Expanding the Use of Biogas with Fuel Cell Technologies

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Biogas with Fuel Cells Workshop

National Renewable Energy Laboratory

Golden, Colorado

6/11/2012

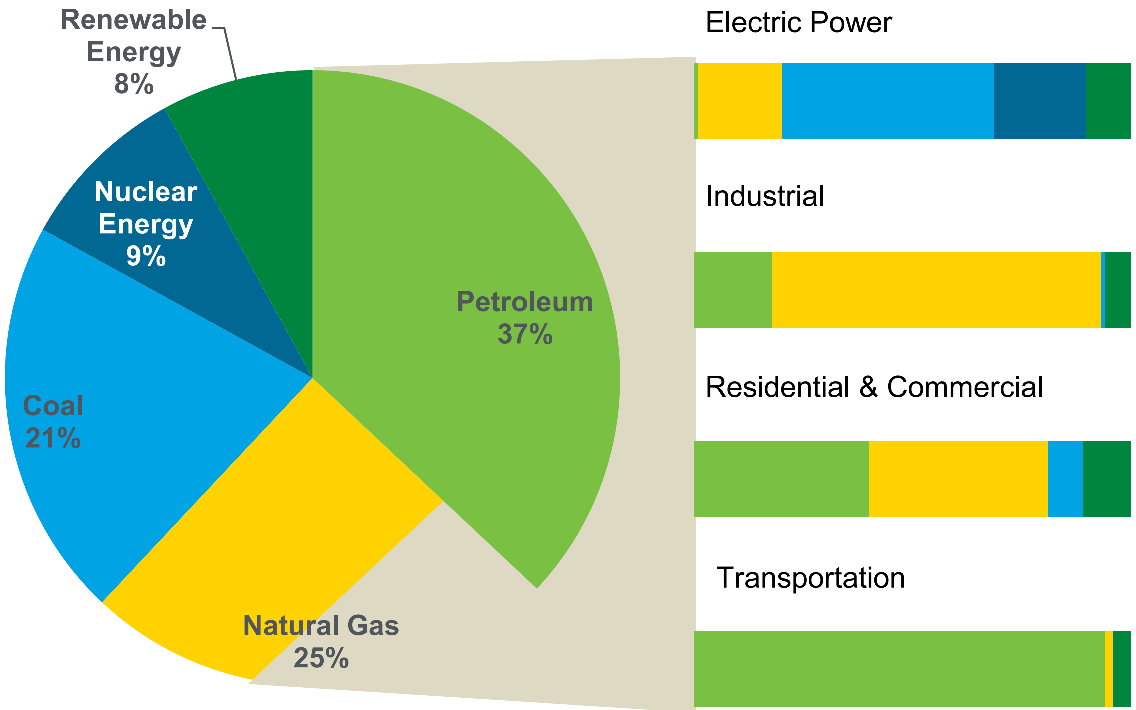
Sunita Satyapal

U.S. Department of Energy

Fuel Cell Technologies Program

Program Manager

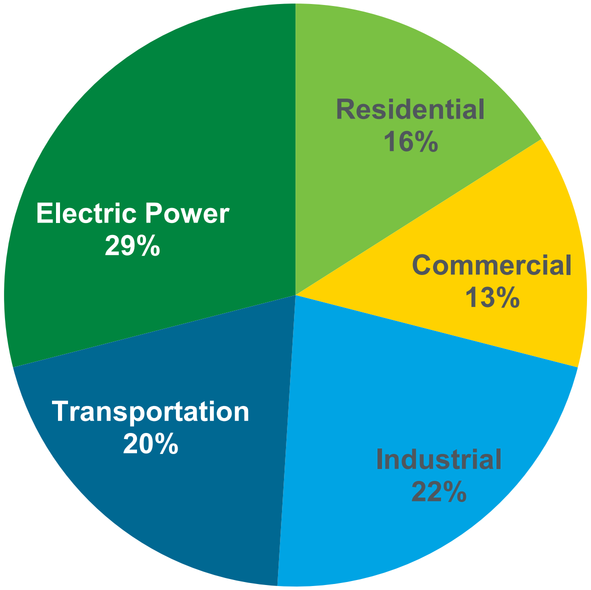
U.S. Primary Energy Consumption by Source and Sector



Total U.S. Energy = 98 Quadrillion Btu/yr

Source: Energy Information Administration, *Annual Energy Review 2010,* Table 1.3

Fuel Cells can apply to diverse sectors



Fuel Cells – An Emerging Global Industry

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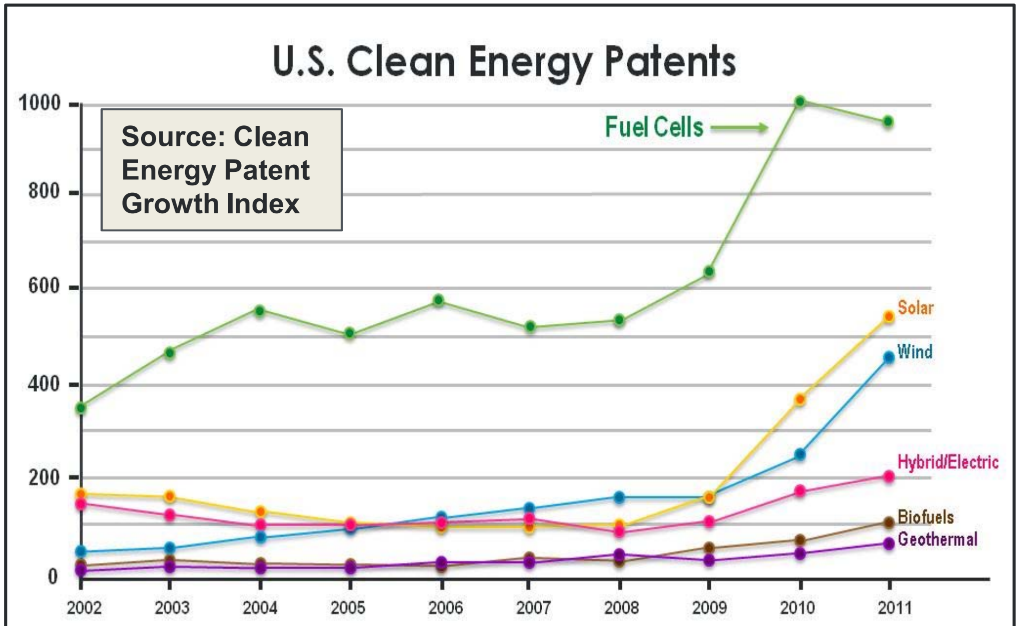
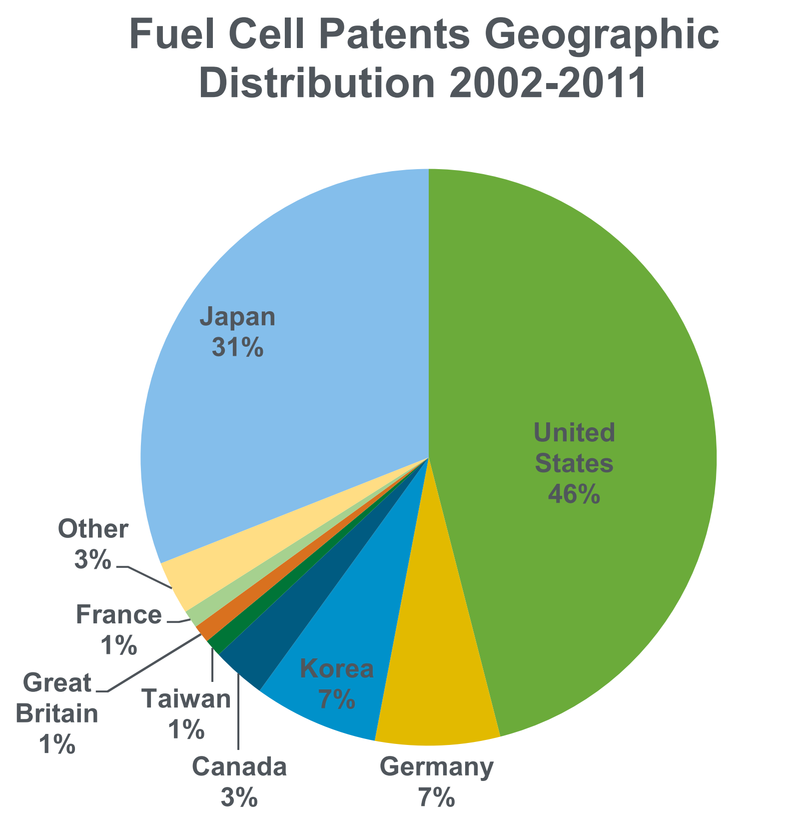


Clean Energy Patent Growth Index

Top 10 companies: GM, Honda, Samsung, Toyota, UTC Power, Nissan, Ballard, Plug Power, Panasonic, Delphi Technologies

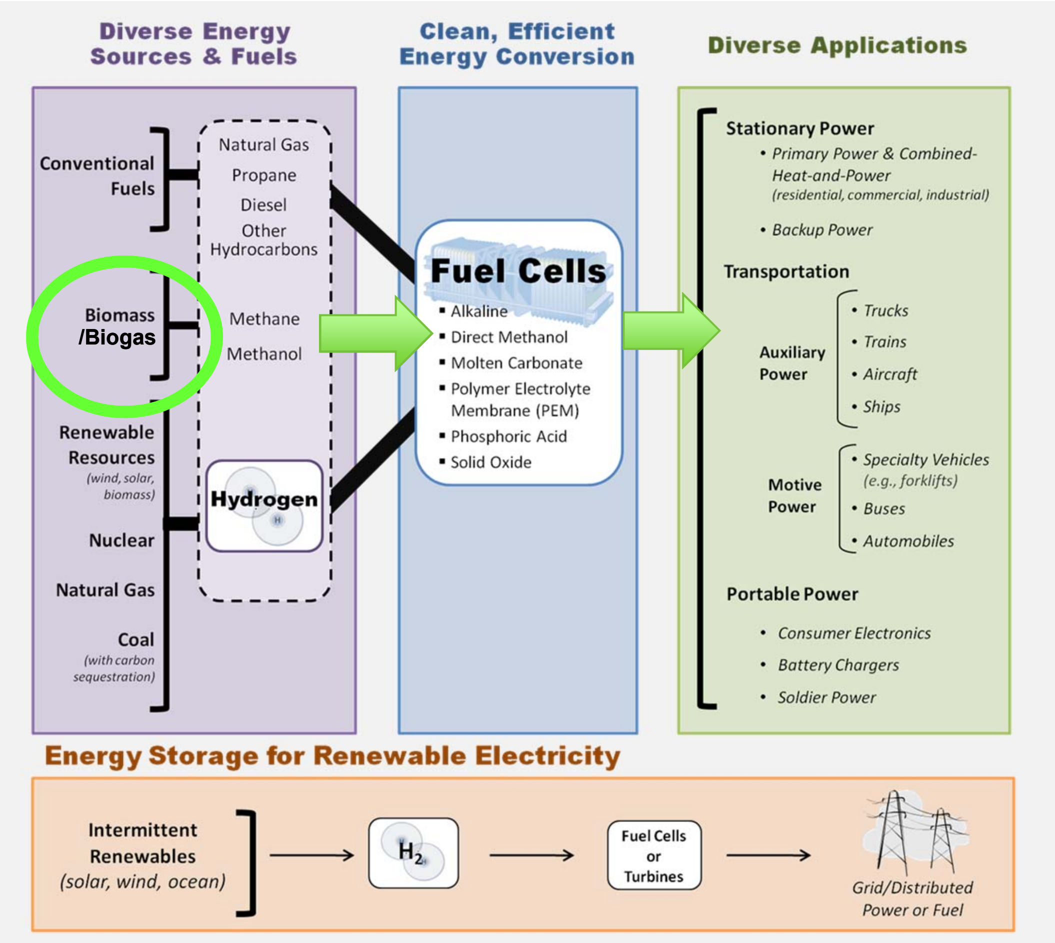


Clean Energy Patent Growth Index[1] shows that fuel cell patents lead in the clean energy field with over 950 fuel cell patents issued in 2011.

- Nearly double the second place holder, solar, which has ~540 patents.

[1] http://cepgi.typepad.com/files/cepgi-4th-quarter-2011-1.pdf

The Role of Fuel Cells



Key Benefits

Very High Efficiency
- **up to 60%** *(electrical)*
- **up to 70%** *(electrical, hybrid fuel cell / turbine)*
- **up to 85%** *(with CHP)*

Reduced CO_2 Emissions
- **35–50%+ reductions** *for CHP systems (>80% with biogas)*
- **55–90% reductions** *for light-duty vehicles*

Reduced Oil Use
- **>95% reduction** *for FCEVs (vs. today's gasoline ICEVs)*
- **>80% reduction** *for FCEVs (vs. advanced PHEVs)*

Reduced Air Pollution
- **up to 90% reduction in criteria pollutants** *for CHP systems*

Fuel Flexibility
- **Clean fuels** — *including biogas, methanol, H_2*
- **Hydrogen** — *can be produced cleanly using sunlight or biomass directly, or through electrolysis, using renewable electricity*
- **Conventional fuels** — *including natural gas, propane, diesel*

Worldwide Commitment to H2 and Fuel Cells

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The world's leading automakers have committed to develop FCEVs. Germany and Japan have announced plans to expand the hydrogen infrastructure.

Major Auto Manufacturers' Activities and Plans for FCEVs

Toyota
- 2010-2013: U.S. demo fleet of 100 vehicles
- 2015: Target for large-scale commercialization
- "FCHV-adv" can achieve 431-mile range and 68 mpgge

Honda
- Clarity FCX named "World Green Car of the Year"; EPA certified 72mpgge; leasing up to 200 vehicles
- 2015: Target for large-scale commercialization

Daimler
- Small-series production of FCEVs began in 2009
- Plans for tens of thousands of FCEVs per year in 2015 – 2017 and hundreds of thousands a few years after
- In partnership with Linde to develop fueling stations.
- ***Recently moved up commercialization plans to 2014***

General Motors
- 115 vehicles in demonstration fleet
- 2012: Technology readiness goal for FC powertrain
- 2015: Target for commercialization

Hyundai-Kia
- 2012-2013: 2000 FCEVs/year
- 2015: 10,000 FCEVs/year
- "Borrego" FCEV has achieved >340-mile range.

Volkswagen
- Expanded demo fleet to 24 FCEVs in CA
- Recently reconfirmed commitment to FCEVs

SAIC (China)
- Partnering with GM to build 10 fuel cell vehicles in 2010

Ford
- Alan Mulally, CEO, sees 2015 as the date that fuel cell cars will go on sale.

