emerging energy research

Hydrogen and Fuel Cell Advisory
ID# HFC 575-070327

The Hydrogen–Fuel Cell Disconnect:

Fuel Cells are becoming a true comercial commodity, completely independent from the 'Hydrogen Economy'

March 2007
NHA Annual Hydrogen Conference
San Antonio, Texas

James Horwitz
Senior Analyst
+1 617 551 8580
jhorwitz@emerging-energy.com

The Hydrogen – Fuel Cell Disconnect

The Early Days of the Hydrogen Fuel Cell: Optimism Without Foresight

Current Fuel Cell Technologies:
Hydrogen Connections and Disconnections

Fuel Cell Vertical Market Timeline and Players

Fuel Choices – Pros and Cons

Gas Utilities and Refiners as FC Promoters

Conclusion

Optimism Without Foresight

- **The Biggest Obstacle to the Hydrogen Economy has been the 'Chicken or Egg' Conundrum**
  - Hydrogen fuel cells can never achieve commercial-level penetration without available hydrogen infrastructure
  - A hydrogen infrastructure will never be developed without widespread market penetration of fuel cells
  - For either to come first, massive long-term government support is required

The Early Days of the Hydrogen Fuel Cell (1970 – 2000)

- **AFC in Space**
  - Liquid Hydrogen available
  - International Fuel Cell
  - NASA
  - UTC
  - Toshiba

- **PAFC on the Ground**
  - UTC goes stationary
  - Fuji runs with the technology
  - PEM looked at only for vehicles
  - SOFC theoretical

- **Millennium Re-Invention**
  - Ballard, Plug Power, FuelCell Energy Survive
  - PEM applications broaden
  - GE, Siemens, Rolls Royce continue

The Hydrogen – Fuel Cell Disconnect

The Early Days of the Hydrogen Fuel Cell: Optimism Without Foresight

Current Fuel Cell Technologies:
Hydrogen Connections and Disconnections

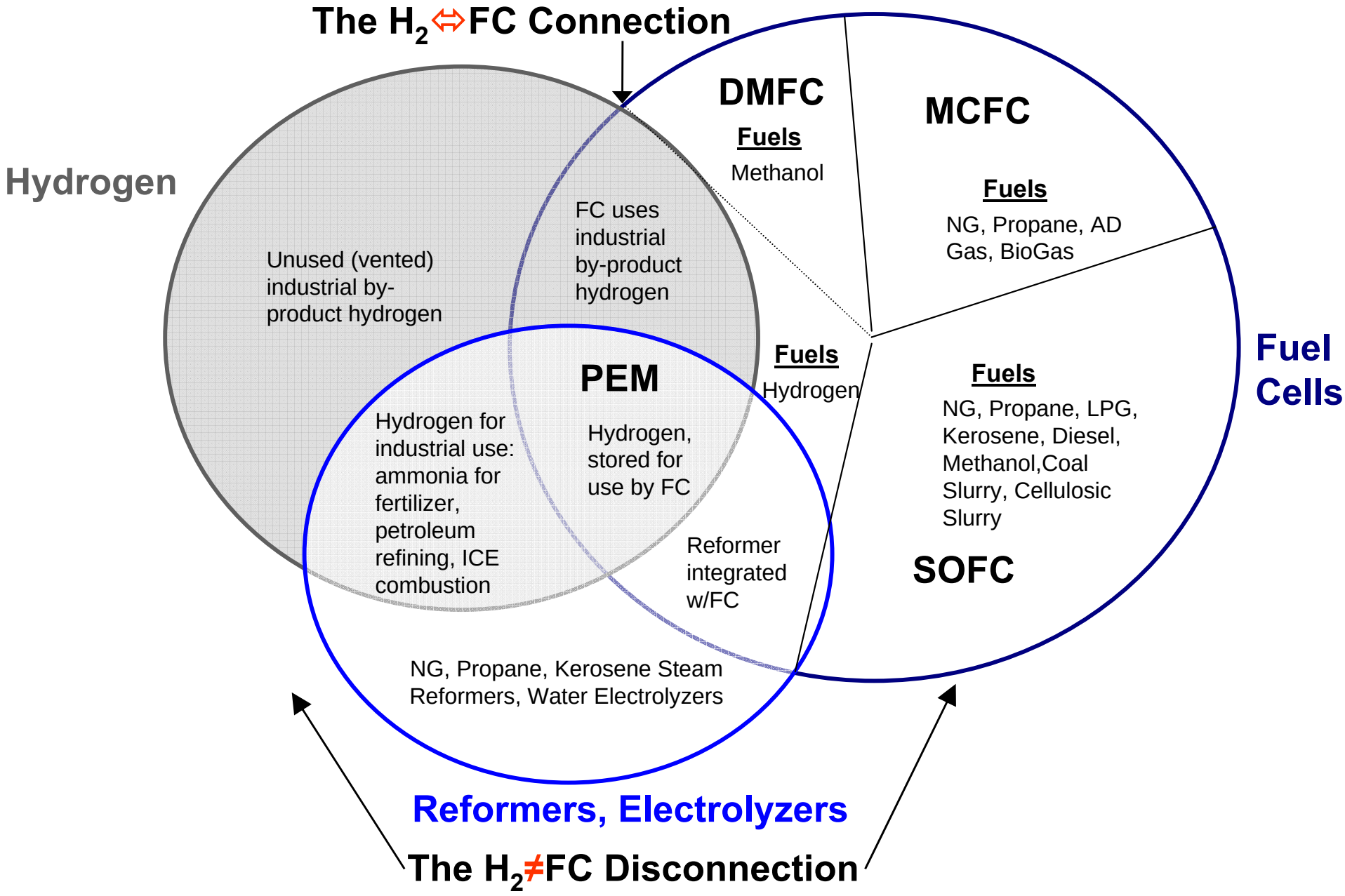
Fuel Cell Vertical Market Timeline and Players

