Balance of Fuel Cell Power Plant (BOP)

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Balance of Fuel Cell Power Plant

In addition to stack, there are other components:

- Fuel processing system that requires a fuel reformer, chemical reactors, heat exchangers, fans/blowers, burner, etc.
- Air management system that requires a compressor, turbine, heat exchangers, fan, motor, water tank, etc.
- Power conditioning system that has inverter, converter, batteries, motor, etc.

Gas Supply Units

•Air and fuel gas have to be supplied to fuel cell systems for cooling and to provide oxygen to the cathode.

•Pumps, fans, compressors, and blowers have to be used.

•Energy of exhaust gases from a fuel cell can sometimes be recovered using a turbine, making use of what would otherwise go to waste.

•The technology for such equipments is very mature developed for other applications.

•The needs of fuel cells vary widely, based on their sizes and applications, and so we need to look at a wide range of ‘gas supply devices’.

•***Compressors*** - their different types and performance, such as the temperature rise of a gas as it is compressed and the power needed to run an air compressor.

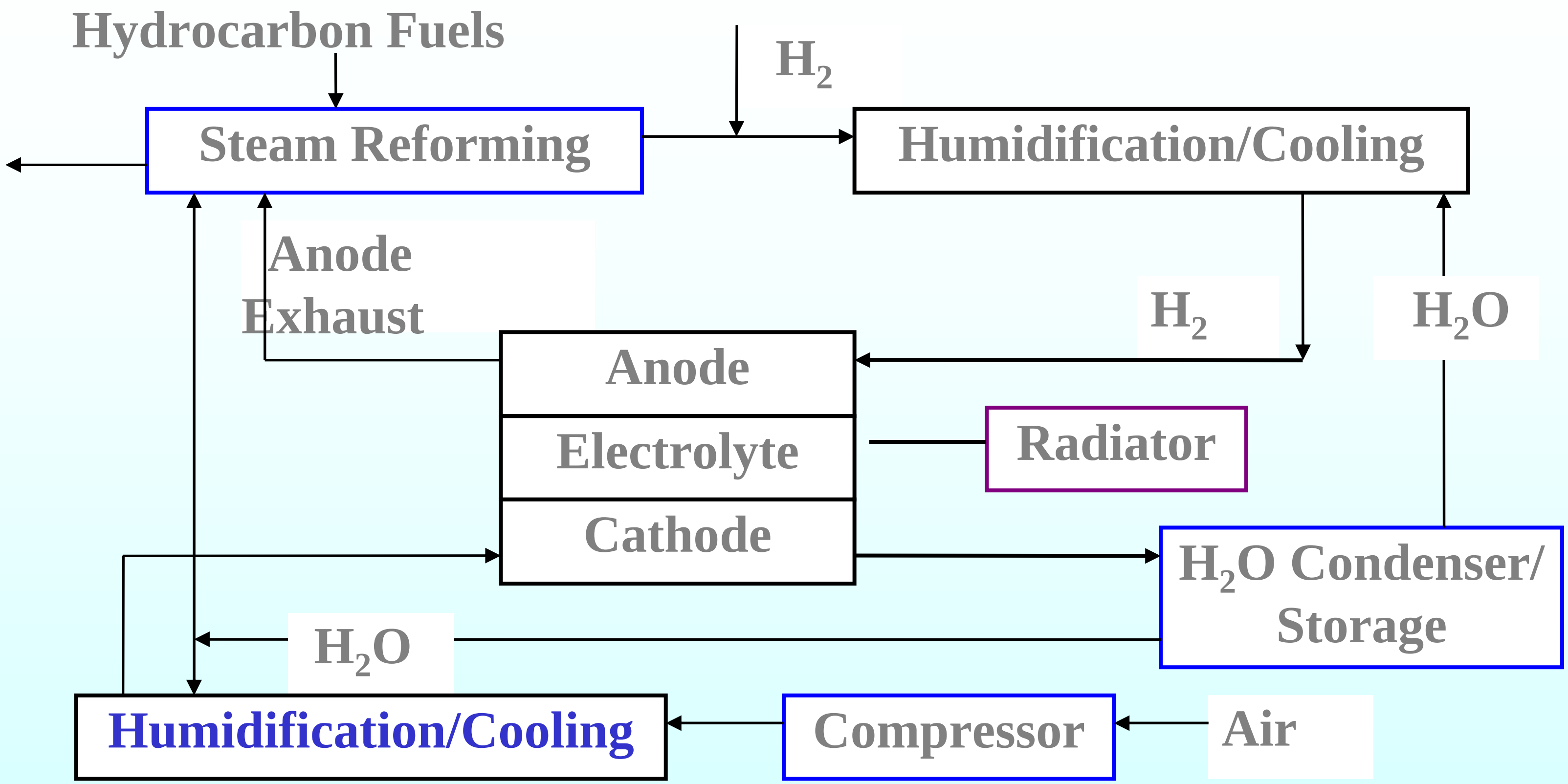
•***Turbines*** - to harness the energy of exhaust gases, the working conditions and performance.

•***Ejectors*** - a very simple type of pump that can often be used to circulate hydrogen gas if it comes from a high pressure tank, or for recycling anode gases.

•***Fans and blowers*** - for cooling and for cathode gas supply in small fuel cells.

•***Membrane or diaphragm pumps*** - to pump reactant air and hydrogen through small (200W) to medium (3kW) PEMFCs.

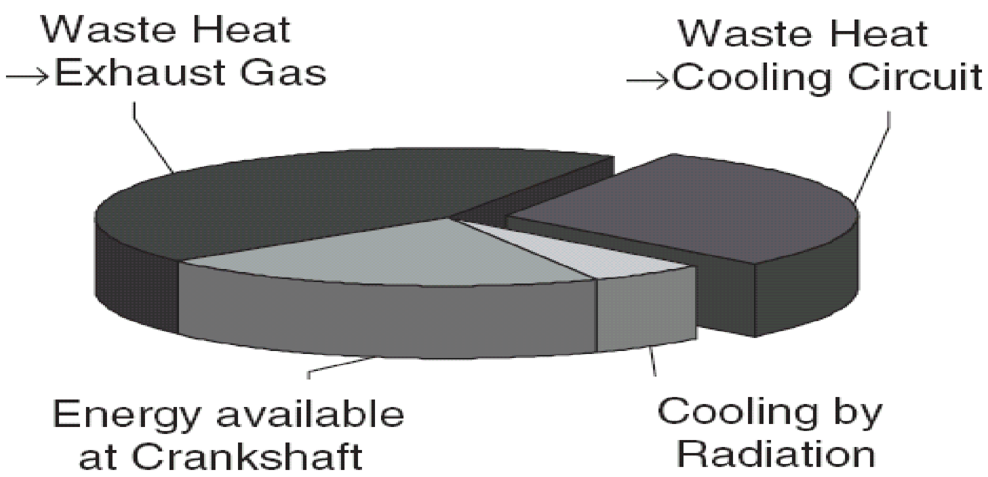
Heat Exchangers in PEMFC Systems



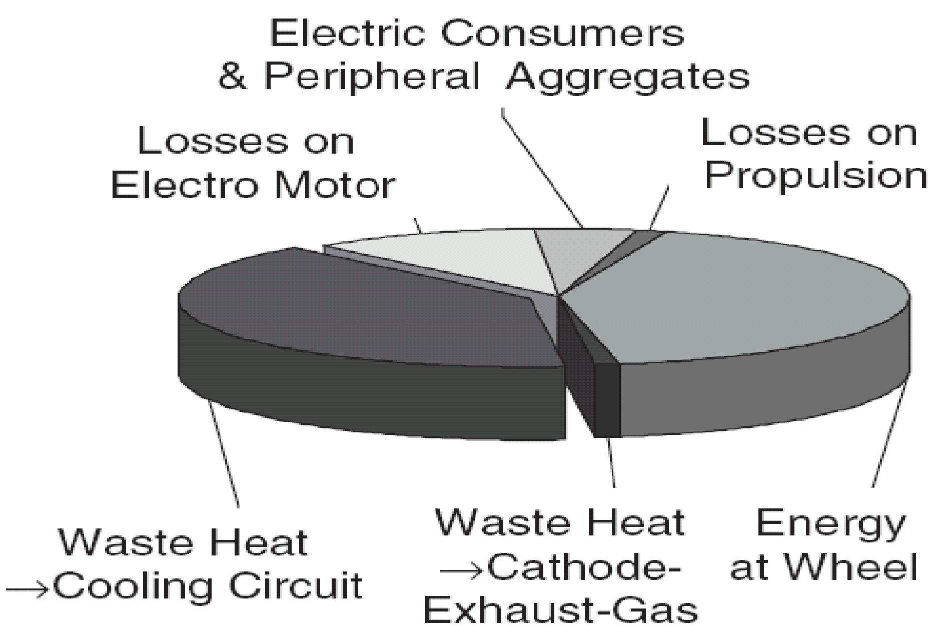
- Cooling of the compressed air
- Cooling of the stack
- Fuel reforming

Operating Temperature@80ºC

Energy Distribution: Vehicle with Otto-Cycle Engine



Energy Distribution: Vehicle with H2-Fuelcell Drive



	Power / radiator / exhaust
IC:	33/**33**/33%;
PEMFC:	40/**50**/10%

PEMFC: Larger heat load to radiator

PEMFC: High Temperature Required

- For H_2-fueled PEMFCs, 110-120 ^oC best fitted for heat rejection, a bit high tolerance to CO (50 ppm) as a gain;