BMW
- BMW and GM plan to collaborate on the development of fuel cell technology

Based on publicly available information during 2011

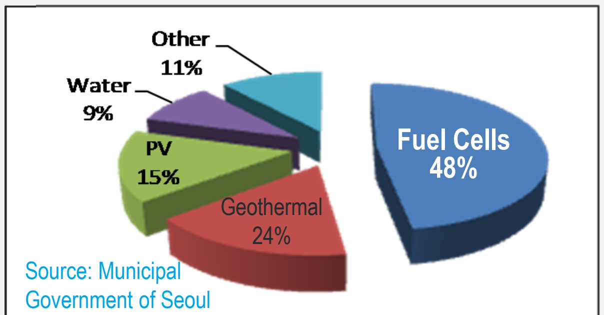
H_2Mobility - evaluate the commercialization of H_2 infrastructure and FCEVs
- Public-private partnership between NOW and industry stakeholders including: Daimler, Linde, OMV, Shell, Total, Vattenfall, EnBW, Air Liquide, Air Products

UKH_2Mobility will evaluate anticipated FCEV roll-out in 2014/2015
- 13 industry partners including: Air Liquide, Air Products, Daimler, Hyundai, ITM Power , Johnson Matthew, Nissan, Scottish & Southern Energy, Tata Motors, The BOC Group, Toyota, Vauxhall Motors

13 companies and Ministry of Transport announce plan to commercialize FCEVs by 2015
- 100 refueling stations in 4 metropolitan areas and connecting highways planned, 1,000 station in 2020, and 5,000 stations in 2030.

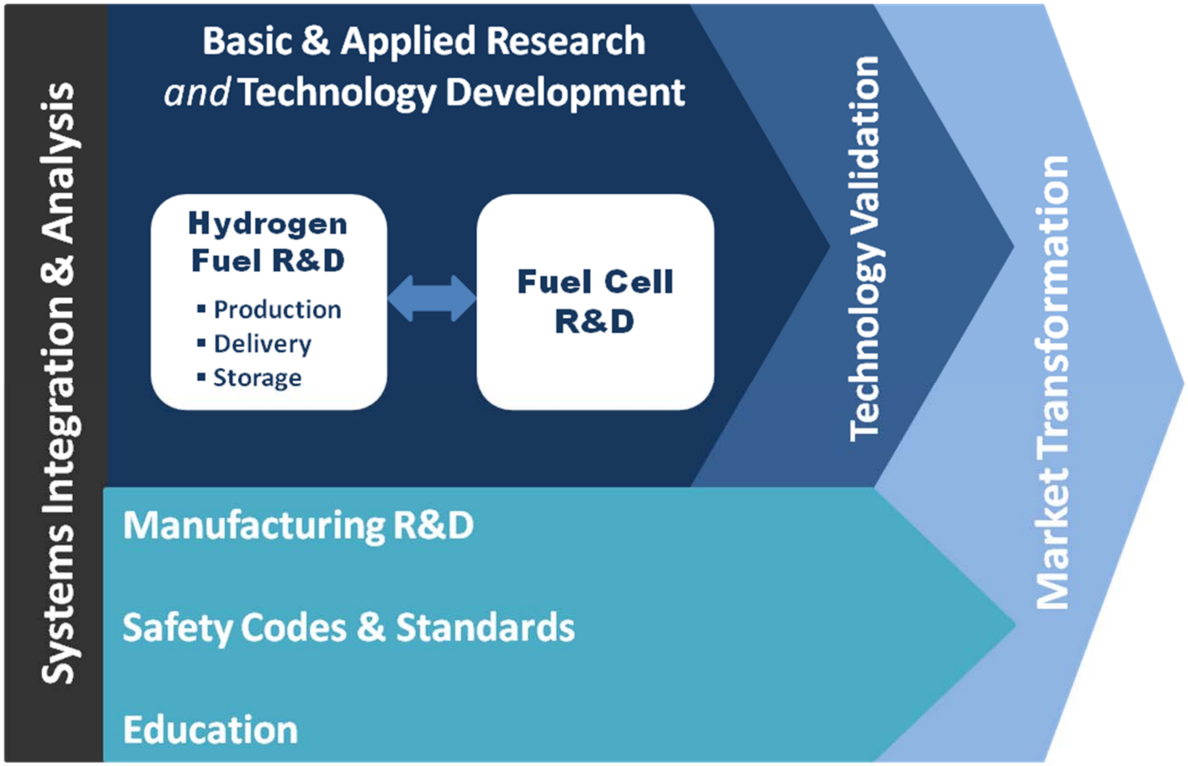
Example: Seoul plans for **~ 48% of its renewable energy to come from fuel cells**

Anticipated Renewable Energy Generation in Seoul, Korea by 2030



DOE Program Structure

The Program is an integrated effort, structured to address all the key challenges and obstacles facing widespread commercialization.



WIDESPREAD COMMERCIALIZATION ACROSS ALL SECTORS

- Transportation
- Stationary Power
- Auxiliary Power
- Backup Power
- Portable Power

Nearly 300 projects currently funded

at companies, national labs, and universities/institutes

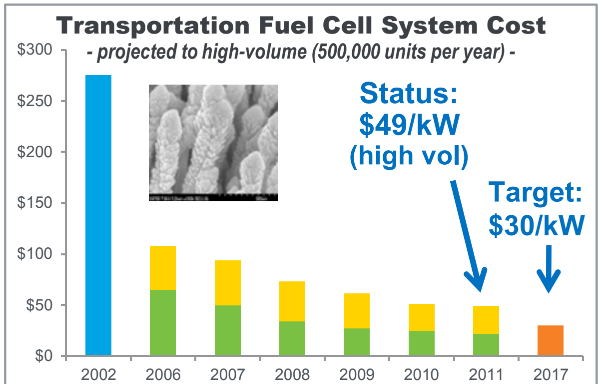
More than $1B DOE funds spent from FY 2007 to FY 2011

Federal Role in Fuel Cells: RD&D to Deployments

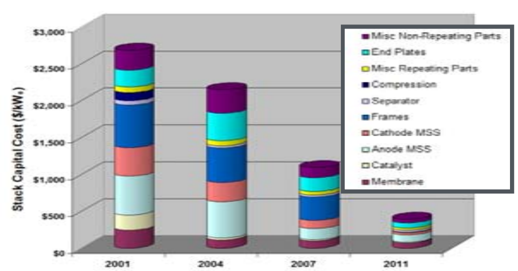
DOE R&D

- *Reduces cost and improves performance*

Examples:



→ Reduced cost of fuel cells 30% since 2008, 80% since 2001



→ Reduced cost of electrolyzer stacks 60% since 2007

DOE Demonstrations & Technology Validation

- *Validate advanced technologies under real-world conditions*
- *Feedback guides R&D*

Examples—validated:

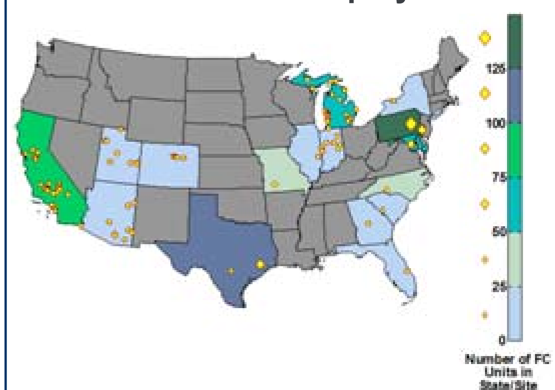
- ***59% efficiency***
- ***254 mile range (independently validated 430-mile range)***
- ***75,000-mi durability***

Program also includes enabling activities such as codes & standards, analysis, and education.

Deployments

- ***Market Transformation***
- ***DOE Recovery Act Projects***
- ***Government Early Adoption (DoD, FAA, California, etc.)***
  - ***IDIQ****
- ***Tax Credits: 1603, 48C***

Recovery Act & Market Transformation Deployments



- ***1,000 fuel cell deployments in ~ 2 years***
- ***1 million hours of operation***

**IDIQ = indefinite duration/indefinite quality*

Early Market Deployment Summary

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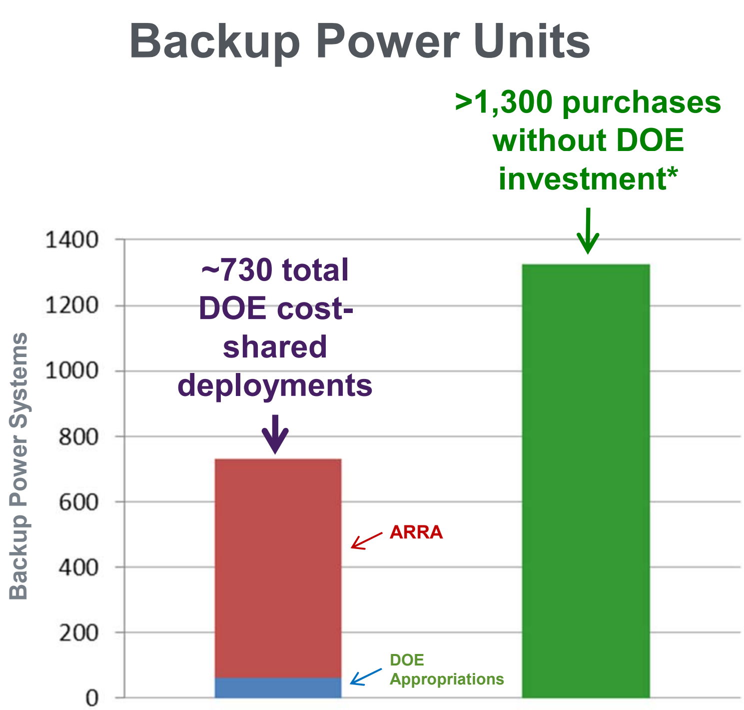
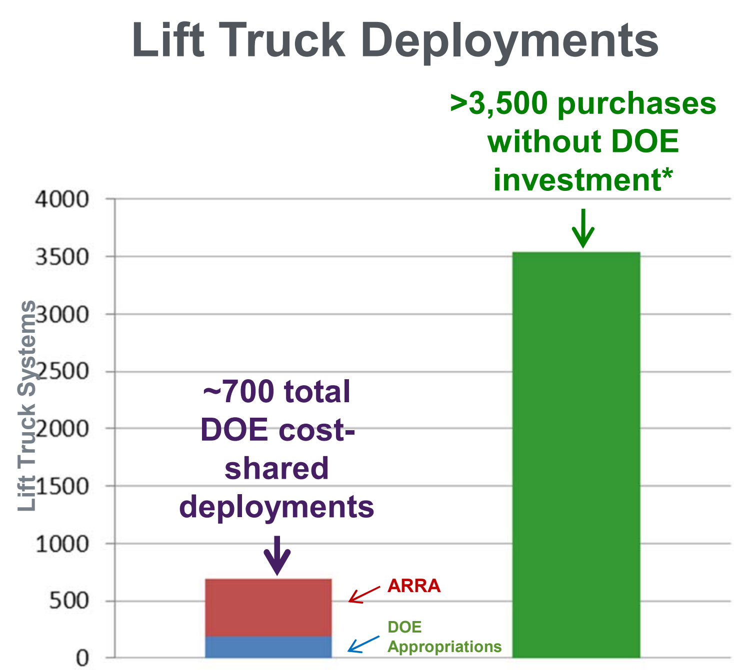
Early market deployments of approximately 1,400 fuel cells have led to more than 5,000 additional purchases by industry—with no further DOE funding.



Leveraging DOE funds:

DOE deployments led to almost 2X additional purchases by industry.



Leveraging DOE funds:

DOE deployments led to >5X additional purchases by industry.

**industry purchases include units on order*

Opportunities for Distributed Generation (DG) and Efficient use of Natural Gas- and Biogas?

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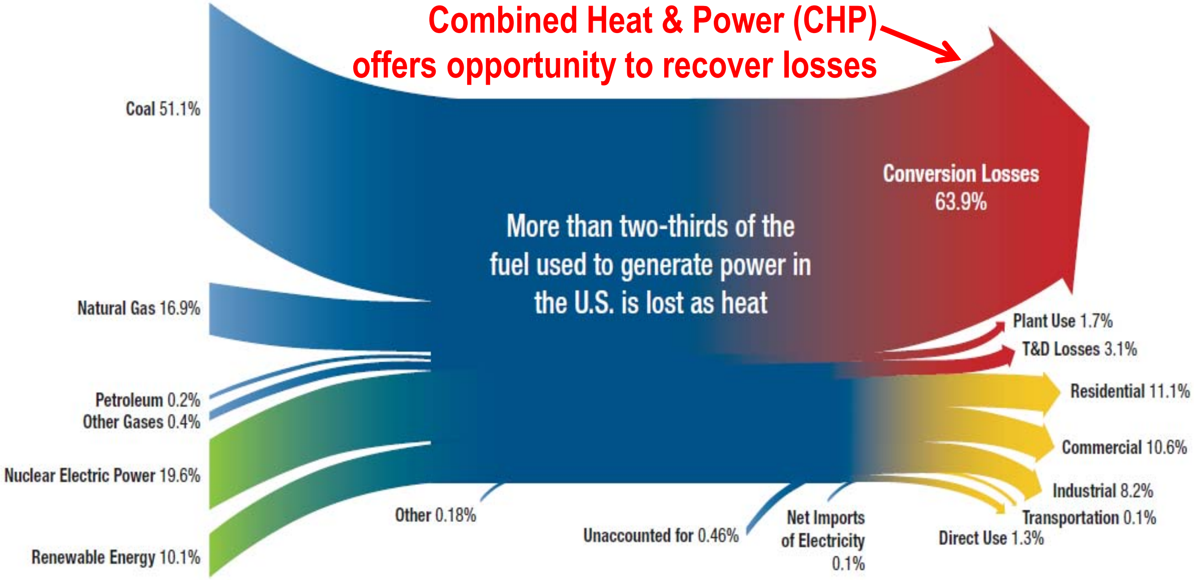
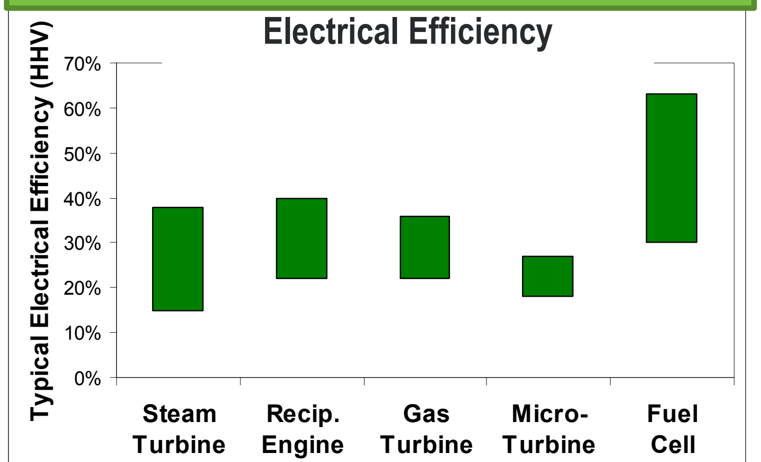


