Project Title: Hydrogen Recycling System Demonstration
Recipient: H2Pump LLC
Principal Investigator: Rhonda Staudt
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DOE Manager: Jim Alkire
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Award Number: DE-EE0006091
Project Start Date: 01/01/13
Project End Date: 03/30/15

Notice: The following is a compilation of progress reports and presentations submitted by H2Pump to the DOE's Fuel Cell Technologies Office for award number DE-EE0006091 and a final report submitted by H2Pump to the New York State Research and Energy Development Authority (NYSERDA). NYSERDA co-funded the work along with DOE. The reports cover the project activities from January, 2013 through November, 2014, when H2Pump reported to DOE that they were no longer a viable business. This compilation has been uploaded to OSTI by DOE as a substitute for the required Final Technical Report, which was never received by DOE.

VII.3 Hydrogen Recycling System Evaluation and Data Collection

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DOE Managers
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Jim Alkire
Phone: (720) 356-1426
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Contract Number: DE-EE0006091

Project Start Date: January 2013
Project End Date: June 2014

Overall Objectives

The objective of this project is to demonstrate the product readiness and to quantify the benefits and customer value proposition of H2Pump's Hydrogen Recycling System (HRS-100™) by installing and analyzing the operation of multiple prototype 100-kg per day systems in real world customer locations. The data gathered will be used to measure reliability, demonstrate the value proposition to customers, and validate our business model. H2Pump will install, track and report multiple field demonstration systems in industrial heat treating and semi-conductor applications. The customer demonstrations will be used to develop case studies and showcase the benefits of the technology to drive market adoption. The objectives of the project are to:

- Validate commercial assumptions around the Hydrogen Recycling Agreement including customer assumptions and system performance.
- Build case studies of the HRS-100™ in customer operations that can be used as credible demonstrations quantifying the operating cost savings, emissions reduction and production efficiency improvement.
- Expand the Beta test fleet into additional customer environments to accelerate learning, problem identification, resolution and reduce the risk of product launch
- Provide data to the National Renewable Energy Laboratory (NREL) for in-depth analysis of system performance characteristics and identify areas for improved data gathering and performance causal analysis. All of the data acquired by the systems will be made available for NREL. The minimum data includes stack voltage and current, system power, and hydrogen flow rate. Data frequency can be no less than a one minute interval. Maintenance and repair logs should also be provided to NREL, specifying time, maintenance item, or reason for repair. NREL will also be provided with all gas analysis to help determine whether certain gases result in higher degradation.
- Prepare and test commercial infrastructure elements such as installation, commissioning, reporting, operation, and maintenance.

Fiscal Year (FY) 2013 Objectives

- Create and deploy a database tool for retrieval of data logs to monitor and analyze system performance.
- Install and commission four of the eight systems in the first quarter of 2013 and provide data to NREL to perform degradation calculations.
- Execute Go/No-Go review.
- Install and commission the four remaining systems in the second half of 2013 and provide data to NREL to perform degradation calculations.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(D) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

(G) Hydrogen from Renewable Resources

FY 2013 Accomplishments

- Installed and commissioned an HRS-100™ system at Ulbrich Stainless Steel in Wallingford, CT.
- Installed and commissioned an HRS-100™ system at Pall Corporation in Cortland, NY.
- Installed and debugged two HRS-100™ systems at Rome Strip Steel in Rome, NY in conjunction with a gas treatment system for oil removal and CO reduction.
- Implemented method for data retrieval, sharing and analysis with NREL while database development is underway.

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INTRODUCTION

Hydrogen is used in numerous industrial applications including metallurgical and semiconductor processing. Hydrogen intensive metal heat treating applications include stainless steel annealing, brazing, and metal production from ore. Each industrial application uses hydrogen for different purposes; however, in general, hydrogen is used to create an oxygen-free reducing atmosphere and is not consumed by the industrial process. H2Pump has developed a unique hydrogen recycling solution capable of reclaiming nearly 100 kg per day from such industrial processes.

Figure 1 shows how the HRS integrates with a typical industrial furnace or semi-conductor manufacturing tool. The HRS receives the furnace or tool exhaust which is normally flared or exhausted to atmosphere. The HRS requires certain utilities including electricity, water, and nitrogen. The heart of the HRS system is the electrochemical pump stack. The electrochemical process involves the extraction of hydrogen from a gas stream containing hydrogen followed by the formation of "new" hydrogen. This transformational approach is accomplished without mechanical compression. The new hydrogen is returned to the original process.

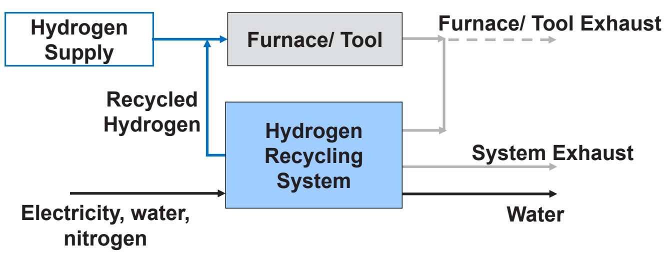

FIGURE 1. Integration of a Hydrogen Recycling System with an Industrial Process

The HRS-100™ system design is represented in Figure 2. The main subsystems and components include incoming gas clean-up, humidification, the pump stack, power supply, heat rejection and the dryer. Most heat treating processes require very low dew point in the hydrogen supply. To ensure adequate quality of the recycled product, H2Pump measures the dew point of the product before returning the hydrogen to the customer's process.

APPROACH

H2Pump is fortunate to have the support of the New York State Energy Research and Development Authority (NYSERDA) as a cost-sharing partner in this project. The NYSERDA award funds 50% of the system material cost, the installation cost, and the ongoing operation and maintenance costs of the demonstration. The DOE award shares the costs of the systems, the database development, and analysis performed by NREL.

A total of eight systems are planned to be installed and monitored during the project. For each site H2Pump follows the steps shown in Figure 3. The first step is establishing the site requirements and installation plan. Activities to uncover site specific issues, including potential gas contaminates are undertaken early in the planning process. Mitigation plans are put in place for known contaminates and the systems are installed and commissioned. Following commissioning, the system will be monitored and the data logs will be given to NREL for analysis.

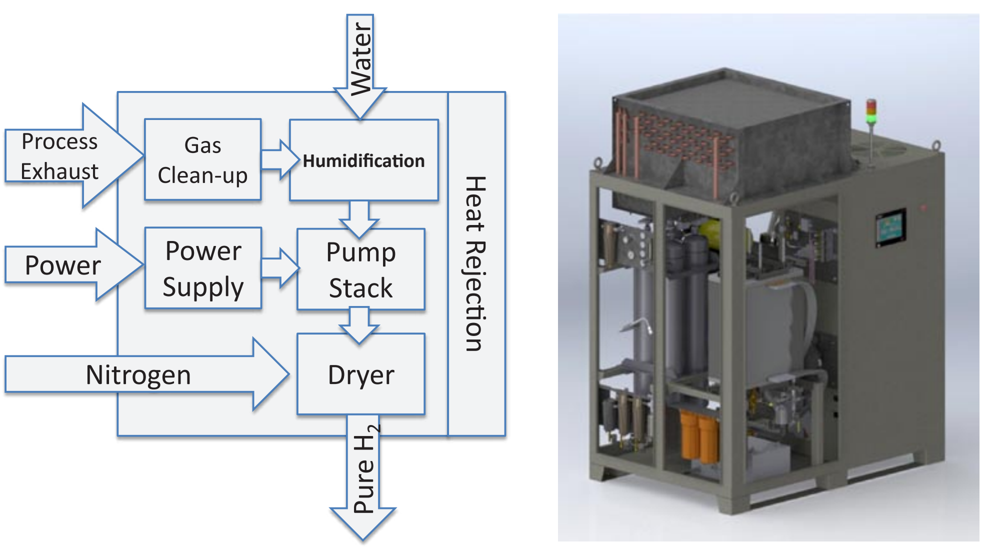

FIGURE 2. HRS-100™ Subsystems and Components

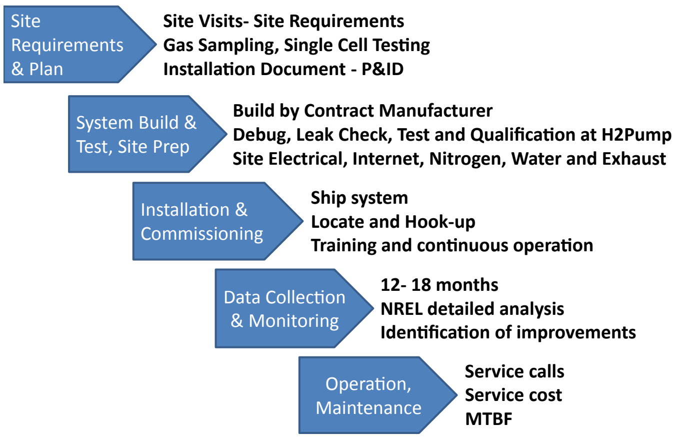

FIGURE 3. Program Approach

RESULTS

As of this report, the first four systems are installed, with only two fully commissioned and reporting only two months of operational data. The installed systems are shown in Figure 4. The final two systems should achieve continuous operation in the third quarter of 2013. Once more systems are reporting data H2Pump will be able to summarize the results and NREL will be able to report their analysis. This has delayed the Go/No-Go decision for a quarter.

CONCLUSIONS AND FUTURE DIRECTIONS

The site planning and commissioning steps are proving to be the most critical and time intensive part of the project. For the remaining four installations in the second part of the project, greater emphasis will be placed on understanding the site actual operational characteristics.

FY 2013 PUBLICATIONS/PRESENTATIONS

1. 2013 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting, May 13–17, 2013, Crystal City, Virginia.

FIGURE 4. Completed HRS-100™ Installs

VII.3 Hydrogen Recycling System Evaluation and Data Collection

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Contract Number: DE-EE0006091

Project Start Date: January 2013
Project End Date: December 2015

Overall Objectives

The objective of this project is to demonstrate the product readiness and to quantify the benefits and customer value proposition of H2Pump's Hydrogen Recycling System (HRS-100™) by installing and analyzing the operation of multiple prototype 100 kg per day systems in real world customer locations. The data gathered will be used to measure reliability and to demonstrate the value proposition to customers. H2Pump will install, track, and report multiple field demonstration systems in industrial heat treating and semi-conductor applications. The customer demonstrations will be used to develop case studies and showcase the benefits of the technology to drive market adoption. The objectives of the project are to:

- Validate commercial assumptions around the Hydrogen Recycling Agreement including customer assumptions and system performance.
- Build case studies of the HRS-100™ in customer operations that can be used as credible demonstrations quantifying the operating cost savings, emissions reduction and production efficiency improvement.
- Expand the Beta test fleet into additional customer environments to accelerate learning, problem identification, resolution and reduce the risk of product launch.
- Provide data to National Renewable Energy Laboratory (NREL) for in-depth analysis of system performance characteristics and identify areas for improved data gathering and perform causal analysis. All of the data acquired by the systems will be made available to the NREL. The minimum data includes stack voltage and current, system power, and hydrogen flow rate. Data frequency can be no less than a one minute interval. Maintenance and repair logs will also be provided to NREL, specifying time, maintenance item, or reason for repair. NREL will also be provided with gas analyses to help determine whether certain gases result in higher degradation.
- Prepare and test commercial infrastructure elements such as installation, commissioning, reporting, operation, and maintenance.

