US DOE Webinar Series

EERE Fuel Cell Technologies Program

2011-2012 Hydrogen Student Design Contest

4 September 2012
On-Campus Tri-Generation Fuel Cell Systems
Featuring Winners of the 2011-2012 Hydrogen Student Design Contest

This Webinar is brought to you by:

U.S. Department of Energy
Hydrogen Education Foundation

12 PM ET, September 4, 2012
Webinar Overview

2. **Contest Introduction** – Emanuel Wagner, HEF
3. **System Overview** – Joseph Daly, FuelCell Energy
4. **Winning Design Presentation** – University of Maryland
5. **Honorable Mention** – Washington State University
6. **Honorable Mention** – University of California, Davis
7. **2012-2013 Contest Theme** – Emanuel Wagner, HEF
8. **Q&A**
Instructions to Ask Questions

Submit questions in writing using the **Questions Panel** in the Control Panel on the right side of your screen (may be minimized).

**This webcast will be recorded.**
Contest Overview

- Emanuel Wagner, Hydrogen Education Foundation

HEF Contest Manager
Hydrogen Education Foundation

- Promotes clean hydrogen energy technologies through educational programs to encourage environmental stewardship, improve energy security, and create green jobs. More info: www.hydrogeneducationfoundation.org

- Programs include:
  - H-Prize
  - H2andYou
  - Hydrogen Student Design Contest
  - Washington Fuel Cell Summit

- For timely updates:
  - Like us at: www.facebook.com/Hydrogen.Education.Foundation
  - Follow us at: @h2andyou
What is the Contest?

- The annual Hydrogen Student Design Contest challenges university students to design hydrogen energy applications for real-world use.

- Technical, multidisciplinary competition
  - Engineering
  - Architecture/planning
  - Industrial design
  - Economics
  - Business/marketing
  - Environmental science
  - Political science
  - Chemistry
History of Contest

- Began in 2004
- Past themes:
  - Residential Fueling
  - Designing a Hydrogen Community
  - Green Buildings with Hydrogen
  - Hydrogen Applications for Airports
  - Hydrogen Power Park
  - Hydrogen Fueling Station
- Several winning designs were built, e.g. the 2008 winning design is now an active hydrogen fueling station at Humboldt State University
2011-2012 Contest Supporters

Media Partners
2011-2012 Theme:

Design a Combined Hydrogen, Heat and Power System for your University Campus – Using Local Resources
Why CHHP?

- Companies around the world are working to make hydrogen technologies a more common reality
- Decentralized renewable hydrogen production supports the transition to the hydrogen economy
- CHHP is a new and effective way to produce clean energy, reducing GHG emissions, health risks and supporting clean air
- Reduction of organic waste materials and capturing methane emissions for energy production
Theme Details

- Plan and design a CHHP system using local resources
- System should be designed for an existing facility or proposed new construction
- System must use available on-site or local fuel, may utilize natural gas when needed
- Design must provide uses for all three end-products
Contest Sections

1. Resource Assessment
2. Technical Design
3. Plan for End Uses
4. Safety Analysis
5. Economic Analysis and Business Plan
6. Environmental Analysis
7. Marketing and Public Education Plan
Who Participated?

- 33 teams from 10 countries registered for 2011-2012 Contest
- 20 team submitted final entries
- Top Teams:

<table>
<thead>
<tr>
<th>University</th>
<th>Award</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Maryland</td>
<td>Grand Prize</td>
<td>91.10%</td>
</tr>
<tr>
<td>Washington State University</td>
<td>Honorable Mention</td>
<td>89.70%</td>
</tr>
<tr>
<td>UC Davis</td>
<td>Honorable Mention</td>
<td>88.30%</td>
</tr>
<tr>
<td>Missouri S+T</td>
<td>Top Ten Finisher</td>
<td>85.80%</td>
</tr>
<tr>
<td>National University of Malaysia</td>
<td>Top Ten Finisher</td>
<td>85.80%</td>
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<tr>
<td>Ohio University</td>
<td>Top Ten Finisher</td>
<td>77.70%</td>
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<tr>
<td>Latvia University</td>
<td>Top Ten Finisher</td>
<td>68.80%</td>
</tr>
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<td>Kyushu University</td>
<td>Top Ten Finisher</td>
<td>68.70%</td>
</tr>
<tr>
<td>Florida International University</td>
<td>Top Ten Finisher</td>
<td>65.50%</td>
</tr>
<tr>
<td>University of Bridgeport</td>
<td>Top Ten Finisher</td>
<td>63.70%</td>
</tr>
</tbody>
</table>
System Overview

