Thermochemical Power Group

Sustainable Energy

Mod.1: Fuel Cells & Distributed Generation Systems

Dr. Ing. Mario L. Ferrari

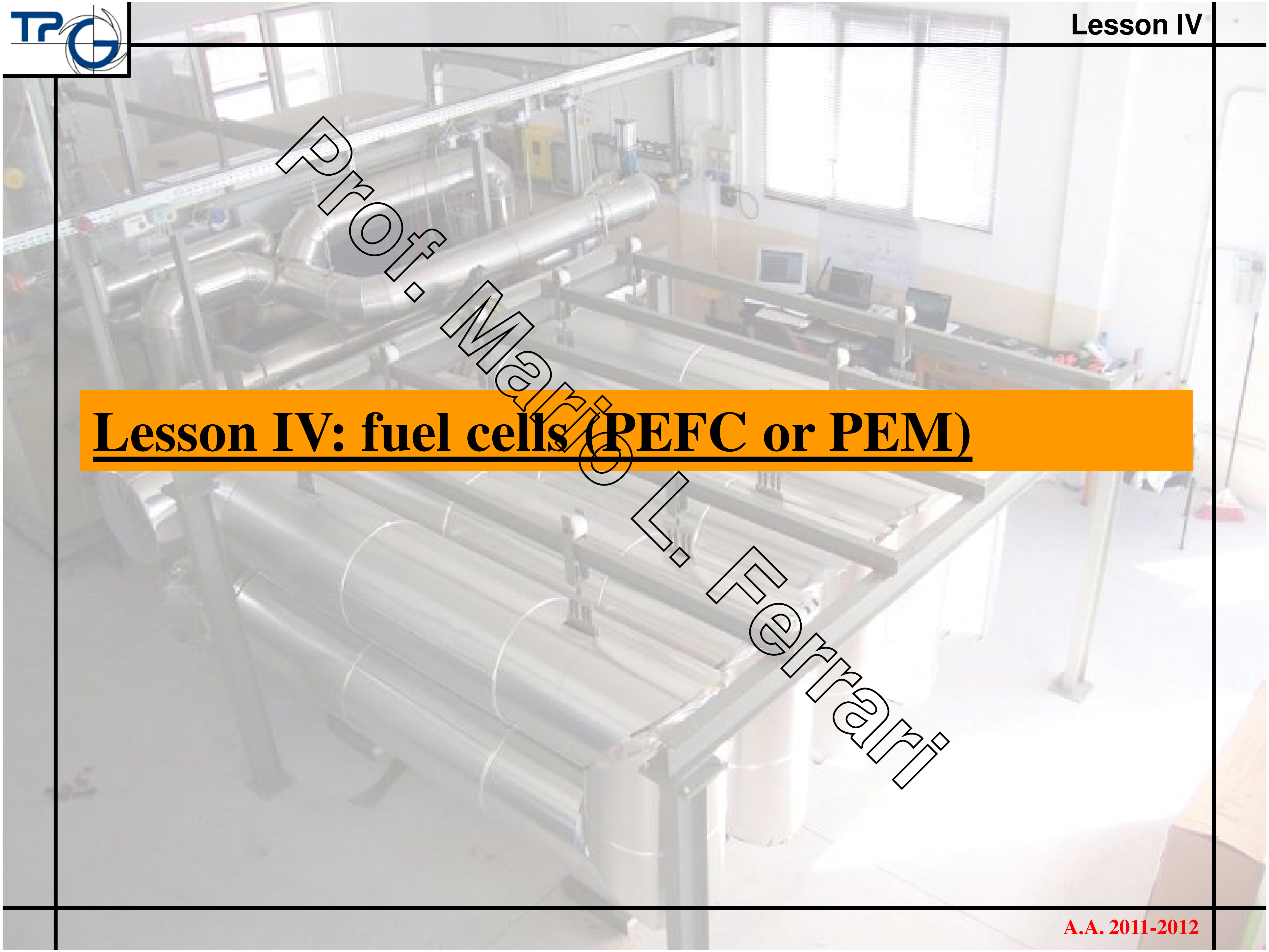
Thermochemical Power Group (TPG) - DiMSET – University of Genoa, Italy

