SYSTEM DESIGN

Lessons Learned

Generic Concepts

Characteristics & Impacts

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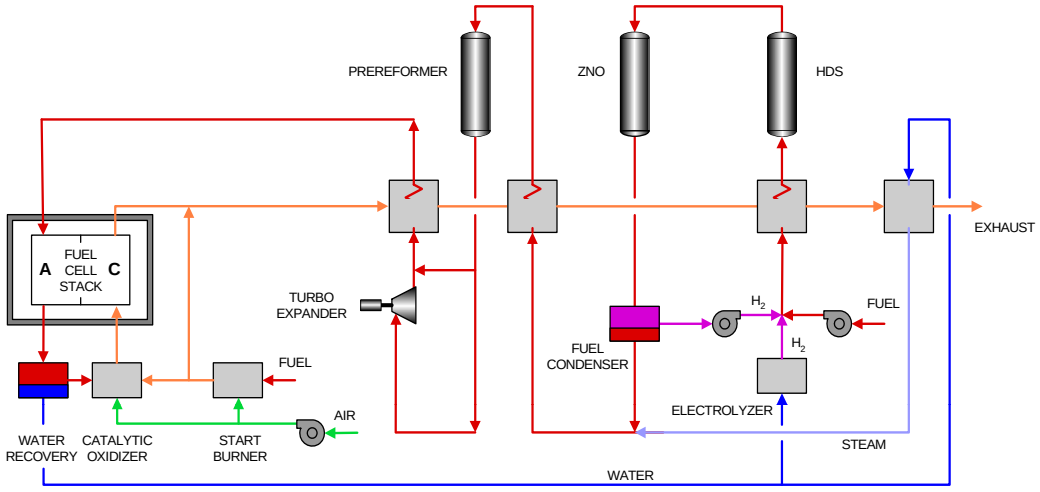
Ship Service Fuel Cell Program
Lessons Learned

625 Molten Carbonate Ship Service Fuel Cell (NATO F76/JP5 Logistics Fuel)

Ship Service Fuel Cell Program

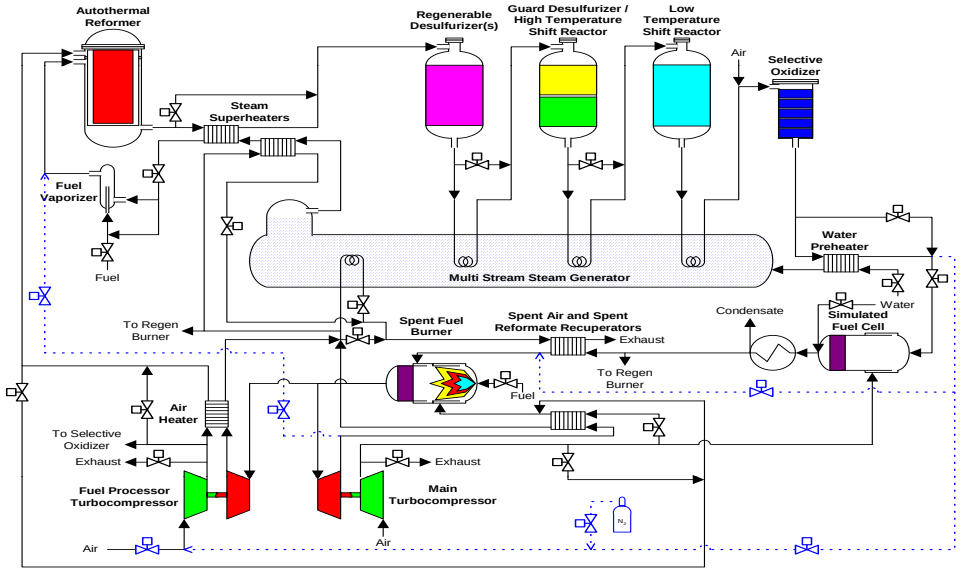
- MCFC with steam reformer
- Fuel reformer built for methane production
- 302 Hours On Load Operation
- 48% Efficiency



