U.S. Department of Energy Fuel Cell Technologies Office

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

Converting Landfill Gas – to – Hydrogen at the BMW Assembly Plant: Building on a Landfill Methane Outreach Program Success Story

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Fuel Cell Technologies Office
South Carolina Research Authority
Alternative Energy Programs

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DOE Hydrogen & Fuel Cells Program

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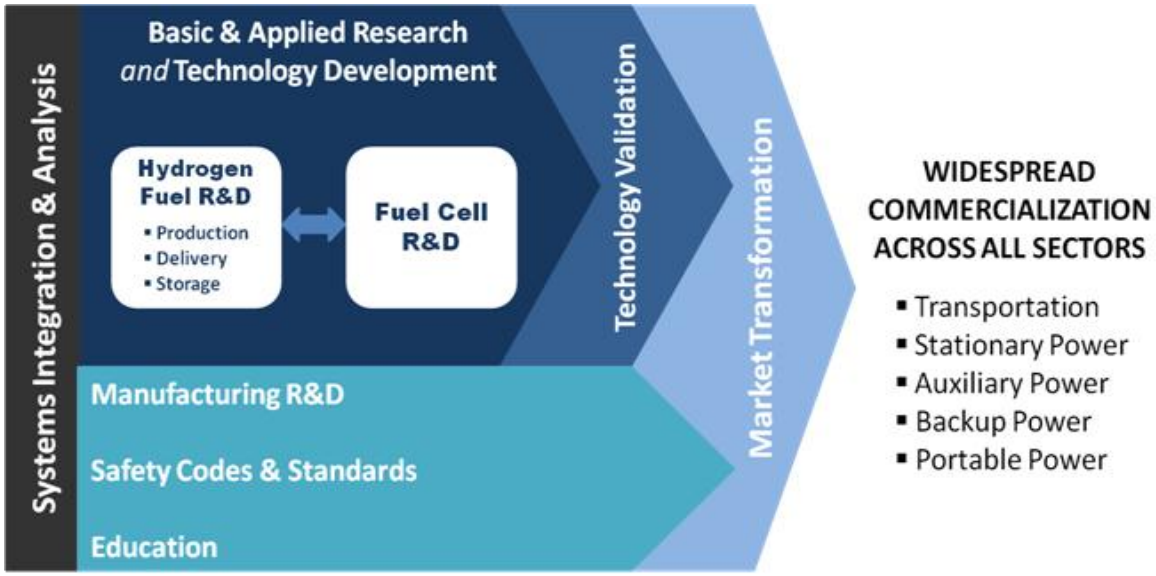
Mission: Enable widespread commercialization of a portfolio of hydrogen and fuel cell technologies through applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges.

Key Goals: Develop hydrogen and fuel cell technologies for early markets (stationary power, lift trucks, portable power), mid-term markets (CHP, APUs, fleets and buses), and long-term markets (light duty vehicles).

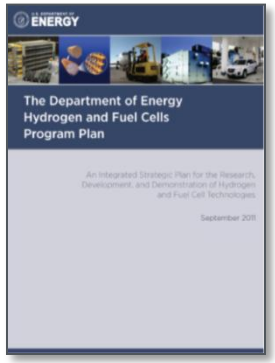


WIDESPREAD COMMERCIALIZATION ACROSS ALL SECTORS

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

Key Targets for FCEVs

- **$30/kW**
- **5000-hr durability *(150,000 miles)***
- **60% efficiency**
- **> 300-mile driving range**



Hydrogen & Fuel Cells Program Plan Update to the *Hydrogen Posture Plan* (2006). Includes Four DOE Offices: EERE, FE, NE, and Science.

DOE has a long-standing and substantial commitment to hydrogen and fuel cells:

- **Nearly 300 projects currently funded by DOE at companies, national labs, and universities/institutes**
- **More than $1.3 billion invested from FY 2007 to FY 2012 across four DOE offices**

Fuel Cells Overview and Benefits

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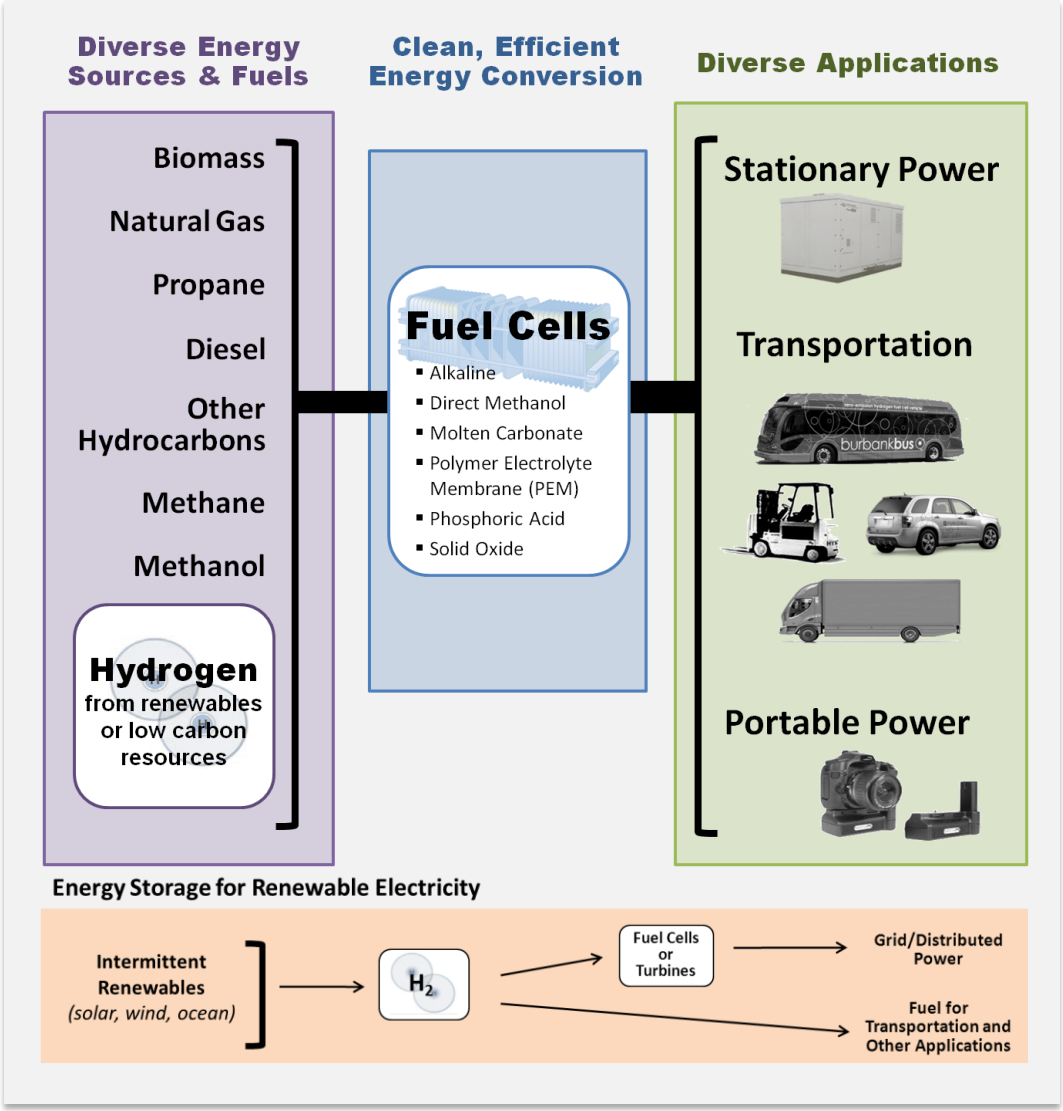
The Role of Fuel Cells