Campus Universitario di Savona

www.campus-savona.it SPES s.c.p.A. Università degli Studi di Genova

Environmental & Energy Engineering

University of Genova



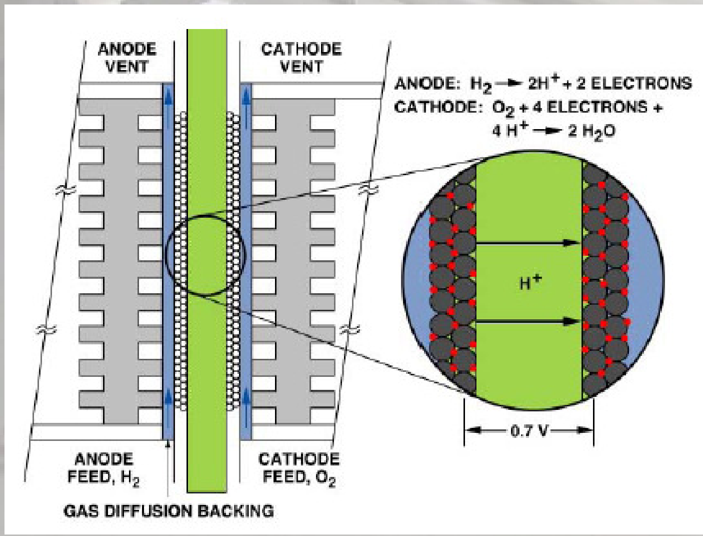
Lesson IV: fuel cells (PEFC or PEM)

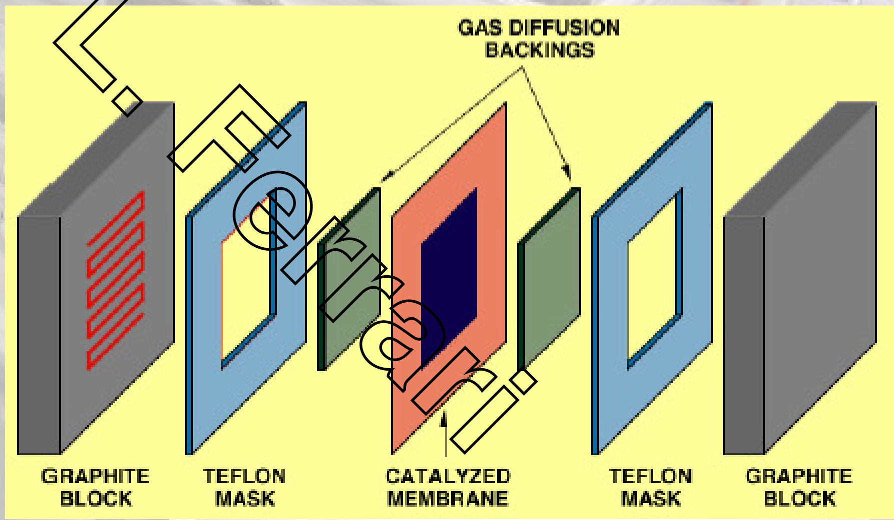
Main Characteristics

- ✓Able to efficiently generate high power densities.
- ✓Attractive for certain mobile and portable applications.
- ✓Automobile applications.
- ✓A solid phase polymer membrane is used as the cell separator/electrolyte.
- ✓The cell operates at relatively low temperatures (60°C-80°C).
- ✓Sealing, assembly, and handling are less complex than most other fuel cells.
- ✓Faster start-up than higher temperature fuel cells.
- ✓PEFC are particularly suitable for operation on pure hydrogen.
- ✓Fuel processors have been developed for the use of conventional fuels (such as natural gas or gasoline).
- ✓A type of PEFC allows the direct use of methanol as fuel. **It is called DMFC**.
- ✓The DMFC is the leading candidate technology for the application of fuel cells to cameras, notebook computers, and other portable electronic applications.

Cell Components (usually planar cells)

✓The ion exchange membrane.
✓An electrically conductive porous backing layer.
✓An electro-catalyst (the electrodes) at the interface between the backing layer and the membrane.
✓Cell interconnects and flow plates that deliver the fuel and oxidant to reactive sites via flow channels and electrically connect the cells.





Membrane

✓The function of the ion exchange membrane is to provide a conductive path, while at the same time separating the reactant gases.