500 kWe Integrated Fuel Processor (NATO F76/JP5 Logistics Fuel)

Ship Service Fuel Cell Program

- Low Temperature PEM with ATR reformer
- Gas clean up process
- Waste heat recovery to pressurize process
- Process stability issues prevented significant integrated operation



SSFC Design Issues & Lessons Learned

- **High Complexity with Auxiliaries**
  - Industrial reforming method adapted for shipboard use
  - Low space velocity reactors
  - Component accessibility
  - Imbedded Instrumentation
  - Greatest impact on overall density
- **High Pressure Gas Storage**
  - High pressure combustible gas
  - Shipboard vent requirements
- **Start Time**
  - Fuel Cell & reformer requirements – large thermal mass
  - Heat up technique – direct vs indirect start process
- **Marinization**
  - Design for shipboard operation requires integrated packaging
  - Design methods for inherently safe operation are different (industrial vs shipboard use)
  - Control and dynamic operation needs to be accounted for up front in overall design
- **Price Point**
  - Total system design will affect overall price point (parts count)
  - Need to follow existing model for incorporation of power generation (gas turbine/diesels) into fleet

Navy Fuel Cell Processor Development

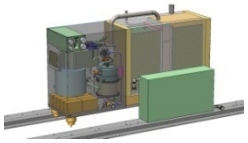
Ship Service Demonstration

625kW SSFC Demo
45-50% Efficient

Fuel Cell S&T

Modular Fuel Cell Systems

High Power Shipboard System



Low Power, High Efficiency Tactical Power System

Ship Service Fuel Cell Program Lessons Learned

- Enable 3X improvement in volumetric density over SSFC demonstrators
- Risk Reduction of Fuel Cell Subsystems through scaled breadboard demonstration

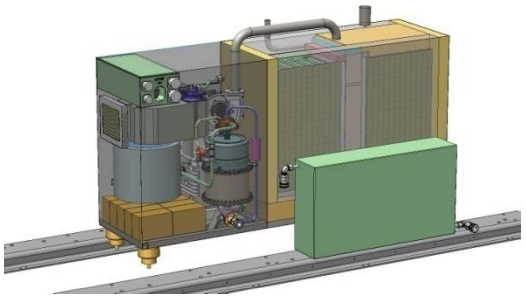
Future Full Scale Modular Fuel Cell System Design for Multi Platform Application

Solid Oxide Fuel Cell Tactical Power
Low Sulfur JP8 Fuel

Total Power	5 kW	10kW	5 MW
Efficiency	25 %	30-40%	50 %
Airborne Noise	50 db	60db	110 db
Volumetric Density	20 w/l	25w/l	35 w/l
Gravimetric Density	20 w/kg	35w/kg	40 w/kg
Start Time	15 min	30min	24 hrs
Life (MTBO)	1000 hrs	1250hr	10000 hrs
Hours per year operating	500 hrs	750hrs	9000 hrs
Scheduled Maintenance	250 hrs	250hrs	9000 hrs
Water Neutrality	0	100%	100%
Electric System Interface		450VAC, 3Phase	
Power Quality		Mil-Std-1332	
Environmental		Mil-Std-810	
Emissions		No Std Identified	
EMI		Mil-Std-461	
Shock & Vibration		Mil-Std-810	

Solid Oxide Fuel Cell Tactical Power
Low Sulfur JP8 Fuel

Towable Power



SOFC System

Vehicle Based APU

Measure	Demonstration Goal @ TRL 6
Power Output	10 kW
Efficiency	30-40%
System Weight	35 W/Kg
System Volume	20-30 W/liter (Power Core)

Shipboard Fuel Cell System Biofuel

Heavy Vehicle

Commercial

Small Marine

Commercial Marine

Electronics

Residential, APU

Automotive

Industrial, Dist. Gen

Locomotive

.01 .1 1 10 100 1,000 10,000

DMFC

SOFC

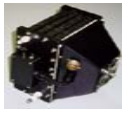
PEM/HT PEMFC

MCFC

PAFC

Multiple Modules

POWER (kWe)

