxygen in pure or mixture (air) - is fed continuously to the cathode.

Fuel cells operating principle and construction

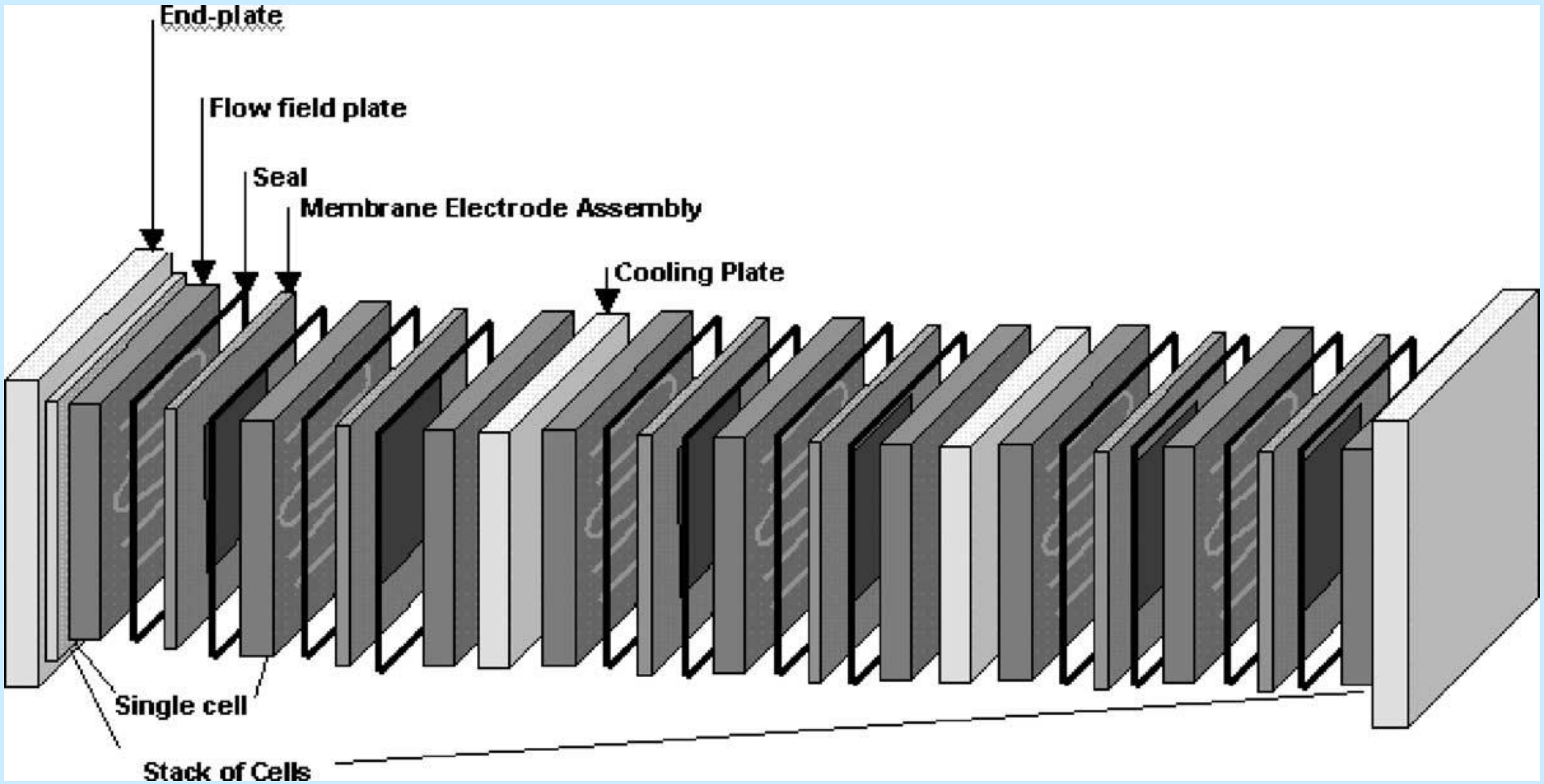


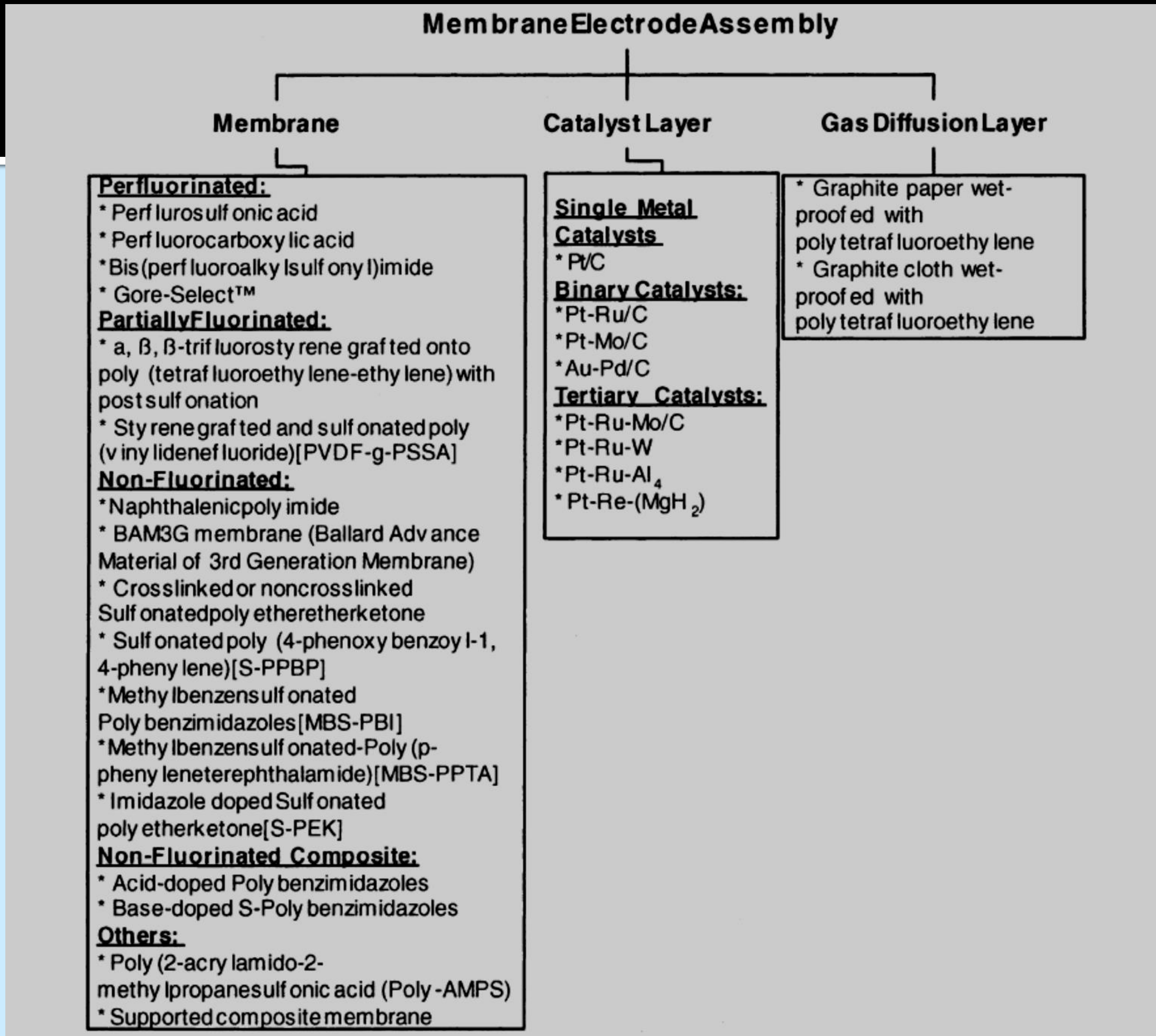
Chemical reactions in a fuel cell

Chemical reactions taking place in a fuel cell:

- On anode: 2H2 $= 4H^{+} + 4e$
- On cathode: O2+4e= $2O^{-2}$
  $2O^{-2} + 4H^{+} = 2H_2O$

PEM fuel cell stack hardware.




Membrane Electrode Assembly
Membrane
Catalyst Layer
Gas Diffusion Layer
Perfluorinated:
* Perflurosulfonic acid
* Perfluorocarboxylic acid
*Bis(perfluoroalkylsulfonyl)imide
* Gore-Select™
Partially Fluorinated:
* a, ß, ß-trifluorostyrene grafted onto poly (tetrafluoroethylene-ethylene) with post sulfonation
* Styrene grafted and sulfonated poly (vinylidenefluoride)[PVDF-g-PSSA]
Non-Fluorinated:
*Naphthalenic polyimide
* BAM3G membrane (Ballard Advance Material of 3rd Generation Membrane)
* Crosslinked or noncrosslinked Sulfonated polyetheretherketone
* Sulfonated poly (4-phenoxybenzoyl-1, 4-phenylene)[S-PPBP]
*Methylbenzensulfonated Polybenzimidazoles[MBS-PBI]
*Methylbenzensulfonated-Poly (p-phenyleneterephthalamide)[MBS-PPTA]
* Imidazole doped Sulfonated polyetherketone[S-PEK]
Non-Fluorinated Composite:
* Acid-doped Polybenzimidazoles
* Base-doped S-Polybenzimidazoles
Others:
* Poly (2-acrylamido-2-methylpropanesulfonic acid (Poly-AMPS)
* Supported composite membrane
Single Metal Catalysts
* Pt/C
Binary Catalysts:
*Pt-Ru/C
*Pt-Mo/C
*Au-Pd/C
Tertiary Catalysts:
*Pt-Ru-Mo/C
*Pt-Ru-W
*Pt-Ru-Al4
* Pt-Re-(MgH2)
* Graphite paper wet-proofed with polytetrafluoroethylene
* Graphite cloth wet-proofed with polytetrafluoroethylene

Fuel cells operating principle and construction

The principle of operation of the fuel cell is well known, significant progress has been made nowadays in developing materials for the construction of electrodes, membranes, seals and catalysts. The aim of research is to extend the life and efficiency of the cells, while reducing its cost of production. In addition, new technologies are developed fabrication of cells, by replacing the mechanical processing, precision spray technology. The effects of research are already visible to final consumers: the life cycle is lengthening and fuel cell produced electricity prices fall.

Types of fuel cells

The division is based on fuel cells used in the cell electrolyte. Electrolyte used determines the temperature of the reaction occurring in the cell and fuel cell power. Each cell has advantages and disadvantages, which determine the field of applications for each type of cell.

Fuel cells clasification

Electrolyte	PEM membrane	Phosphoric acid	Molten carbonate	Solid oxides
Working temperature	80ºC	Approx. 200ºC	650ºC	800-1000ºC
Electric charge carrier	Hydrogen ions	Hydrogen ions	Carbonate ions	Oxygen ions
Reformer	External	External	Internal or External	Internal or External
Basic cell components	Based on carbon	Based on graphite	Stainless steel	Ceramics material
Catalyst	Platinum	Platinum	Nickel	Perovskity (Calcium metatynian)
Efficiency (%)	40-50	40-50	Above 60	Above 60
State of development	comercial	Working	Prototype	Prototype

Figure 1.2 Basic cathode–electrolyte–anode construction of a fuel cell.

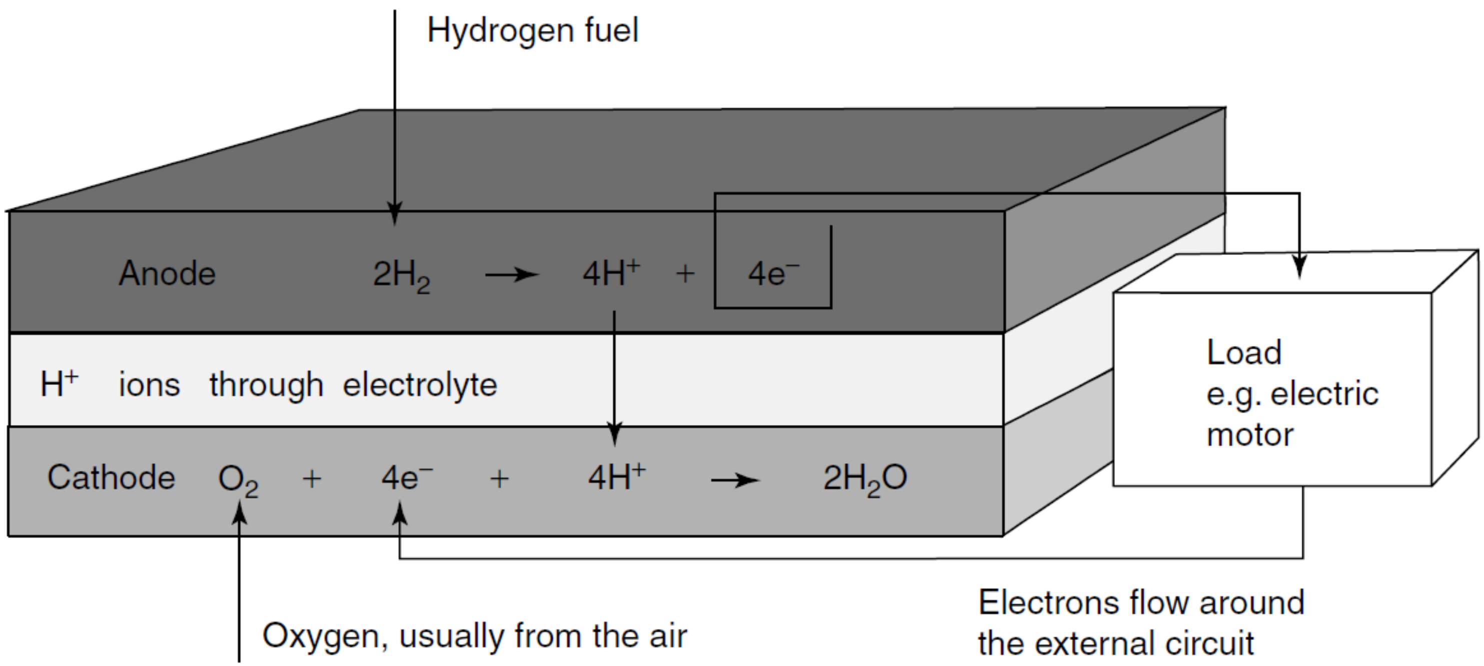
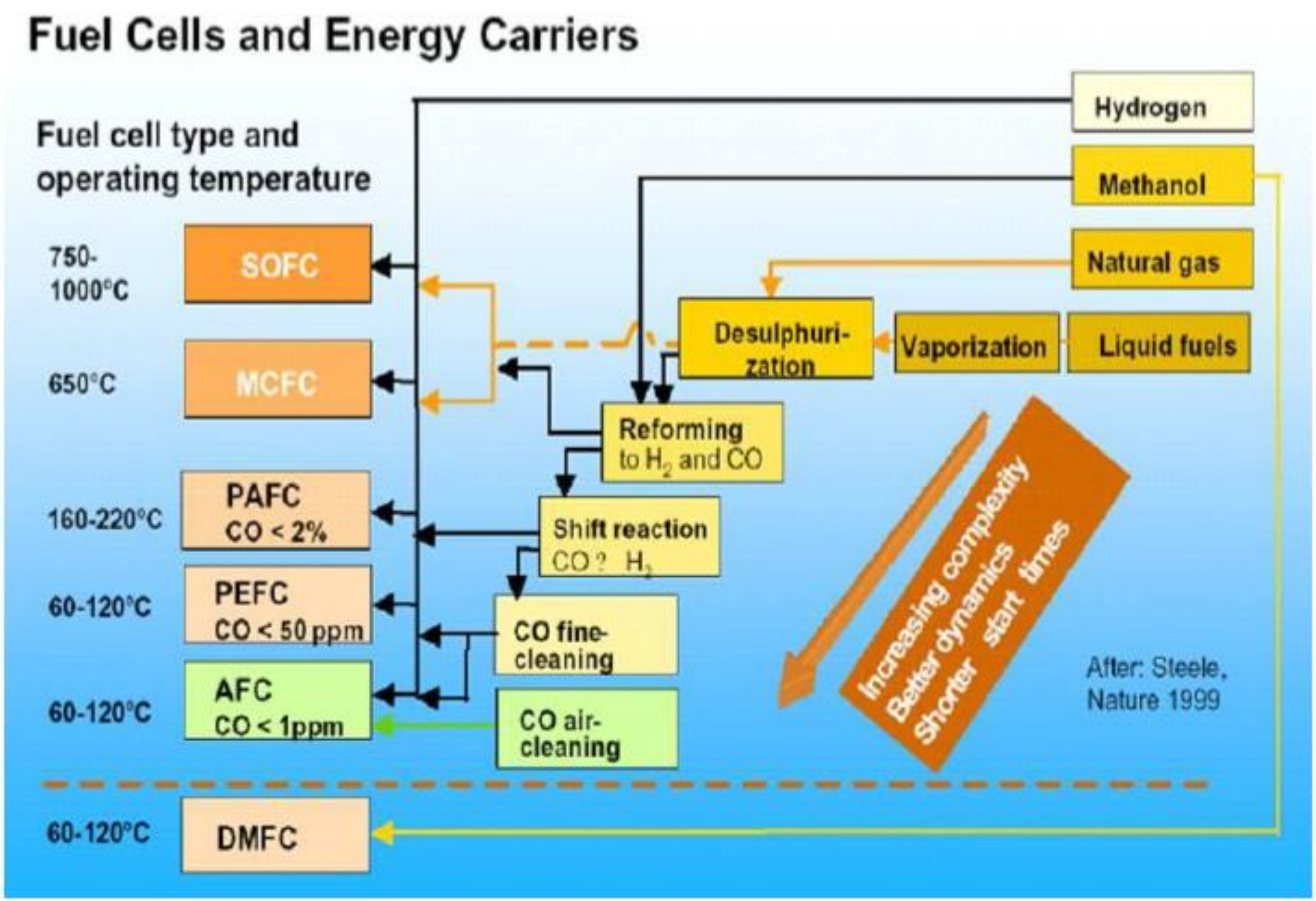
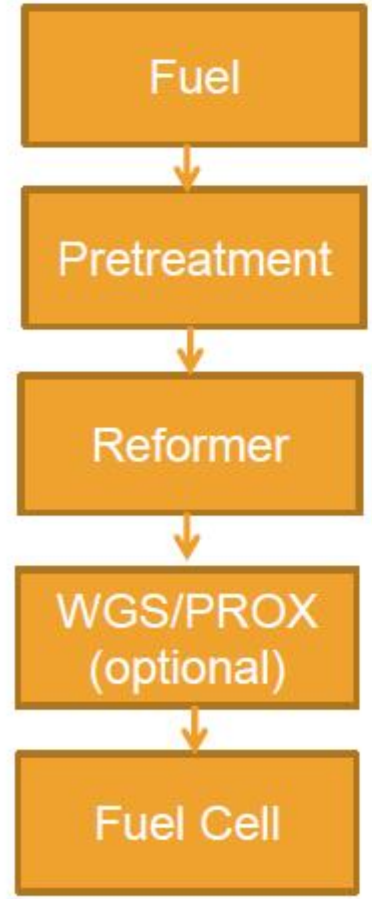


Figure 1.3 Electrode reactions and charge flow for an acid electrolyte fuel cell. Note that although the negative electrons flow from anode to cathode, the 'conventional current' flows from cathode to anode.



