Fuel Cell 101

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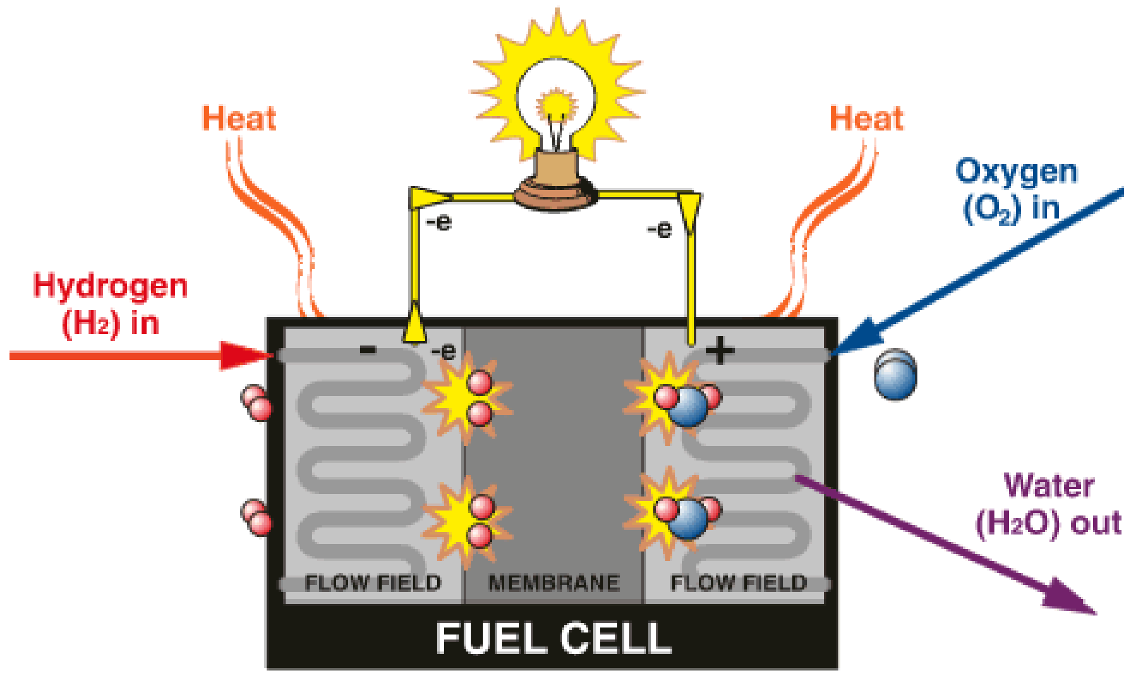
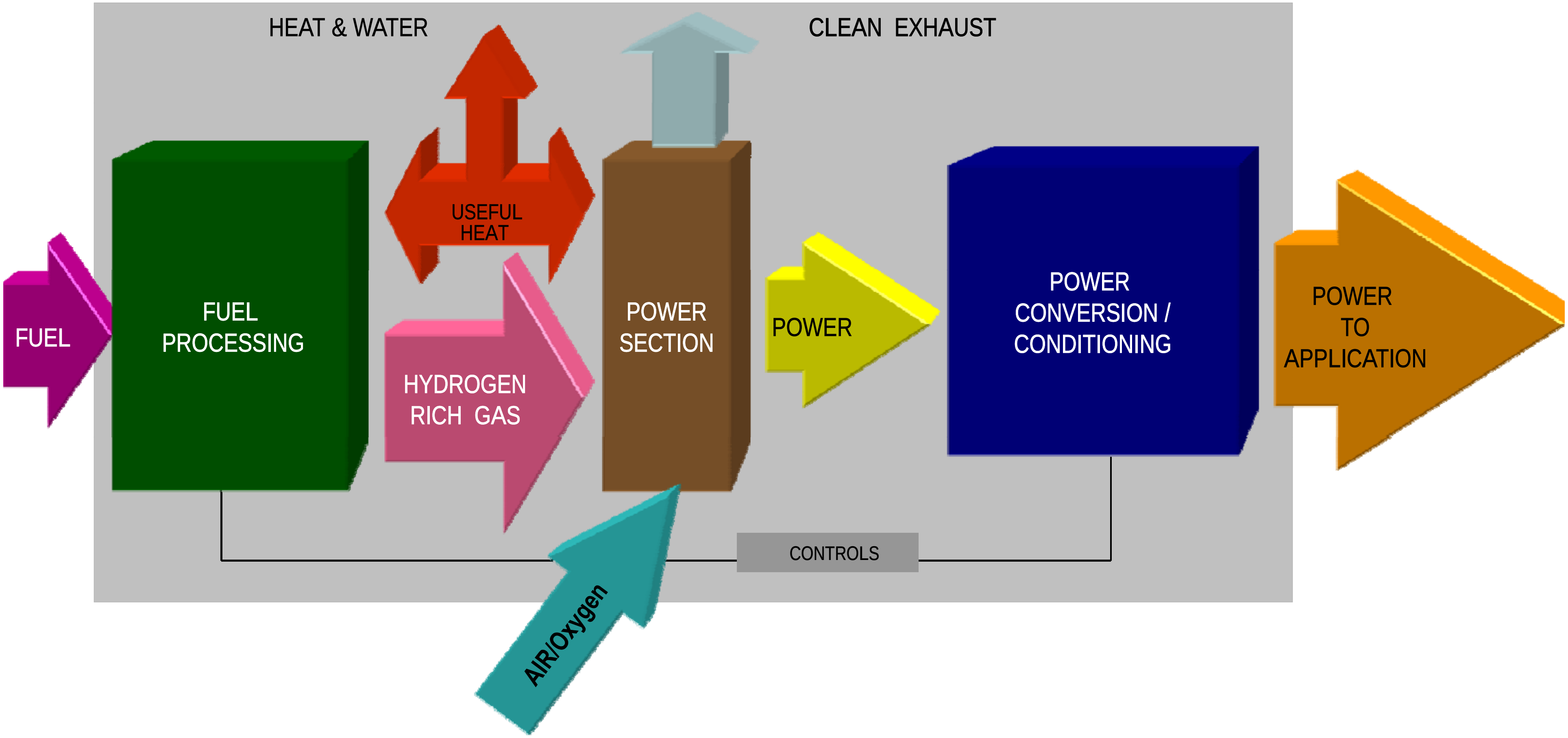
Fuel Cell Operation

- A Fuel Cell is an electrochemical power source
- It supplies electricity by combining hydrogen and oxygen electrochemically without combustion.
- It is configured like a battery with anode and cathode.
- Unlike a battery, it does not run down or require recharging and will produce electricity, heat and water as long as fuel is supplied.



