Hydrogen Recycling System Evaluation and Data Collection

Rhonda Staudt
H2Pump LLC
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PHONE: 518.783.2241 • EMAIL: INFO@H2PUMPLLC.COM
11 NORTHWAY LANE NORTH
LATHAM, NY 12110

Company Background

Limited Liability Corporation with headquarters in Latham, NY

- **Founded in October of 2005**
- **Hydrogen reclamation and recycling solutions**
- **Recipient of R&D awards from the US Department of Energy, US Department of Defense and New York State Energy Research and Development Authority**
- **InterTech Group is a strategic partner and investor**
- **19 employees**

Commercial Hydrogen Market

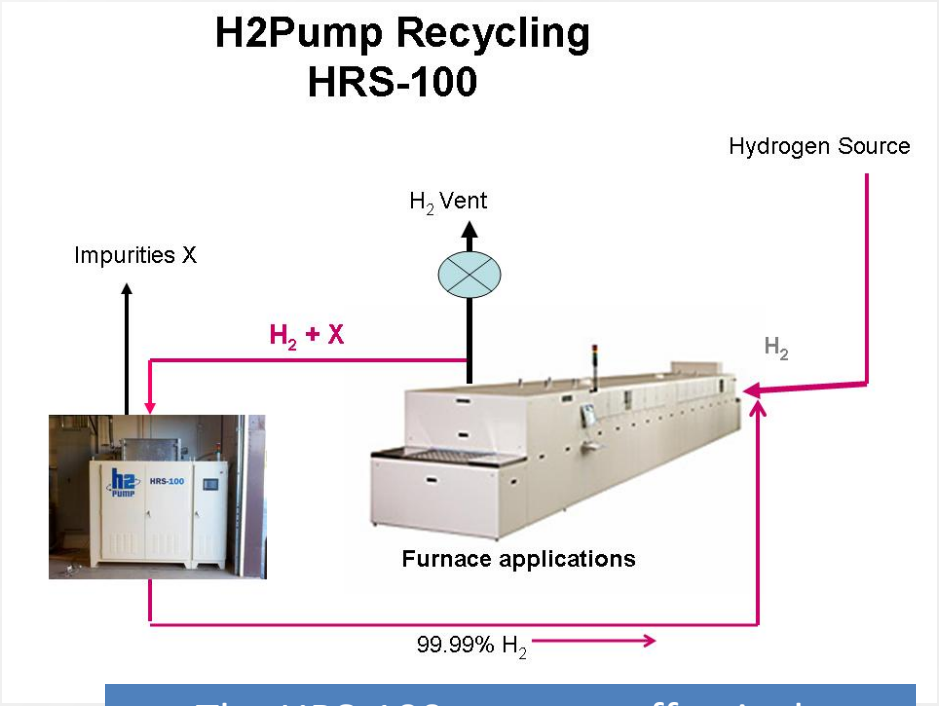
Industrial Processes Using Hydrogen:

- **Metals processing (steel, annealing, sintering, brazing)**
- **Semi-conductor & LED processing**
- **Ceramics processing**
- **Chemical by-product H2**
- **Float glass manufacturing**

LED Fabs

Reduction Furnace

The Opportunity

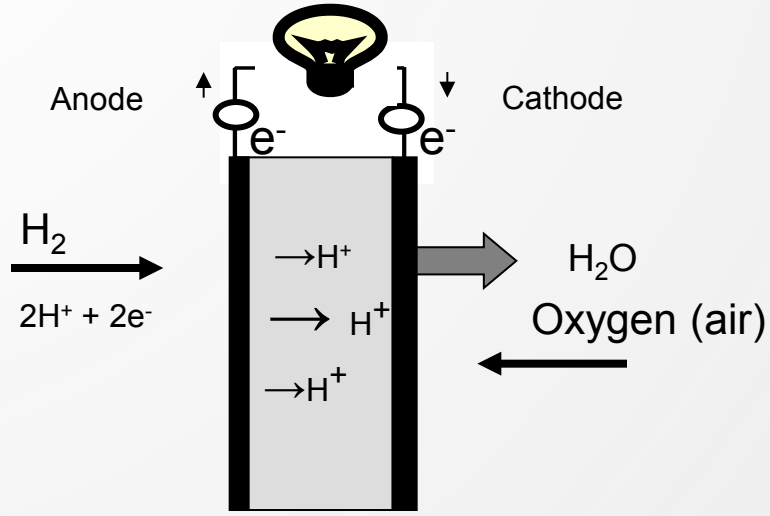


Industrial operations flare or vent hydrogen rich furnace exhaust gas into the atmosphere today