Key Benefits

Very High Efficiency
- **> 60%** *(electrical)*
- **> 70%** *(electrical, hybrid fuel cell / turbine)*
- **> 80%** *(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 ICEs)*
- **>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*

Fuel Cell Lift Trucks

Here is a zero-emission fuel cell vehicle…

It is a fuel cell powered forklift truck. Compared to conventional lift trucks, these hydrogen-fueled vehicles are providing economic benefits through labor productivity and more efficient use of warehouse space.

Medium and Heavy Duty Road Vehicles

Other zero emission fuel cell vehicle technologies include…

Heavy Duty Vehicles

Full-size buses

Drayage Trucks

Waste Hauling Trucks

Medium Duty Vehicles

Shuttle buses

Baggage Tow Tractors

Delivery Vehicles

These H2-fueled vehicles will replace diesel engines

Other Transportation Applications

Auxiliary Power Units (APUs)

Refrigerated Semi Trucks

Refrigerated Box Trucks

Mobile Specialty Products

Mobile Light Towers

Mobile Generators

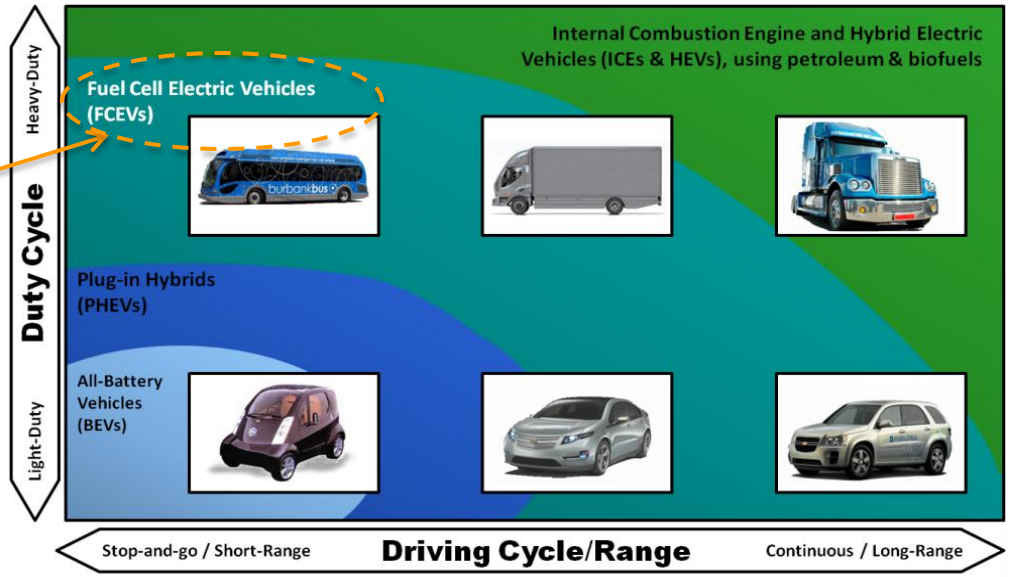
These H2-fueled fuel cell power systems will also be replacing diesel engines

Fuel Cells: Part of a Diverse Portfolio

Transportation: A diverse portfolio to meet the full range of driving cycles and duty cycles in the nation's vehicle fleet.

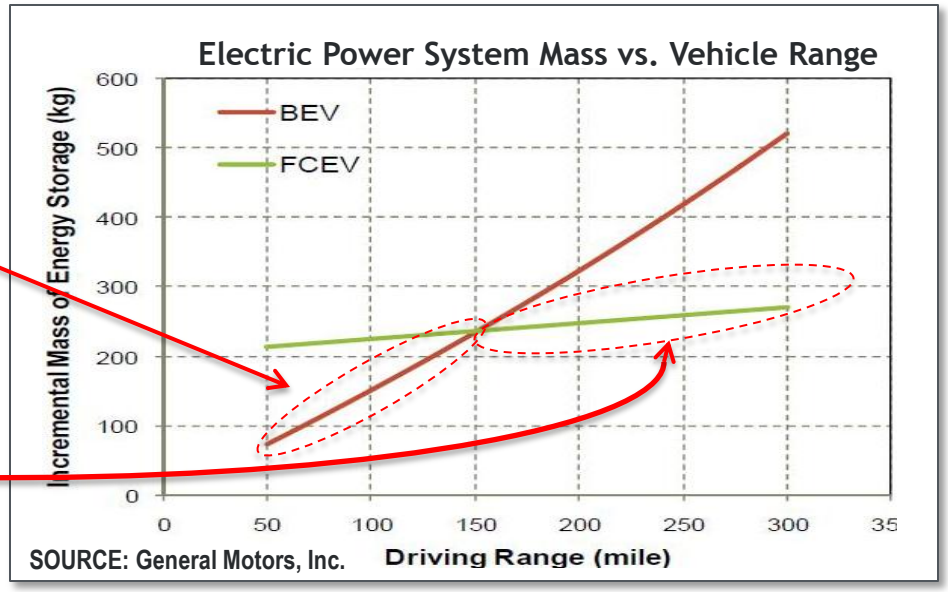
H_2 and fuel cells can play a key role

— by enabling longer driving ranges and heavier duty cycles for certain vehicle types *(including **buses**, **light-duty cars & trucks**, **delivery vans**, and **short-haul trucks**)*