Fiscal Year (FY) 2014 Objectives

- Modified Statement of Project Objectives will include a new objective: H2Pump will perform extensive furnace exhaust gas stream analyses at each site and implement solutions to mitigate contaminates.
- Execute Go/No-Go review.
- Install and commission the remaining three systems in the fourth quarter of 2014 and provide data to NREL to perform degradation calculations.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(D) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

(G) Hydrogen from Renewable Resources

FY 2014 Accomplishments

- Completed the development and deployment of a database tool to track system performance and store lifetime data.
- Identified furnace exhaust contaminates at Pall, Rome Strip Steel, and Ulbrich deployment sites through extensive gas sampling and analysis by an external lab.
- Implemented solutions at Pall and Rome Strip Steel for containment of sulfur compounds, CO, and other contaminates harmful to the pumping stack.
- Implemented automatic controls at Pall, increasing the daily recycle rate by three times.

- Provided data to NREL quarterly to assess system performance. Demonstrated less than 10 kWh/kg at most operating points.

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INTRODUCTION

Hydrogen is used in numerous industrial applications including metallurgical and semiconductor processing. Hydrogen intensive metal heat treating applications include stainless steel annealing, brazing, and metal production from ore. Each industrial application uses hydrogen for different purposes; however, in general, hydrogen is used to create an oxygen-free reducing atmosphere and is not consumed by the industrial process. H2Pump has developed a unique hydrogen recycling solution capable of reclaiming nearly 100 kg per day from such industrial processes.

Figure 1 shows how the HRS integrates with a typical industrial furnace or semi-conductor manufacturing tool. The HRS receives the furnace or tool exhaust that is normally flared or exhausted to atmosphere. The HRS requires certain utilities including electricity, water, and nitrogen. The heart of the HRS system is the electrochemical pump stack. The electrochemical process involves the extraction of hydrogen from a gas stream containing hydrogen, followed by the formation of "new" hydrogen. This transformational approach is accomplished without mechanical compression. The new hydrogen is returned to the original process.

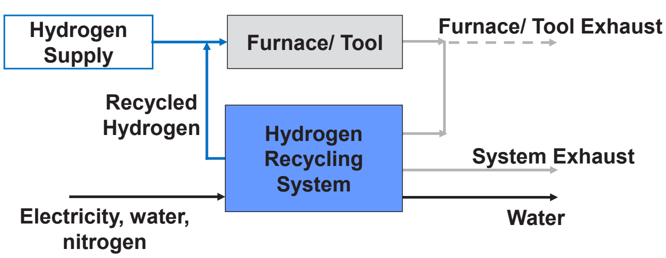


FIGURE 1. Integration of a Hydrogen Recycling System with an Industrial Process

The HRS-100™ system design is shown in Figure 2. The main subsystems and components include incoming gas clean-up, humidification, the pump stack, power supply, heat rejection and the dryer. Most heat treating processes require a very low dew point in the hydrogen supply. To ensure adequate quality of the recycled product, H2Pump measures the dew point of the product before returning the hydrogen to the customer's process.

APPROACH

H2Pump is fortunate to have the support of the New York State Energy Research and Development Authority as a cost sharing partner in this project. The New York State Energy Research and Development Authority award funds 50% of the system material cost, the installation cost, the ongoing operation, and maintenance costs of the demonstration. The DOE award shares the costs of the systems, the database development and the analysis performed by NREL.

A total of seven systems are planned to be installed and monitored during the project. The first step is establishing the site requirements and installation plan. Activities to uncover site specific issues, including potential gas contaminates are undertaken early in the planning process. Mitigation plans are put in place for known contaminates, and the systems are

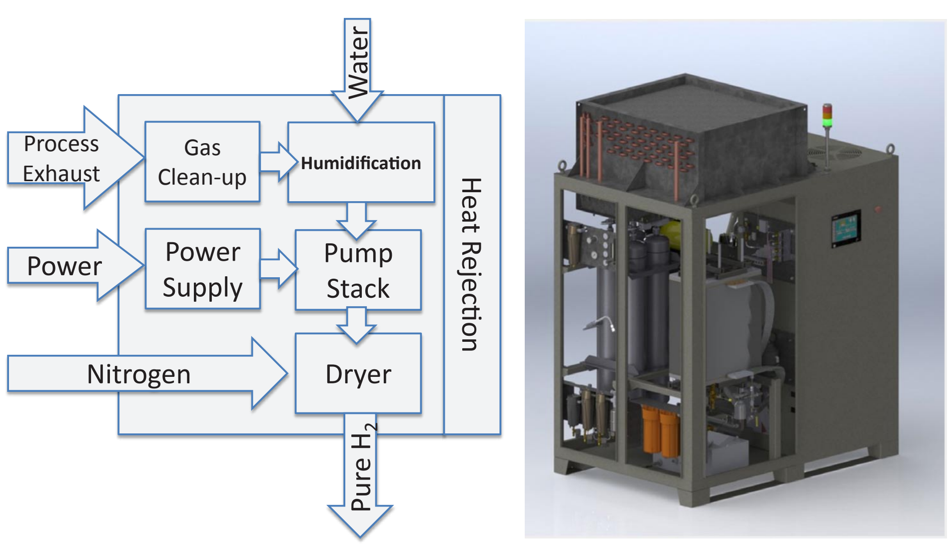


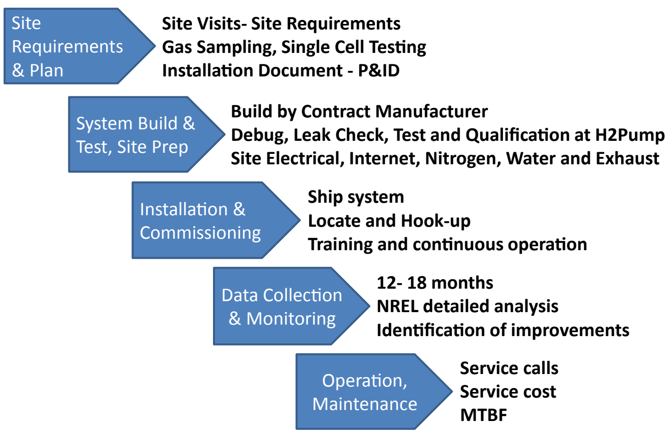
FIGURE 2. HRS-100™ Subsystems and Components

installed and commissioned. Following commissioning, the system will be monitored and the data logs will be given to NREL for analysis (Figure 3).

RESULTS

As of the writing of this report, H2Pump has completed exhaust gas sampling and analyses for the three sites shown in Figure 4 and implemented proprietary solutions for additional gas cleanup prior to the HRS-100™. The solutions include adsorbents for sulfur removal, catalytic CO reduction and oil clean-up. The implementation of control methods for auto-start and ramp-up has greatly increased the recycle rate. Under manual operation, the system at Pall Corporation only operated during daytime hours often missing a second or third shift since the system had to be remotely started and manually ramped up. With the implementation of exhaust sensing and controls, the daily recycle rate has increased 10 fold. The system output still depends on the customer's operating schedule but no longer requires remote intervention. Additionally, the gas sampling showed the presence of trace amounts of sulfur in the exhaust that may have been contaminating the stack. The stack in the Pall system has never been replaced indicating that the solution for sulfur removal was effective and did not permanently damage the stack.

H2Pump has implemented promising gas management solutions at Ulbrich and Rome Strip Steel and is awaiting verification of the efficacy of the solutions.



MTBF - mean time between failure

FIGURE 3. Site Installation and Monitoring Steps

CONCLUSIONS AND FUTURE DIRECTIONS

The site planning and commissioning steps are proving to be the most critical and time intensive part of the project. Revising the Statement of Project Objectives to include greater focus on identifying and mitigating the harmful or poisonous constituents in the furnace exhaust

FIGURE 4. Recycling Demonstration at Pall Corporation, Ulbrich Specialty Strip Mill, and Rome Strip Steel

gas has dramatically improved the system performance. For the remaining three installations in the second budget period of the program, greater emphasis will be placed on understanding the exhaust gas composition and implementing and refining solutions.

SPECIAL RECOGNITIONS & AWARDS/ PATENTS ISSUED

1. Granted US Patent 8,663,448 B2 on March 4, 2014, *Hydrogen Furnace System and Method*, Glenn Eisman.

2. Granted US Patent 8,734,632 B1 on May 27, 2014 *Hydrogen Furnace System and Method*, Glenn Eisman.

FY 2014 PUBLICATIONS/PRESENTATIONS

1. 2014 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting, June 16–20, 2014, Washington, D.C.

Hydrogen Recycling System Evaluation and Data Collection

Rhonda Staudt
H2Pump LLC
May 16, 2013

This presentation does not contain any proprietary, confidential, or otherwise restricted information

TV018

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Overview

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**
- **18 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

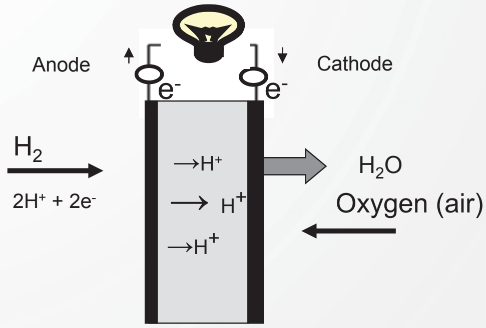
Reduction Furnace

The Opportunity

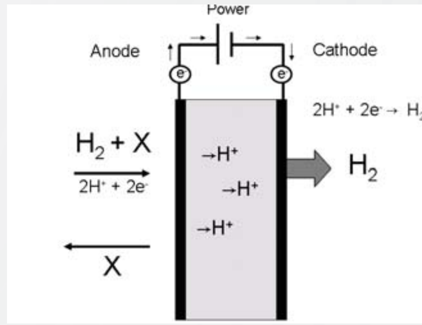
Industrial operations flare or vent hydrogen rich furnace exhaust gas into the atmosphere today

H2Pump Core Technology

Utilizing modified fuel cell technology for hydrogen recovery and recycling



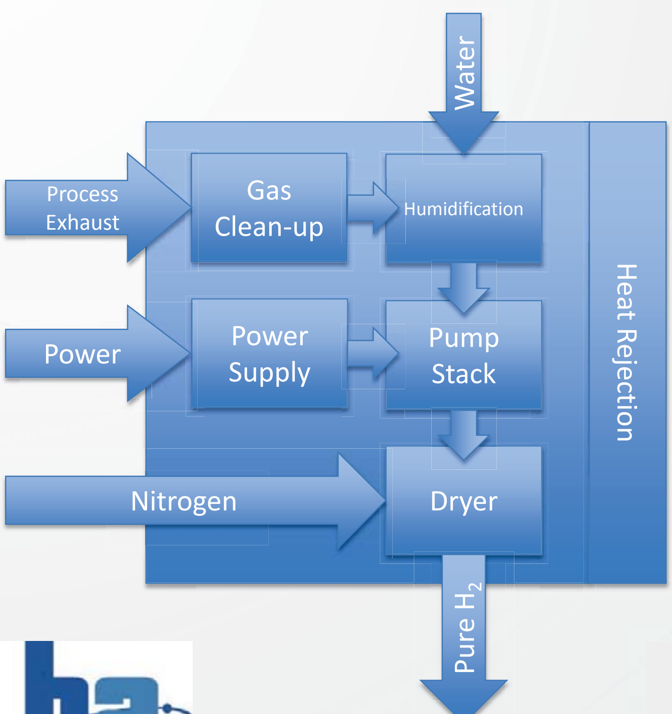
Fuel Cell
Chemical energy converted directly to electricity



Hydrogen Recycling
Electricity utilized to drive separation process

- Purify, pressurize and “pump” in a single step
- Reliable non-mechanical process
- Ambient pressure exhaust gas operation
- Up to 90% recovery of hydrogen
- Leverages existing fuel cell supply base
- Eliminates Oxygen associated failures modes

HRS-100™



Overview

Timeline

- Project start date: 1/2/13
- Project end date: 6/30/14*
- Percent complete: 15%

* Project continuation and direction determined annually by DOE

Budget

- Total project funding $1.06M
  - DOE share: $499K
  - Contractor share: $567K
- Funding for FY13: $966K
  - DOE share: $453K
  - Contractor share: $514K

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

Objective:

- To ***demonstrate*** the product readiness and quantify the ***benefits*** of H2Pump's Hydrogen Recycling System (HRS-100™) by ***installing and analyzing*** the operation of eight 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 Fabs and semi-conductor applications.
- The demonstrations will be used to ***develop case studies*** and showcase the benefits of the technology to drive market adoption.

