

Stationary & Transportation Fuel Cell Applications

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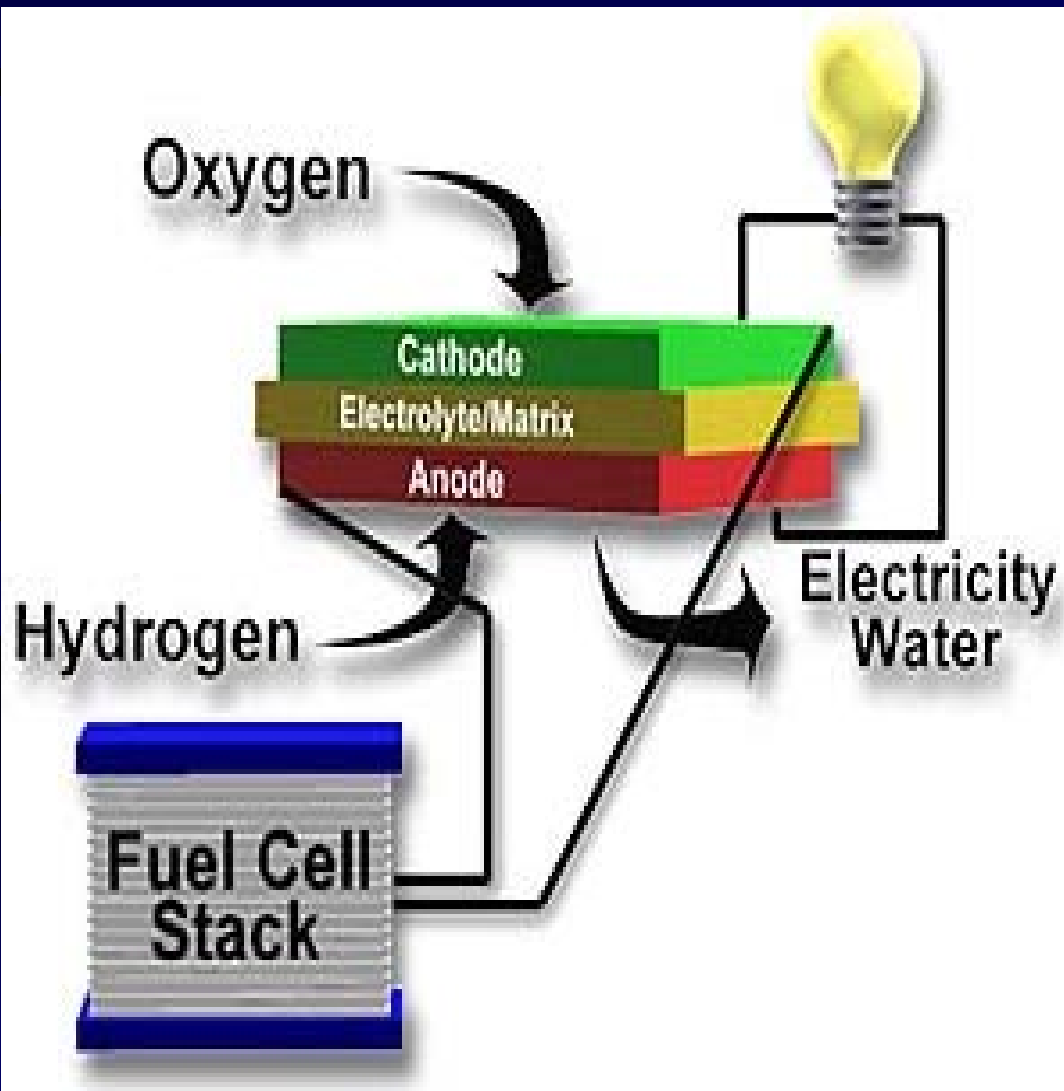
What Are Fuel Cells?

- Fuel cells produce electricity through electrochemical reactions
- Converts chemical energy of reactants (fuel and oxidizer)
- Similar to batteries but are continuously supplied fuel and oxidizer
- Unlike thermal generators (steam power plants, engine/generators, and gas turbines)
- Low voltage direct current electricity
- Nearly zero air emissions