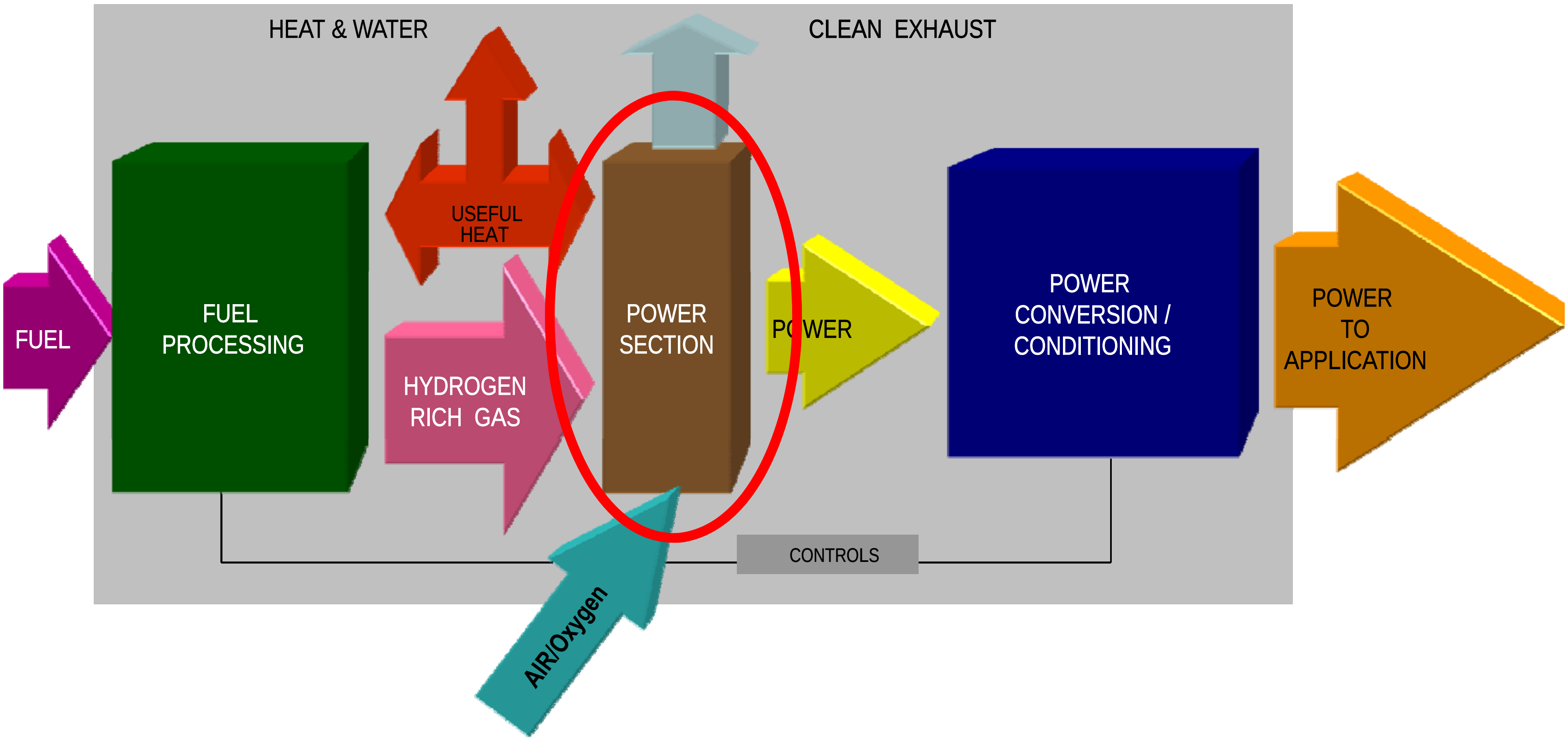
$H_2 \longrightarrow 2H^+ + 2e^-$ | $O_2 + 2H^+ + 2e^- \longrightarrow 2H_2O$

Fuel Cell System



Distribution Statement A: Approved for public release; distribution is unlimited.

Fuel Cell System



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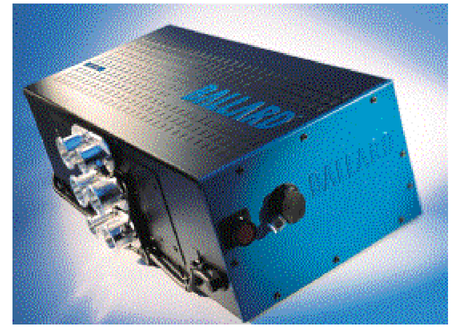
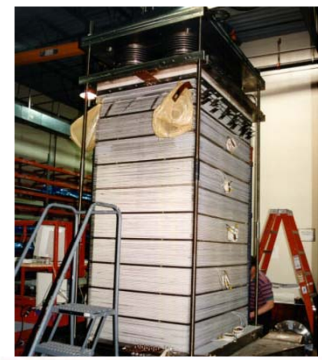
Fuel Cell Types

	Electrolyte	Cell Temp
Proton Exchange Membrane (PEM)	Polymer Membrane (Solid)	70-90 C
Phosphoric Acid (PAFC)	Phosphoric Acid (Liquid)	120-180 C
High Temp PEM (HTPEM)	Phosphoric Acid Polymer (Solid)	120-180 C
Molten Carbonate (MCFC)	Potassium Lithium Carbonate (Liquid)	650 C
Solid Oxide (SOFC) (Tubular, planar)	Solid Zirconium Oxide Ceramic (Solid)	700-950 C