- Joe Daly, FuelCell Energy

Manager Test & Validation Services at FuelCell Energy
Combined Heat, Hydrogen and Power from DFC® Fuel Cell

FCE Information Towards Design: Hydrogen Education Foundation’s 2011-2012 CHHP Contest

Joseph Daly, Fred Jahnke
Pinakin Patel
September 4, 2012

Powering a Cleaner Future Today
Outline

- Fuel Cell Background
- Process
- Design Specifications
- End Products and Uses
<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Operating Temp. °F</th>
<th>Charge Carrier</th>
<th>Cell Hardware</th>
<th>Catalyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer Electrolyte Membrane</td>
<td>200</td>
<td>H⁺</td>
<td>Carbon /Metal Based</td>
<td>Platinum</td>
</tr>
<tr>
<td>Phosphoric Acid</td>
<td>400</td>
<td>H⁺</td>
<td>Graphite</td>
<td>Platinum</td>
</tr>
<tr>
<td>Carbonate Direct Fuel Cell®</td>
<td>1200</td>
<td>CO₃⁻</td>
<td>Stainless Steel</td>
<td>Nickel</td>
</tr>
<tr>
<td>Future</td>
<td>1800</td>
<td>O⁻</td>
<td>Ceramic</td>
<td>Perovskites</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Future Solid Oxide</th>
<th>Phosphoric Acid</th>
<th>Future Solid Oxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Oxide</td>
<td>Alkali Carbonate</td>
<td>Yttria Stabilized Zirconia</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Catalyst</th>
<th>Platinum</th>
<th>Platinum</th>
<th>Nickel</th>
<th>Perovskites</th>
</tr>
</thead>
</table>

**Background – Fuel Cell Technologies**

<table>
<thead>
<tr>
<th>Fuel Cell Type</th>
<th>Polymer Electrolyte Membrane</th>
<th>Phosphoric Acid</th>
<th>Carbonate Direct Fuel Cell®</th>
<th>Future Solid Oxide</th>
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</thead>
<tbody>
<tr>
<td>Polymer Electrolyte Membrane</td>
<td>Ion Exchange Membrane</td>
<td>Phosphoric Acid</td>
<td>Alkali Carbonate</td>
<td>Yttria Stabilized Zirconia</td>
</tr>
<tr>
<td>Operating Temp. °F</td>
<td>200</td>
<td>400</td>
<td>1200</td>
<td>1800</td>
</tr>
<tr>
<td>Charge Carrier</td>
<td>H⁺</td>
<td>H⁺</td>
<td>CO₃⁻</td>
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<td>Platinum</td>
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<td>Nickel</td>
<td>Perovskites</td>
</tr>
</tbody>
</table>
**Internal Reforming DFC® Technology**

**HYDROCARBON FUEL** (e.g. Natural Gas)

**ANODE**

\[ CH_4 + 2H_2O \rightarrow 4H_2 + CO_2 \]

\[ H_2 + CO_3^- \rightarrow H_2O + CO_2 + 2e^- \]

**CATALYST**

**ELECTROLYTE**

**CATALYST**

**CATHODE**

\[ \frac{1}{2}O_2 + CO_2 + 2e^- \rightarrow CO_3^- \]

Opportunity

25-35% Excess H2, CO + CO2

**Exhaust**

**AIR + CO2**

H2 Co-production expands market for fuel cells
CHHP System Design Basis

• Specifications for Simple Cycle DFC Power Plant
  ➢ Fuel in
  ➢ Water in
  ➢ Electrical efficiency (e.g. 47%)
  ➢ Facility Exhaust waste heat

• Specifications for Hydrogen Production
  ➢ Anode exhaust composition
  ➢ DFC Fuel Utilization
  ➢ Impact on simple-cycle waste heat
  ➢ Supplemental Fuel Option
Design a CHHP System for your University Campus

- Power source is high efficiency internal reforming fuel cell.
  - e.g., FuelCell Energy’s Direct Fuel Cell (DFC)
  - The internal reforming creates hydrogen for the fuel cell reaction and excess hydrogen for export.
- DFC simple cycle power plant size options and costs:

<table>
<thead>
<tr>
<th>Model</th>
<th>Net AC kW</th>
<th>Cost ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFC300</td>
<td>300</td>
<td>$3,500</td>
</tr>
<tr>
<td>DFC1500</td>
<td>1,400</td>
<td>$2,400</td>
</tr>
<tr>
<td>DFC3000</td>
<td>2,800</td>
<td>$2,300</td>
</tr>
</tbody>
</table>

- Fuel Options: Natural Gas, Biogas, Propane, etc.
  - Heat rate, fuel consumption, efficiency (47%), emissions (NOx, SOx, PM10, CO2), exhaust temp. and heat capacity, flow rate, sound levels, etc.
Fuel Specification for CHHP System

- Baseline Fuel: Natural gas

- Examples of Renewable Fuels:
  - Biogas derived from anaerobic digester, landfill
    - Minimum methane content 60%
  - Syngas derived from thermal gasification.
    - Must be methane rich, at least 50% methane

- Fuel pretreatment
  - Non required for pipeline natural gas
  - Clean up required for renewable/other fuels
    - Sulfur, siloxane, and halogens down to sub-PPMV level.

- Renewable fuels may be blended with natural gas.
Basis for Hydrogen Co-Production

- Anode Exhaust Composition (at fuel utilization of 65%)
  - H$_2$ 10%
  - H$_2$O 40%
  - CO 5%
  - CO$_2$ 45%
  - N$_2$ 0.3 – 0.8% (fuel dependent)
  - CH$_4$ <1%

  (Shifted and Dried) H$_2$ = 23%
  H$_2$O negligible
  CO < 1%
  CO$_2$ = 77%

- Impact of Hydrogen Co-Production on Heat Energy available for recovery:
  - Available heat energy is reduced from simple-cycle specification on a one-for-one basis of the heat value of hydrogen product exported.

- Supplemental Fuel Option:
  - Supplemental fuel may be added to facilitate greater hydrogen production.

- Fuel Utilization – maintain 65%.
Configuration – Simple Cycle

CO-GEN HEAT

HEX

H₂, CO, CO₂, H₂O

AGO

AIR

Fuel

WATER

A

DFC

C
Configuration – H2 Recovery
CHHP System: Enabler for FCV, EV, Smart Grid

- Enhanced Energy Security
- Maximize Green Energy Use
- Water Independent
- Load Following
- Fuel Flexible
- Ultra Clean
- Provides Distributed H₂ for Multiple Uses
- Compensates for Intermittent Supplies

Fuel (NG/BioGas/Propane) → Base Load Fuel Cell → Co-Produced Hydrogen → Hydrogen Storage → Fuel Cell Cars → Wind and Solar Power (Intermittent)

Micro-GRID → Power → Load Following Fuel Cell

Heat
Winning Design

- University of Maryland

- Presenters:
  - Jennie Moton
  - Daniel Spencer
  - Richard Bourne
  - Kyle Gluesenkamp
  - William Gibbons

Report is available at:
Combined Heat, Hydrogen, and Power Plant Design for the University of Maryland

UMD CHHP Design Team

represented by Jennie Moton, Daniel Spencer, Richard Bourne, Kyle Gluesenkamp, and William Gibbons

Advisor: Prof. Greg Jackson, Associate Director, UMERC

2011-2012 Hydrogen Student Design Contest

sponsored by the Department of Energy
Hydrogen Education Foundation’s 2011-2012 Competitive Challenge

Design Objective:
Combined Heat Hydrogen and Power (CHHP) plant for a campus utilizing local renewable waste resources.

UMD System Design Value Proposition:

- Reduction of ~6,700 metric tons/yr landfill waste removal
- Electric power: average 1.2 MWe to reduce external load
  - offsets power purchased from the grid
- Steam: ~160 kg/hr at 900 kPa, 260°C for on-campus cooling/heating
- Hydrogen Fueling Station: ~17.8 kg H₂/hr
  - approximately 250 kWe net power in PEMFC systems for UMD shuttles, i.e., ~ 6 – 8 fuel cell powered buses
CHHP System Summary

- Waste streams converted to methane via gasification and digestion
- Methane is reformed to $\text{H}_2$ in anode and utilized to produce electricity
- Excess $\text{H}_2$ is recovered from the fuel cell anode exhaust
- Remaining thermal energy in exhaust is used to create steam for cooling and heating
UMD Campus Existing Infrastructure

• Existing infrastructure on campus was considered in the design stages of the project.