✓The material is an electrical insulator

✓The standard electrolyte material in PEFCs belongs to the fully fluorinated Teflon®-based family

✓The membrane is characterized by its equivalent weight (inversely proportional to the ion exchange capacity).

✓The type used most often in the past was a melt-extruded membrane manufactured by DuPont and sold under the label **Nafion® No. 117** (perfluorosulfonic acid polymer) .

✓Nafion consists of a fluoropolymer backbone, similar to Teflon®, upon which sulfonic acid groups are chemically bonded.

✓In selected fuel cell tests and water electrolysis systems, lifetimes of over 50,000 hours have been demonstrated.

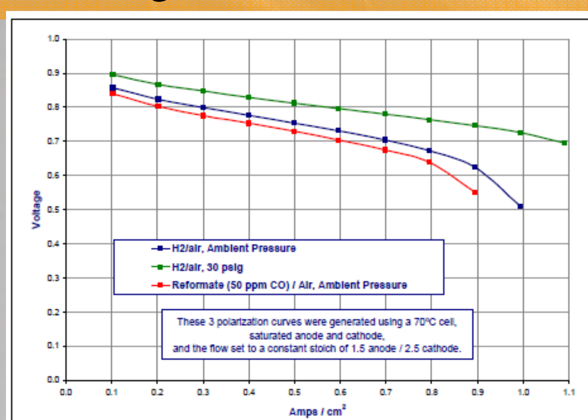
✓Alternative membranes: Dow Chemical Company produced XUS 13204.10 (a short chain membrane with higher degree of water interactions and lower electrical resistance), W.L. Gore produces internally-supported membranes, solution-cast film process (to reduce costs and improve manufacturing throughput efficiency).

Porous Backing Layer

- ✓The polymer membrane is sandwiched between two sheets of porous backing media (also referred to as gas diffusion layers or current collectors)
- ✓The functions of the backing layer are:
  - ➢act as a gas diffuser;
  - ➢provide mechanical support;
  - ➢provide an electrical pathway for electrons;
  - ➢provide channel product water away from the electrodes.
- ✓The backing layer is typically a carbon-based fibre (the layer incorporates a hydrophobic material, such as polytetrafluoroethylene to prevent water from "pooling" (gases in freely contact with the catalyst sites))
- ✓One PEFC developer uses pure graphite (passive water control)
- ✓removing the water through the porous plate is necessary for:
  - ➢to have less water in the spent reactant streams;
  - ➢to reduce parasitic power needs of the oxidant exhaust condenser;
  - ➢to have higher fuel utilization values;
  - ➢to better control temperature values (better distributions).

Electrode-Catalyst Layer

- ✓The catalyst layer is in intimate contact with the membrane and the backing layer
- ✓It "fixes" the catalyst particles within a layered structure
- ✓First school: binder was polytetrafluoroethylene: a non-wetting component within the electrode itself
- ✓Second school: hydrophylic electrode in which the binder was perfluorosulfonic acid
- ✓The catalyst for H_2 is platinum-based for both the anode and cathode (pure platinum or graphite supported platinum
- ✓The catalyst for fuel from reformer is alloy of platinum containing ruthenium
- ✓Low platinum loading electrodes (≤1.0 mg Pt/cm^2 total on the anode and the cathode) are regularly used, and have performed as well as earlier, higher platinum loading electrodes (2.0 to 4.0 mg Pt/cm^2).



- ✓Catalist poisoning problems from CO
- ✓CO has to be carefully removed
- ✓Research activities on 120°C-160°C PEFC:
  - ➢No CO poisoning problems
  - ➢Membrane impregnated with H_3PO_4
  - ➢Modified Nafion (Nafion 112)