Fuel Choices – Pros and Cons

Gas Utilities and Refiners as FC Promoters

Conclusion

Hydrogen, Reformers, and Electrolyzers, Fuel Cells



The Hydrogen – Fuel Cell Disconnect

The Early Days of the Hydrogen Fuel Cell: Optimism Without Foresight

Current Fuel Cell Technologies:
Hydrogen Connections and Disconnections

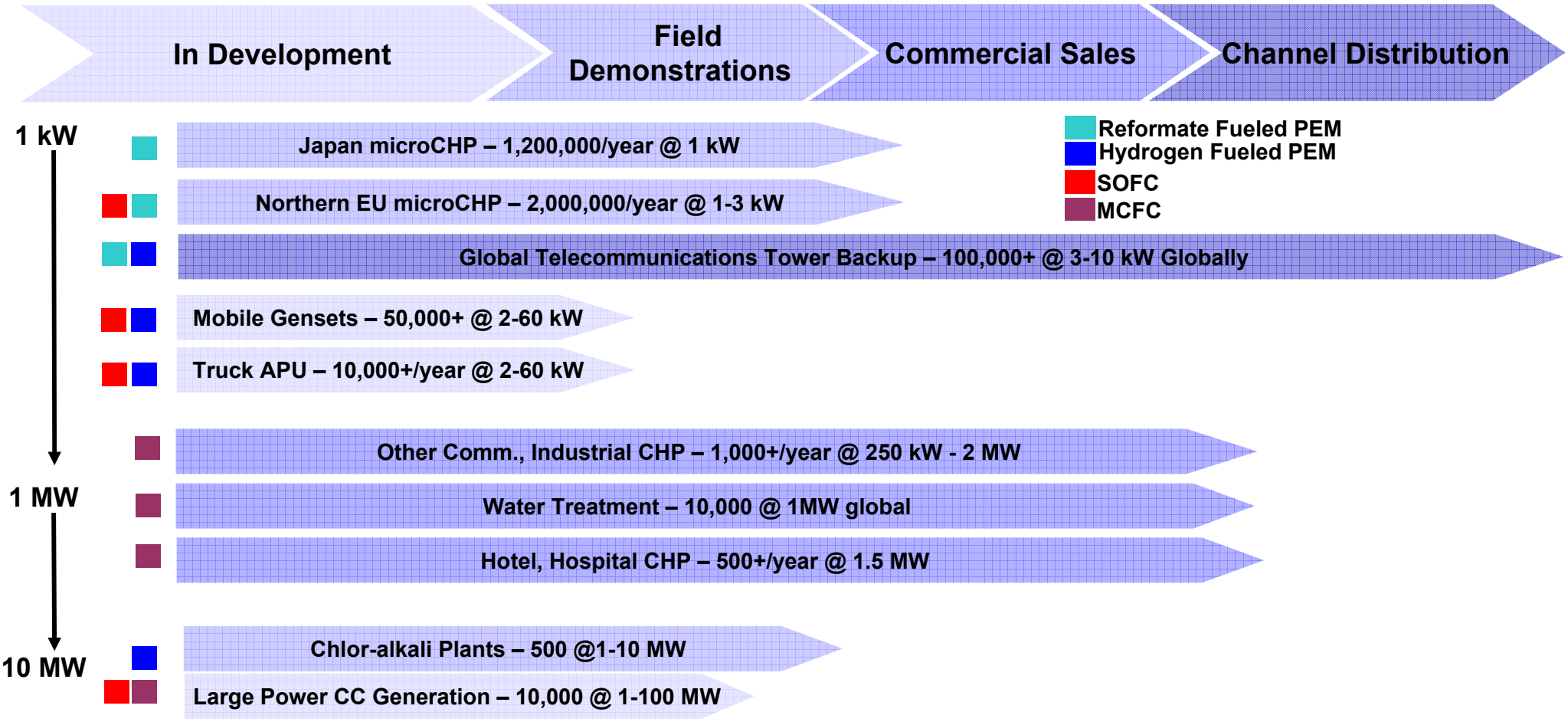
Fuel Cell Vertical Market Timeline and Players