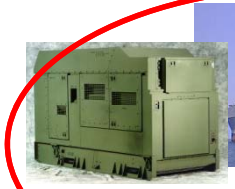


Soldier Power

Portable Power

UV/Small Craft/ Submersible

Vehicles, Small MEP



Ship Service , Large MEP

Military

Shipboard Fuel Cell System
Biofuel

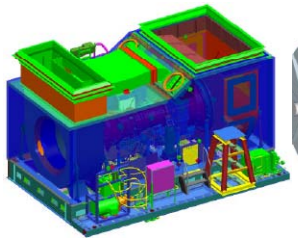
Total Power	5 kW	----------	5 MW
Efficiency	25 %	----------	50 %
Airborne Noise	50 db	----------	110 db
Volumetric Density	20 w/l	----------	35 w/l
Gravimetric Density	20 w/kg	----------	40 w/kg
Start Time	15 min	----------	24 hrs
Life (MTBO)	1000 hrs	----------	10000 hrs
Hours per year operating	500 hrs	----------	9000 hrs
Scheduled Maintenance	250 hrs	----------	9000 hrs
Water Neutrality	0	----------	100%
Electric System Interface			
Power Quality			
Environmental			
Emissions			
EMI			
Shock & Vibration			

Other Criteria to Consider

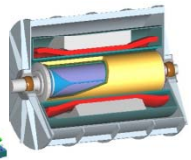
- Exhaust temperatures
- Airflow
- Maintenance envelope
- Equipment removal concept
- Duty Cycle
- Structureborne Noise

Notional Electric Architecture

Power Generation

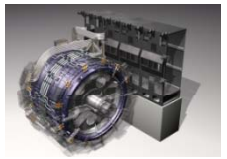


HTS Generator

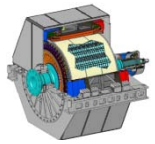


Adaptive Fault & Recovery Technology

Motor / Motor Drive



Permanent Magnet



HTS

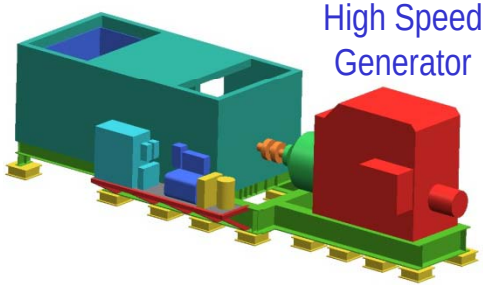
Adv. Induction

Homopolar

DC or 60 - 240 Hz

Power Generation

High Speed Generator



Power Electronics

Bidirectional Power Conversion Module (PCM)

Service Loads

Pulse Loads

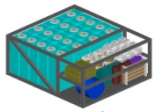
DC

DC

Distributed Power Generation/ Fuel Cells

Energy Storage

Rotating Machine



Capacitor

Battery

Shipboard Fuel Cell Characteristics & Impacts

1st Step: Shipboard Power Needs
Operating w Biofuel








2nd Step: Specification Prioritization

Action:

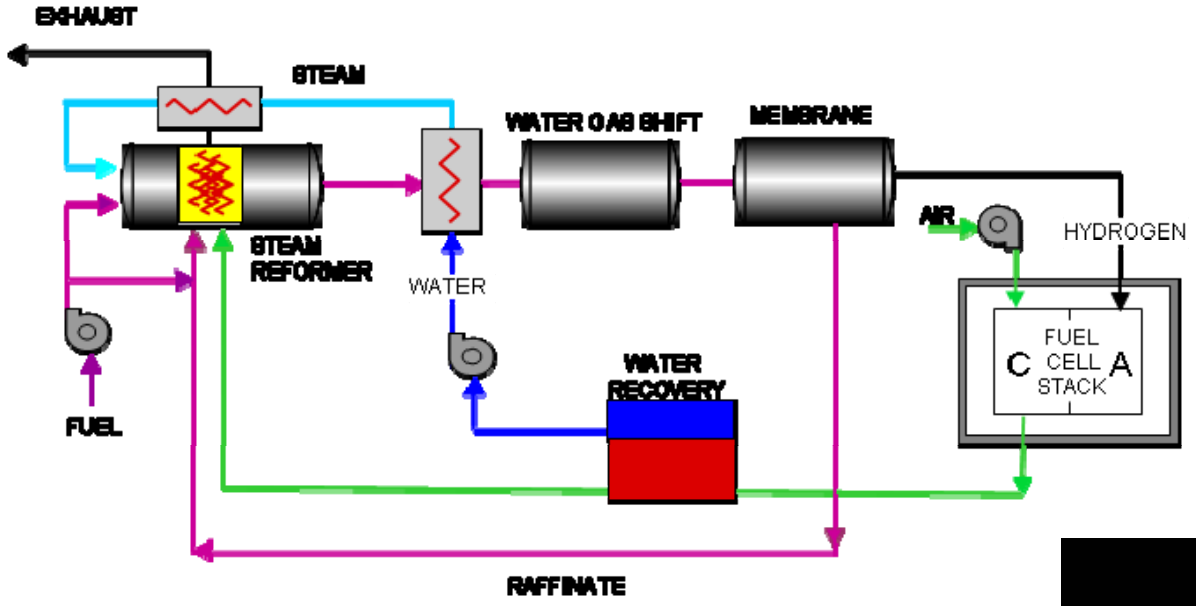
Prioritize & identify shipboard fuel cell characteristic information based on Shipboard Power Need

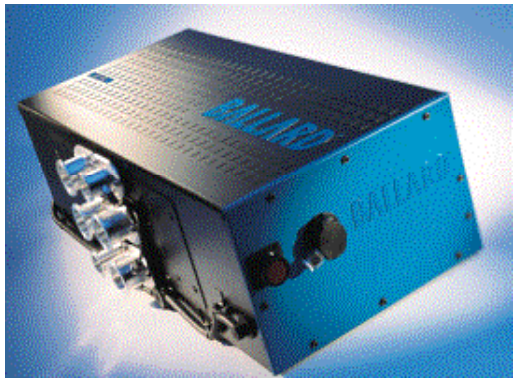
	Total Power
	Efficiency
	Airborne Noise
	Volumetric Density
	Gravimetric Density
	Start Time
	Life (MTBO)
	Hours per year operating
	Scheduled Maintenance
	Water Neutrality
	Electric System Interface
	Power Quality
	Environmental
	Emissions
	EMI
	Shock & Vibration