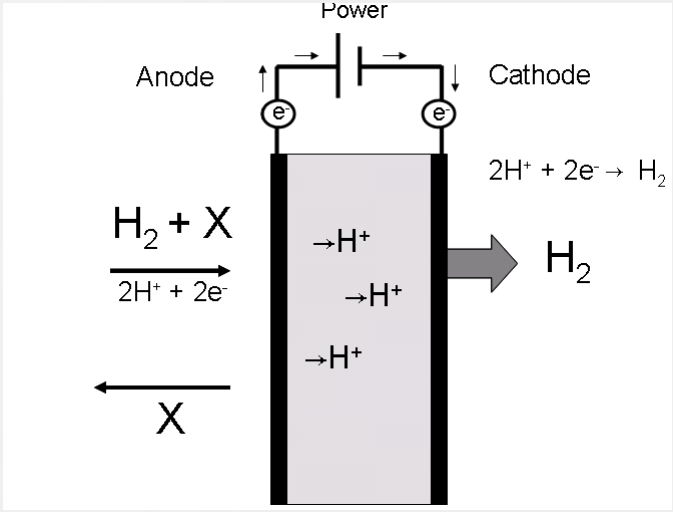
The HRS-100 can cost effectively reclaim, purify and pressurize the hydrogen exhaust

H2Pump Core Technology

Utilizing modified fuel cell technology for hydrogen recovery and recycling



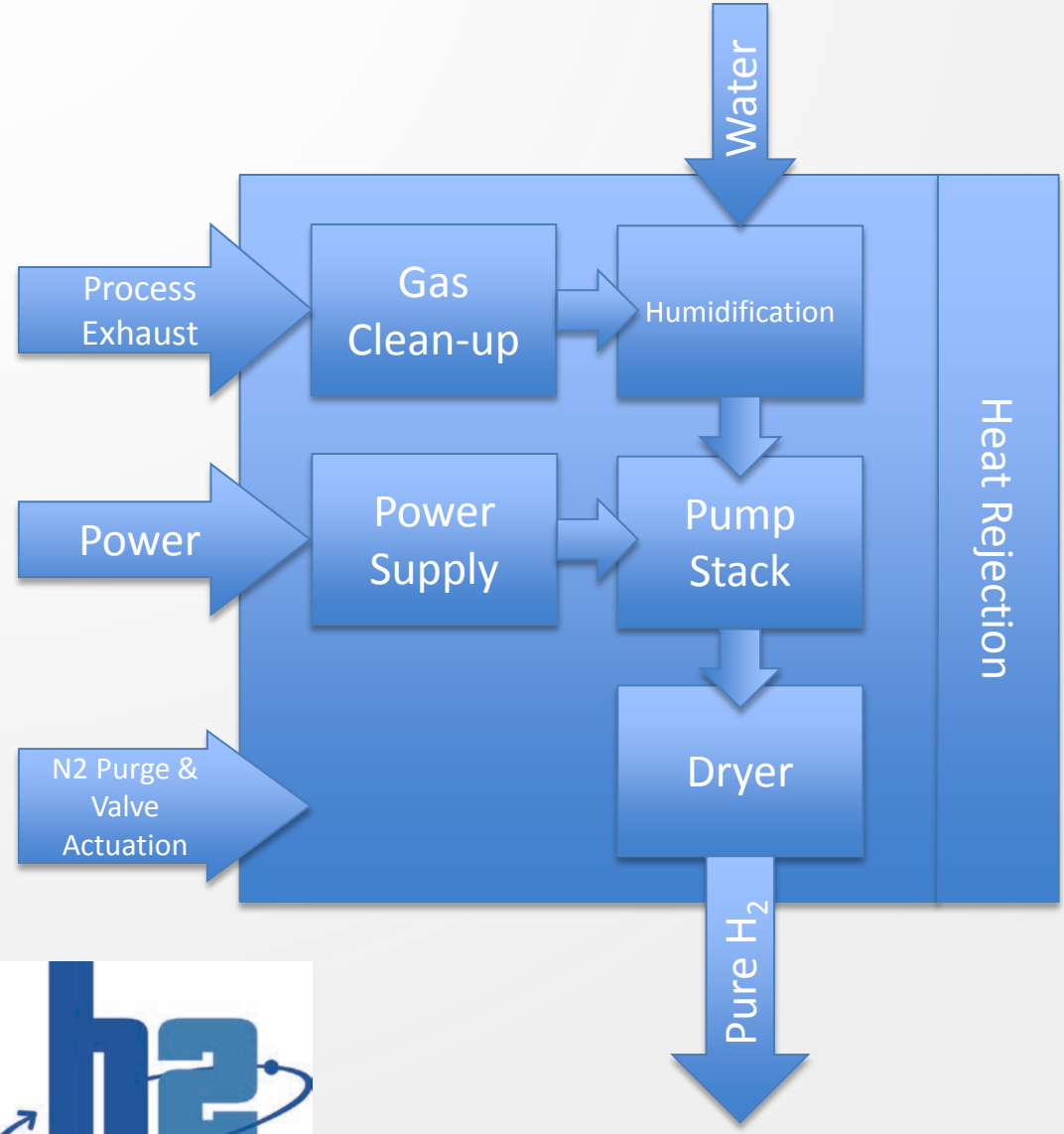
Fuel Cell
Chemical energy converted directly to electricity