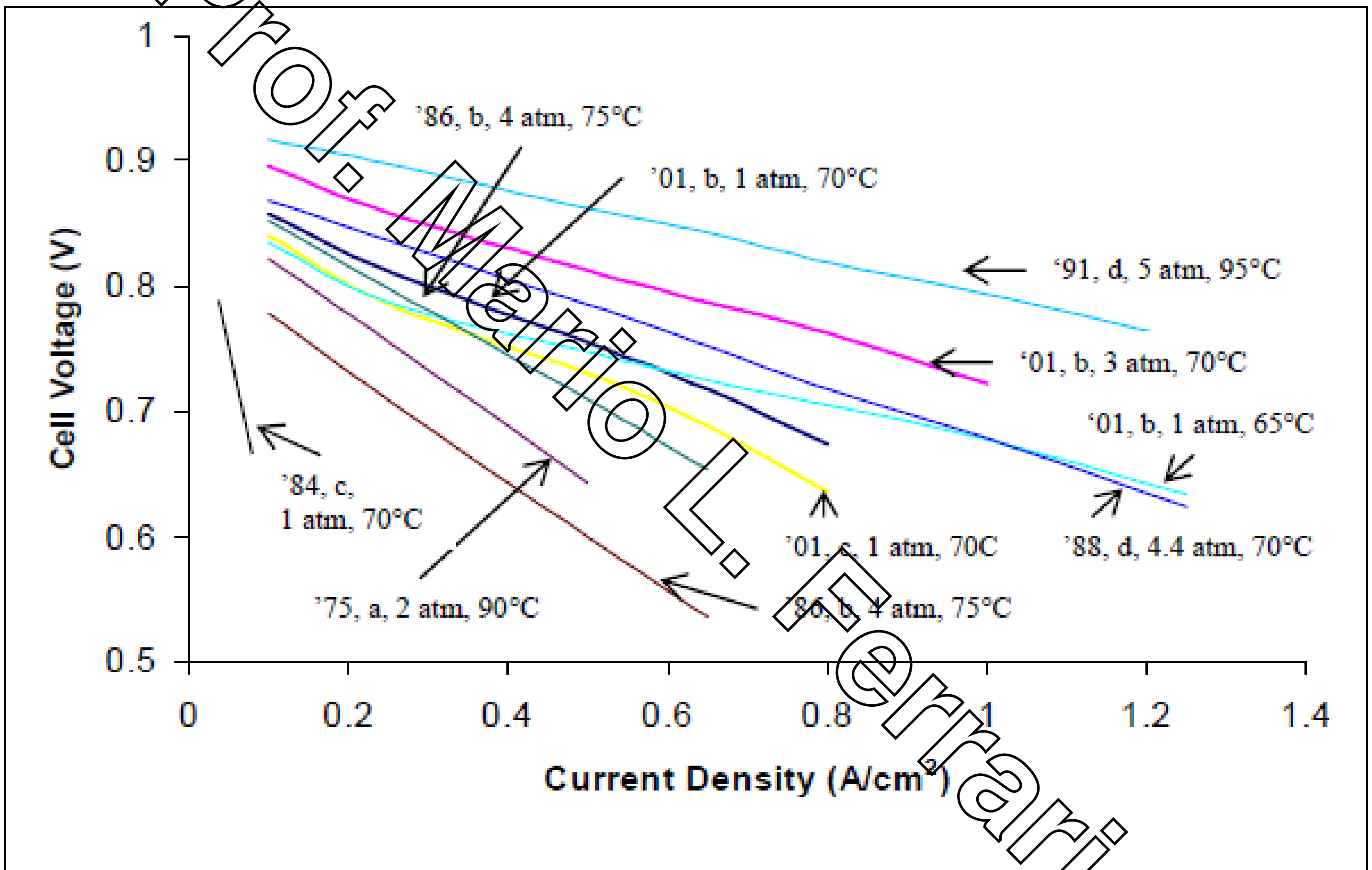
Water and Thermal Management

✓A critical requirement is to maintain high water content in the electrolyte to ensure high ionic conductivity.
✓Maintaining high water content is particularly critical when operating at high current densities (approximately 1 A/cm^2) because mass transport issues associated with water formation and distribution limit cell output.
✓Water content is determined by balance of water during operation.
✓Water transport factors:
- water drag through the cell (liked to transport and membrane)
- back-diffusion from the cathode (osmotic action along with the proton)
- the diffusion of water in the fuel stream through the anode

✓The objective of the stack engineer is to ensure that all parts of the cell are sufficiently hydrated, and that no excessive flooding occurs

✓Most PEFCs presently use cast carbon composite plates for current collection and distribution, gas distribution, and thermal management.
✓Cooling is accomplished using a circulating fluid, usually water that is pumped through integrated coolers within the stack.
✓Metal (usually coated) plates are used as an alternative by some developers.