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**

Low Temperature PEM System





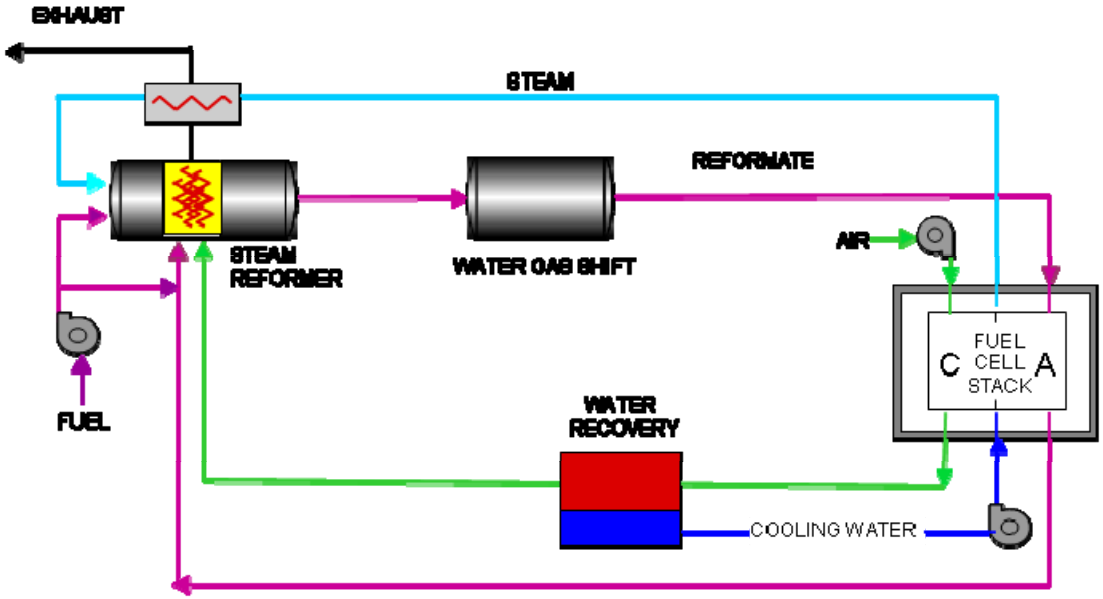
Ballard Fuel Cell

Fuel Cell Stack Characteristics

- **Manufacturer:** GM, Ballard etc.
- **Fuel:** Pure H2
- **Temperature:** 60 C

GM Automotive Fuel Cell

Phosphoric Acid Fuel Cell System

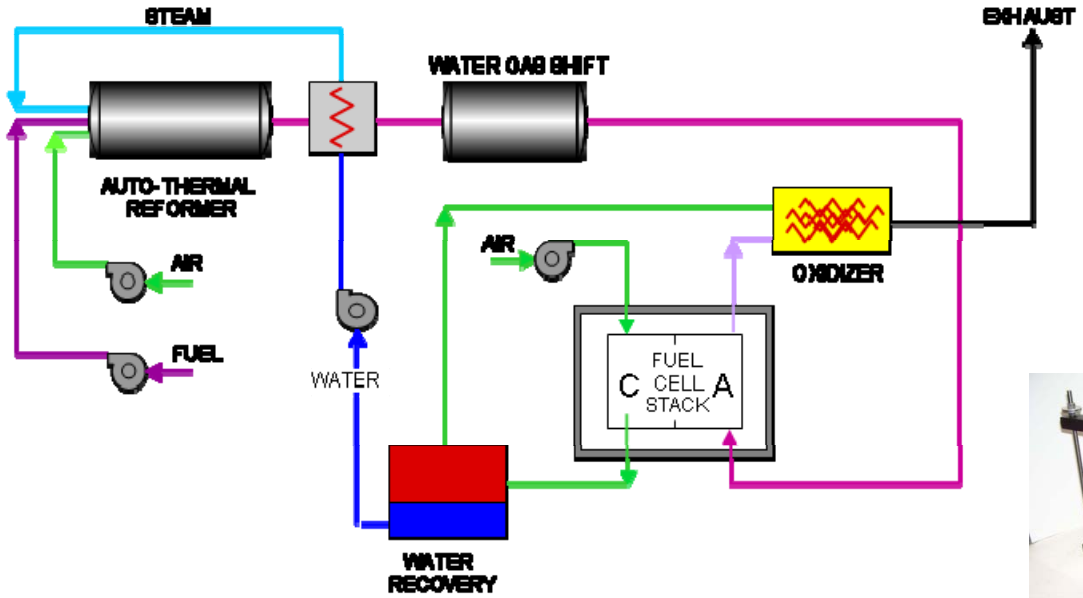


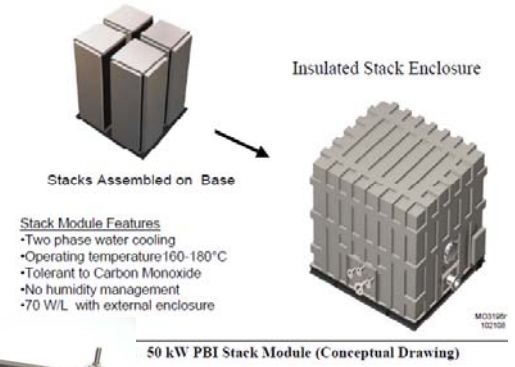
UTC PureCell 400

Fuel Cell Stack Characteristics

- **Manufacturer:** United Technologies Company
- **Fuel:** H_2 rich reformate
- **Temperature:** 180 C

