Development of a Renewable Hydrogen Energy Station

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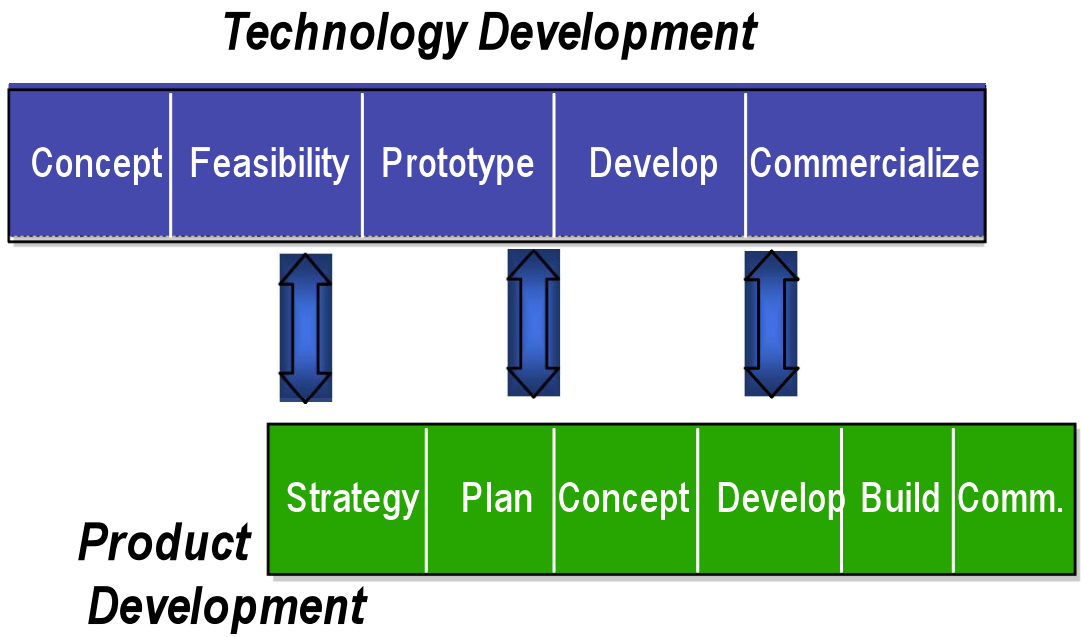
Presentation Outline

- Hydrogen Energy Station Technology Overview
- Process Description
- Performance and Economic Parameters
- Proposed Demonstration on Renewable Feedstock
- Status of Shop Validation Test
- Conclusion

Objectives

- **Determine the economic and technical viability of a hydrogen energy station designed to co-produce power and hydrogen**

Utilize technology development roadmap to provide deliverables and go/no-go decision points