Hydrogen Recycling
Electricity utilized to drive separation process

- Purify, pressurize and "pump" in a single step
- Reliable non-mechanical process
- Ambient pressure feed gas
- Up to 90% recovery of hydrogen
- Leverages existing fuel cell supply base

HRS-100™-100 kg/day H2 Recycling System



Overview

Timeline

- Project start date: 1/2/13
- Project end date: 12/31/2015*
- Percent complete: 40%

* Reflects SOPO modification approved in April 2014. Project continuation and direction determined annually by DOE.

Budget

- Total funding spent as of 3/31/14: $487K
- Total project funding $1.066M
  - DOE share: $499K
  - Contractor share: $567K
  - Contractor cost share percentage: 53%

Barriers

- TV 3.6D. Lack of Hydrogen Refueling Infrastructure Performance and Availability Data
  - Efficiency: 10 kWhr/kg
  - Availability: 80%
- TV 3.6G. Hydrogen from Renewable Resources

Partners

- NYSERDA & NREL
- Site Hosts:
  - Ulbrich Stainless Steel
  - Pall Corporation
  - Rome Strip Steel
  - SUNY, Albany- College of Nanoscale Sciences and Engineering (CNSE)

Relevance

Program Objective (modified SOPO):

- To demonstrate the product readiness and quantify the benefits of H2Pump's Hydrogen Recycling System (HRS-100™) by installing and analyzing the operation of ***seven*** pre-commercial 100 kg per day systems in real world customer locations.
- H2Pump will install, track and report multiple field demonstration systems in industrial heat treating & LED Fab applications.
- ***H2Pump will perform extensive furnace exhaust gas stream analysis at each site and implement solutions to mitigate contaminates***
- The demonstrations will be used to develop case studies and showcase the benefits of the technology to drive market adoption.

Our objectives and project plan address DoE barriers regarding system performance and cost for hydrogen related infrastructure.

Relevance

DoE Barrier	Metric	Target 2013- 2014
D. Lack of Performance and Availability Data	System Efficiency • Recycling rate (kg/day) • Electrical consumption (kWhr/kg)	 > 80 < 10
	Availability %	> 80%
	Annual run time (24/7) - hours	> 7,000
	Mean time between failure - hours	> 1,200
G. Hydrogen from Renewable Resources	Stack life time - hours	> 14,000
	Annual service cost	$15,000
	Annual projected savings	$40,000

Plan & Approach

Site Requirements & Plan

- **Site Visits- Site Requirements**
- **Gas Sampling, Single Cell Testing**
- **Installation Document - P&ID**

System Build & Test Site Prep

- **Build by Contract Manufacturer**
- **Debug, Leak Check, Test and Qualification at H2Pump**
- **Site Electrical, Internet, Nitrogen, Water and Exhaust**

Installation & Commissioning

- **Ship system**
- **Locate and Hook-up**
- **Training and continuous operation**