High Temperature PEM/PBI System





Stack test Module

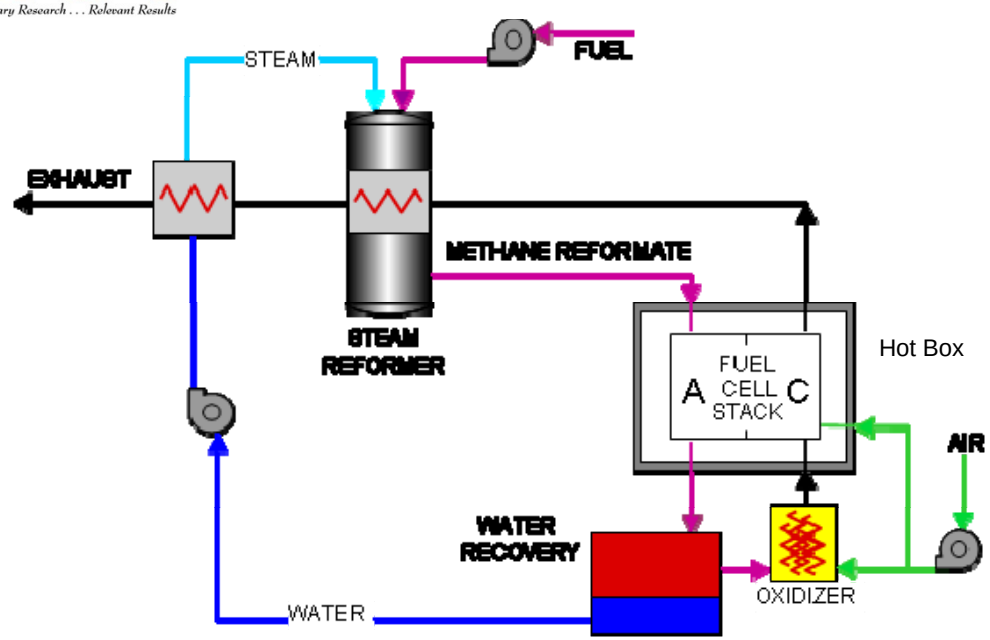
Fuel Cell Energy

Fuel Cell Stack Characteristics

- **Manufacturer: Enercell, FCE etc.**
- **Fuel: H_2 rich reformate**
- **Temperature: 180 C**

