Expanding the US Biogas - Fuel Cell Program

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

5th Annual Global Biogas Congress

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U.S. Greenhouse Gas and Methane Emissions

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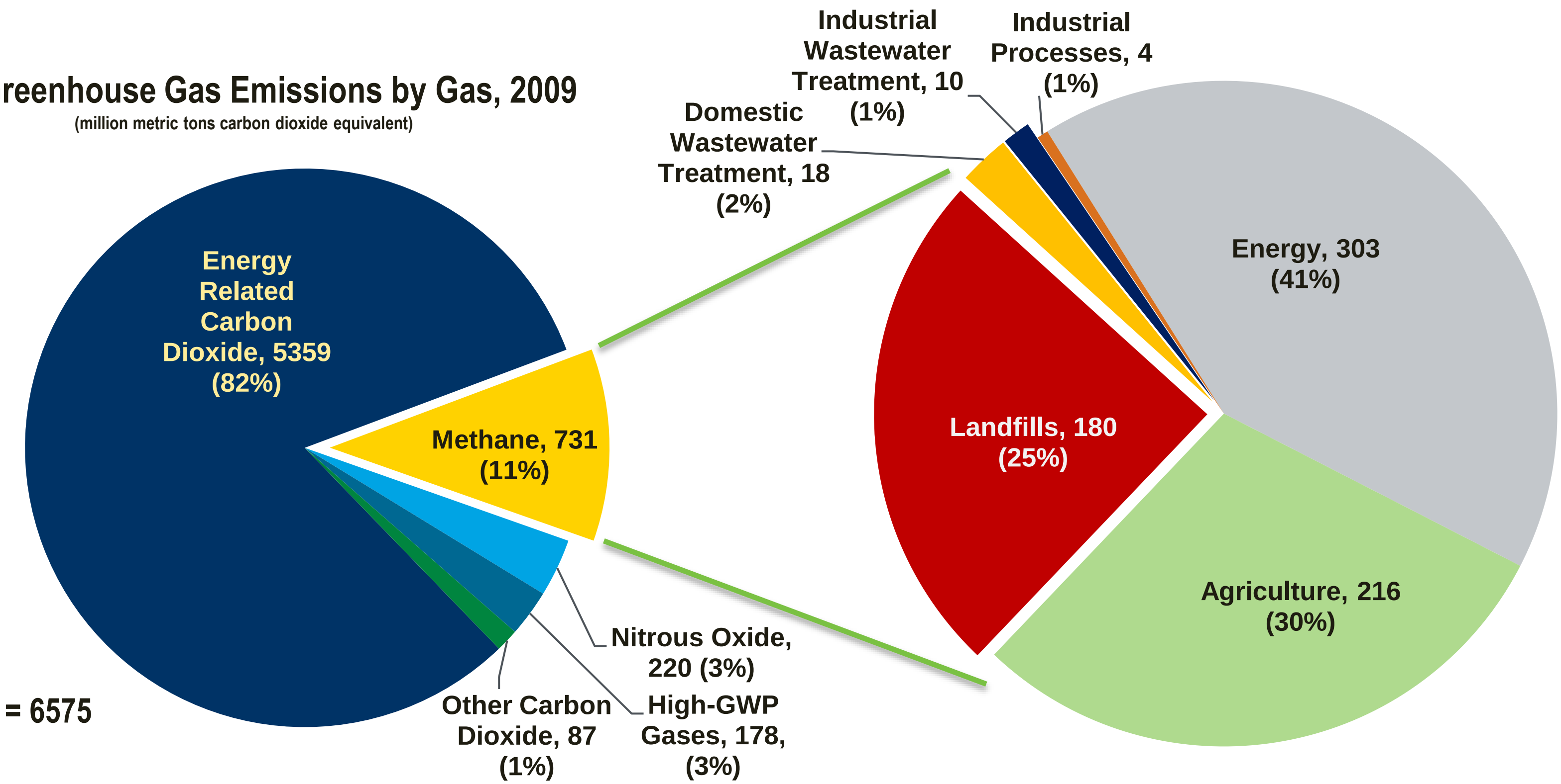
Landfills and Wastewater Treatment contribute ~30% of Methane Emissions in the U.S.

U.S. Methane Emissions by Source , 2009

(million metric tons carbon dioxide equivalent

U.S. Greenhouse Gas Emissions by Gas, 2009

(million metric tons carbon dioxide equivalent)



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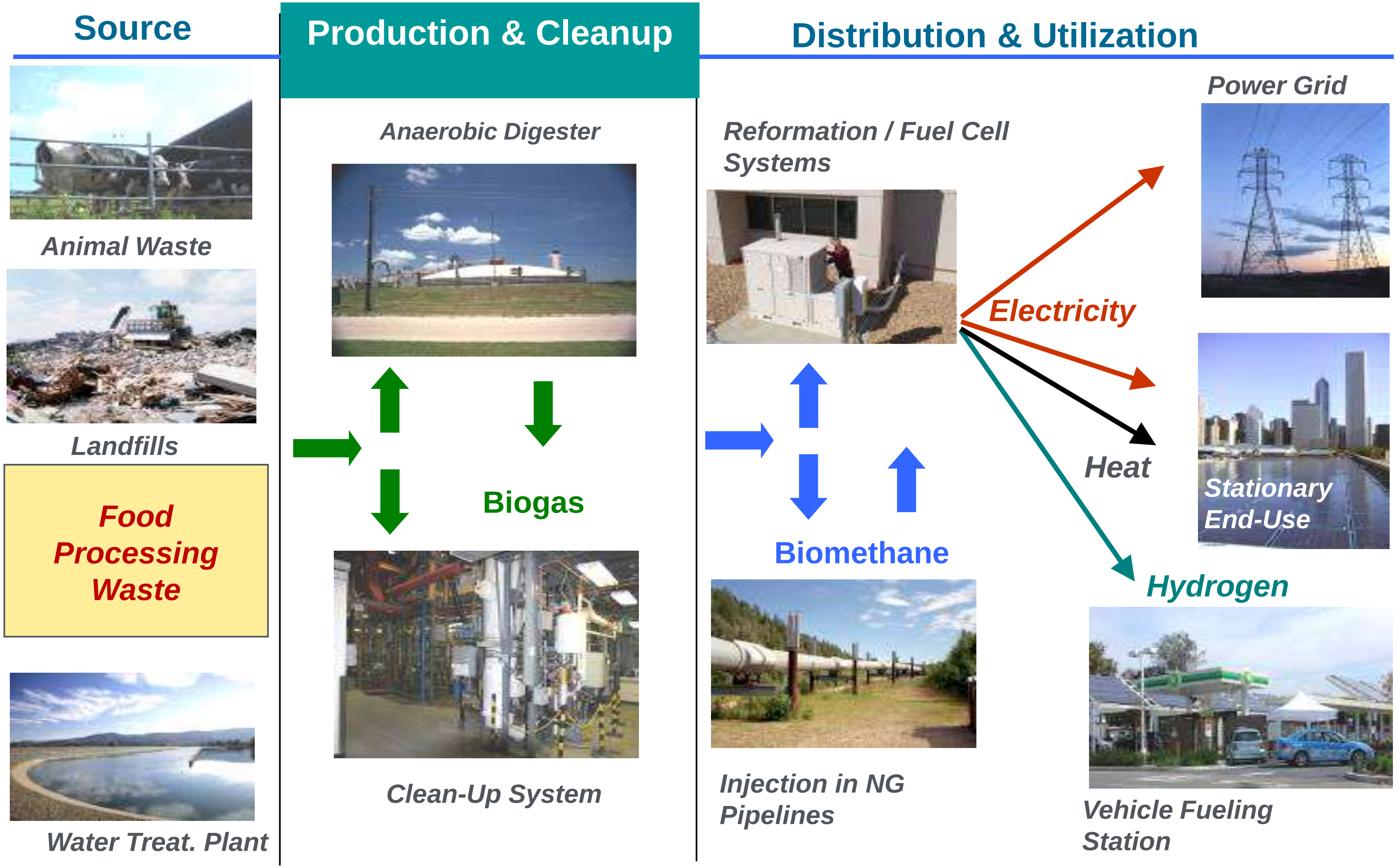
Fuel cells operating on bio-methane or hydrogen derived from bio-methane can mitigate energy and environmental issues and provide an opportunity for their commercialization. Other drivers are: need for fuel diversity/flexibility, evolving policies for renewables, and related incentives.