• UMD has on campus a natural-gas-fired combined cycle power plant that produces up to 25.9 MW\textsubscript{elec}.

• Intermediate pressure steam (900 kPa, 260 C) shipped around campus
  – Above 70 MW of heating for campus buildings in winter
  – Approximately 13 MW of building cooling in summer provided by steam-turbine-driven chillers
UMD Campus Carbon Footprint

- Greatest gains to be made in reduction of power demand and transportation.
Feedstock Waste Streams

Combined monthly power from waste streams collected from UMD campus and City of College Park for 10 months in 2011.
Gasifier and Fuel Processing

- Metal separator, shredder, feed to gasifier (Thermogenics Model # 106)
- \( O_2 \) gasifying agent - high reaction rates and minimal syngas dilution
- Moving bed, refractory lined to enable high temp operation

1 kg of waste (paper + plastic), ratio ~3:1, Energy content ~ 25 MJ/kg\(_{\text{waste}}\)

0.944 kg\(_{\text{steam}}\)/kg\(_{\text{waste}}\)

Oxygen generator \( \rightarrow \) Gasifier \( \rightarrow \) Syngas Cleanup \( \rightarrow \) Methanation Reactor \( T = 400^\circ \text{C}, \ P = 30 \text{ bar} \) \( \rightarrow \) C(S) and \( H_2O \) removal \( \rightarrow \) DFC

$$ T_{\text{gasifier}} = 900^\circ \text{C} \quad P_{\text{gasifier}} = 1 \text{ bar} $$

Ambient air feed

Cyclone

Electrostatic precipitator

Chiller (tar removal)

Acid gas removal

Pipeline NG as needed to meet anode feed specs

5% \( H_2 \)

<0.002% \( CO \)

55% \( CO_2 \)

40% \( CH_4 \)
Anaerobic Digester

- Complete mix, mesophilic (32-35 °C; 21-day retention; 1,520 m³)
- Wastes Processed: food, stall waste, leaves, yard waste
- Amount of waste processed: 1.56 m³/hr
- Amount of biogas produced: 32.7 m³/hr

CHHP Sankey Diagram (Energy)
Fuel Cell Energy 1.5 MW MCFC

- 1.5 MW_{elec} Molten Carbonate Fuel Cell (MCFC) used as power plant and H\textsubscript{2} production
  - Electric efficiency in simple-cycle configuration: 47%
  - Net electrical output in plant: 1.4 MWe
  - Fuel consumption: 308 standard m\textsuperscript{3}/hr
  - Average water consumption: 1.0 m\textsuperscript{3}/hr
  - Exhaust temperature: 370 +/- 30 °C
Heat Recovery System

- CHHP system utilizes 3 thermal loops:
  1. A high pressure steam system provides supplemental steam to the methanation reactor to increase CH₄ production for fuel cell anode
  2. A medium pressure steam system provides steam to the existing campus steam system for heating and heat activated cooling
  3. A hot water loop provides heat for the digester and other process heating applications
- Condensate is collected from campus and water-gas shift reactor
H₂ Recovery, Compression, and Storage

- Water gas shift/heat exchanger reactor (WGS/HEX)
- Pressure Swing Adsorption (PSA) H₂ Separation
- H₂ compressed and stored in 1500 kg cylindrical storage tanks at 34.5 MPa
Environmental Analysis

- **Avoided fuel consumption**: 52,000 MW-hr/yr.

- **Equivalent CO₂ emissions reduction**:
  - 13,000 metric tons/yr
  - Over 4% of 300,000 metric tons/yr. for entire campus and commuter operation. (according to campus Carbon Footprint Report)
System Economics

Analysis assumptions
- 20-year system lifetime
- 3% financing (fixed payment) over 20 years
- 2% inflation
- Operating costs: variable fraction of capital cost (6.25%, 7.5%, 8.75%, 10%)

Annual Cashflow breakdown for OpEx = $1M/yr (8.75% CapEx)

- System feasibility strongly dependent on managing operating costs.
- Operating costs of ~$1M/yr are realistic
Challenges and Opportunities for CHHP Technology Advances

• Cost effective waste separation
• Efficient O₂ from air separation
• Durable methanation catalyst and reactor designs
• Regenerable sulfur and/or silicon traps for fuel cell and/or reactors.

