The Role of the Fuel Cell System in Sustainable Power Generation

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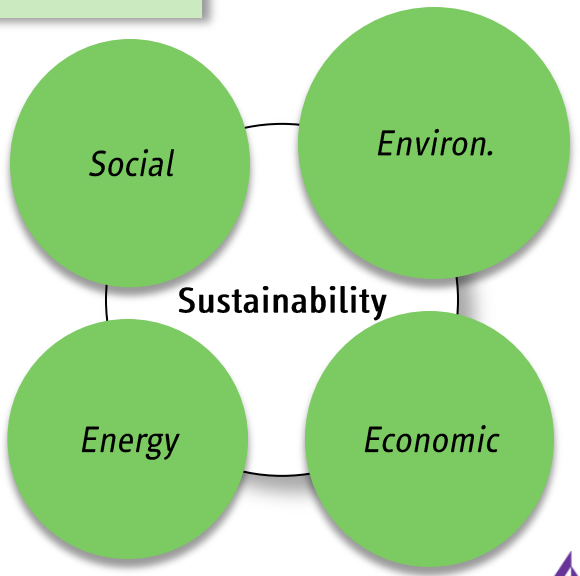
Outline

- Definition of Sustainability
- Energy Demand and Supply
- Fuel Cell and Hydrogen Technologies
- Case Study: 4 kW Bio-SPK Based Fuel Cell System
- Case Study Conclusion
- Fuel Cell Industry Status and Outlook

Definition of Sustainability

..... the standard and most generally used definition of sustainability is: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"



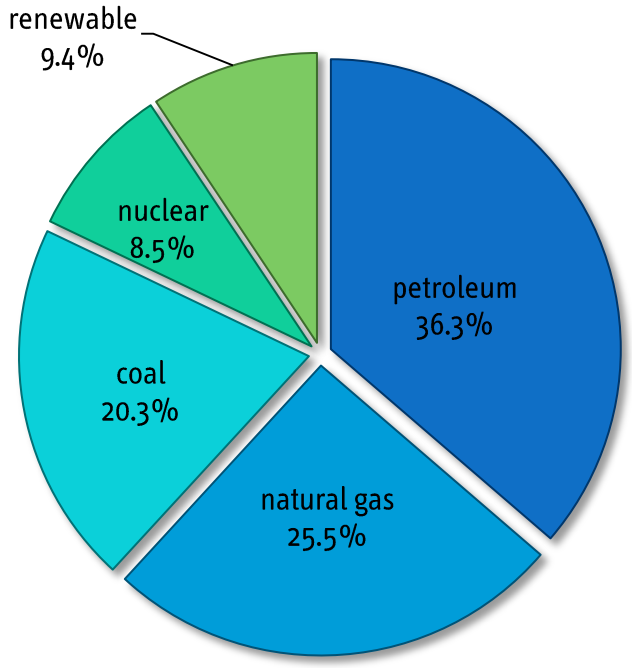
Energy Sustainable Technologies

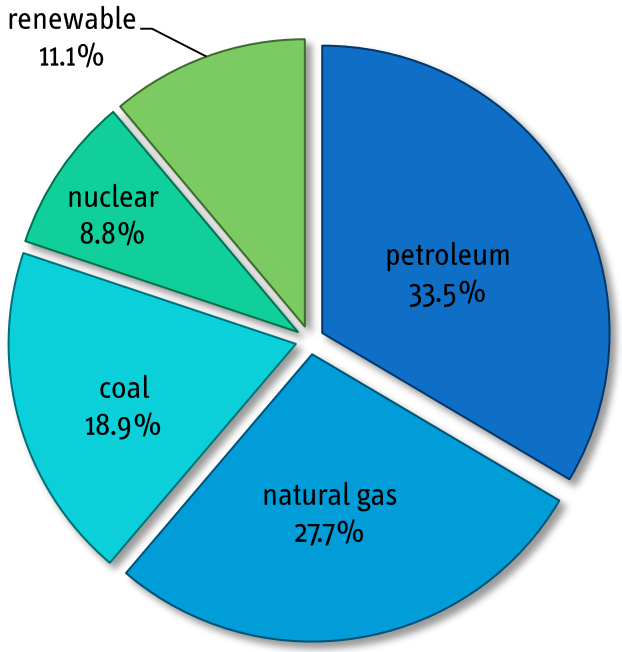
(George Crabtree, John Sarrao, 2009 in "the road to sustainability")

- ✓ lasts a long time
- ✓ does no harm
- ✓ leaves no change

ref: hydrogen and fuel cell technologies for sustainable future, Ibrahim Dincer, 2008