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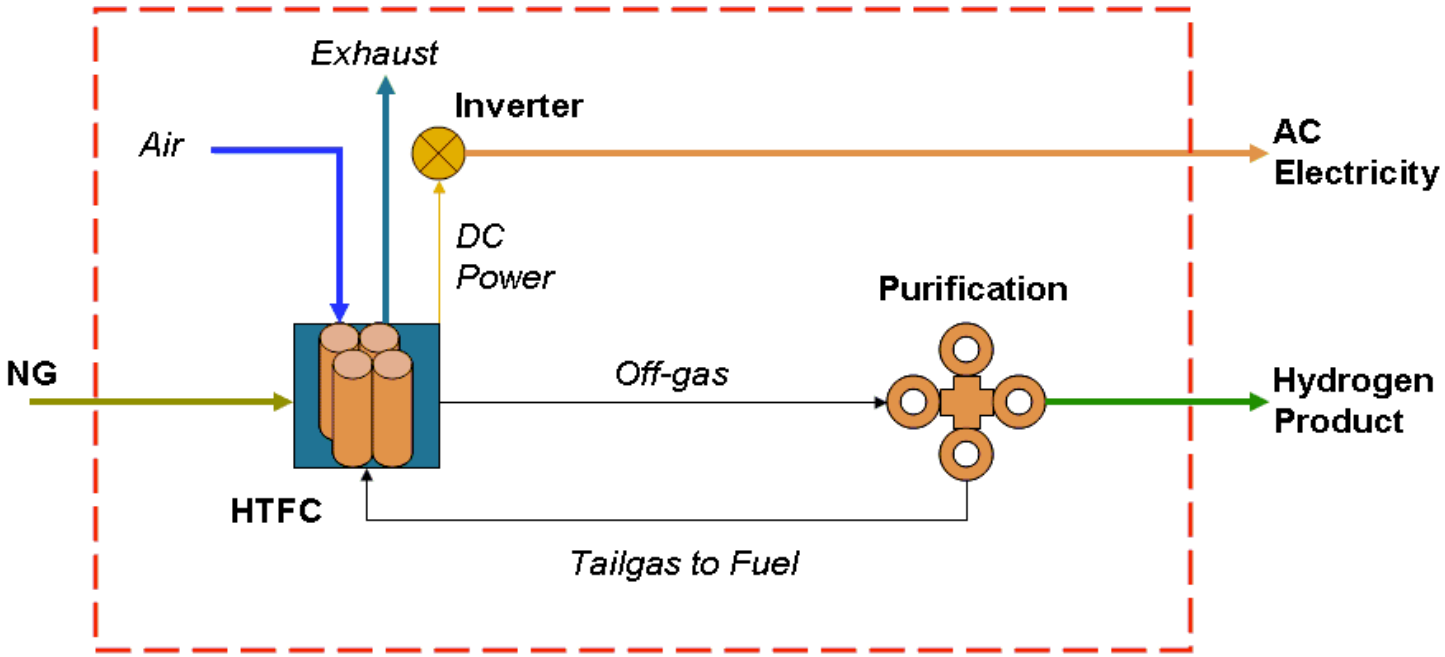
Hydrogen Energy Station Concept



Potential Co-Production Efficiency (LHV): 55 - 60%

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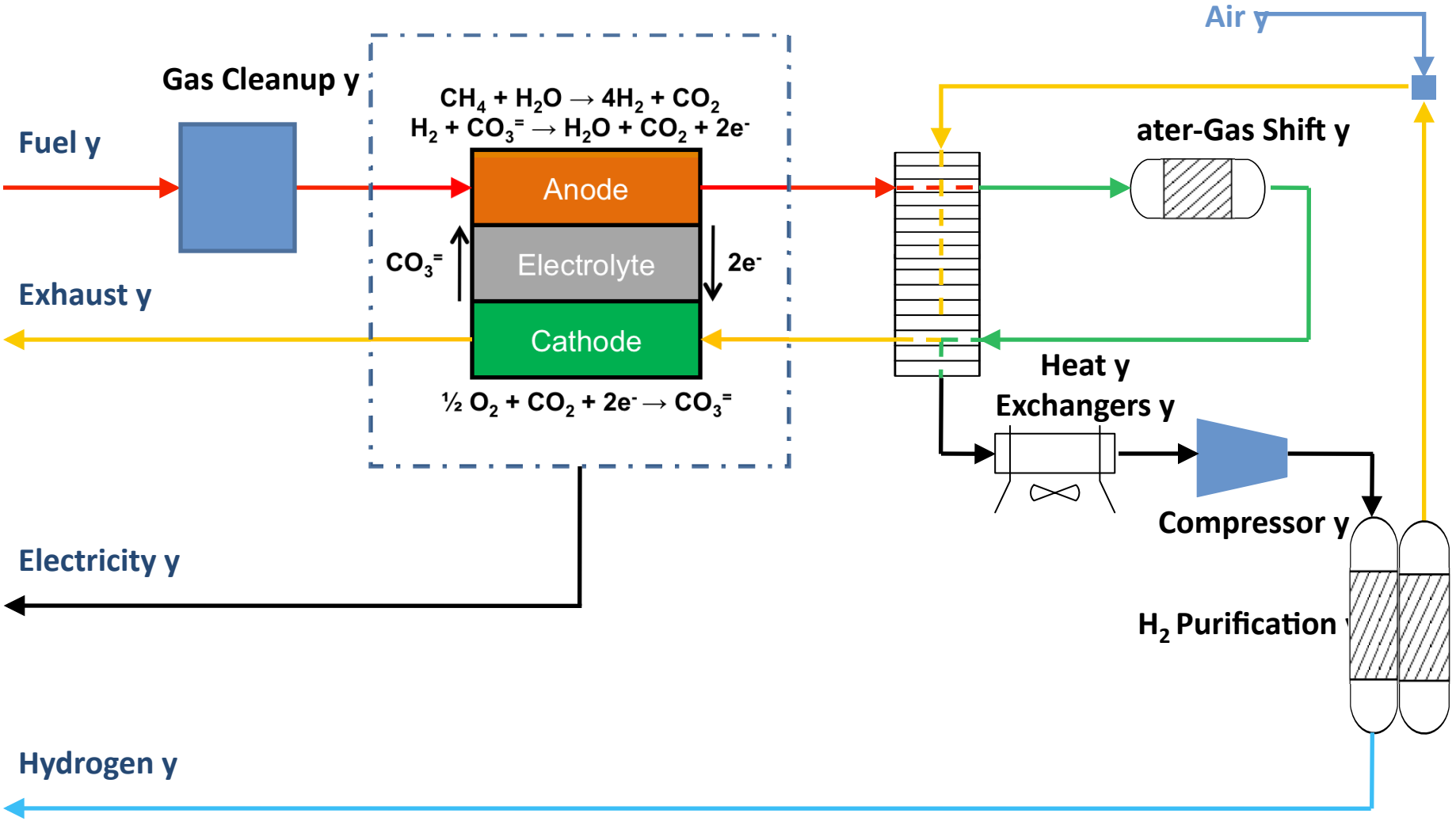
Approach