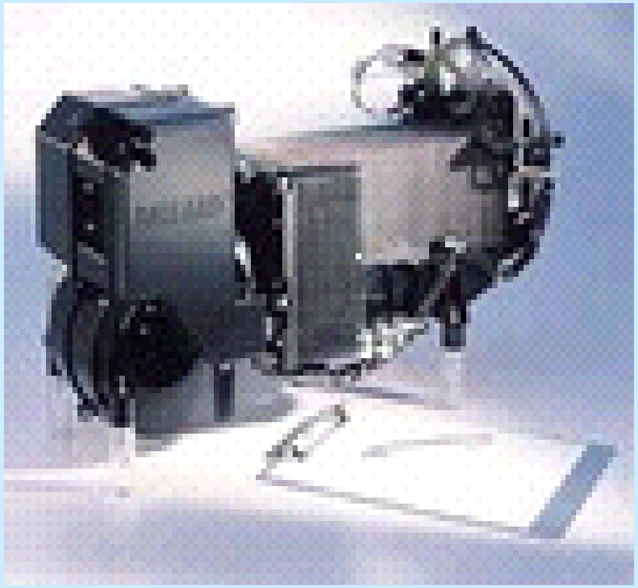


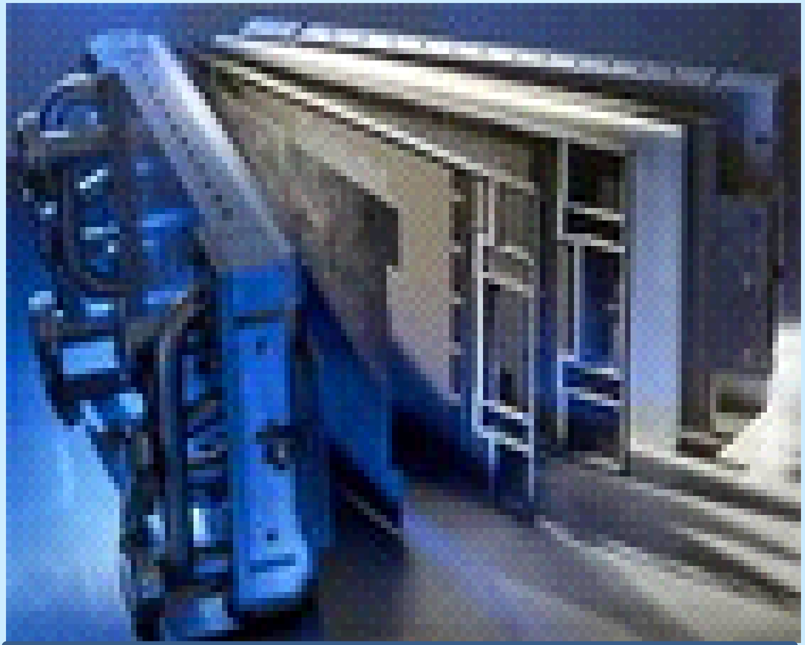
[MCFC Molten carbonate fuel cell; PAFC Phosphoric acid fuel cell; PEFC (PEM) Photonic exchange fuel cell; AFC Alkaline fuel cell; DMFC Direct methanol fuel cell]

PEM (Proton Exchange Membrane or Polimer Electrolyte Membrane).

- PEM fuel cells are powered by pure hydrogen or reformate. PEM cell membrane is a polymer material such as Nafion. A characteristic feature of PEM cells is high efficiency in electricity production - up to 65% and a small amount of generated heat. An important advantage of PEM cells is their good adaptation ability in systems subjected to variable loads and short commissioning time. These features result from the low temperature reactions occurring in the cell - 60 to 100 degrees Celsius.
- PEM cells are primarily used to power vehicles and the construction of stationary and portable power generators.

Types of fuel cells





fuel cell system 1,2 kW (Ballard)

Elements of fuel system PEM

DMFC (Direct Methanol Fuel Cell)

- DMFC cells have a polymer membrane, such as PEM cells. The difference between cell DMFC and PEM cell is in the construction of the anode, which in the DMFC cell allows for the internal reforming of methanol to obtain hydrogen to power the cell. DMFC cells eliminate the problem of fuel storage, are attractive for portable applications because of the low temperature reaction occurs (about 80 degrees Celsius). DMFC cell is characterized by lower efficiency compared to the PEM cells and is 40%. DMFC cells are used for building batteries for portable devices, and offer performance unattainable with standard battery - notebook powered with 250 ml methanol tank, running for 12 hours which is inaccessible to ordinary batteries of similar weight / volume.

Types of Fuel Cells

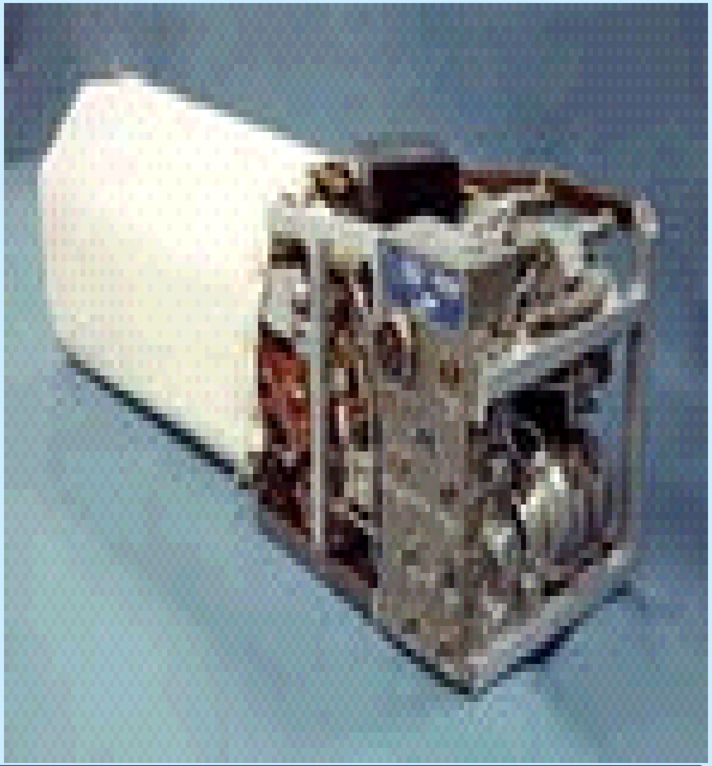
fuel cell system to 20 watts for portable computers

DMFC cell for mobile phones

Types of Fuel Cells

- AFC (Alkaline Fuel Cell). These are the first fuel cells, for the first time used in aeronautics. KOH electrolyte solution. The reaction proceeds at temperatures from 100 to 250 ° C. The reaction temperature abuse of KOH solution concentration, higher reaction temperature allow you to achieve better efficiency of these cells for the generation of electricity and heat. AFC cells have been used on the space shuttles were Apollo to the cogeneration of electricity and heat. AFC cells are fragile to any contamination and the fuel needs to be clean, which is an obstacle to their commercialization.

Types of Fuel Cells

AFC fuel cell used in the space shuttle

Phosphoric Acid (PAFC)

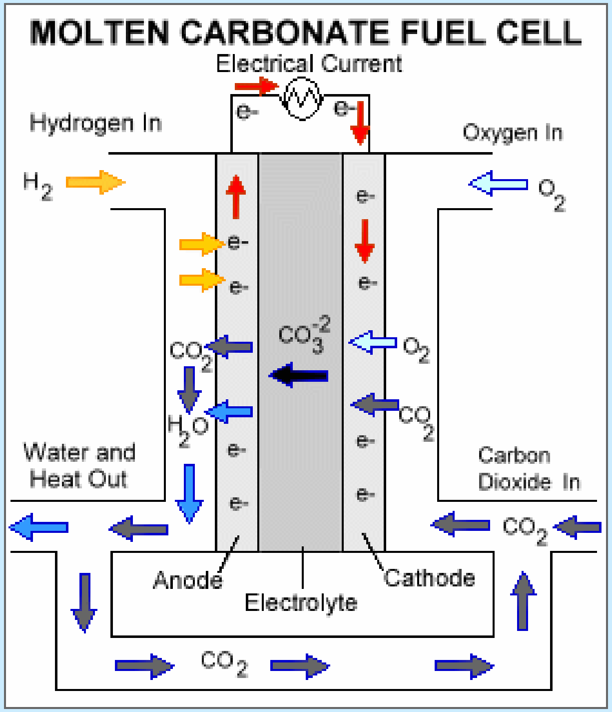
- PAFC cells are used for construction of cogeneration of electricity and heat. The efficiency of electricity generation is 40%, additional water vapor produced by the cell, can be converted into heat. Electrolyte in the cell is PAFC phosphoric acid (H3PO4). The advantage of cells is high tolerance to carbon monoxide which allows for the use of multiple fuels (it is important, however, fuel desulphurisation).

Phosphoric Acid (PAFC)

Electricity cogeneration system with a capacity of 200kW, using PAFC cell

MCFC (Molten Carbonate Fuel Cell)

- MCFC electrolyte in the cell is a molten carbonate Li / K. MCFC cells operate at high temperatures and are used for the production of small and medium power capacity. High temperature reactions occurring in the cell allows the use of a wide range of fuels (natural gas, diesel, hydrogen, propane)



MCFC (Molten Carbonate Fuel Cell)

MCFC fuel cell system with a capacity of 280kW

Solid Oxide (SOFCs)

- SOFC cells have a membrane made of oxide ceramics. It works in high temperatures from 650 to 1000 degrees Celsius. The result of high temperature reactions in the SOFC cell is the high efficiency cogeneration systems in the electricity and heat - up to 85%. This characteristics along with long time of reaching full efficiency cause that SOFC cells is used in stationary CHP (cogeneration heat and power). SOFC cells is characterized by high tolerance to fuel contaminants (carbon oxides and sulfur dioxide), which allows the use of a wide range of fuels

Fuel cells characteristics

- The most commonly used in industrial fuel cells is cell type PEM / DMFC and SOFC. The popularity of these cells is due to their high efficiency and a membrane made of solid materials - no moving parts in the cell is a big advantage in industrial applications.
- SOFC cell type is characterized by high temperature and slow response to load changes. Therefore, SOFC cells used in the construction of stationary electric power generators and heat, working continuously with the same load

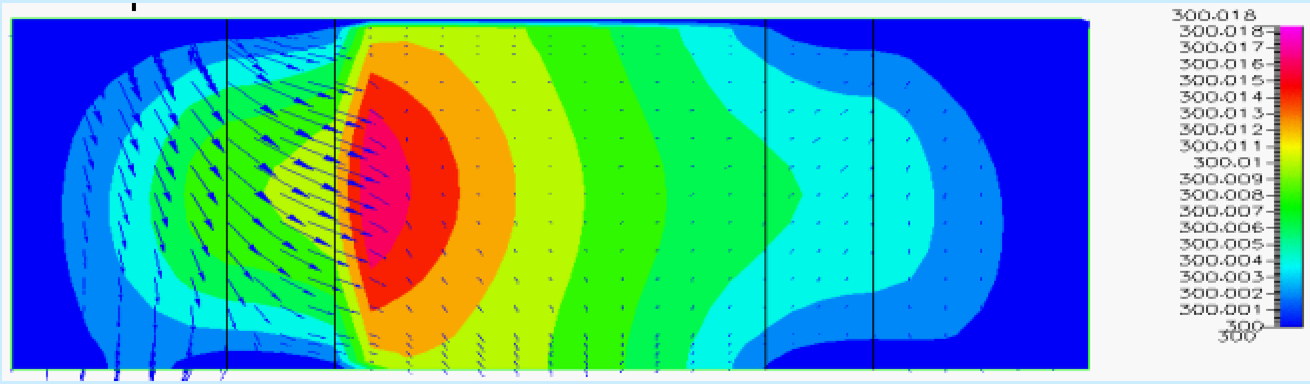
Fuel cells characteristics

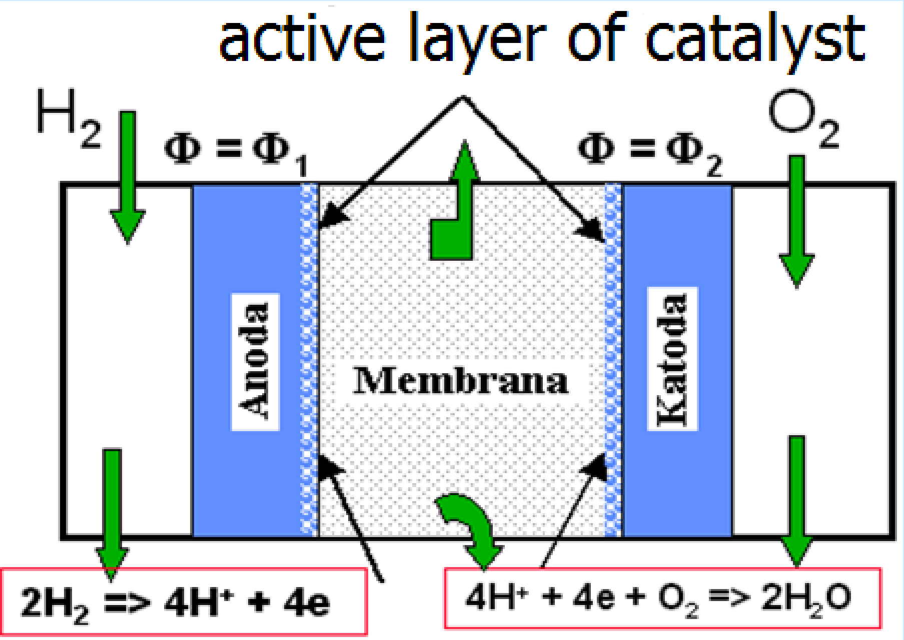
- The PEM and DMFC cells are characterized by low temperature reaction and are used to build both small and large sources of energy. The difference between PEM and DMFC cell is a type of fuel used. DMFC cell is powered by methanol. Methanol is the fuel of easy storage, which, combined with a low reaction temperature makes the DMFC cell ideal for use as a low-power battery.

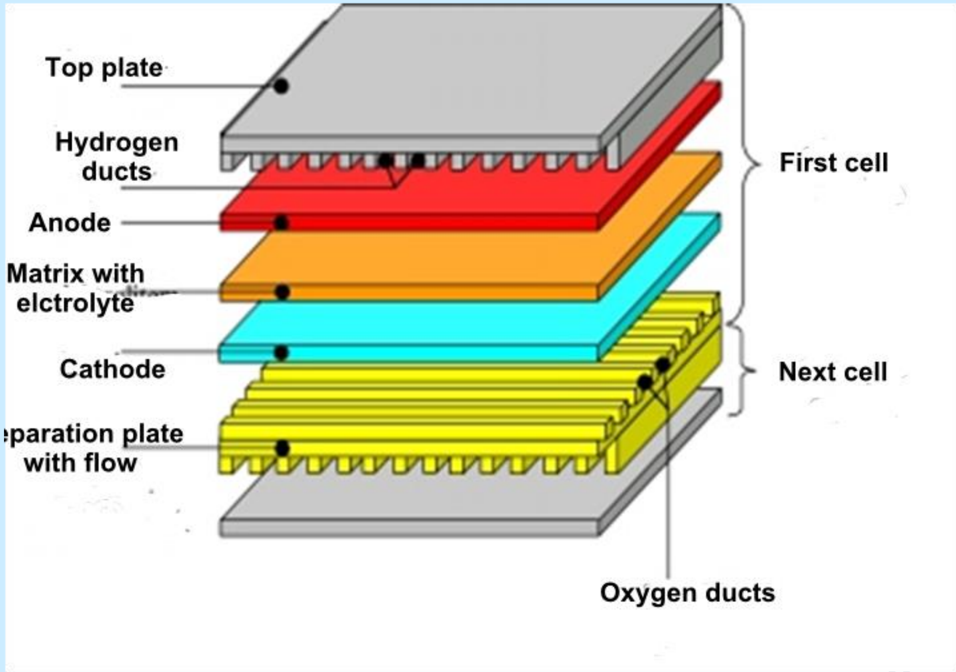
Fuel cells characteristics

- PEM cell is characterized by high efficiency (40% - DMFC, 65% - PEM). PEM fuel cell is the hydrogen or reformate. In the case of reformate, the system must be equipped with so-called fuel processor that produces hydrogen from the used fuel. This raises the cost of the system, but in many cases it is profitable units such as stationary power generation where it is easy access to natural gas.
- Cells PEM / DMFC and SOFC, are already present on the consumer market, they can be purchased as a standalone device (fuel cell stack), as well as finished devices

Using hydrogen to produce electricity - fuel cells







Reactions at the Cathode and Anode

***Total reaction*:**

$$2O_2 + CH_4 \rightarrow 2H_2O + CO_2$$

In a fuel cell powered by natural gas, the whole process begins with the separation of pure hydrogen in a device called a reformer (1).