Fuel Choices – Pros and Cons

Gas Utilities and Refiners as FC Promoters

Conclusion

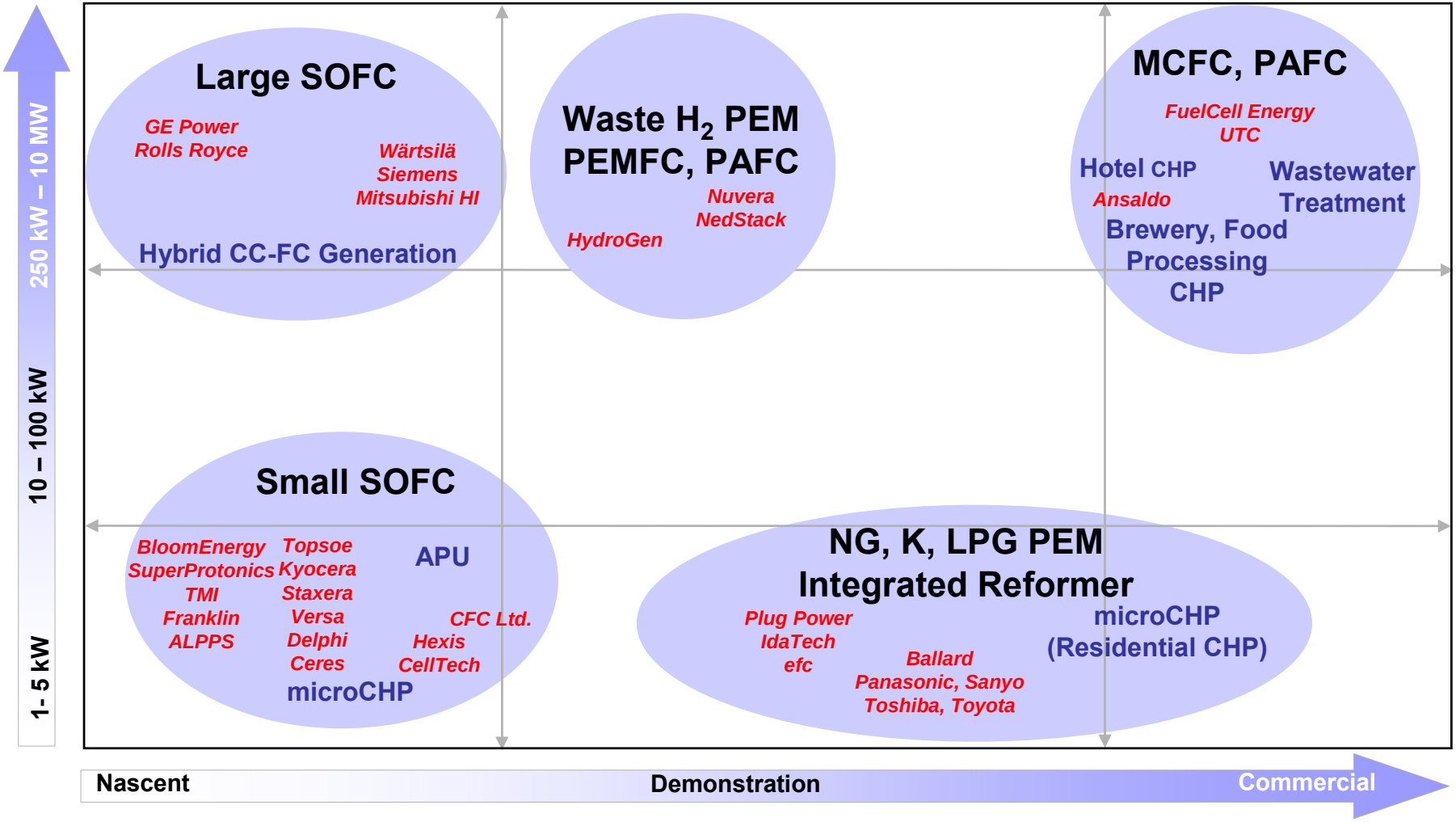
1 kW+ non-Delivered H_2 FC Vertical Market Timeline



Source: Emerging Energy Research

Major stationary markets using NG, LPG, Propane, and even AD gas for fuel cells providing primary source power will result in hundreds of megawatts of sales over the next 10 years.

Non H_2 Economy Dependent FC Vertical Market Players



Source: Emerging Energy Research

Of the hundreds of potential FC applications, only PEM-based mobility requires a hydrogen infrastructure. Even there, fork lifts with on-site reforming are becoming a viable application, and Nuvera is working on vehicle on-board reforming.