Source: http://www.chpcenterse.org/pdfs/ORNL_CHP_Report_Dec_2008.pdf

Range of electrical efficiencies for DG technologies



Source: EPA, Catalog of CHP Technologies, December 2008

Examples of fuel cell deployments using natural gas

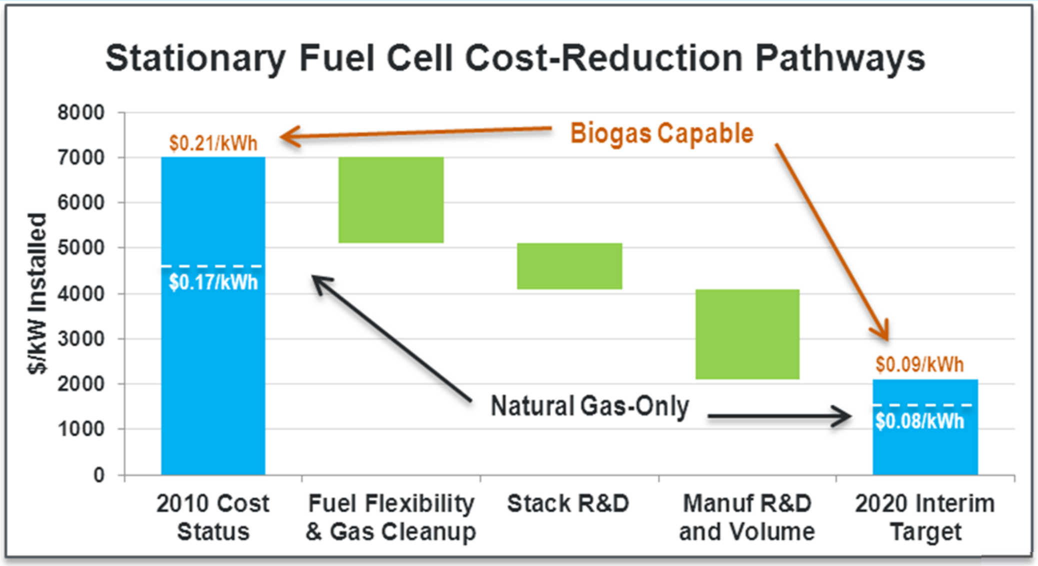
***Supermarkets** one of several in the food industry interested*

Critical Loads- e.g. banks, hospitals, data centers

*New World Trade Center (Freedom Tower) will use **12 fuel cells totaling 4.8MW***

Challenges and Strategy: Stationary Applications

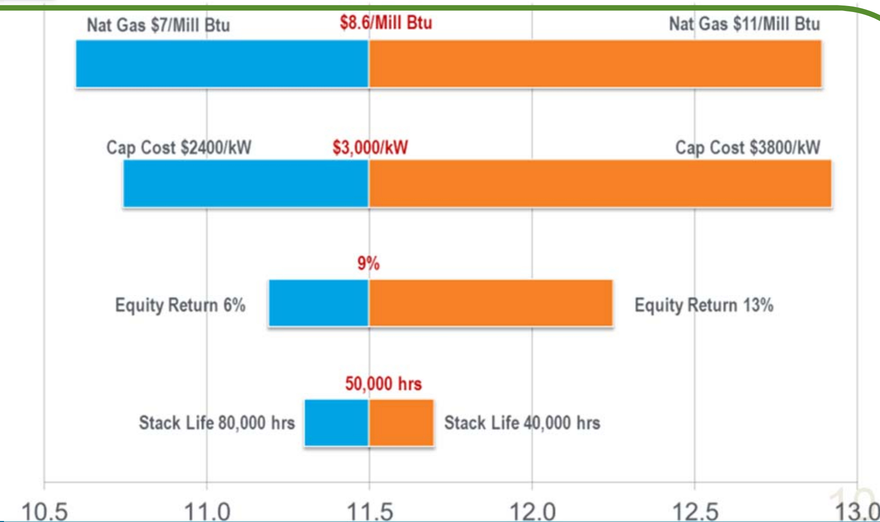
Further reduction in capital cost of medium scale DG/CHP(100kW-3 MW) need to be pursued to facilitate widespread commercialization



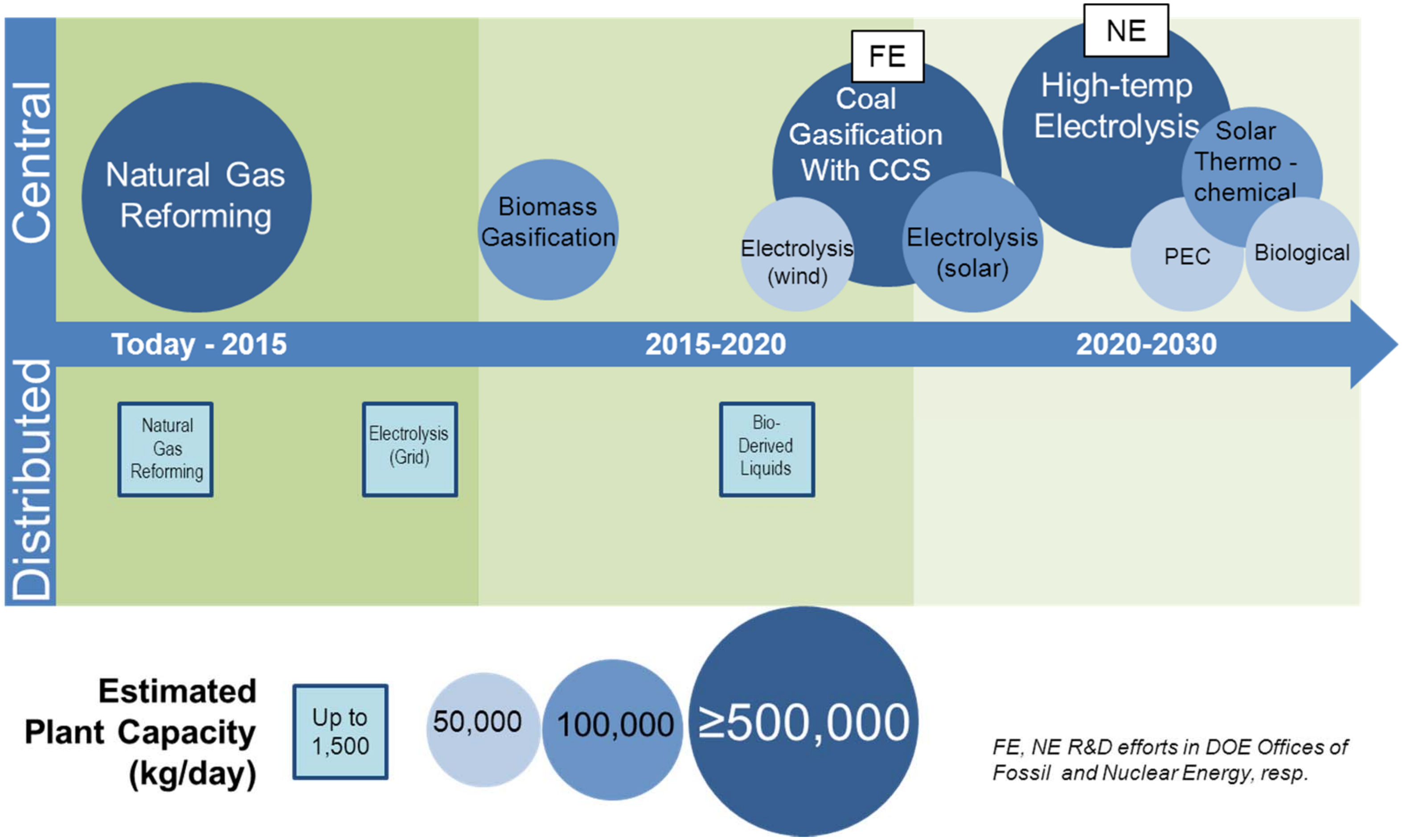
- Further reduction of fuel cell system cost required to expedite commercialization
- Natural gas availability and fuel cell performance (efficiency) gains will enhance the technology's market attractiveness
- Development of a cost-effective process for removing fuel contaminants would allow for fuel flexibillity
- Also applicable for trigen (H_2 production)

Sensitivity analysis around 2015 targets assesses impact of fuel cell system cost and durability on commercialization prospects

Technical Parameters (2015)	
Electric Efficiency (LHV)	45.0%
Combined Effic.(LHV)	87.5%
Size, MWe	1
Operating Life, years	20
Equipment, $/kWe	2,300
Engineering& Installation, $/kWe	700
Fixed O&M, $/MWh	13
Variable O&M, $/MWh	8.0



Develop technologies to produce hydrogen from clean, domestic resources at a delivered and dispensed cost of \$2-\$4/gge H_2 by 2020



FE, NE R&D efforts in DOE Offices of Fossil and Nuclear Energy, resp.

HTAC Subcommittee: H_2 Production Expert Panel
Review underway to provide recommendations to DOE

H_2 Production & Delivery Cost Status

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The revised hydrogen threshold cost is a key driver in the assessment of Hydrogen Production and Delivery R&D priorities

Projected High-Volume Cost of Hydrogen Production[1] (Delivered[2])—Status

Distributed Production (near term)

- Electrolysis

  Feedstock variability: $0.03 - $0.08 per kWh

- Bio-Derived Liquids

  Feedstock variability: $1.00 - $3.00 per gallon ethanol

- Natural Gas Reforming

  Feedstock variability: $4.00 - $10.00 per MMBtu

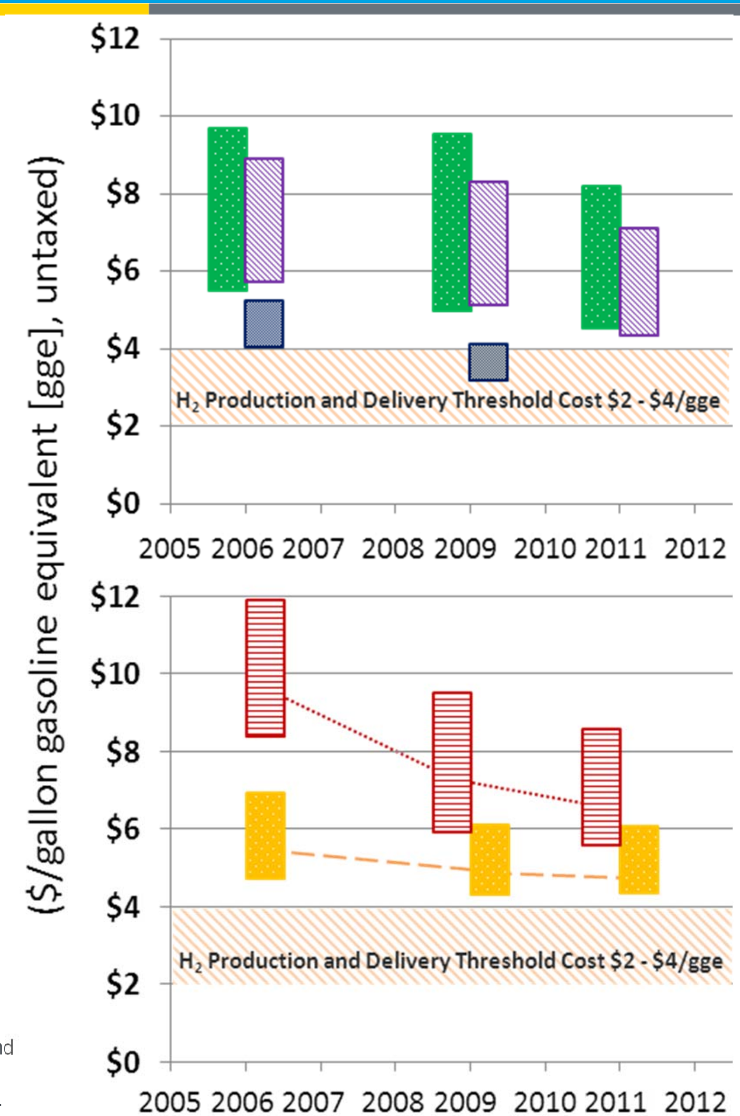
Central Production (longer term)

- Electrolysis

  Feedstock variability: $0.03 - $0.08 per kWh

- Biomass Gasification

  Feedstock variability: $40- $120 per dry short ton



Notes:
[1] Cost ranges for each pathway are shown in 2007$ based on high-volume projections from H2A analyses, reflecting variability in major feedstock pricing and a bounded range for capital cost estimates.
[2] Costs include total cost of production and delivery (dispensed, untaxed). Forecourt compression, storage and dispensing added an additional $1.82 for distributed technologies, $2.61 was added as the price of delivery to central technologies. All delivery costs were based on the Hydrogen Pathways Technical Report (NREL, 2009).

Two Main Options for Low-cost Early Infrastructure

1. Hydrogen delivered from central site

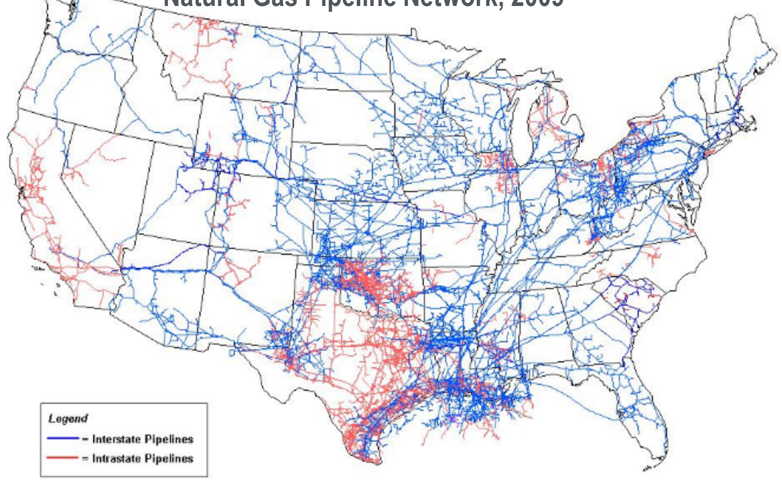
- Low-volume stations (~200-300 kg/day) would cost <$1M and provide hydrogen for $7/gge *(e.g., high-pressure tube trailers, with pathway to $5/gge at 400–500 kg/day- comparable to ~$2.10/gallon gasoline untaxed)*

2. Distributed production (e.g. natural gas, electrolysis)

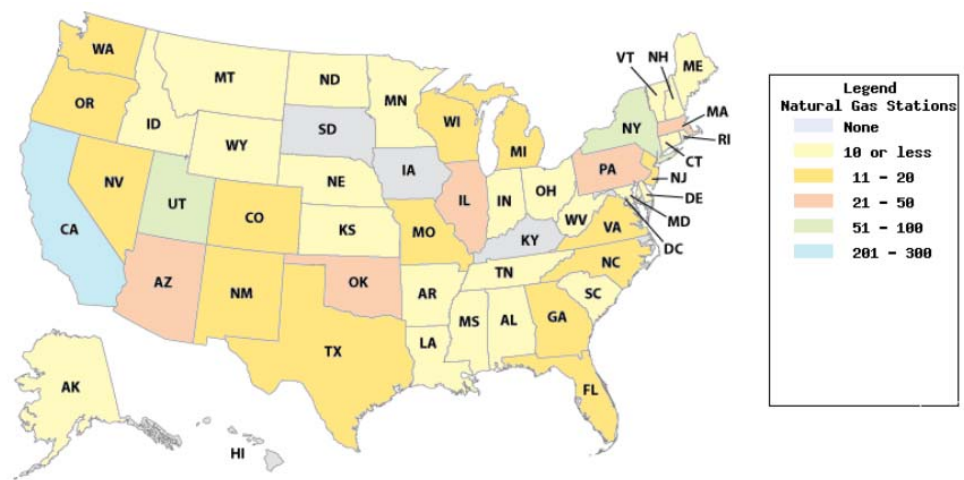
Other options

1. Co-produce H_2, heat and power (tri-gen) with natural gas or biogas
2. Hydrogen from waste (industrial, wastewater, landfills)