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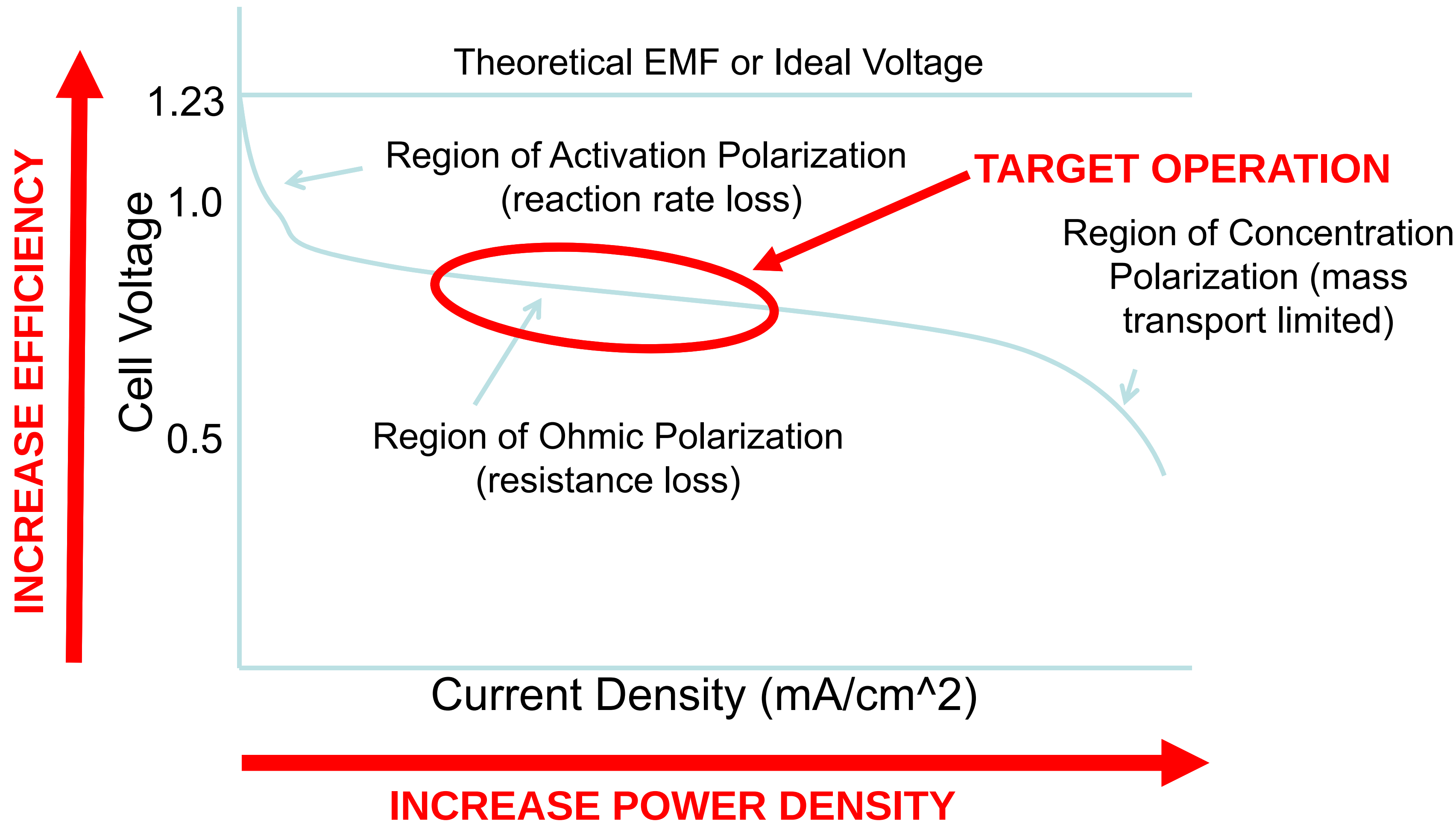
Fuel Cell Types

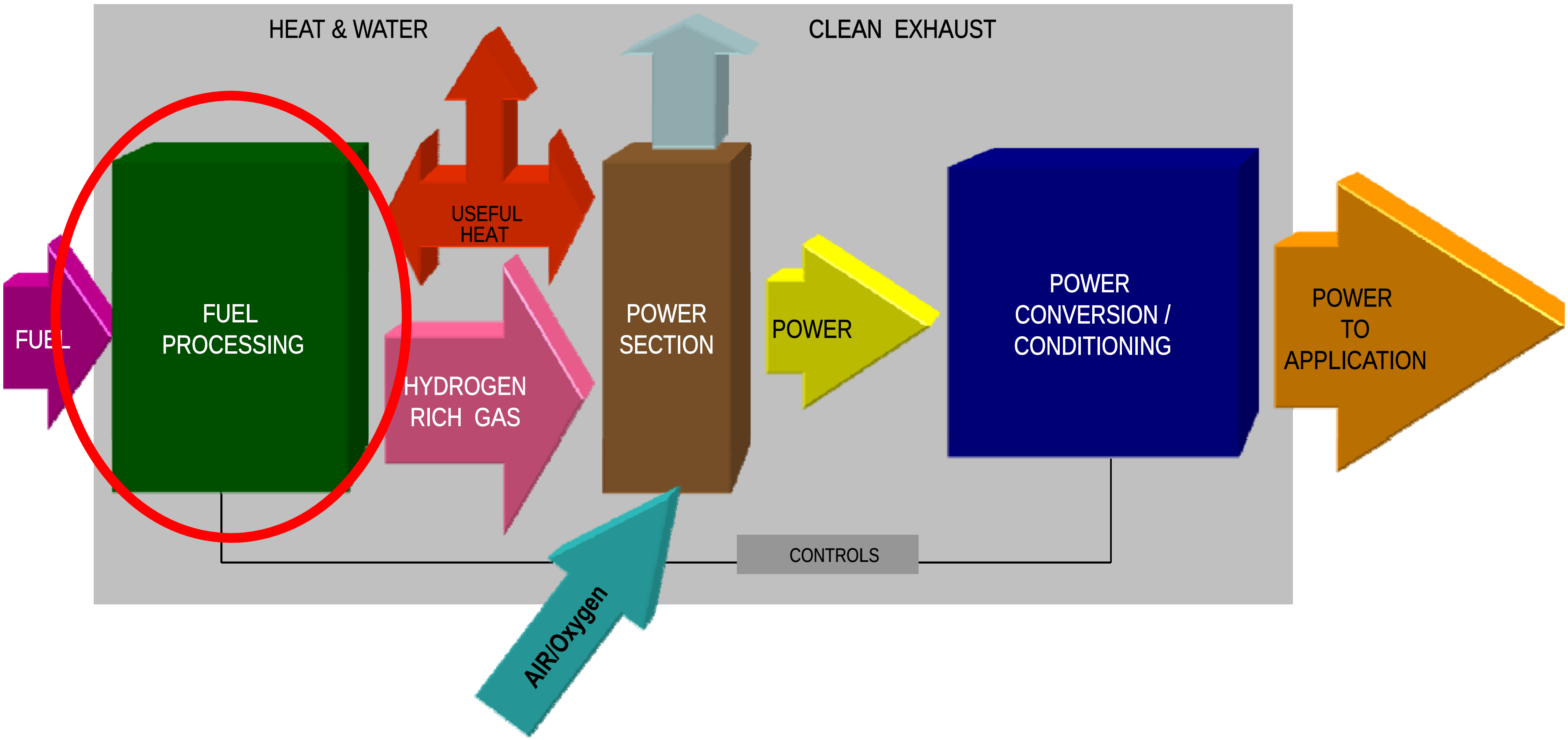
	Electrolyte	Cell Temp	Fuel
Proton Exchange Membrane (PEM)	Polymer Membrane (Solid)	70-90 C	**Pure Hydrogen**
Phosphoric Acid (PAFC)	Phosphoric Acid (Liquid)	120-180 C	**Hydrogen rich reformate**
High Temp PEM (HTPEM)	Phosphoric Acid Polymer (Solid)	120-180 C	**Hydrogen rich reformate**
Molten Carbonate (MCFC)	Potassium Lithium Carbonate (Liquid)	650 C	**Methane rich reformate**
Solid Oxide (SOFC) (Tubular, planar)	Solid Zirconium Oxide Ceramic (Solid)	700-900 C	**Hydrogen rich reformate**