The Hydrogen – Fuel Cell Disconnect

The Early Days of the Hydrogen Fuel Cell: Optimism Without Foresight

Current Fuel Cell Technologies:
Hydrogen Connections and Disconnections

Fuel Cell Vertical Market Timeline and Players

Fuel Choices – Pros and Cons

Gas Utilities and Refiners as FC Promoters

Conclusion

Liquid and Gaseous Fuels

	Fuel	Chemical Formula	Boiling Point ºC	Heat Capacity MJ/Kg	Source	Fuel Cell Types	Fuel-specific Developers
Liquids (at 25° C)	**Fuel Oil**	$C_{20}H_{42}+\ldots+C_{40}H_{82}$	-	-	Partially refined from petroleum	-	None - Hard to handle, ignite
	Diesel	$C_{16}H_{34}+C_{18}H_{38}+C_{19}H_{40}$ + trace Sulfur, etc.	300	63	Partially refined from petroleum	SOFC	CellTech, TMI, Versa, Staxera
	Kerosene	$C_{12}H_{26}+C_{13}H_{28}+C_{14}H_{30}$	216	46	Liquid refined from petroleum	PEM, SOFC	Nippon Oil, Idemitsu Kosan
	Methanol	CH_3OH	65	22	Liquid oxidized from Natural Gas	DMFC, SOFC	Hitachi, NEC, DoCoMo, Etc., Wärtsilä (Topsoe)
Gases	**LPG (Liquefied Petroleum Gas)**	$C_3H_8+C_4H_{10}+C_5H_{12}$ Propane + Butane + Pentane	-0.5	32	Gases refined from petroleum	PEM, SOFC	Ceres Power, Cosmo Oil, Jomo (Sanyo, Toshiba)
	Propane	C_3H_8	-42	32	Gas refined and purified from petroleum	PEM, MCFC, SOFC	Plug Power, IdaTech
	Natural Gas (Methane)	CH_4	-164	37	Naturally occurring, minimal refining	PAFC, MCFC, PEM, SOFC	UTC, FCE, Plug Power, Tokyo Gas, Osaka Gas, Matsushita
	BioGas or Anaerobic Digestor Gas	CH_4 + Impurities	-164	34	Composting Organic Waste	MCFC, SOFC	FuelCell Energy, Fuji
	Hydrogen	H_2	-253	120	Electrolyzed from water, reformed from hydrocarbons	PEM, PAFC, AFC, SOFC	ReliOn, HydroGenics, Nuvera, Nedstack, HydroGen, Ballard

Source: IEA, Emerging Energy Research

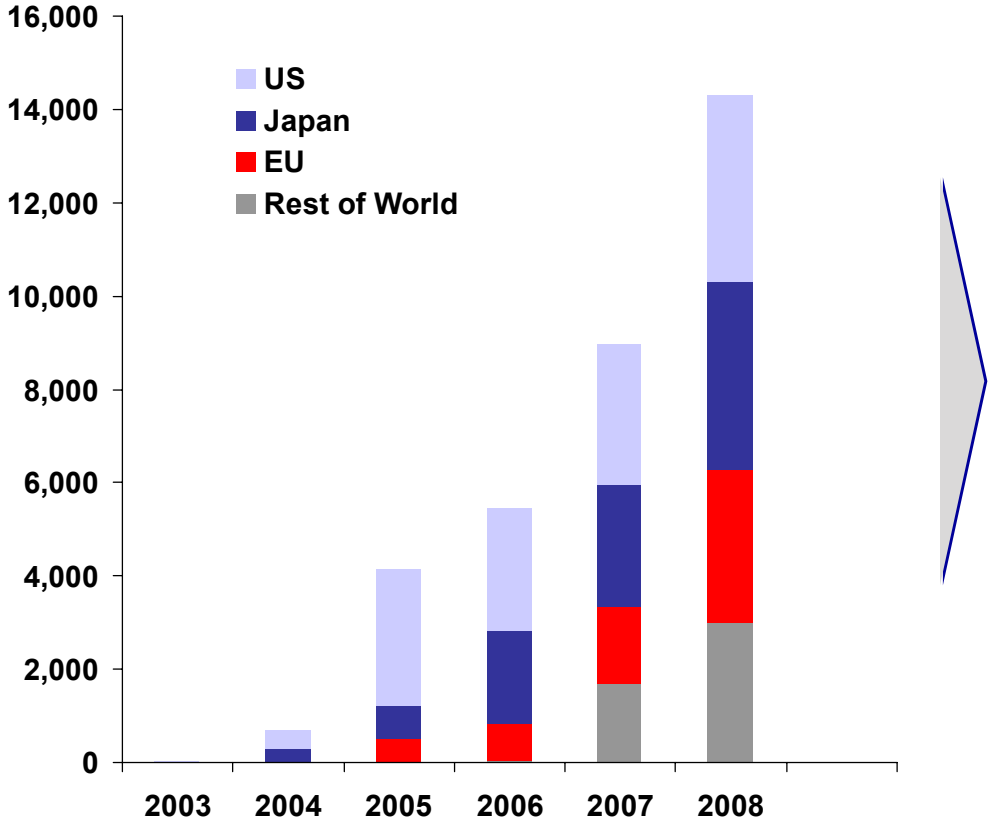
Note: Heat capacity figures in megajoules per kilogram (by weight)
A megajoule is about 3.5 kW hours of energy

The energy available from a particular fuel is directly related to its hydrogen content. Heavier fuels are more viscous and are more difficult for fuel cells to use. Gases are harder to contain and transport.