Source: National Renewable Energy Laboratory

Biogas as an Early Source of Renewable Hydrogen and Power

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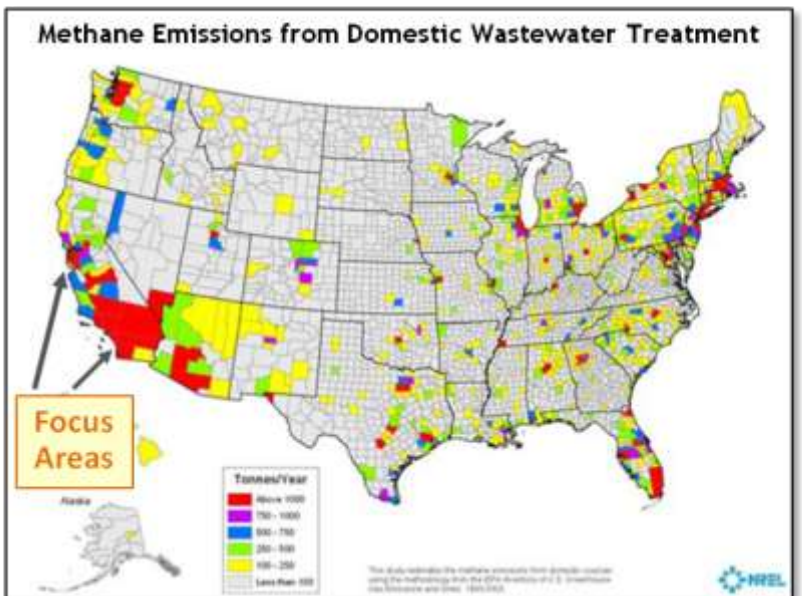
- ***The majority of biogas resources are situated near large urban centers—ideally located near the major demand centers for hydrogen generation for hydrogen fuel cell vehicles (FCEVs) and power generation from stationary fuel cells.***
- ***Hydrogen can be produced from this renewable resource using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

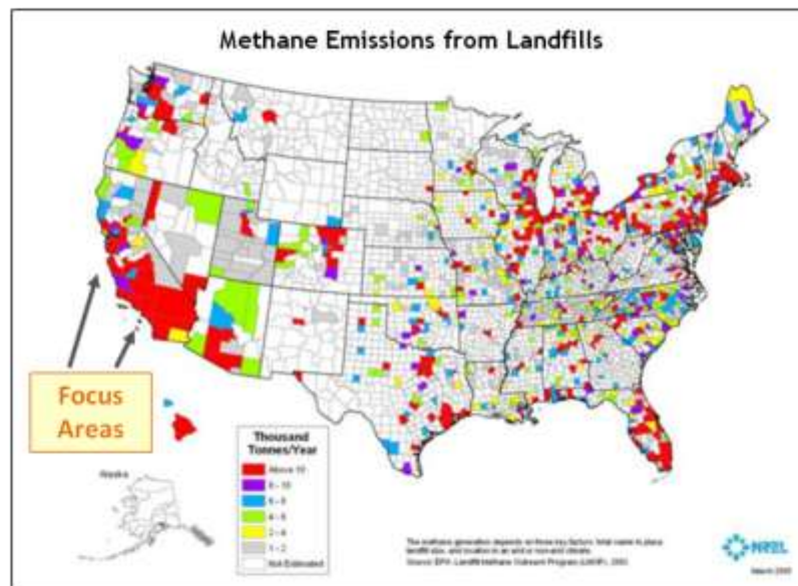
SOURCE: Wastewater Treatment, *could provide enough H_2 to refuel ~**100,000 vehicles per day.***

- 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.