- Air Products Cooperative Agreement with U.S. DOE (30 September 2001) defined 4 phases:
  - Phase 1 – Feasibility: Evaluate PEM and HTFC
    - Completed FY04
  - Phase 2 – Preliminary System Design
    - Completed FY06
  - Phase 3 – Detailed Design and Construction
    - Completed March 2009
  - Phase 4 – Operation, Testing, Data Collection
    - Ongoing

Hydrogen Energy Station

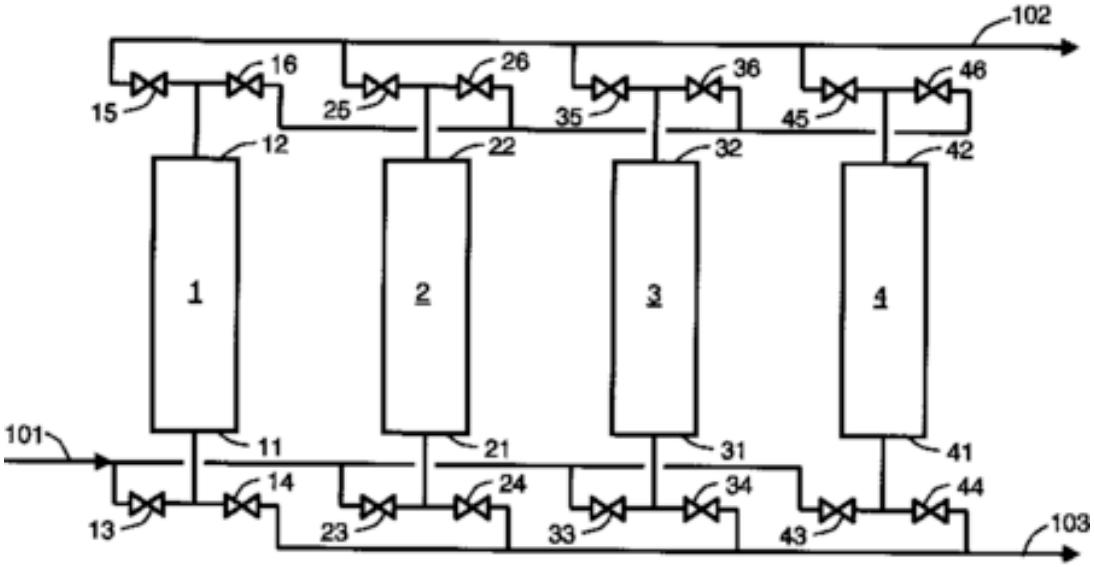


Hydrogen Energy Station Projected Performance by Phase

	Units	Phase 1	Phase 2	Phase 3
Overall Efficiency (Net Power + H2 Product) / (Fuel)	LHV	60%	66%	66%
Power Efficiency Net Power / (Total Fuel – H2 Product)	LHV	49%	49%	50%
Hydrogen Efficiency (H2 Product – Purification Power) / H2 Product	LHV	68%	68%	77%
Hydrogen Product	Kg/day	~ 88	~ 175	~ 175
Net Power w/o & w/ Hydrogen	kW	~ 247 / 207	~ 300 / 243	~ 300 / 250
Natural Gas Flow	Nm3/hr	~ 55	~ 74	~ 74