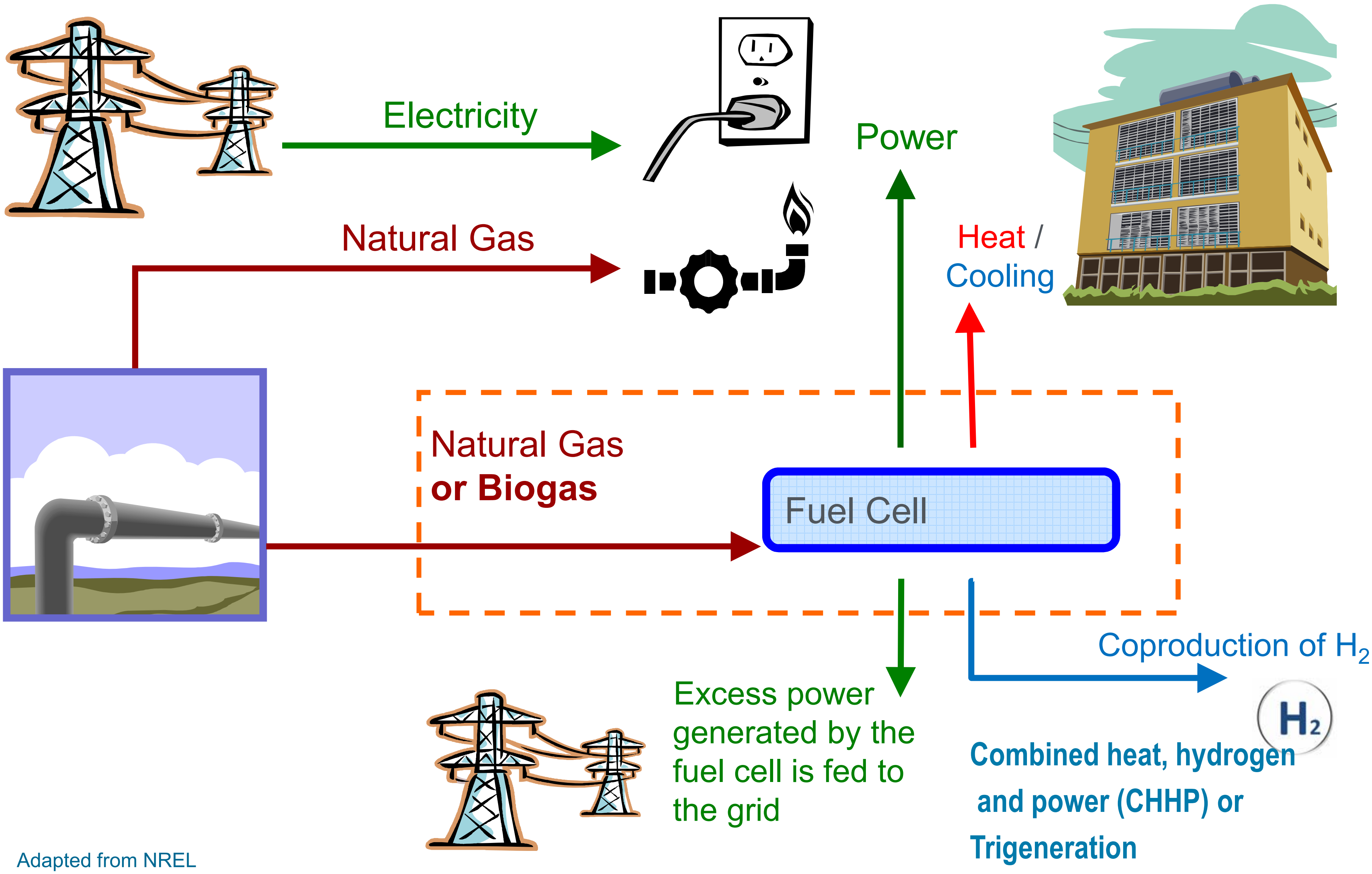
Natural Gas Pipeline Network, 2009



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System



Natural gas fueling stations



Adapted from NREL

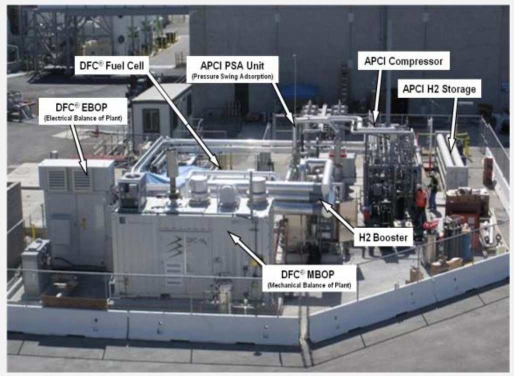
Tri-Generation of Heat, Hydrogen, and Power

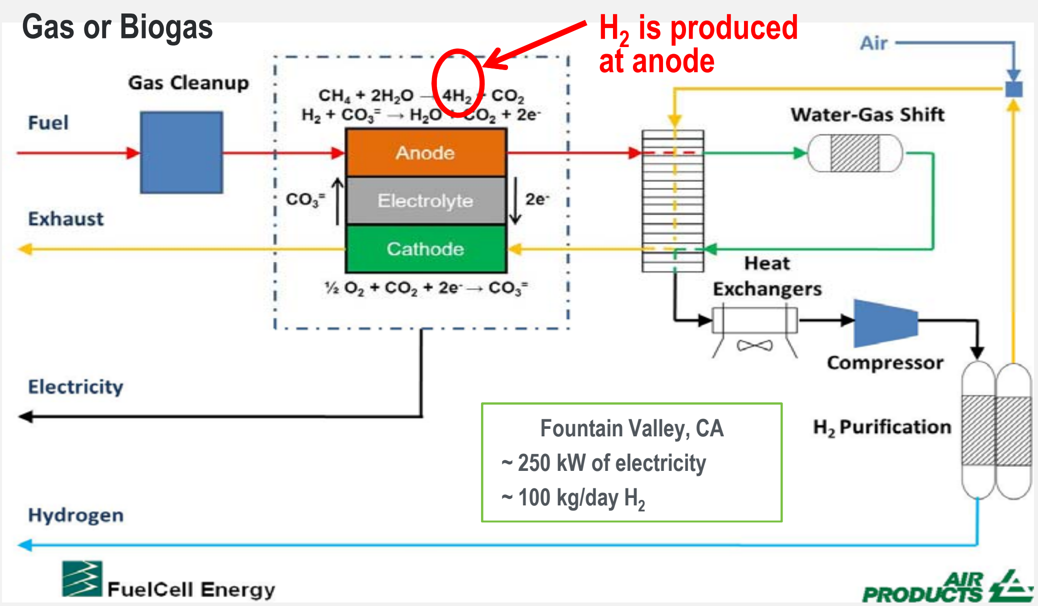
Potential Opportunity

Does a synergy exist between stationary and transportation sectors?

Demonstrated world's first Tri-generation station (54% efficiency – H_2 and power)

-Anaerobic digestion of municipal wastewater-

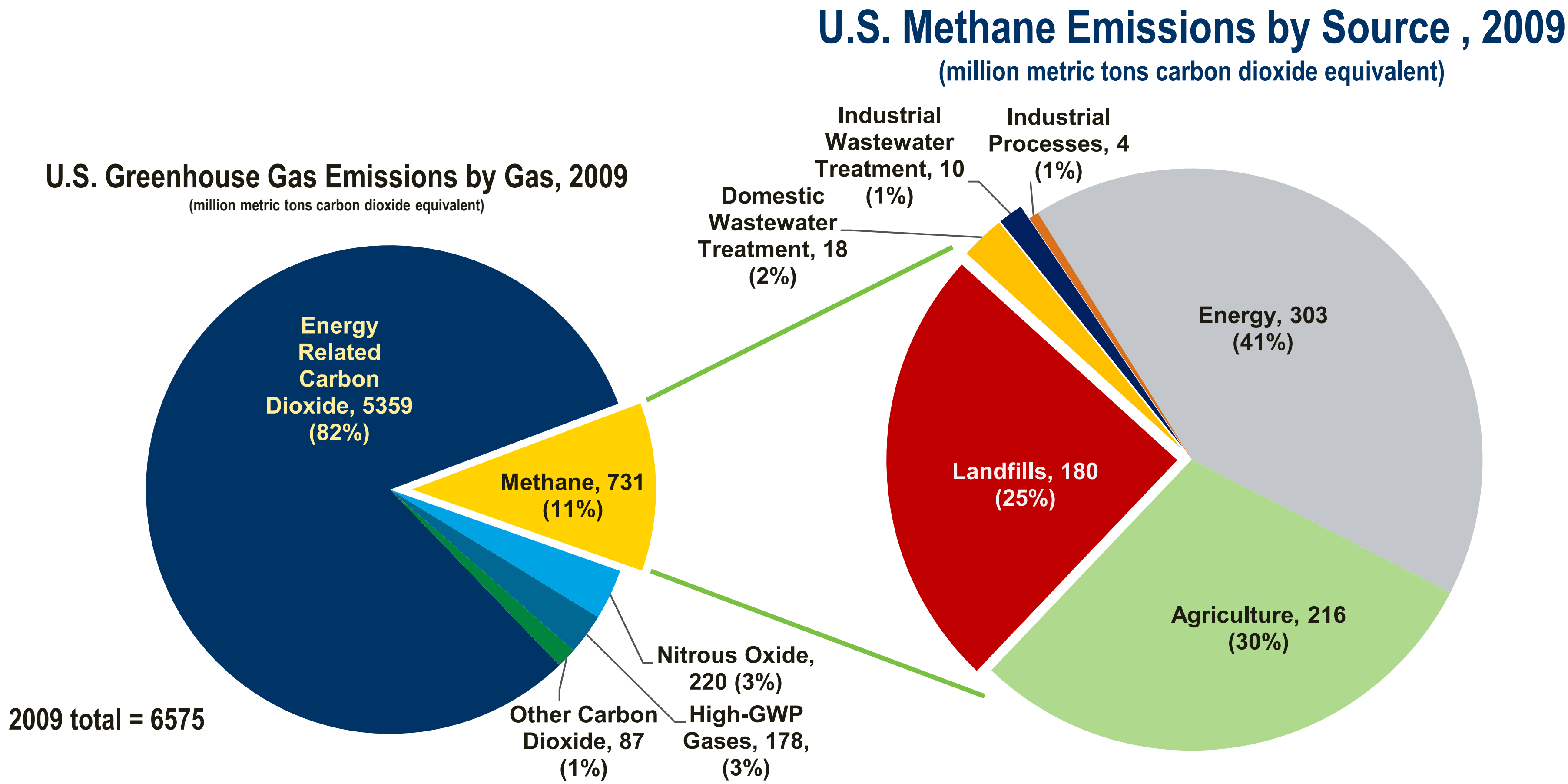




Is tri-generation a viable option for H_2 production and synergy with biogas?

- Co-produce H_2, power, and heat for multiple applications?
- More efficient use of natural gas?
- Use a renewable resource in anaerobic digester gas?
- Use off-gas from other waste material processing (e.g., gasifiers)?
- Establish an early market infrastructure?

Landfills and Wastewater Treatment contribute ~30% of Methane Emissions in the U.S.



Source: U.S. Energy Information Administration Emissions of Greenhouse Gases in the United States 2009

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Opportunities for Biogas Applications

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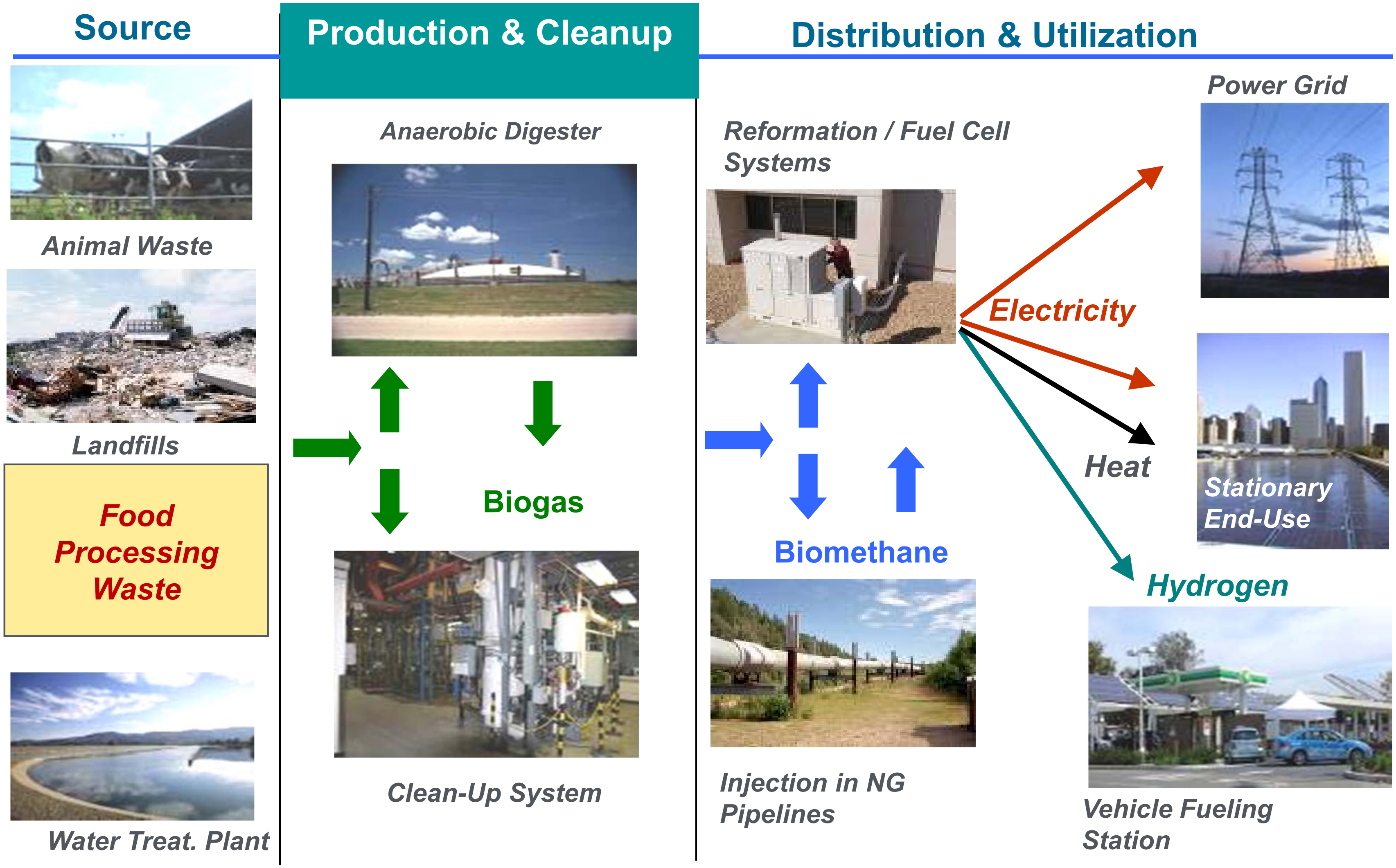
Fuel cells operating on bio-methane or hydrogen derived from bio-methane can mitigate energy and environmental issues and provide an opportunity for their commercialization. Other drivers are: need for fuel diversity/flexibility, evolving policies for renewables, and related incentives.