• Current capital costs of overall plant requires minimal operating costs for a reasonable payback, even with existing credits. Capital cost reduction in major components remains the critical challenge.

• A test plant at a university campus (like UMD) facility provides ideal location for implementing urban waste for CHHP in order to promote such technological advances
  – Educational vehicle for industry, R&D community, future engineers
  – Flexible and forward thinking facilities managers with aggressive mandates to reduce energy requirements and carbon footprint
Is CHHP feasible?
Technical/Economic Challenges and Future Studies

- Detailed assessment of available waste resources
- Appropriate solution for recyclable waste?
- Arrangement for times of low resource input.
- CHHP System upfront cost/profitable waste.

University’s Commitment to Sustainability

“I hope we will have some form of waste to energy on campus before I retire, and hopefully we can use some of your design concepts.”

from Joan Kowal, Energy Facilities Manager at UMD
University of Maryland Team Members

Jennie Moton
Kyle Gluesenkamp
Will Gibbons
Sahil Popli
James Daniel Spencer
Abdul Bari
Pritham Prabhakher
Pruthvish Patel
Uzair Ahmed
Rich Spadaccini
Bracha Mandel
Rob Nisson
Jonathan Chung
Brian Hoge
Islam Ibrahim Ahmed Ahmed Gomaa
Richard Bourne
Diane Mcgahagan
Chetali Gupta
Andrew Taverner
Jiaojie Tan
Dulany Wagner
Meron Tesfaye
Yiqing Wu
Viviana Monje
Hannah Shockley
Shariq Hashme
Jorge Prado
Casey Smith

Prof. Greg Jackson (Faculty Advisor, Associate Director of UMERC)
We would like to thank the following, without their help this project would have been impossible.

Corporate Partners
World Hydrogen Energy Conference 2012
FuelCell Energy
Thermogenics Inc.
Advanced Green Energy Solutions LLC
Clayton Industries
Applied Compression Systems
Pepco Energy Services
BioFerm Energy
TEMCo Industrial Power Supply
GDF Suez Energy NA

UMD Faculty and Staff
Joan Kowal (campus energy manager)
Bill Guididas
Michael Dwyer
Dr. Stephanie Lansing
Sally DeLeon
Erika Laubach

And special thanks to the City of College Park for their waste
Honorable Mention

○ Washington State University

○ Presenters:
  ● Brennan Pecha

Report is available at:
CougsCARE: Clean And Renewable Energy at Washington State University

Brennan Pecha

Eli Chambers

Jake Bair

Dr. Jacob Leachman

Dr. Su Ha

Other Authors: Cale Levengood, Shi-Shen Liaw

Faculty Advisors: J. Leachman, M. Garcia-Perez, and S. Ha

September 4, 2012
Special Thanks to Hydrogen Education Foundation

- Opportunity to learn about technologies
- Competitive incentive to come up with something feasible
- Finally something tangible to put knowledge to work
Problem and Solution

- WSU “Climate Action Plan”: President Elson Floyd vows 15% CO$_2$ reduction by 2020
- EPA restricts field burning for farmers
  - (No use for field residue)
- Lignocellulose feedstock- what do we do with it?
- Technologies exist, unique to each situation
An Abundance of Wheat Straw: Palouse Biomass Residue 2005 (tonnes)

- Wheat Straw, 291,517
- Barley Straw, 147,605
- Grass Seed Straw, 8,681
- Other Field Residue, 10,750

Total: 511,563 tonnes
Solution

• System mass/energy balance, economic analysis

• Thermochemical conversion - step by step

• Production of methane to feed to DFC
Pyrolysis

- The pyrolysis reactor, producing char and pyrolysis vapor
- 68 wt% pyrolysis vapor, 32 wt % char
Gasification

Pyrolysis

Gasification

Methanation

Syngas Upgrading

Fuel Cells

H₂ Separation

Gasification

Biochar In

CO+H₂

Steam In

Ash Out

Heating Rods
Methanation and Syngas Upgrading

- Methanation: \( H_2 + CO \rightarrow CH_4 \)
- The methane concentration raised with a water gas shift reactor, a CO\(_2\) scrubber, and a H\(_2\) separation membrane
Fuel Cell Electricity + H₂ Separation

- DFC: Reformer + molten carbonate fuel cell
- Residual hydrogen can be separated and used
Plant and Straw Storage Location