Process Improvements during Design Phase

- **Improvement in hydrogen purification cycle:**
  - **Phase 1: 300 psig inlet, 75% H2 recovery**
  - **Phase 3: 150 psig inlet, > 85% H2 recovery**
- **Patent application filed**



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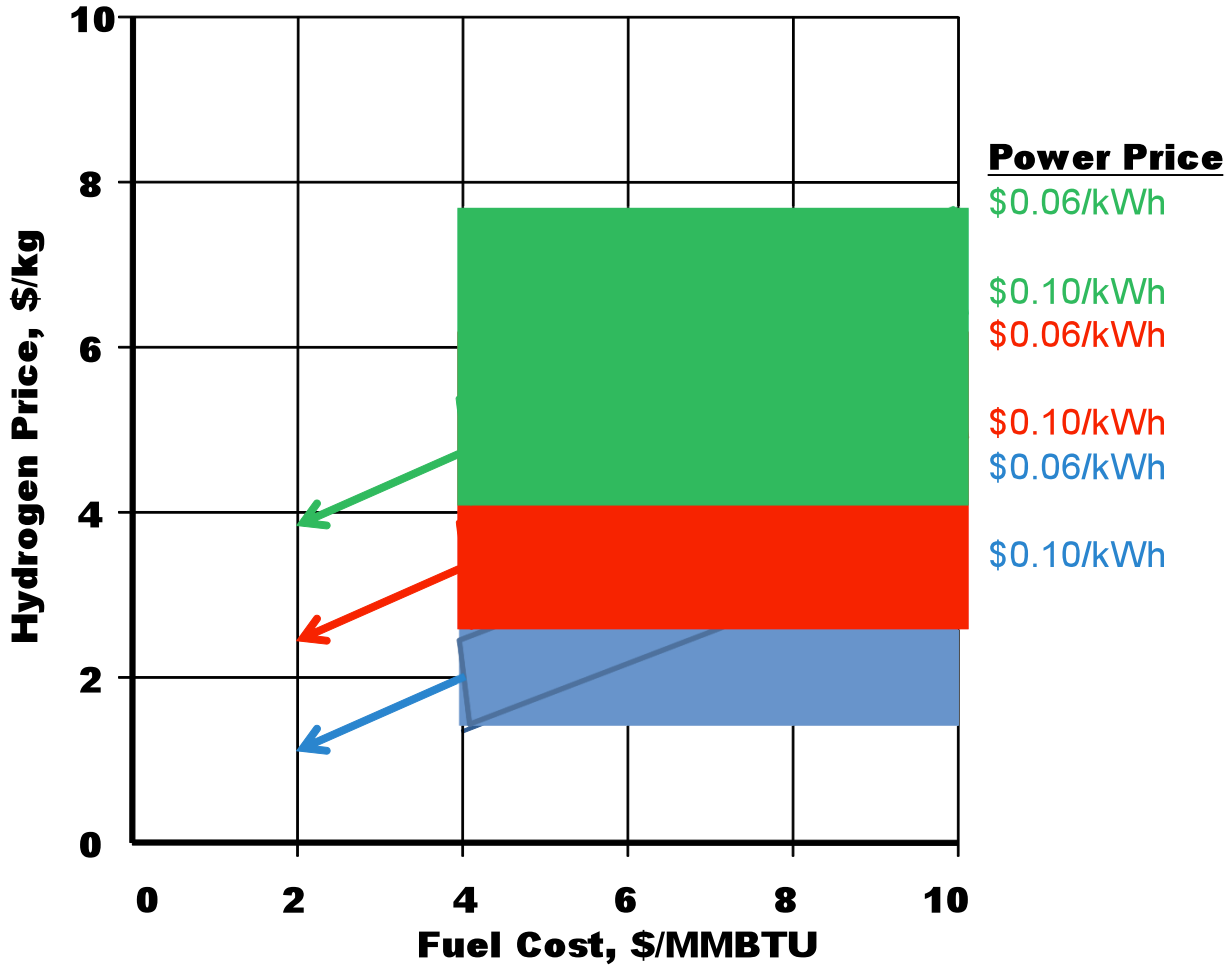
Emissions Performance of DFC® Molten Carbonate Fuel Cell