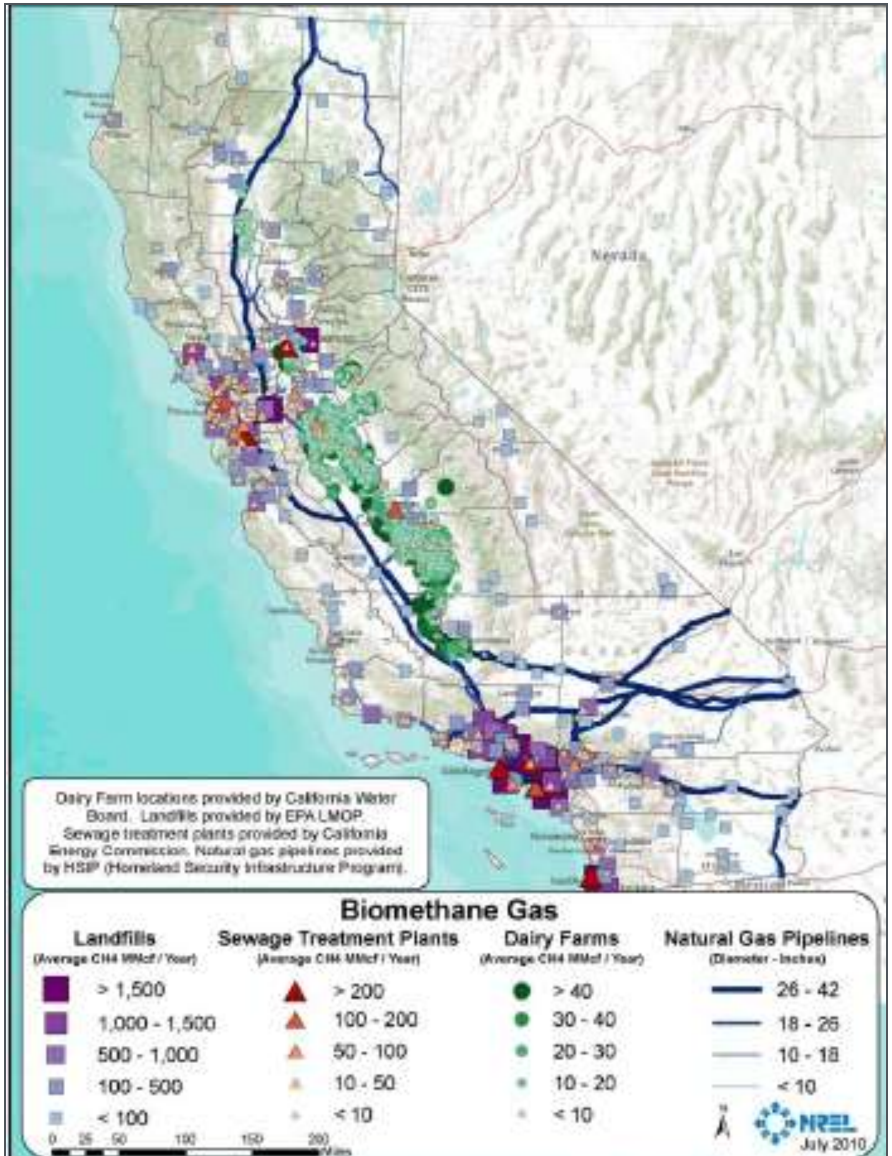


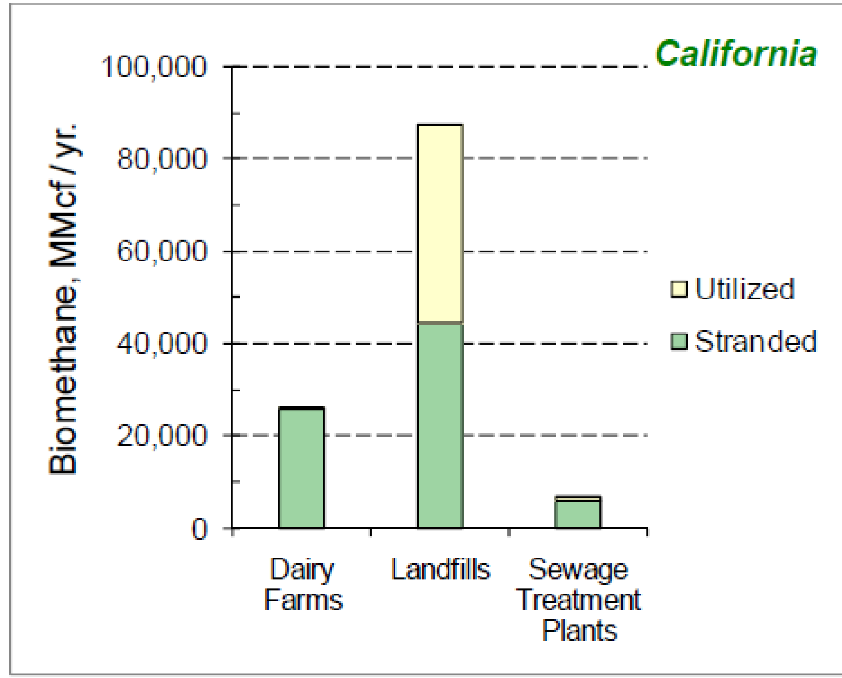
SOURCE: Landfills, *could provide enough H_2 to refuel **2-3 million vehicles/day**.*

- 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**.**



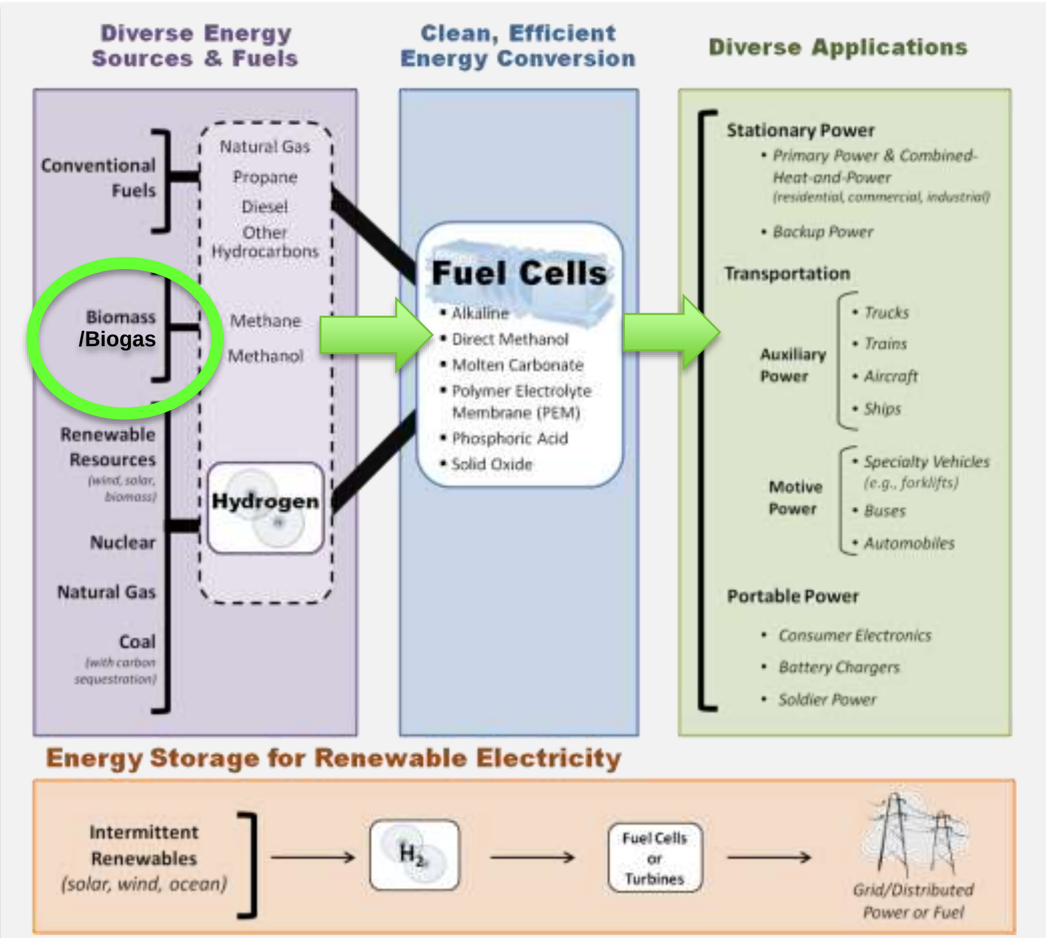
Potential Biogas Sources in California





- Select biogas resources: Landfills, sewage treatment plants, and dairy farms.
- Transmission lines are reasonably accessible to most of biogas sources.
- Landfills offer greater biogas potential.
  - Landfills have the dominant share at 75%, followed by dairy farms at 22%.
- Total biomethane potential is about 5% of NG consumption.