***Reforming reactions*:**

$$CH_4 + O_2 \rightarrow 2H_2 + CO_2$$

Arising from the carbon dioxide (2) is disposed on the outside. The same applies to the use of methanol. Then the hydrogen goes to the proper cell (3), causing further chemical reactions: a platinum catalyst at the anode "pulls" the electrons from the gas (4), and positively charged ions (protons) "dissolve" in the electrolyte (5).

***Reaction at the anode*:**

$$2H_2 \rightarrow 4H^+ + 4e^-$$

Electrically inert oxygen fed to the cathode (6) captures the free electrons, causing a direct current (8). Negatively charged oxygen ions react in the electrolyte with protons which are also located in the electrolyte, producing water (7).

***Reaction at the cathode*:**

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

The energy potential of fuel cells

	ENERGY STORAGE	ENERGY STORAGE
FUELL CELLS	*[Wh/kg]*	*[Wh/l]*
Decaline Liquid hydrogen	2400 33000	2100 2500
Lithium borohydride	2800	2500
Solid metal hydride	370	3300
Methanol	6200	4900
Hydrogen in graphite nanofibres	approx. 16000	approx. 32000
BATTERIES		
Lead-acid	30	80
Nickel-cadmium Nickel-hydride	40 60	130 120
Lithium-ion	130	300

Hybrid system with a steam turbine and gas from the absorption of CO2 and H2 production

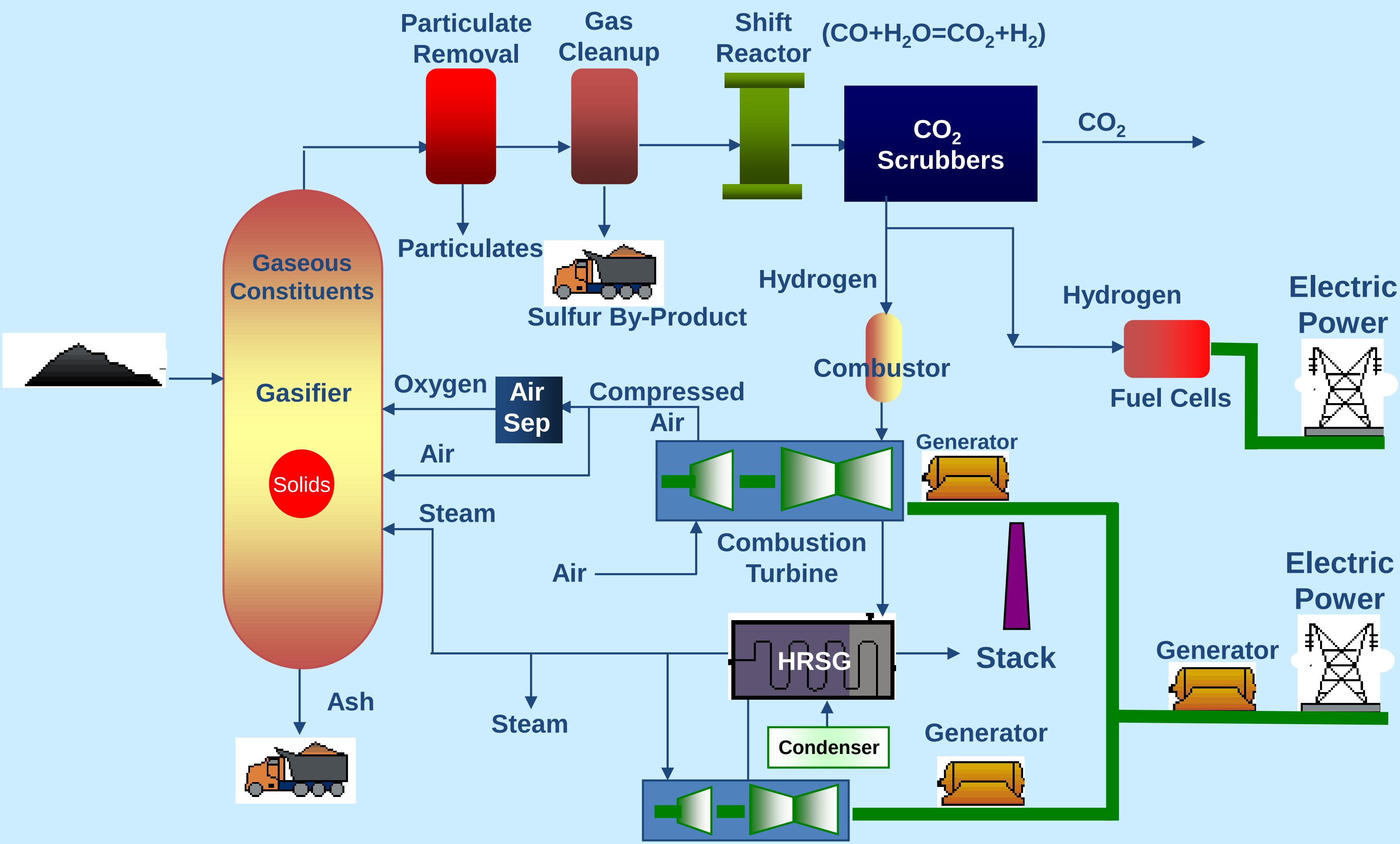


Diagram of hydrogen production and fuel cell system

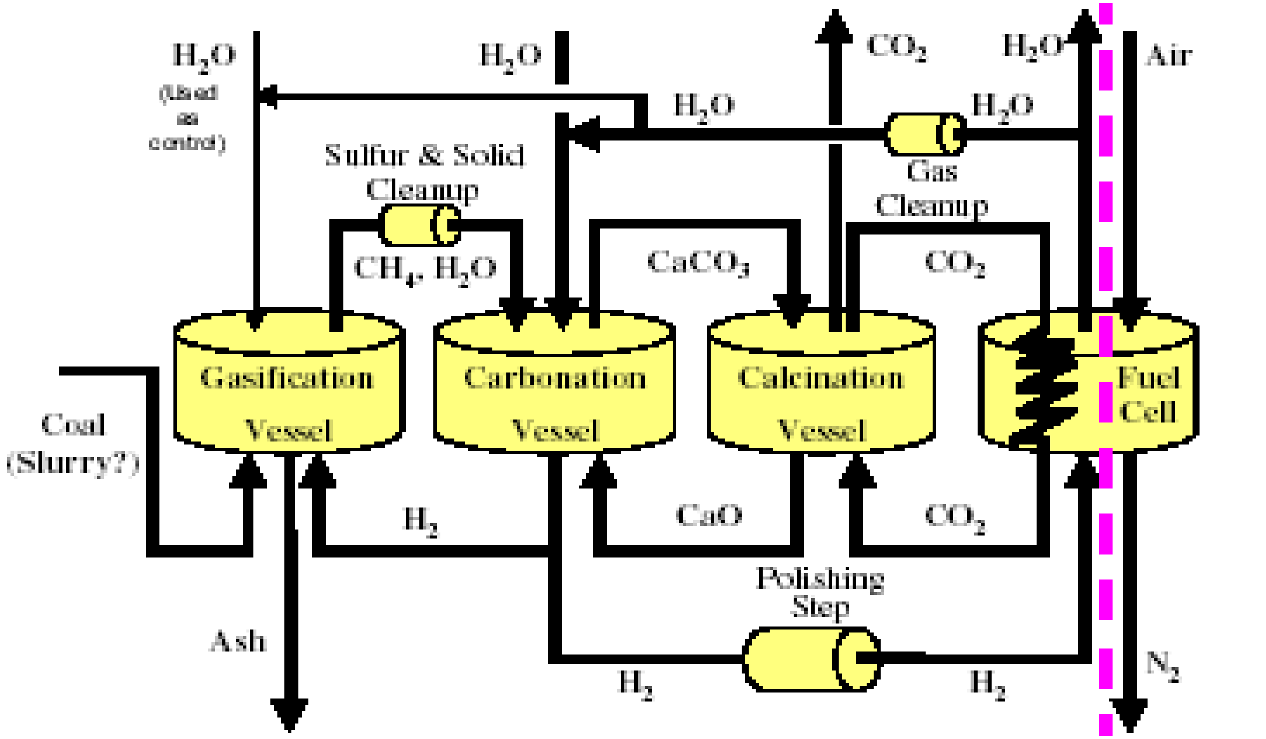


Figure 4: Schematic of the anaerobic hydrogen production and fuel cell system. Material flows are idealized to the predominant components. The major reactions are as follows:

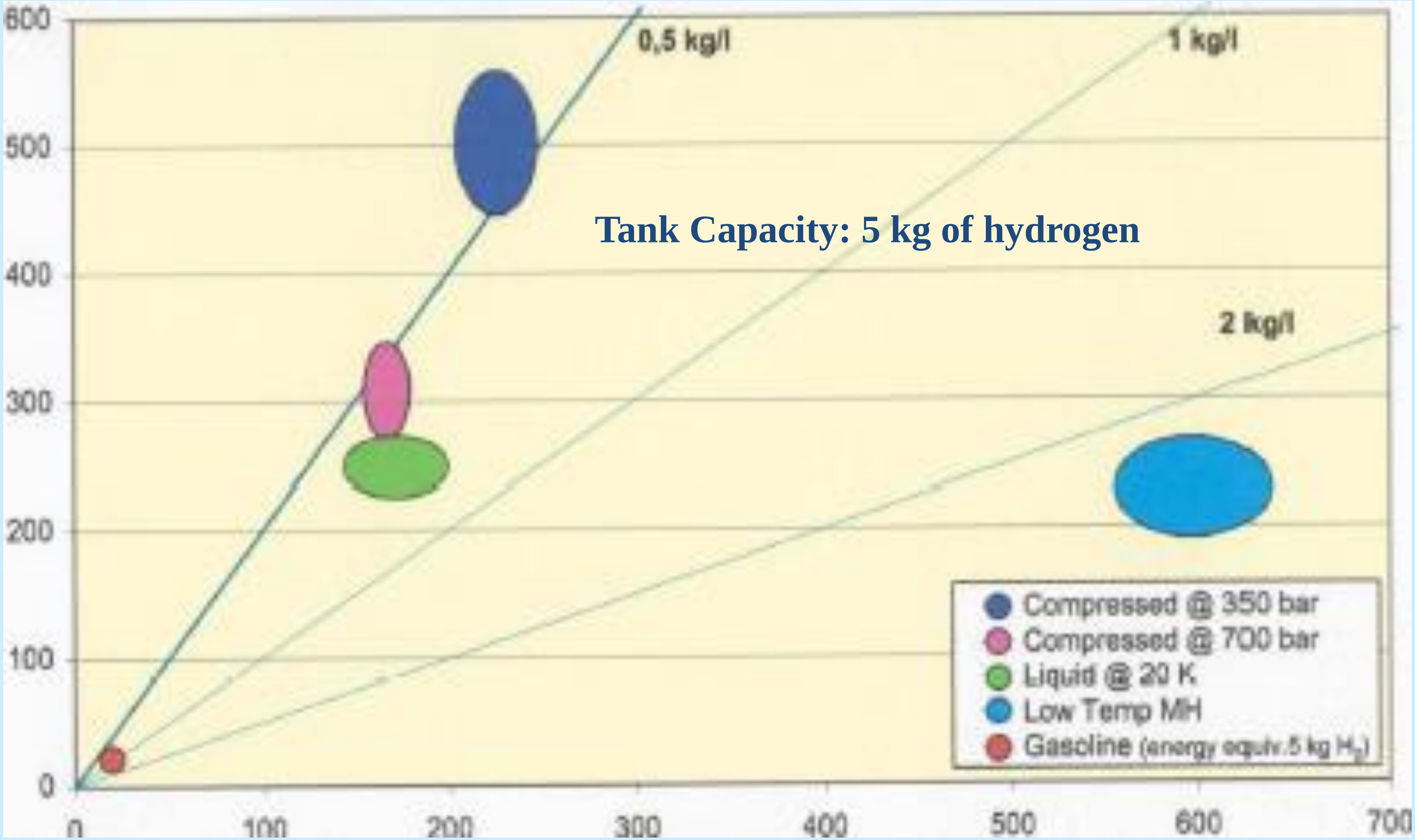
Gasification Vessel: $C + 2H_2 \rightarrow CH_4$, $H_2O(liquid) \rightarrow H_2O(gas)$

Carbonation Vessel: $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$, $CaO + CO_2 \rightarrow CaCO_3$

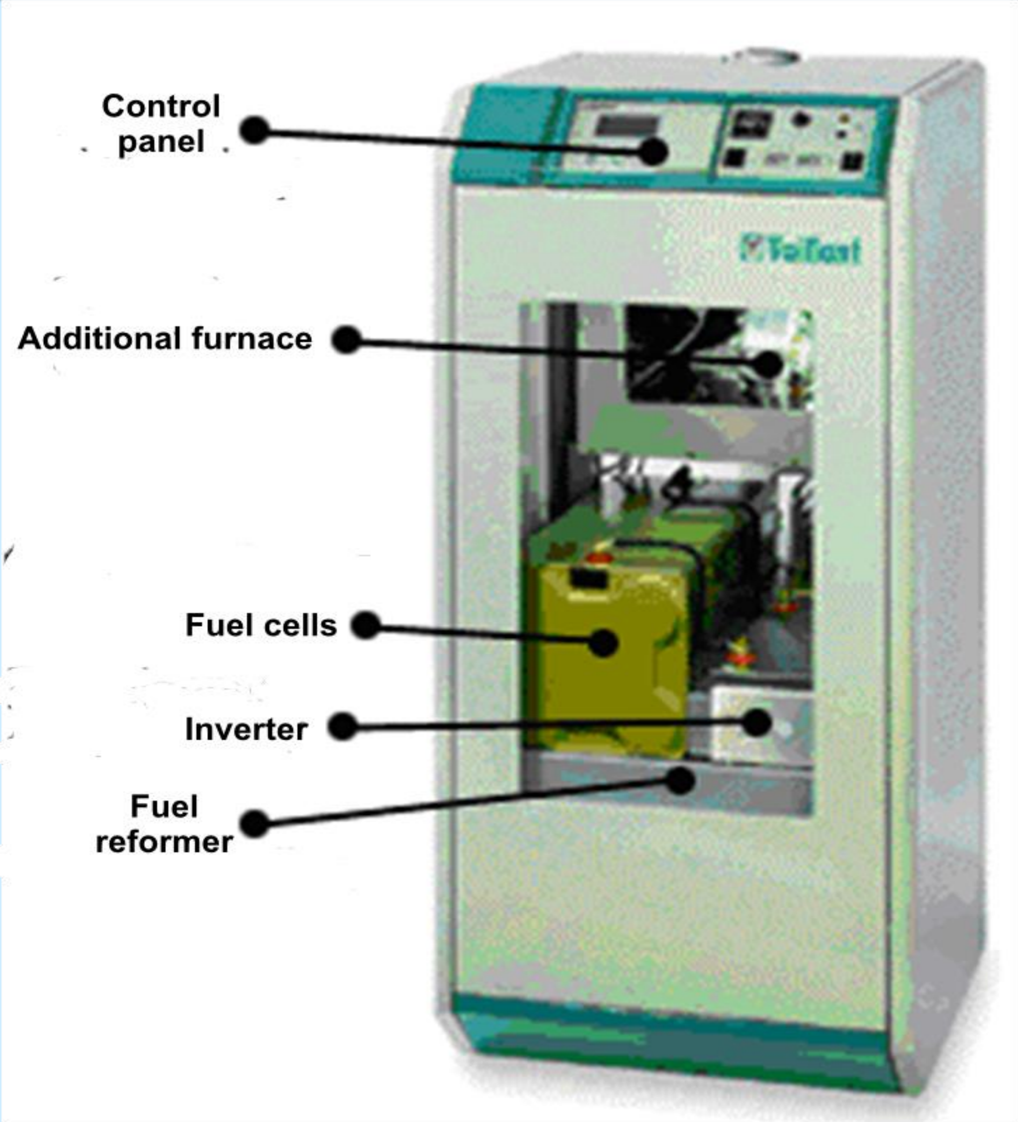
Calcination Vessel: $CaCO_3 \rightarrow CaO + CO_2$

Fuel Cell: $2H_2 + O_2 \rightarrow 2H_2O$

Methods of storing hydrogen



Boiler with fuel cell



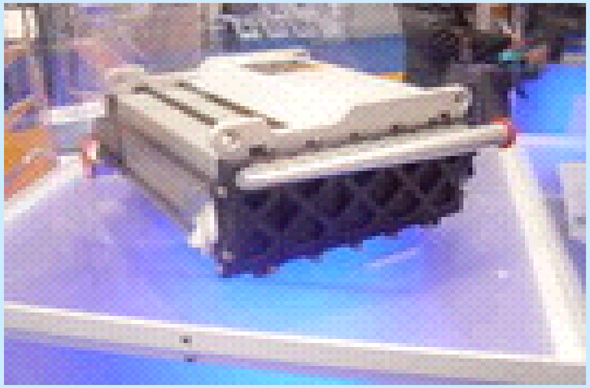
Hydrogen station for fuel cell

Advantages of fuel cells

- High quality of supplied energy. The energy supplied by fuel cells are very resistant to interference. Fuel cells are an ideal power source for medical devices, measuring instruments, computers, etc.
- High efficiency. Fuel cells are characterized by high energy density. A fuel cell is always smaller and lighter than other energy sources with comparable power. In addition, fuel cells generate electricity directly from a chemical reaction, so there is no fuel combustion process. In mobile applications, fuel cells produce electricity directly serving to drive, as opposed to internal combustion engines where it is produced by the mechanical energy converted into mechanical gears to drive energy. The efficiency of fuel cells to generate electricity even reaches 50%. In the process of cogeneration of electricity and heat, fuel cells achieve efficiency up to 85%

Advantages of fuel cells

- Possibility of using different types of fuels. Fuel cells can be powered by any fuel rich in hydrogen. Obtaining hydrogen from the fuel can be carried inside a fuel cell, the so-called. internal reforming or outside the cell in an external device called: fuel reformer. Thanks to the phenomenon of electrolysis, hydrogen for fuel cells can be produced using alternative energy sources.
- Environmental protection. Pollution resulting from energy production, "conventional" methods are the cause of environmental degradation and the reason for the emergence of new diseases of civilization. A fuel cell produces 25 times less pollution than combustion generators. In the case of hydrogen fuel cell power, the amount of trace impurities is produced. scalability. Individual fuel cells can be combined to achieve the desired level of power generated. Teams of fuel cells with different shapes is used both to power a single light bulb and to drive industrial machinery.