U.S. Energy Demand and Forecast



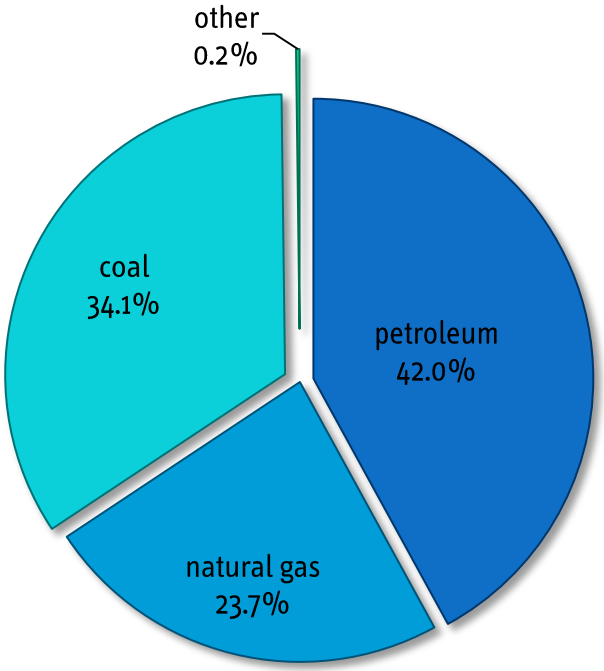


97.2 quadrillion BTU in year 2011
501.551 quadrillion BTU worldwide

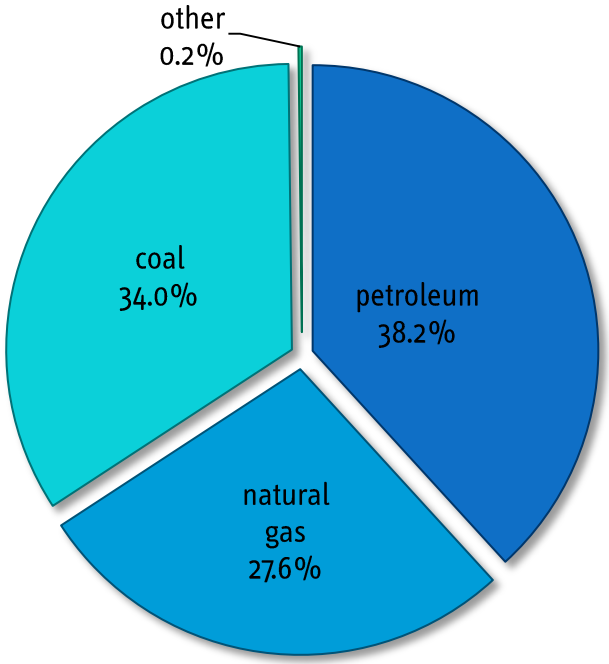
107.64 quadrillion BTU in year 2040

reference: annual energy review 2011

CO_2 Emissions

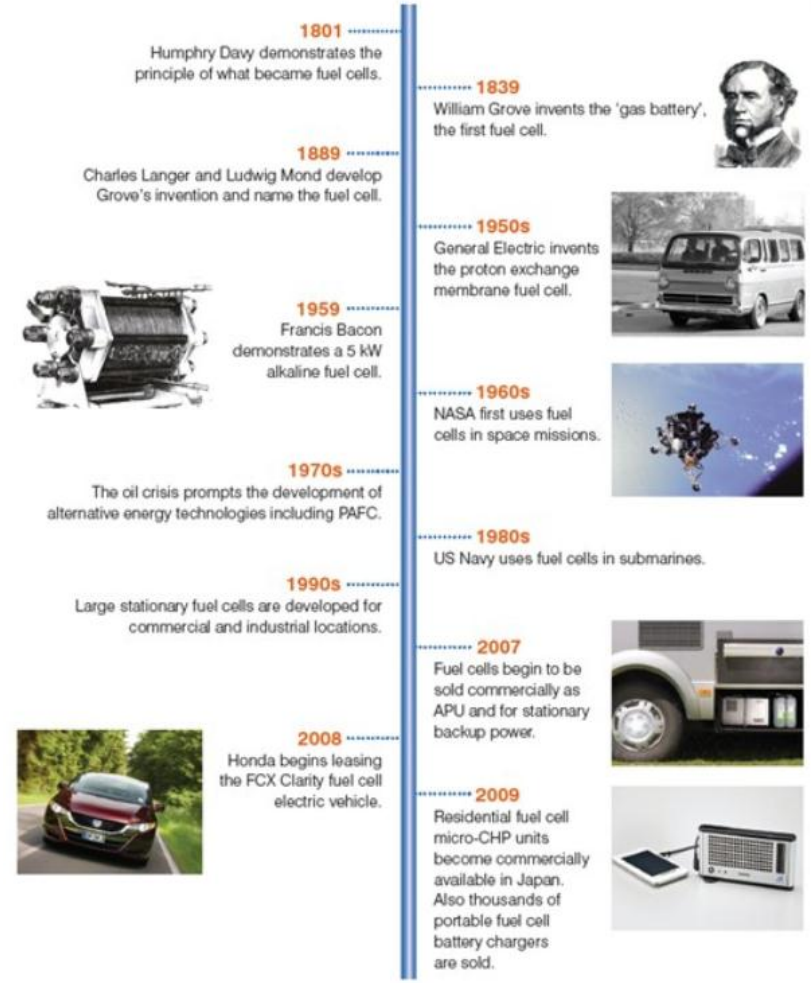


2011 U.S.
5.471 billion metric ton



2040 U.S.
5.691 billion metric ton

Fuel Cell History