Polarization Curve

Polarization or Operational Voltage, V, Curve



Fuel Cell System



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Fuel Reforming

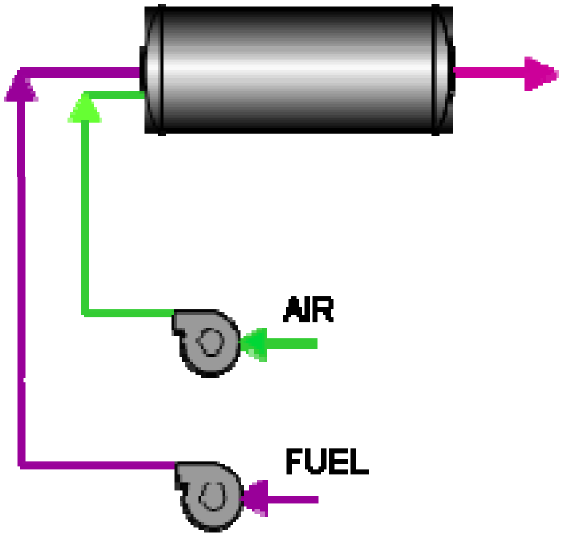
- **Fuel Reforming refers to processes that change the fuel from a liquid hydrocarbon to a gas-phase, fuel-rich, stream**
  - **Fuel Reforming is an endothermic process**
  - **Heat is required to sustain the reaction**

- **Several processes exist; most practical ones are:**
  - **Partial Oxidation Reforming (with air)**
  - **Steam Reforming (with steam)**
  - **Autothermal Reforming (with air and steam)**

- **Water Gas Shift is an equilibrium reaction, used to convert Carbon Monoxide and Steam into Carbon Dioxide and additional Hydrogen**

Partial Oxidation Reforming

Delphi POX Reformer



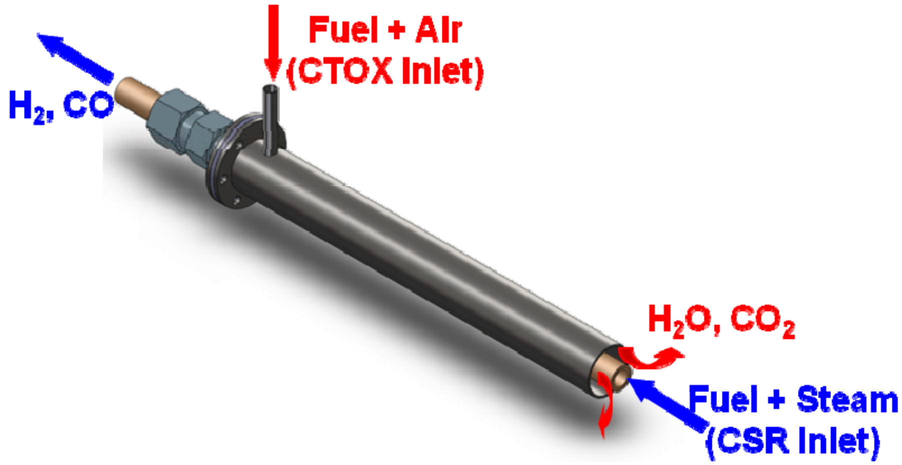
Output
CO
H_2
N_2

- Air reacts with fuel to form Carbon Monoxide and Hydrogen.
- Heat is supplied by oxidizing a portion of the fuel inside the reformer.

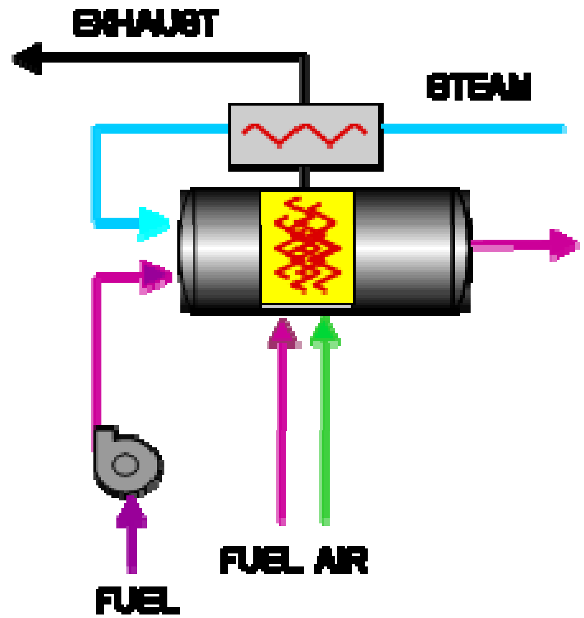
- **Pros:** Simple adiabatic reformer, high power density, high contaminant tolerance, no steam required
- **Cons:** Low efficiency, susceptible to soot formation, low pressure operation, nitrogen dilution of the product fuel

$$C_8H_{18} + 4\,(O_2 + 3.8\,N_2) \rightarrow 8\,CO + 9\,H_2 + 3.8*4\,N_2$$

Steam Reforming



PCI High Density Steam Reformer



Output
CO
H_2

- Steam reacts with fuel to form Carbon Monoxide and Hydrogen.
- Heat is supplied by burning fuel external to the reformer, through heat exchange