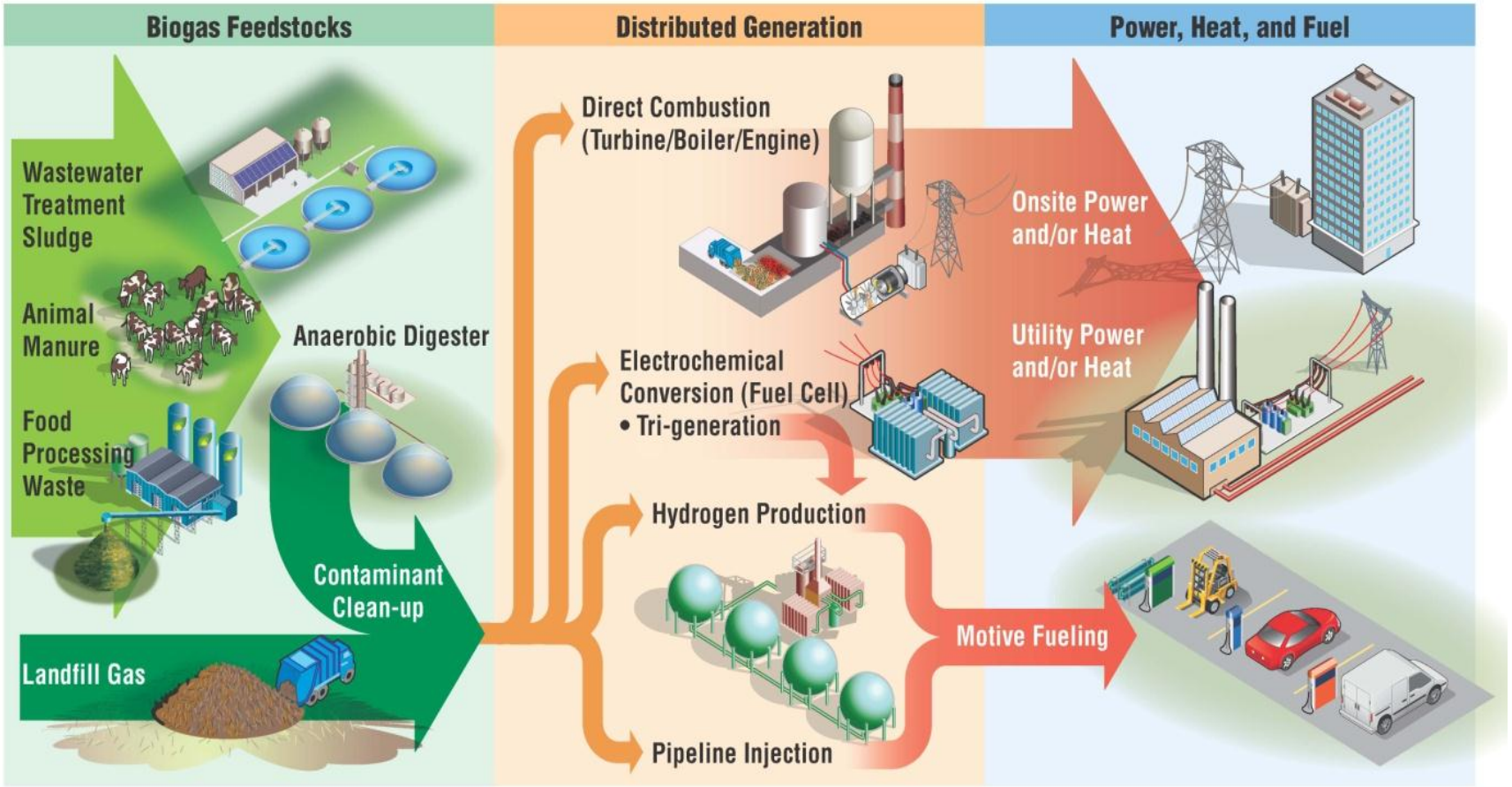


Advantages of Batteries and Fuel Cells:

- For shorter distances, batteries are more effective in terms of system mass
- ***Fuel cells can provide the driving ranges of today's vehicles without the weight penalty***
- ***But there are challenges: H_2 production, infrastructure, fuel cell cost & durability***



The Biogas-To-Energy Process



The "New" Business Case: Using biogas to provide <u>both</u> electric power and/or heat <u>and</u> transportation fuel

Biogas as an Early Source of Renewable Hydrogen and Power- Preliminary Analysis

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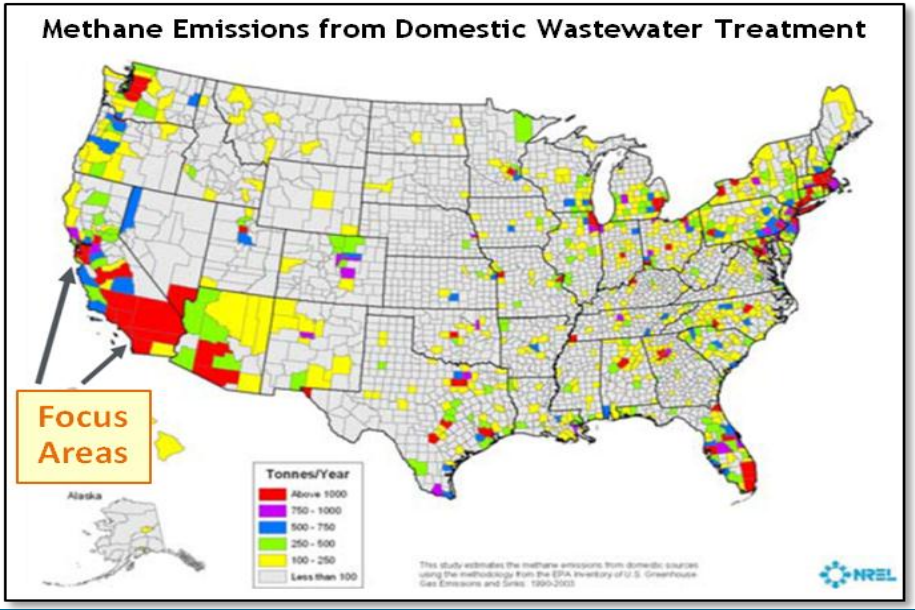
- ***The majority of biogas resources are situated near large urban centers—ideally located near the major demand centers for hydrogen generation for hydrogen fuel cell vehicles (FCEVs) and power generation from stationary fuel cells.***
- ***Hydrogen can be produced from this renewable resource using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

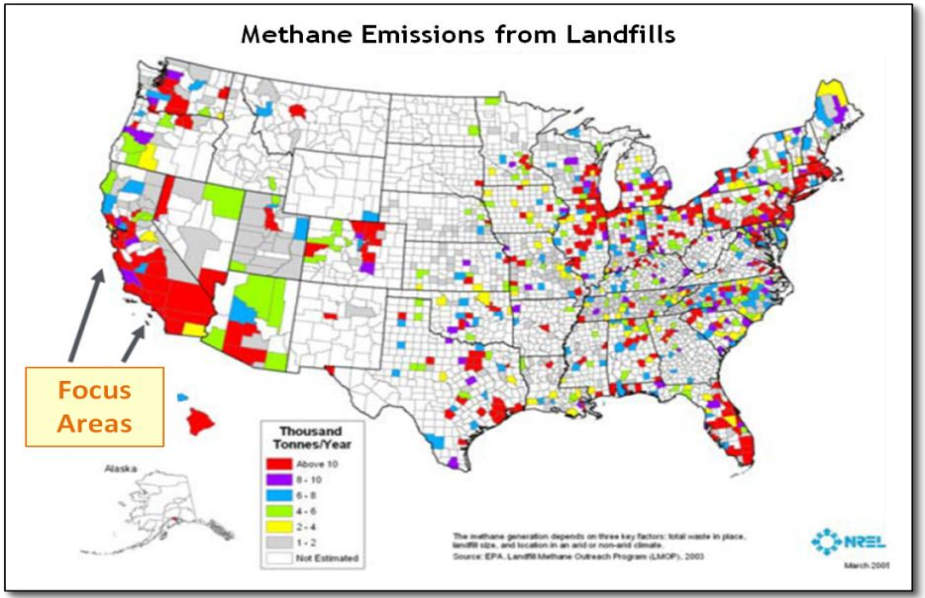
U.S. biogas resource has capacity to produce ~5 GW of power at 50% electrical efficiency.