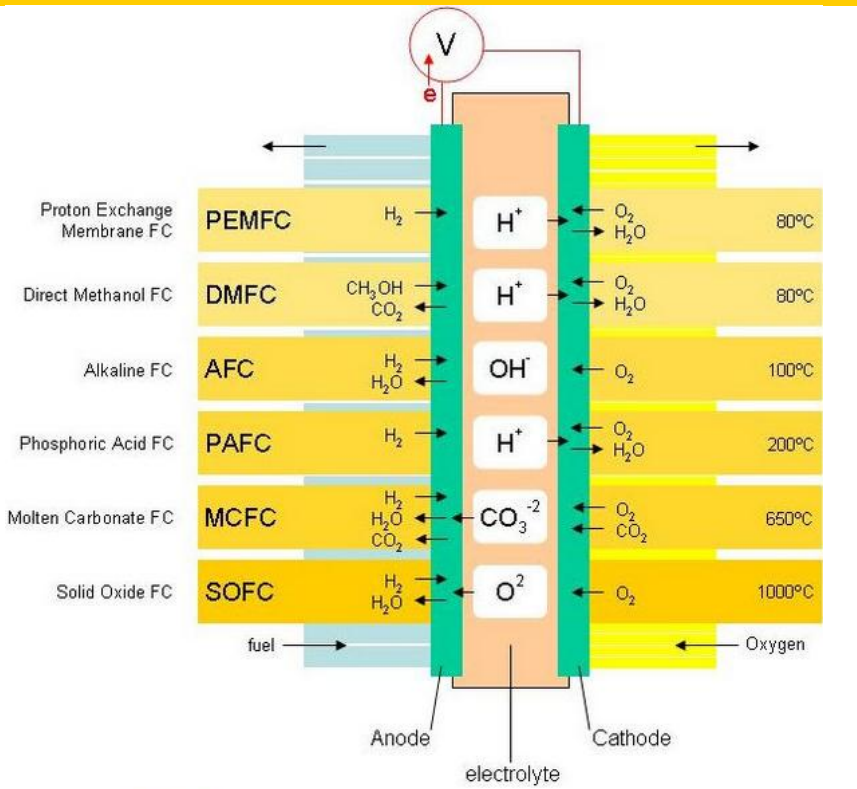
Oct 2012, Ballard 1.1 MW ClearGen fuel cell operated at Toyota Headquarter in Torrance, California

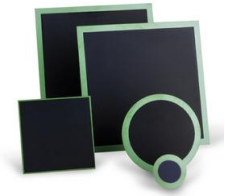
Today there are 2771+ fuel cell forklift trucks in active service

By 2012 there were 45 fuel cell buses (27 active, 10 in development, and 8 retired)

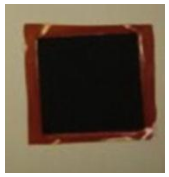
The first mass produced fuel cell vehicle, 2013