Mobile 50kW PEM fuel cell system for use in transport

Milli-Watt fuel system for propelling miniature devices developed at Pacific Northwest National Laboratory

PDA Hitachi Fuel Cell

Impact on the environment

- Impact on the environment of fuel cells depends largely on the method of obtaining the fuel used in them. Hydrogen can not be used as a primary energy source, but it is necessary to produce the hydrogen used in them. Although the production of hydrogen by electrolysis is fairly high efficiency, in conjunction with the fact that when used in automotive, it is necessary to store hydrogen at high pressures is the total efficiency of the cells may fall below the most efficient internal combustion engines.

The use of fuel cells

- Portable devices, small power batteries. Fuel cells are increasingly seen as a substitute for conventional batteries used in the small electronic devices (laptops, cameras, mobile phones, MP3 players, etc.)
- There is a huge market for manufacturers of fuel cells. Virtually all major companies producing mobile devices are involved in research on fuel cells.
- The use of fuel cells in portable electronic devices allows for the separation of parser energy from the fuel tank of a fuel cell system, which provides greater flexibility in the design phase. Fuel cells also have a higher theoretical energy density than conventional batteries and unlike a long time charging the battery, just fill the fuel cell to run, which requires only a minimal outlay of time.
- Cells PEMFC and DMFC due to its properties for low temperature are used to this type of solutions.
- A segment of mobile devices through its dynamic growth forces us to seek new sources of energy needed to power the devices having ever greater energy requirements (larger screen, new features, etc.).
- However, there is still a lot of problems, mostly technical in nature, hindering the global commercialization of fuel cells in portable devices electronics sector

Fuel cells for portable devices

Toshiba

Antig Technology i AVC Corp

MTI MicroFuel Cells

Stationary Systems - generators of electricity and CHP heat, small power plants.

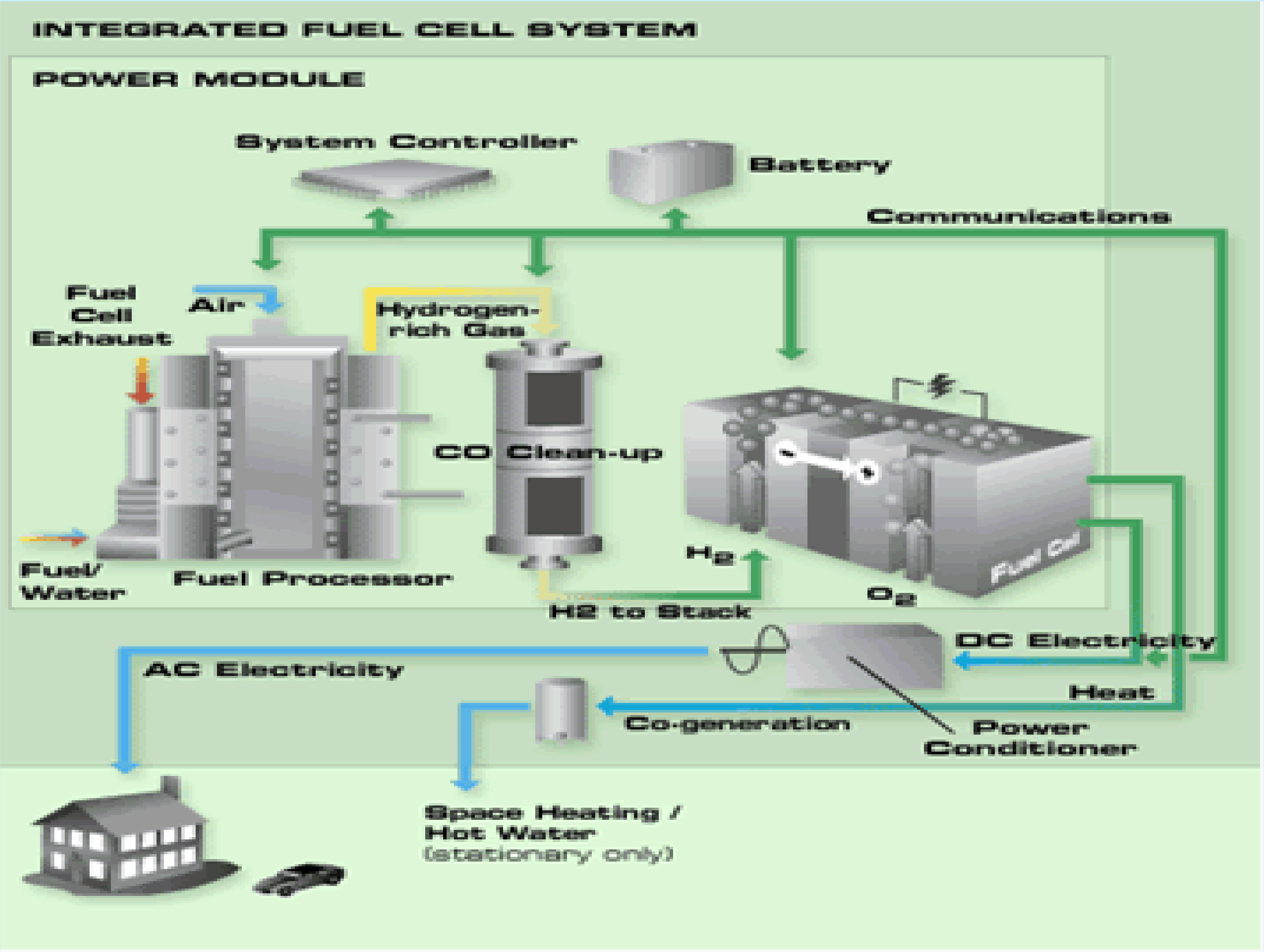
- Stationary systems are both small household units producing electricity and heat (CHP systems) or the auxiliary power source with capacity of kilowatts, and large power plants with a capacity of several megawatts.
- Such devices are used in areas where availability of electricity is essential, and so in hospitals, military bases, office buildings and industry. Stationary fuel cell systems are used as additional facilities that generate electricity, which is the energy put into the network as emergency systems in hospitals and other buildings, or for applications requiring high reliability.
- Fuel cells are perfectly scalable and allow for the construction of small power plants, the order of several MW. The first power plants produce electricity for the police station in New York, Central Park and many other places.
- Advanced work continues on the implementation of CHP electricity generators (called Combined Heat and Power), using the fuel cell stack to generate electricity and heat.
- Generators with a capacity of 1-10 kW are able to supply electricity and heat houses, offices, public buildings. Generators based on fuel cell technology to supply electricity precise parameters, have no moving parts and are able to provide access to energy for longer than the current generators.
- Generators with the fuel cells system are powered by hydrogen or hydrocarbon compounds. This technology is very quiet, efficient, and produces minimal amounts of impurities.
- At present, this technology requires further development and research on it, due to insufficient power value achieved

Fuel cells in domestic CHPs

Ballard system

CFC's CHP generator with reformer

Nuvera's energy generator with fuel reformer and an example of its application



Means of transport, communication

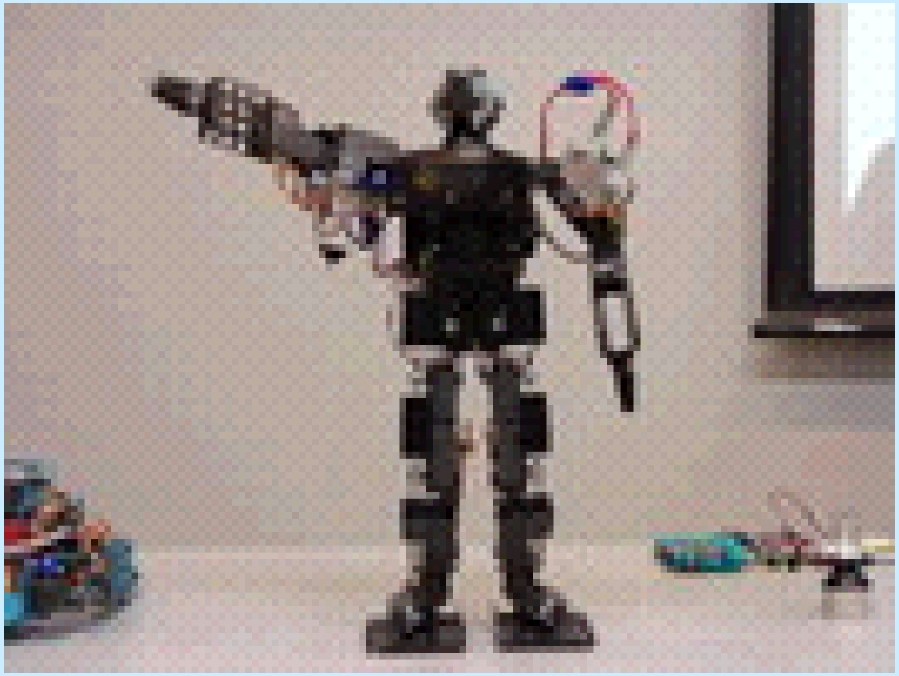
- Currently, almost every prominent automotive company in the market is in advanced testing fuel cell vehicle. Currently, the profitability of the vehicle FCV (Fuel Cell Vehicle), matched the modern hybrids. With the widespread use of fuel cell technologies, vehicle FCV certainly become very popular.
- Advantages of fuel cells as propulsion means of transport are: high efficiency (65% for the fuel cell compared with 35% for the internal combustion engine), the lack of vibration and noise associated energy production, energy production electric motors directly driving, lack of fuel during the stop, stability torque and many others.
- According to the announcement of the producers, the first FCV will go into series production before 2015. Currently, the main problem in the commercialization of FCV cars is their high price.
- Fuel Cell Technology also included other segments of transport, but this is not as noticeable as in the case of cars. There are already unmanned aircraft powered by fuel cell engines, and even wheelchairs drawing energy from the use of this technology

Means of transport, communication

ROBOTICS

- Robotics is a field in which the efficient source of energy is an important issue, especially for mobile robots, power independent energy source. Parameters such as weight / volume, efficiency, quality of energy supplied to have a significant impact on the design of robots and robot parameters. Fuel cells provide a secure source of energy, able to power the electrical systems used in robotics. At the same time power system weight, based on fuel cell technology is relatively small compared to the amount of energy produced. Due to these advantages, fuel cells quickly found use as a source of power in robotics

ROBOTICS

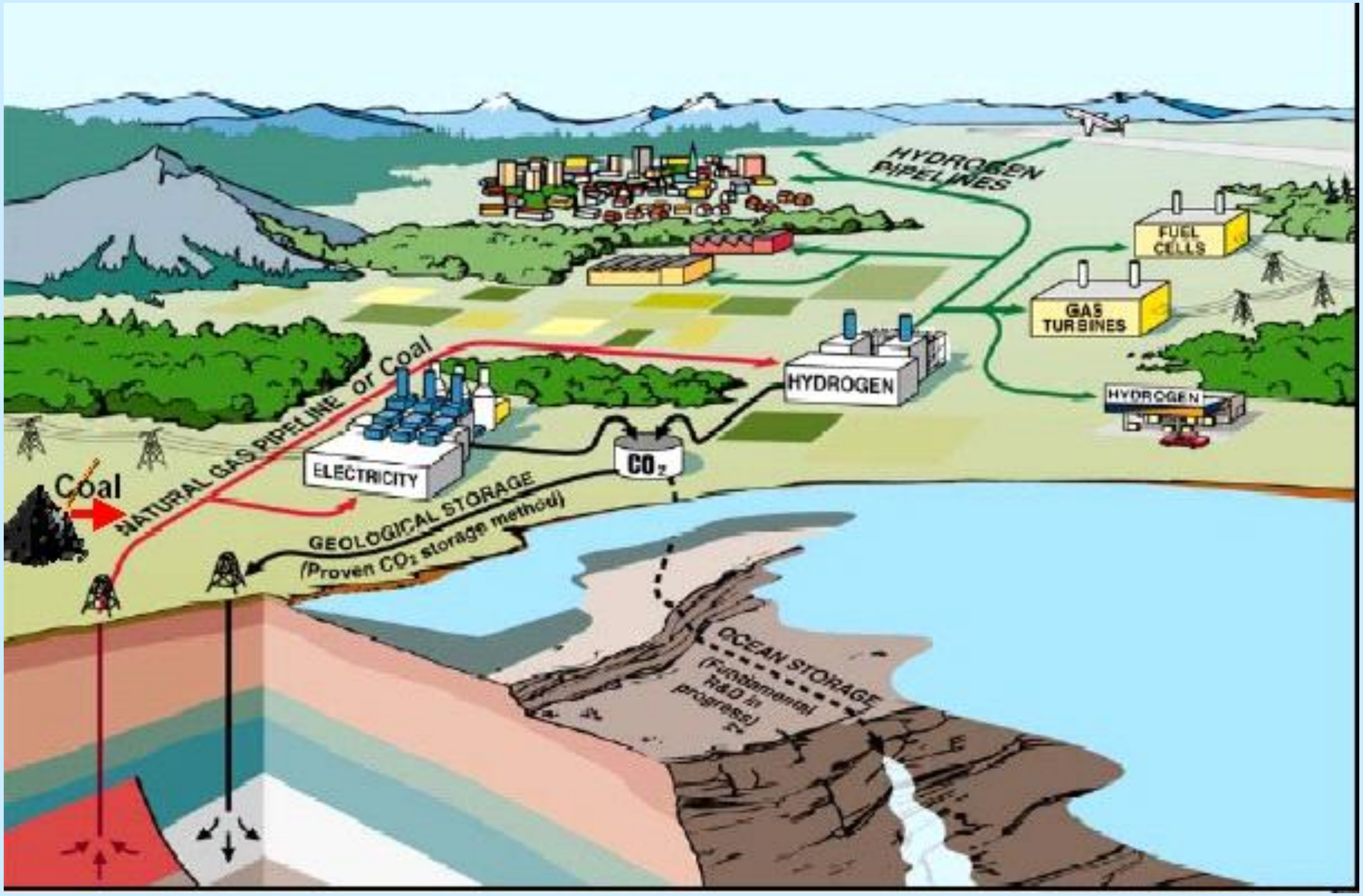


Speecys-FC is the world's first fuel cell powered robot

Robot Guardrobo D1 through fuel cells can operate non-stop for a week

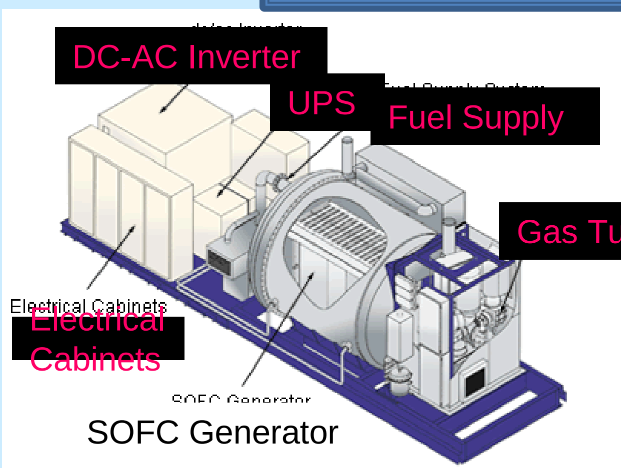
CONCEPT

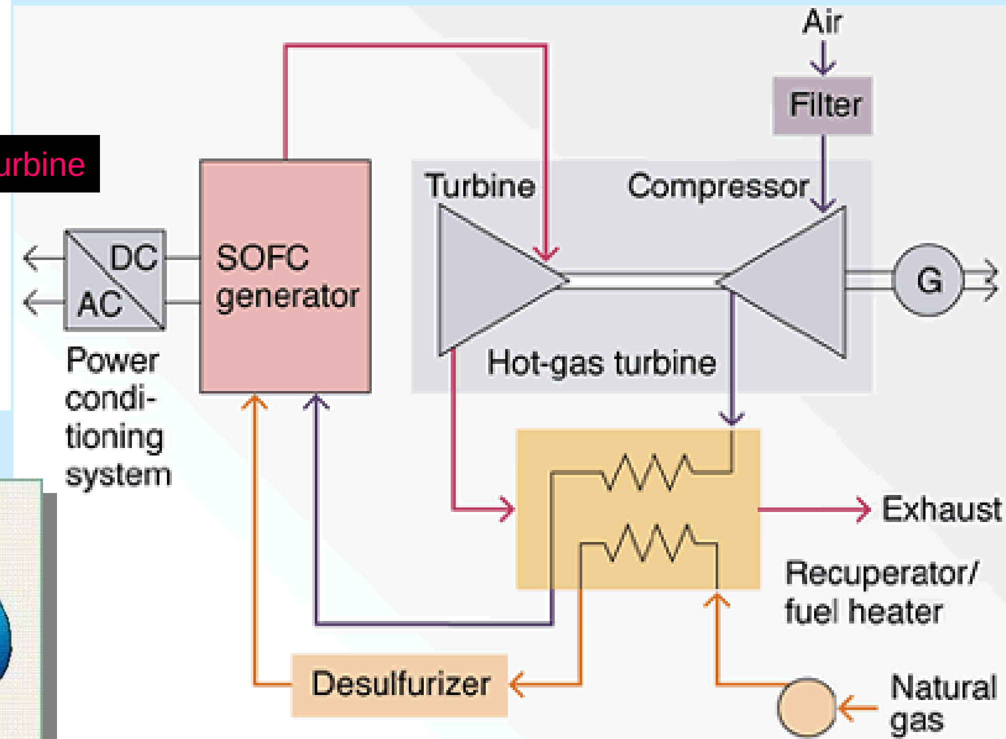
The concept of a system of energy production from fossil fuels with zero CO2 emissions