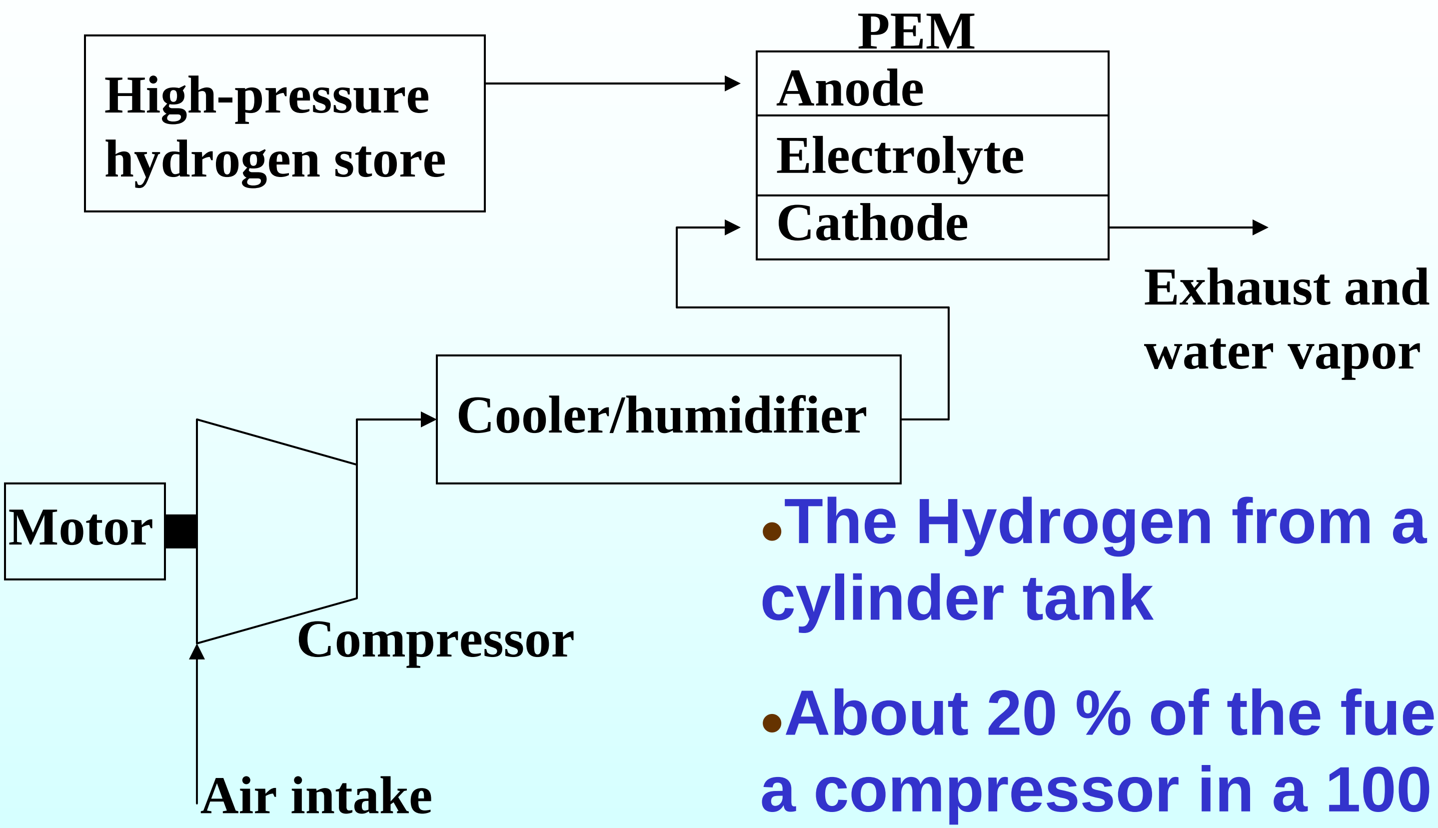
- For hydrocarbon-based H_2-reformate, 140-160^oC shows better CO-tolerance (0.1-0.5%), then PROX elimination;

- At 160 ^oC, oxygen reduction activity improved, but not significant impacts due to a loss in equilibrium voltage;

- Carbon-support material stability becoming problemtic if higher than 160^oC;

120^oC suggested for high-*T* membrane R&D.

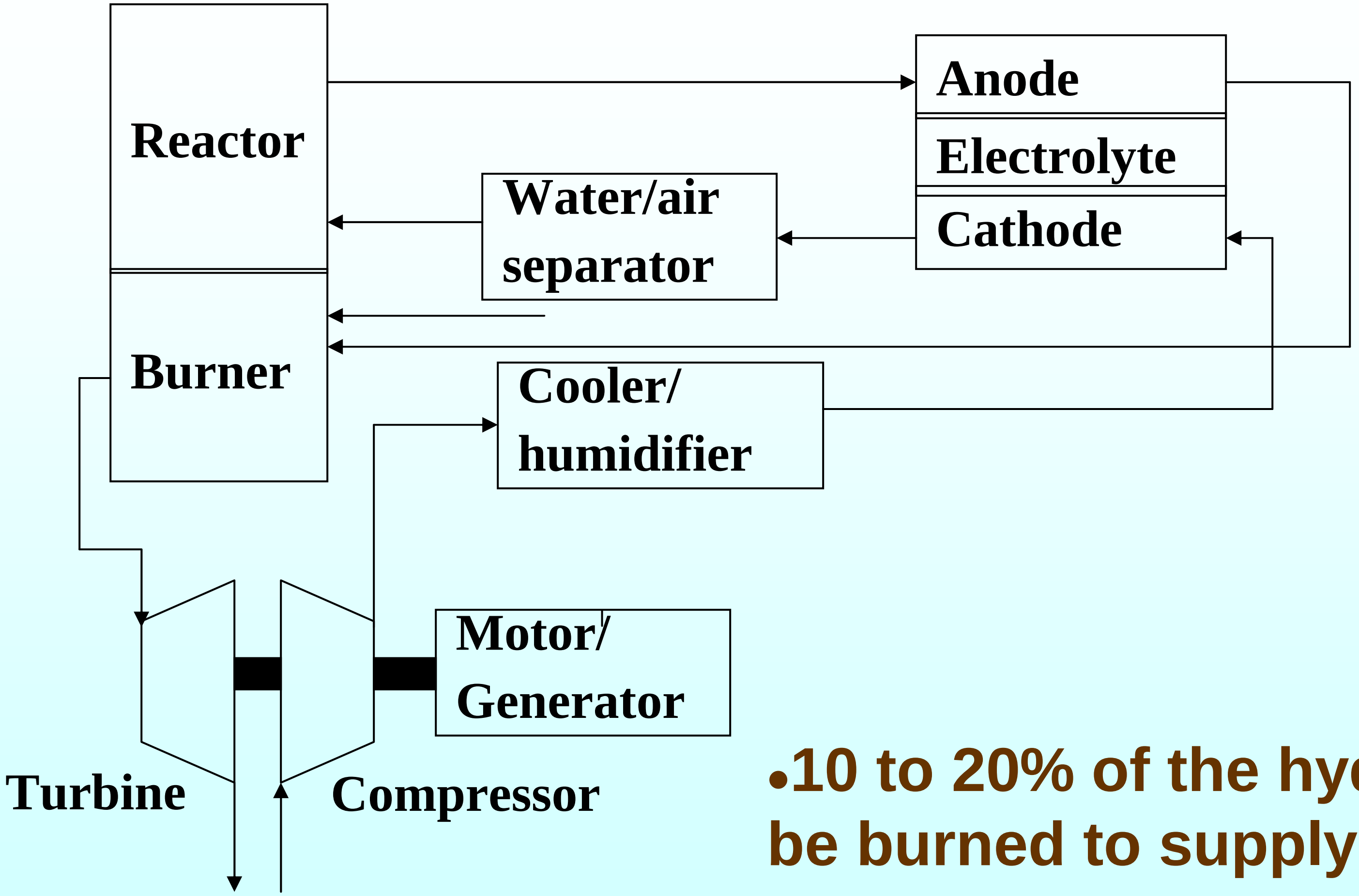
Cooling of Compressed Air



- The Hydrogen from a high-pressure cylinder tank
- About 20 % of the fuel cell power for a compressor in a 100 *kW* system

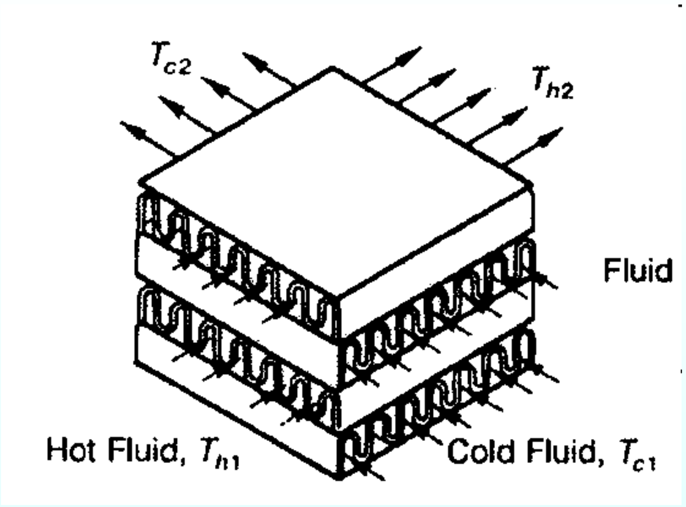
Air supply to cathode at 2-3 *atm*; EX: 20^{o}*C* air compressed from 1 to 2 *atm*. Temperature will be 175^{o}*C;*

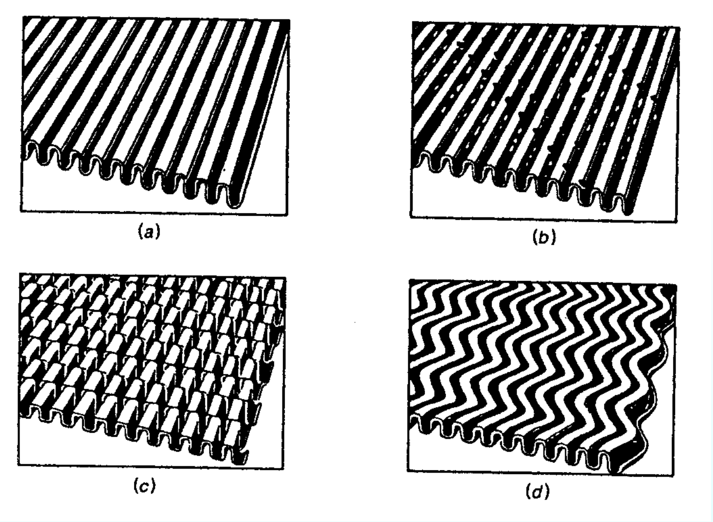
Fuel Reforming



- 10 to 20% of the hydrogen will be burned to supply heat for the reactor

Example:Plate-Fin Heat Exchanger





- **Type of Fluid: Gas-to-gas**
- **Applications: Trucks, cars, airplane**

- **Mass and Volume reduction- Compact Design**

Energy Recovery, Process Industry, Air-Conditioning System, *etc*.