Fuel Cell Technologies

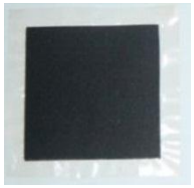




SOFC



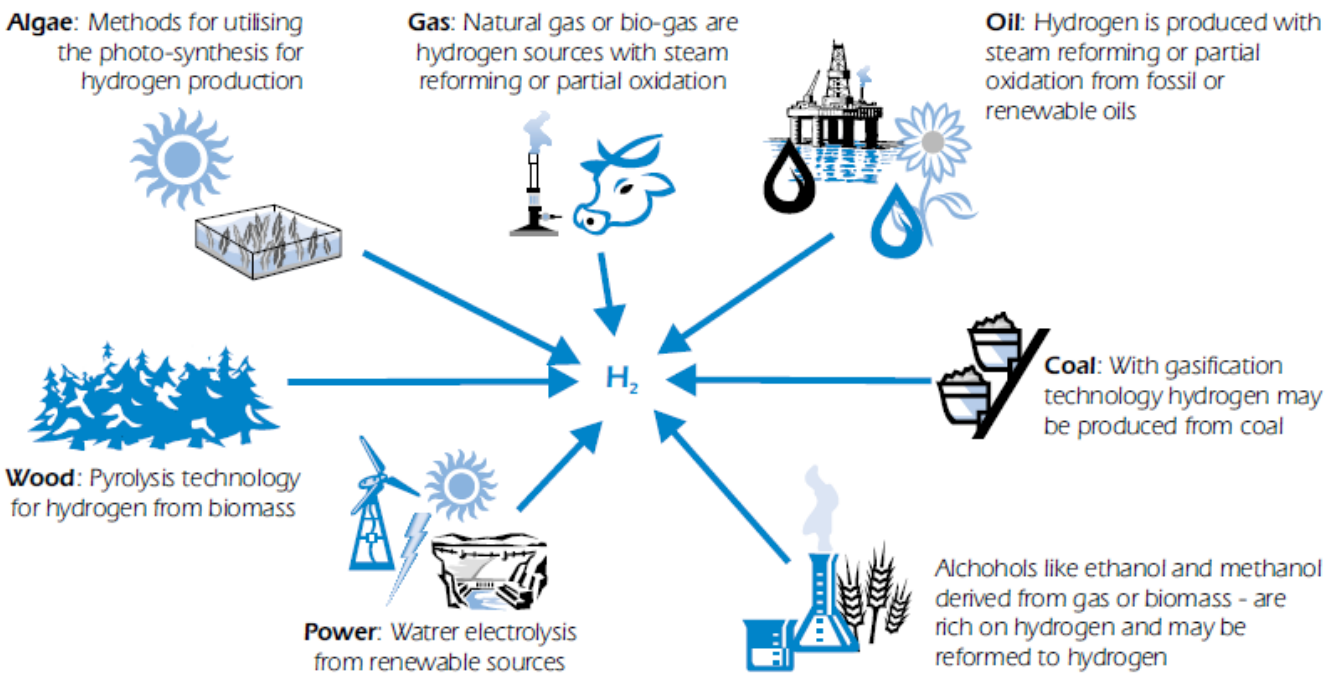
PBI-FC



PEMFC

Fuel Cell Type	Common Electrolyte	Operating Temperature	Typical Stack Size	Efficiency
Polymer Electrolyte Membrane (PEM)	Perfluoro sulfonic acid	50-100°C 122-212° typically 80°C	< 1kW–100kW	60% transpor-tation 35% stationary
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90-100°C 194-212°F	10–100 kW	60%
Phosphoric Acid (PAFC)	Phosphoric acid soaked in a matrix	150-200°C 302-392°F	400 kW 100 kW module	40%
Molten Carbonate (MCFC)	Solution of lithium, sodium, and/ or potassium carbonates, soaked in a matrix	600-700°C 1112-1292°F	300 kW-3 MW 300 kW module	45-50%
Solid Oxide (SOFC)	Yttria stabi-lized zirconia	700-1000°C 1202-1832°F	1 kW–2 MW	60%

Hydrogen Sources



- fossil resources (natural gas, coal, and petroleum)
- renewable resources (biomass, bio-oil)
- water electrolysis from renewable energy sources (sunlight, wind power, hydro power)

ref: hydrogen production and storage, R&D priorities and gaps, 2006

Hydrogen Production Methods

Hydrogen can come from fossil fuels, and biomass through catalytic chemical reactions:

- steam reforming

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

- partial oxidation

  $C_xH_y + O_2 \rightarrow CO_2 + CO + H_2 + heat$

- autothermal reforming

  $C_xH_y + H_2O + O_2 \rightarrow CO_2 + CO + H_2$ (slightly exothermic)

- water gas shift reaction

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

About 9 million tons hydrogen produced in US each year

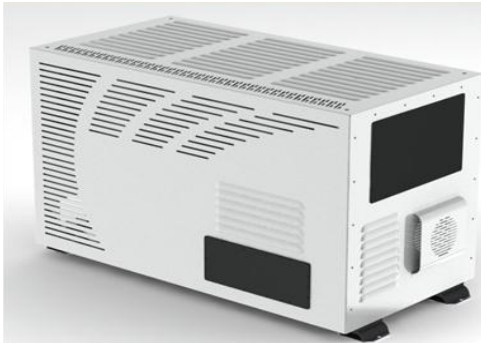
95% of hydrogen produced from steam reforming of natural gas

Fuel Cell R&D Activities at InnovaTek

5 kW ULSD fuel processor for HT-PEM fuel cell distributed power generation, 2009

5 kW HT-PEM for airplane APU, 2011

15 kW bio-SPK fuel processor For HT-PEM fuel cell airplane APU, 2012



4kW ethanol HT-PEM fuel cell light truck APU, 2010

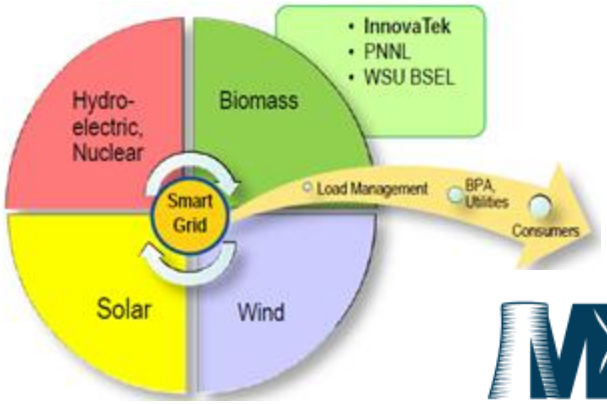
4 kW bio-SPK/SOFC distributed power generator, 2013