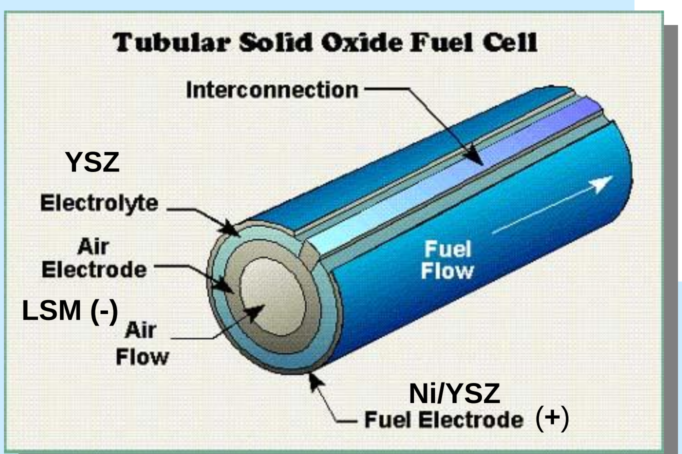


CONCEPT

Hybrid Fuel Cell

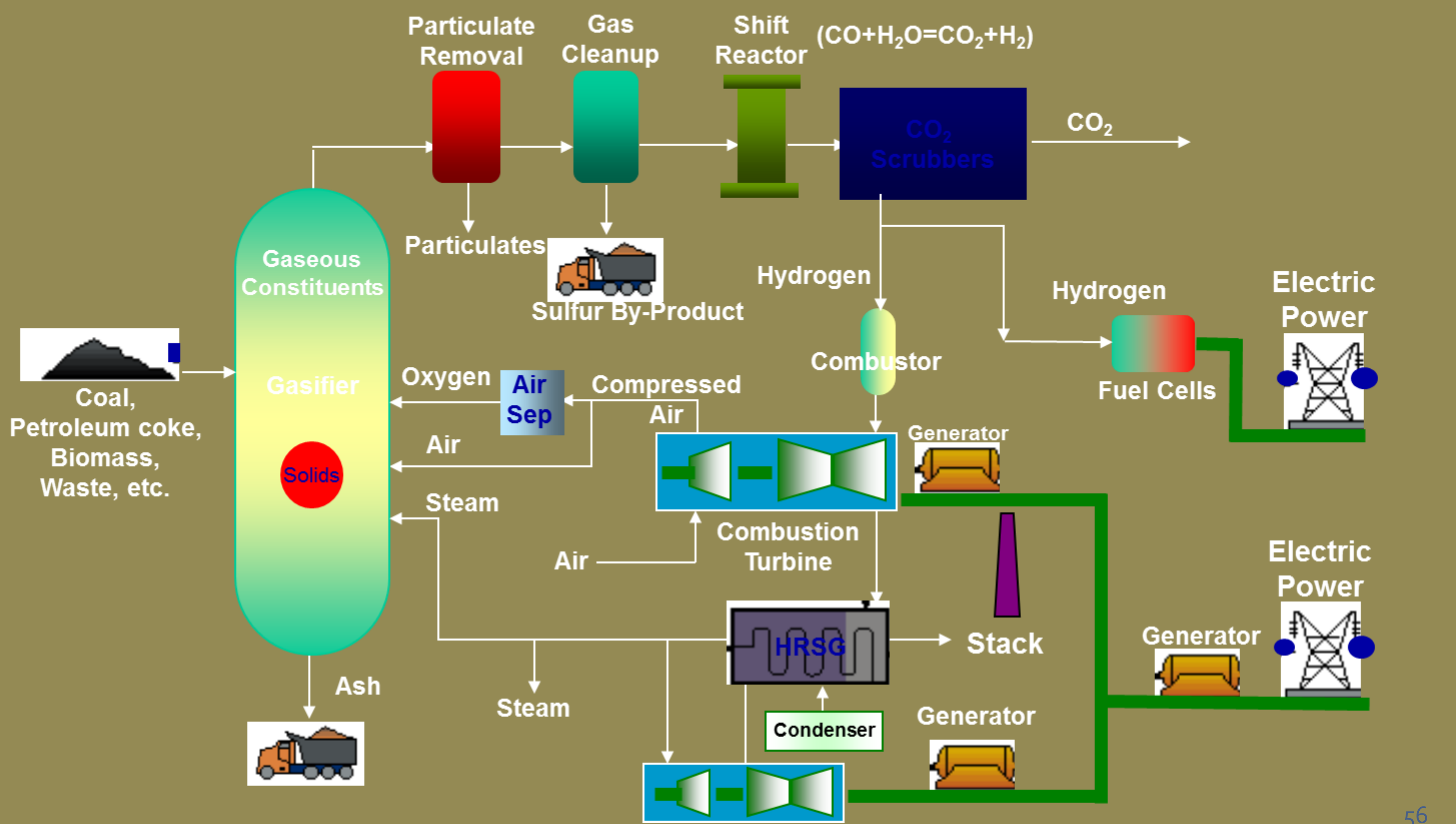






Siemens-Westinghouse
220 kWe $\eta_{th} = 58\%$

Hybrid system with a steam turbine and gas from the absorption of CO2 and H2 production



SOFC- SOLID OXIDE FUEL CELLS

Contemporary materials engineering in the design of functional materials for fuel cells

Global Warming

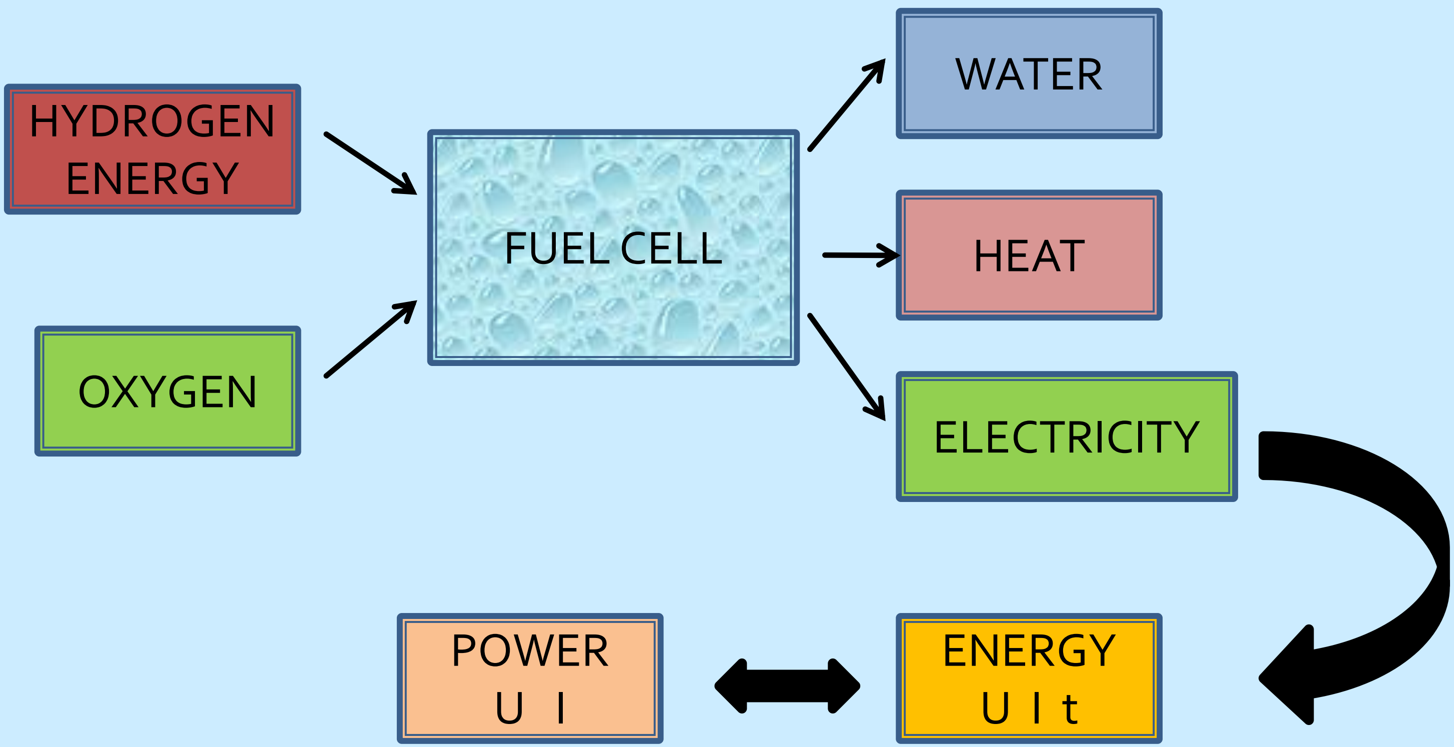
carbon dioxide, nitrous oxide and methane let short-wave radiation (light). But the light is absorbed at Earth's surface and thus converted into long-term radiation. These molecules are three-atomic impenetrable to infrared thus preventing its evaporation

This causes the so-called. greenhouse effect and may cause global climate change

Global warming

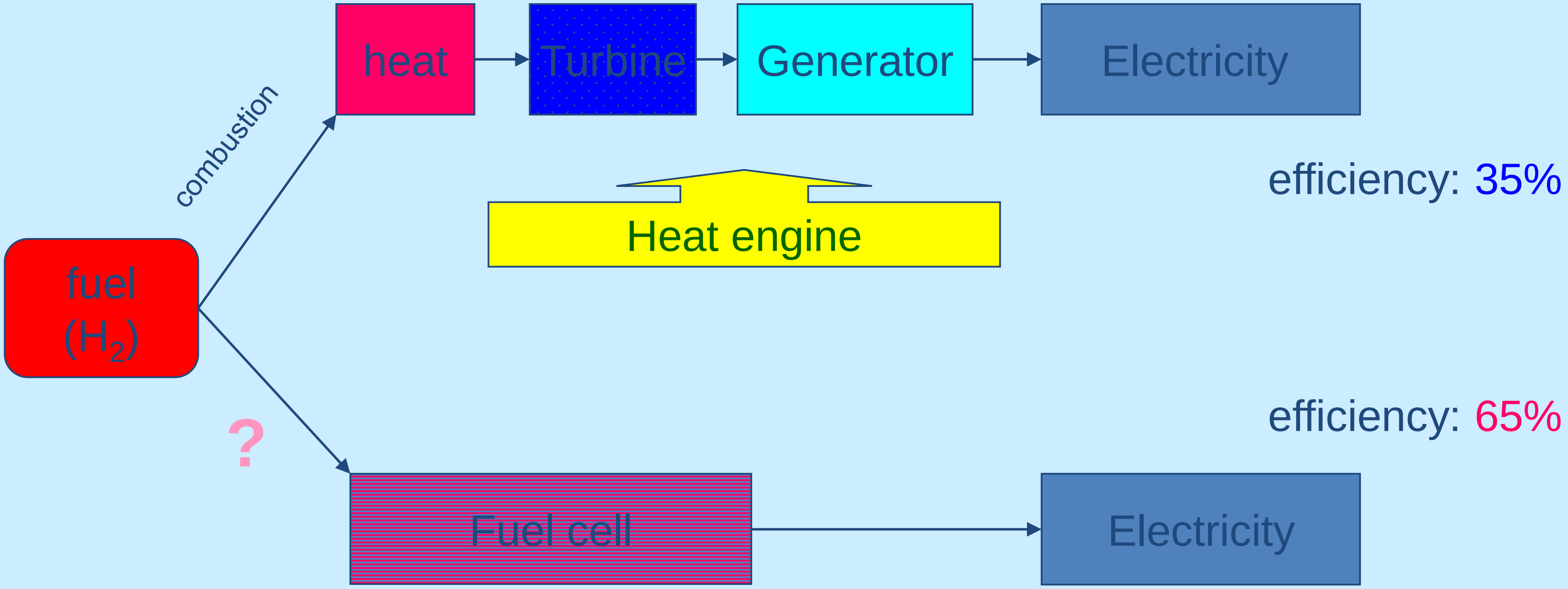
Violent weather

Chemical energy conversion into electrical in fuel cell

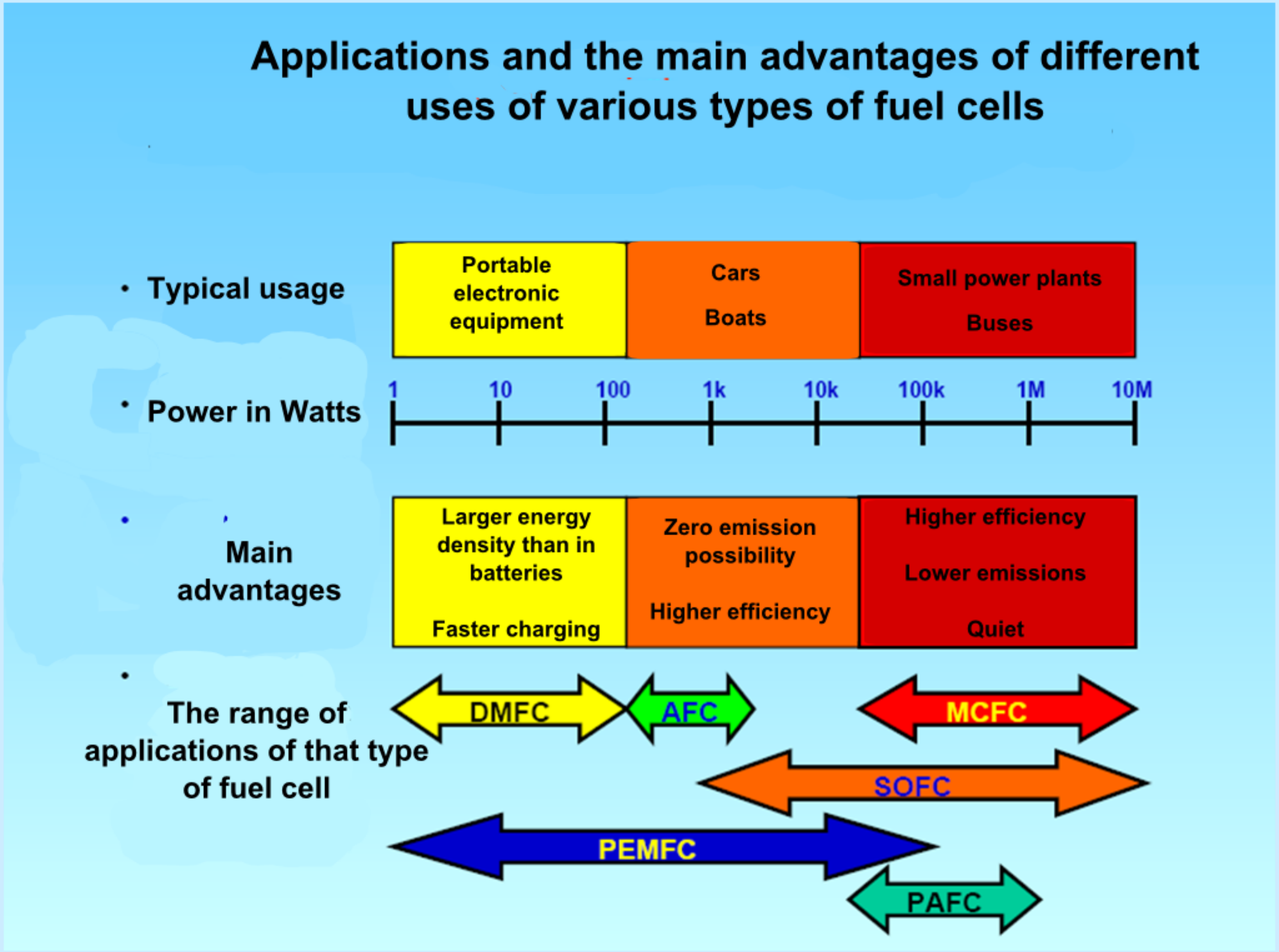


FUEL CELLS and CLASSIC THERMAL MACHINES

- Chemical into electric energy conversion:

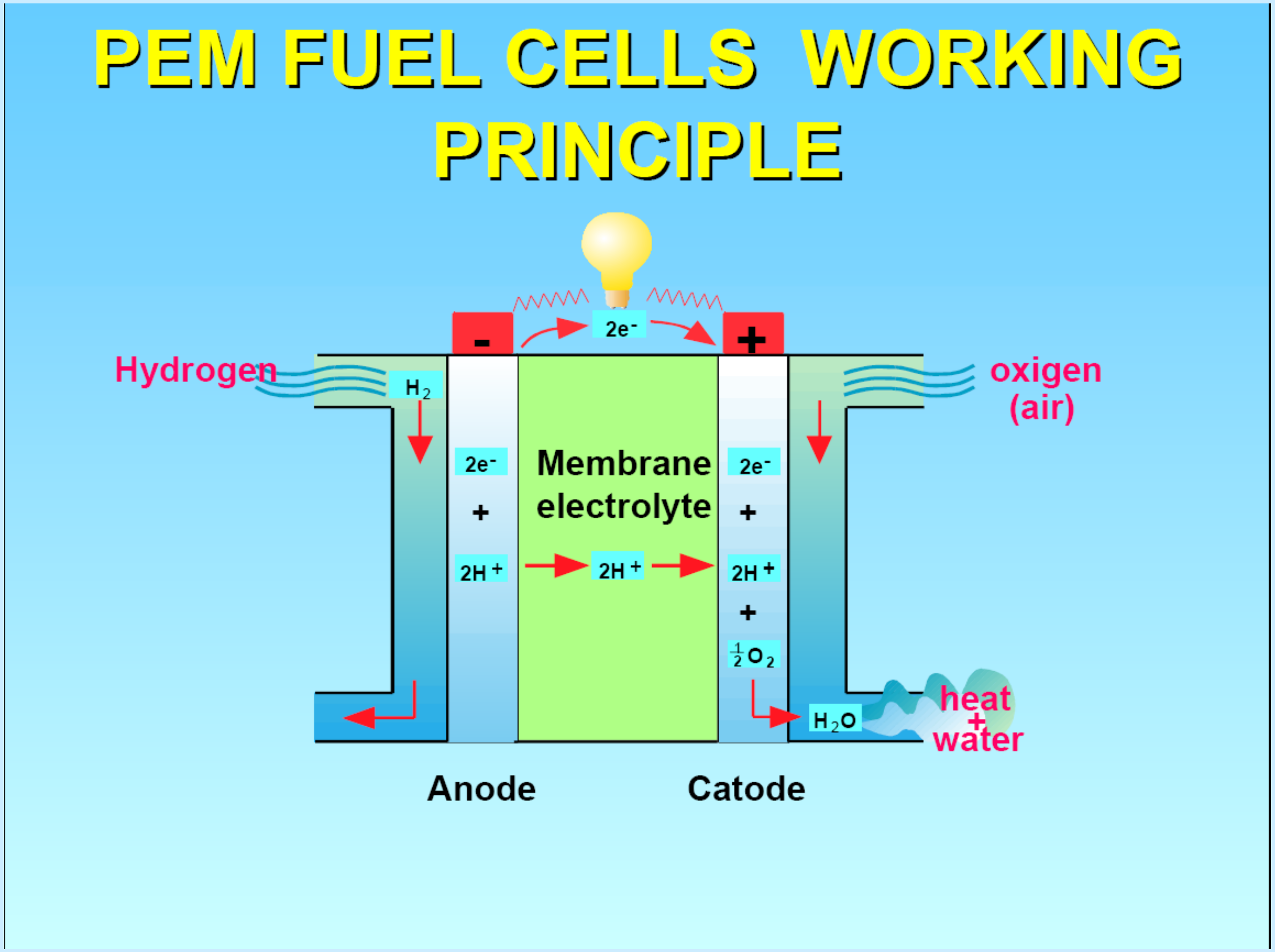


Applications and the main advantages of different uses of various types of fuel cells



Society of the hydrogen era

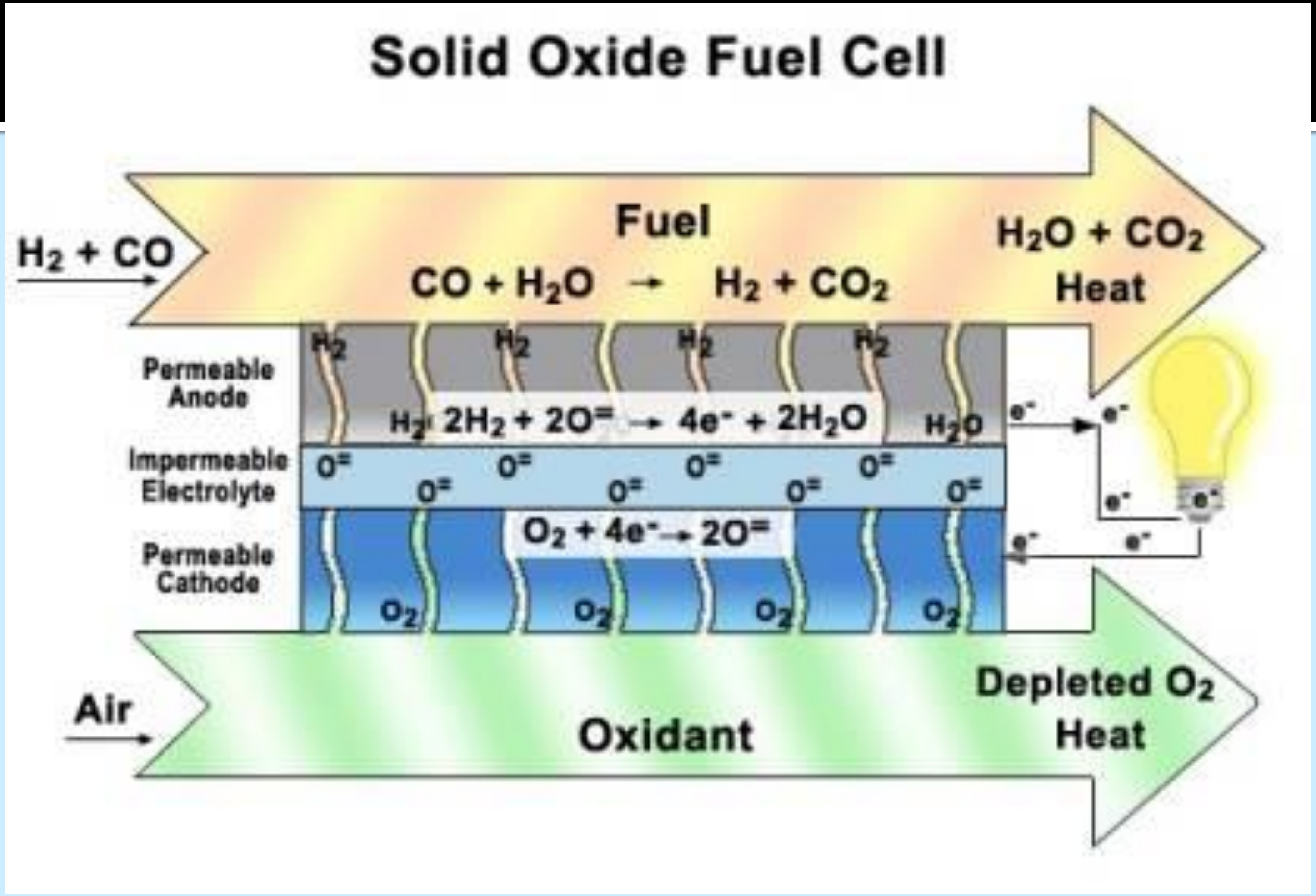
PEM FUEL CELLS WORKING PRINCIPLE



SOFC

- Solid Oxide Fuel Cell

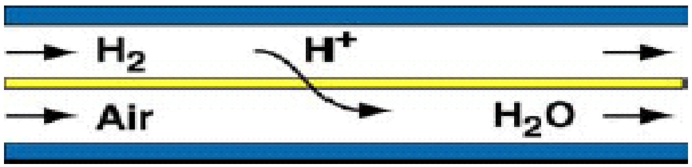
- High Temperature Oxide Fuel Cells


Solid Oxide Fuel Cell
Fuel
H2 + CO
CO + H2O → H2 + CO2
H2O + CO2
Heat
Permeable Anode
2H2 + 2O= → 4e- + 2H2O
Impermeable Electrolyte
O2 + 4e- → 2O=
Permeable Cathode
Air
Oxidant
Depleted O2
Heat

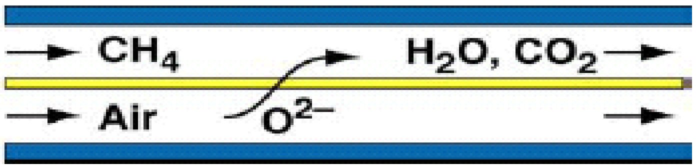
Similarities between the PEM and SOFC

- Proton Exchange Membrane (PEM)
- Polymer Electrolyte
- Proton conductivity of the electrolyte
- low temperatures (~ 100 ° C)
- fuel - H2
- CO - poisons the electrode-electrolyte
- requires precise reforming / separation
- a specific catalyst-metal
- small thermal inertia
- refined technology

- Solid Oxide Fuel Cell (SOFC)
- ceramic electrolyte
- Conductivity, oxygen ions
- high temperature (~ 700 ° C)
- hydrocarbon fuel
- CO poisoning is not
- Custom CPOX reforming or partial oxidation
- cheap catalyst
- High thermal inertia
- development - Technology



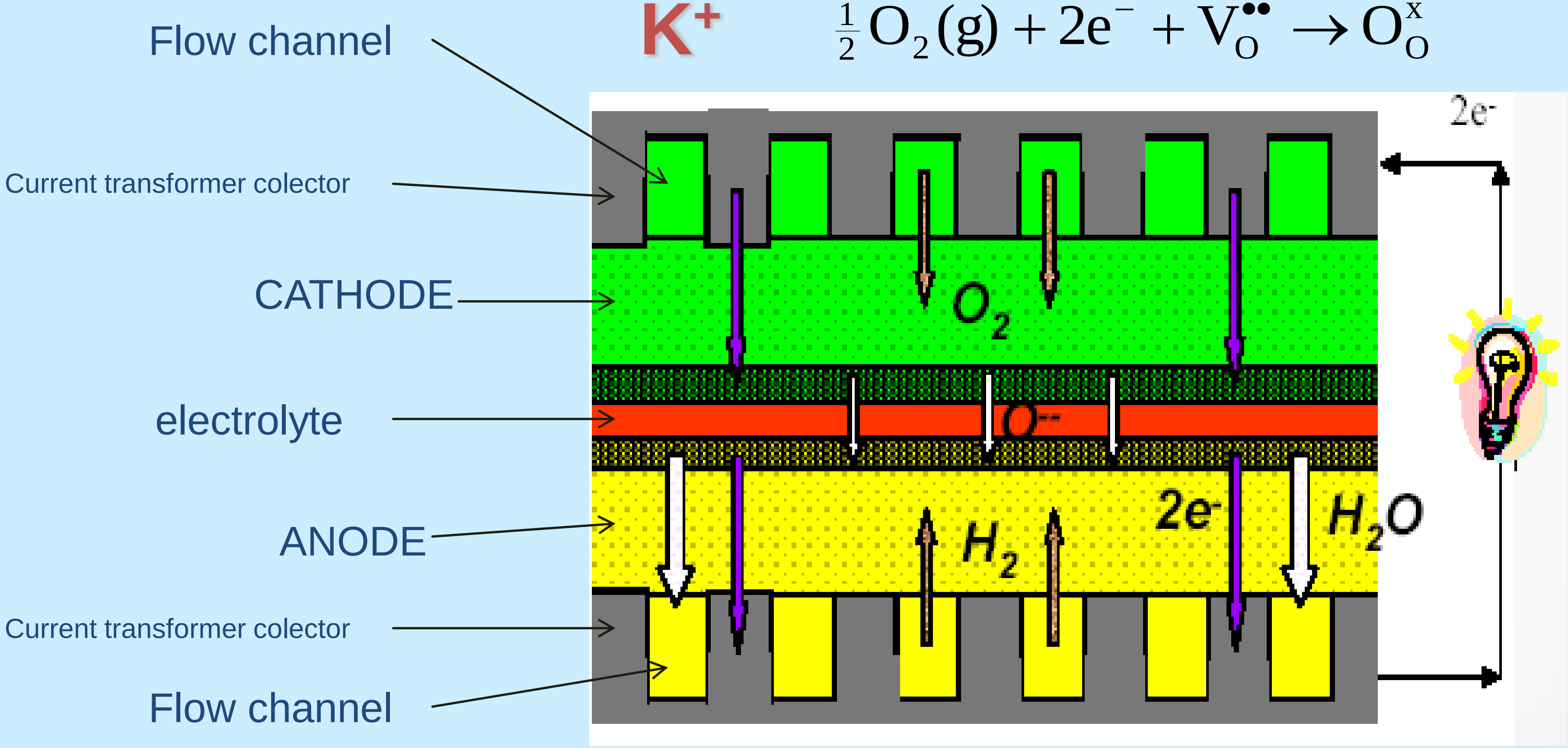
PEM



SOFC

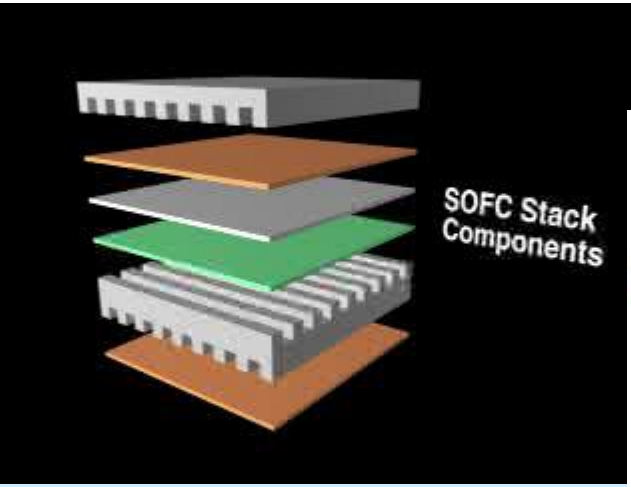
Ceramic oxide fuel cell (SOFC)

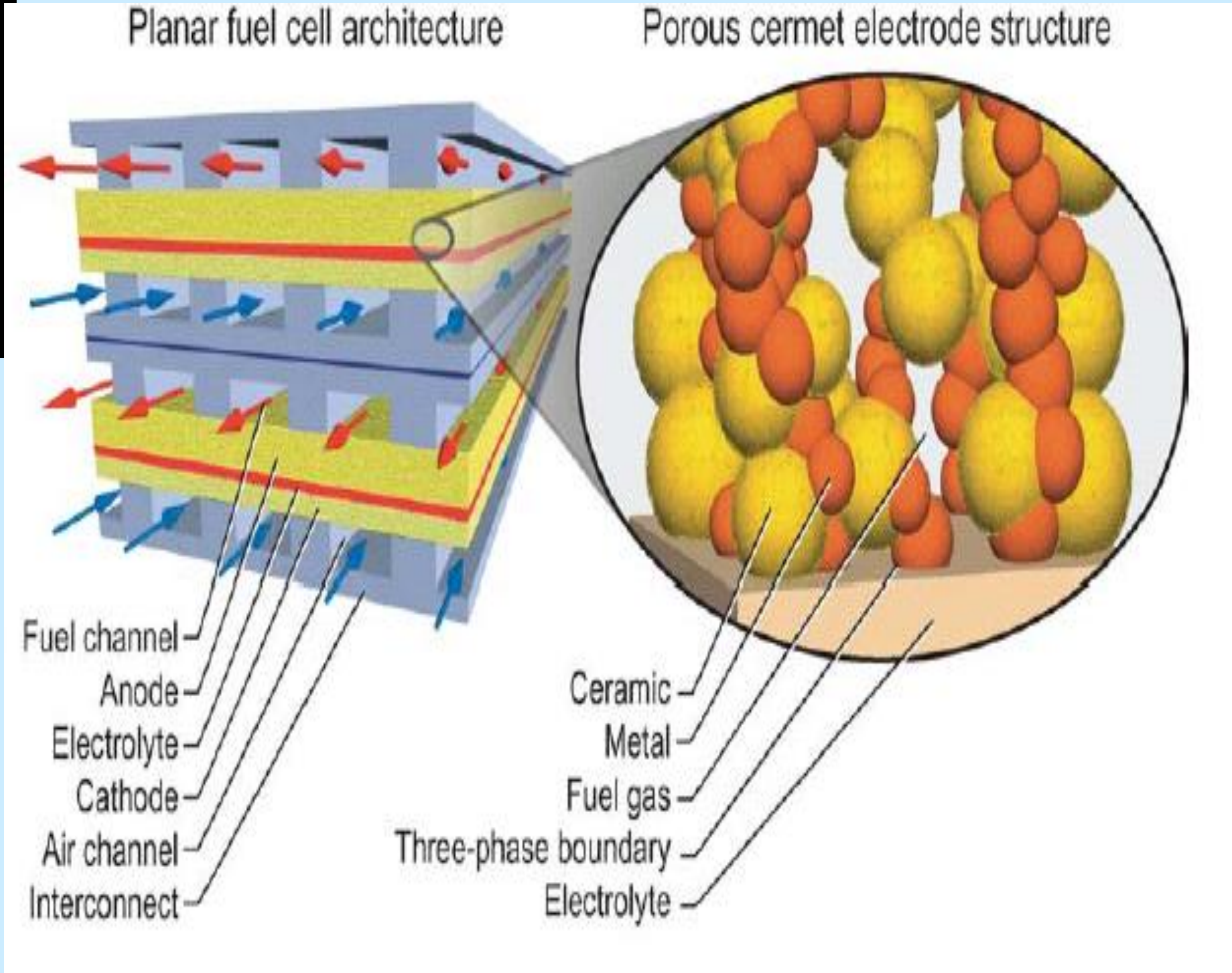
K⁺ $\frac{1}{2}O_2(g) + 2e^- + V_O^{\bullet\bullet} \rightarrow O_O^x$