Source: National Renewable Energy Laboratory

Biogas as an Early Source of Renewable Hydrogen and Power

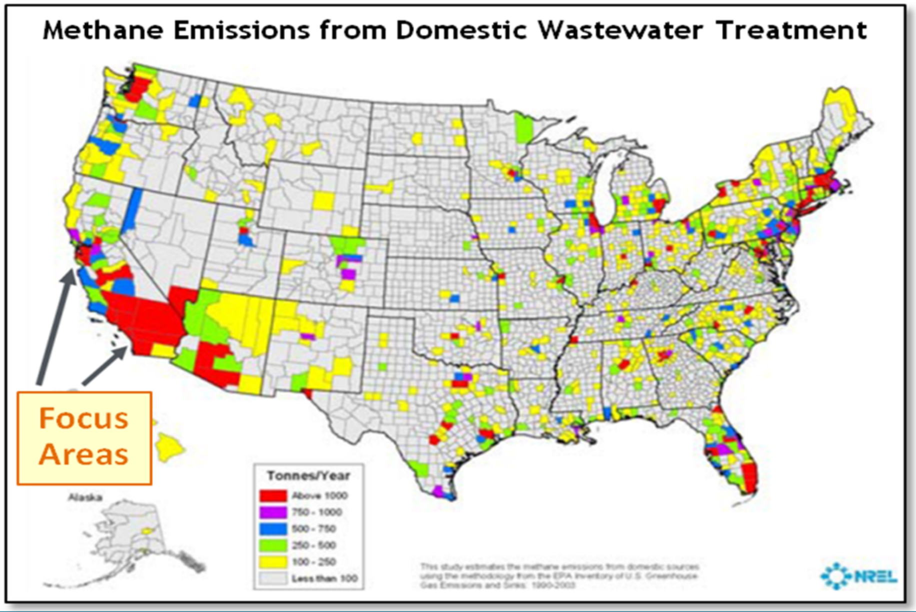
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- ***The majority of biogas resources are situated near large urban centers—ideally located near the major demand centers for hydrogen generation for hydrogen fuel cell vehicles (FCEVs) and power generation from stationary fuel cells.***
- ***Hydrogen can be produced from this renewable resource using existing steam-methane-reforming technology.***

U.S. biogas resource has capacity to produce ~5 GW of power at 50% electrical efficiency.

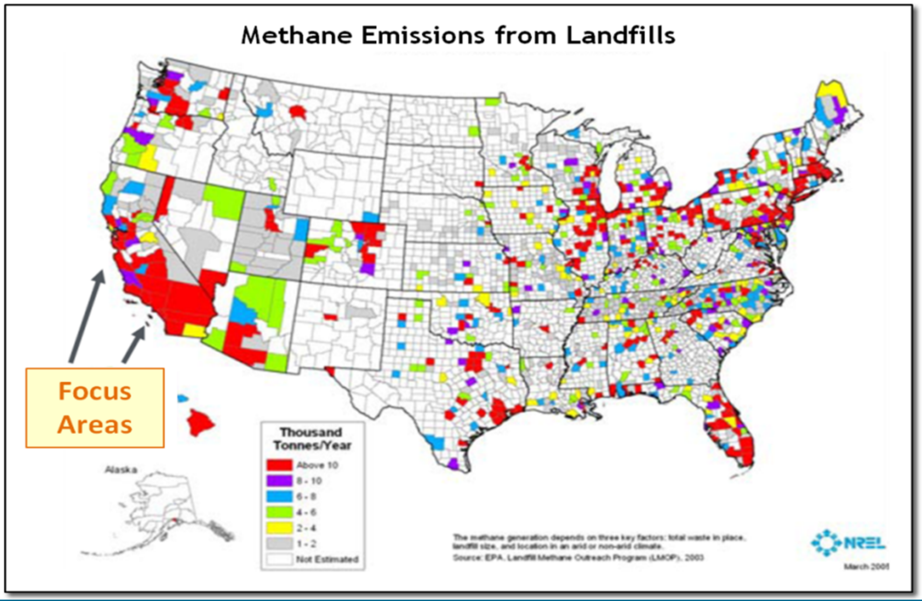
SOURCE: Wastewater Treatment, *could provide enough H_2 to refuel **~600,000 vehicles/ day.***

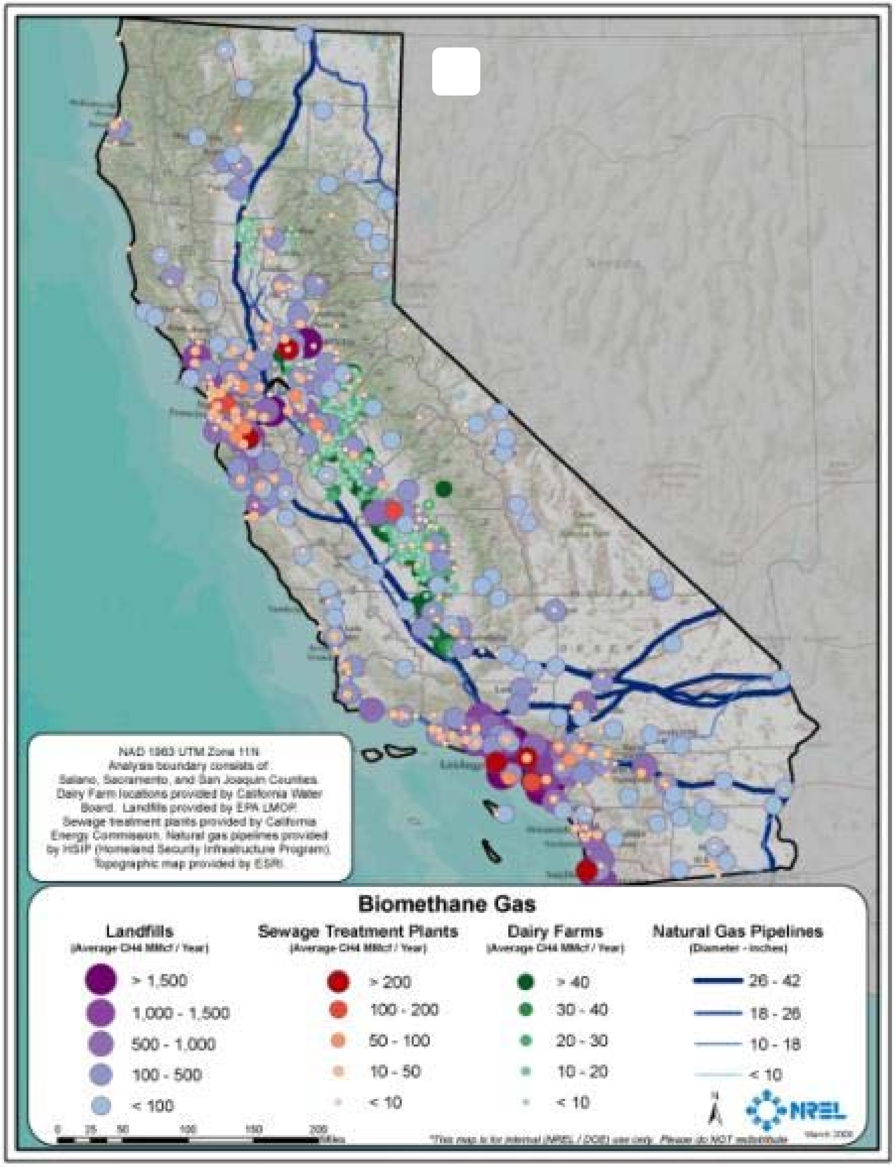
- 500,000 MT per year of methane is available from wastewater treatment plants in the U.S.
- ~50% of this resource could provide **~340,000 kg/day** of hydrogen.

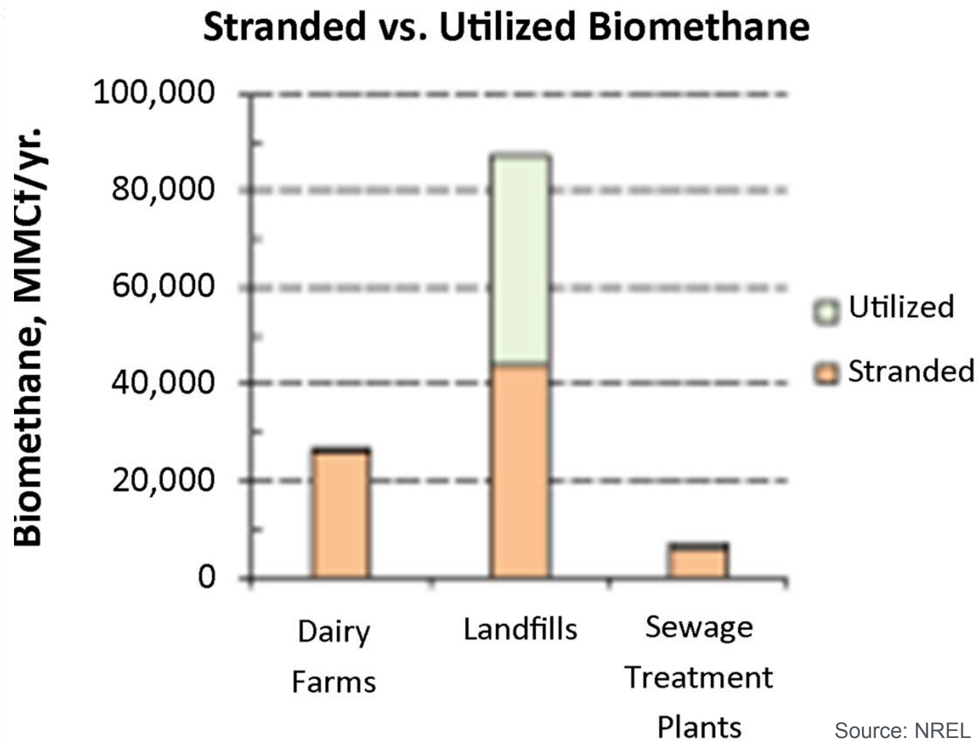


SOURCE: Landfills, *could provide enough H_2 to refuel **~13 million vehicles/day**.*

- 12.4 million MT per year of methane is available from landfills in the U.S.
- ~50% of this resource could provide **~8 million kg/day** of hydrogen.







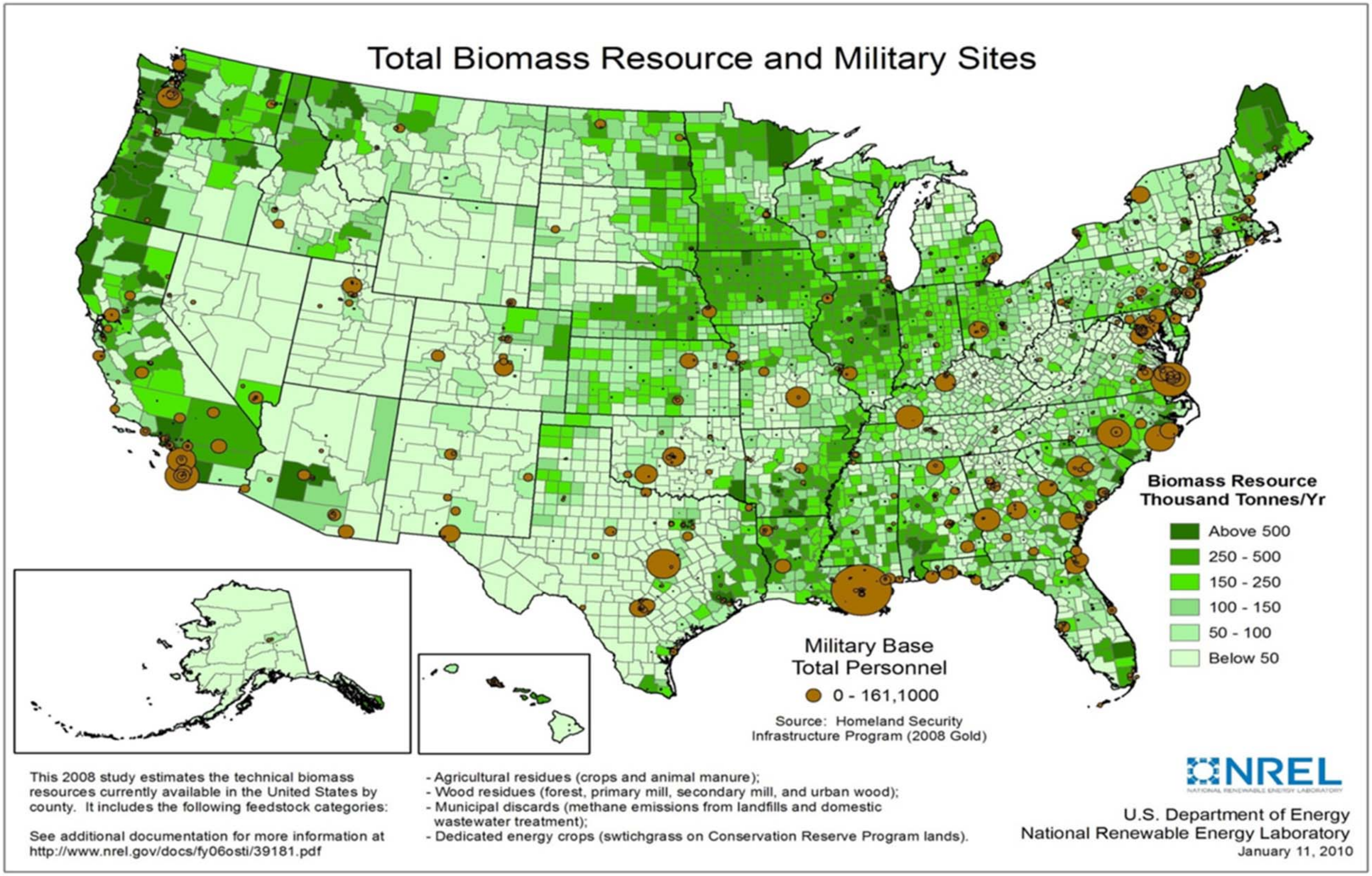
Source: NREL

Example:

Landfills offer ~1.6 M tons/yr of bio-methane.