Case Study 4 kW Bio-SPK SOFC Fuel Cell for Distributed Power Generation

Objective

develop and demonstrate a fuel cell distributed energy system that operates with 2nd generation bio fuels (do not compete with food)

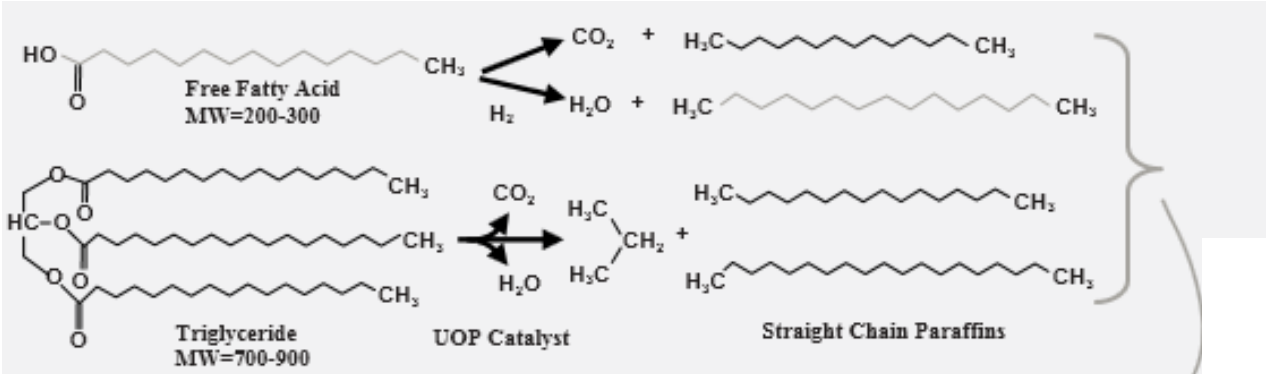
- system based upon InnovaTek's steam reforming process and SOFC
- non-food bio fuels include pyrolysis oil and bio kerosene
- demonstrate in Richland Renewable Energy Park and tied with grid



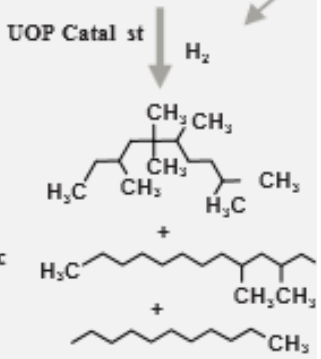
MCEI
MID-COLUMBIA ENERGY INITIATIVE
POWERED BY THE TRI-CITY DEVELOPMENT COUNCIL

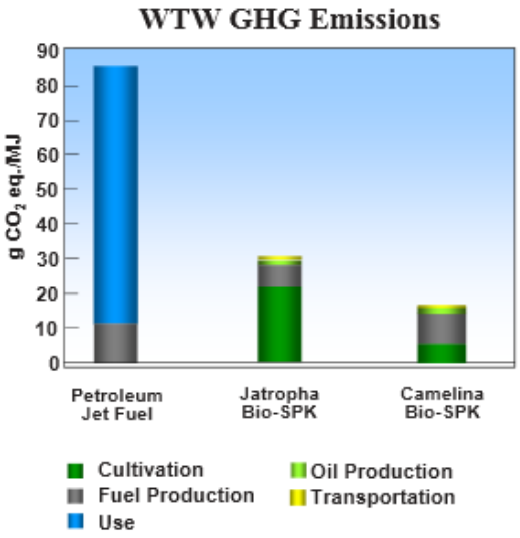
Mid-Columbia Energy Initiative:
Meets 2020 electrical load growth needs with renewables.

2nd Generation of Bio Fuel
Bio-SPK (Synthetic Paraffin Kerosene)