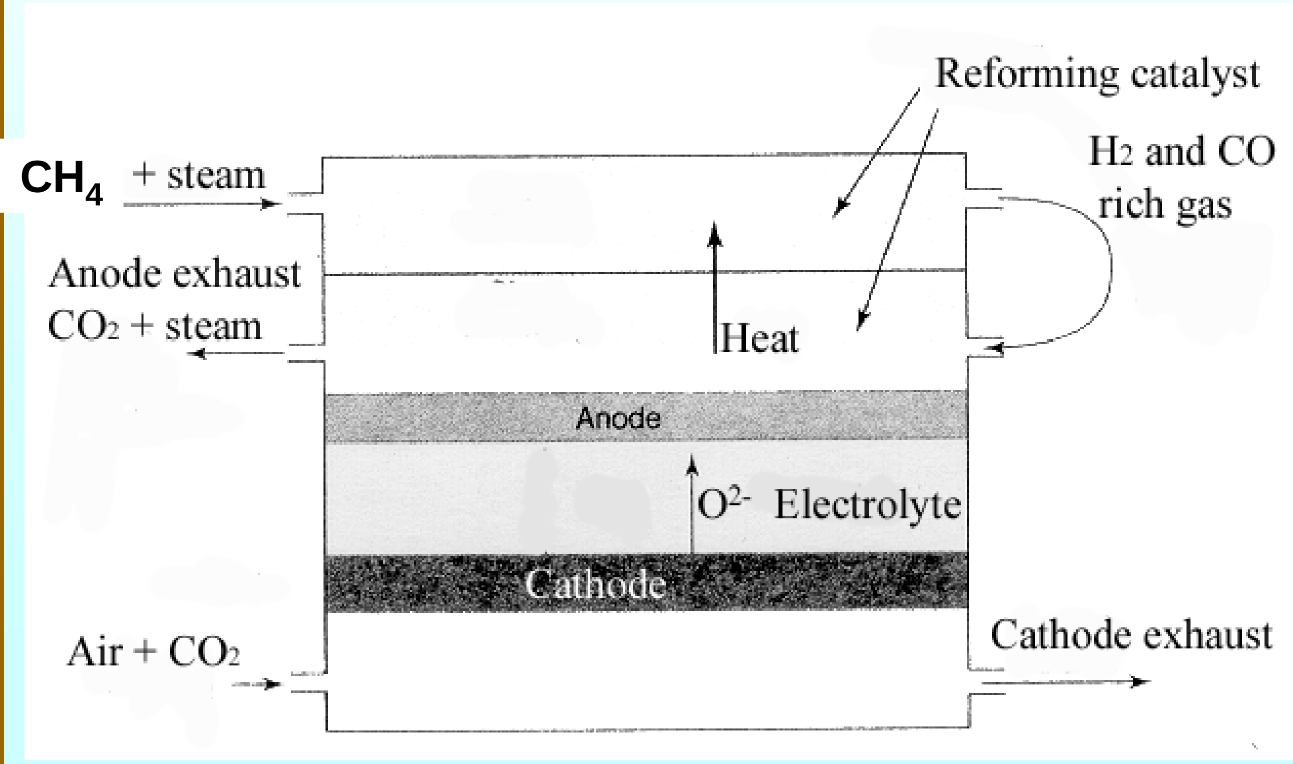
SOFC Heat Balance

Internal reforming:

$$CH_4 + H_2O \rightarrow CO + 3H_2 \quad \boxed{(\Delta H = 206 kJ/mol)}$$

Fuel cell:

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad \boxed{(\Delta H = -242 kJ/mol)}$$

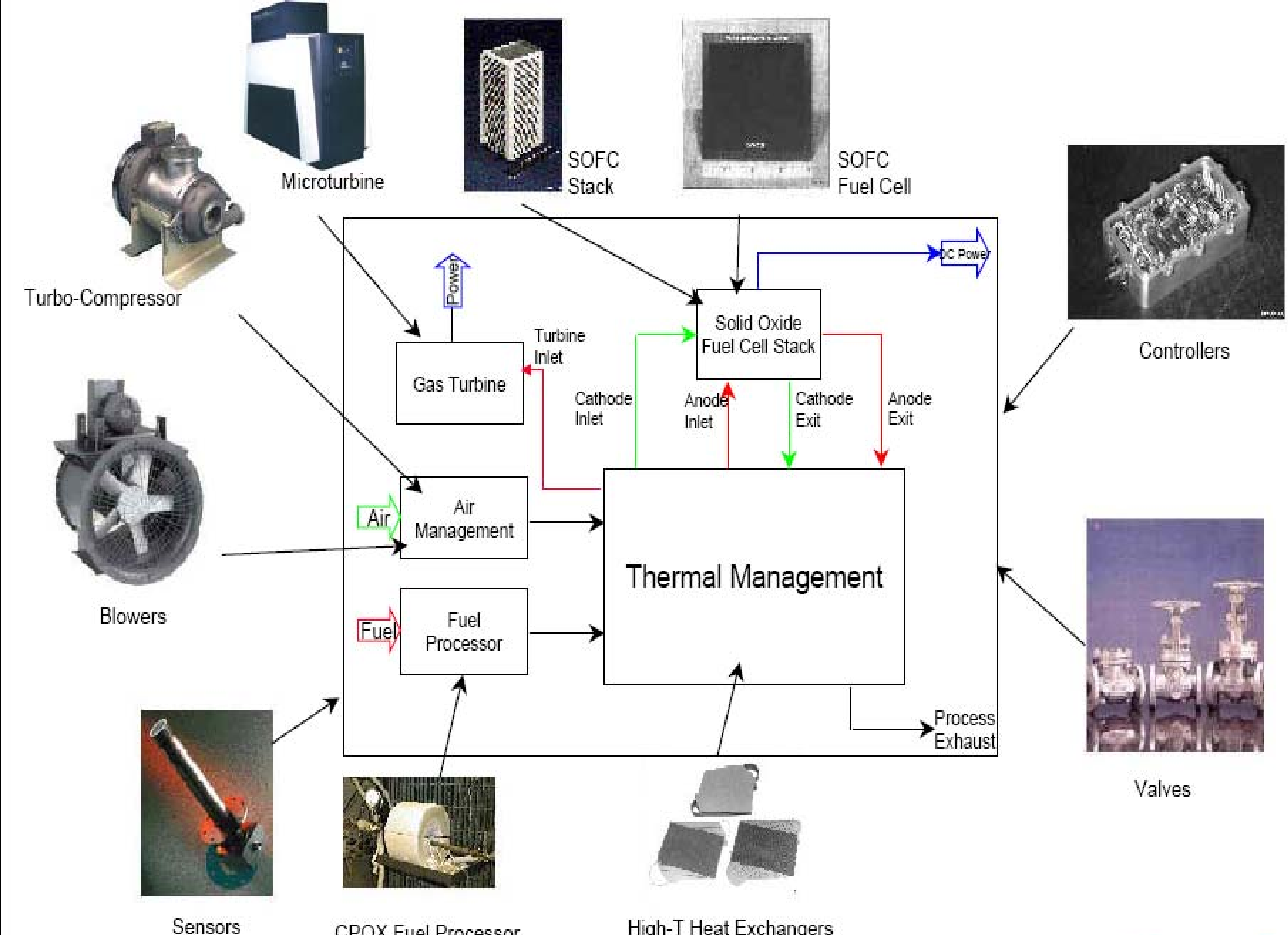


To preheat the anode and cathode streams

To Recover heat from the exhaust streams

General Demands for Heat Exchangers

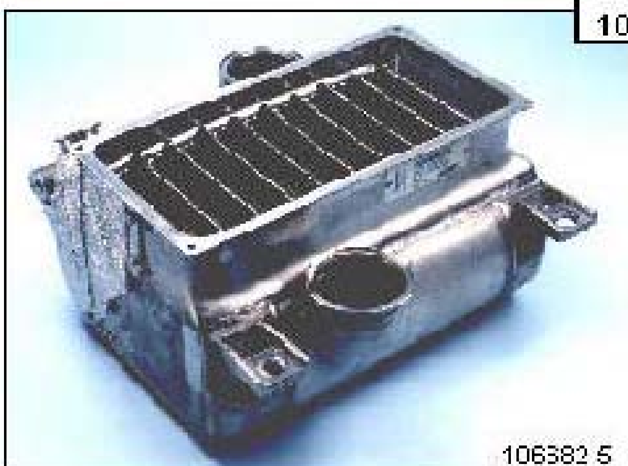
- **Compactness**
- **Low pressure drop**
- **Elimination of the hot spot (SOFC)**
- **High Effectiveness (PEMFC)**


Microturbine
SOFC Stack
SOFC Fuel Cell
Turbo-Compressor
Controllers
Power
DC Power
Solid Oxide Fuel Cell Stack
Gas Turbine
Turbine Inlet
Cathode Inlet
Anode Inlet
Cathode Exit
Anode Exit
Air
Air Management
Thermal Management
Fuel
Fuel Processor
Process Exhaust
Blowers
Valves
Sensors
CPOX Fuel Processor
High-T Heat Exchangers