- ➢ **Only ~50% of the landfill biomethane is used**

Potential Resources Near DOD Sites



DEMO Deployment – BMW Plant

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Validate fuel cell powered material handling equipment low-cost hydrogen from land fill gas including performance, operation and maintenance, durability, and reliability under real-world operating conditions.

Project Lead: SCRA
Project Partners:
- **BMW**
- **Gas Technology Institute**
- **Ameresco, Inc.**

Phase 1: Feasibility Study
Completed 26 October 2011

Phase 2: LFG-to-Hydrogen Conversion
8 months nominal; target completion date: July 2012
Critical milestones:
Land, interconnect, start up and test equipment
Monitor hydrogen purity for at least 2 months

Phase 3: Side-by-Side Trial (to be funded)
6 months from satisfactory completion of monitoring portion of Phase 2
Target completion date: January 2013
Critical milestones:
Operate test group of MHE to attain 25,000 run hours
Continue monitoring hydrogen purity of LFG-sourced hydro

Examples of Fuel Cell CHP Industry Deployments

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The Food Industry and Waste Treatment are emerging markets for stationary fuel cells

Source: Gills Onions

- **Completed Food Producer Deployments:**
  - **Gills Onions (CA, 600 kW)**
    - **2-300kW fuel cells**
    - **Generates power for facility @ 47% electrical efficiency**
    - **Processes ~32 scfm of biogas per fuel cell**
  - **Sierra Nevada Brewery (CA, 1 MW)**
    - **Generates ~100% of brewery's electrical demand**
    - **Waste heat used for generating steam and boiling beer**

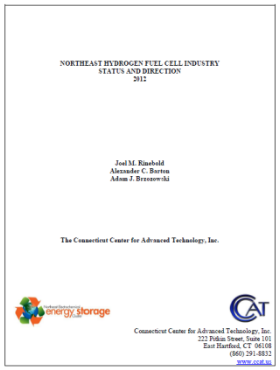
Waste Treatment Deployments: Nine Sites Include

- **Orange County Sanitation District (CA, 300 kW)**
  - **1-300 kW fuel cell**
  - **Operates on biogas from wastewater treatment plant**
  - **Produces >100 kg/day of fuel cell grade hydrogen (99.9999% purity)**
- **Tulare (CA, 1 MW)**
  - **4-300 kW fuel cells**
  - **Generates ~50% of waste water treatment plant's electrical demand**
  - **Waste heat used for anaerobic digestion process**

Recently Released States Reports

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Northeast Hydrogen Fuel Cell Industry Status and Direction



Report by Joel M. Rinebold, Alexander C. Barton, and Adam J. Brzozwski

Connecticut Center for Advanced Technology, Inc.

Highlights potential for fuel cell industry in northeast US detailing relevant information on products and markets, employment, and system efficiency and cost.

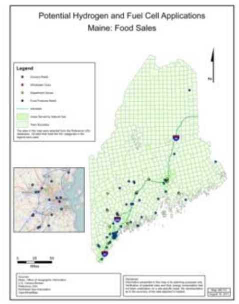
1.85 GW opportunity identified.

See report: http://dl.dropbox.com/u/53527617/NORTHEAST%20HYDROGEN%20FUEL%20CELL%20INDUSTRY%20STATUS%20AND%20DIRECTION%202012.pdf

State by state plans identifying fuel cell opportunities and potential implementation strategies (drafts in process)

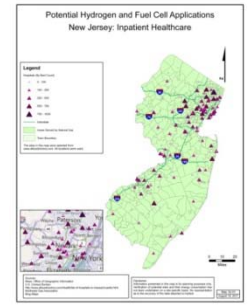
Targets: Geographic Information System (GIS) Mapping

Food Sales

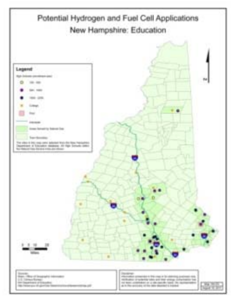


Food Services

Inpatient Healthcare

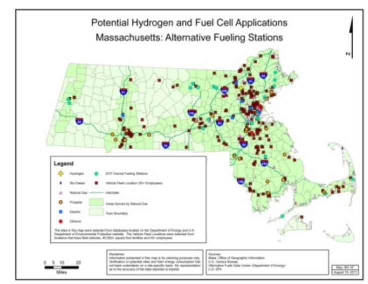


Education

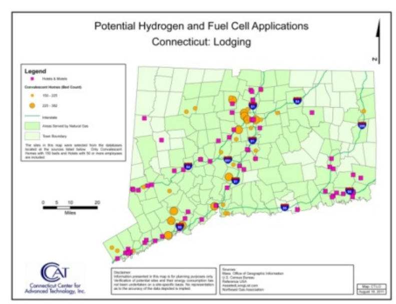


Airports (Military)

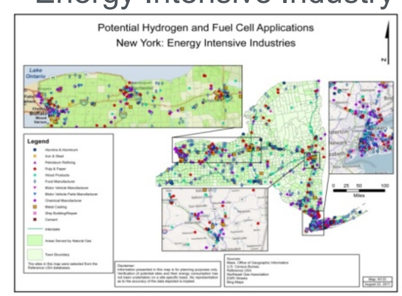
Alternative Fueling Stations



Lodging



Energy Intensive Industry



Targets: Breakdown Example for 300 kW Stationary

Category	Total Sites	Potential Sites	MWs	MW-hrs per year	MW at 90% Capacity Factor	Aggregate Annual Thermal Output		CO2 emissions
						MMBTU	MWh	
Education	18,335	2,190	210.9	1,662,735.6	189.81	4,478,301.22	1,312,515.01	434,286.20
Food Sales	51,300	1,201	360.3	2,840,605.2	324.27	7,650,696.67	2,242,290.94	642,698.16
Food Services	64,600	387	116.1	915,332.4	104.49	2,465,295.26	722,536.71	219,715.25
Inpatient Healthcare	3,994	422	126.6	998,114.4	113.94	2,688,254.78	787,882.41	232,631.61
Lodging	8,033	884	265.2	2,090,836.8	238.68	5,631,320.45	1,650,445.62	484,156.44
Public Order & Safety	3,310	313	93.9	740,307.6	84.51	1,993,895.14	584,377.24	179,454.82
Energy Intensive Industries	4,758	429	128.7	1,014,670.8	115.83	2,732,846.69	800,951.55	223,655.68
Government Operated Buildings	1,255	90	27.0	212,868.0	24.30	573,324.48	168,031.79	49,990.87
Wireless Telecommunication Towers*	3,960	397		-	-	-	-	-
WWTPs	578	16	4.8	37,843.2	4.32	101,924.35	29,872.32	8,417.75
Landfills	213	14	4.2	33,112.8	3.78	89,183.81	26,138.28	7,327.39
Airports (w/ AASF)	842	50 (20)	16.2	127,720.8	14.58	343,994.69	100,819.08	31,414.59
Military	14	14	4.2	33,112.8	3.78	89,183.81	26,138.28	59,737.86
Ports	120	19	5.7	44,938.8	5.13	121,035.17	35,473.38	10,272.06
Total	**161,312**	**6,426**	**1,363.8**	**10,752,199.2**	**1,227.42**	**28,959,256.51**	**8,487,472.60**	**2,064,422.25**

* No Base Load

Policies and Incentives

	ME	NH	VT	MA	RI	CT	NY	NJ
Energy Policy								
Mandatory Renewable Portfolio Standard (RPS)	■	■		■	■	■	■	■
Fuel Cell Eligibility	■			*	*	■	■	*
Interconnection Standards (Includes Fuel Cells)		*	*	*	*	■	■	*
Net Metering (Includes Fuel Cells)	■	*	*	*	*	■	■	*
Public Benefits Fund (Includes Fuel Cells)	■		*	*	*	■	■	*
Renewable Greenhouse Gas Initiative (RGGI) Member	■	■	■	■	■	■	■	■
State Incentives for Fuel Cells								
Performance-Based	■				*	■	■	
State Grant Program	■		*	⁂	*	■	■	
State Loan Program	■		*		*	■		
State Rebate Program								*
Property Tax Incentive (Commercial)			*					*
Sales Tax Incentive			*				■	
Industry Recruitment/ Support				*		■		*
Property-Assessed Clean Energy (PACE) Financing	■			**			■	

■ (green) All fuel cell types; * Fuel cells using renewable fuels; ** Renewable energy eligible technology to be locally determined; ⁂ eligible through Green Communities program

www.dsireusa.org

Hydrogen Requirements for Carbon Feedstocks also Adds to Demand

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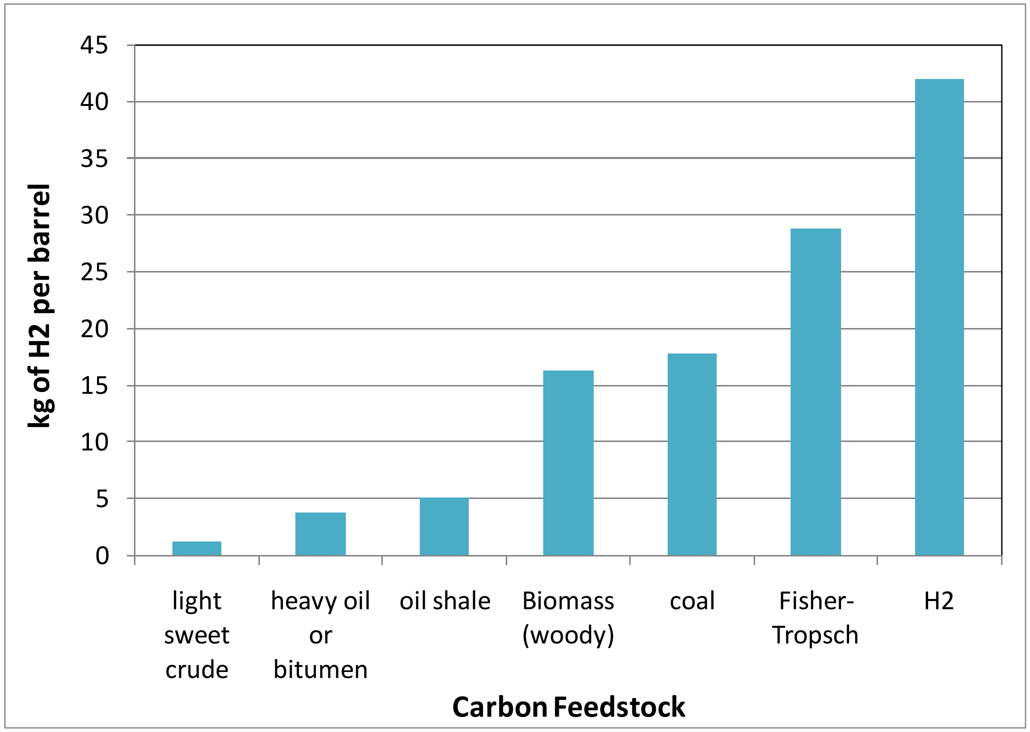
Hydrogen requirements for processing of carbon feedstocks to produce liquids fuels[1]



[1]"Review of the Potential of Nuclear Hydrogen for Addressing Energy Security and Climate Change," James E.O'Brien, *Nuclear Technology*, VOL. 178 nr 1, pp 55-65, April 2012.

Hydrogen Demand for Biomass Upgrading

Production of pyrolysis oil from corn stover

- Annual corn stover production is ~400 million tons and represents ~40% of the biomass resource in the U.S.[1]
- Thermal conversion of ~2000 metric tons/d of corn stover yields ~3,500 bbls /day of pyrolysis oil.[2]
- Upgrading and stabilization of pyrolysis oil to naphtha and diesel products requires ~49,000 kg/d (~18 million kg/yr.) of hydrogen.
- Thermal conversion of the corn stover biomass to upgraded pyrolysis oil would require ~9-10 million metric tons/yr.

Notes:
[1]Amount of corn stover was obtained from second Billion Ton Study.
[2]Source for the hydrogen demand was an NREL study Techno-Economic Analysis of Biomass Fast Pyrolysis to Transportation Fuels by Mark M. Wright, Justinus A. Satrio, and Robert C. Brown Iowa State University Daren E. Daugaard ConocoPhillips David D. Hsu NREL

Key Questions - Examples

- What RD&D is needed by government and industry to enable more biogas use for fuel cell?
  - What are the key challenges?
  - What are the next steps to address them?
  - What are the priorities?
- What are the best near term applications (now to 2015)?
- What are the best mid-term applications (2016 -2020)?
- Other Questions:
  - How will biogas be integrated with the NG infrastructure? Can tri-gen/other options be used to produce H_2 for biomass processes?
  - What other issues do we need to address?

Thank You

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Supplemental Material

EERE H_2 & Fuel Cells Budgets

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FY12 Appropriations: " The **Committee recognizes the progress and achievements** of the Fuel Cell Technologies program. The **program has met or exceeded all benchmarks, and has made significant progress** in decreasing costs and increasing efficiency and durability of fuel cell and hydrogen energy systems."

EERE FCT Funding *($ in thousands)*			
Key Activity	**FY 2011 Allocation**	**FY 2012 Appropriation**	**FY 2013 Request**
Fuel Cell Systems R&D	41,916	44,812	38,000
Hydrogen Fuel R&D	32,122	34,812	27,000
Technology Validation	8,988	9,000	5,000
Market Transformation	0	3,000	0*
Safety, Codes & Standards	6,901	7,000	5,000
Education	0	0	0
Systems Analysis	3,000	3,000	3,000
Manufacturing R&D	2,920	2,000	2,000
Total	$95,847	$103,624	$80,000*

FY 2013 House Mark: $82M Senate Mark: $104 M

Future Directions

Continue critical R&D

Hydrogen, fuel cells, safety, codes and standards, etc.