Hydrogen generated from biogas can fuel ~8-13M FCEVs/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.

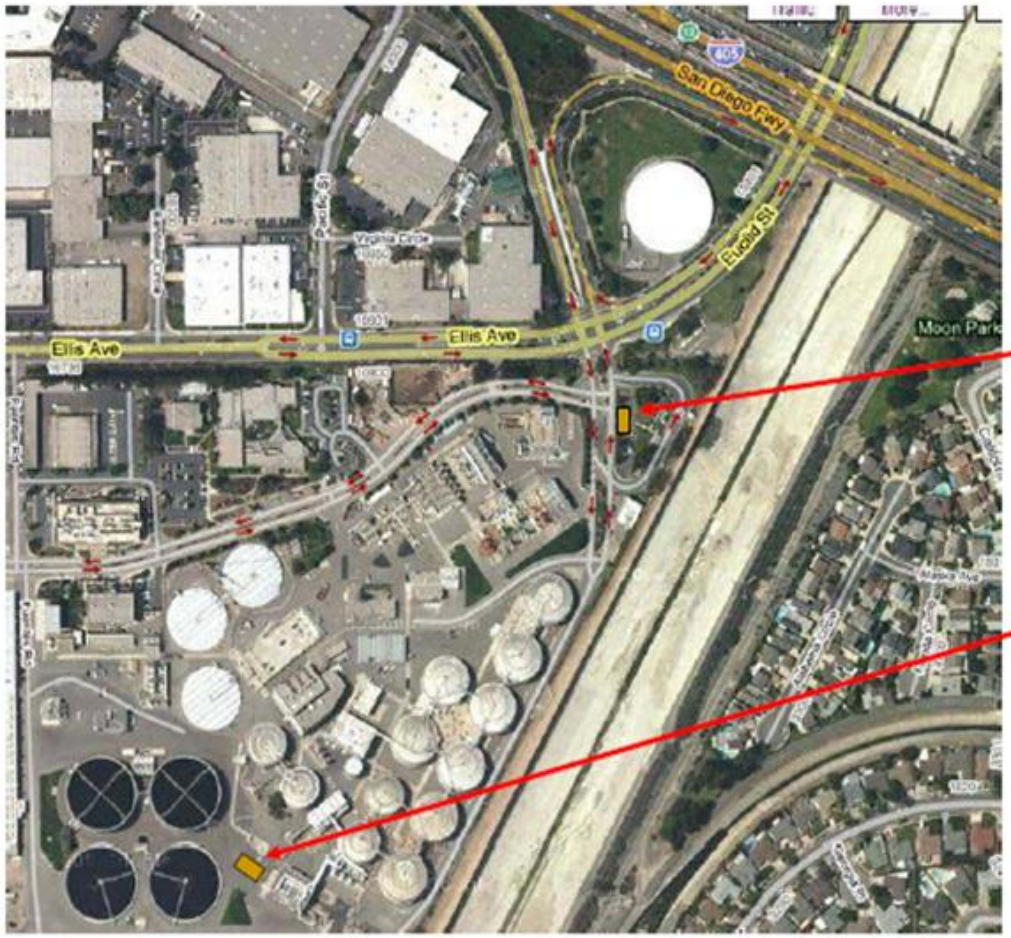


- 12.4 million MT per year of methane is available from landfills in the U.S.
- ~50% of this resource could provide **~8 million kg/day** of hydrogen.



Wastewater Biogas-to-Hydrogen Project: Orange County SD, California

- Operation on ADG: > 3,900,000 SCF processed & used
- Electricity produced: > 800,000 kWh
- Hydrogen produced: > 7,500 lbs (3,400 kg)



Orange County Sanitation District (OCSD) - site

Renewable H_2 Filling Station

ADG fueled DFC-H2 ® Production Unit

Renewable Power Plants Can Make Hydrogen Fuel

Hydrogen Delivery Process:

H2-fueled shuttle buses

Hydrogen Dispensing under Grid Management Program

Hydrogen Delivery Trailer uses unique cascade fill process that required no onsite compressor