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)*

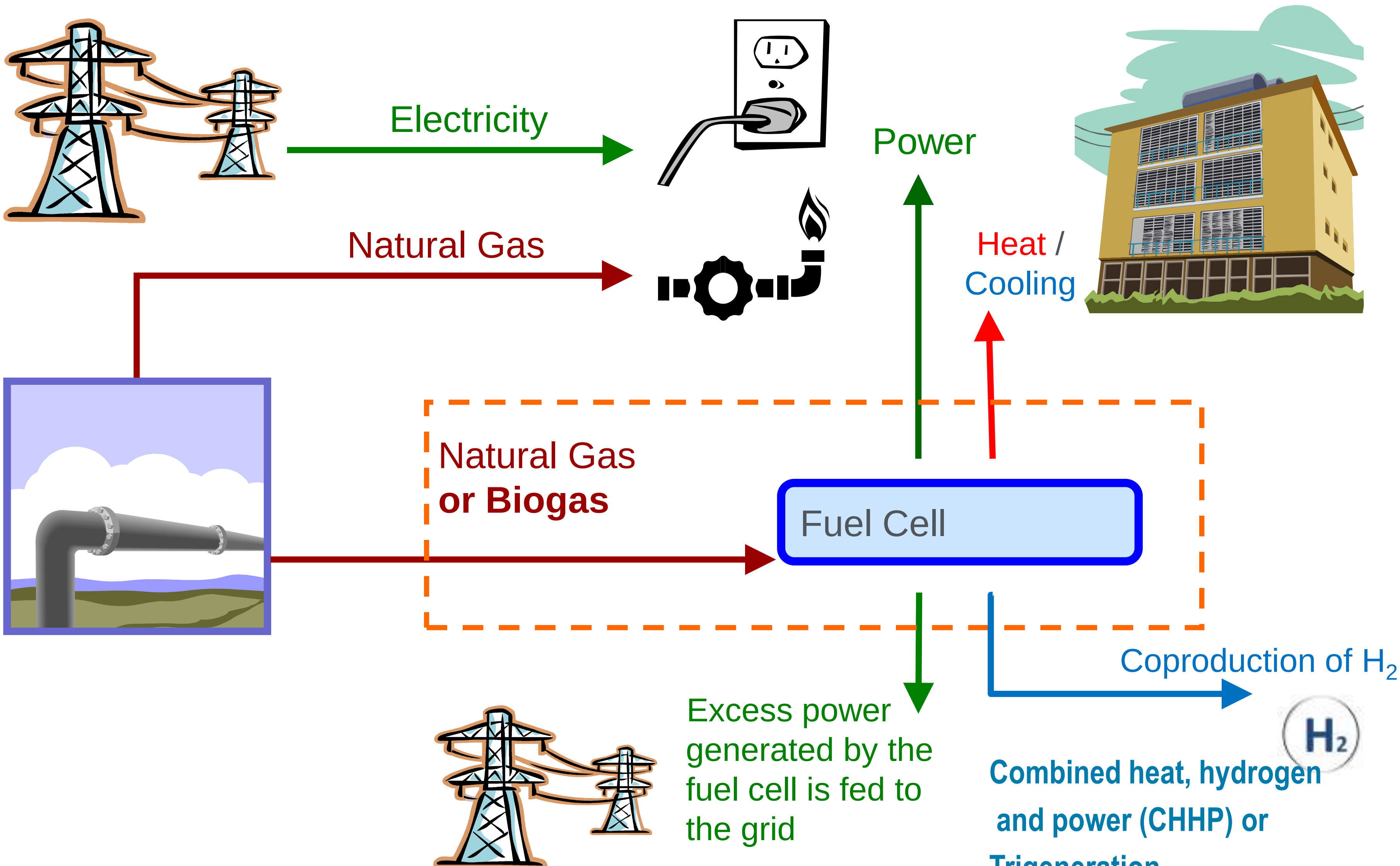
Reduced Air Pollution

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

Fuel Flexibility

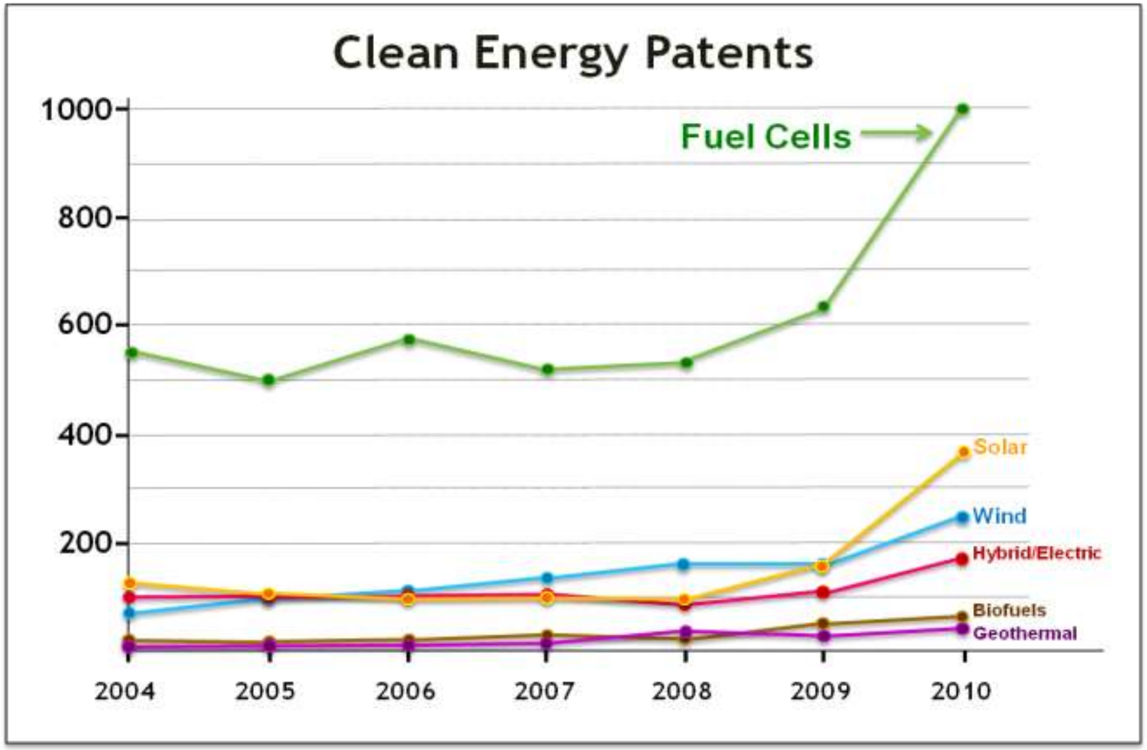
- **Clean fuels** — *including biogas, methanol, H_2*
- **Hydrogen** — *can be produced cleanly using sunlight or biomass directly, or through electrolysis, using renewable electricity*
- **Conventional fuels —** *including natural gas, propane, diesel*

Overview of Combined Heat-Power



Adapted from NREL

Fuel Cell Patents Reflect Emerging Growth



Clean Energy Patent Growth Index[1] shows that fuel cell patents lead in the clean energy field with nearly 1,000 fuel cell patents issued worldwide in 2010.