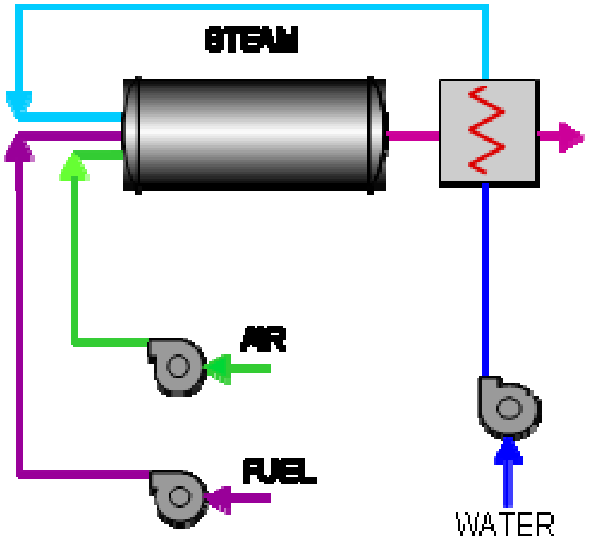
•**Pros:** High efficiency, capable of high pressure, air compression not required, fuel not diluted by nitrogen

•**Cons:** Higher complexity, low power density, scalability, low contaminant tolerance, high steam flow, high temperature heat exchange

$$C_8H_{18} + 8\ H_2O \rightarrow 8\ CO + 17\ H_2$$

Autothermal Reforming

PCI 250kW Autothermal Reformer



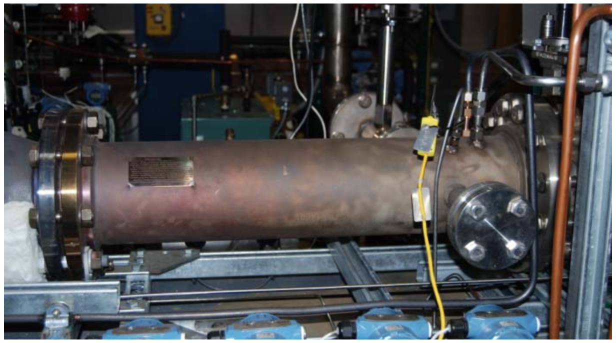
Output
CO
H_2
N_2

- Combines partial oxidation with steam reforming. Air and Steam react with fuel to form Carbon Monoxide and Hydrogen.
- Heat is supplied by oxidizing a portion of the fuel inside the reformer.

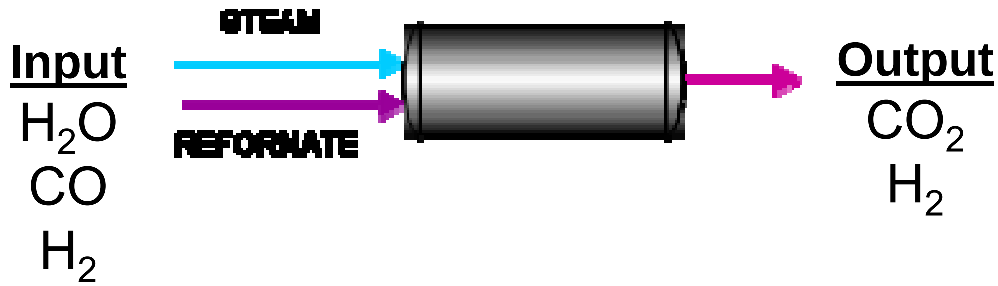
- **Pros:** Adiabatic operation, greater efficiency than POX, high power density, contaminant tolerance
- **Cons:** Higher complexity control, requires steam and air, nitrogen dilutes the fuel stream

$$C_8H_{18} + 3.6\ (O_2 + 3.8\ N_2) + 0.8\ H_2O \rightarrow 8\ CO + 9\ H_2 + 13.7\ N_2$$

Water Gas Shift Reaction



Water Gas Shift Reactor



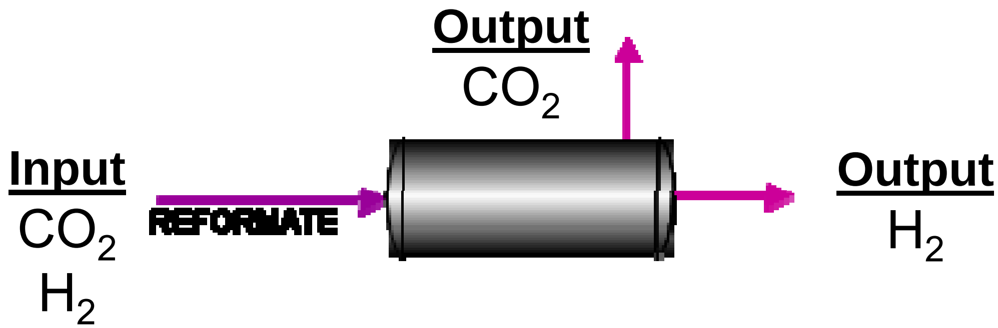
- Steam reacts with Carbon Dioxide to form Carbon Monoxide and increased Hydrogen. The reaction is slightly exothermic.
- Hydrogen yield is limited by temperature kinetics and equilibrium