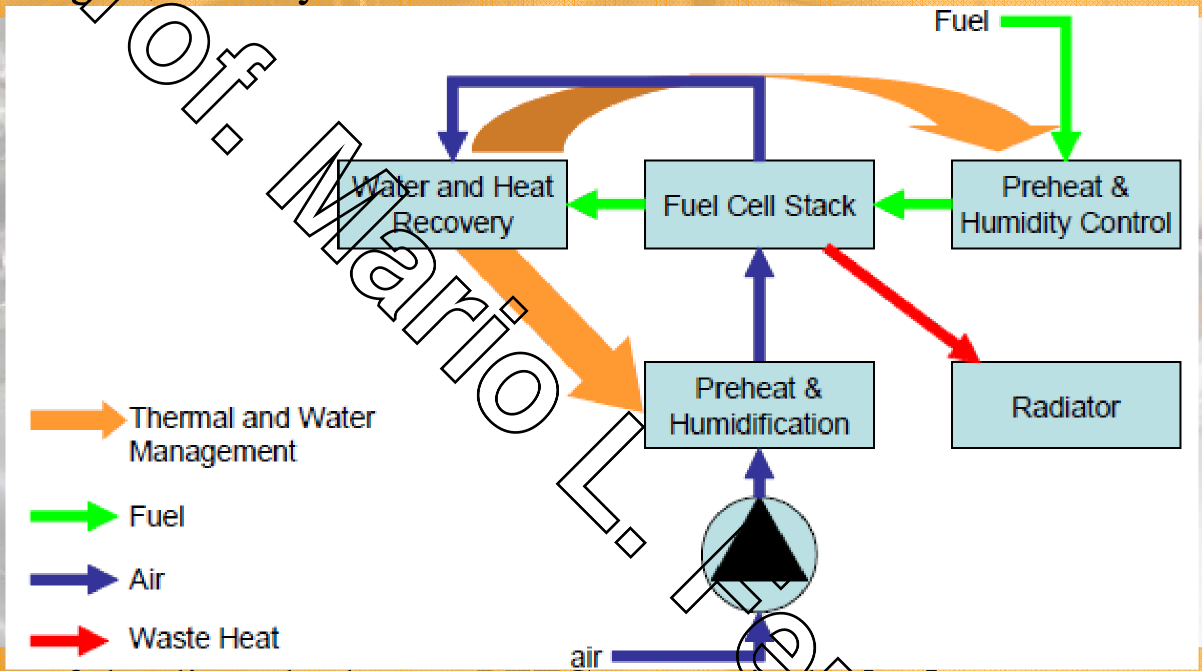
Performance



✓Operating temperature, pressure and technology level have a significant influence on performance

PEFC Systems (1/2)