Steam Plant

Plant & Straw Storage
<table>
<thead>
<tr>
<th>In</th>
<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw</td>
<td>104 tonnes</td>
</tr>
<tr>
<td>Water</td>
<td>164 tonnes</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
</tr>
<tr>
<td></td>
<td>7.97 tonnes</td>
</tr>
<tr>
<td></td>
<td>Pyrolysis Vapor</td>
</tr>
<tr>
<td></td>
<td>29.8 tonnes</td>
</tr>
<tr>
<td></td>
<td>CO₂</td>
</tr>
<tr>
<td></td>
<td>15.8 tonnes</td>
</tr>
<tr>
<td></td>
<td>CO</td>
</tr>
<tr>
<td></td>
<td>18.2 tonnes</td>
</tr>
<tr>
<td></td>
<td>H₂</td>
</tr>
<tr>
<td></td>
<td>428 kg</td>
</tr>
<tr>
<td></td>
<td>Electricity</td>
</tr>
<tr>
<td></td>
<td>105,600 kW-hr</td>
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<tr>
<td></td>
<td>Heat</td>
</tr>
<tr>
<td></td>
<td>86,400 kW-hr</td>
</tr>
</tbody>
</table>
Primary Uses for Products

- Hydrogen to **mass transit**, vehicles, and **system recycling**
- 4.4 MW electricity to grid (Pullman’s draw is 18.5 MW)
- Heat to adjacent **greenhouses**
- Excess pyrolysis vapor to supplement natural gas at the steam plant
### Conservative Cost & Environmental Analysis

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
<th>2012 With CHHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Usage from Avista</td>
<td>162,352,083 kW-hr/year</td>
<td>125,630,000 kW-hr/year</td>
</tr>
<tr>
<td>Estimated Unit Cost ($)</td>
<td>0.062/kW-hr</td>
<td>0.062/kW-hr</td>
</tr>
<tr>
<td>Electricity Cost ($)</td>
<td>10,065,000</td>
<td>7,789,000</td>
</tr>
<tr>
<td>Natural Gas for Steam Production ($)</td>
<td>5,837,000</td>
<td>4,404,000</td>
</tr>
<tr>
<td>Fueling Cost for Campus Vehicles ($)</td>
<td>833,000</td>
<td>372,000</td>
</tr>
<tr>
<td>Avoided CO₂ Emissions</td>
<td>0 tons/year</td>
<td>54,000 tons/years</td>
</tr>
<tr>
<td>CHHP System Op. Cost ($)</td>
<td>-</td>
<td>5,560,200</td>
</tr>
<tr>
<td>Total Energy Costs ($)</td>
<td>16,735,000</td>
<td>18,125,200</td>
</tr>
<tr>
<td><strong>Net Savings with CHHP System ($)</strong></td>
<td><strong>(1,390,200)</strong></td>
<td><strong>(1,390,200)</strong></td>
</tr>
</tbody>
</table>
Future Development, Now!

- Refining plant location, size, equipment selection (Ha, Garcia-Perez, Mehrizi-Sani)
- Ammonia synthesis via Haber reactions (Leachman, Haselbach)
- Economic & soil-mineral nitrogen & phosphorous cycle analyses (Fortenbery, Pan)
- Production of plastics, concrete from char/ash, preliminary proposal and marketing (All above)
A Win-Win for the Community

1. It minimizes air pollution to benefit overall community health
2. It creates clean energy to supplement the grid of an expanding WSU campus
3. It finally gives Whitman County farmers a use for their wasted straw
Thank You!

- Special thanks to:
  - Drs. Leachman, Ha, & Garcia; The Bair family
  - Ryan Terry of WSU Energy Services; Avista

- Faculty contact: Jacob Leachman, jacob.leachman@wsu.edu

- View full report at www.HydrogenContest.org
Honorable Mention

- University of California, Davis

- Presenters:
  - Mengjing (Irene) Yu

Report is available at:
Combined Hydrogen, Heat, and Power (CHHP) Plant Design

University of California, Davis
Presenter: Mengjing (Irene) Yu

Team Members: Maya Biery Maggie Mei
Elisha Clerigo, Abigail Bonifacio, Suzann Muy, Dustin Cutler, Roshni Varghese, Farah Quader