- **Pros:** Simple adiabatic reactor, increases hydrogen yield from all types of reformers, hydrogen yield better at lower temperatures.
- **Cons:** Low power density, requires additional steam, low contaminant tolerance, poor kinetics at low temperature

$$CO + H_2O \rightarrow CO_2 + H_2$$

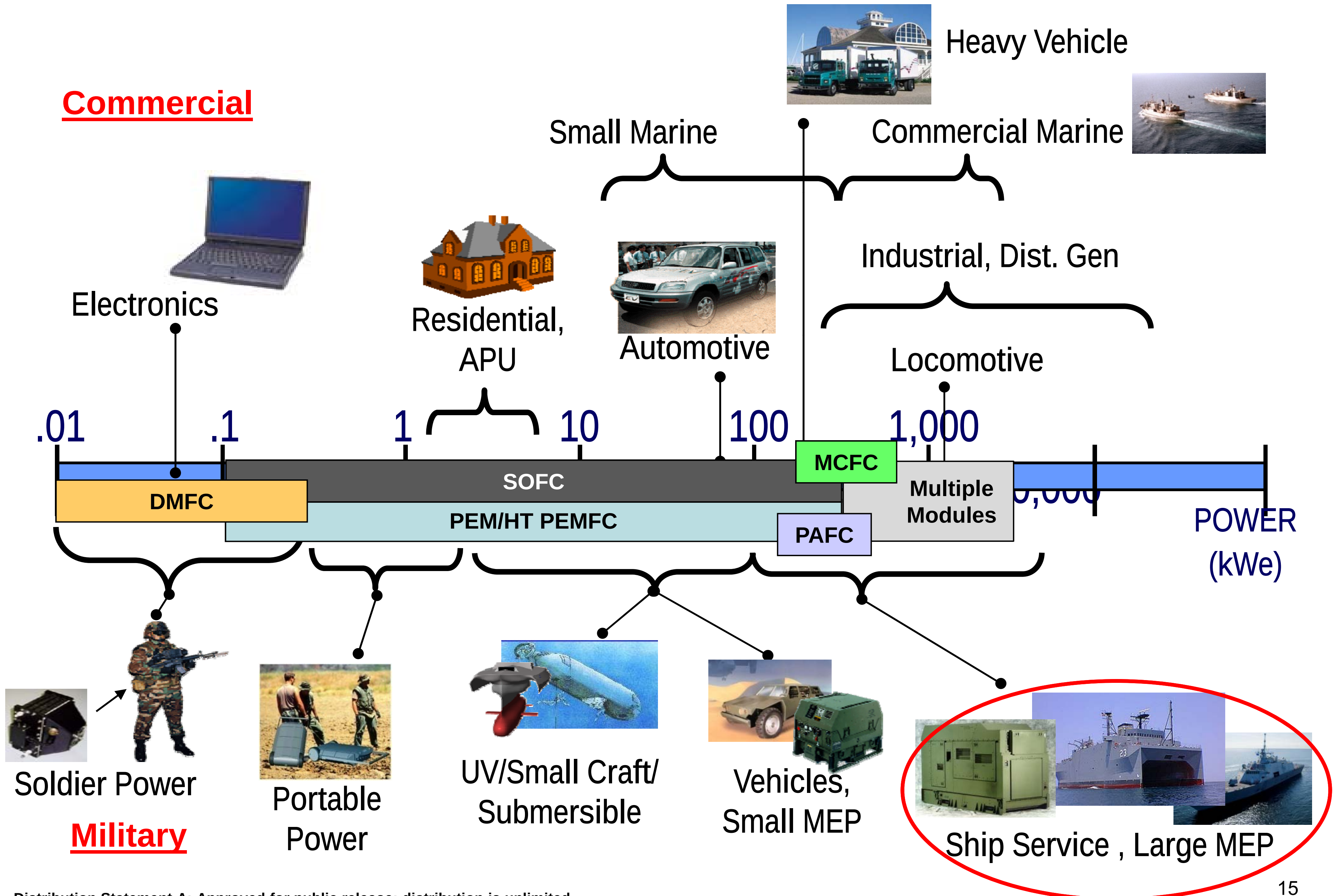
Membrane Separation

P&E Pd Membrane



- Palladium-alloy membranes can be used to separate pure Hydrogen from a Hydrogen-rich reformate stream
- Mechanism involves diffusion of hydrogen atoms through the solid membrane metal. Produces high-purity hydrogen
- Hydrogen yield is limited by the difference in hydrogen gas partial pressure across the membrane

- **Pros:** Simple reactor, no moving parts, makes ultra high purity hydrogen, low power requirements
- **Cons:** Expensive materials, high pressure reformers increase yield



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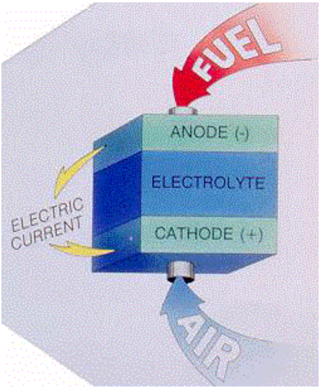
Fuel Cell Benefits



Reduced Acquisition & Life Cycle Costs

- Greater System Efficiencies
- Reduced Maintenance Costs
- Enables Spiral Development