Enercell HT PEM

Molten Carbonate Fuel Cell System



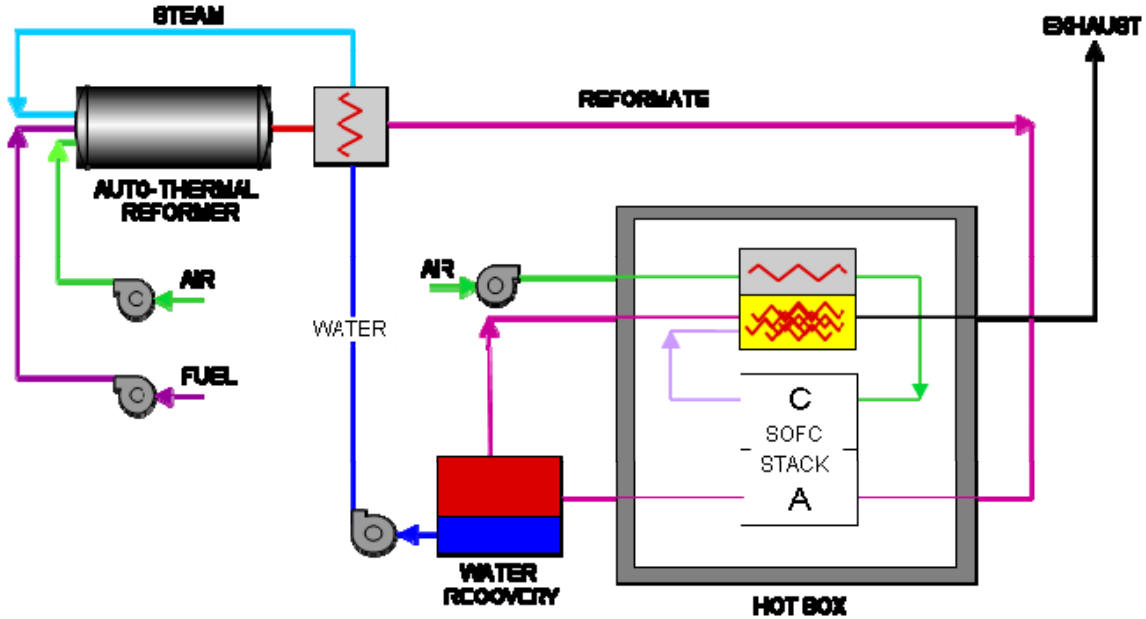
MCFC Stack

FCE SSFC Module

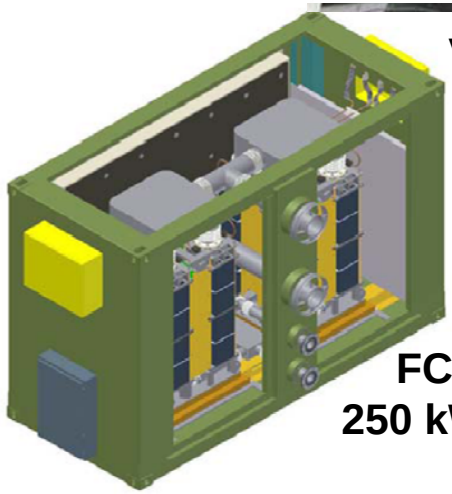
Fuel Cell Characteristics

- **Manufacturer:** Fuel Cell Energy
- **Fuel:** CH_4 rich reformate
- **Temperature:** 650 C

Solid Oxide Fuel Cell System



Versa 25 kW SOFC Stack



FCE Conceptual 250 kW SOFC Module

Fuel Cell Stack Characteristics

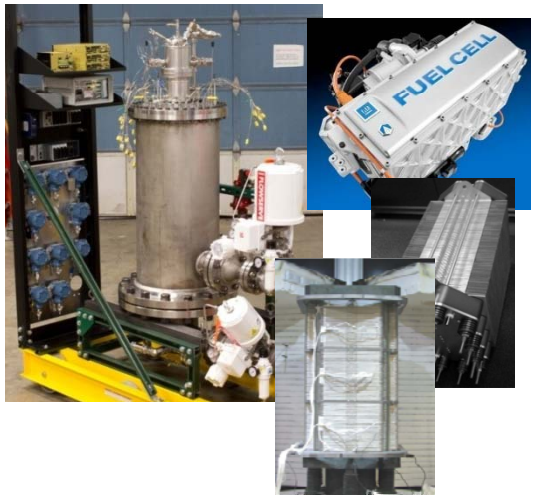
- **Manufacturers:** Versa, Delphi, RR etc.
- **Fuel:** H_2 rich reformate
- **Temperature:** 800 C

3rd Step: Technology Assessment for Shipboard Fuel Cell System - Biofuel

Ship Service Demonstration

625kW SSFC Demo
45-50% Efficient

Fuel Cell Components



Modular Fuel Cell Systems

Ship Service Fuel Cell Program Lessons Learned

- Technical Challenges of Advanced Fuel Cell Components Operating on Biofuel
- System Integration of Advanced Fuel Cell Components based on Shipboard Power Need

High Power Shipboard System

Questions?

Shipboard Fuel Cell System Installation