Fuel Cell History

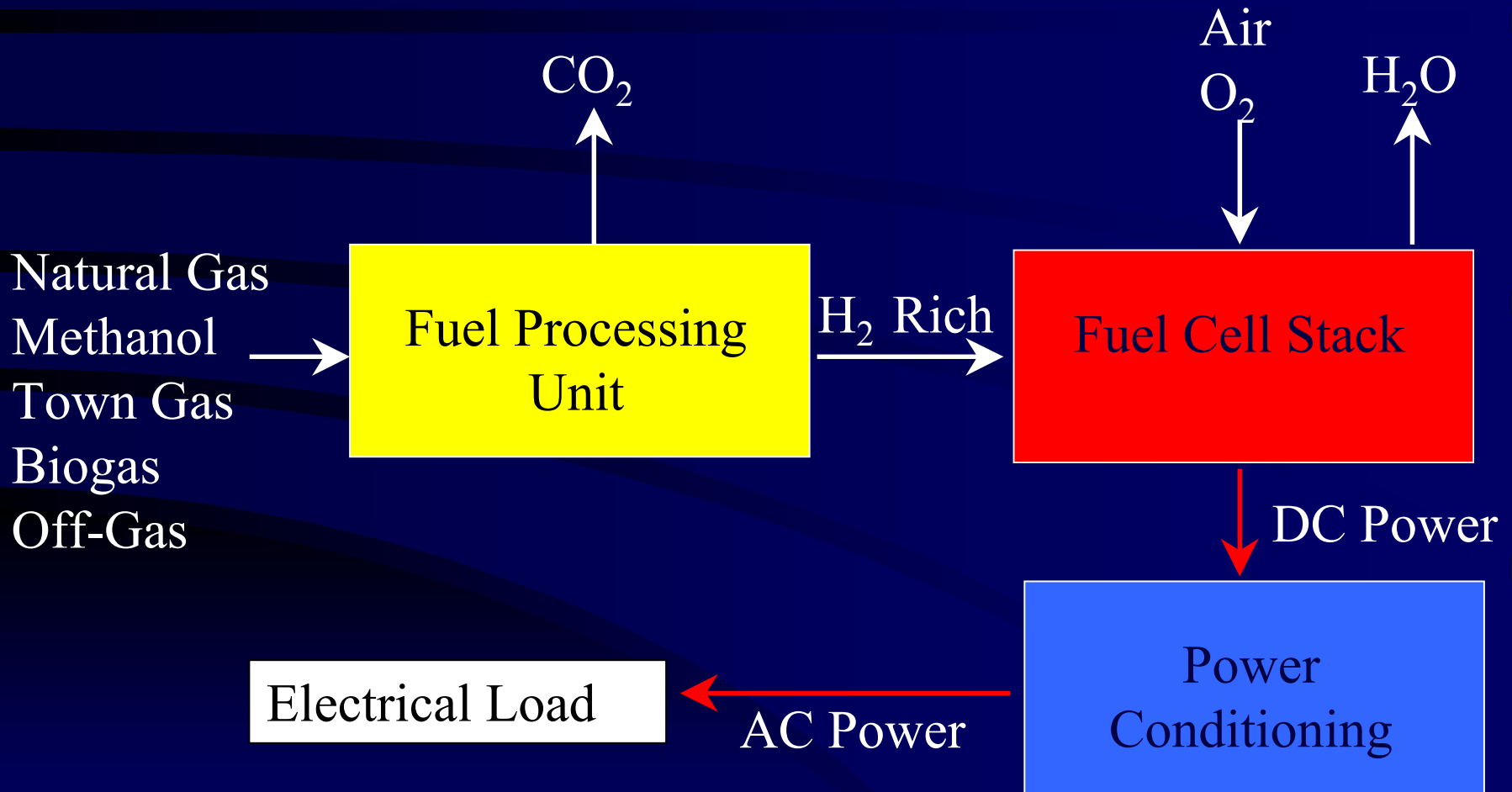
- Natural Fuel Cells
 - Electric Fish
 - Galvanic Corrosion
- Gaseous Voltaic Battery Sir William Grove, 1839
- Fused Salt Electrolyte, A.C. Becquerel, 1855
- Hydrogen/Oxygen Fuel Cell, Francis T. Bacon, 1932
 - Alkaline Electrolyte
 - 5 kW System Developed, 1959
- 750 W FC for Underwater Vessel, Allis-Chalmers 1959-1963
- Space Programs, 1960 - today

Fuel Cell Stack Construction



- Fuel cell stacks made of many individual cells.
- Each cell consists of
 - cathode
 - electrolyte
 - anode
 - separator plate
- Thermal, electrical, chemical & mechanical tolerances