Global FC Shipments by Fuel Class – Internal or On-Site Reforming

Natural Gas

Global Market kW Shipments

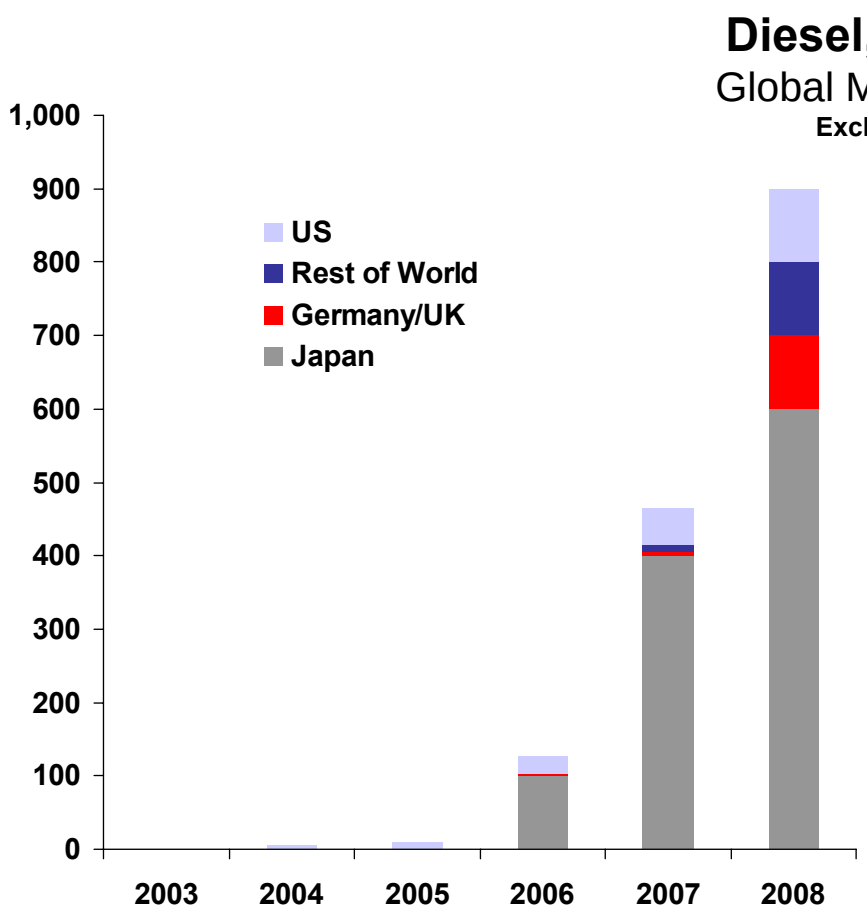


Note: Figures for 2006 are approximate; 2007 and 2008 projected from outstanding orders
Source: Companies, Emerging Energy Research

- **US growth can equal other regions assuming state-based clean generation incentives continue.**
- **PG&E is supporting sales in CA, while in the Northeast, KeySpan is finally showing some interest.**
- **The EU will provide increasing incentives. Holland has a comprehensive NG pipeline and is supportive of residential CHP. Most major gas suppliers have development agreements with FC developers.**
- **Canadian NG supplier Enbridge hopes to run with FCE's DFC-ERG application.**
- **Korean POSCO has ordered a 2.4 MW system from FCE for late 2007 or 2008 completion.**

Wherever there are natural gas pipelines, all fuel cell technologies are viable distributed generation and CHP solutions. The gas utilities become power companies.

Global Shipments by Fuel Class – Internal or On-Site Reforming



- **These are more complex hydrocarbons, and sulfur in diesel is a major FC contaminent.**
- **Japanese heating fuel refiners have been successful with reformers integrated with PEM FCs.**
- **SOFC technology research is targeting diesel compatability, and many US developers are claiming success.**
- **Linde (BOC) hopes the Ceres SOFC will work well with delivered LPG by 2008.**