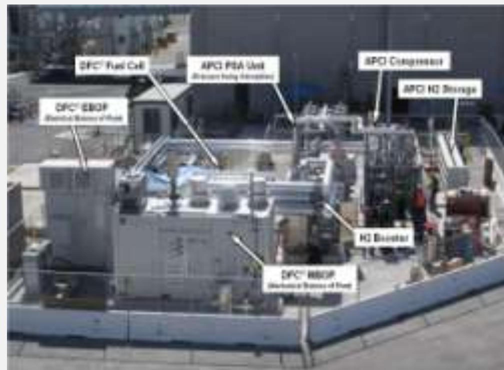
- **3x more than the second place holder, solar, which has just ~360 patents.**
- **Number of fuel cell patents grew > 57% in 2010.**

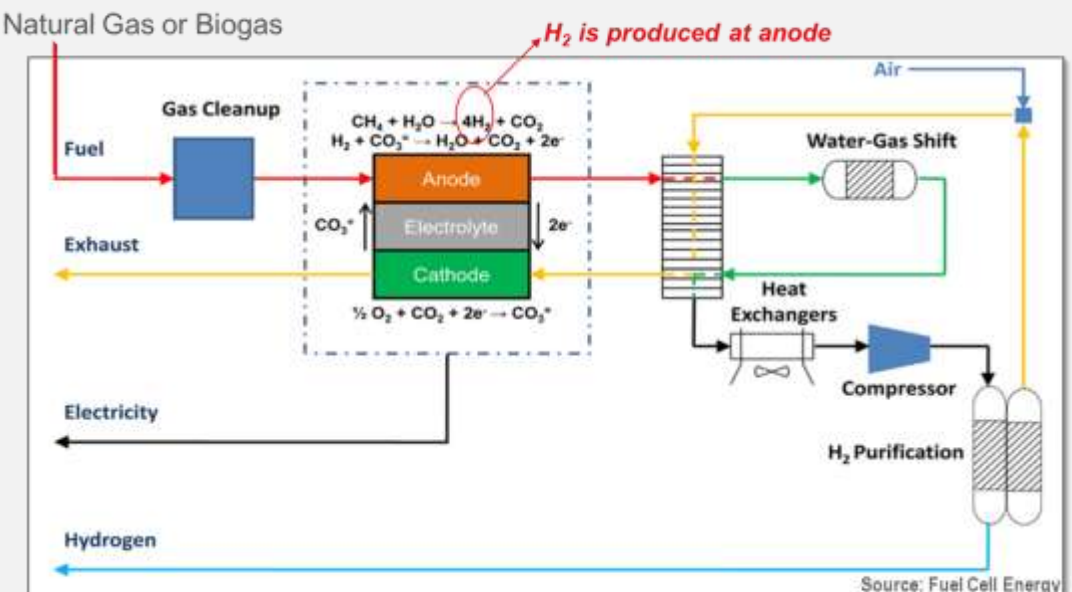
[1} 2010 Year in Review at: http://cepgi.typepad.com/heslin_rothenberg_farley_/

"Energy Department Applauds World's First Fuel Cell and Hydrogen Energy Station in Orange County"

Demonstrated world's first Tri-generation station (CHHP with 54% efficiency)

-Anaerobic digestion of municipal wastewater-





Fountain Valley demonstration

- ~250 kW of electricity
- ~100 kg/day hydrogen capacity (350 and 700 bar), enough to fuel 25 to 50 vehicles.
- 47% LHV electrical efficiency (>80% LHV overall efficiency)

Examples of Fuel Cell CHP Industry Deployments

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**

Biogas Barriers

Use of biogas for hydrogen production as transportation fuel and stationary fuel cells for power and heat generationwill 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

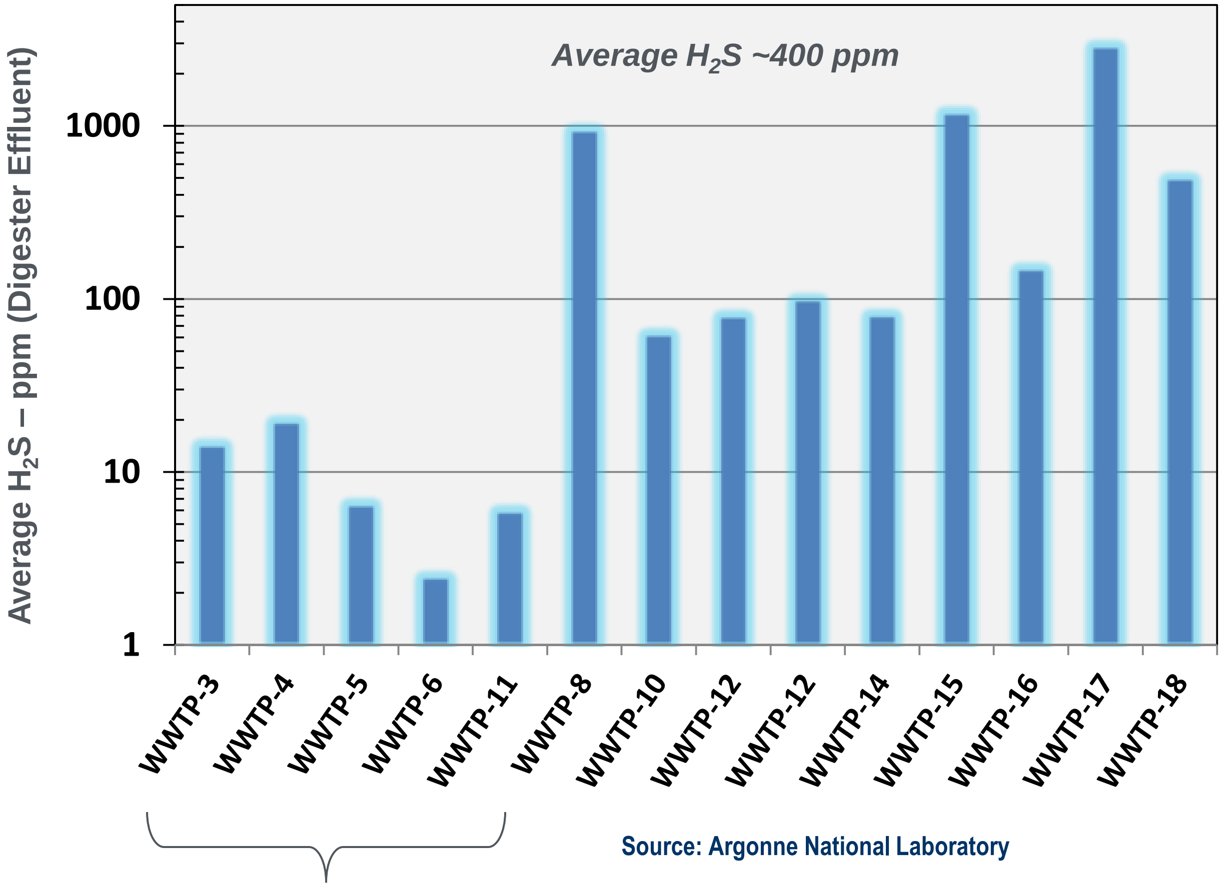
- ***Sulfur***
  - Corrosive, affects catalyst and electrolyte
  - Rapid initial followed by slower voltage decay. Effect may be recoverable
  - Tolerance limits 0.5-5 ppm
  - More severe effect with CH_4/CO rich fuels to Fuel Cell and anode recirculation
- ***Siloxanes***
  - Thermally decompose forming 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