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

	Task	% Complete
Phase 1	Task 1.0: Data Collection and Reporting Tool	30%
	Task 2.0: System #1 at Ulbrich	90%
	Task 3.0: System #2 at Ulbrich	
	Task 4.0: System #3 at Pall Corporation	100%
	Task 5.0: System #4 & #5 at Rome Strip Steel	100%
	Go/ No Go Decision	
Phase 2	Task 6.0: System #6 at TBD	
	Task 7.0: System #7 at CNSE- MOCVD	
	Task 8.0: System #8 at CNSE- EUV	
	Task 9.0: Program Management	
	Task 10.0: Extended Runtime	

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

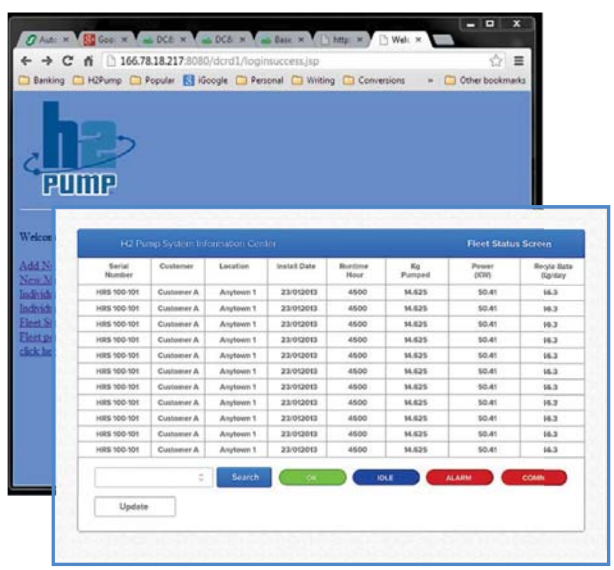
Accomplishments and Progress

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

- Access to NREL
  - Stack degradation
  - Efficiency improvements
  - Sensor elimination
  - Optimization



Accomplishments and Progress

Site: 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

Task 3.0 Ulbrich (System #2)

✓ Site Requirements and Plan
✓ System Build, Test
- Installation delayed pending #1

Accomplishments and Progress

Site: 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

Accomplishments and Progress

Site: Rome Strip Steel- Rome, NY

Task 5.0 Rome (System #4 & #5)

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

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

Proposed Future Work

April 2013- Go/ No Go Decision Meeting, Database On-line

April 2013- Complete Site Plan and Install- CNSE- MOCVD

May 2013- Complete Site Plan and Install at CNSE- EUV

June 2013- Complete Site Plan and Install at Site TBD

Quarterly data reviews with NREL

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

Four of eight installs completed in 1Q13

Database and reporting tool complete by April 2013

Remaining installs complete in 2Q13

Operation and maintenance thru 2013 and 2014

Hydrogen Recycling System Evaluation and Data Collection

Rhonda Staudt
H2Pump LLC
June 19, 2014

This presentation does not contain any proprietary, confidential, or otherwise restricted information

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Company Background

Limited Liability Corporation with headquarters in Latham, NY

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- **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:

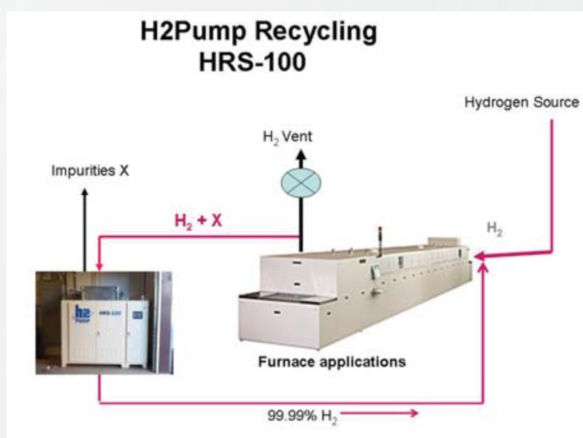
- Metals processing (steel, annealing, sintering, brazing)
- Semi-conductor & LED processing
- Ceramics processing
- Chemical by-product H2
- Float glass manufacturing

LED Fabs

Reduction Furnace

The Opportunity

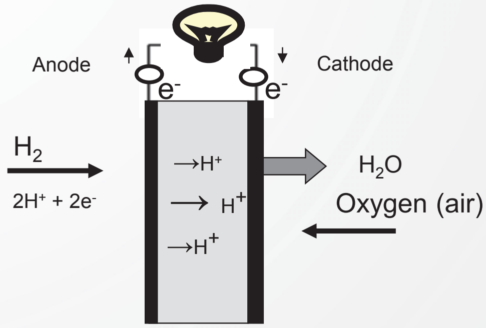
Industrial operations flare or vent hydrogen rich furnace exhaust gas into the atmosphere today



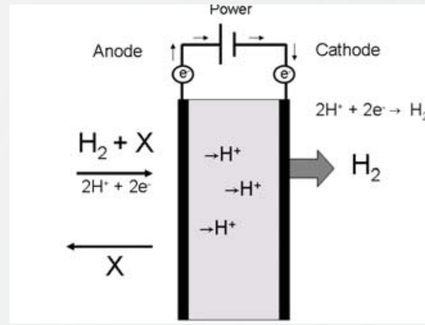
The HRS-100 can cost effectively reclaim, purify and pressurize the hydrogen exhaust

H2Pump Core Technology

Utilizing modified fuel cell technology for hydrogen recovery and recycling



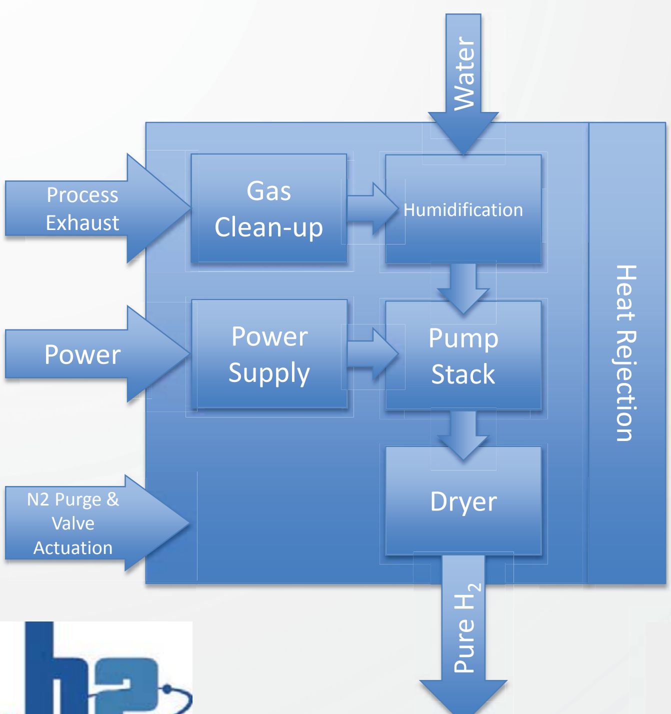
Fuel Cell
Chemical energy converted directly to electricity



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.

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

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%

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

Budget Period	Task	% 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

- H_2, N_2, Ar, CO, CO_2, CH_4, NH_3, S, etc.
- Particulate
- Amount of each is process dependent
- Amounts can vary during the application cycle

Feed Gas Clean-up (pre-treatment)

- H_2, N_2, Ar, CO_2
- CO < 200 ppm
- NH_3 < 100 ppm
- No S
- Minimal particulate

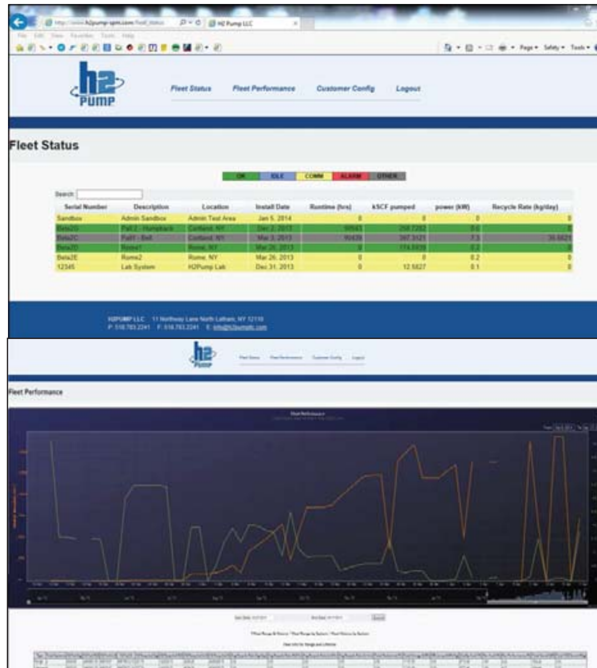
Accomplishments and Progress

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

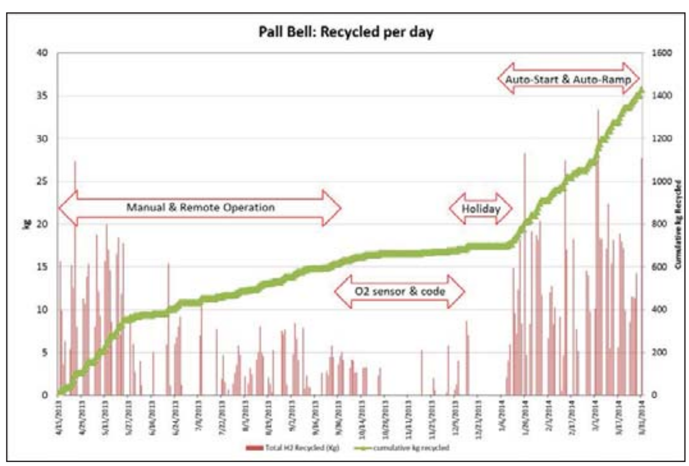
System Status as of 3/31/14

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

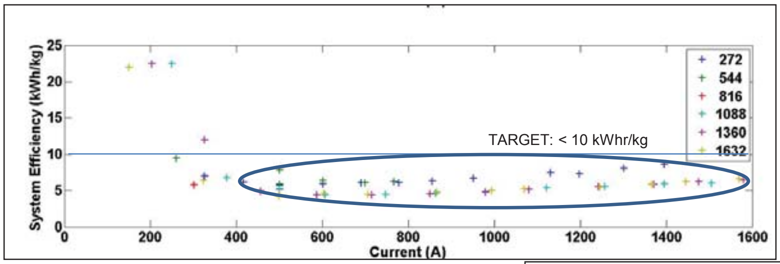
Accomplishments and Progress

Task 4.5- Operate and Maintain

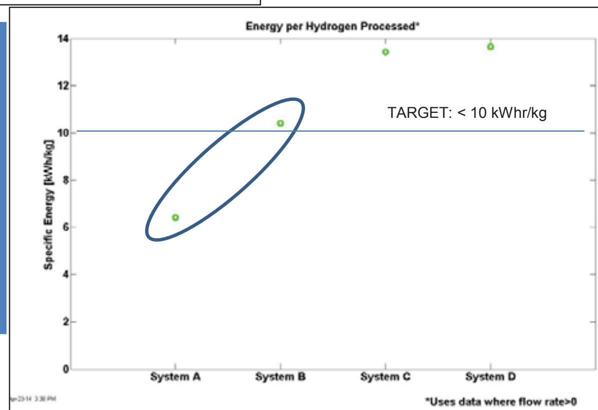
- Manual operation during the first 6 months of operation led to the development of automated controls including:
  - Start-up
  - Ramp-up
  - Stack controls
- System is up to 80% availability and recycled 731kg in 1Q2014