Faculty Advisor: Julie Schoenung, Paul Erickson
CHHP Overview

Manure → Anaerobic Digestion → Biogas Treatment → Biogas → Air

Exhaust Heat → DFC 300

- Fuel Cell Exhaust → Water-Gas Shift Reaction
- Vapor-Liquid Separation
- Pressure Swing Adsorption
- Compressed Hydrogen Storage

Hot Water → Steam → Greenhouse

Heat Recovery Unit

Electricity → Substation

CHHP Campus Greenhouse

Hydrogen Cylinders

Hydrogen Community

CO₂

Water

68
Feedstock Overview

- The feedstock for DFC300 is biogas produced from digesting manure and rice straw, both readily available in Davis.
- Collectable manure can come from cattle, milk cow, horse, sheep, lamb, and goat. Total manure available per day is 27,387 kg.
- 95% of rice production in California takes place within 161km of Sacramento. Annually, California produces 1.3 billion kg of straw waste.
- Combination of manure and rice straw gives good carbon-nitrogen ratio and optimum moisture content.
Technical Design

Hydrogen Purification
Water-Gas Shift Reaction

\[\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2\]

Reactor Design:
- Fixed Bed Plug Flow Reactor with Shell and Tube Configuration
- Optimum Temperature is 350°C
- Cooling Water Jacket
- Catalyst is Iron Oxide containing 5-15% \(\text{Cr}_2\text{O}_3\)
Vapor-Liquid Separation

Vessel Specifications:
- Vessel Dimension is Calculated using Design Heuristic
- Liquid Hold-Up Time is 3 to 5 Minutes
- An Entrainment Wire Mesh Served as Mist Eliminator
Hydrogen Purification

Pressure Swing Adsorption (PSA)

- H₂-CO₂ Mixture is Compressed to 200 psig Before Entering PSA
- Catalyst is Zeolite, Activated Carbon, Silica Gel
- Cycling Schedule: Pressurization, Regeneration, Repressurization
- Minimum of 2 Adsorbers

Photo Credit: Full System Engineering Co., LTD.
• Hydrogen is Stored at 5000 psig
• Hydrogen Flow Rate is 29 scfm
• Composite Material for the Tank
• Tuffshell® Fuel Storage Systems
• DFC300 produces 62 kg hydrogen per day
• Hydrogen is transported to the Hydrogen Community using hydrogen cylinders
• A 60 kW and a 5 kW Altergy Freedom Energy PEM fuel cell is used to generate electricity
• Capable of supporting approximately 51 households

Photo Credit: Altergy Freedom Energy
Exhaust Heat
Exhaust heat is recovered to produce steam and hot water. Steam is used for steam heating greenhouses. Hot water is mainly for nearby buildings and facilities.

Electricity
A substation including meters, breakers, transformer, and transmission lines is built to support the interconnection. CHHP itself consumes about 126 kW of electricity, so net electricity available is about 154 kW.
Thank You
2012-2013 Contest

The theme of the 2012-2013 Hydrogen Student Design Contest is “Development of a Hydrogen Fueling Infrastructure in the Northeast United States”.

The challenge for student teams is to create a feasible plan for the implementation of a hydrogen infrastructure, using only commercially available technology, designed to facilitate fuel cell vehicle travel within and between major urban areas in the Northeast and Mid-Atlantic.
2012-2013 Contest

Identifying the Hydrogen Production and Fueling Station Locales
- develop a comprehensive list of potential hydrogen production locations using any commercially available technology for hydrogen production
- develop a comprehensive list of possible hydrogen refueling station locations

Rollout Scheme
- devise a detailed timeline to rollout their hydrogen infrastructure
- amount of hydrogen production and fueling stations must meet or exceed the demand for hydrogen at that time

Cost and Economic Analysis
- address all the costs associated with building the proposed infrastructure

Hydrogen Storage and Fueling Station Regulations
- review of existing regulation pertaining to hydrogen fueling and storage in the Northeast
- develop suitable regulations for the states in which new fueling stations are proposed

Marketing and Education Outreach
- develop a plan to educate and market the new hydrogen infrastructure to the public
How to Register

- Details on the Contest and team registration at [www.hydrogencontest.org](http://www.hydrogencontest.org)

- Team leader is only person required to sign up
  - Registration Deadline - October 1, 2012
  - Team Member List due - October 15, 2012
Question and Answer

- Please type your question into the question box
Thank you!

- The presentation will be made available after the conclusion of the webcast.

- Deadline to register for 2012-2013 Contest is October 1, 2012

www.hydrogencontest.org