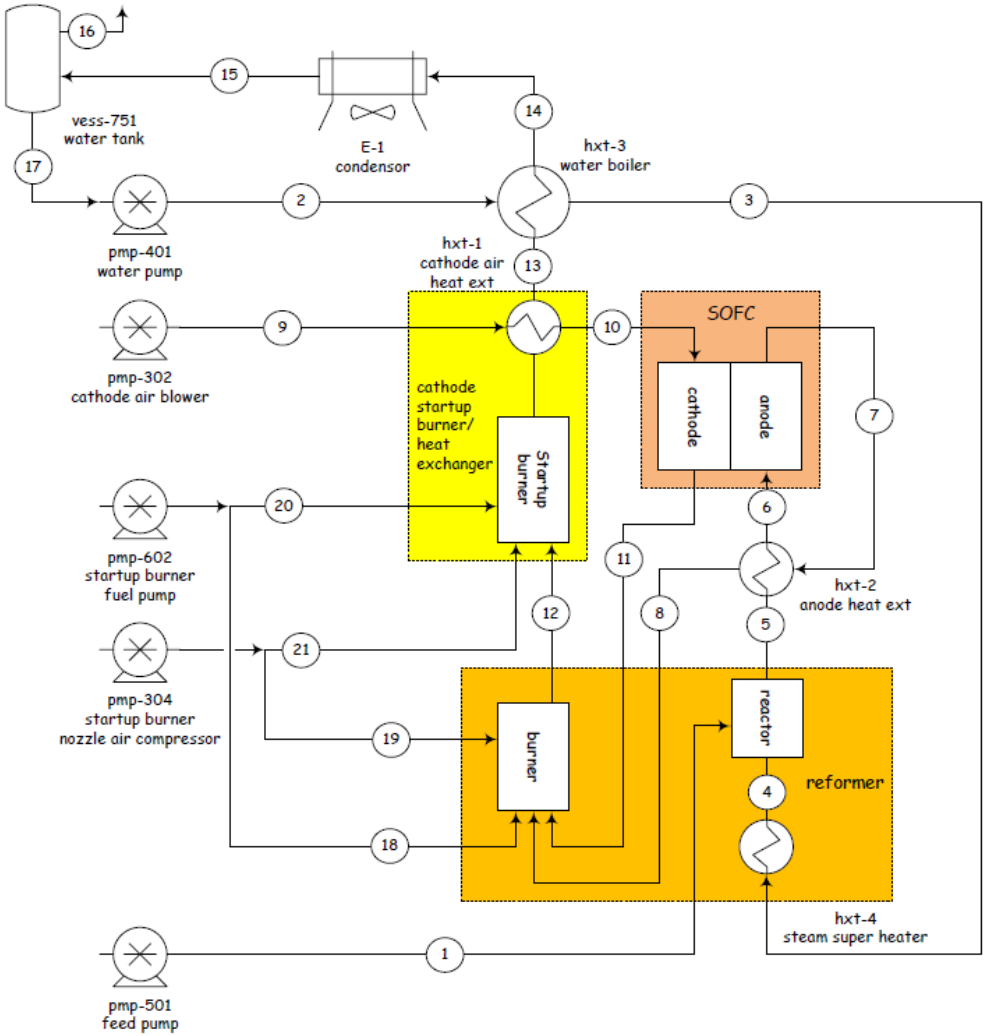
- Natural oils contain oxygen, have high molecular weight
- 1st reaction removes oxygen – product is diesel range waxy paraffins
- 2nd reaction "cracks" diesel paraffins to smaller, highly branched molecules
- End product is same as molecules already present in aviation fuel
- End product is independent of starting oil

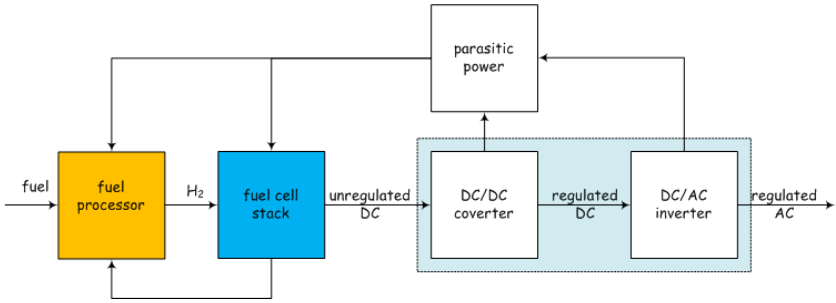




http://www.boeing.com/commercial/environment/pdf/PAS_biofuel_Exec_Summary.pdf

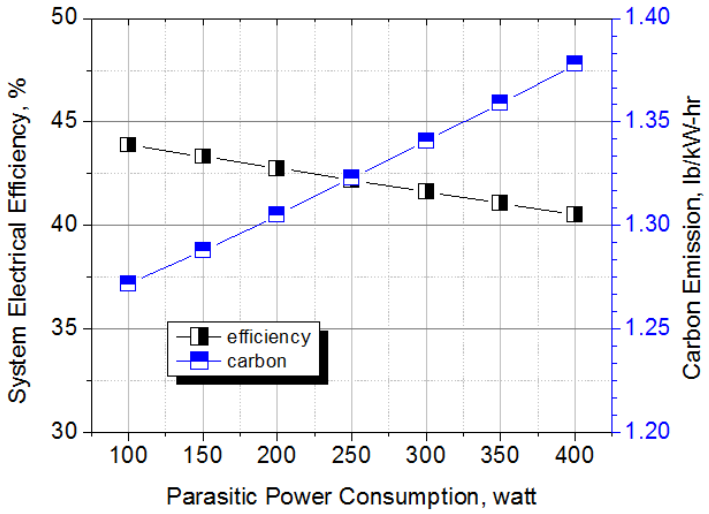
Process Design for 4 kW Bio-SPK SOFC Fuel Cell





total $\eta_{\text{ele}} = \eta_{fps} \times \eta_{csa} \times \eta_{pe} \times \eta_{me} \times U_{csa}$