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

QUARTERLY PROGRESS REPORT

Cooperative Agreement DE-EE0006091
Hydrogen Recycling System Demonstration

SUBMITTED BY

H2Pump LLC
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Latham, NY 12110

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SUBMITTED TO

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REPORTING PERIOD

7/1/2014 through 9/30/2014

SUBMITTED ON

October 30, 2014

Table of Contents

1. Project Goals/Objectives

The objective of this project is to demonstrate the product readiness and to quantify the benefits and customer value proposition of H2Pump's latest Hydrogen Recycling System (HRS-100) by installing and analyzing the operation of multiple prototype 100 kg per day systems in real world customer locations. The data gathered will be used to measure reliability, demonstrate the value proposition to customers and validate our business model. H2Pump will use the proposed funding to install, track and report multiple field demonstration systems in industrial heat treating and semi-conductor applications. The customer demonstrations will be used to develop case studies and showcase the benefits of the technology to drive market adoption. The objectives of the program are to:

- Validate commercial assumptions around Hydrogen Recycling Agreement including customer assumptions and system performance
- Build case studies of the HRS-100 in customer operations that can be used as credible demonstrations quantifying the operating cost savings, emissions reduction and production efficiency improvement
- Expand the Beta test fleet into additional customer environments to accelerate learning, problem identification, resolution and reduce the risk of product launch
- Provide data to NREL for in-depth analysis of system performance characteristics and identify areas for improved data gathering and performance causal analysis. All of the data acquired from the systems will made available for NREL. The minimum data includes stack voltage and current, system power, and hydrogen flow rate. Data frequency can be no less than a one minute interval. Maintenance and repair logs should also be provided to NREL, specifying time, maintenance item or reason for repair. NREL will also be provided all gas analysis to help determine whether certain gases result in higher degradation.
- Prepare and test commercial infrastructure elements such as installation, commissioning, reporting, operation and maintenance

2. Background

H2Pump will create a data monitoring and reporting tool to enable easy metrics gathering and performance tracking. The data reporting system will monitor general information such as run hours, kg of hydrogen pumped and daily rate. Also critical to the value proposition is the power used to run the system and therefore the pumping efficiency. Important customer metrics such as projected savings and emissions reduction will be displayed based on specific customer attributes. Other runtime charts that look at key performance characteristics will be logged and monitored including pumping stack performance.

A total of eight systems are planned to be installed and monitored during the 18 months of the project. Two systems will be of one design and six systems will be of a later design. The major difference between the design iterations is the control system. The electronics for the second design are PLC based with more robust industry standard components. Also, the first two systems were built in a lab environment, while the later design will be built by a contract manufacturer based in New York State. The data collected shall provide a distinct differentiation relative to design maturity.

Site owners participating in the project include heat treating project partners:

Ulbrich Stainless- Wallingford, CT (Task 2.0)
Rome Strip Steel- Rome, NY (Task 5.0)
Pall Corporation- Cortland, NY (Task 4.0)

The TBD site has been identified and will be hosted also by Pall Corporation in Cortland, NY (Task 6.0)

And, from Semi-conductor fabrication research our project partners include:

University at Albany, College of Nano Science and Engineering - Albany, NY (Task 7.0)

The project start date was January 1, 2013.

3. Accomplishments

Accomplishments the reporting period (July 1- Sept 30, 2014)

- H2Pump and the DoE held a No/ No Go discussion on September 25th to review the status of the Program. The call was attended by James Alkire, Jason Marcinkoski, Kim Cierpik, Jennifer Kurtz and Genevieve Saur.
  - 2 of 4 systems had achieved the 2,500 kg criteria, 1 system met the stack degradation target.
  - H2Pump accepted the DOE offer for a "no cost extension" in order for one more system to achieve the required output rate.

Accomplishments the previous reporting period (Apr 01- June 30, 2014)

- Completed the initial release of the database and gave NREL access to the database on June 18th. (Task 1)
- Implemented and evaluated desulfurization solutions at Pall and CO solutions at Rome. (Task A)
- Performed gas sampling at Ulbrich and analyzed results. (Task A)

Accomplishments the reporting period (Jan 01- Mar 31, 2014)

- Negotiated program modification and submitted revised SOPO and budget to address system performance issues.
- Delivered initial release of database and systems began reporting Feb 6th. (Task 1)
- Installed sulfur removal solution at Ulbrich (Task 2)
- Performed Gas Sampling at Pall and Rome (Task A)

Accomplishments the reporting period (Oct 01- Dec 31):

- H2Pump enabled controls and exhaust sensing technology at Pall to increase the recycle rate.
- H2Pump identified harmful stack contaminants at Ulbrich through independent exhaust gas analysis and can now prepare solutions for implementation.
- H2Pump implemented remote monitoring of the Skid at Rome to better understand methanizer performance.
- Database development continued with the initial release planned for Feb 1, 2014.

Accomplishments the reporting period (July 01- Sept 30):

- Retained services of new contractor for database development
- Identified site for TBD-Task 6
- Held a teleconference review with the DoE on Oct 3rd.

Accomplishments the reporting period (April 01- June 30):

- Attended and presented at the DoE Annual Merit Review in May
- Transferred daily files to NREL for analysis for Ulbrich (Task 2.0) and Pall (Task 5.0)
- Prepared data analysis with NREL for Go/ No Go decision in June

Accomplishments 1Q2013 (Jan 01- Mar 31):

- Completed the installations of three systems at industrial heat treaters
- Held project kick-off meeting with James Alkire, Jason Marcinkoski, Kim Cierpik, Elvin Yuzugullu Nick Barilo and Jennifer Kurtz on March 26, 2013 and toured the installation at Pall Corporation.

4. Progress and Status

In 1Q14 H2Pump and the DoE negotiated a modified Statement of Program Objectives and the Go/ No-Go criteria based on the learning so far in the program. A project task (Task A) was added in Budget Period I to allow H2Pump the opportunity to perform gas sampling to identify the different contaminates at each site. H2Pump must show through independent evaluation that the source of the contamination has been corrected and that the system is capable of recycling at the intended rate. Further, the renegotiated criteria states that three of the four systems from Budget Period I will recycle 2,500kg each and at least one of the systems should have a degradation rate less than 15 µV/kg H2 /cell. Figure 1 shows the NREL reporting of the cumulative performance.

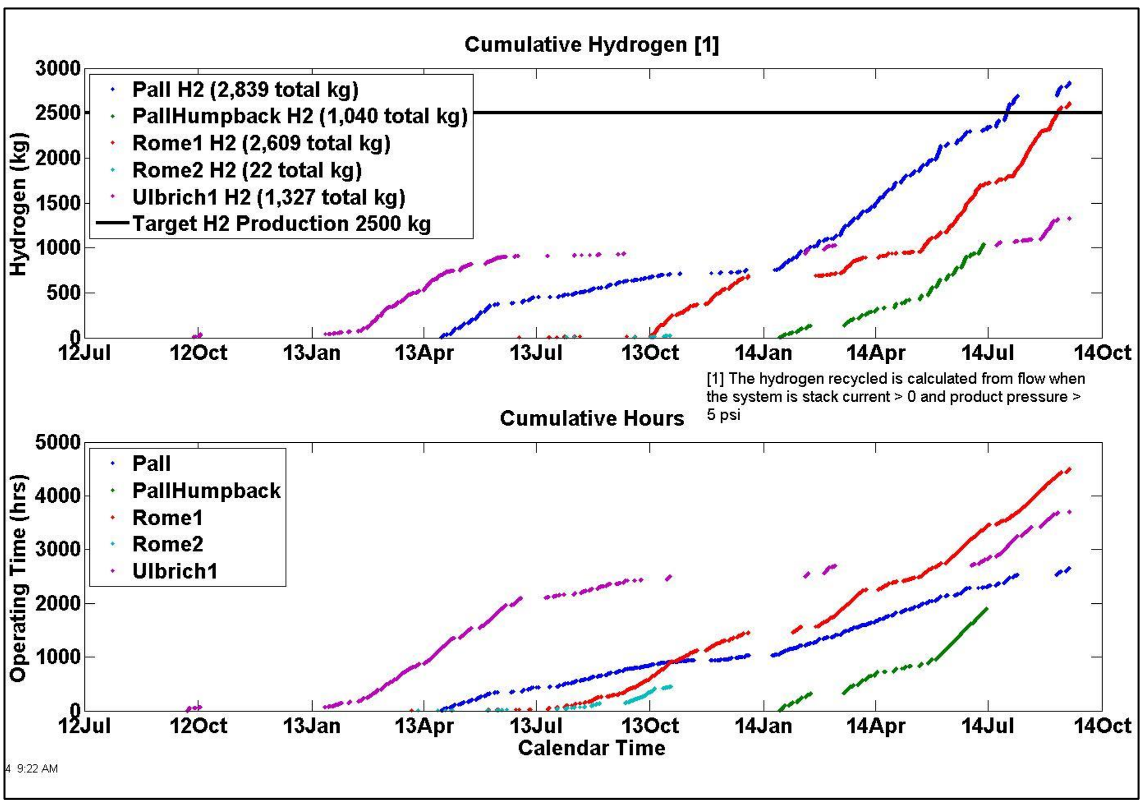


Figure 1: NREL reporting of Kg recycled and Runtime

By the Go/ No Go Discussion on September 25th, 2014 one system at Rome and one system at Pall had achieved the 2,500 kg criteria. The system at Ulbrich had a stack replacement and had not achieved the criteria. Table 1 summarizes the metrics reported at the Go/No Go Review.

Table 1: System Performance Summary by Site

Metric	Pall	Rome #1	Rome #2	Ulbrich
First Operation Date	March 4, 2013	March 27, 2013	March 27, 2013	Jan 2013
Operational status	automatic	Running continuous	Not running	manual
New Setpoint	1,000 amps	700 amps	-	700-900 amps
Old Setpoint	500 amps	250-400 amps	250-400 amps	300 amps
Expected run time-dependent on customer operation	8-10 hrs/ day M-F	24 hrs/ day 5- 7 days	24 hrs when flow exceeds System #1	24 hrs/ day 7 days
Runtime as of 8/31/14 (hrs)	2,102	3,185	-	2,765
Task A Results	H2S, COS	High and variable CO, COS, high hydrocarbons, water vapor		Some CO, many sulfur species, some hydrocarbons
Solution	Desulf (DP-45)	Resized methanizer + DP-45+ coalescing filter, No spray tower		Initially DP-45 then activated carbon

As reported, all of the systems except Rome #2 have more than doubled their output rates from those in 2013, which is a major accomplishment. The system specific data and gas analysis will be reported in the Task sections for each system.