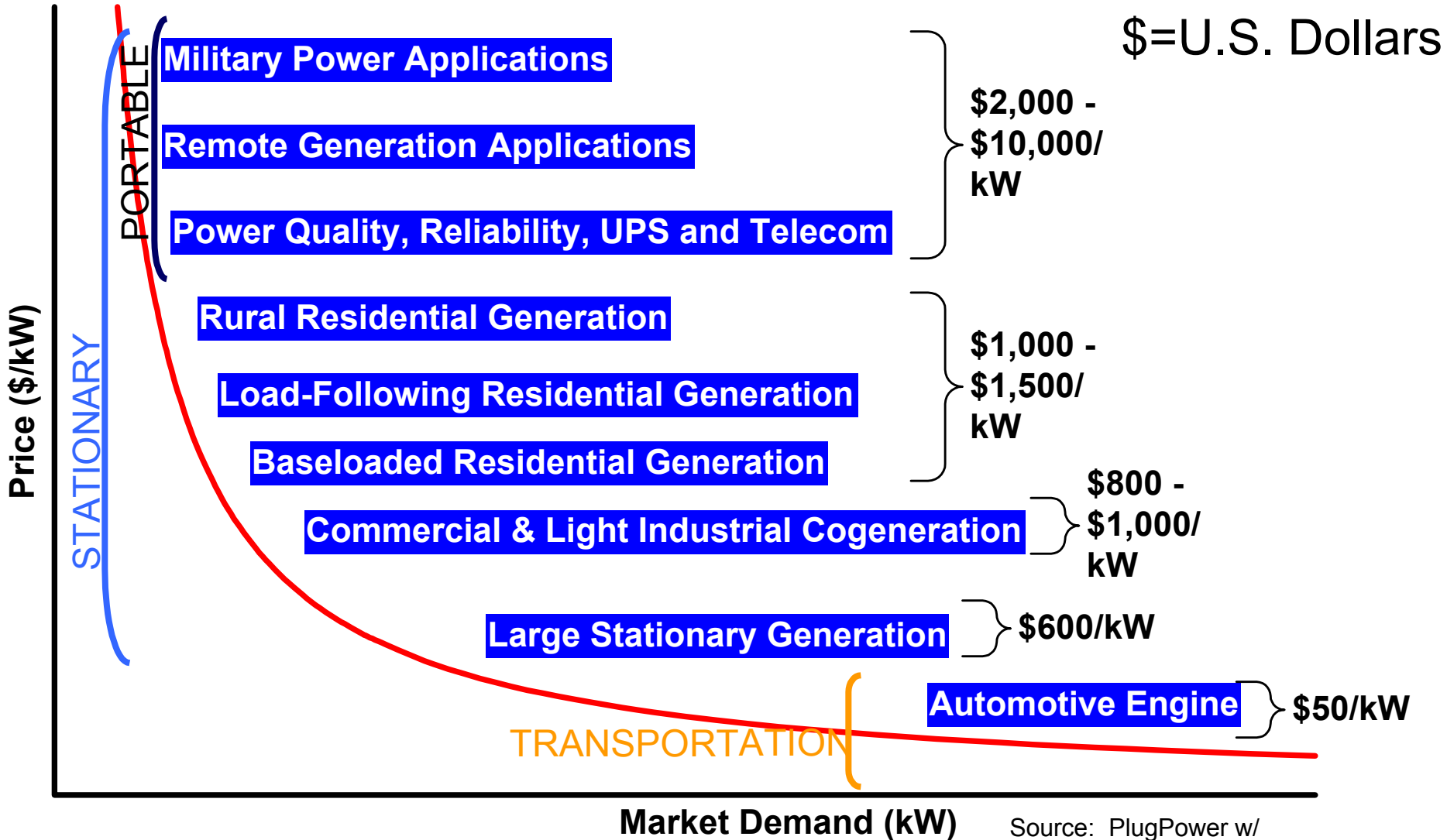
Fuel Cell Power Plant Systems General Configuration



Fuel Cell Types & Performance

Type	Electrolyte	Operating Temperature	Electric Efficiency (LHV)
Alkaline Fuel Cell (AFC)	Potassium Hydroxide	65°C - 220°C	70% (Pure H ₂)
Proton Exchange Membrane Fuel Cell (PEM)	Sulphonated Solid Fluoropolymer	80°C	40%
Phosphoric Acid Fuel Cell (PAFC)	Phosphoric Acid	205°C	40%
Molten Carbonate (MCFC)	Molten Alkali Carbonate	650°C	50%
Solid Oxide Fuel Cell (SOFC)	Zirconia-Based Ceramics	800-1000°C now, 600-1000°C in 10 years	60% (Hybrid)

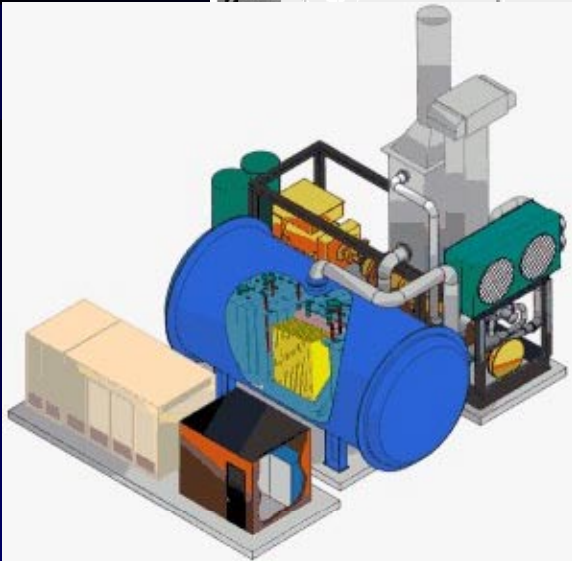
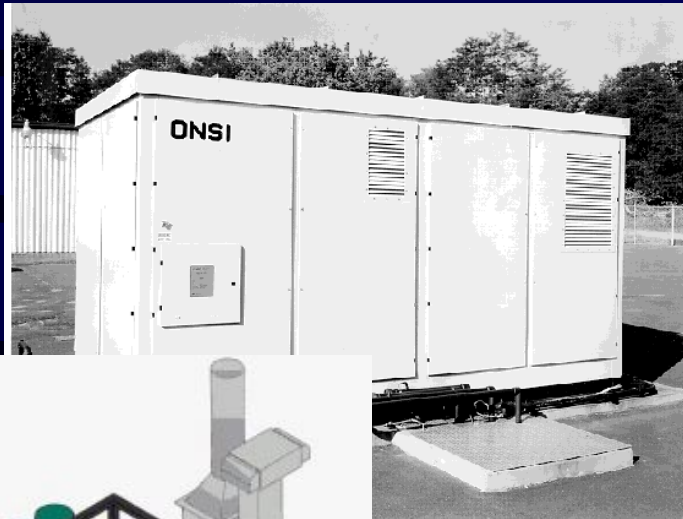
Fuel Cell Applications



Source: PlugPower w/
Modifications by AESC, Inc.