Hydrogen Dispensing under Hawaii Power Park Program

Geothermal Powered Hydrogen Production

Landfill Gas-to-Hydrogen Project

at the

BMW Assembly Plant

in

Greer, South Carolina

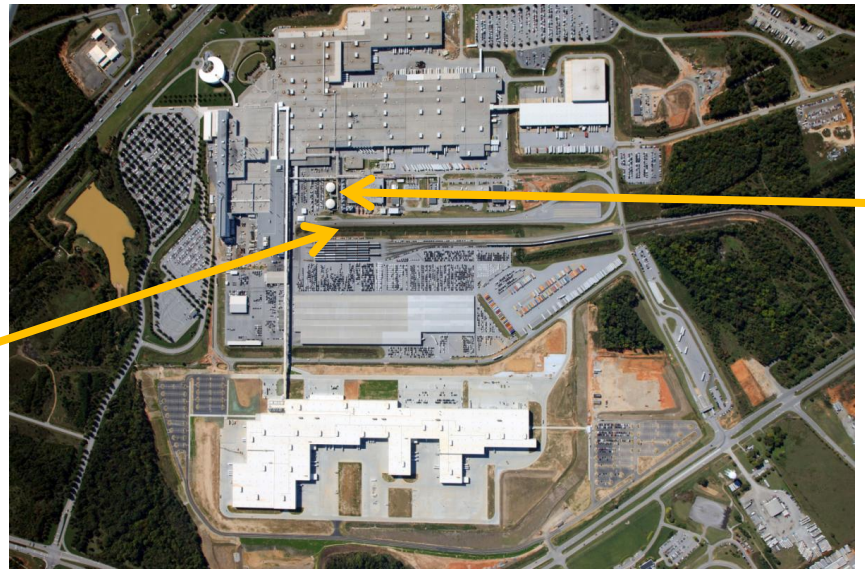
The BMW X3

In order to make one of these…

…BMW Starts Here

Palmetto Landfill, Wellford, SC

A "Waste-to-Energy" Success Story

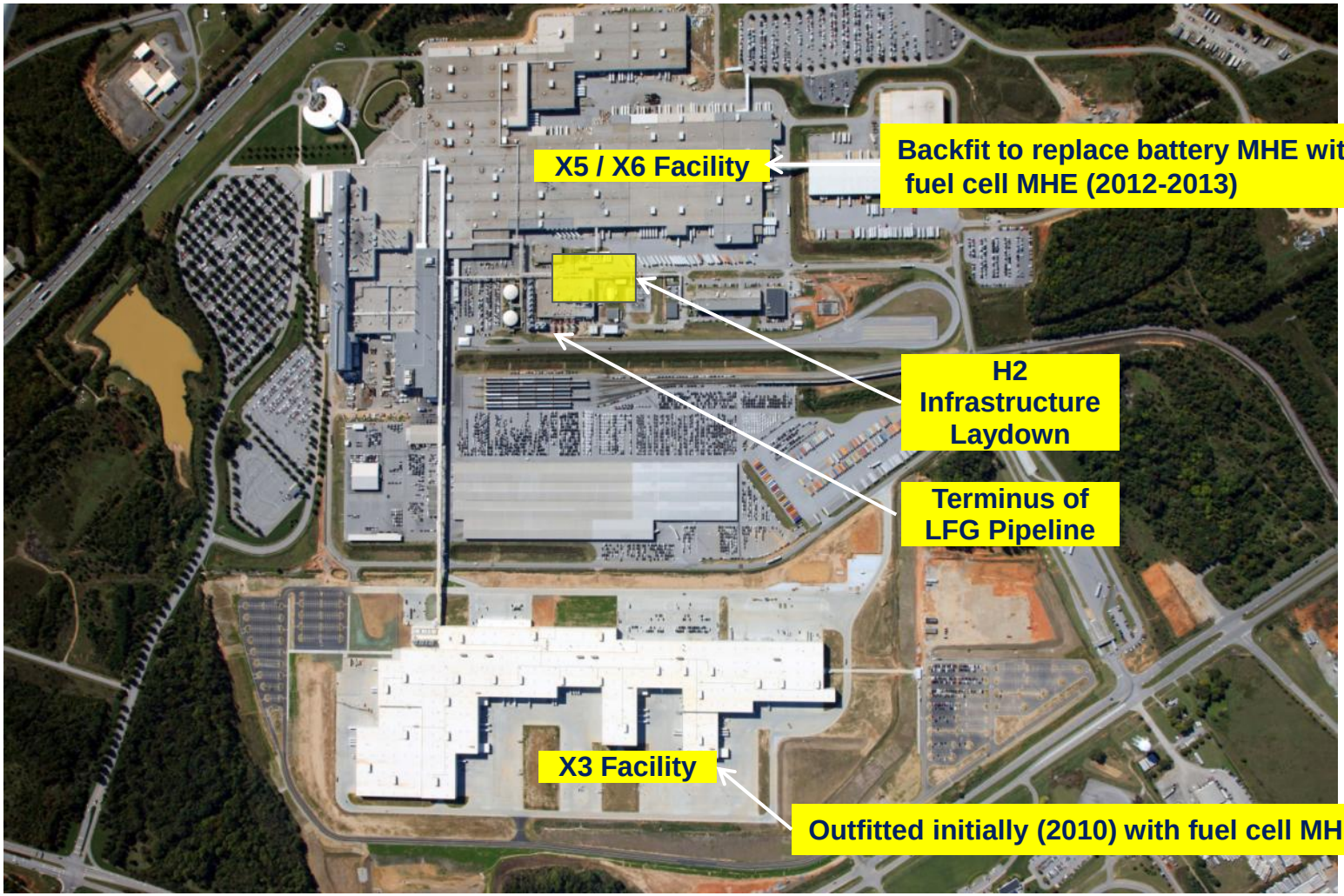


The EPA Landfill Methane Outreach Program

Searching for the "Next Big Thing"

- BMW's Landfill Gas – to – Energy project dates back to 2002
  - Currently provides 25% of the electricity and 33% of the total energy to operate the entire manufacturing and assembly process
- Corporate culture places high premium on environmental sustainability
- Opportunity: convert the on-site fleet of material handling equipment (fork lifts, "tuggers" and other assembly support equipment) from battery power to fuel cells. Rationale for the decision includes:
  - Increased productivity
    - Time savings
    - Energy savings
    - Space savings (no battery charging / cooling spaces required)
  - Improved safety (eliminates 3500-pound battery change-outs)
  - Lower hazardous material inventory / disposal

Hydrogen and Fuel Cell Initiatives



2010 to Present

Site-Wide MHE Conversion

275 units to date; largest fuel cell MHE fleet in North America

Transition to the Future

An on-site, renewably-generated hydrogen production capability

Project Relevance

- Validate there is a viable business case for full scale operation should the LFG-to-hydrogen conversion technology prove viable
  - Ensure we're not doing science for science's sake
  - Gives BMW leadership confidence to move forward with scale-up, should they so choose
  - Lays the groundwork for proving the business case for future adopters (some external inquiries ***already*** received)

- Validate the technical solution will work in a "real world" landfill gas – to – hydrogen environment
  - Addresses key DOE technology validation barriers
  - None of the individual technology pieces are "new science"
    …. but no one has assembled these proven pieces into this particular "whole"
    …. until now

Project Team Members

- South Carolina Hydrogen and Fuel Cell Alliance (private, not-for-profit)
  - Prime contractor with DOE
  - Providing education and public outreach
- BMW (industry)
  - Host site
  - Providing on-site engineering and services support and $250K cash cost share
- SCRA (private, not-for-profit)
  - Subcontractor to SCHFCA
  - Providing overall program management; financial management; subcontracts administration; compliance and reporting to sponsors and $70K cash cost share
- Gas Technology Institute (private, not-for-profit)
  - Subcontractor to SCRA
  - Principal equipment provider for technical validation portion of the project; providing support for business case analysis and $30K in-kind cost share in Phase 2
- Ameresco (industry)
  - Subcontractor to SCRA
  - Providing lead for business case analysis and on site engineering support for technical validation portion of the project

Project Accomplishments

- Technologies exist and are commercially available to achieve the expected level of clean-up required to meet specifications of hydrogen generation system providers. These technologies are very mature.
- At the 500 kg/day level, with the existing landfill gas (LFG) supply and equipment at the host facility, onsite production of hydrogen using LFG as the hydrocarbon feedstock appears to be cost competitive, if not advantageous, over hydrogen sourced from vendors, produced offsite and transported to the facility.
  - **Adopting RINs for LFG-sourced hydrogen will improve the business case significantly**
  - Although the analysis presented within the feasibility study are specific to the LFG equipment and constituents at the host facility, the basic principles of hydrocarbon feedstock clean-up and reformation to hydrogen should apply to agricultural waste streams, wastewater systems, digester gases and other process off-gases.
- Successfully proved the technical ability to recover sufficiently pure methane from an incoming stream of LFG to permit follow-on hydrogen recovery using traditional steam methane reformation technology
- Successfully produced hydrogen of sufficient purity to satisfy industrial standards (SAE J2719) for fuel cell use

Next Steps

- **Conduct fueling operations with BMW's existing MHE fleet using LFG-sourced hydrogen**
- **Provide final report to BMW and to DOE**
  - BMW consider using results to support business decision to pursue full-scale deployment
  - DOE to build public case for widespread adoption
- **Promote opportunities for replication in other locations where LFG sources and potential end users exist**
  - Interest already being expressed by organizations in CA, HI, and TX

Summary

EPA and DOE – FCTO Coordination

- Work collaboratively to qualify H2 from LFG and WWTP biogas-to-hydrogen as a biofuel under RFS2;
- Work on outreach actions collaboratively like EPA LMOP;
- Work collaboratively to qualify fuel cell technologies for Diesel Emissions Reduction Act (DERA) program.