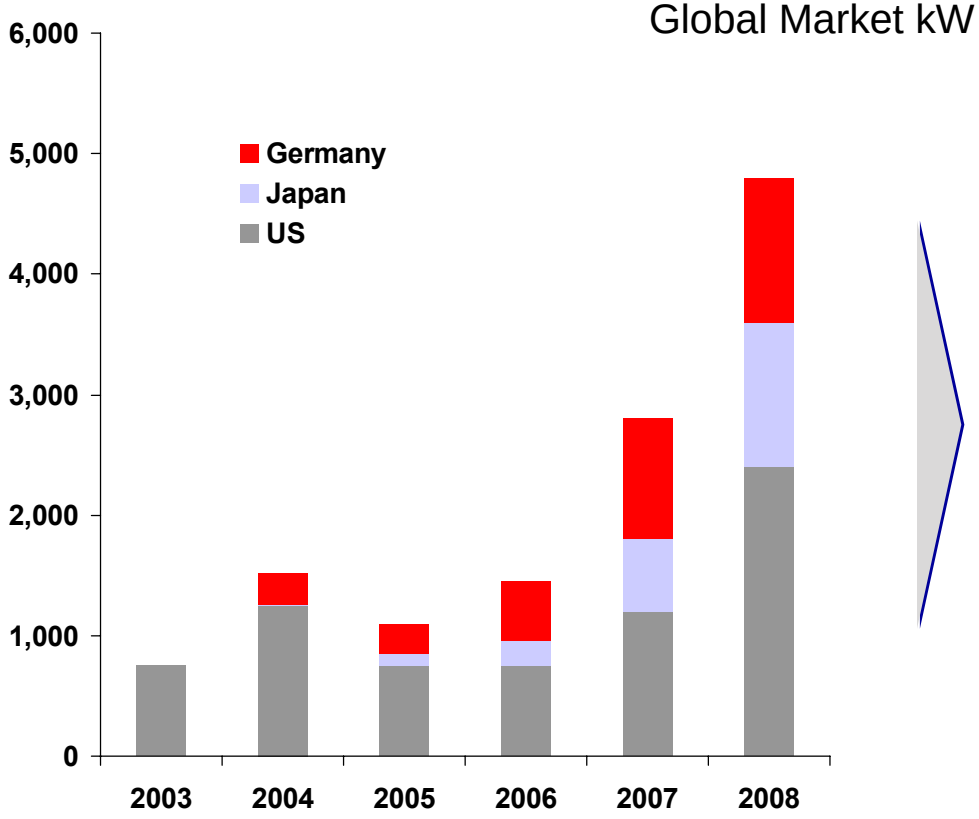
Note: Figures for 2006 are approximate; 2007 projected from outstanding orders
Source: Companies, Emerging Energy Research

Nippon Oil leads world in kerosene reformer technology. Kerosene is the delivered heating fuel of choice in Japan. Idatech and Plug Power will expand sales of small remote LPG/Propane PEM fuel cells in the US and globally. The fuel-versatile SOFC market promises to blossom during 2008.

Global Shipments by Fuel Class – Internal or On-Site Reforming

Anaerobic Digestor Gas

Global Market kW Shipments



Figures for 2006 are approximate, 2007 projected from outstanding orders.
Source: Company information, Emerging Energy Research

- **FuelCell Energy has the only successful major AD gas installations at present. Initial 2003 and 2004 LA and Seattle water treatment plant installations paved the way.**
- **Linde has signed on to distribute for FCE with water treatment plants as a target market.**
- **Subsidies from states augment federal subsidies when fuel cells use renewable fuels.**
- **SOFC holds promise for the future, but most AD installations use all of the heat generated by the MCFC.**

FuelCell Energy is having increasing success with wastewater treatment plants, breweries, and food processors. Subsidies in the US are more generous for renewable rather than just clean generation. The rest of the world, particularly the Middle East and mainland Asia, will follow once technology is established.