Conduct strategic, selective demonstrations of innovative technologies

Continue to conduct key analysis to guide RD&D and path forward, determine infrastructure needs

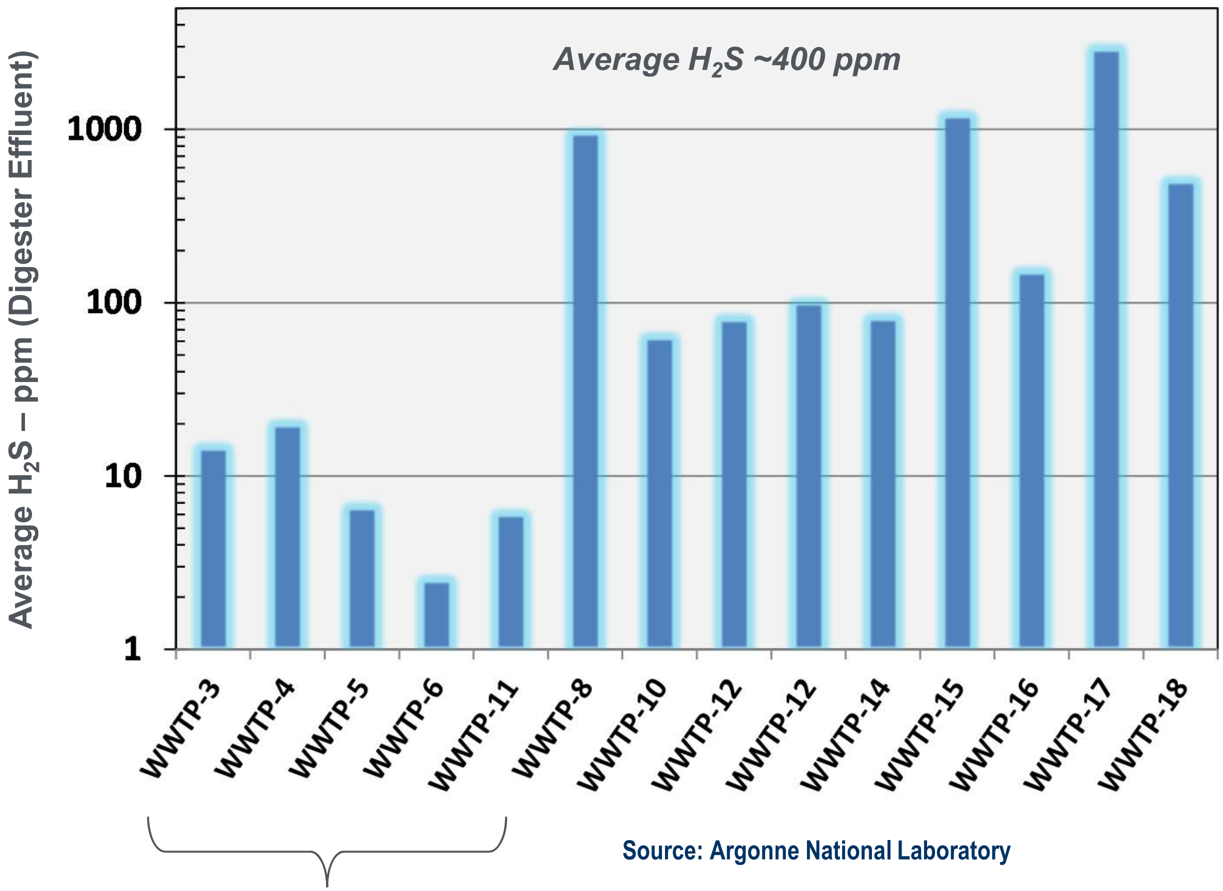
Leverage activities to maximize impact

*In FY 2013, the Program plans to leverage activities in other EERE Programs (e.g., Advanced Manufacturing and Vehicle Technologies in key areas), *subject to appropriations.*

Hydrogen Sulfide (H_2S) Content of Digester Gas

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

The bulk of total sulfur species in the digester gas is mainly H_2S



Source: Argonne National Laboratory

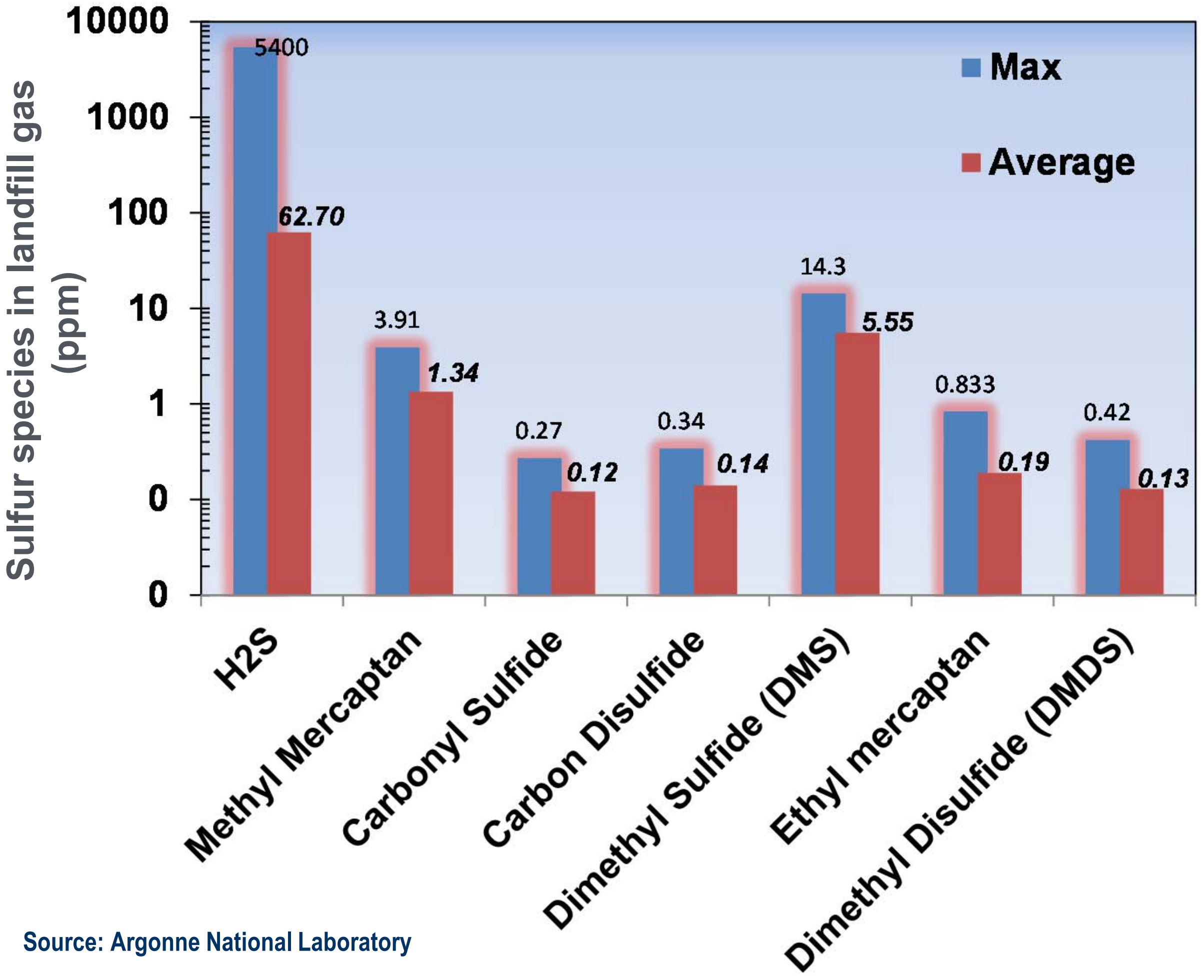
- H_2S show variability in the order of 10 to 1000 ppm
- DMS, Mercaptans can vary from ppb to few ppm
- Iron salts used in the water treatment process sequesters sulfide
- Impacts Reformer/Fuel cell catalyst/Electrolyte. Sulfur impurities need to be reduced to levels of ~0.1-1 ppm

Low H_2S content due to iron salt used in the waste water treatment process, i.e. for sludge thickening, phosphate precipitation

Sulfur Species Content of Land Fill Gas

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Land Fill Gas contains a wide spectrum of sulfur compounds creating a challenge for impurity cleanup



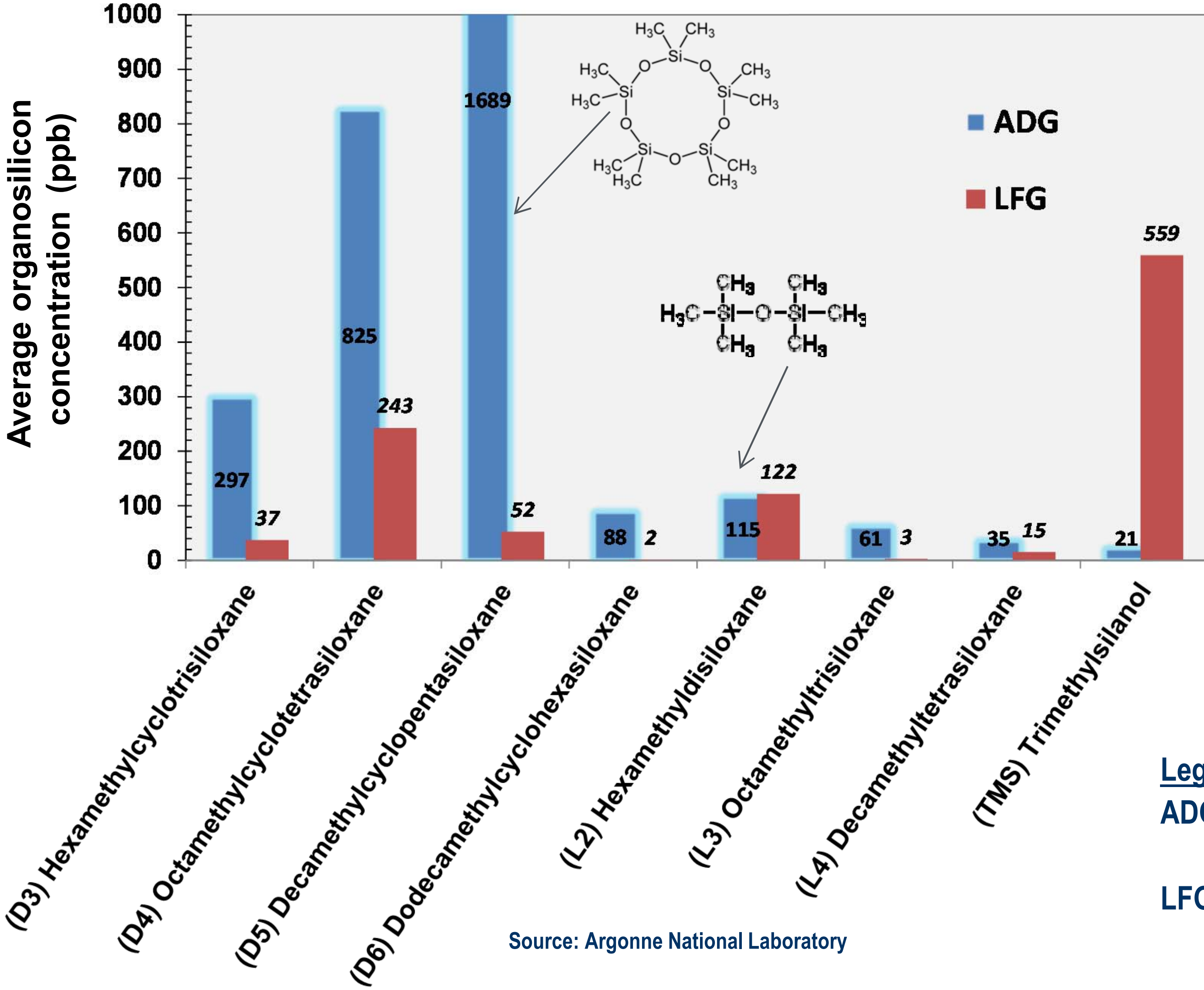
Source: Argonne National Laboratory

Concentration of organic sulfur is higher in landfill gas in particular Dimethyl Sulfide (DMS)

Siloxane Content of Land Fill and Anaerobic Digester Gases

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Digester gas contains predominately cyclic (D4,D5) organosilicon (siloxanes) species



- Cyclic compounds (D4 & D5) are dominant in WWTP gas
- Concentration of linear compounds and TMS are usually low
- ADG temperature affects speciation and concentration of siloxane compounds
- Solid silica deposits on surfaces. Tolerance level often require “below detection limit”

Legend:

ADG – Anaerobic Digestion Gas

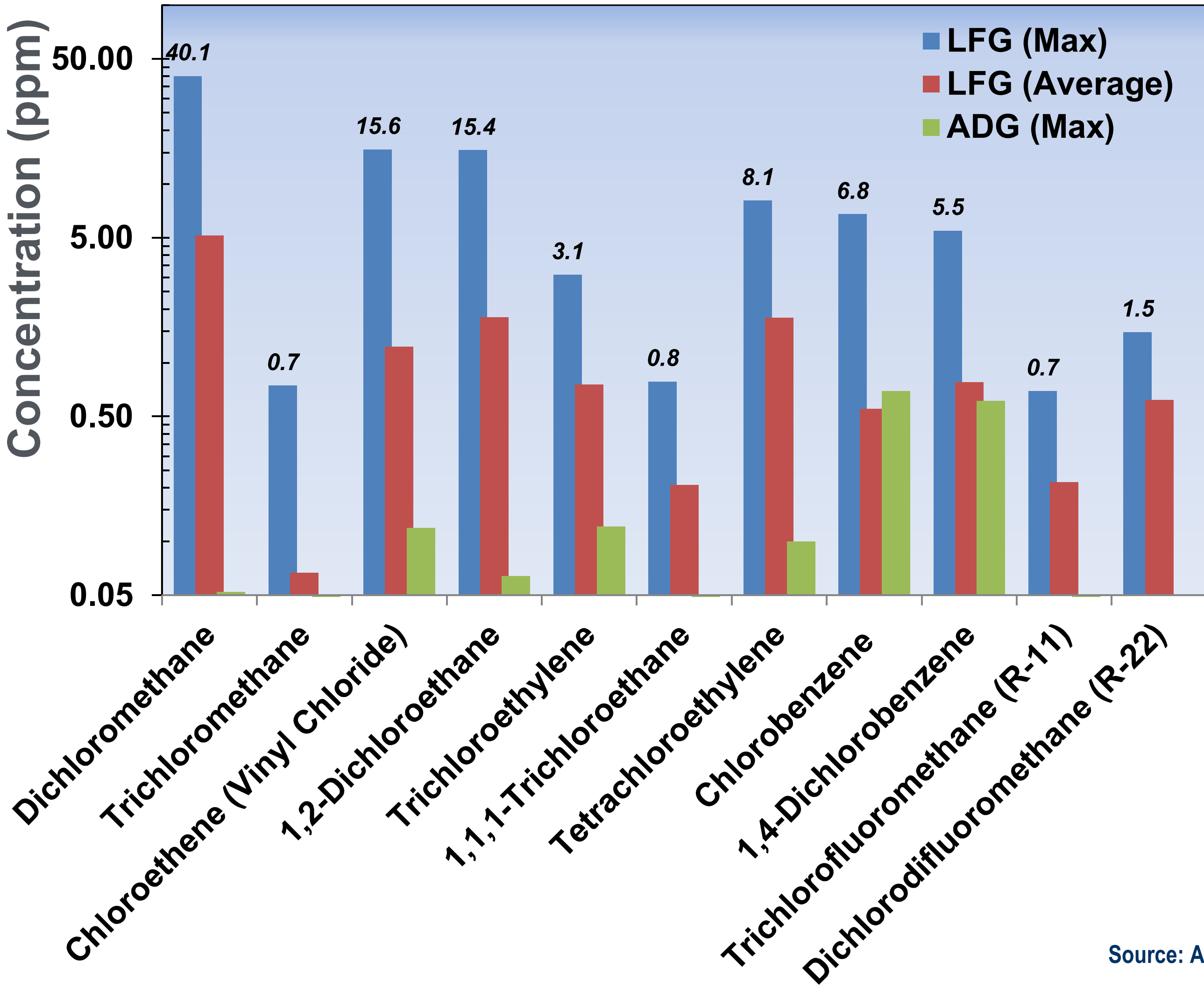
LFG – Land Fill Gas

Source: Argonne National Laboratory

Halocarbon Content of Land Fill and Anaerobic Digester Gases

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Landfill gas contains a variety of halocarbons and at much higher concentrations than Digester Gas



- Concentration of halogens are generally much lower in WWTP than LFG gas
- Chlorine is the dominant

  halogen species
- Forms corrosive gases, combustion or reforming
- Affects long-term performance of fuel cell

Legend:

ADG – Anaerobic Digestion Gas

LFG – Land Fill Gas

Source: Argonne National Laboratory

What are the tolerance limits for the Fuel Cells?