Task 1.0: Create data collection, monitoring & reporting tool and database

Subtask 1.1 Requirements Document- Complete

Subtask 1.2 Select Supplier- Complete

Subtask 1.3 Instruct NREL- Complete

Task 2.0: Operate, maintain, implement data monitoring and reporting for System #1 at a heat treating facility- Ulbrich- Wallingford, CT.

Subtask 2.1 Install monitoring software - Complete

H2Pump will upload data to NREL manually through the secure data share.

Subtask 2.2 NREL data access - Complete

Subtask 2.3 Operate and Maintain

The sulfur solutions fixes implemented in the prior quarter are proving to be effective. The system has run continuously since August recycling over 675 kg of hydrogen with the new short stack and desulfurization fixes. Also implemented in September is a change to the TSA regeneration cycle. The graph in Figure 2 supports the improved performance.

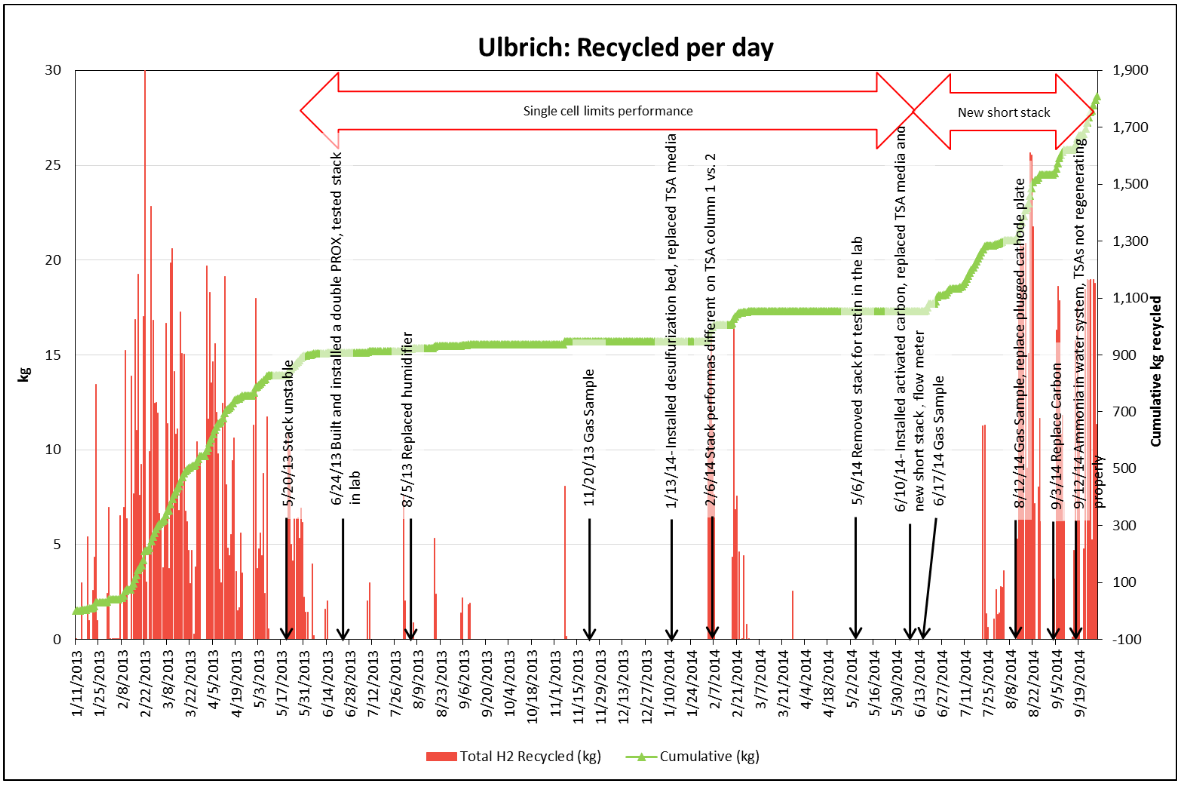


Figure 2: Ulbrich Performance

Unfortunately, after the installation of the new stack, the system output was lower and unable to achieve the 2,500kg required to pass the Go/No Go criteria. If the performance track continues, it is estimated that the system would meet the criteria in about 90 days.

<u>Subtask 2.3.1 Gas Samples showing containment of contaminates- Task A</u>

As stated in the previous reporting period, gas samples were taken to determine the effectiveness of the carbon bed for removing sulfur. The results from samples taken before and after the carbon bed are shown in Table1. Both H_2S and COS were detected before the carbon bed, in the furnace exhaust. The after sample shows no sulfur. An additional gas sample was taken in August to look for sulfur break through.

Table 2: Ulbrich Gas Samples

Site	Ulbrich- DoE	
Date of Sample	17-Jun-14	17-Jun-14
Time of Sample		
Report No.	33018	33018
Sample Container #	0923, 5008	0879, 0926
State of System		
Constituent (ppm)	Carbon bed Inlet	Carbon Bed Outlet
Ammonia (ppm v/v by FTIR)	nd	nd
Water Vapor (ppm v/v by MM)	350	76
Total Hydrogen (balance)	99.80%	99.90%
Dew Point (°F @ 0 psig)	-26	-48
Volatile Sulfur Compounds (ppb)		
H2S	14	nd
COS	5	nd
SO2	nd	nd
Methyl Mercaptan	nd	nd
Ethyl Mercaptan	nd	nd
Dimethyl Sulfide	nd	nd
Carbon Disulfide	nd	nd
Isopropyl Mercaptan	nd	nd
t-Butyl Mercaptan	nd	nd
n-Propyl Mercaptan	nd	nd
Methyl Ethyl Sulfide	nd	nd
sec-Butyl Mercaptan	nd	nd
Thiophene	nd	nd
Isobutyl Mercaptan	nd	nd
Diethyl Sulfide	nd	nd
n-Butyl Mercaptan	nd	nd
Dimethyl Disulfide	nd	nd
3-Methyltiophene	nd	nd
Tetrahydrothiophene	nd	nd
2-Ethylthiophene	nd	nd
2,5-Dimethylthiophene	nd	nd
Diethyl Disulfide	nd	nd
Unknown Compounds	nd	nd

Subtask 2.4 Monitor and Periodic Gas Samples- Work on this task will begin after the Go/ No Go Decision.

Task 4.0: Build, install and commission system #3. Operate, maintain and implement data monitoring and reporting for system #3 at a heat treating facility- Pall Corporation, Cortland, NY.

Subtask 4.1 Build and Install- Complete

Subtask 4.2 Commission- Complete

Subtask 4.3 Install reporting software- Complete

Subtask 4.4 NREL Data Access- Complete

At the Go/ No Go Review NREL prepared an assessment of the stack degradation rate. NREL performed the analysis in two ways. Figure 3 shows what we will term as the Macro Degradation Method. In this method a target flow is selected. If the system was running at the maximum capacity this would be 3.3- 4.2 kg/ hr. Because the operation at Pall does not run continuously, but is a batch process, a lower rate indicative of a daily rate was selected. For the first analysis 2.45 kg/ hr was used as the target rate. Following the process described in Figure 3, the degradation was calculated to be 5 µV/ kg/ cell.

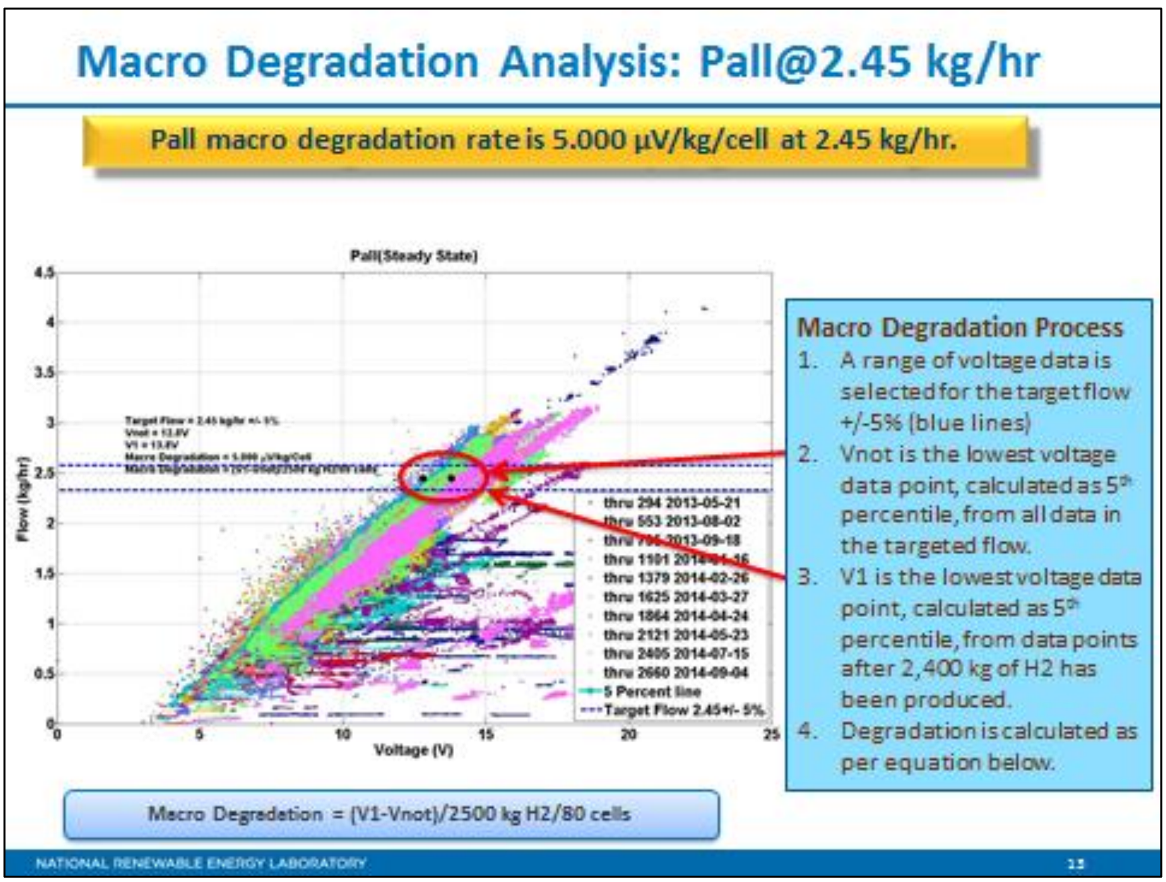


Figure 3: NREL Analysis of Macro- Degradation for Pall

NREL also performed the degradation analysis using the Linear Fit Method described in Figure 4. The method was used to verify the macro-degradation method. The Linear fit method, again using the target rate of 2.45 kg/ hr, resulted in 3.7 µV/ kg/ cell. Either method results in a degradation rate that meets the Go/ No Go criteria.