Data Collection & Monitoring

- **12- 18 months**
- **NREL detailed analysis**
- **Identification of improvements**

Operation, Maintenance

- **Service calls**
- **Service cost**
- **MTBF**

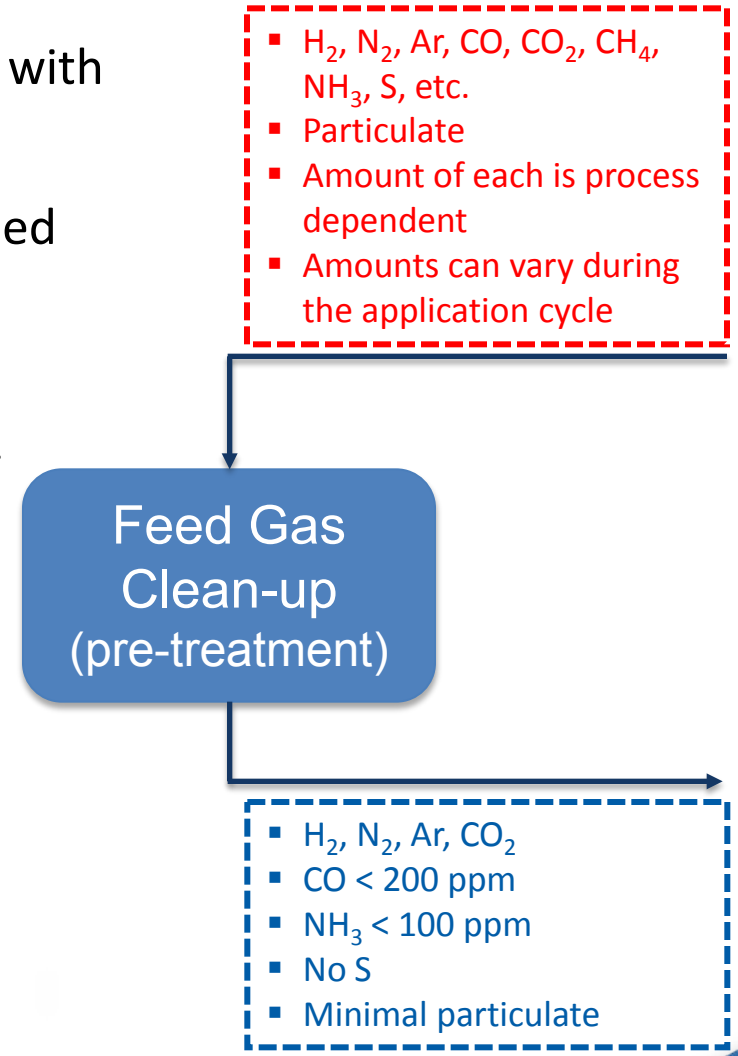
Plan & Approach

		% Complete
Budget Period 1	Task 1.0: Data Collection and Reporting Tool	95%
	Task 2.0: System #1 at Ulbrich	75%
	Task 4.0: System #3 at Pall Corporation	90%
	Task 5.0: System #4 & #5 at Rome Strip Steel	75%
	Task A*: Site Gas Composition and Analysis	25%
	Go/ No Go Decision	
Budget Period 2	Task 3.0: System #2 at Redifoils	
	Task 6.0: System #6 at Pall w/ Humpback Furnace	
	Task 7.0: System #7 at CNSE- MOCVD	
	~~Task 8.0: System #8 at CNSE- EUV~~	deleted
	Task 9.0: Program Management	
	Task 10.0: Extended Runtime	

* Go/ No Go Decision delayed until Task A is completed and performance of the first four systems is improved.

New Task A: Gas Sampling and Analysis

- Core HRS-100™ is engineered to perform with a known composition
- Clean-up (pre-treatment) equipment added upstream of HRS
  - Customized for each application
  - Implementing solutions for wide range of species and levels
    - Gas phase
      - Catalytic reaction
      - Adsorption
    - Liquid phase (oils, etc)
      - Separation / Filtration
    - Particulates
      - Filtration / Separation