Hydrogen Sulfide (H_2S) Content of Digester Gas

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



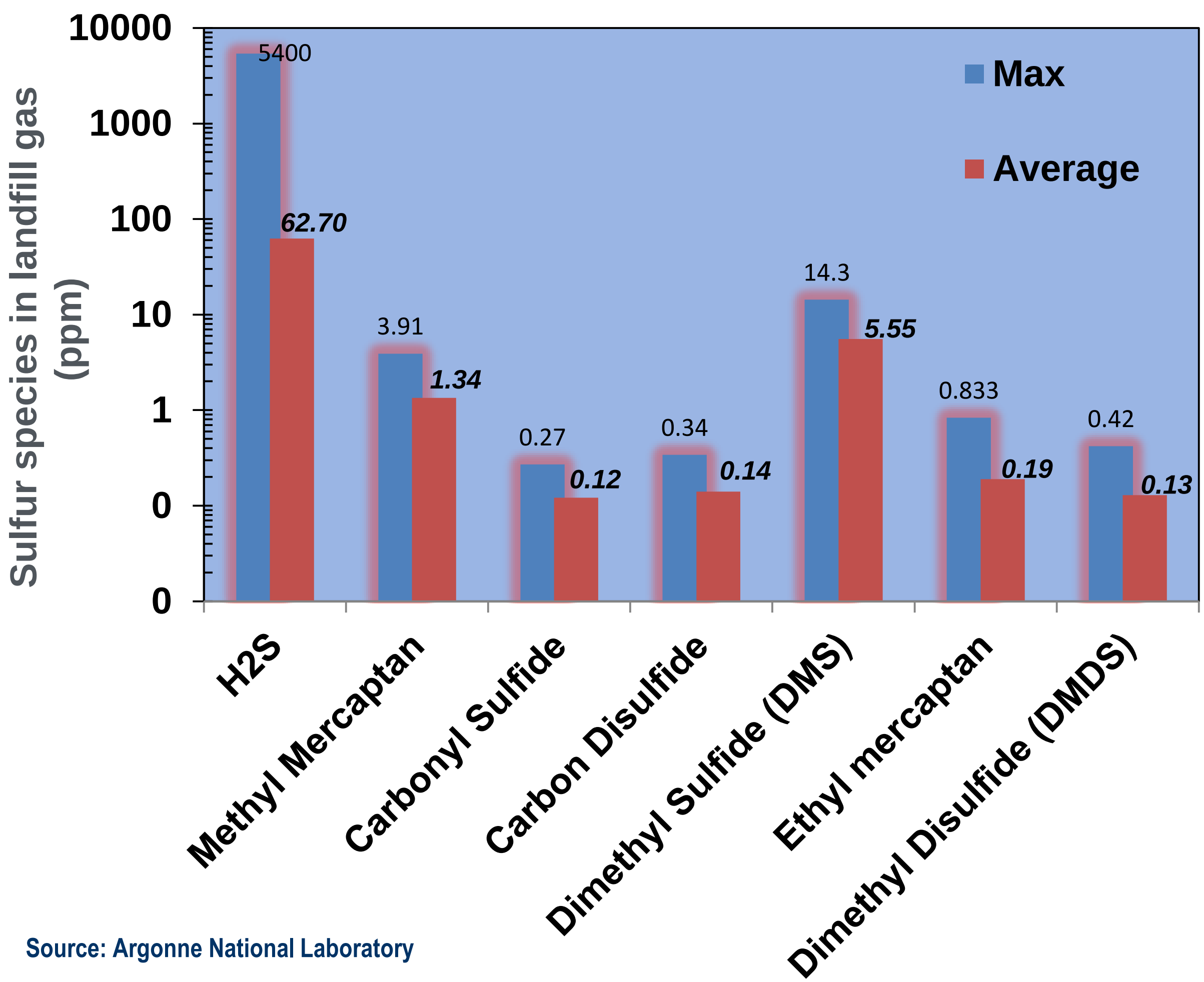
Source: Argonne National Laboratory

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

- 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

Sulfur Species Content of Land Fill Gas

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

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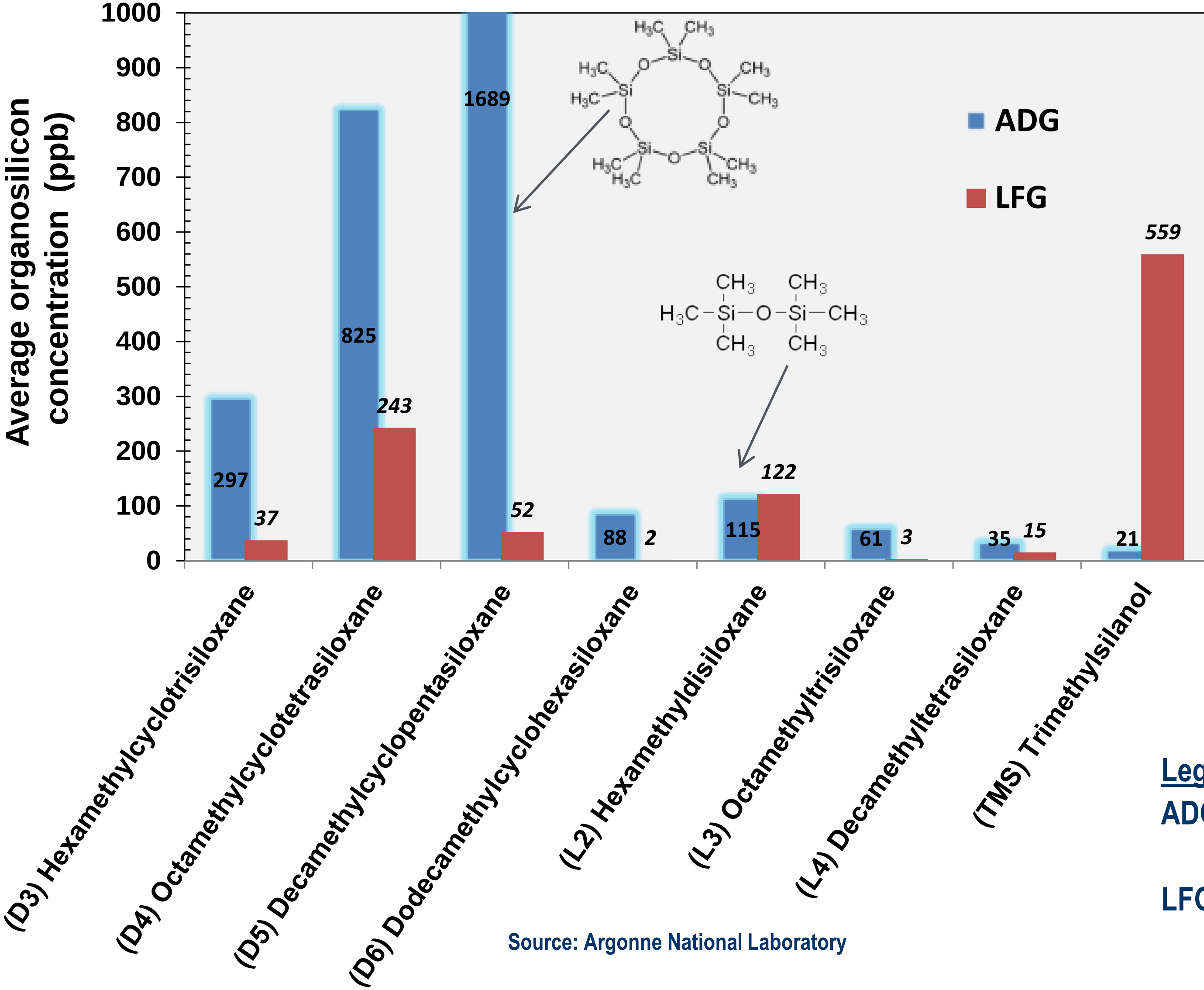