Fuel Cell Applications

STATIONARY



TRANSPORTATION



Stationary Fuel Cell Applications

- Small residential or micro-application PEM fuel cells
 - 1 kW -> 5 kW
 - Natural gas, propane, town gas
- Commercial combine heat and power (CHP) PAFC and MCFC
 - 50 kW -> 500 kW
- Industrial CHP PAFC, MCFC & SOFC
 - 200 kW -> +1 MW
- Distributed utility PAFC, MCFC & SOFC

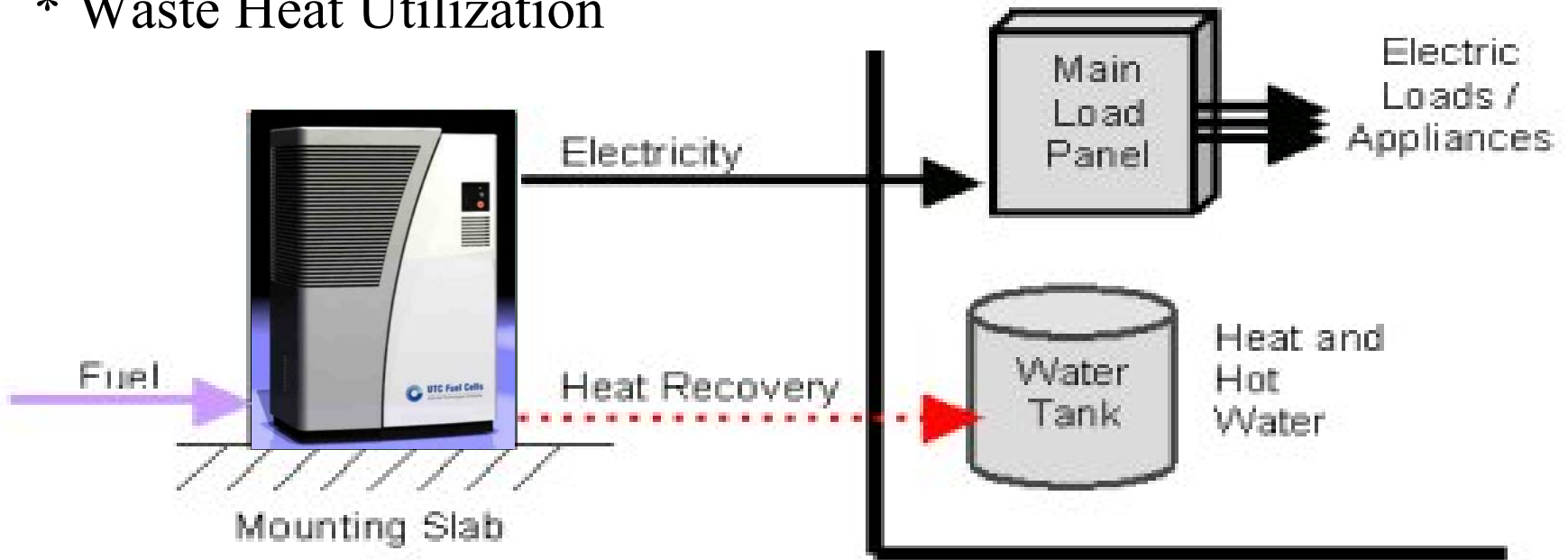
Residential Applications



UTC Fuel Cells

A United Technologies Company

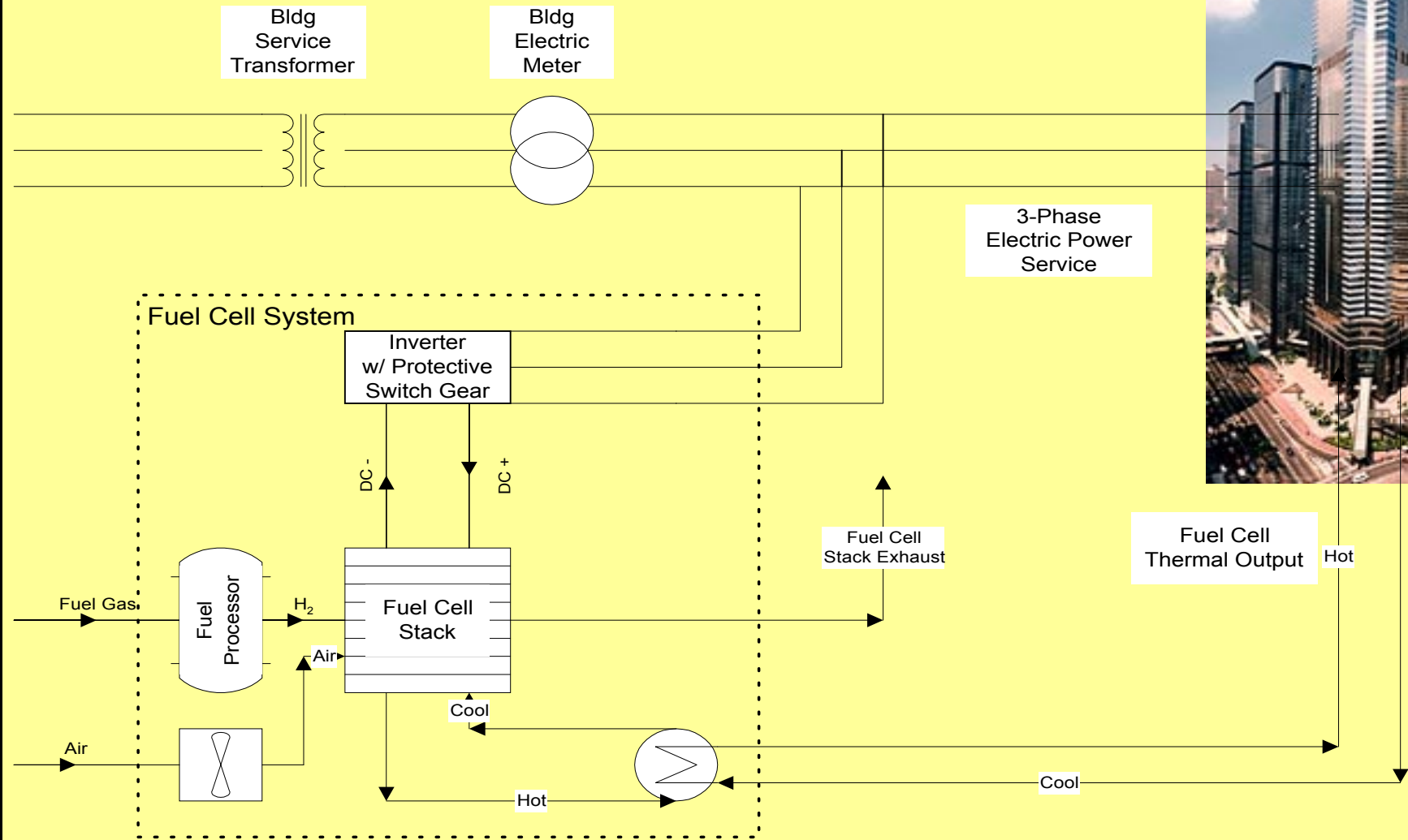
- * Simple Cycle 1-5 kW Load Following
- * Natural Gas, Propane, Town Gas
- * Waste Heat Utilization