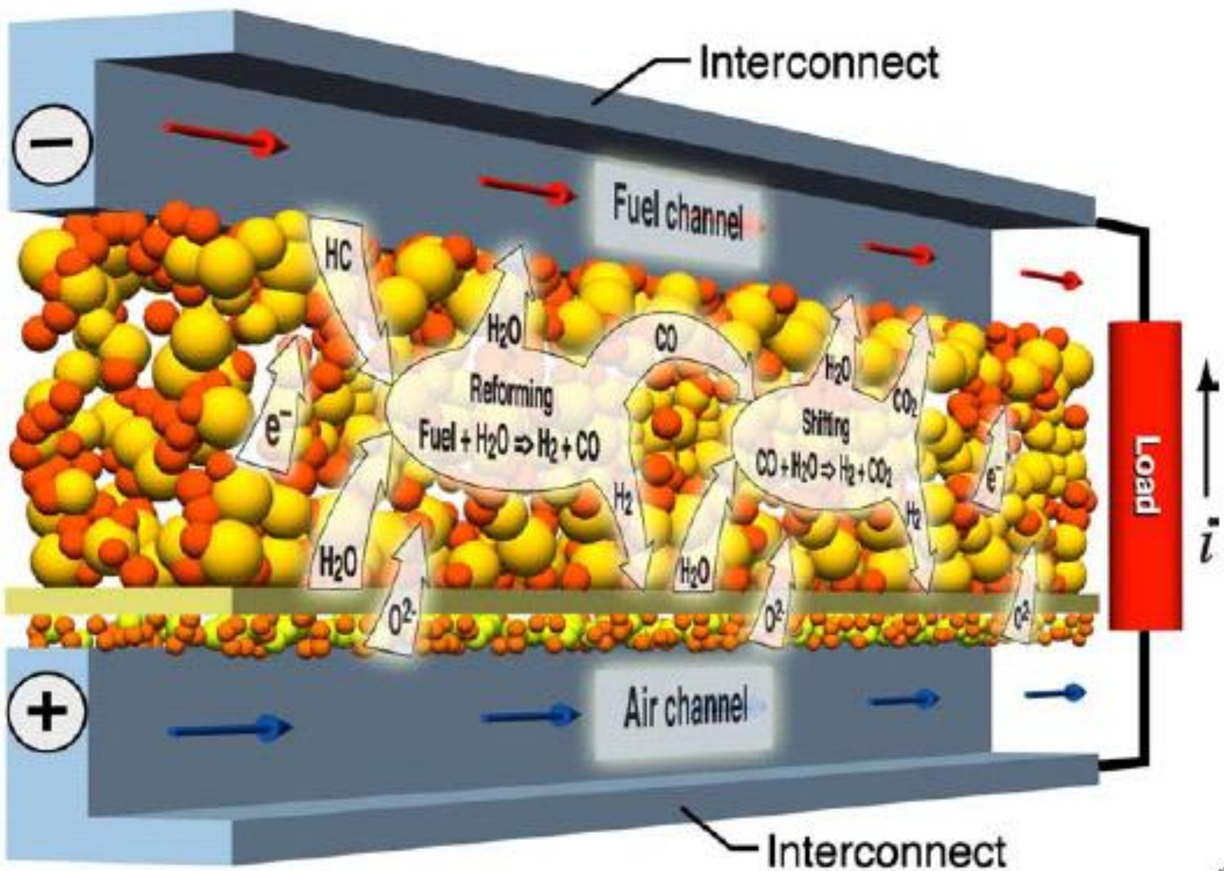
A⁻ $H_2(g) + O_O^x \rightarrow H_2O + V_O^{\bullet\bullet} + 2e^-$

Components and mechanism of SOFC single cell work

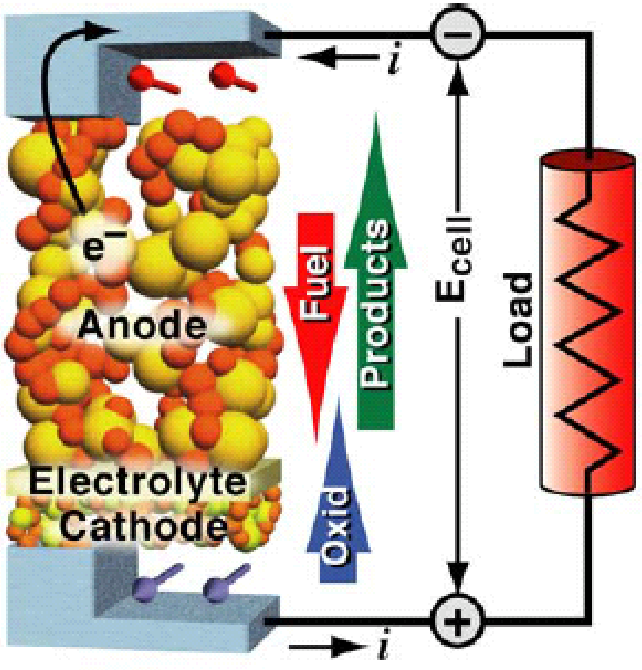


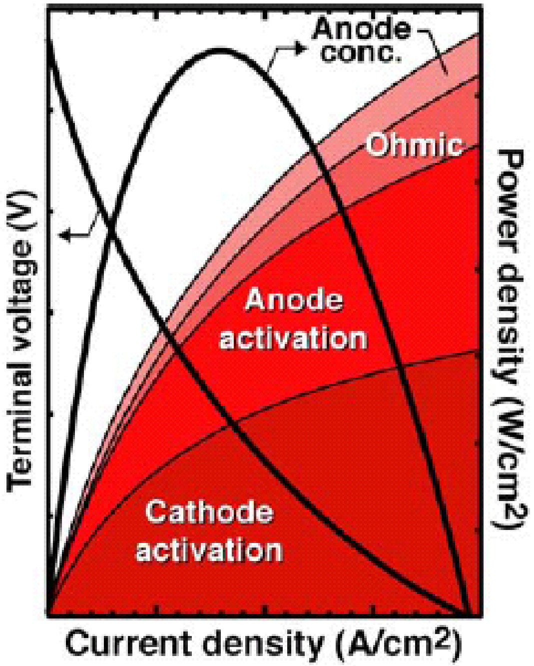


What is the role of the anode structure in promoting reforming, shifting, and CPOX?



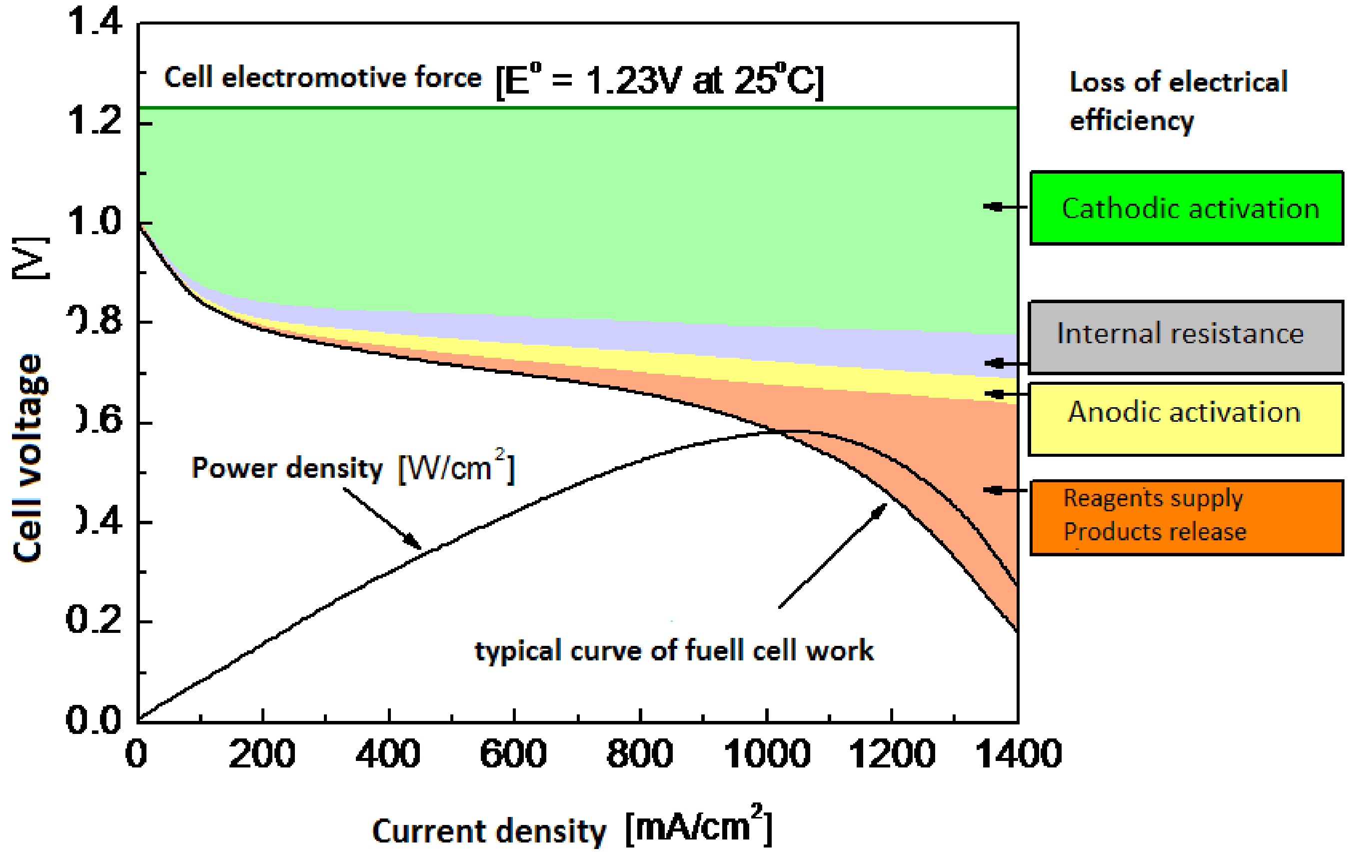
Cell perfomance depends on the chemical potential of fuel and oxidizer and on internal losses



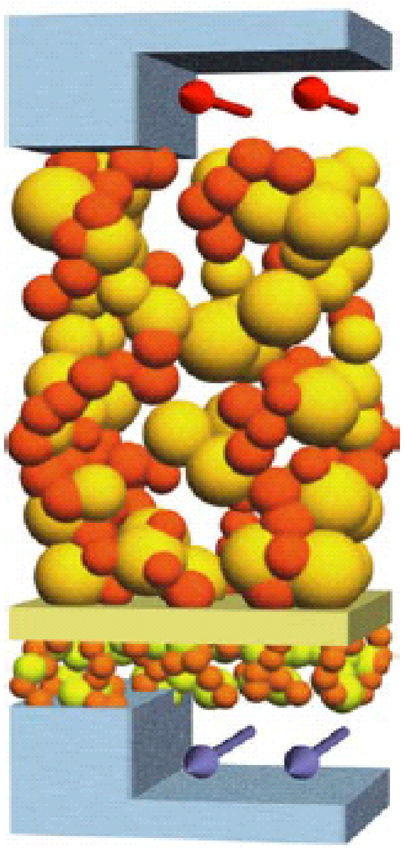


30_ICS_7/04.p17

Voltage in a working fuel cell



The ohmic overpotential through the electrolyte depends greatly on temperature



Ohmic overpotential

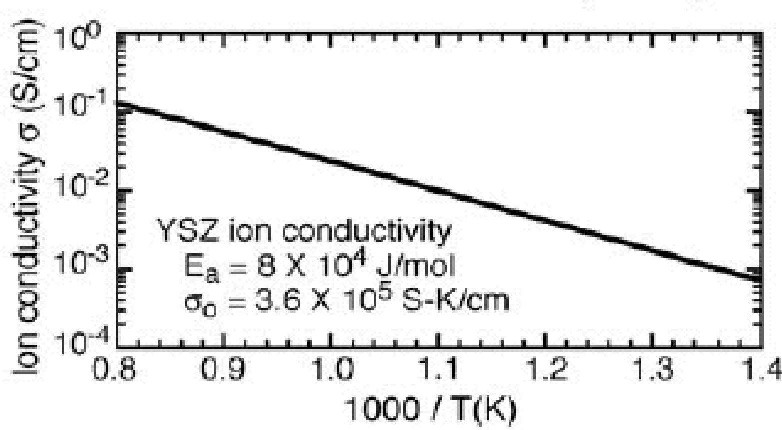
$$\eta_{\mathrm{ohm}} = iR_{\mathrm{el}}$$

Electrolyte resistance

$$R_{\mathrm{el}} = \frac{L_{\mathrm{el}}}{\sigma_{\mathrm{el}}}$$

Electrolyte ion conductivity

$$\sigma_{\mathrm{el}} = \sigma_0 T^{-1} \exp\left(-\frac{E_{\mathrm{el}}}{RT}\right)$$



Requirements for solid electrolyte

- The high ionic conductivity (> 10-1 S / cm)
- No conduction electron
- Stability over a wide range of oxygen partial pressures (1 - 10-20 atm.)
- Thermal and chemical compatibility with electrode materials at the work cell
- The possibility of obtaining a dense sintered with good mechanical properties (KIc, endurance)

The temperature of 1000 ° C in the SOFC …

- Desirable ~ 40 000 hours of SOFC cell
- Thermal degradation and corrosion of materials
- Need for ceramic interconnectors
- The high cost and unreliability
- Technology economically unviable

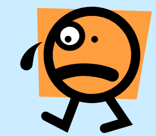
The strategic goal SOFC cell technology:

Lowering temperature to ~ 600 ° C

BENEFITS

- ✓ The ability to use low-cost, steel interconnectors
- ✓ Easier construction of cell

REQUIREMENTS

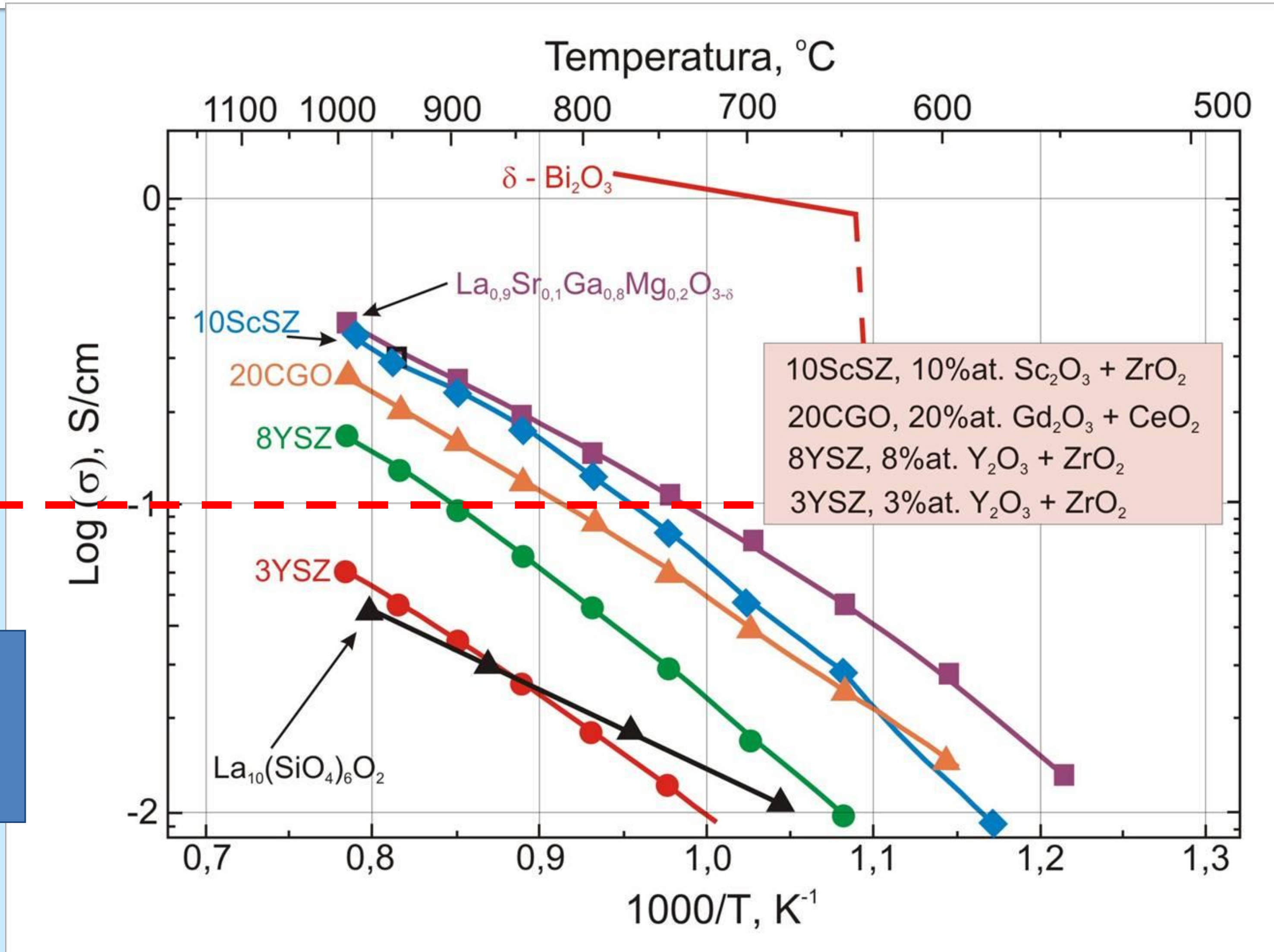


- ➢ New electrolytes operating at lower temperatures
- ➢ The new electrode materials, catalytically active at lower temperatures

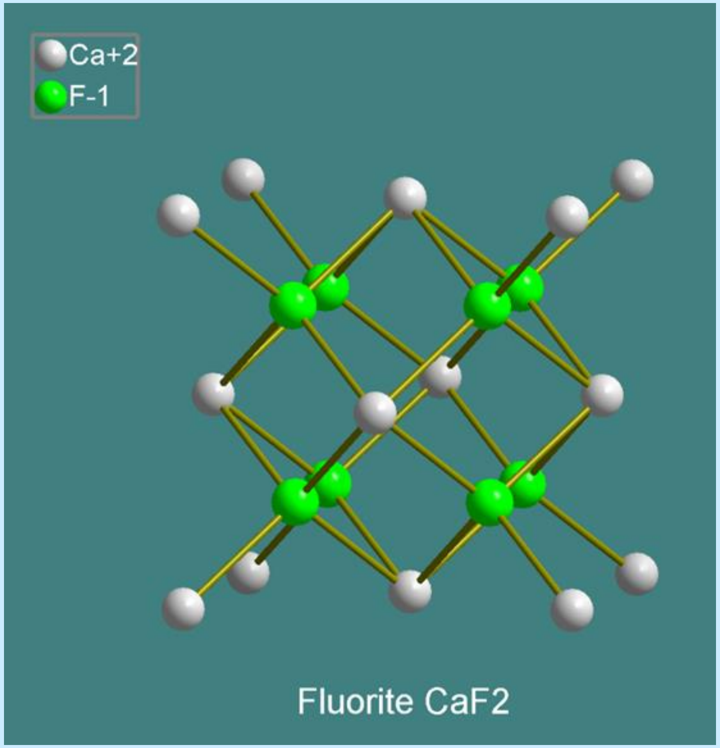
Conductivity of electrolytes currently used in SOFC cells

10^{-1} S/cm

required electrical conductivity



Cerium oxide CeO_2

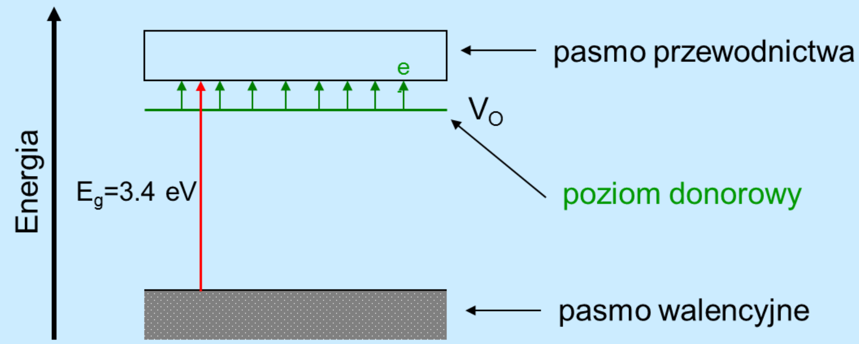


- CeO 2 crystallizes in the fluorite structure (Fm3m). Do not show polimofizm.
- Undoped CeO 2 is a semiconductor-type conductivity in a row no 10-5 S / cm at 600 ° C.
- The introduction of dopants with lower valence forces the oxygen and changes in the conduction mechanism.