Thank You

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For information about the U.S. Department of Energy Fuel Cell Technologies Program:

hydrogenandfuelcells.energy.gov

Back Up Info

Well-to-Wheels GHG Emissions

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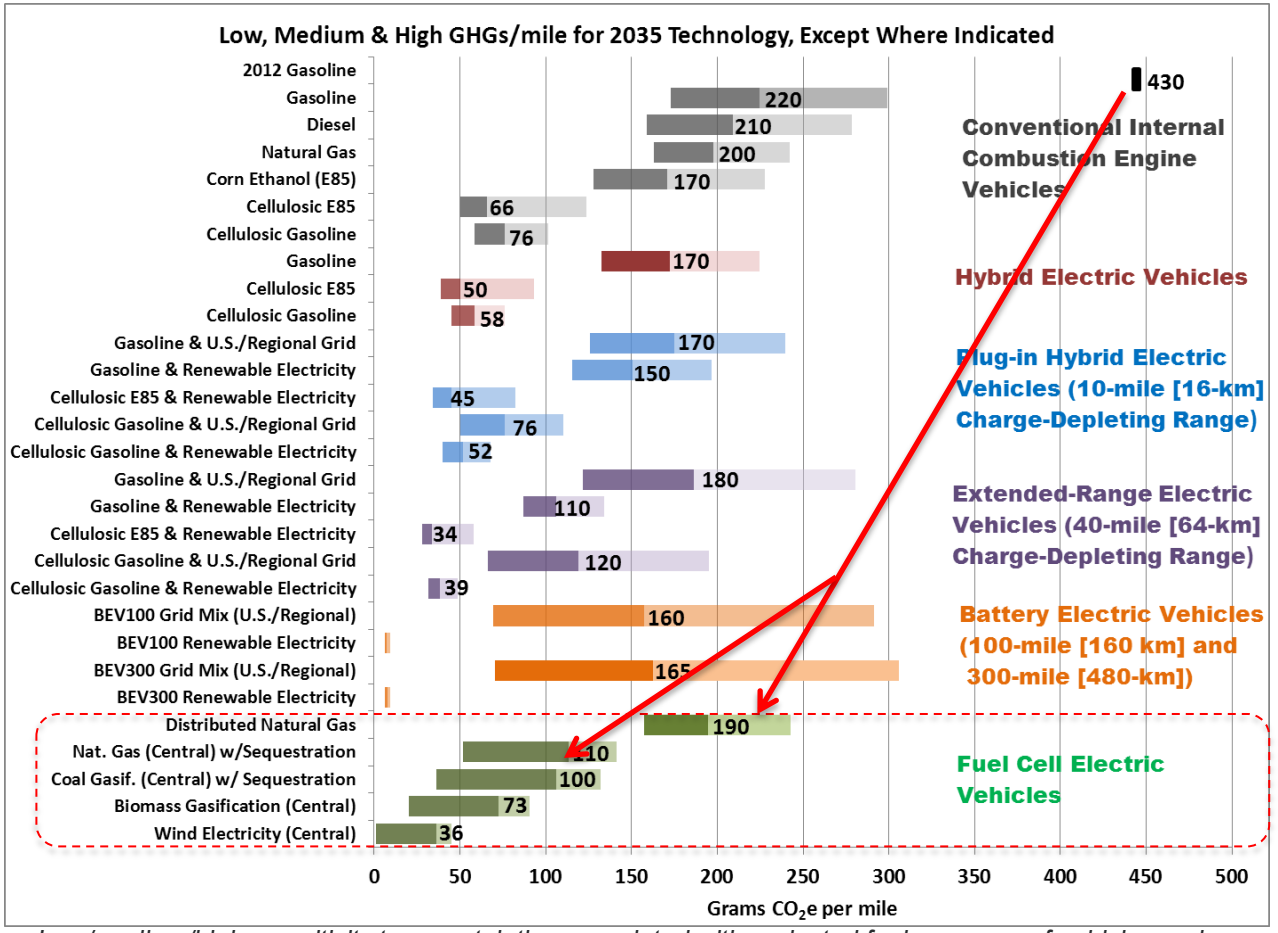
Analysis by Argonne National Lab, National Renewable Energy Lab and EERE (Vehicles, Fuel Cells, & Bioenergy Technologies Offices) shows benefits from a portfolio of options

- **Updated, peer-reviewed analysis (EERE multi-Office coordination)**
- **Hydrogen from natural gas can reduce GHG emissions by >50% (significantly more if centrally produced and with carbon capture)**

Well-to-Wheels Greenhouse Gas Emissions for 2035 Mid-Size Car

(Grams of CO2-equivalent per mile)



Low/medium/high: sensitivity to uncertainties associated with projected fuel economy of vehicles and selected attributes of fuels pathways, e.g., electricity credit for biofuels, electric generation mix, etc.

See reference for details:
http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

Biogas Contaminant Clean Up: A Key Step

Biogas clean-up can increase power costs by as much as two cents per kWh

Common cleanup processes and relative cost

Upgrade Method	Contaminant Removal	Cost to Upgrade ($/1000 cu ft)
Biological	H_2S	1.86
Iron Oxide (sulfa treat)	H_2S	0.79
Iron Oxide (Sulphur Rite)	H_2S	1.49
Membrane	CO_2, H_2O	2.13
Water Scrubber	H_2S, CO_2	0.38
PSA	CO_2	2.53
Activated Carbon	H_2S	0.45
Amine	H_2S, CO_2	4.58

Source: Handley, Ian. "Biogas Technologies and Integration with Fuel Cells." Biogas and Fuel Cells Workshop. Golden, CO. June 11–13, 2012.
http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/june2012_biogas_workshop_handley.pdf

Fuel purity requirements for high temperature fuel cells (values in ppm)

Type of Fuel Cell	PAFC	MCFC	SOFC
H_2S	2.0	0.1 – 5.0	1.0
COS, CS_2, mercaptan		1.0	
Organic sulfur		6.0	
H_2S, COS, CS_2		0.5 – 10.0	
HCl, ppm		0.1	"few"
Halogens	4.0	0.1 – 1.0	1.0 – 5.0
Halogenated organics		0.1	
NH_3	1.0	10,000	5,000
Siloxanes		1.0	0.01
Tars		2,000	

Source: Ahmed, "Biogas Impurities."

Fuel cells require high levels of fuel purity that demand complex clean-up systems.