Drawing not to scale

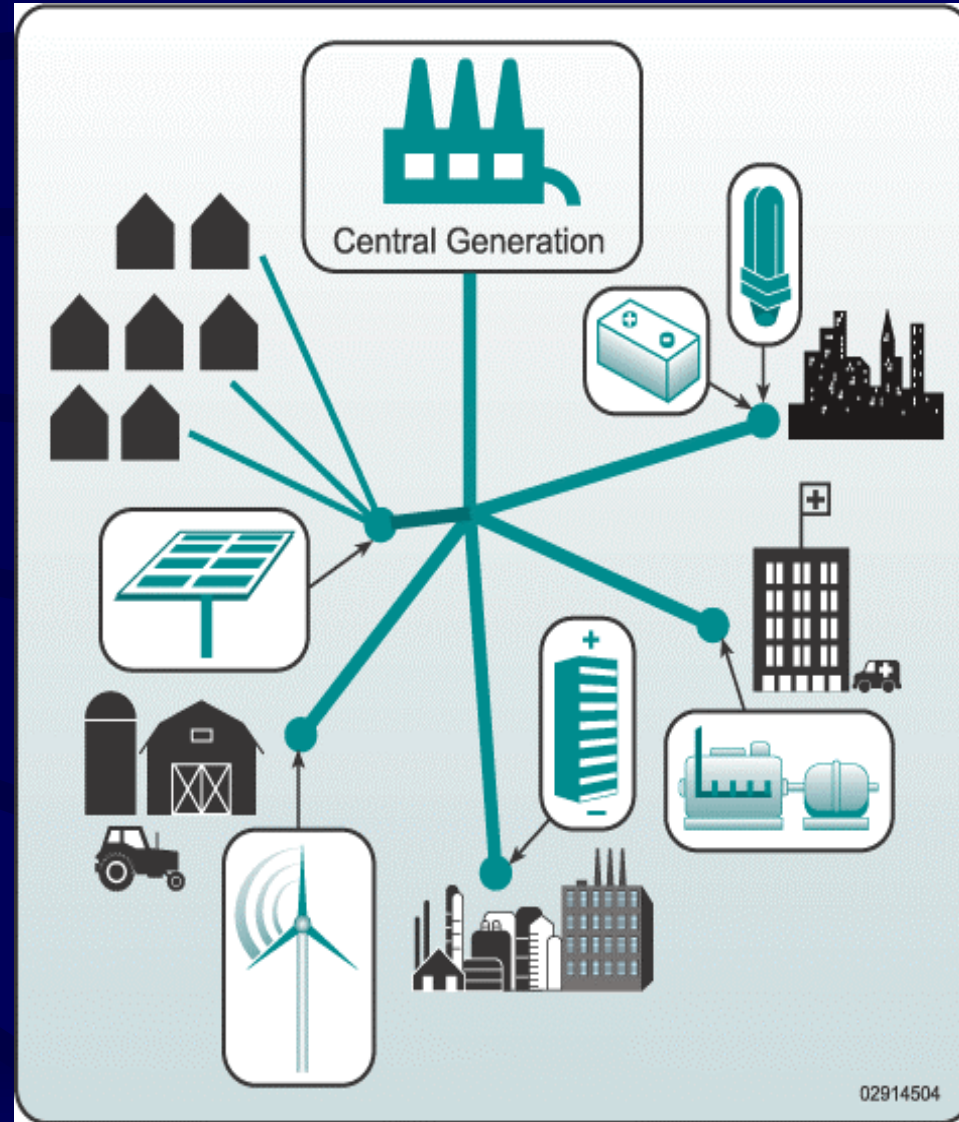
Commercial/Industrial CHP

- * 50 - 500 kW Base Load or Load Following
- * Natural Gas, Propane, Town Gas
- * Space Heating/Cooling, DHW, Process Heating