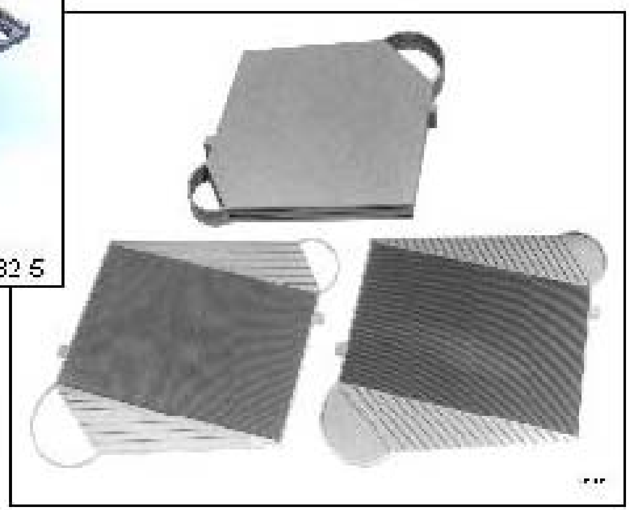
Heat Transfer / Thermal Management

Commercial Recuperators

757-300 RR Precooler



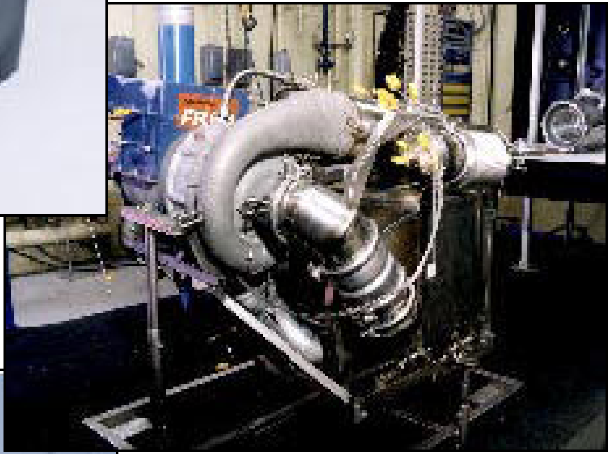
F22 Primary Heat Exchanger



Si_3N_4 Ceramic Heat Exchanger

Turbo-machinery

RAH-66 Fan



50 kW Turbogenerator

Trident Gas Hydraulic Assembly Turbopump

PEMFC Turbocompressor

Controls

- Model-base control and optimization algorithms including Fuel Cell Dynamics
- Component Library
- Rapid prototyping
- Load following control

System for PEMFC

- Sensors
- Relative humidity
- Mass air flow
- Hydrogen
- Carbon monoxide

Hydrogen Sensor

System Development Approach

- **Low-cost fabrication processes and materials along with compact, lightweight component designs**
  - **SOFC:** Tape calendering fabrication process, stack designs incorporating thin-electrolyte cells and thin-foil metallic interconnects
  - **Fuel processor:** Catalytic partial oxidation (CPOX)
- **Component designs based on system requirements and other design methodologies (e.g., design-for manufacturing, design-to-cost)**
- **Focus on lessons learned from small (50W to several kW) system operation**

PEMFC Systems

•Many parameters affect PEMFC performance, such as operating temperature and pressure, air stoichiometry, reactant humidity, water retaining properties of the gas diffusion and membrane.

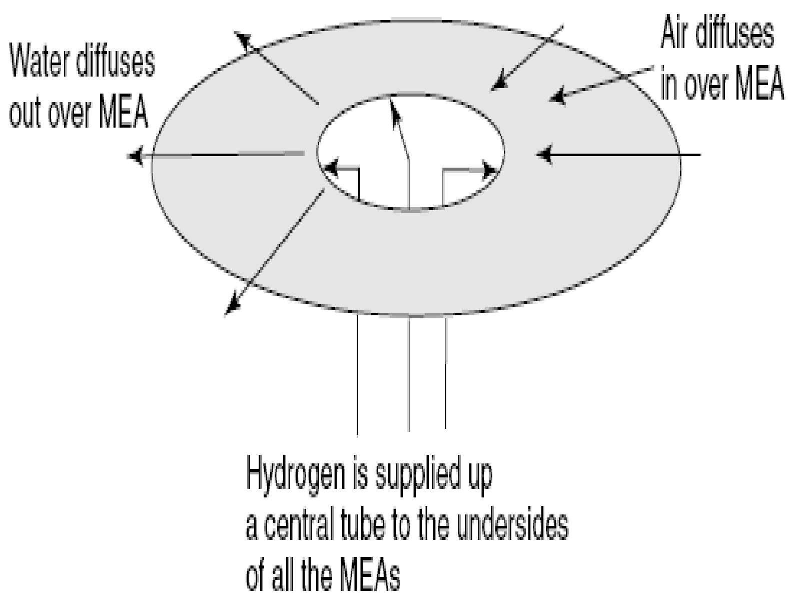
•Three typical PEM fuel cell systems are outlined here to illustrate the BOP issues:

- ***Small 12-W system***
- ***Medium 2-kW system***
- ***205-kW fuel cell engine***

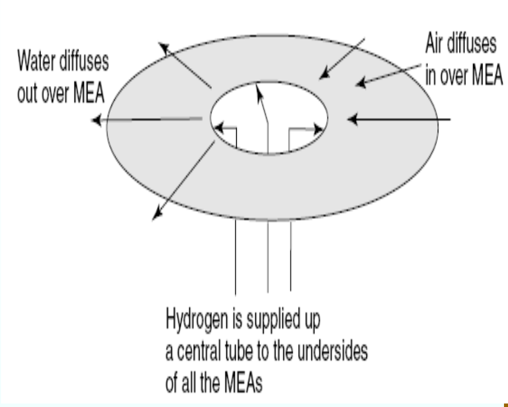
Small 12-W PEMFC system

•Designed for use in remote conditions, such as when camping, in boats, for military applications and for remote communications

•No ventilation fans or other moving parts. The stack is the small cylinder in the middle of the picture

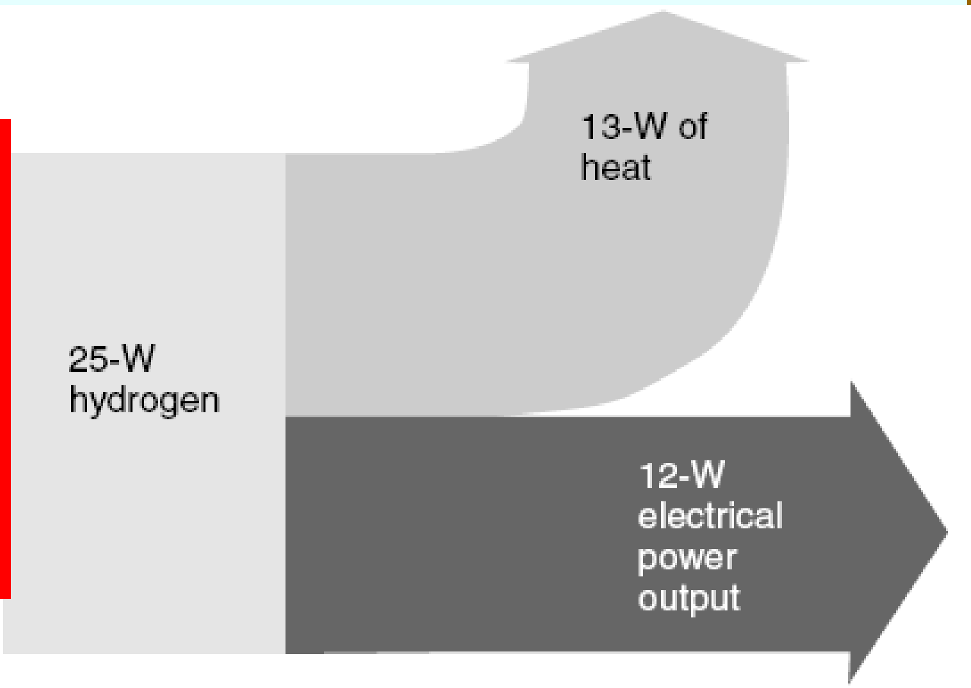


- Hydrogen feed is to the anodes on the underside of each MEA. The top of each MEA has a thick gas diffusion layer that allows oxygen to diffuse in and water to diffuse out to the edge where it evaporates.



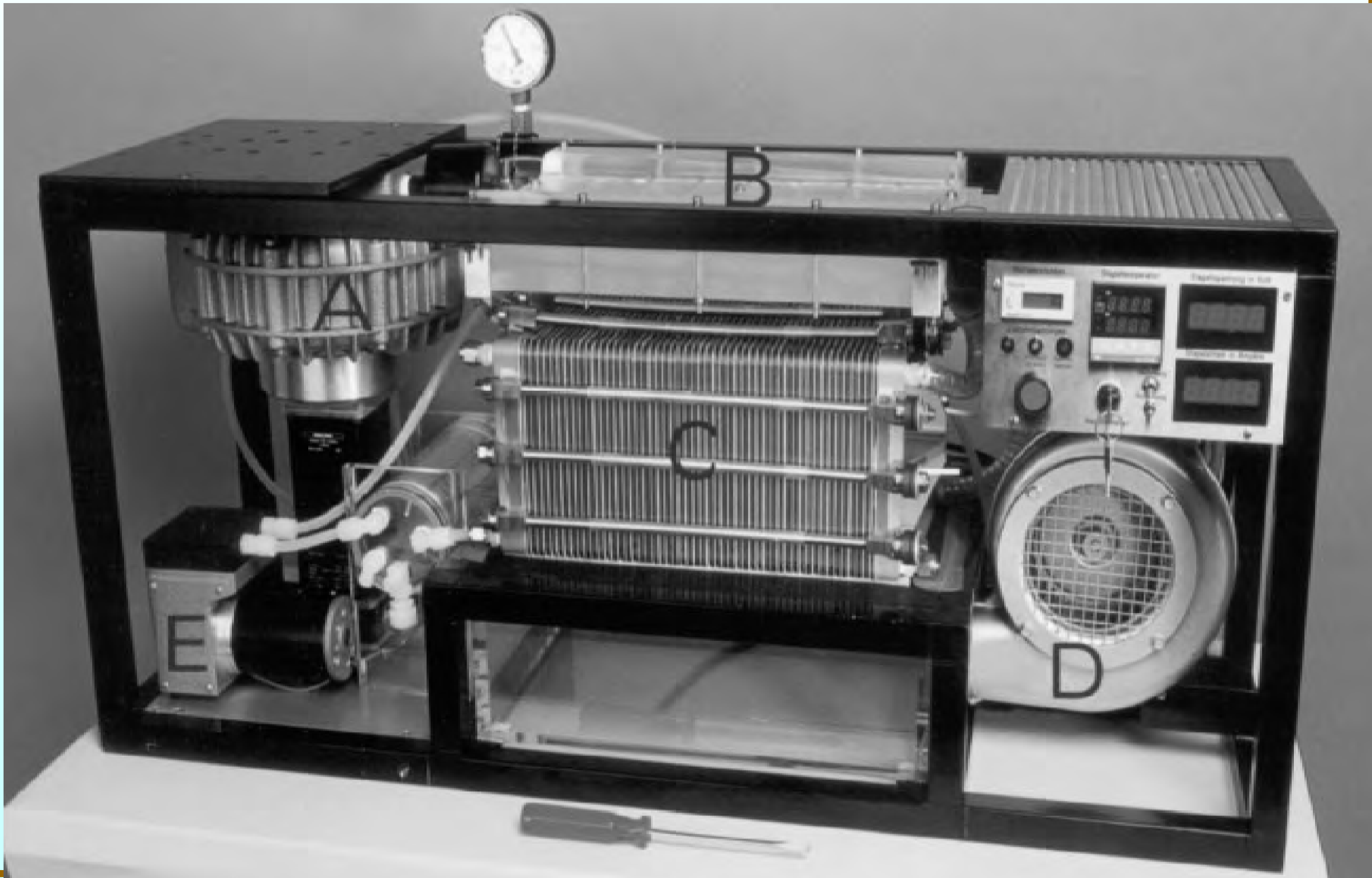
- The entire periphery is exposed to the air, so there is sufficient air circulation without any need for fans or blowers.