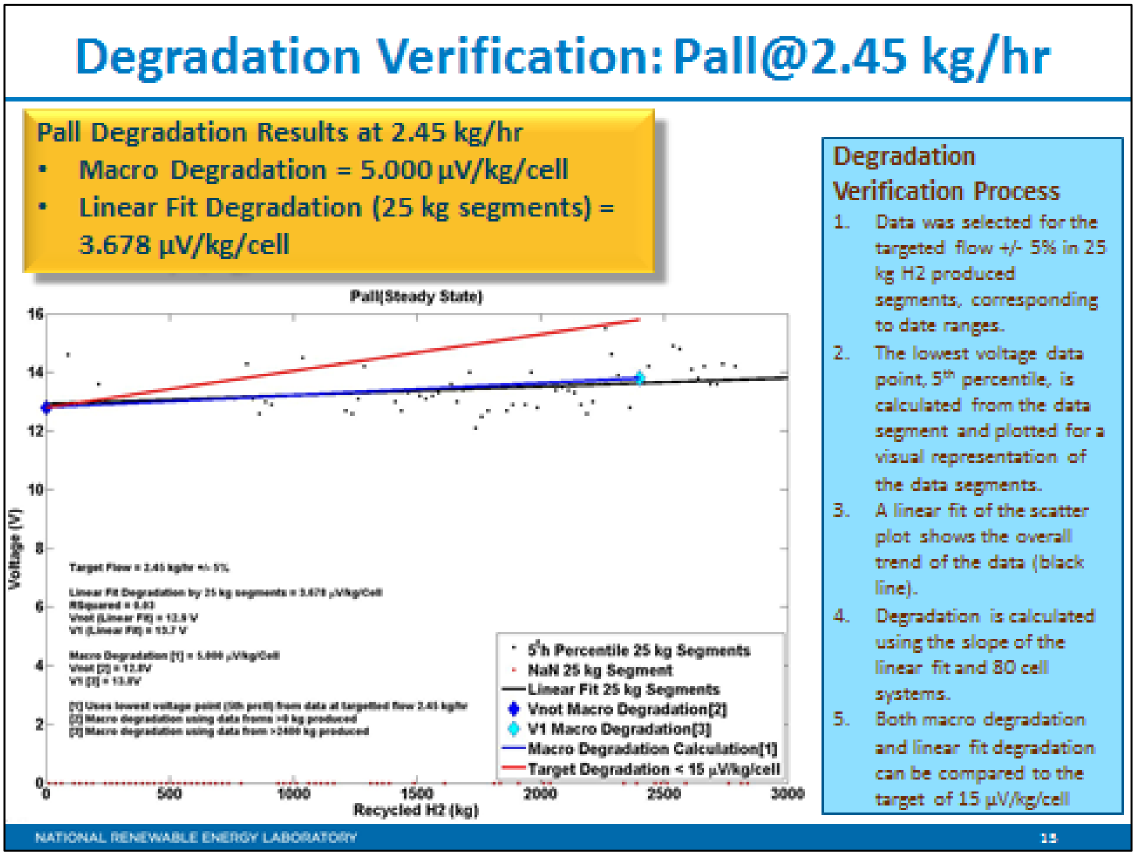


Figure 4: NREL Analysis of Linear Fit Degradation for Pall

H2Pump also requested that NREL run the analysis at 1.7 kg/ hr where the system operated on a daily basis. The macro-degradation analysis calculated 4.5 µV/ kg/ cell and the linear fit method calculated 2.6 µV/ kg/ cell, slightly lower than the calculated rates at 2.45 kg/ hr but close enough to confirm that the Go/ No Go criteria was met.

Subtask 4.5 Operate and Maintain

Figure 5 shows the daily operation of the system since installation. H2Pump attributes the increase in daily output beginning in 2014 to implementation controls and sensing hardware that detects exhaust flow signaling that the system may start-up and uses a thermal conductivity sensor to control the system blower preventing air from entering the furnace exhaust trunk. H2Pump has continued to optimize the controls to improve start-up times and limit the lost opportunity. It is important to note that daily start-stops does not impact the degradation rate of the pumping stack as it does with a fuel cell.

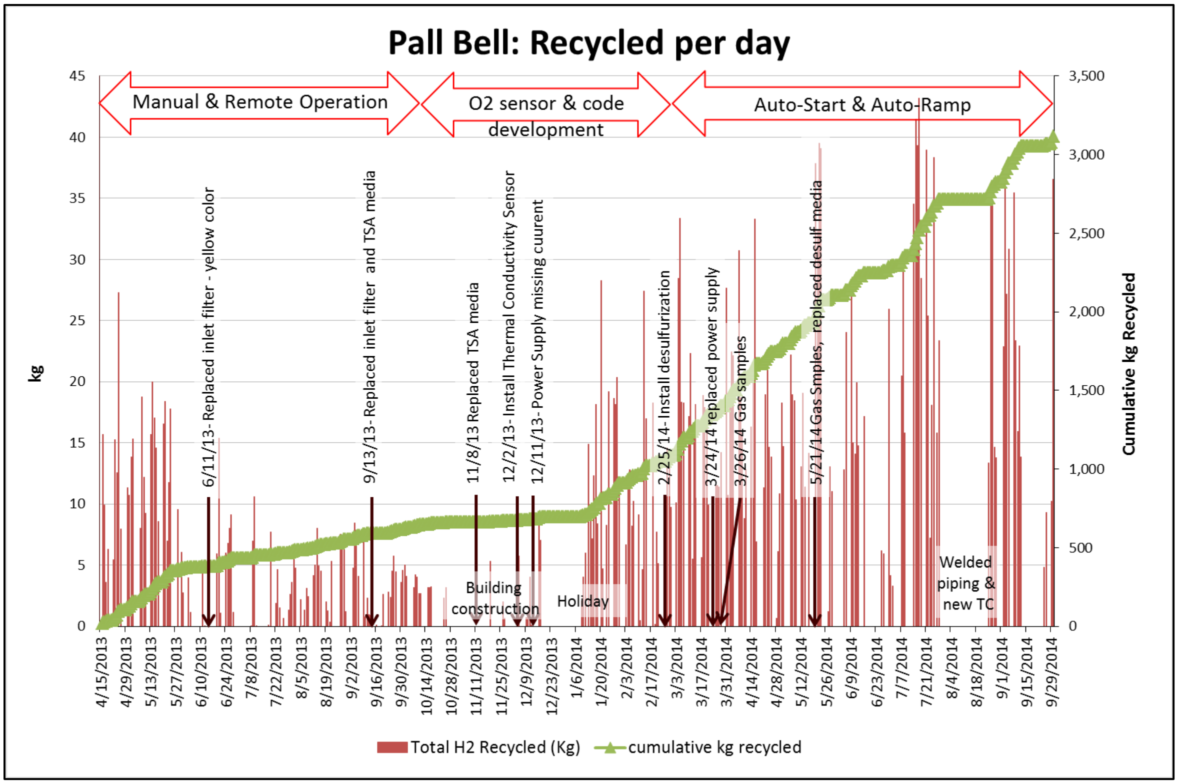


Figure 5: Pall Bell Furnaces- HRS Recycled Hydrogen

<u>Subtask 4.5.1 Gas Samples showing containment of contaminates- Task A</u>

No further Gas samples were taken during this reporting period.

<u>Subtask 4.6 Monitor and periodic gas samples</u>- Work on this task will begin after the Go/ No Go Decision.

Task 5.0: Build, install and commission system #4 and #5. Operate, maintain and implement data monitoring and reporting for system #4 and #5 at a heat treating facility at Rome Strip in Rome, NY.

<u>Subtask 5.1 Build and Install 2 Systems- Complete</u>

<u>Subtask 5.2 Commission 2 systems- Complete</u>

<u>Subtask 5.3 Install Reporting Software- Complete</u>

<u>Subtask 5.4 Provide NREL access to data- Complete</u>

At the Go/ No Go Review NREL prepared an assessment of the stack degradation rate. NREL performed the analysis in two ways. Figure 6 and 7 show the results of the Macro Degradation Method and Linear Fit Degradation Method for the Rome #1 system. At this site the hourly rate is limited by the number of furnaces running and the 8 hour “burn-off” instituted to prevent high oil and very high CO in the feed to the system. The target rate of 1.2 kg/ hr was selected. The degradation rates were calculated to be 18.5-26.5 µV/ kg/ cell respectively.