Digester gas contains predominately cyclic (D4,D5) organosilicon (siloxanes) species



Source: Argonne National Laboratory

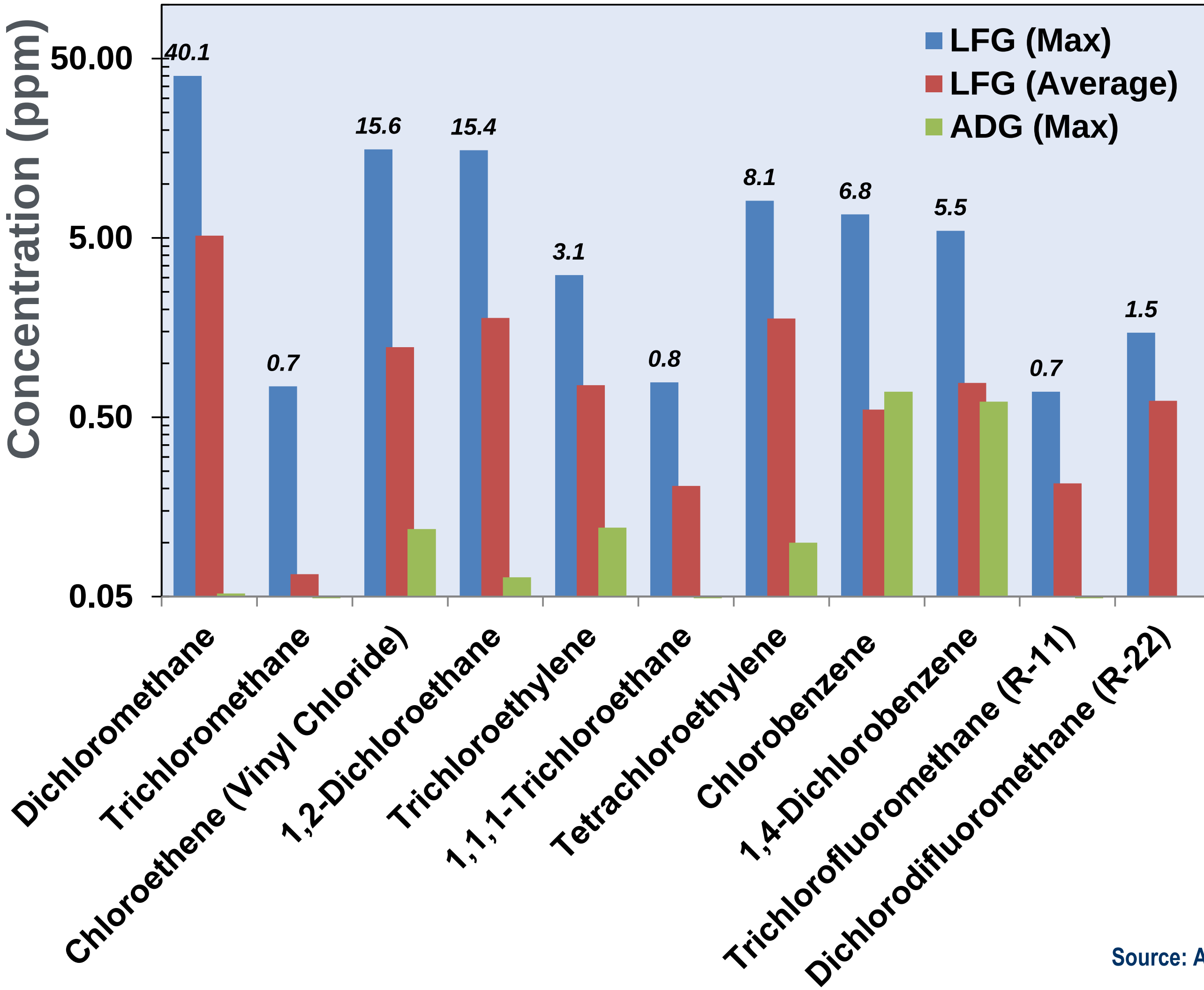
- Cyclic compounds (D4 & D5) are dominant in WWTP gas
- Concentration of linear compounds and TMS are usually low
- ADG temperature affects speciation and concentration of siloxane compounds
- Solid silica deposits on surfaces. Tolerance level often require “below detection limit”