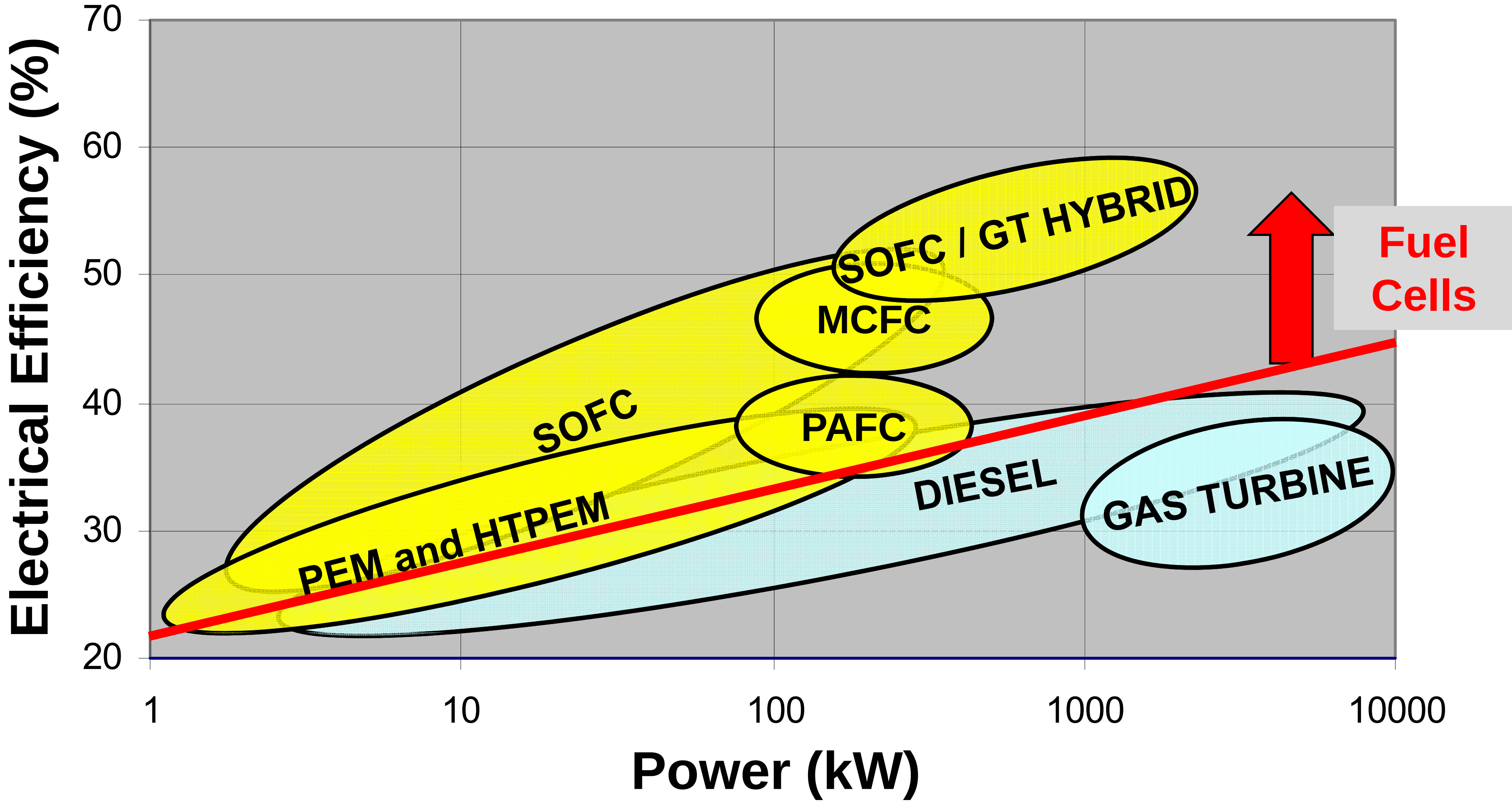
Enhanced Survivability

- Reduced IR Signature
- Reduced Acoustic Signature
- Distributed Power Generation

Design Flexibility

- Modular Approach to Ship Power
- Multi Platform Applicable

Power Generation Technologies



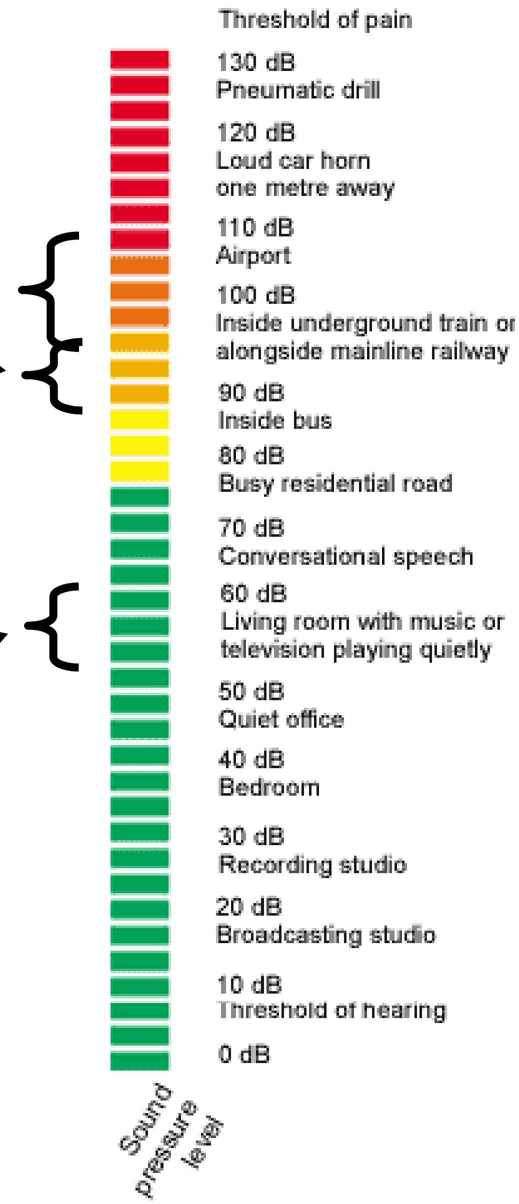
Even at It's Infancy, Fuel Cell System Efficiency Starts Where the Other Technologies End

Airborne Noise

Diesels

Gas Turbines

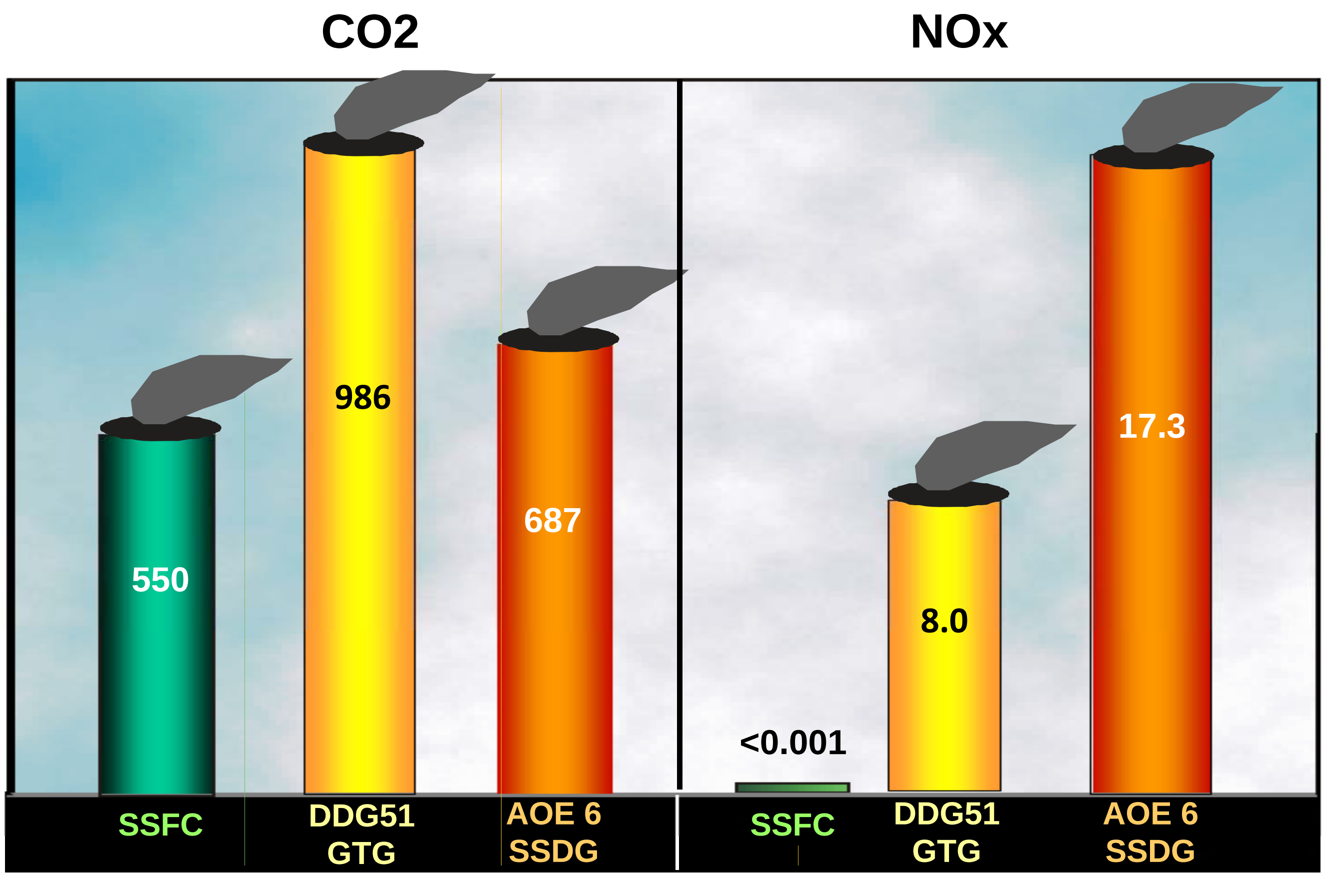
1st Generation SSFC Module
(w minimal isolation)