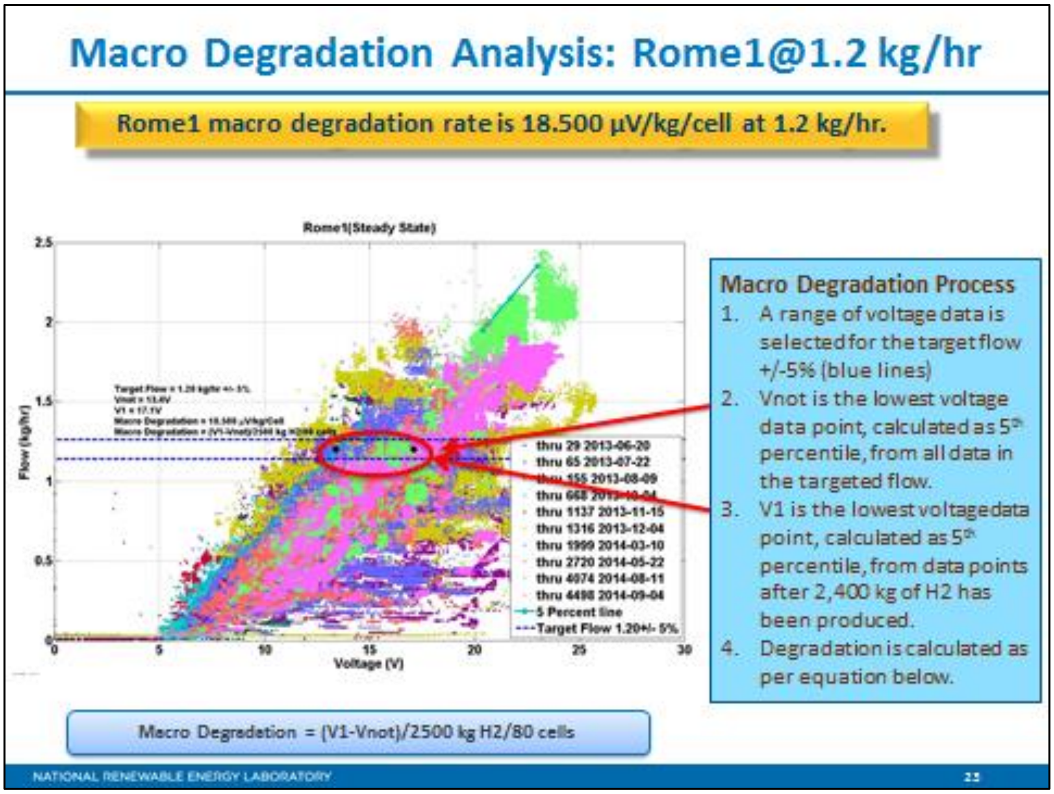


Figure 6: NREL Analysis of Macro- Degradation for Rome 1

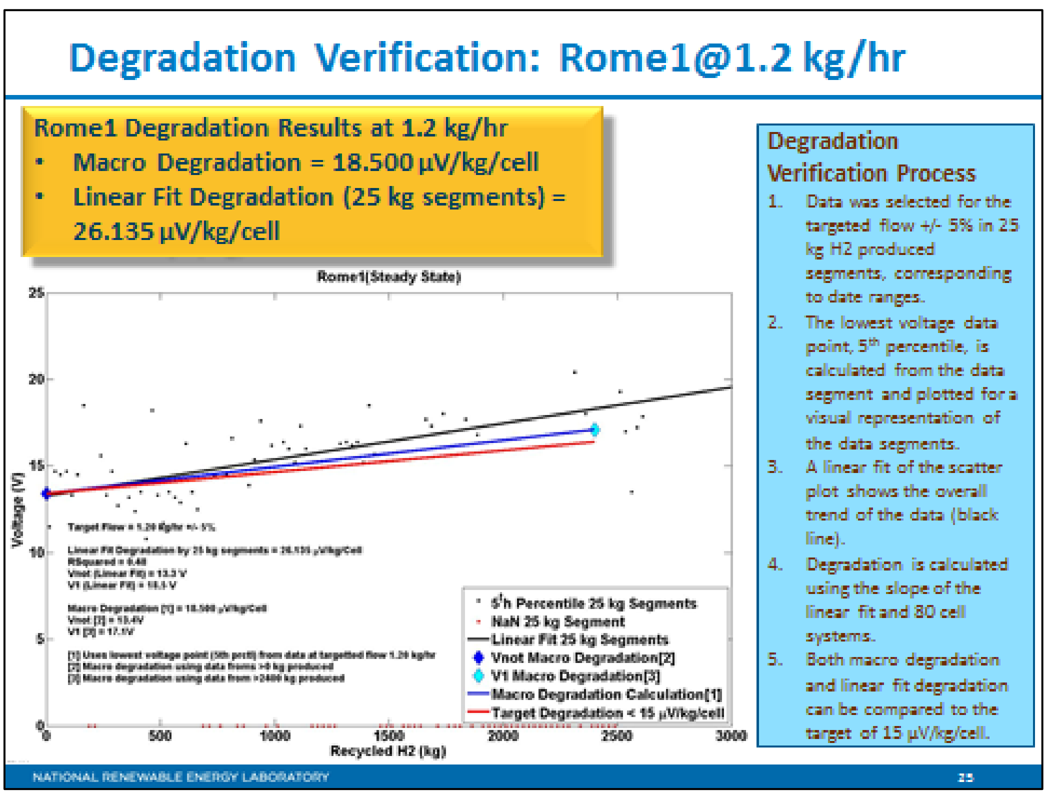


Figure 7: NREL Analysis of Linear Fit Degradation for Rome 1

NREL also performed the analysis at 0.9 kg/ hr, which yielded 14.5 µV/ kg/ cell for the macro-degradation method and 20.6 µV/ kg/ cell for the linear fit method. The exact cause of degradation could be due to sulfur reaching the stack prior to the installation of the desulfurization fix or process change.

Subtask 5.5 Operate and Maintain

Rome System #4 operated more consistently during this reporting period and surpassed the required 2,500 kg criteria. Figure 8 shows the system kg recycled since its installation. As shown in the graph since the installation of the new methanizer, the sulfur removal bed and adjustment to the furnace operator's process at the end of March, the system performance has improved dramatically.

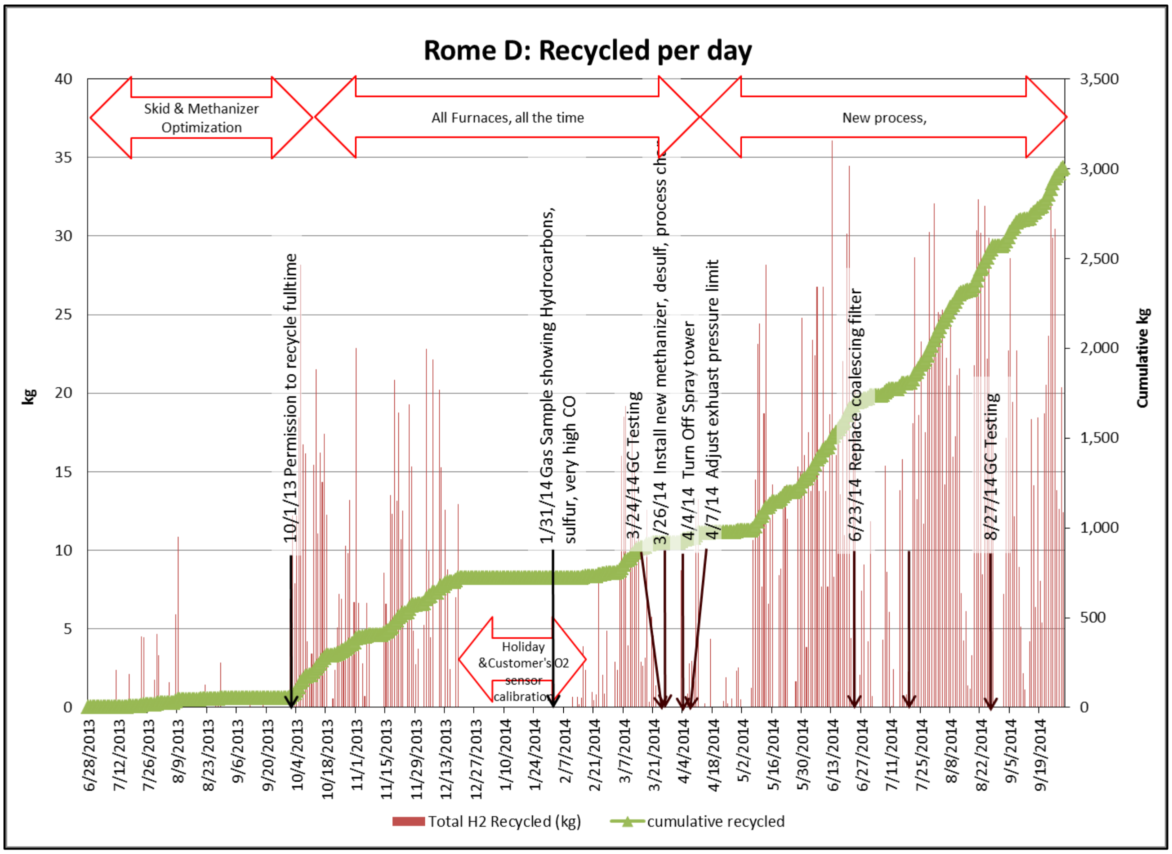


Figure 8: Rome HRS Recycled Hydrogen

Subtask 5.5.1 Gas Samples showing containment of contaminates –Task A

As explained in the last reporting period, H2Pump utilized gas chromatography to monitor the gas constituents during the furnace cycle. Since the original study of furnace cycles in Q1, the customer made various process adjustments. As shown in Figure 9, The CO peak occurred after 6.0 hours of operation at 4,196 ppm and was still at 916 ppm after 8.0 hours. If several furnaces were feeding exhaust to the HRS at the same time and hitting their peak the amount of CO would overwhelm the methanizer. So in March with the installation of the new methanizer the operators were instructed to send the exhaust to the HRS after 10 hours.

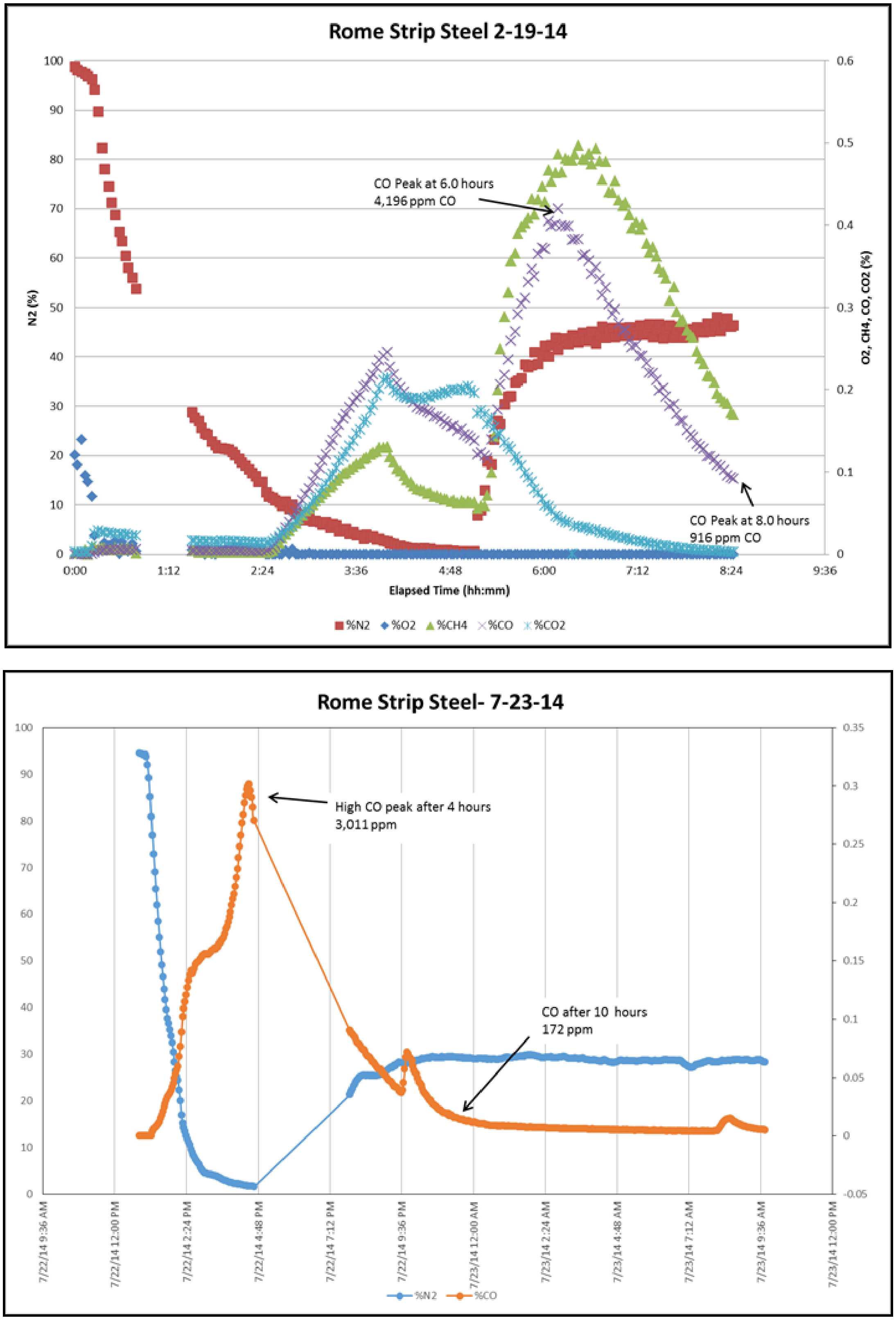


Figure 9: GC study at Rome

By limiting the amount of CO, the system performance has increased dramatically. After the customer had changed certain process parameters, the team reassessed the furnace operating cycles again in July. As shown in Figure 9, the CO peak is occurring at 4 hours and is below 200 ppm by 10 hours. The furnace operators were told to send gas to the HRS after 8 hours. Even with these adjustments, there is still insufficient gas to operate system #5, however the output of system #4 has increased.

Subtask 5.6 Monitor and periodic gas samples- Work on this task will begin after the Go/ No Go Decision.

Budget Period II:

Task 3.0: Commission system #2. Operate, maintain and implement data monitoring and reporting for System #2 at a heat treating facility

This task was moved from Budget Period I to Budget Period II in the revised SOPO. The system has been upgraded at H2Pump's facility to be equivalent to the Rome and Pall systems. It has been verified in the lab and will be shipped and installed at Redifoils in Farmington, CT. The customer has delayed the installation of the system until 4Q2014.

Task 6.0: Build, install and commission system #6. Operate, maintain and implement data monitoring and reporting for system #6 at heat treating facility at Pall Corporation, Cortland, NY.