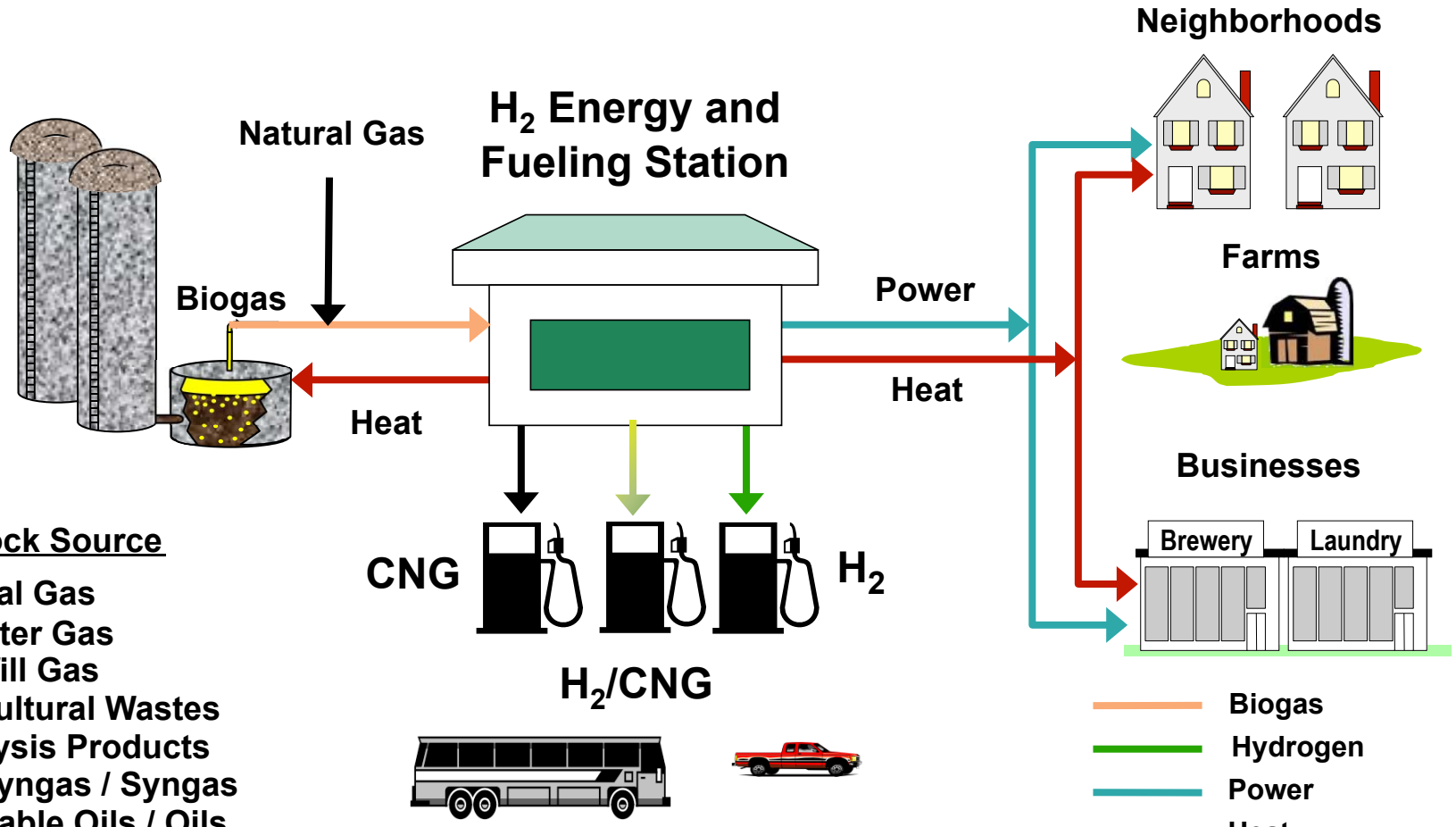
	NO_x (lb/MWh)	SO_x (lb/MWh)	CO_2 (lb/MWh)
Average US Fossil Fuel Plant	4.200	9.21	2,017
Microturbine (60 kW)	0.490	0	1,862
Small Gas Turbine (250 kW)	0.467	0	1,244
DFC Fuel Cell 47% efficiency	**0.016**	**0**	**967**
DFC Fuel Cell – CHP 80% efficiency	**0.016**	**0**	**545**