The supply is 25W of hydrogen power, and output is 12W of electrical power. The losses are simply 13W of heat – there are no other losses, around 48% efficiency at the rated power.

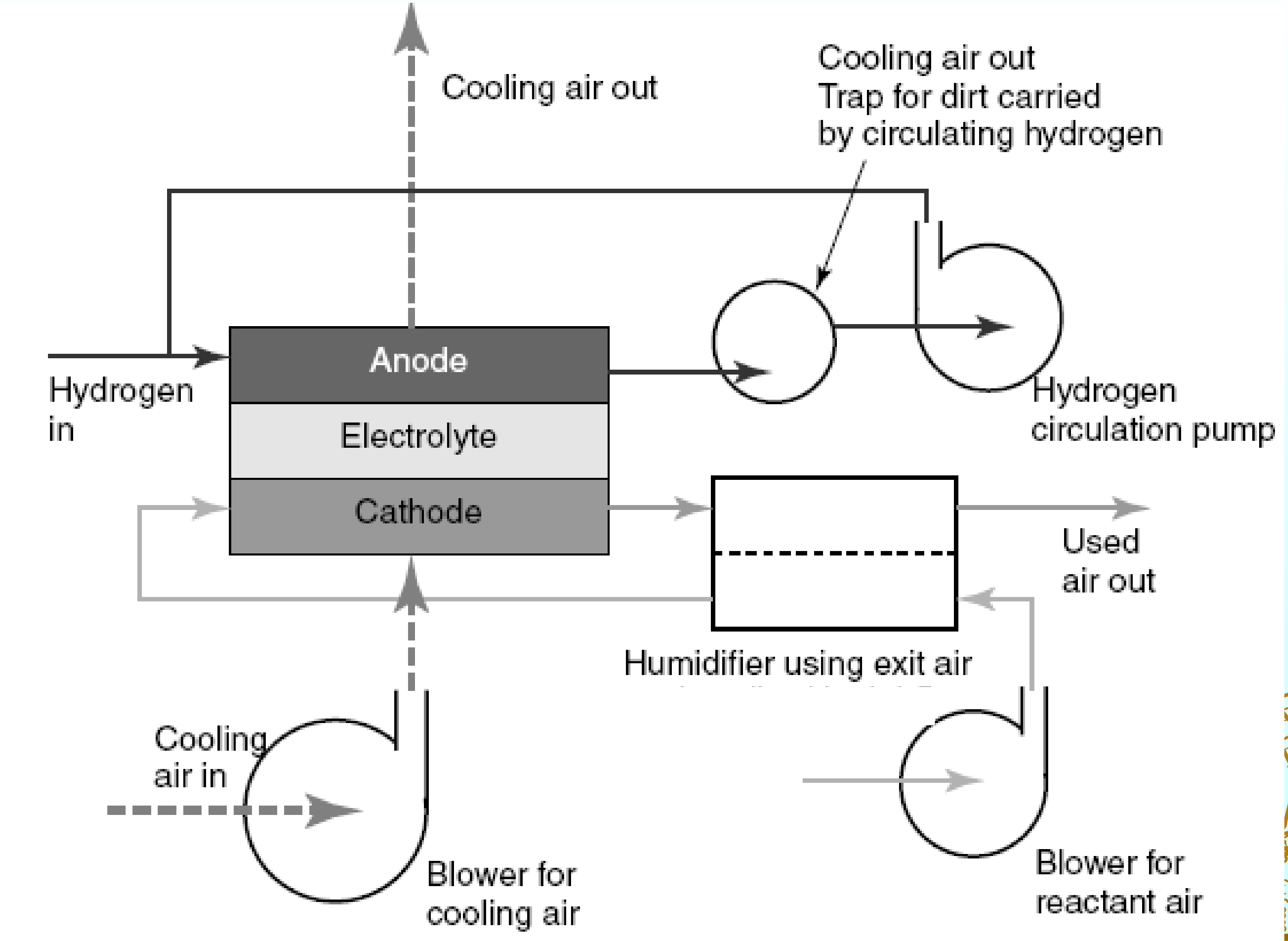


Medium 2-kW PEMFC System

The reactant air is pumped by pump **A**, through the humidifier **B**, to the stack **C**. Coolant air is blown up through the stack by blower **D**. The hydrogen fuel is circulated using the membrane pump **E**.



There is a separate air cooling, and the reactant air is humidified using the exit air as illustrated. The hydrogen gas is circulated using a pump.

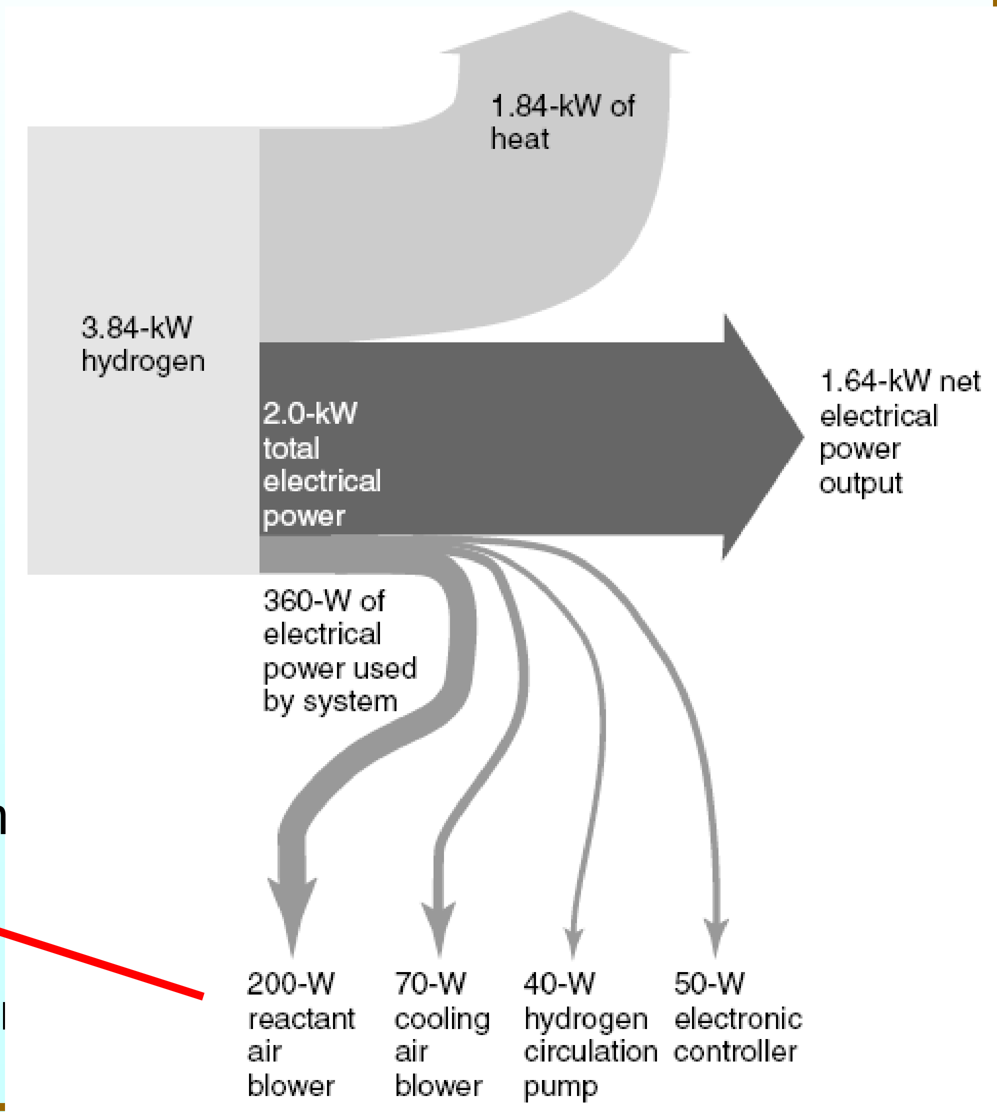


The output power is 1.64 kW, heat loss 1.8kW together with 360W of electrical loss (to drive the three blowers and pumps and to electronic controller. The net output efficiency is 42.5% (LHV)

•The reactant airflow is less than the cooling airflow, but against a pressure of about 0.1 bar above the atmospheric pressure, due to the long length and narrowness of the reactant air path through the stack and humidifier, i.e., **200W** VS. **70W** for the cooling air.

•The hydrogen gas flow rate is much less and the pump only requires **50W**.

•All these pumps need controlling, with extra **40 W**.