Biogas clean-up technologies are well known; however, biogas clean-up typically requires a custom-designed suite of equipment:

- Variability of types and concentration of contaminants for each site is high;
- Seasonal factors can lead to changes in the concentration of contaminants.

Project Context

- This initiative (converting landfill gas to hydrogen), in this geography (South Carolina) provides an excellent "fit" for DOE's Market Transformation efforts
  - **Why LFG-to-Hydrogen?**
    - **Probably the most challenging waste stream** from which hydrogen could be recovered; if economically and technically viable, less-daunting hydrocarbon waste streams could be "in play"(agriculture waste, wastewater treatment, etc.)
  - **Why South Carolina?**
    - South Carolina is a **"net importer" of municipal solid waste**; there are many "candidate" landfill sites in the state where this solution may be viable
    - South Carolina has a **high concentration of large manufacturing facilities** (BMW, Boeing, Michelin, Bridgestone-Firestone, etc.) and **major warehousing and distribution facilities** with **large inventories of material handling equipment** (MHE), many of which are within 20 miles of an active landfill

- Several South Carolina manufacturers *already* use landfill gas energy for heat/power; several *already* have elected to convert their MHE inventory to fuel cells; marrying the two could significantly increase fuel cell MHE market penetration goals *in the private sector*

Foundation for Growth

- **Landfill can be a foundation for multiple renewable energy initiatives:**
  - **LFG clean-up yields "green" methane**
    - Fuel for garbage trucks
    - Fuel for commercial natural gas vehicles
    - Baseload power production using large (1 MW) stationary power fuel cells
  - **Recovery of hydrogen from "green" methane**
    - Fueling source for material handling fleets or other "specialty vehicles"
    - Fueling source for 5 KW emergency backup power generators that operate quietly (and indoors if required)
  - **Particularly useful for warehousing and distribution operations**
    - Can combine "green" methane to fuel 18-wheelers with hydrogen production to fuel indoor MHE fleet – spreads infrastructure costs broadly
  - **Additional economic benefits through RECs and other clean energy credits/initiatives**
    - EPA is considering "counting" "green" methane and hydrogen derived from "green" methane as a renewable fuel