NO_x and SO_x are negligible compared to conventional technologies

Hydrogen Energy Station Economics



Hydrogen Energy Station Vision



Feedstock Source

- Natural Gas
- Digester Gas
- Landfill Gas
- Agricultural Wastes
- Pyrolysis Products
- Bio-Syngas / Syngas
- Vegetable Oils / Oils
- Other Methane Sources

Renewable hydrogen – for onsite requirements or regional distribution

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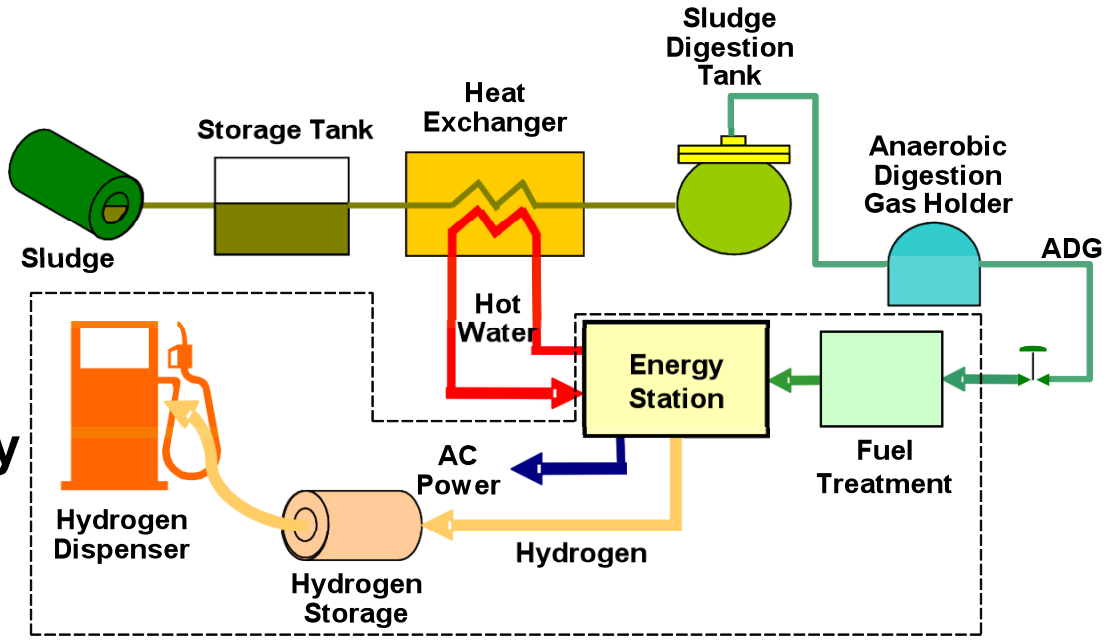
Demonstration of Hydrogen Energy Station Vision

- DOE Program – Natural Gas Feed
- Potential Host Site Identified - OCSD
  - Orange County Sanitation District, Fountain Valley, CA
  - Municipal Wastewater Treatment
  - Existing CNG Refueling Station
  - Ability to Achieve Production of both Renewable Hydrogen and Electricity
  - Renewable Hydrogen Available for Use

Proposal to California Air Resources Board (June 2008)

Fountain Valley Station

- 100 kg/day capacity, renewable hydrogen supply
- 350 and 700 bar fueling capability
- Host site: Orange County Sanitation District
- Anaerobic digestion of municipal wastewater
- Hydrogen production using Hydrogen Energy Station



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Hydrogen Energy Station Shop Validation Test – DFC® System

All DFC®-H_2-PSA Equipment Installed and Commissioned

Hydrogen Ready Fuel Cell Module

Mechanical Balance of Plant (MBOP)