The Hydrogen – Fuel Cell Disconnect

The Early Days of the Hydrogen Fuel Cell: Optimism Without Foresight

Current Fuel Cell Technologies:
Hydrogen Connections and Disconnections

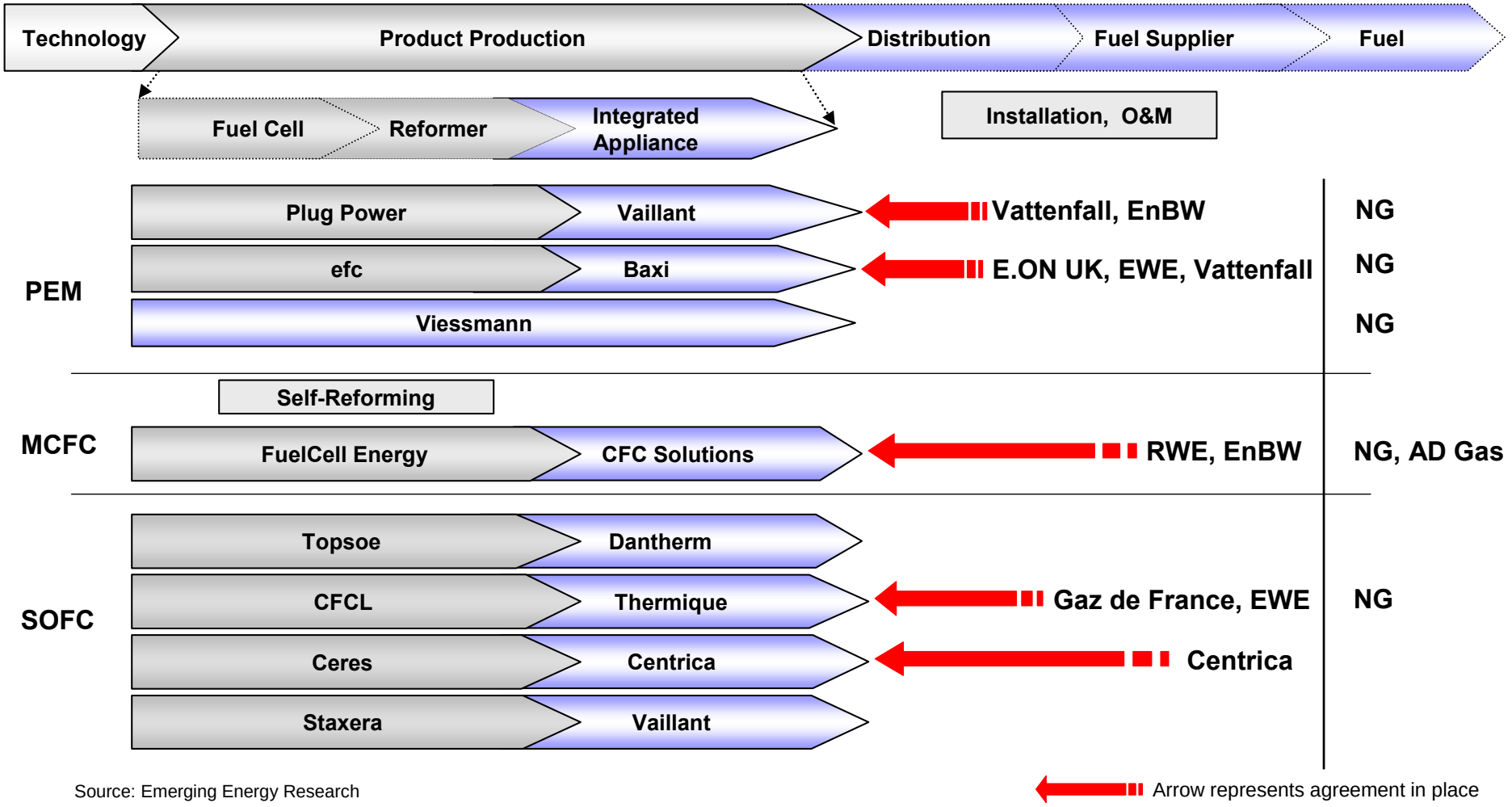
Fuel Cell Vertical Market Timeline and Players

Fuel Choices – Pros and Cons

Gas Utilities and Refiners as FC Promoters

Conclusion

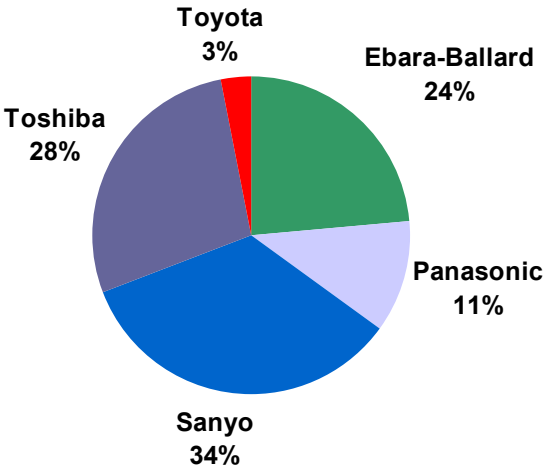
EU CHP Market Driven by Utilities



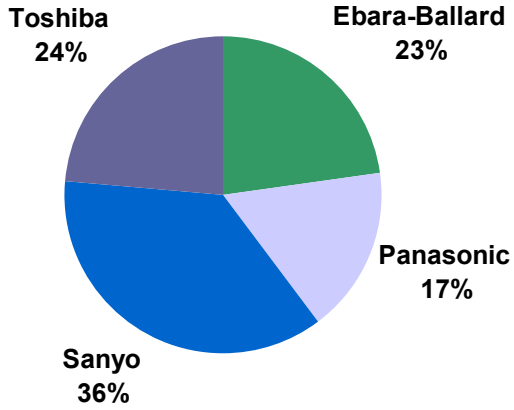
Experienced heating equipment manufacturers like Vaillant, Viessmann, Dantherm, Thermique, and Baxi have already partnered with gas utilities. No less than five additional continental gas suppliers installed Hexis SOFC mCHP systems 2003–2005, and are watching the current market closely.