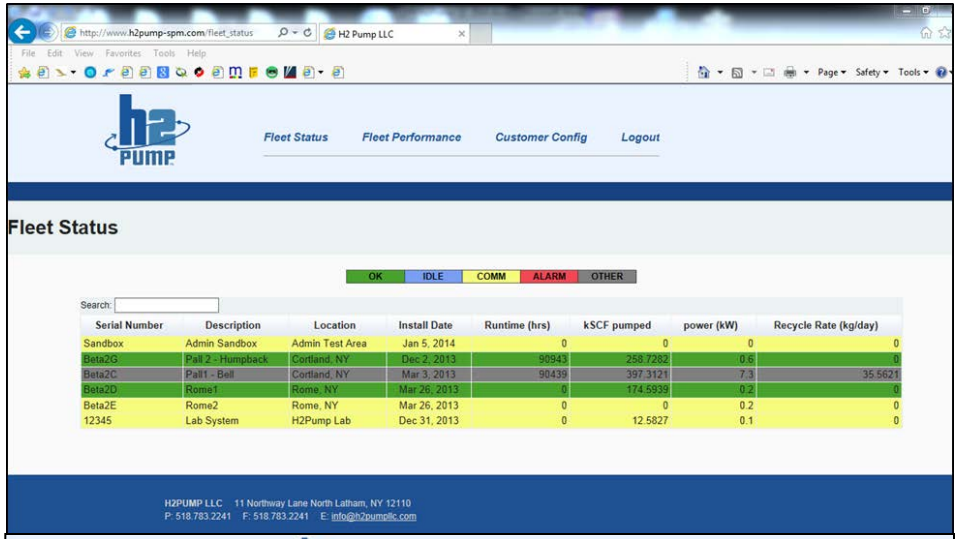
Accomplishments and Progress

Task 1.0: Create Data Collection, Monitoring and Reporting Tool and Database

- ✓ Create a Requirements Document
  - Fleet Status
  - Customer Screen
  - Database
  - Administration
- ✓ Select a supplier

Work remaining

- Access to NREL
- Bug and code fixes



Accomplishments and Progress

Ulbrich Specialty Strip Mill
Wallingford, CT

Task 2.0 Ulbrich (System #1)

- Many types of SS foil
- Multiple continuous furnaces
- Varying Oil and CO

✓ Site Requirements and Plan
✓ System Build, Test, Site Prep
✓ Installation and Commissioning

Pall Corporation
Cortland, NY

Task 4.0 Pall (System #3)

- Annealing of SS filters
- Two bell furnaces
- Cyclic operation

✓ Site Requirements and Plan
✓ System Build, Test, Site Prep
✓ Installation and Commissioning

Rome Strip Steel
Rome, NY

Task 5.0 Rome (System #4 & #5)

- Integrate 16 bell furnaces
- Varying furnace operation
- High Oil content
- High CO content
- Dual HRS-100™ units

✓ Site Requirements and Plan
✓ System Build, Test, Site Prep
✓ Installation and Commissioning