Distributed Utility Applications

- DU is the deployment & coordinated operation of small onsite & “in-grid” generators, with load management.
- 50 kW - 10 MW fuel cell power plants
- Conventional & renewable fuels (land-fill gas, off-gas, digester gas)



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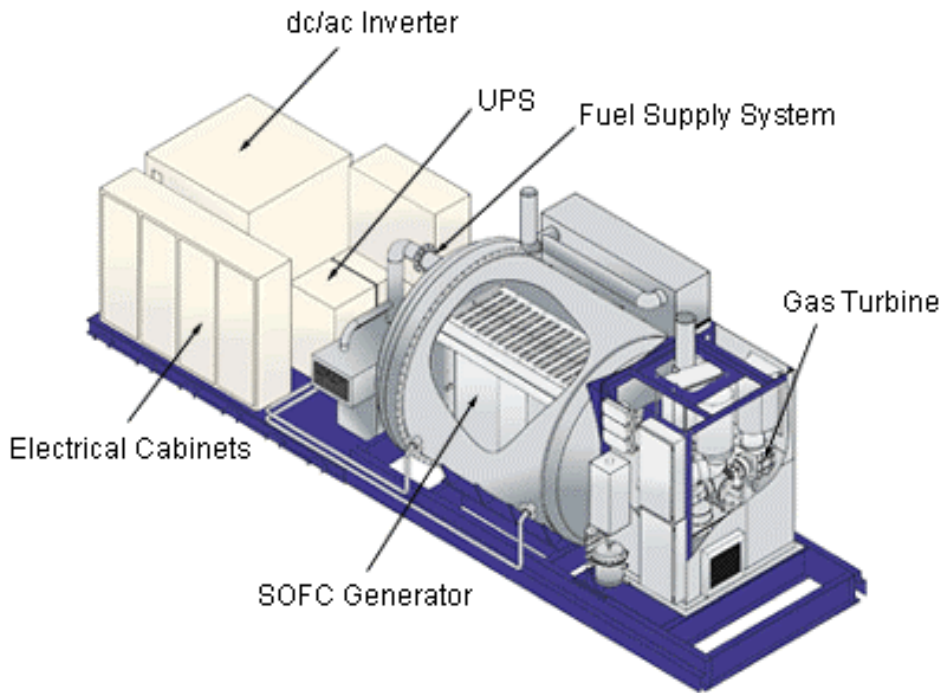
Distributed Power Generation



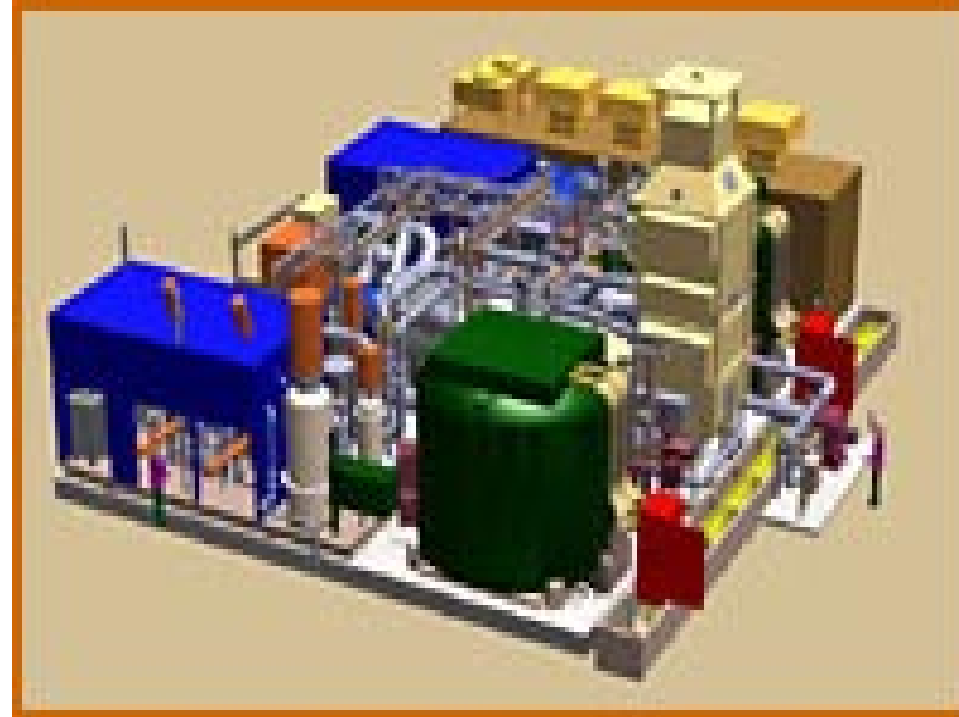
U.S. Department of Energy

Office of Energy Efficiency and Renewable Energy

Distributed Utility Fuel Cells



300 kW Hybrid SOFC
Source: SiemensWestinghouse



3 MW Molten Carbonate Fuel Cell
Source: FuelCell Energy

Transportation Fuel Cell Applications

- PEM fuel cells are primary technology under development for vehicle power.
- Bus & personal vehicle applications are targeted.
- Compressed H₂, ethanol & methanol.
- Fuel cell power plant cost goals more aggressive than stationary (US\$50/kW vs US\$1,000/kW)
- Power plant life shorter than stationary (5,000 hrs vs 40,000 hrs).