Airborne noise: Sound intensity level (dB) in engine room corrected to 10 feet distance

Emission Comparison

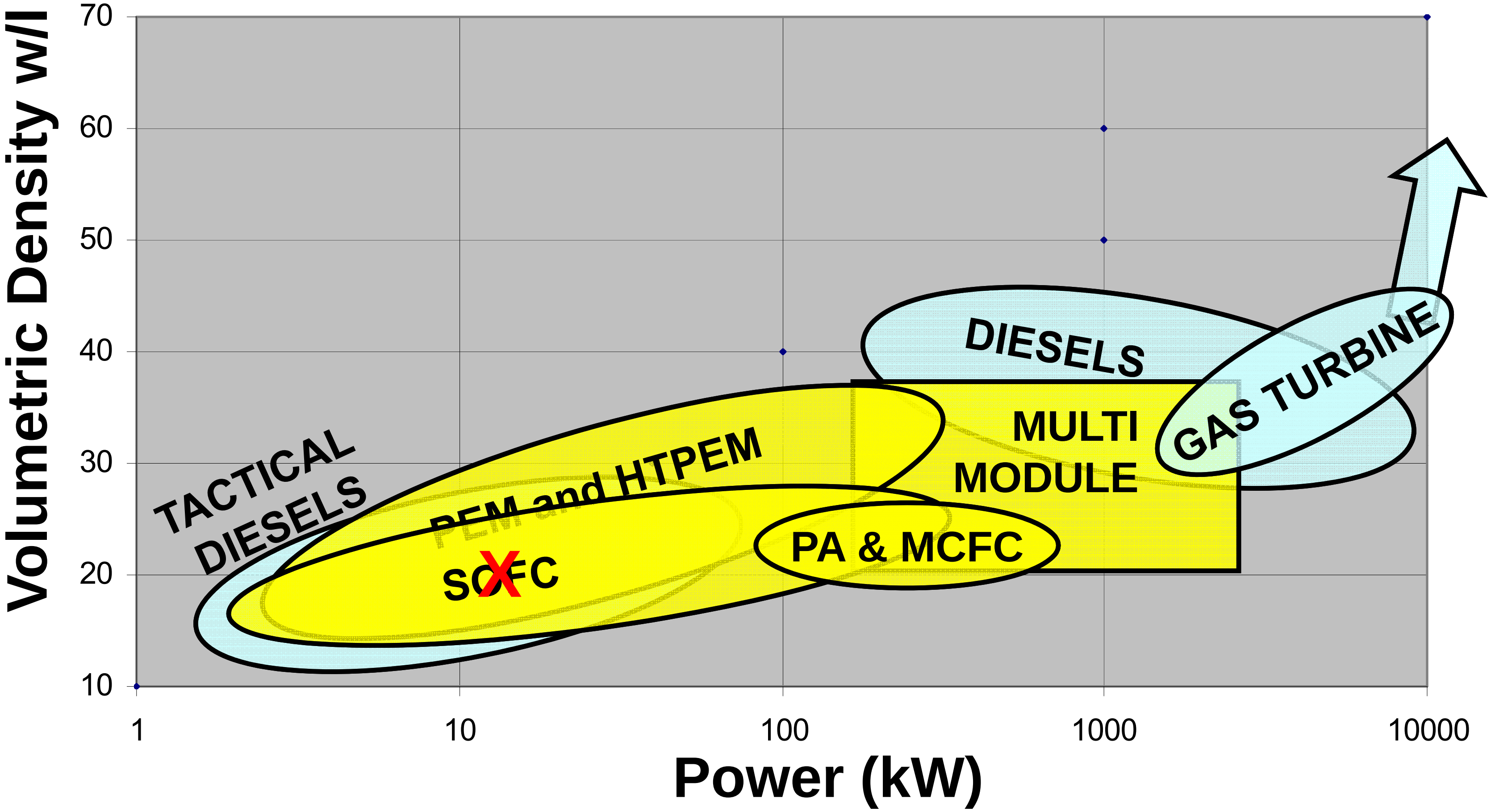
(gm/kw Hr @ 100% Power)



- **Fuel Cells have higher efficiency, with correspondingly lower CO2 emissions.**
- **Fuel cells are not a combustion process, so they have greatly reduced NOx, CO, hydrocarbon, and particulate emissions.**
- **Low SO2 output is a function of higher efficiency and low/no sulfur in fuel**

Power Generation Technologies

Volumetric Density Comparison



Fuel Cell System Volumetric Density Dependent on Overall System Design