Legend:

ADG – Anaerobic Digestion Gas

LFG – Land Fill Gas

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

Policies and Incentives Promoting Fuel Cells and Biogas

Modified Accelerated Cost-Recovery System (MACRS)*	Fuel cell property placed in service between 9/8/2010 1/1/2012 qualifies for 100% first-year bonus depreciation. For 2012, bonus depreciation is still available, but at 50% of the eligible basis.	The property must have a recovery period of 20 years or less under normal federal tax depreciation rules and been acquired and placed in service between 2008 – 2012.
Loan Guarantee Program*	Amount varies. Program focuses on projects with total project costs over $25 million.	Full repayment is required over a period not to exceed the lesser of 30 years or 90% of the projected useful life of the physical asset to be financed.
Alternative Fuel Infrastructure Tax Credit	30% tax credit for qualified fuel cell property or $3,000/kW of the fuel cell nameplate capacity. 10% credit for CHP-system property.	Equipment must be installed by Dec. 31, 2016.
Investment Tax Credit	Offers tax credit of 30% for qualified fuel cell property or $3,000/kW of the fuel cell nameplate capacity. Feature a 10% credit for combined-heat-and-power-system property.	Equipment must be installed by Dec. 31, 2016.
Advanced Power System Technology Incentive Program	1.8¢/kWh for qualifying advanced power system technology and an additional 0.7¢/kWh for a qualifying security and assured power facility for electricity generated.	10,000,000kWh limit per fiscal year. Expires 9/30/2013.
Renewable Electricity Production Tax Credit	2.2¢/kWh for wind, geothermal, closed-loop biomass; 1.1¢/kWh for other eligible technologies (landfill gas, municipal solid waste)	Expires 12/31/2013.
Renewable Energy Production Incentive	1.5¢/kWh in 1993 dollars (indexed for inflation) for biogas, biomass, hydrogen, LFG for combustion turbines, Boilers, condensing turbines, fuel cells, microturbine, reciprocating engine, heat recovery generator, Stirling engine.	Expires 12/31/2026

Fuel Cell Motor Vehicle Tax Credit: $4,000 for LDV, $10,000-$40,000 range for heavier vehicles. Expires 12/31/2014.

Hydrogen Fuel Excise Tax Credit: $0.50/gallon. Hydrogen must be sold or used as a fuel to operate a motor vehicle. Expires 9/30/2014.

Alternative Fuel Infrastructure Tax Credit: $1,000 cap for residential use.

Residential Renewable Energy Credit: Fuel Cell maximum - $500/0.5kW. Fuel cells must have electricity-only generation efficiency greater than 50% and 0.5kW minimum.

Residential Renewable Energy Credit: 30% tax credit. Raises ITC dollar cap for residential fuel cells in joint occupancy dwellings to $3,334/kW. Expires 12/31/2016.

*Applies to fuel cell and CHP technologies

Potential Future Work

- Investigate options to reduce the purification costs and technologies for removing contaminants of biogas streams
- Explore the possibility of formulating a correlation between the cost of the biogas upgrading system and the purification requirements.
- Investigate the effect of combining biogas products from multiple sites/sources on temporal variation of the feed chemical composition for the clean-up process.
- Investigate options to remove limits for transporting purified biogas in natural gas pipelines

Partnerships & Collaboration

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Federal Agencies

- DOC
- DOD
- DOE
- DOT
- EPA
- GSA
- DOI
- DHS
- NASA
- NSF
- USDA
- USPS

– *Interagency coordination through staff-level Interagency Working Group (meets monthly)*
– *Assistant Secretary-level Interagency Task Force mandated by EPACT 2005.*

Universities

~ 50 projects with 40 universities

International

- IEA Implementing agreements – 25 countries
- International Partnership for Hydrogen & Fuel Cells in the Economy – 17 countries & EC, 30 projects

External Input

- Annual Merit Review & Peer Evaluation
- H2 & Fuel Cell Technical Advisory Committee
- National Academies, GAO, etc.

DOE Hydrogen & Fuel Cells Program

Industry Partnerships & Stakeholder Assn's.

- Tech Teams (USCAR, energy companies- U.S. DRIVE)
- Fuel Cell and Hydrogen Energy Association (FCHEA)
- Hydrogen Utility Group
- ~ 65 projects with 50 companies

State & Regional Partnerships

- California Fuel Cell Partnership
- California Stationary Fuel Cell Collaborative
- SC H_2 & Fuel Cell Alliance
- Upper Midwest Hydrogen Initiative
- Ohio Fuel Coalition
- Connecticut Center for Advanced Technology

National Laboratories

National Renewable Energy Laboratory P&D, S, FC, A, SC&S, TV, MN
Argonne A, FC, P&D, SC&S
Los Alamos S, FC, SC&S
Sandia P&D, S, SC&S
Pacific Northwest P&D, S, FC, SC&S, A
Oak Ridge P&D, S, FC, A, SC&S
Lawrence Berkeley FC, A
Lawrence Livermore P&D, S, SC&S
Savannah River S, P&D
Brookhaven S, FC
Idaho National Lab P&D

Other Federal Labs: Jet Propulsion Lab, National Institute of Standards & Technology, National Energy Technology Lab (NETL)

P&D = Production & Delivery; S = Storage; FC = Fuel Cells; A = Analysis; SC&S = Safety, Codes & Standards; TV = Technology Validation, MN = Manufacturing

International Partnerships

International Partnership for Hydrogen and Fuel Cells in the Economy

- ***Representatives from 17 member countries & the European Commission***
- **Facilitates international collaboration on RD&D and education**
- **Provides a forum for advancing policies and common codes and standards**
- **Guided by four priorities:**
  1. Accelerating market penetration and early adoption of hydrogen and fuel cell technologies and their supporting infrastructure
  2. Policy and regulatory actions to support widespread deployment
  3. Raising the profile with policy-makers and public
  4. Monitoring technology developments

Recent Activities:

- Published a brochure on the status of research and commercialization of H_2 and FCs.
- IPHE Infrastructure Workshop (Sacramento, 2010)
- Published Demonstration and Deployment Map
- Published Communiqué on the opportunities associated with using hydrogen and fuel cell technologies
- Fuel Cell Cost Analysis Comparison Published

Website: http:www.iphe.net

International Energy Agency – Implementing Agreements

***Advanced Fuel Cells Implementing Agreement**:* 19 member countries currently implementing six annexes

Hydrogen Implementing Agreement: 21 member countries, plus the European Commission currently implementing nine tasks

Other Collaborations

Joint Technology Initiative (JTI); **MOUs** (NEDO-AIST-LANL, Hiroshima U-LANL); **Bi-lateral agreements, strong international collaboration on safety**

Thank You

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DOE Annual Merit Review: May 14 – 18, 2012

Arlington, VA

http://annualmeritreview.energy.gov/