Electrolytes based on CeO2-y

- Reaction:

$$O_O \leftrightarrow V_O^{\bullet\bullet} + 2e^- + \tfrac{1}{2}O_2 \uparrow$$



- Admixtures substitution: Lanthanides

$$CeO_2 + R_2O_3 \rightarrow Ce_{Ce} + 2R'_{Ce} + 5O_O + V_O^{\bullet\bullet}$$

Li, Cs

$$CeO_2 + Cs_2O \rightarrow Ce_{Ce} + 2Cs_{Ce}''' + 3O_O + 3V_O^{\bullet\bullet}$$

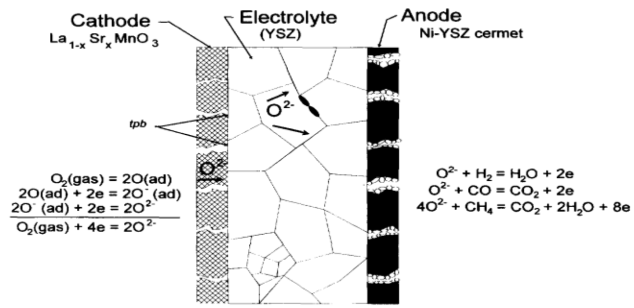


Fig. 3. Operating principle of SOFC.

the cell is given by the free energy (ΔG) of the fuel oxidation reaction, according to E_{ocv} (E_r) $= -\Delta G/nF$ (n = number of electrons transferred, F = Faraday constant). This voltage is typically 1.1–1.2 V for a single cell. Under load conditions the voltage of a single cell decreases to about 0.6–0.9 V and current densities up to 800 mA cm^{-2} can be achieved. The fuel/electric efficiency of a fuel cell is defined as the product of the electric and fuel efficiencies (ϕ_F, ϕ_E). The remaining chemical energy is available as high quality heat, allowing operation of combined cycles with expander, gas and/or steam turbines, thus further boosting fuel/electric efficiency.

The fuel efficiency (ϕ_F) is defined as the ratio of ΔG to ΔH of the fuel oxidation reaction. Fuel efficiencies for hydrogen, carbon monoxide and methane are 94%, 91% and 100% at ambient temperature and 69%, 61% and 100% at 980°C. Internal losses (resistive (IR) within the electrolyte and overpotential (η) at both electrode/electrolyte interfaces) lead to a further decline in the efficiency. The effective voltage, E, available from a fuel cell is given by $E = E_r - IR - \eta$ and the ratio E/E_r is defined as the electric efficiency (ϕ_E).

3 SOFCs — STACK DESIGNS

To achieve workable power outputs, single cells are combined to multi-cell units, the fuel cell stack. Numerous configurations have been reported,[3] differing in geometry, power density and method of sealing. Designs can be classified into (i) self-supporting ones, where the electrolyte (80–250μm in thickness) forms a structural element of the design and (ii) supported concepts, where the electrolyte is deposited as a thin layer ($<50\mu$m) on porous support structures.

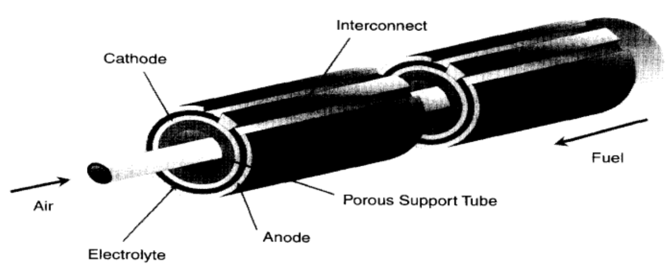
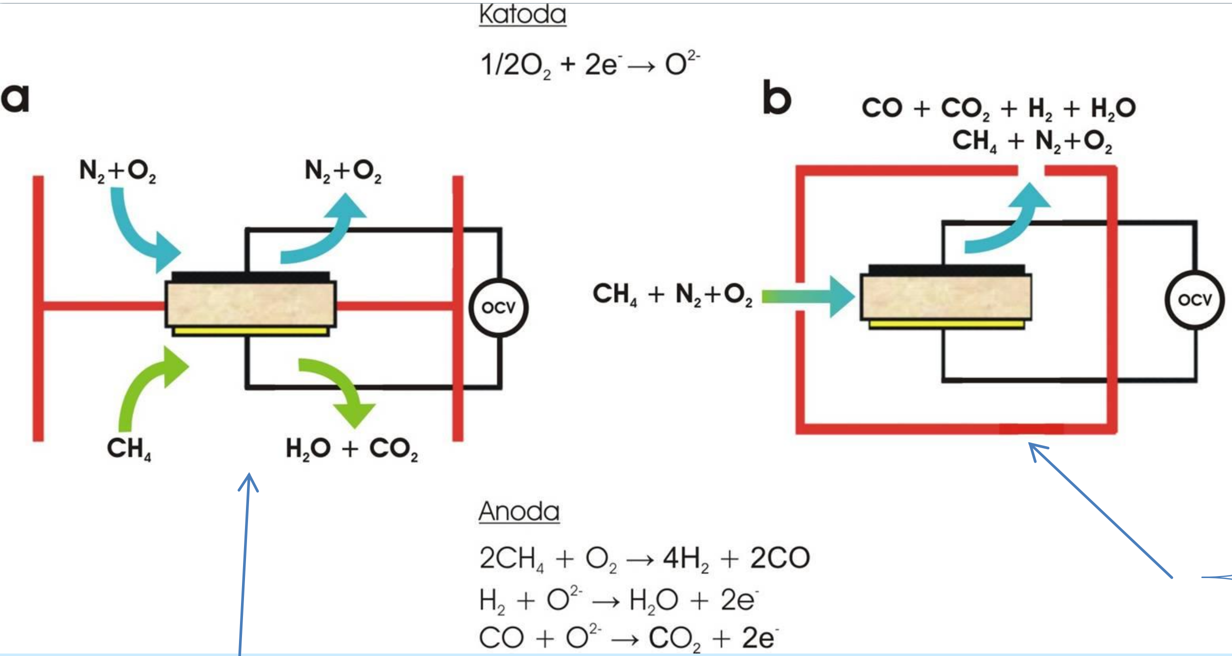


Fig. 4. Westinghouse tubular design SOFC.

The concept of single-chamber cell



- Power mix the fuel and oxidizer
- Selective (vs. O2 - H2) catalytic activity of electrode materials
- Acceptable porous electrolyte
- The simple design of stacks of cells
- The ionic current is dependent on the differential catalytic activity of electrodes
- Partial pressure of oxygen is relatively high - it solves the problem of instability of some electrolytes
- Operating temperature (600oC) - for both electrodes catalyze the higher fuel consumption unproductive

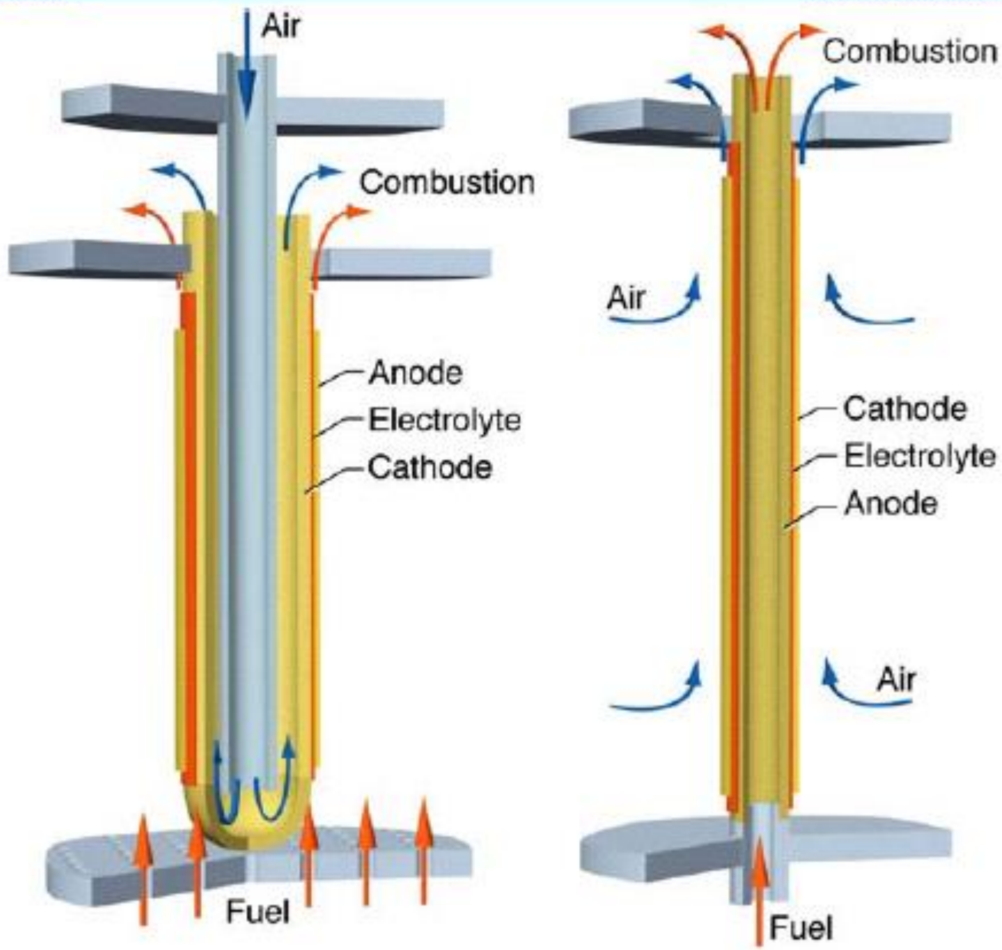
- Separation of fuel and oxidant chambers
- Gas-tight electrolyte
- Troublesome seal the connecting links in the stacks
- The ionic current is dependent on oxygen partial pressure difference on the electrodes

20 Watt system designed and built by ITN Energy Systems, Inc. and Mesoscopic Devices, Inc.

30_ICS_7/04.p40

There are several tubular configurations that offer alternatives to planar systems

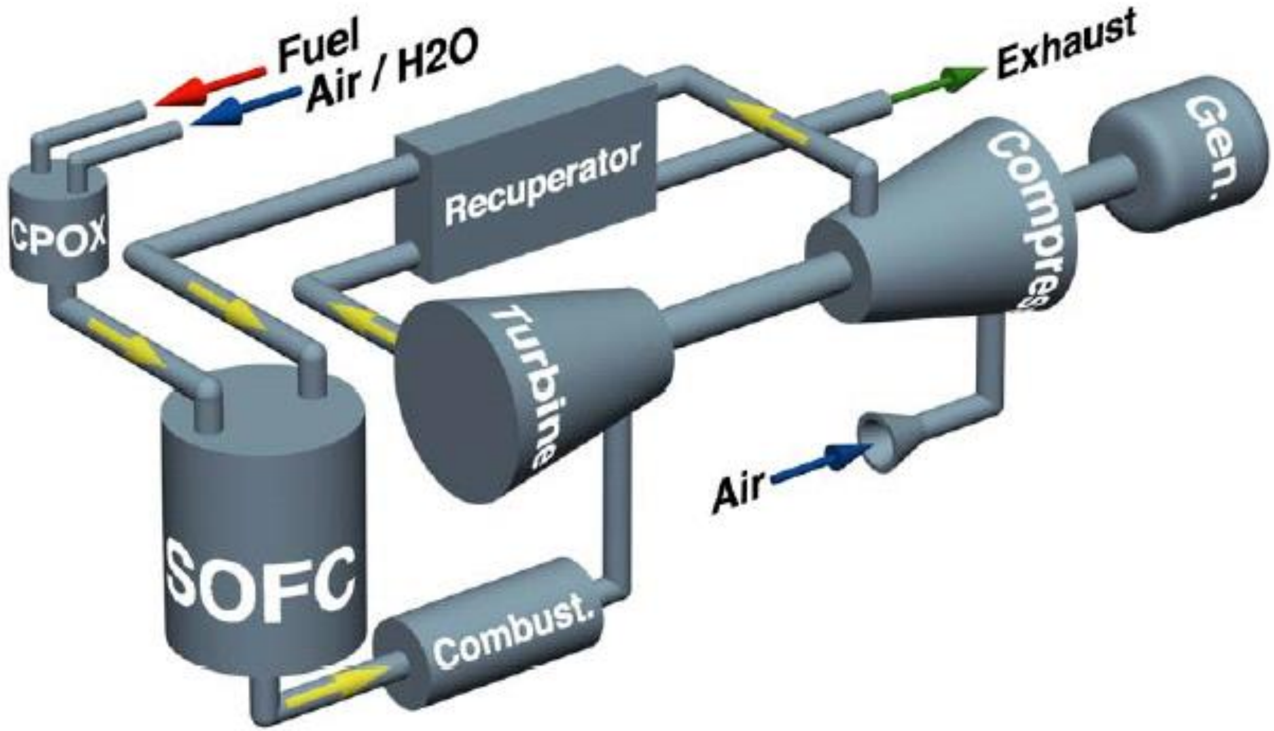
Colorado School of Mines | California Institute of Technology



30_ICS_7/04.p41

Hybrid cycles can offer overall system efficiencies of over 70%

Colorado School of Mines California Institute of Technology

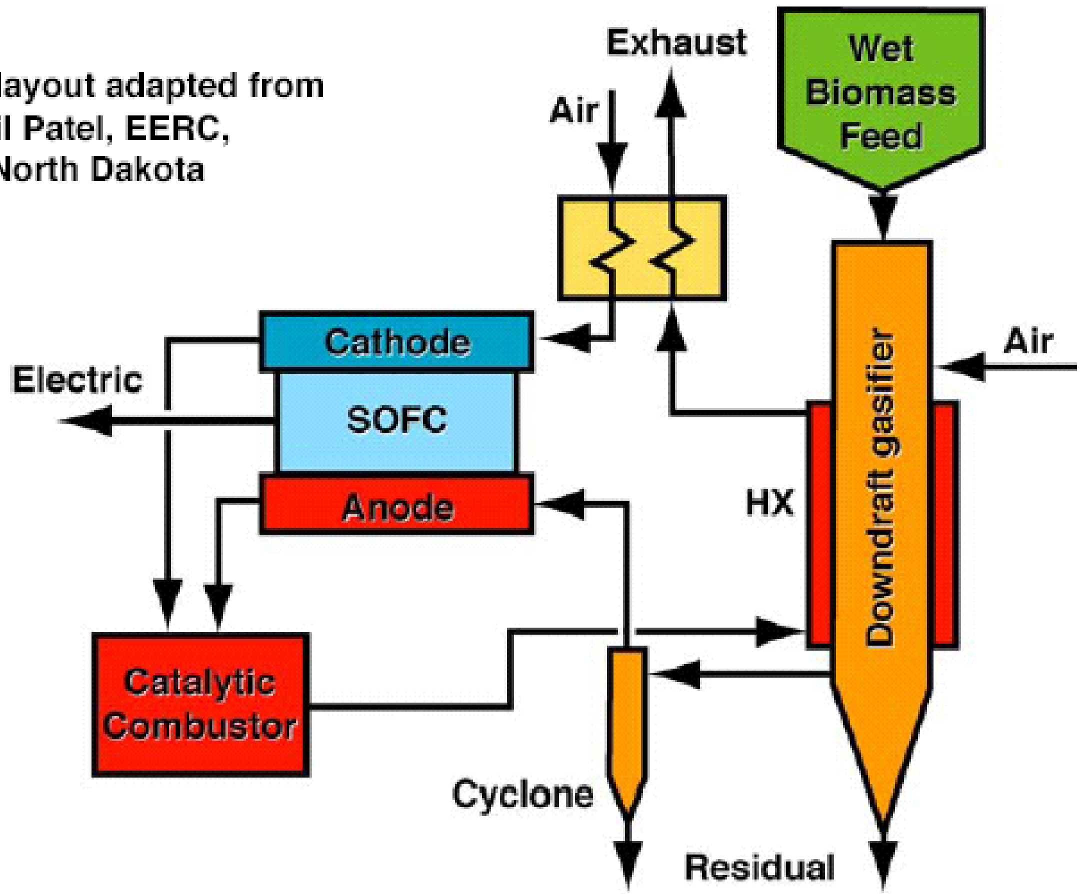


30_ICS_7/04.p42

Biomass gasification and SOFC can be integrated into a hybrid system

Colorado School of Mines **California Institute of Technology**

System layout adapted from
Dr. Nikhil Patel, EERC,
Univ.of North Dakota



30_ICS_7/04.p43