Tri-Generation: System Flow Diagram

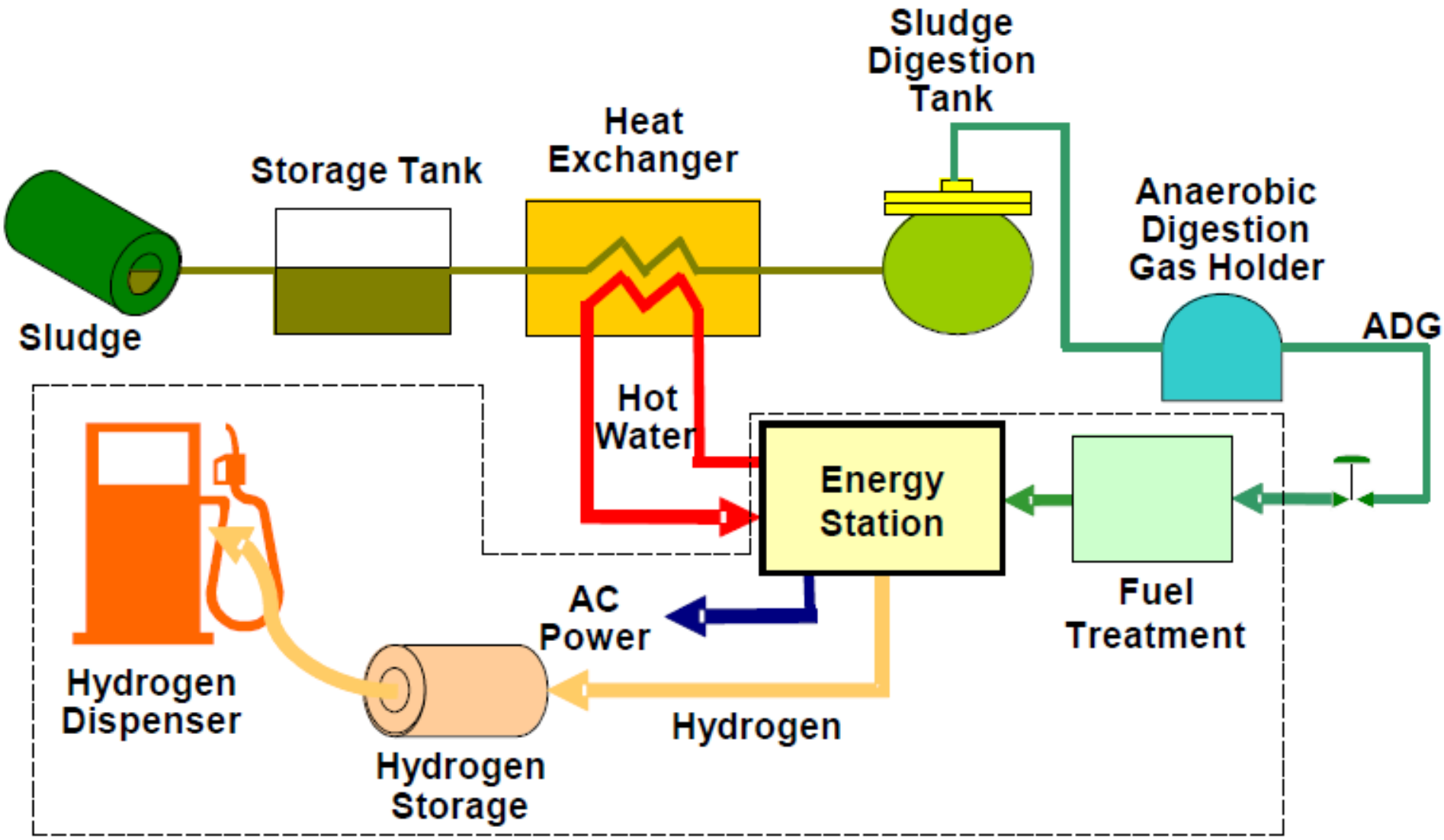


Image source: Air Products

Tri-Generation: System Flow Diagram

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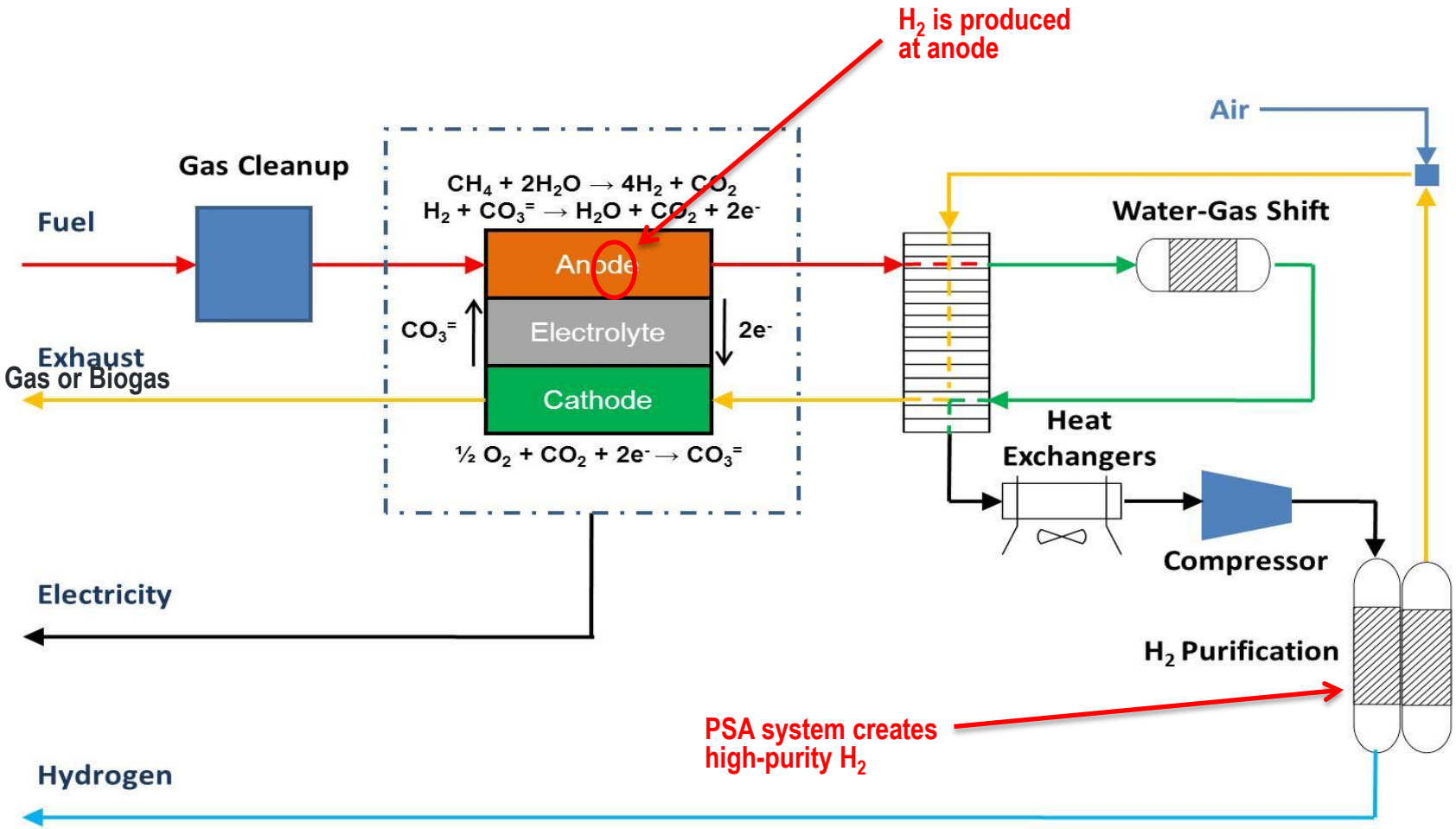
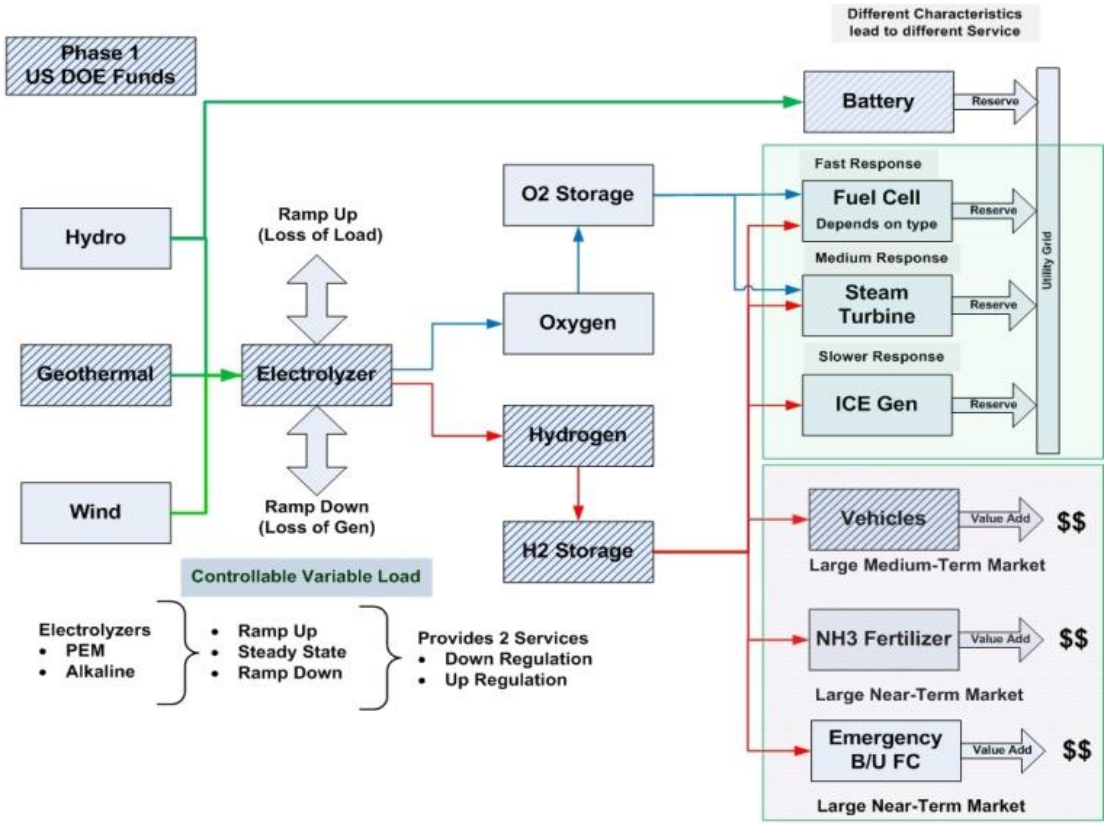
The fuel cell converts 70%-80% of the hydrogen to power, leaving 20%-30% of the hydrogen available for recovery at the anode.



Co-funded by DOE/FCT and multiple partners

Big Island of Hawaii Hydrogen Energy Storage Project

- Operate 65 kg/day PEM electrolyzer under sustained cyclic operation and evaluate frequency variability response
- Produce hydrogen from renewable energy for transportation fuel - one FC shuttle bus for local community bus and two FC buses for Hawaii Volcanoes National Park (HAVO)
- Compare electrolyzer ramp rate capacities to ramp rates required to impact frequency using 1MW Li-titanate battery
- Conduct performance/cost analysis to identify benefits of integrated system including grid services and off-grid revenue streams
- Status: Hydrogen system complete. Initial operation expected Q2 2014



Partners

US DOE	ONR
State of Hawaii	HNEI
PGV	MTA