✓Direct hydrogen PEFC system

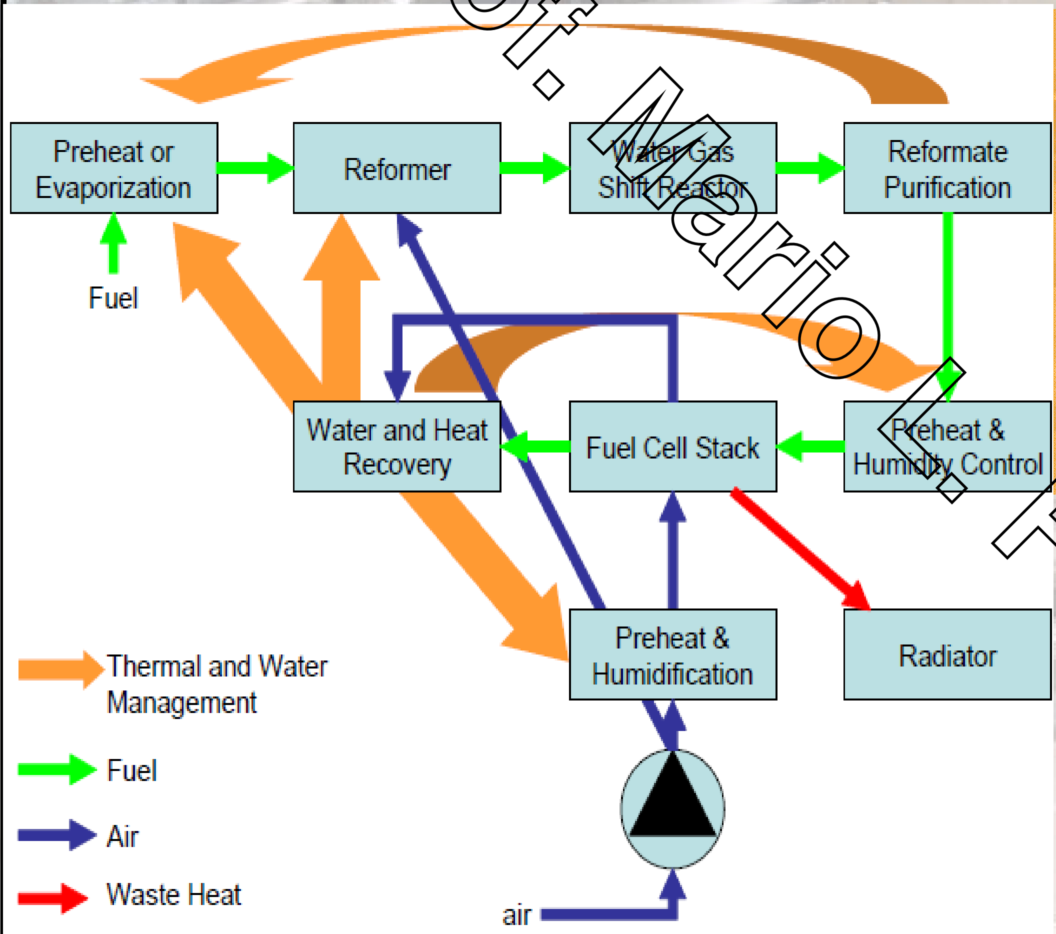


✓A key part of the direct hydrogen PEFC system is the **hydrogen storage tank**. A wide range of hydrogen storage methods is being considered (compromise between energy density, weight, energy efficiency and cost):

- compressed hydrogen storage
- liquid storage
- storage in metal hydrides
- chemical storage

PEFC Systems (2/2)

✓Reformer-Based PEFC Systems



- Fuel preheat and vaporization
- Reformer
  - partial oxidation reformer
  - steam reformer
  - autothermal reformer
- Water gas shift reactor
- Reformate purification

Direct Methanol Fuel Cell (DMFC) Systems

- ✓Special PEFC optimized for methanol
- ✓Very simple system with a fuel that has a relatively high energy density and is a liquid under ambient conditions
- ✓Performance level: 180 to 250 mA/cm^2 but because cell voltages typically range between 0.25 to 0.4 V, the power density ranges between 40 to 100 mW/cm^2
- ✓Low cell voltage is caused by few common problems with the DMFC, several of which result from the cross-over of neutral methanol from the anode to the cathode side
- ✓**Methanol crossed over is lost!**
- ✓This performance still requires platinum loadings that are almost ten times higher (around 3 to 5 mg/cm^2) than needed in high-performance direct hydrogen PEFC

Transportation Applications

- ✓Prime mover for **cars and light truks**
- ✓PEFC systems fuelled by hydrogen, methanol, and gasoline have been integrated into light duty vehicles by at least twelve different carmakers
- ✓The widespread application of PEFC to transportation will not occur until well into the next decade:
  - ➢Volume and weight of fuel cell systems must be further reduced
  - ➢Life and **reliability** of PEFC systems must be improved
  - ➢PEFC systems must be made **more robust** in order to be operable under the entire range of environmental conditions expected of vehicles
  - ➢Additional technology development is required to achieve the necessary **cost reductions**
  - ➢A **hydrogen infrastructure**, and the accompanying safety codes and standards must be developed

Stationary Applications

- ✓Very small-scale **distributed generation** (~1 to 10 kW AC).
- ✓Hundreds of demonstration units have been sited in programs in the U.S., Europe, and Japan (e.g. for mobile phone recharging)
- ✓System efficiency typically ranges from 25% to 32% (based on LHV)
- ✓By recovering the waste heat from the cooling water: the overall thermal efficiency = 80%
- ✓System operating life has been extended to about 8,000 hrs for a single system with a single stack, with degradation of about 5% per 1,000 hours