- Verified operability of hydrogen-ready DFC®300
- Developed procedures for start-up, shut-down and off-normal events
- Achieved stable operation at various loads up to 200 kW-net AC
- Fuel cell with water-gas shift in operation > 6,000 hours

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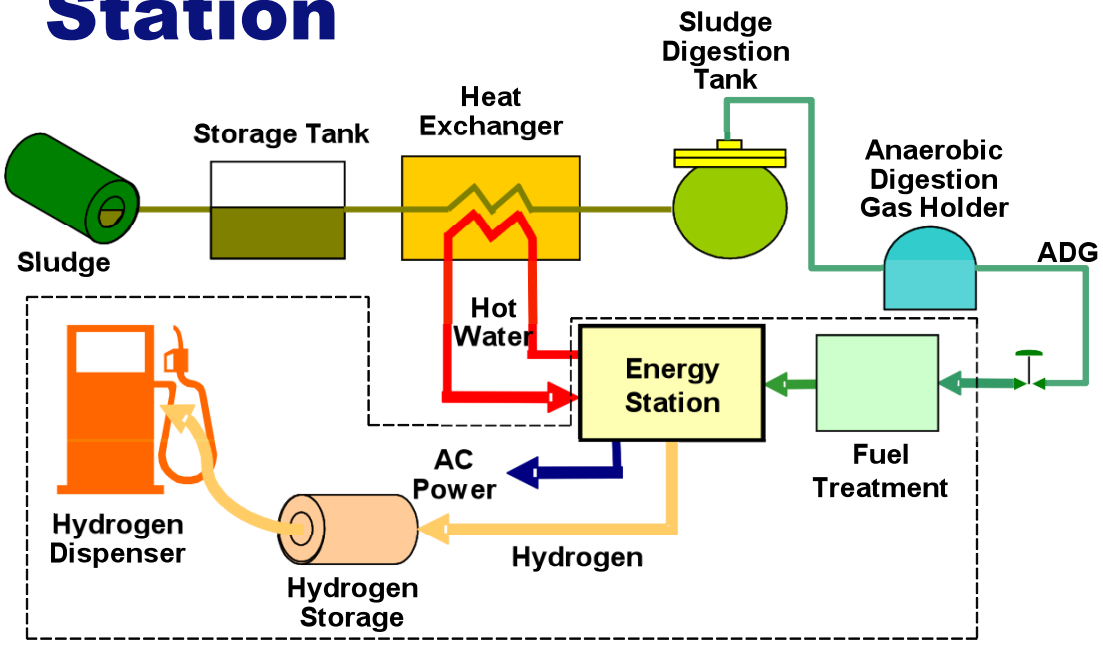
Fountain Valley Renewable Hydrogen Station

Tri-Generation Results

- Produced 5 to 10 lb/hr hydrogen with > 200 kW electricity
- Estimated hydrogen recovery at 80 to 85%
- Product purity <0.2 ppm CO; <2 ppm CO2
- Operation with simulated digester gas feed
- PSA operating map developed (cycle time vs. feed rate)
- Implemented automated integration/deintegration



Anode Exhaust Processing and H_2 PSA

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Future Work

- Operation of Hydrogen Energy Station – Lessons learned from shop test, field trial
- Validation of process economics
- Following DOE Program:
  - Product development activities – Process improvements for second generation system
  - Scale-up based on existing fuel cell products –
    - DFC®-1500 – 400 to 500 kg/day hydrogen plus 1.0 to 1.2 MW
    - DFC®-3000 – 800 to 1,000 kg/day hydrogen plus 2.0 to 2.4 MW

DFC®-300MA

DFC®-1500

Summary

- **Determine the economic and technical viability of a hydrogen energy station designed to co-produce power and hydrogen**
  - **Concept defined – FuelCell Energy's molten carbonate fuel cell plus Air Products' hydrogen purification system**
  - **Design and fabrication of demonstration unit completed**
  - **Shop test at FuelCell Energy's facilities in Danbury, CT**
  - **Plans for demonstration operation on renewable feedstock at Orange Co. Sanitation District, Fountain Valley, CA**
    - **Hydrogen refueling station under DOE's California Hydrogen Infrastructure Project**
    - **Other funding: California Air Resources Board, South Coast Air Quality Management District**
  - **Validate process economics based on system performance**

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