System performance limited in 2013 due to issues with unknown contaminates

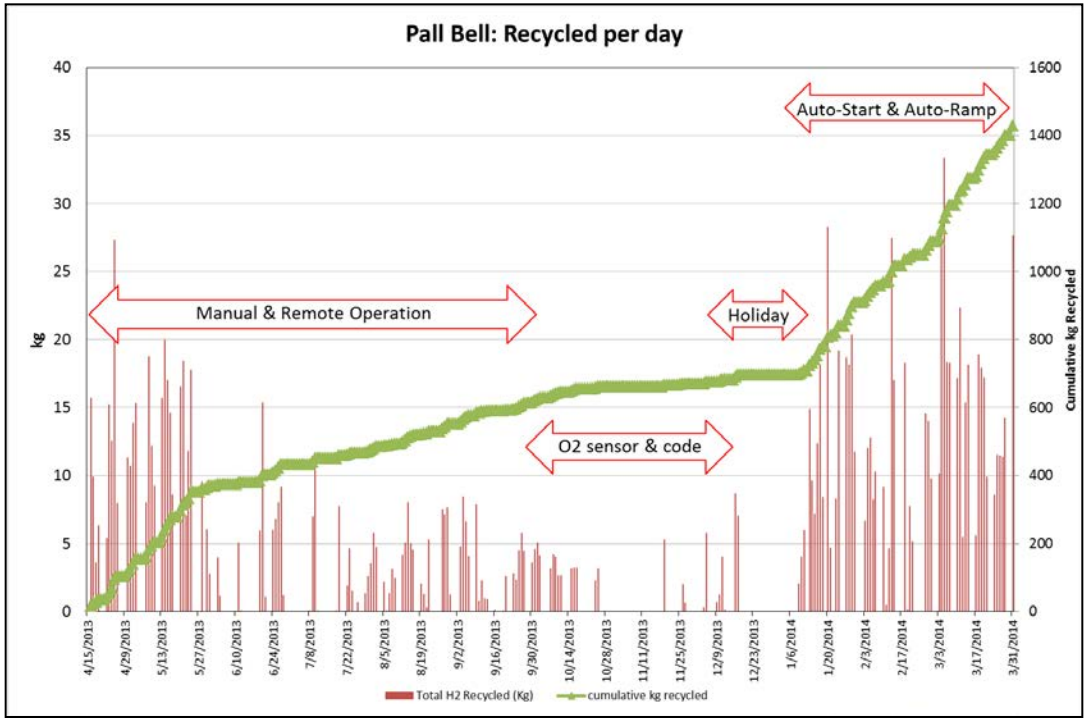
System Status as of 3/31/14

Metric	Rome #1	Rome #2	Pall	Ulbrich
Delivery Date	March 22, 2013	March 4, 2013	Feb 11, 2013	Dec 2012
First Operation Date	March 27, 2013	March 27, 2013	March 4, 2013	Jan 2013
Characteristics of customer operation	24 hrs/ day 5- 7 days	24 hrs when flow exceeds System #1	8-10 hrs/ day M-F	24 hrs/ day 7 days
Cumulative Recycled	918 kg	61 kg	1,428 kg	1,052 kg
Recycling time	1,337 hrs	205 hrs	1,270 hrs	1,872 hrs
Expected recycle rate	10- 15 kg/ day	10- 15 kg/ day	8-10 kg/ day	10- 15 kg/ day
Key integration issues	Controls for 2 systems in tandem. Multiple furnaces with varying CO		2 bell furnaces cycling- daily start/ stops	Multiple furnaces, Varying CO
Remaining integration issues	Oil removal system interactions with HRS 100, unknown contaminates		Sulfur species	Sulfur species