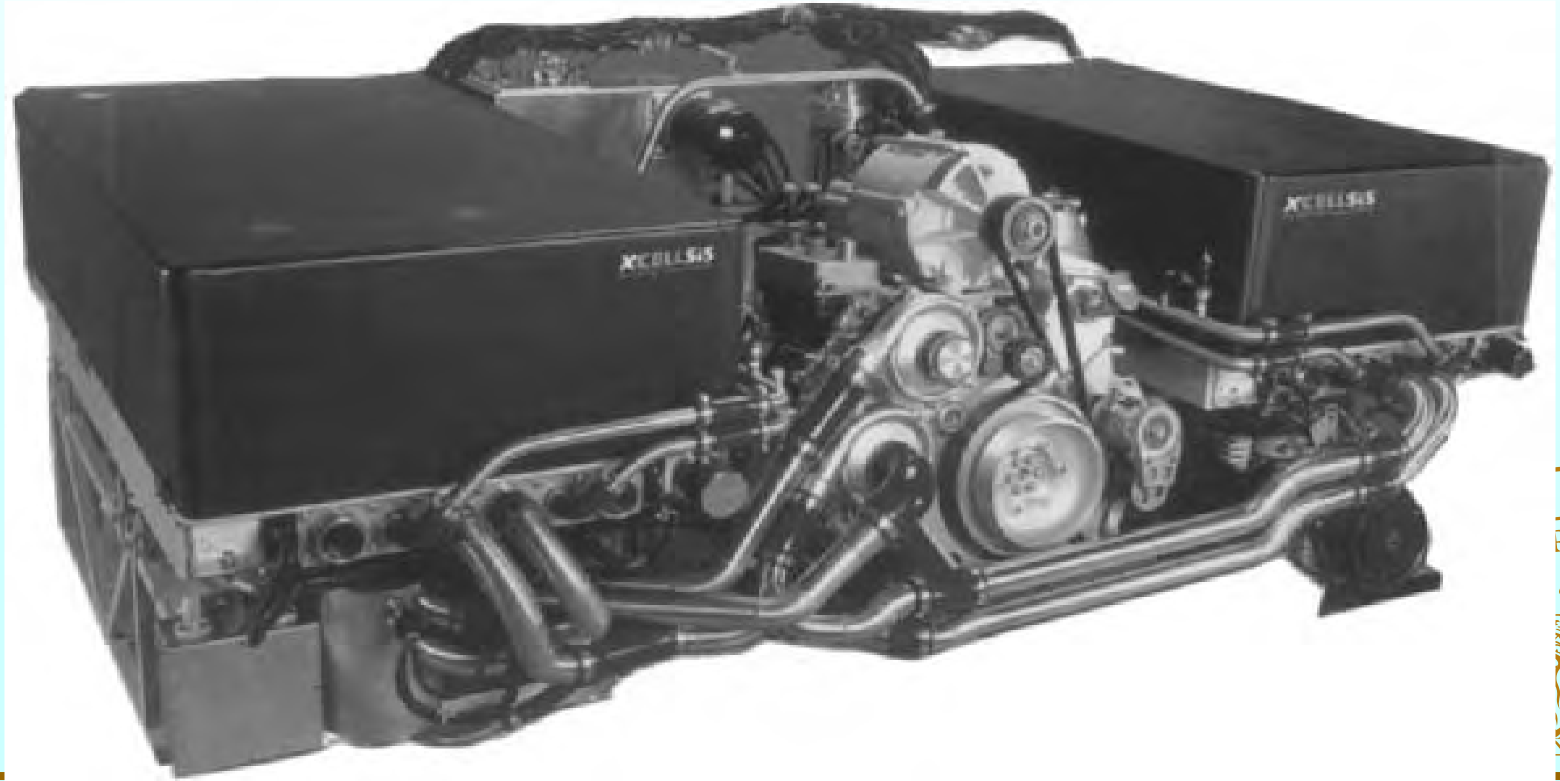


205-kW PEMFC System

•Two stacks (750 cells in series for each) developed by Ballard for bus application, water and glycol cooling, P=3 bar.

•The net maximum output power is 205 VS. total 260 kW, with 55kW consumed by pumps and compressors in the system.

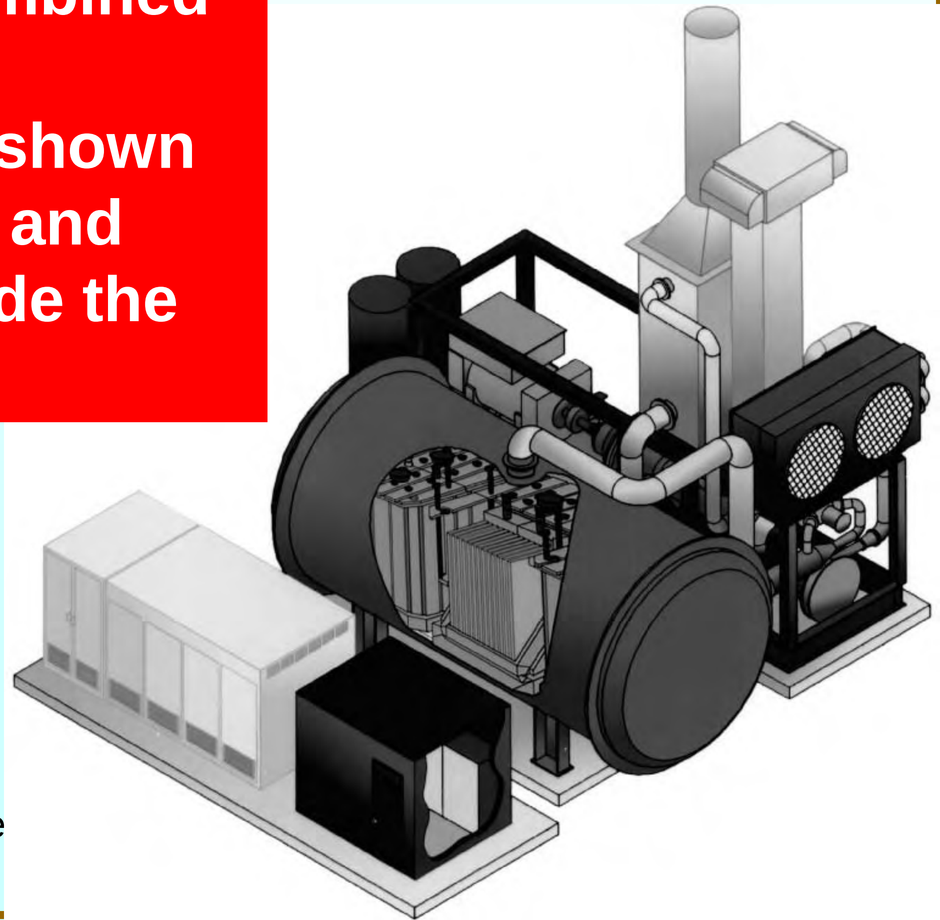
•The unit is about 2.5m wide, 1.6m deep, and 1.33m high.



SOFC Combined System

•SOFC could be combined with a gas turbine or/and steam turbine in a combined cycle.

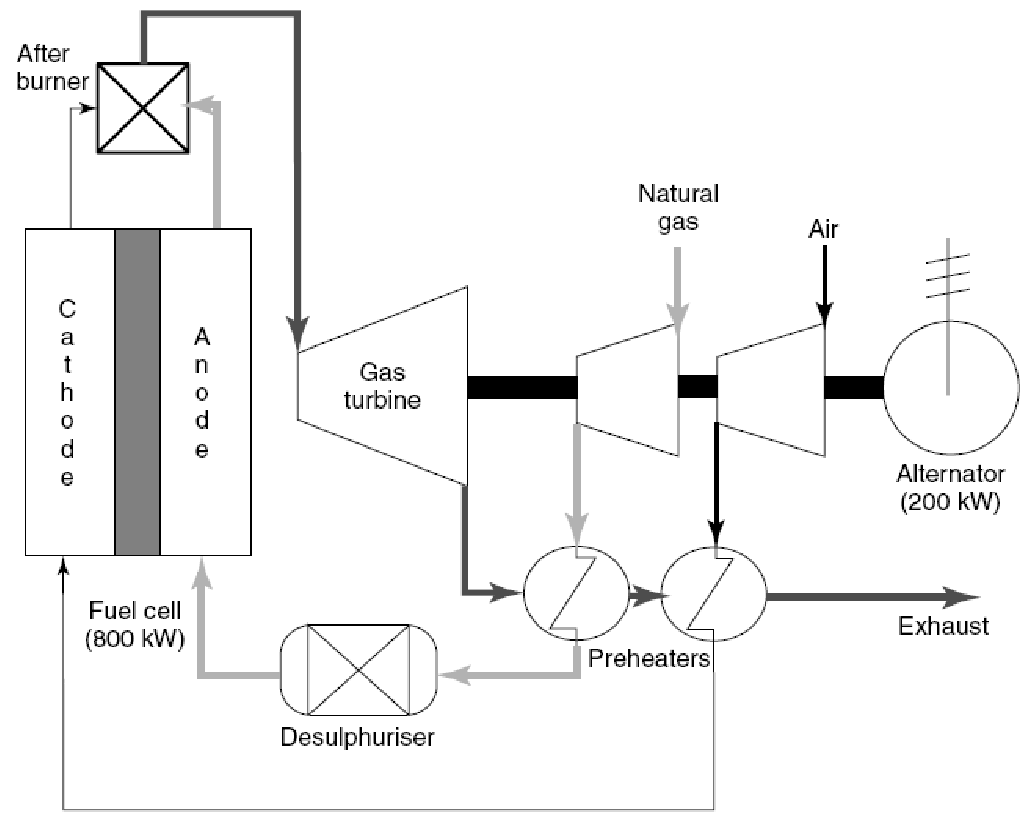
A 300-kW class SOFC/GT combined cycle plant built by Siemens Westinghouse. The SOFC is shown in the middle of the diagram, and operates at about 10 bar inside the cylindrical pressure vessel.