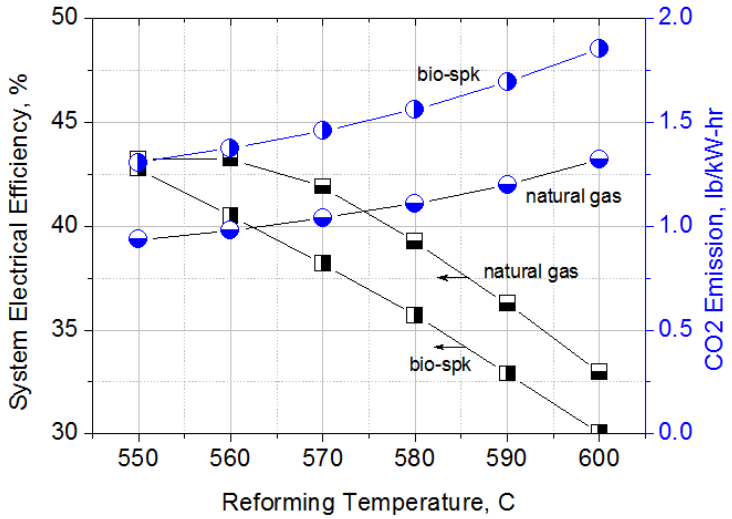
Efficiency and Carbon Emissions



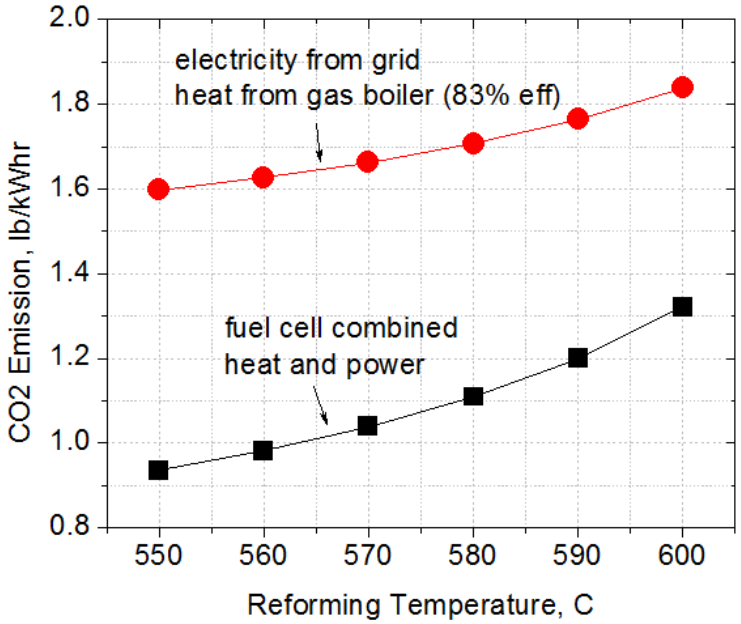
Fuel	Lbs of CO_2 per Million Btu	Heat Rate (Btu per kWh)	Lbs CO_2 per kWh
Coal			
Bituminous	205.300	10,128	2.08
Sub-bituminous	212.700	10,128	2.15
Lignite	215.400	10,128	2.18
Natural gas	117.080	10,414	1.22
Distillate Oil (No. 2)	161.386	10,414	1.68
Residual Oil (No. 6)	173.906	10,414	1.81

Last updated: June 13, 2013

http://*www.eia.gov/tools/faqs/faq.cfm?id=74&t=11*



Fuel Cell Combined Heat and Power



reference: progress report on *the large-scale stationary fuel cell demonstration project in Japan, by New Energy Foundation, April 2009, http://ieahia.org/pdfs/Task18_Japan_Residential_FC_Report.pdf*

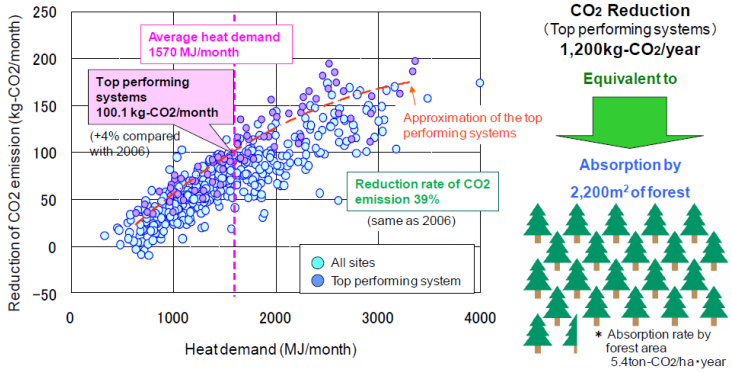


Figure 2.6.1 CO_2 emissions reduction by PEFC systems

Note: Data from 456 sites, January–December 2008 (NG and LPG).