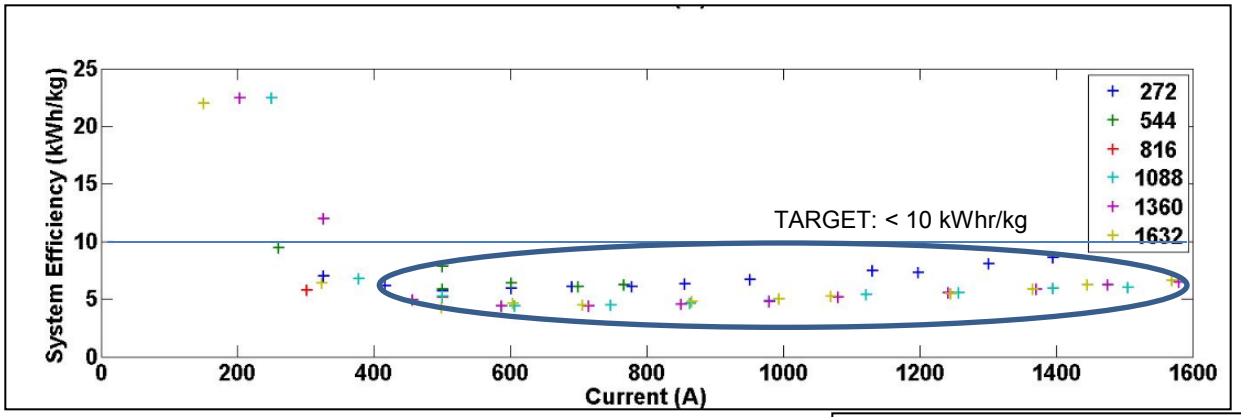
Accomplishments and Progress

Task 4.5- Operate and Maintain

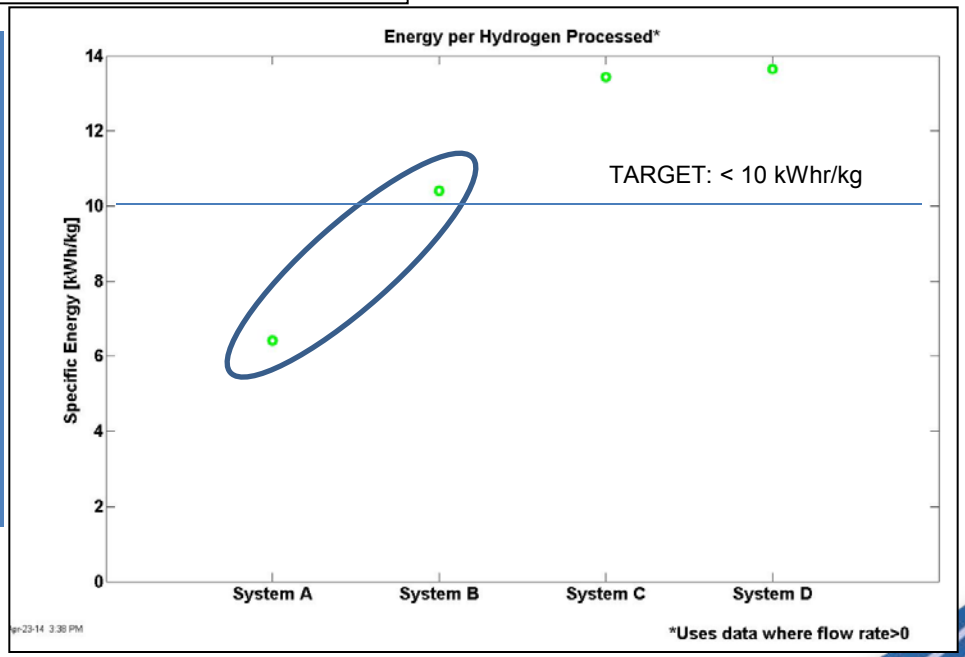
- Manual operation during the first 6 months of operation led to the development of automated controls including:
  - Start-up
  - Ramp-up
  - Stack controls
- System is up to 80% availability and recycled 731kg in 1Q2014



Accomplishments and Progress



- System is most efficient at normal operating points
- NREL's analysis confirms that 2 of 4 systems meet the efficiency target (System A&B)
- Two systems not meeting target are under utilized and have insufficient runtime (System C&D)



Proposed Future Work

May- July 2014- Site mitigation plans implemented and demonstrated for CO and sulfur

Quarterly data reviews with NREL

Sept 2014- Go/ No Go Decision Meeting

June- Sept 2014- Complete installations of Budget Period 2 systems

Sept 2014- Begin data analysis & reporting of Budget Period 2 systems

Collaborations

NREL- Data Analysis

NYSERDA- NYS Demo Cost share

NYS Engineering Firms- Hesnor Engineering, Zeller Corporation, O'Brien and Gere and Edwards Vacuum

Site Hosts (Industry)- Ulbrich, Pall, Rome Strip Steel, CNSE

Summary

DoE Barrier	Metric	Target 2013- 2014	Current Status
D. Lack of Performance and Availability Data	System Efficiency • Recycling rate (kg/day) • Electrical consumption (kWhr/kg)	 > 80 < 10	 Max 33 < 10
	Availability %	> 80%	80% at Pall in March 2014
	Annual run time (24/7) - hours	> 7,000	2,200*
	Mean time between failure - hours	> 1,200	Not measured
G. Hydrogen from Renewable Resources	Stack life time – hours	> 14,000	> 5,000 projected**
	Stack degrade for Go/No go µV/kgH2/cell	< 15	***
	Annual service cost (includes stack replacement at 1 and 3 years)	$15,000	Not measured
	Annual projected savings	$40,000	See reviewer's comment slide

* From installation thru 1Q14 (< 12 months). No sites running 24/7
** Based on 1,600 hours of operating data analyzed by NREL
*** More operating hours needed for valid calculation

Resolving site issues will improve all metrics

Response to Reviewer Comments

“ Cost data needs to be more transparent”

“ $40,000 annual saving is a rough estimate and will need to be validated”

Assumptions:

- $5.50/kg merchant hydrogen
- $3.22/kg recycled hydrogen
- 10 kWhr/ kg of recycled hydrogen
- Electricity cost is $0.059/ kWhr
- 80 kg/day for 24 hours of operation

Calculation :

{(80kg/day*$5.50)-[(10kWhr/kg*80kg*$0.059/kWhr)+(80kg*$3.22/kg)]}* (365 days/ year*80%)= $39,500 annual savings