	300 kW	1 MW
Electrical net AC efficiency	>55%	>55%, approaching 60%
SOFC AC power	244 kW	805 kW
Gas turbine AC power	65 kW	220 kW
Total net AC power	300 kW	1014 kW
Pressure ratio of turbine compressor	3–4	3–4
Emissions: CO_2	$<350\ \mathrm{kg\ MWh^{-1}}$	$<350\ \mathrm{kg\ MWh^{-1}}$
Nox	<0.5 ppm	<0.5 ppm
CO	0 ppm	0 ppm
Sox	0 ppm	0 ppm
Particulates	0 ppm	0 ppm
Ground noise level (5 m from housing)	<75 dBa	<75 dBa

Overall performance of Siemens Westinghouse 300-kW and 1-MW class hybrid systems

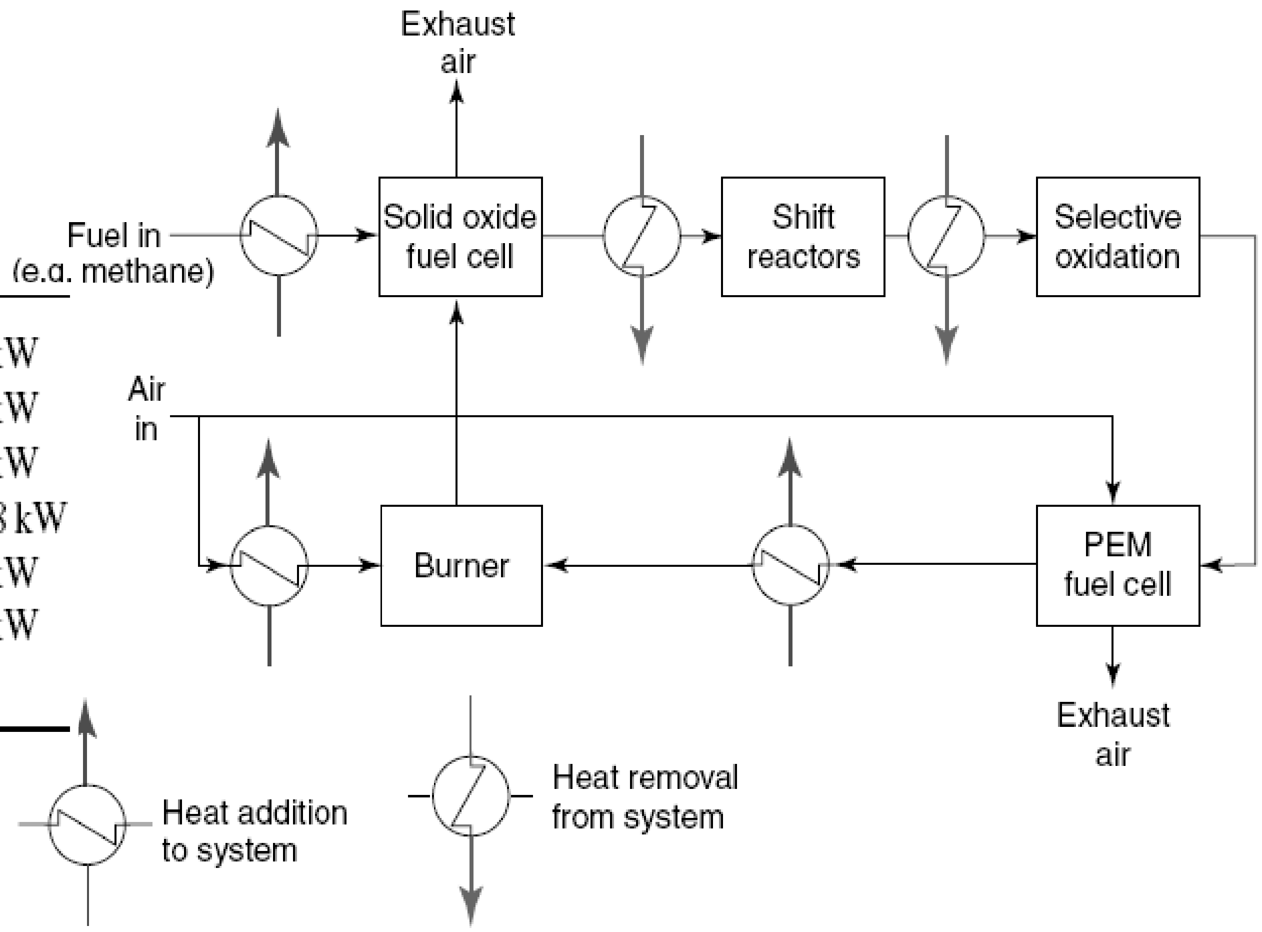
Fuel



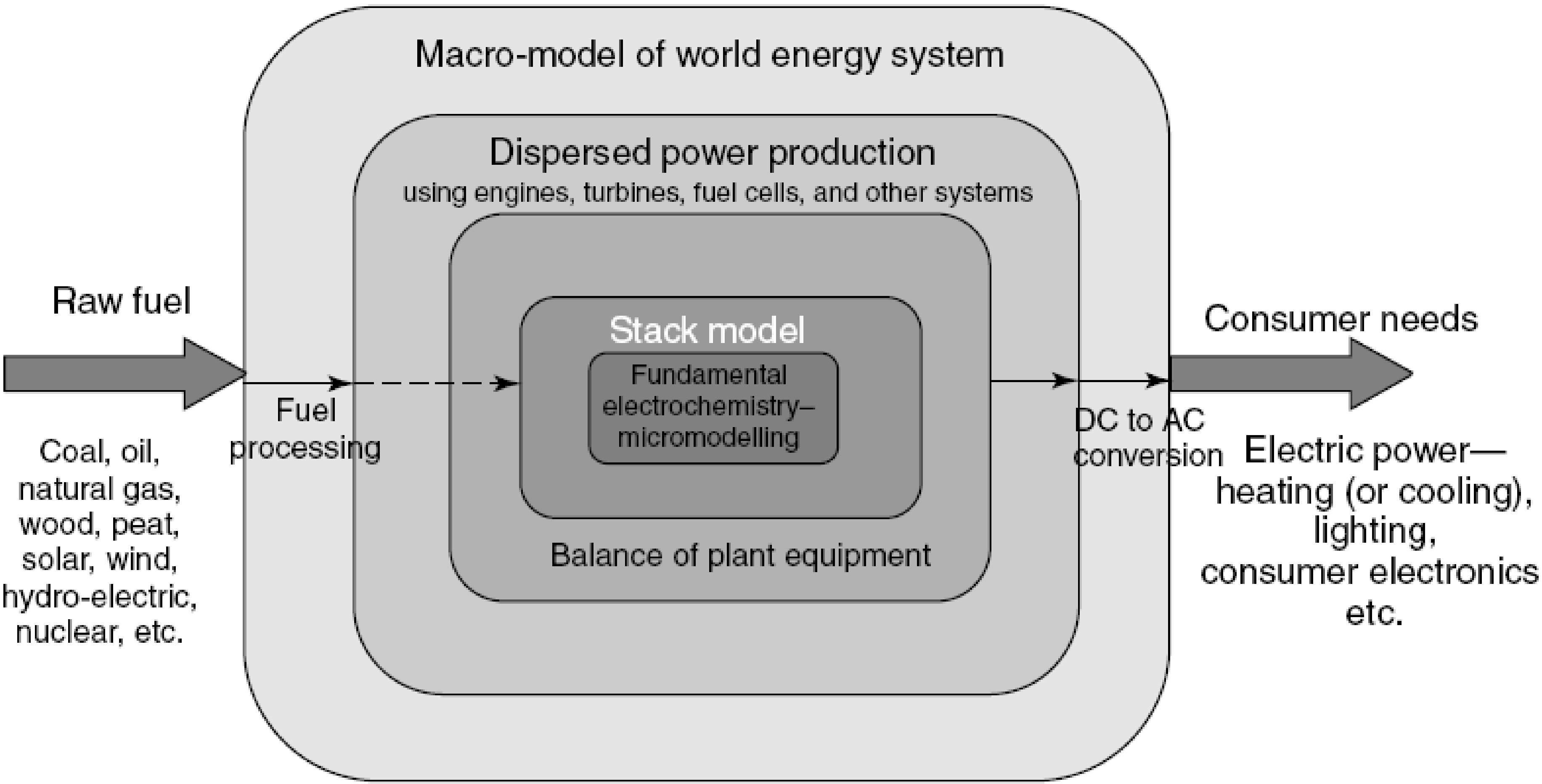
SOFC / PEMFC Combined System

The advantages are enhanced by operating in synergy, and the internal reforming SOFC is run under conditions giving low fuel utilisation. This enables a high power output for a relatively low stack size, and higher efficiency than SOFC or PEMFC alone.

SOFC stack power	369.3 kW
PEM stack power	146.7 kW
Turbine power	100.3 kW
Compressor power	−100.8 kW
Net power output	515.5 kW
Electrical output	489.7 kW
Overall efficiency (%) LHV	61