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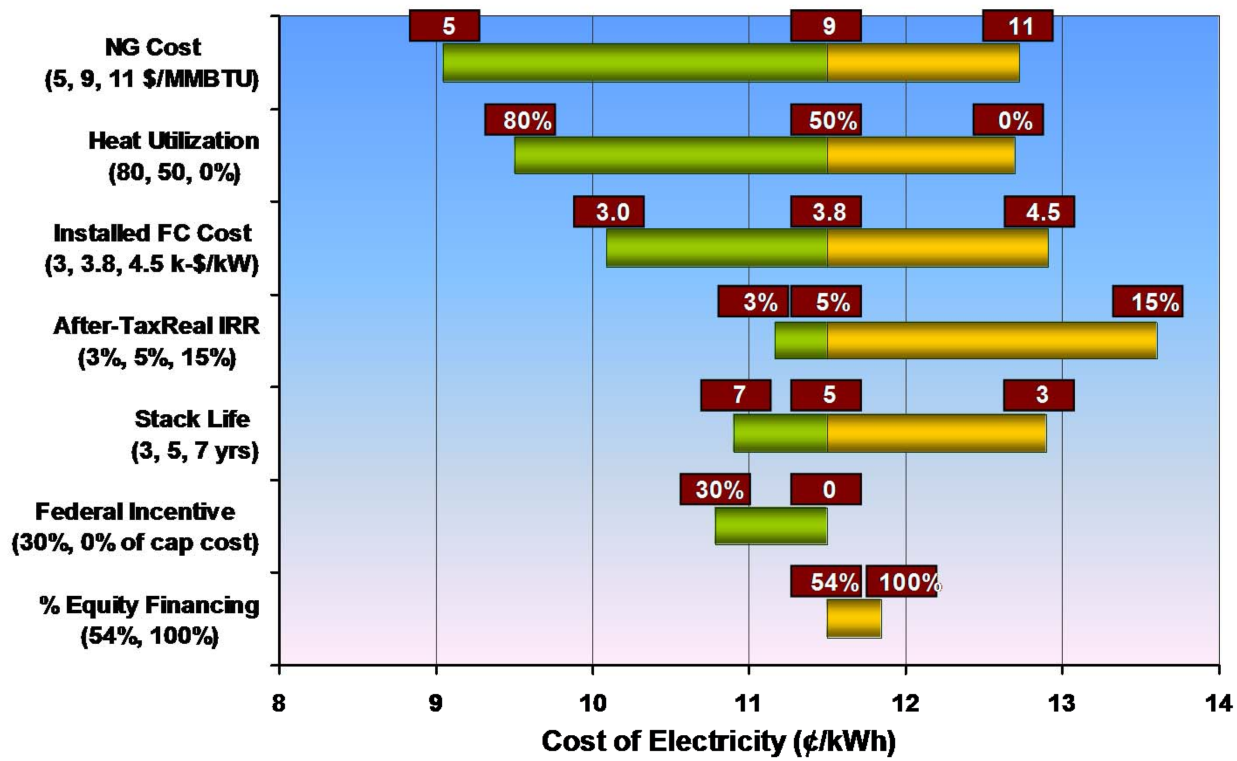
- ***Sulfur***
  - Corrosive, affects catalyst and electrolyte
  - Rapid initial followed by slower voltage decay. Effect may be recoverable
  - Tolerance limits 0.5-5 ppm
  - More severe effect with CH_4/CO rich fuels to Fuel Cell and anode recirculation
- ***Siloxanes***
  - Thermally decompose forming glassy layers
  - Fouls surfaces (HEx, sensors, catalysts)
  - Few studies on the effects on FC's, but tolerance limits may be practically zero
- ***Halogens***
  - Corrosive, affects electrolyte
  - Long term degradation effect
  - Tolerance limits, 0.1-1 ppm

Impurity	Tolerance	Reference
Molten Carbonate Fuel Cells		
H_2S	0.1 0.5 0.1-5 ppm	(Tomasi, *et al.*, 2006) (Abe, Chaytors, Clark, Marshall and Morgan, 2002) (Moreno, *et al.*, 2008) (Desiduri, 2003)
COS, CS_2, mercaptan	1 ppm	(Tomasi, Baratieri, Bosio, Arato and Baggio, 2006)
Organic Sulfur	<6 ppm	(Lampe, 2006)
H_2S, COS, CS_2	0.5-1 <10 ppm	(Cigolotti, 2009) (Lampe, 2006)
Halogens (HCl)	0.1-1 ppm	(Moreno, McPhail and Bove, 2008) (Desiduri, 2003), Lampe, 2006) (Abe, Chaytors, Clark, Marshall and Morgan, 2002)
Halides: HCl, HF	0.1-1 ppm	(Cigolotti, 2009)
Alkali Metals	1-10 ppm	(Tomasi, Baratieri, Bosio, Arato and Baggio, 2006) (Moreno, McPhail and Bove, 2008)
NH_3	1 % 1-3	(Moreno, McPhail and Bove, 2008) [Desiduri, 2002], [Fuel Cell Handbook, 2002] (Cigolotti, 2009)
		(Moreno, McPhail and
Siloxanes: HDMS, D5	10-100 <1 ppm	(Cigolotti, 2009) (Lampe, 2006)
Tars	2000 ppm	(Cigolotti, 2009)
Heavy Metals: As, Pb, Zn, Cd,Hg	1-20 ppm	(Cigolotti, 2009)

Source: Argonne National Laboratory

Cost of Electricity from Commercial-Scale Stationary Fuel Cell



Performance Parameters

System Electric Efficiency	= 45% (LHV Basis)
System Total Efficiency	= 77% (LHV Basis)
System Size	= 1,400 kW
System Life	= 20 years
Capital cost	= $3.5 million
Installed cost	= $5.3 million

Financial Assumptions

Startup year	= 2010
Financing	= 54% equity
Interest rate	= 7%
Financing period	= 20 years
After-tax Real IRR	= 5%
Inflation rate	= 1.9%
Total tax rates	= 38.9%
Depreciation schedule	= 7 years (MACRS)
Payback period	= 11 years

Stack replacement cost distributed annually

Operation Assumptions

System utilization factor	= 95%
Restacking cost	= 30% of installed cap. cost
Heat value	= cost of displaced natural gas from 80% efficient device

Source: NREL Fuel Cell Power Model

MCFC 1.4 MW

Challenges & Strategy

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Application-driven targets for commercial viability in terms of cost and performance recently revised and updated

Example of system level targets:

Technical Targets: 1–10 kW_e Residential Combined Heat and Power and Distributed Generation Fuel Cell Systems Operating on Natural Gas			
Characteristic	2011 Status	2015 Targets	2020 Targets
Electrical efficiency at rated power	34-40%	42.5%	>45%
CHP energy efficiency	80-90%	87.5%	90%
Equipment cost, 2-kW_{avg} system	NA	$1,200/$kW_{avg}$	$1,000/$kW_{avg}$
Equipment cost, 5-kW_{avg} system	$2,300 - $4,000/kW	$1,700/$kW_{avg}$	$1,500/$kW_{avg}$
Equipment cost, 10-kW_{avg} system	NA	$1,900/$kW_{avg}$	$1,700/$kW_{avg}$
Transient response (10 - 90% rated power)	5 min	3 min	2 min
Start-up time from 20°C ambient temperature	<30 min	30 min	20 min
Degradation with cycling	<2%/1,000 h	0.5%/1,000 h	0.3%/1,000 h
Operating lifetime	12,000 h	40,000 h	60,000 h
System availability	97%	98%	99%

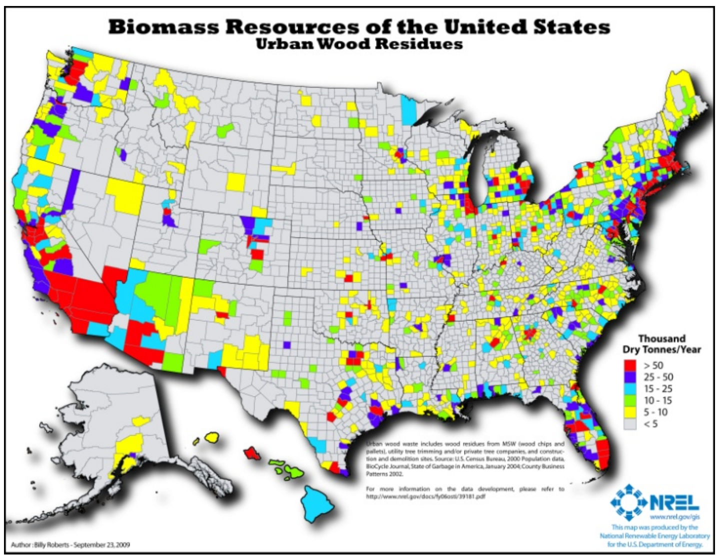
Targets revised for the complete portfolio guiding R&D for transportation, stationary, and portable applications

Revised targets in recently released MYRDD Plan
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html

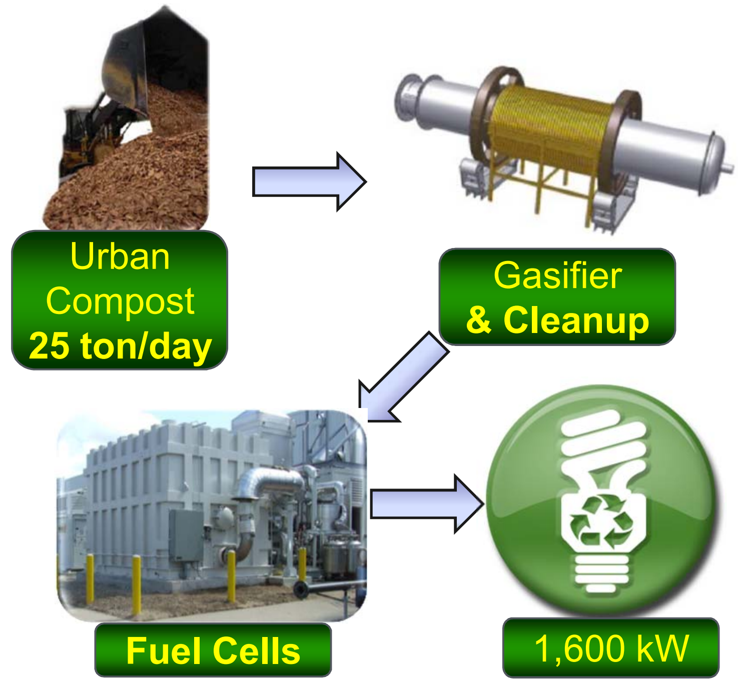
Waste To Energy Example
Los Alamitos Joint Forces Training Base (JFTB)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Los Alamitos JFTB



National Renewable Energy Laboratory
Innovation for Our Energy Future



Resource potential for Los Alamitos
- 300 tons/day
- 19,200 kW

Urban wood waste is an abundant feedstock around the US

Examples of DOE Funded Fuel Cell Deployments

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U.S. Fuel Cell Deployments Using DOE Market Transformation and Recovery Act Funding

Primarily forklifts and back-up power units

Tactical WTE Efforts & Demos*

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **Defense Advanced Research Projects Agency (DARPA) and Army Research Lab (ARL)**
  - Basic research and fundamental technology development (MISER, etc)
- **Natick Soldier RDEC (NSRDEC)**
  - Combination of SBIR and mission funded projects for Waste to Energy Converter (WEC) since 2000 Contractors include Community Power Corp (CPC), Infoscitex, General Atomics, and Green Liquid and Gas Technologies
  - Targeting PM Force Provider for technology transition / deployment
  - Mobile Encampment Waste to Electrical Power System (MEWEPS) project with CPC, second field demonstration scheduled at Ft. Irwin, CA in Feb 2011
- **Edgewood Chemical / Biological Center (ECBC)**
  - Tactical Garbage to Energy Refinery (TGER) AIDE project with DLS, Purdue University, and CPC, field demonstration executed in theater
- **Communications-Electronics RDEC (CERDEC)**
  - Biofuel / Tactical Quiet Generator Hybrid Waste to Energy project with CPC, contract on-going

Other Potential Opportunities

- Fort Stewart 94,000 lbs/hr steam Wood Chip Plant (off line).
- Aberdeen Proving Ground - Offsite plant supplies approx 70,000 lbs/hr (peak) and approx 452,000 Mlbs total 350 psi steam/year.
- The Eielson Air Force Base system processed over 560 tons of paper products in the base's central heat and power plant which provided 7.82 mmBtu of energy (program currently suspended because the pellet plant is inoperable).
- Hill Air Force Base, which generated 2.1 MW of electricity from landfill gas and has plans to expand to 3.2 MW.
- Dyess Air Force Base which is pursuing a 5.5 MW municipal solid waste energy plant.
- SUNY – Cobleskill Bioenergy Center

* Information provided by Daniela Caughron, APG

Use of biogas for hydrogen production as transportation fuel and stationary fuel cells for power and heat generation will be impacted by contaminant content and cleanup costs.

Barriers

High level of contaminants

High variability of contaminant concentrations

High capital cost for contaminant removal

Low experience level with biogas cleanup

Location of resources relative to demand centers and understanding cost impacts of transportation

Activities

Held workshops to understand gaps for utilizing biogas for hydrogen and power production

Working with Argonne National Laboratory to understand impact of biogas impurities on stationary fuel cell performance

Working with National Renewable Energy Laboratory on location of biogas resources and development of biogas H2A model for biogas cost analysis

FY 2012 FOAs	FY 2012 Funding
Collect Performance Data on Fuel Cell Electric Vehicles (deadline extended 6/18)	$6.0 million
Hydrogen Fueling Stations and Innovations in Hydrogen Infrastructure Technologies (closed 5/11)	$2.0 million
Fuel Cell Powered Baggage Vehicles at Commercial Airports	$2.5 million
Zero-Emission Cargo Transport Vehicles (Vehicle Technologies, closes 5/15)	$10.0 million

Requests for Information

- Fuel Cell RFIs on Targets for Lift Trucks and Backup Power
- Potential Topics for H-Prize—*extended to May 31, 2012* (www.hydrogenandfuelcells.energy.gov/m/news_detail.html?news_id=18182)
- Storage RFI on Early Market Targets
  (Posted on eXCHANGE at https://eere-exchange.energy.gov/Default.aspx#6d785cb1-552e-44bd-98e3-e27a7e3fea0b)