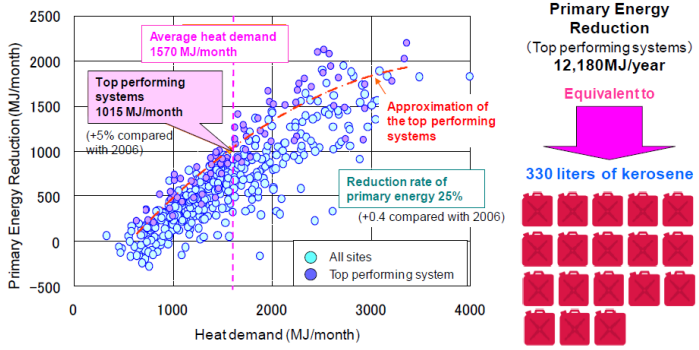


Figure 2.5.1 Energy-saving effect of PEFC systems

Note: Data from 456 sites, January–December 2008 (NG and LPG).

Case Study: Conclusions

"The overall environmental benefits of stationary fuel cells depend on a complex interaction between efficiency, type of fuel supply, end-user requirements, availability of links with grid networks and the technologies with which they are being compared……"

reference: fuel cells for a sustainable future, Jane Powell, Michael Peters, Alan Ruddell, and Jim Haalliday, March 2004

- The fuel cell technology is a sustainable power generation technology if hydrogen is from renewable source (biomass)
- Fuel cell system with greater electrical efficiency (40% or higher) can economically compete against other technologies if hydrogen is from fossil fuels, up to 40% CO_2 reduction is possible
- Fuel cell CHP system can achieve over 90% total energy efficiency, with even greater energy saving and CO_2 reduction

Fuel Cell Applications and Markets

Honda FCX fuel cell car

UTC (now ClearEdge Power)
fuel cell Bus

Bloom Energy
ES-570 200 KW SOFC

FuelCell Energy
DFC 300 2.8 MW MCFC

Fuel cell forklift trucks

Fuel cell portable
battery charger

Fuel cell portable
charger

ClearEdge Power (OR) 5 KW
Fuel cell mCHP

Relion (WA) fuel cell for
backup power

UltraCell (CA) 25 W
Portable charger

Tokyo Gas 700 W
mCHP fuel cell unit

Fuel Cell 2012 Status

2012 Fuel Cell Customers

Repeat customers in blue

Adobe Systems	+ 0.4 MW
Americold	+ 0.6 MW
Apple	+ 5 MW
AT&T	+ 9.6 MW
CBS Studios	+ 4.8 MW
Coca-Cola	+0.5 MW; +56 forklifts
eBay	+ 6 MW
JMB Realty	+ 0.4 MW
Lowe's	+ 161 forklifts
Mercedes-Benz	+72 forklifts
News Corp.	+ 0.4 MW
Owens Corning	+ 0.4 MW
Procter & Gamble	+ 340 forklifts
Roger's Gardens	+ 0.015 MW
San Jose Sharks	+ 0.4 MW
Sysco	+ 524 forklifts
Walmart	+ 3.6 MW

+ 32.1 MW
+ 1,131 forklifts

Top Fuel Cell Power Customers

1	at&t	17.1 MW at 28 sites
2	Walmart	10.4 MW at 26 sites
3	ebay	6.5 MW at 2 sites
4	Apple	5.3 MW at 2 sites
5	KAISER PERMANENTE	5.0 MW at 7 sites
6	Coca-Cola	3.1 MW at 4 sites
7	COX	3.0 MW at 5 sites
8	CBS	2.4 MW at 2 sites
9	Sheraton	2.3 MW at 5 sites
10	Adobe	1.6 MW at 2 sites

Top Fuel Cell Lift Truck Customers

1	Sysco	700+ forklifts at 7 sites
2	Walmart	509 forklifts at 3 sites
3	P&G	340 forklifts at 4 sites
4	central grocers	234 forklifts at 1 site
5	BMW	230+ forklifts at 1 site
6	WinCo FOODS	200+ forklifts at 1 site
7	Kroger	161 forklifts at 1 site
8	LOWE'S	161 forklifts at 1 site
9	Wegmans	140+ forklifts at 1 site
10	Coca-Cola	96 forklifts at 2 sites

reference: the business case for fuel cells 2012, America's partner in power, by fuel cells 2000