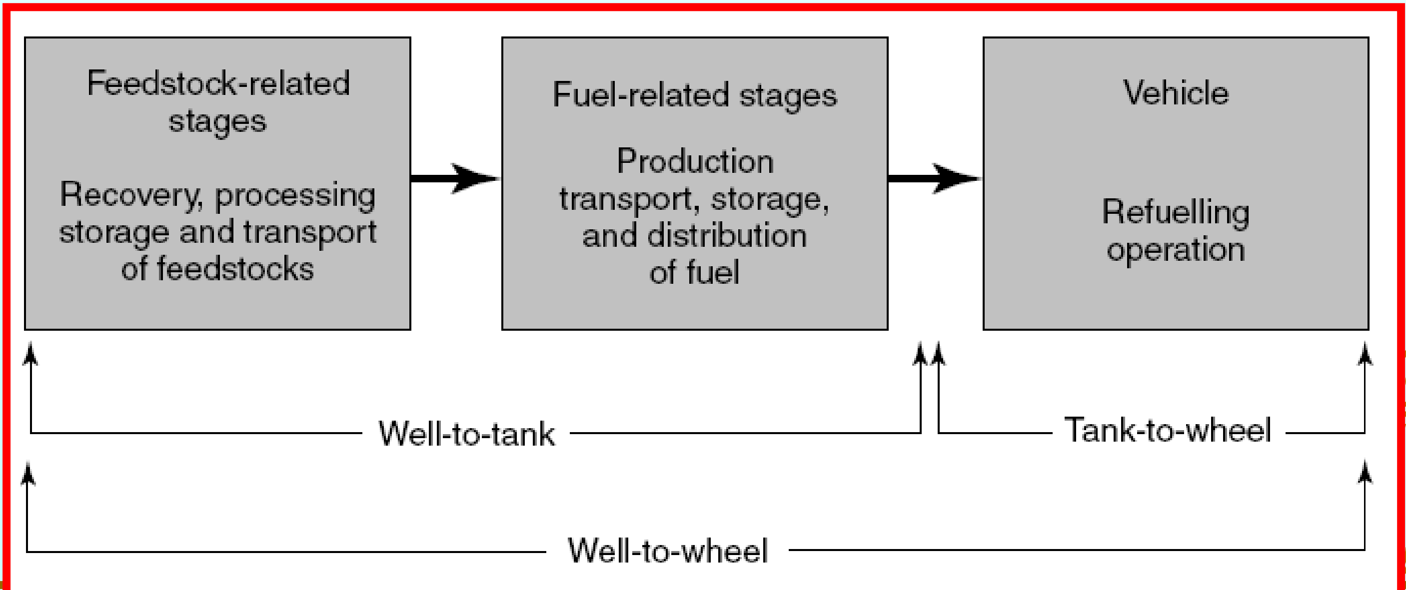
Fuel Cell System Analysis



Analysis Methods

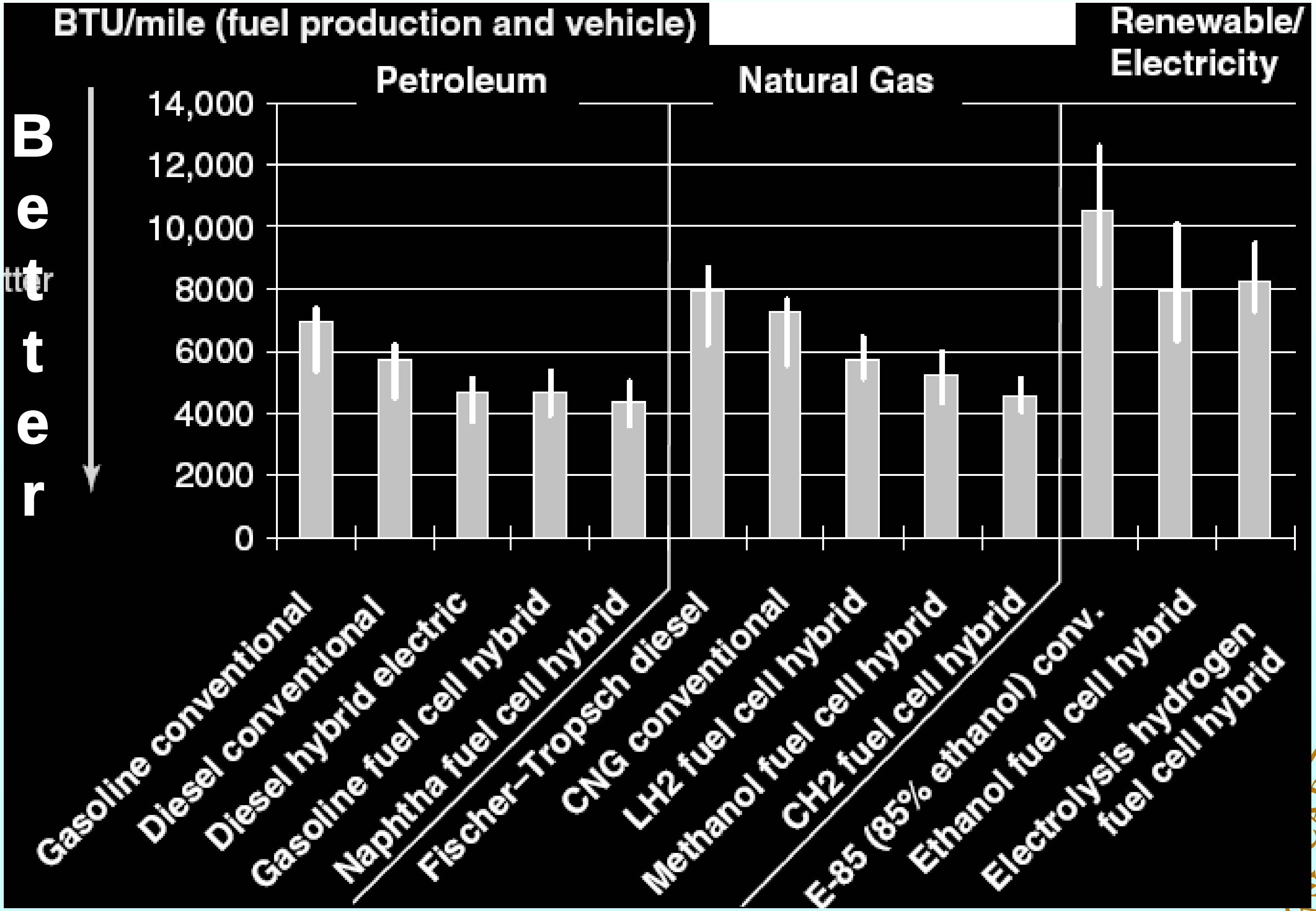
Well-To-Wheels Analysis

- System developers need to understand that they cannot just consider emissions from the stack in isolation, but instead need to look at the **whole system** from ‘well-to-wheels.’
- When fuel is converted, or packaged, or transported, there is an associated loss of energy. The more conversion and transportation steps, the greater the loss.



Case Study: GM Analysis

•Well-to-wheel **energy consumption** for the GM North America study



Major Findings

•***Total energy use***: For the same amount of energy delivered to the vehicle tank, of 75 fuel types studied, petroleum-based fuels and compressed natural gas exhibit the lowest energy losses from the well-to-tank (WTT).

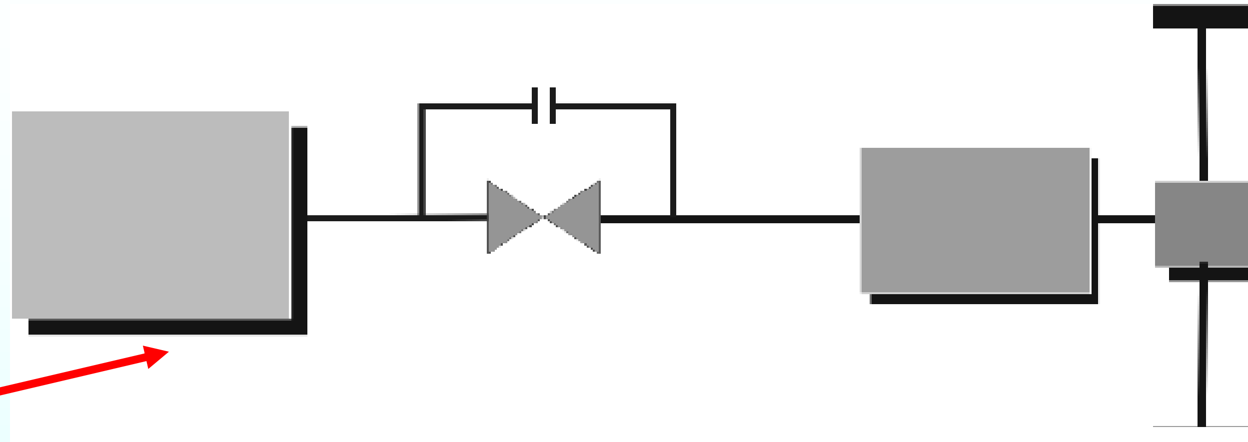
•***Greenhouse gas (GHG) emission***: Ethanol (derived from renewable cellulose sources such as corn) offers a significant reduction in GHG emissions.

•***Tank-to-wheels efficiency***: Hydrogen-based FCVs exhibit significantly higher fuel economy than those employing on-board fuel processors.

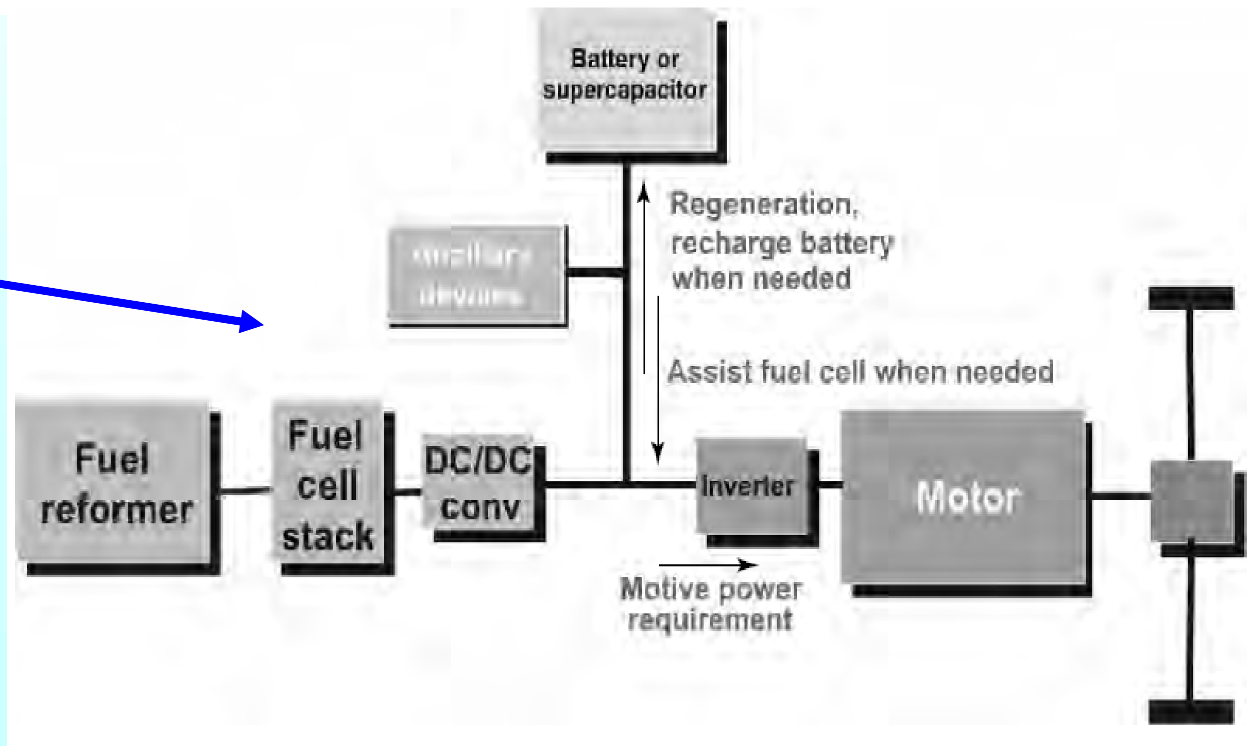
•***Overall well-to-wheels efficiency***: Hybrid systems offer consistently higher fuel economy than conventional vehicles.

Power-Train or Drive-Train Analysis

•In a conventional diesel or gasoline-fuelled vehicle, energy is transmitted by a mechanical power train.



•In an FCV the power train is electrical.



•In a hybrid vehicle it may be a combination of the two.