Fuel Cell Bus Applications

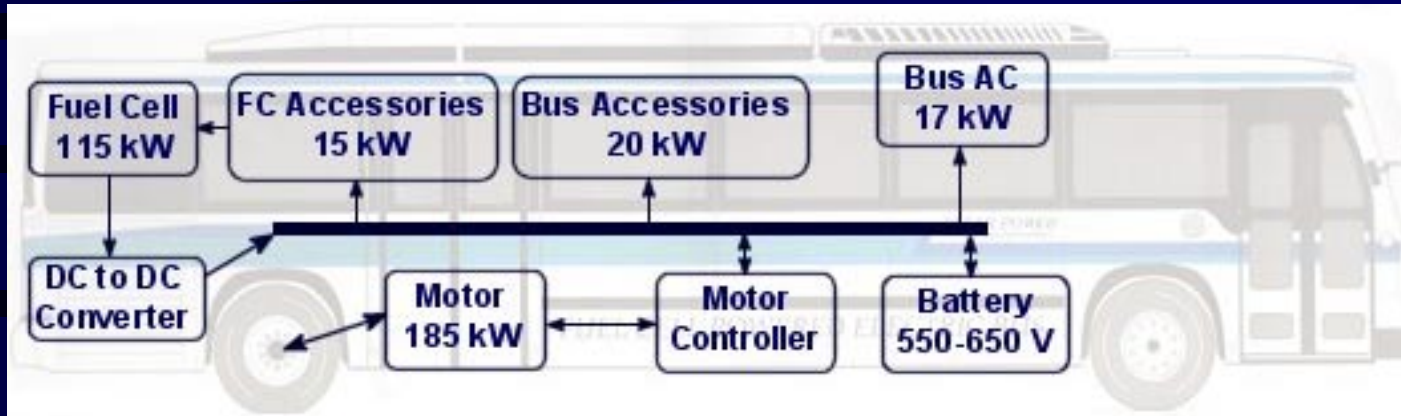


XCELLSIS X1 BUS

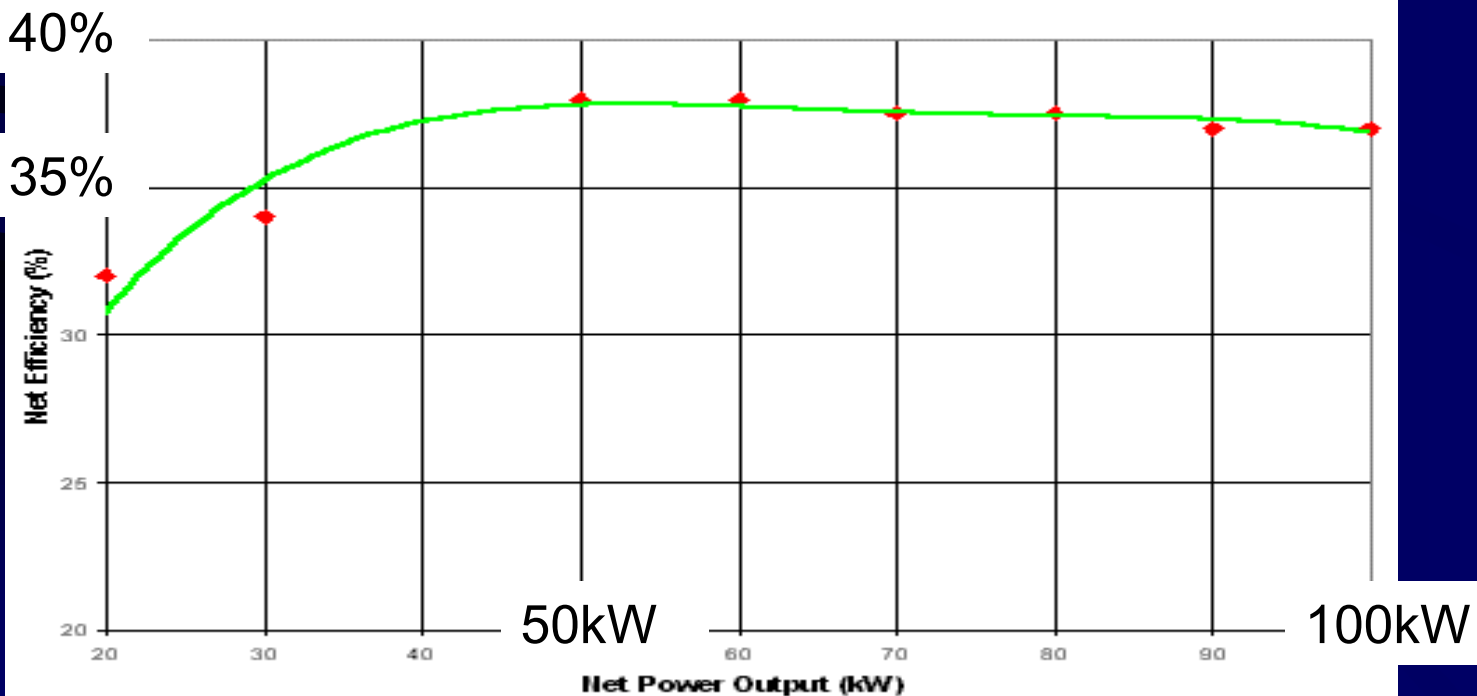


*GEORGETOWN
UNIVERSITY*

Fuel Cell Bus Drive System



XCELL SiS 100 kW Methanol-Fueled PEMFC Bus Engine Efficiency

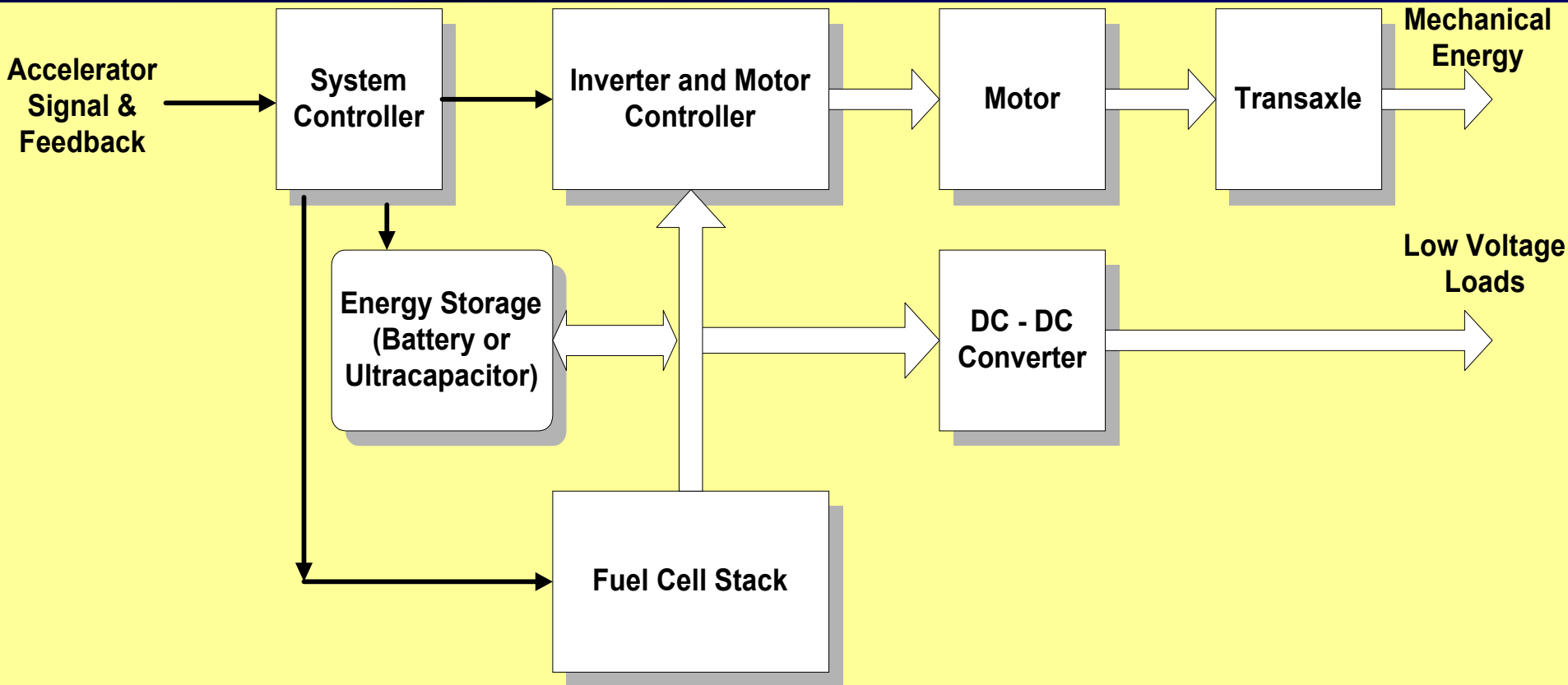


Based on LHV of methanol and with FCS accessories included

Personal Fuel Cell Vehicles



Fuel Cell Vehicle Drive Train



- Critical Operating Parameters

- Time to startup/warm-up
- Miles between fueling
- Acceleration

- Miles between maintenance
- Maintainability

Why Fuel Cells?

- Fuel cell electric generation is clean, no or little air emissions.
- Fuel cells are efficient. They are not limited by Carnot theoretical efficiency.

Fuel Cell Challenges to Commercialization

- COST

- Fuel cell power plant capital cost currently too high.
- Requires higher power density systems.

- COMPLEXITY

- Fuel cell power plants are complex & require specialized maintenance.

- FUEL PROCESSING

- Reforming of natural gas & other “simple” hydrocarbons commercial.
- On-board reforming for transportation adds complexity & cost.
- Direct hydrogen fuel cells require H₂ storage & infrastructure.

Key Concurrent Events

- Advances in transportation fuel cells will accelerate stationary applications.
- Stationary applications will deploy commercially before transportation.
- Recent developments in hydrogen storage (sodium borohydride & nanotubes) could provide “break-limit” for transportation.