Japanese Government Provides Subsidies to Utilities

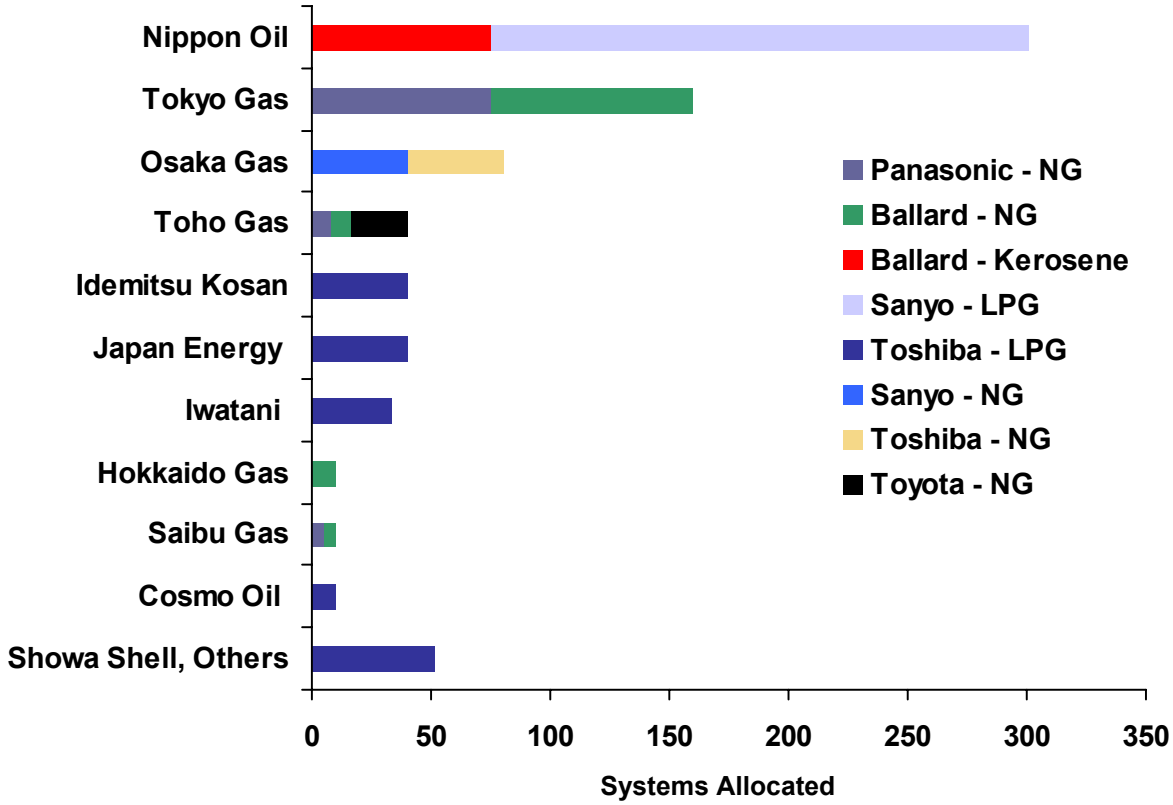
FY 2006 – 777 Systems



FY 2005 – 480 Systems



NEDO - NEF Residential Fuel Cell Program



Source: NEDO, Emerging Energy Research

The Large-Scale Demonstration Program has engaged Japan's leading energy companies, and has promoted fuel diversity. Tokyo Gas and Osaka Gas supply their own natural gas reformers while Nippon Oil and other refiners have designed kerosene and LPG reformers.

The Hydrogen – Fuel Cell Disconnect

The Early Days of the Hydrogen Fuel Cell: Optimism Without Foresight

Current Fuel Cell Technologies:
Hydrogen Connections and Disconnections

Fuel Cell Vertical Market Timeline and Players

Fuel Choices – Pros and Cons

Gas Utilities and Refiners as FC Promoters

Conclusion

Conclusion: The Chicken Has Landed

- **MCFC, SOFC, reformer technology advances obviate need for hydrogen infrastructure to precede**
  - FCE paving the way for AD Gas
  - Ethanol and methanol attractive for SOFC developers
  - Reformer technology advancing – lower cost, smaller size, higher efficiency
- **The Chicken (fuel cells) has landed**
  - Hopefully the impending commercial success will lay the groundwork for a future hydrogen economy

Emerging Energy Research

Emerging Energy Research provides analyst-directed advisory services on an annual subscription basis, providing market intelligence, competitive analysis and strategy advice in response to the specific needs of our clients. These services provide value-added support of clients' competitive and market strategies, and are intended to be interactive, offering clients direct access to EER experts.

Advisory service clients receive a stream of market and company briefs, ongoing market data and forecast support, telephone inquiry privileges, and regular analyst briefings. While much of the content is syndicated, clients also receive ongoing individual support of market assessment and strategy development needs.

For more information on EER's advisory services, please contact Marcel van Galen at mvangalen@emerging-energy.com, or contact one of our offices:

Cambridge

Emerging Energy Research
700 Technology Square
Cambridge, MA 02139 USA
Phone: +1 617 551 8480
Fax: +1 617 551 8481

Barcelona

Emerging Energy Research
Paseo de Gracia 60, 3B
Barcelona 08007 Spain
Phone: +34 93 467 6750
Fax: +34 93 467 6754