As reported in previous quarters H2Pump and NYSERDA selected Pall Corporation for the TBD installation. The site was selected because it will be the first integration with a Humpback furnace. H2Pump delivered the system to the location in November and the system was hooked-up to the facilities. The system is installed and running as of this reporting period and has recycled over 1,100 kg of hydrogen since installation. The system data has been given to NREL for analysis but is insufficient to calculate a degradation rate.

Task 7.0: Build, install and commission system #7. Operate, maintain and implement data monitoring and reporting for system #7 at a semi-conductor fabrication facility at the College of Nano Science and Engineering (CNSE) in Albany, NY.

During the quarter site preparation activities were contracted and quoted with CNSE for the mechanical and electrical hook-ups. The site preparation work was completed on May 30th and H2Pump began the rigorous safety process which is part of semiconductor manufacturing. The system operated initially in August. Since that time the MOCVD tool was shutdown for maintenance.

Task 8.0: Build, install and commission system #8. Operate, maintain and implement data monitoring and reporting for system #8 at a semi-conductor fabrication facility

This task has been deleted from the revised SOPO.

Task 9.0: Project Management and Reporting

H2Pump prepared the Go/ No Go Presentation with input from NREL and held the Go/No Go discussion on September 25th, 2014.

Task 10.0: Extended runtime monitoring by NREL

Work on this task did not start during this reporting period.

5. Plans for Next Quarter

- H2Pump will continue to monitor and perform service operations for Ulbrich-System #1, Pall-System #3and Rome-System #4 and #5
- Ulbrich System #1 will operate continuously and achieve the 2,500 kg criteria for the Go/No Go evaluation.
- NREL will continue to receive data for analysis.

6. Products

A. Publications, Conference Papers, and Presentations
Prepared the DoE Annual Report.

B. Inventions, Patent Applications, and Licenses
None to report at this time.

C. Website(s)
None to report at this time.

7. Changes or Problems

A. Scope Issues

No new issues to report at this time.

B. Schedule Delays

The Go/ No Go Decision in September was delayed until Ulbrich reaches the 2,500 kg requirement which should be reached by year end.
H2Pump was offered and accepted a no cost, 180 day extension.

C. Changes that have a Significant Impact on Expenditures

No new issues to report at this time.

8. Schedule Progress

A. Task Schedule Update- All dates are subject to change pending the rewrite of the SOPO based on the delay of the Go /No Go Decision.

Table 1: Task Schedule

Task Number	Subtask Number	Task Title	Task Completion Date				Task Progress Notes
			Original Planned	Revised Planned	Actual Completed	Current % Complete (0-100)	
1.0		Create data collection, monitoring and reporting tool and database					
	1.1	Create a Requirements document	Jan 15, 2013		Jan 15, 2013	100%	
	1.2	Identify and select supplier	Jan 30, 2013	TBD	Aug 30, 2013	100%	New contractor identified.
	1.3	Provide NREL with database access	Mar 30, 2013	Feb 1, 2014	June 18, 2014	100%	NREL database access on June 18, 2014 for systems #2-7
2.0		Operate, maintain, implement data monitoring and reporting for System #1 (Ulbrich)					
	2.1	Install monitoring software	Mar 30, 2013	Jan 2, 2014		0%	Database not compatible with old electronics platform. Will provide data manually.
	2.2	Provide access to NREL for data analysis	Mar 30, 2013	Mar 1, 2014		100%	Data provided by manually uploading to NREL's datashare
	2.3	Operate and maintain system	On-going for 12 months				
	2.3.1	Perform Task A Gas sampling		Aug 29, 2014	Aug 12, 2014	90%	Waiting for results of break through sample.
	2.4	Sample gas quality- as required	Quarterly				
3.0		Commission, operate, maintain, implement data monitoring and reporting for System #2 (Redifoils)					
	3.1	Install and commission System #2	Feb 28, 2013	Oct 1, 2014			Move task to Budget Period 2
	3.2	Install monitoring software	Mar 30, 2013	Oct 1, 2014			Move task to Budget Period 2

	3.3	Provide access to NREL for data analysis	Mar 30, 2013	Oct 1, 2014			Move task to Budget Period 2
	3.4	Operate and maintain system	On-going for 12 months				Move task to Budget Period 2
	3.5	Sample gas quality- as required	Quarterly				Move task to Budget Period 2
4.0		Build, install and commission system #3. Operate and maintain. (Pall- Bell)					
	4.1	Build, deliver and install System #3	Jan 31, 2013	Feb 11, 2013		100%	
	4.2	Commission system #3	Feb 28, 2013	Mar 4, 2013		100%	
	4.3	Install monitoring software	Mar 30, 2013	Feb 15, 2014	Feb 28, 2014	100%	
	4.4	Provide access to NREL for data analysis	Mar 30, 2013	Mar 1,2014	June 18, 2014	100%	Data provided by manually uploading to NREL's data share
	4.5	Operate and maintain system	On-going for 12 months			75%	
	4.5.1	Perform Task A Gas sampling		May 31, 2014	May 20, 2014	100%	Solution implemented for sulfur
	4.6	Sample gas quality- as required	Quarterly				
5.0		Build, install and commission system #4 and #5. Operate and maintain.					
	5.1	Build, deliver and install System #4 and #5	Mar 30, 2013	Mar 22, 2013		100%	
	5.2	Commission system #4 and #5	Apr 30, 2013	Mar 27, 2013		100%	
	5.3	Install monitoring software	Apr 30, 2013	Feb 15, 2014		100%	
	5.4	Provide access to NREL for data analysis	Apr 30, 2013	Mar 1, 2014	Jun 18, 2014		
	5.5	Operate and maintain system	On-going for 12 months			75%	
	5.5.1	Perform Task A Gas sampling		Jul 31,2014	Mar 26, 2014	100%	Solution implemented for sulfur and CO.
	5.6	Sample gas quality- as required	Quarterly		Oct 2014		
A		Site Gas composition and Analysis					

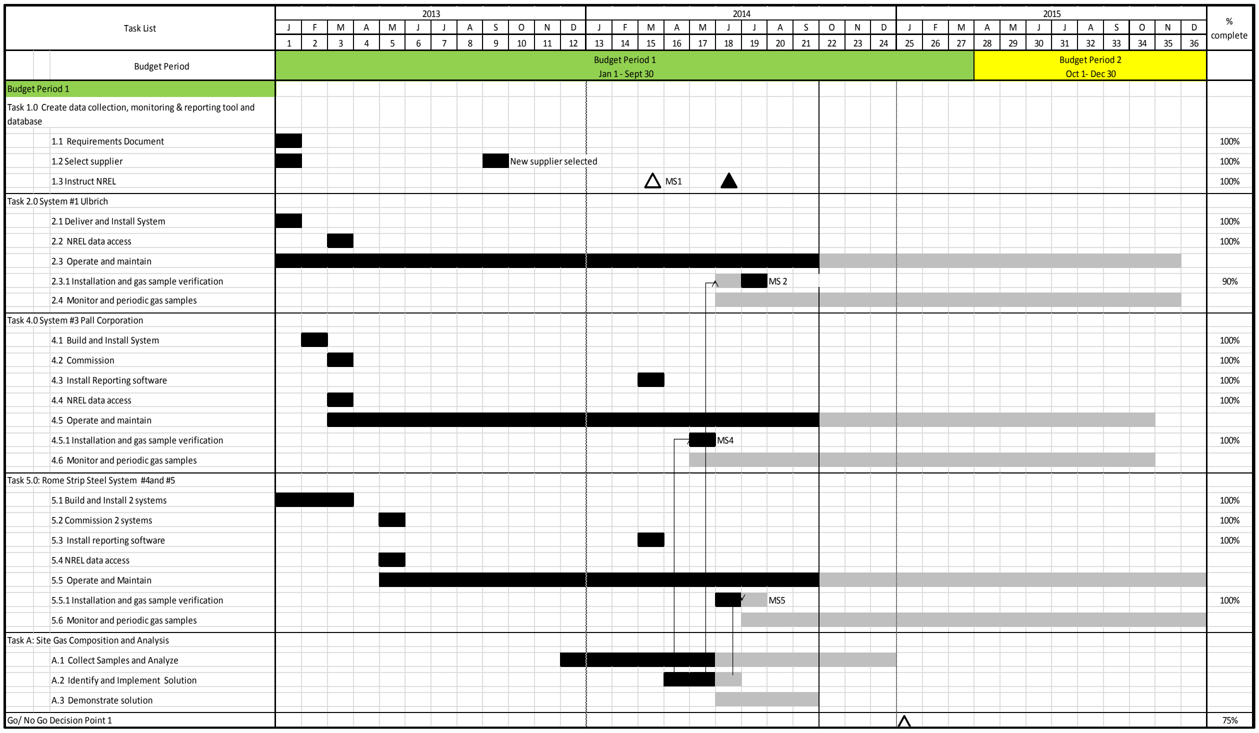
	A.1	Collect Samples for each Site		Dec 2014		90%	Waiting for reports to determine if additional samples are necessary
	A.2	Identify and Implement Solutions		Sept 2014		90%	New Task
	A.3	Demonstrate Solutions		Sept 2014		70%	New Task
6.0		Build, install and commission system #6. Operate and maintain. Pall- Humpback					
	6.1	Build, deliver and install System #6	May 31, 2013		Dec 2013	100%	Phase 2 on hold pending Go Decision
	6.2	Commission system #6	Jun 30, 2013		Jan 2014	100%	
	6.3	Install monitoring software	Jun 30, 2013		Feb 25, 2014	100%	
	6.4	Provide access to NREL for data analysis	Jun 30, 2013	Oct 1, 2014			After Go/ No Go
	6.5	Operate and maintain system	On-going for 12 months				
	6.6	Sample gas quality- as required	Quarterly				
7.0		Build, install and commission system #7. Operate and maintain. CNSE MOCVD					
	7.1	Build, deliver and install System #7	Jun 30, 2013	May 2014		100%	Phase 2 on hold pending Go Decision
	7.2	Commission system #7	Jul 31, 2013	Aug 2014		75%	
	7.3	Install monitoring software	Jul 31, 2013				
	7.4	Provide access to NREL for data analysis	Jul 31, 2013	Oct 1, 2014			After Go/ No Go
	7.5	Operate and maintain system	On-going for 12 months				
	7.6	Sample gas quality- as required	Quarterly				
8.0		~~Build, install and commission system #8. Operate and maintain.~~					Deleted from Program
9.0		Program Management and Reporting	On-going				

B. Milestone Schedule Update

Table 2: Milestone Schedule

Milestone Number	Milestone Description	Milestone Date			Milestone Progress Notes
		Original Planned	Revised Planned	Actual Completed	
MS1	Data collection and reporting tool development complete and accessible by NREL	Mar 30, 2013	Jan 17,2013	March 6, 2014	
MS2	System #1 is being monitored and reporting data to NREL	Mar 30, 2013	Aug 2014	Sept 2014	Replaced stack in June-Only 600kg since replacement. Gas samples indicate contaminates are contained.
MS3	System #2 is commissioned	Feb 28, 2013	Oct 2014		Task moved to Budget Period II
MS4	System #3 is commissioned	Feb 28, 2013	May 2014	May 2014	Contaminate mitigation has been demonstrated, Achieved 2,500 kg and < 15 µV/ kg/ cell.
MS5	System #4 & #5 are commissioned	Apr 30, 2013	July 2014	July 2014	Achieved 2,500 kg on System #4.
MS6	System #6 is commissioned	Jun 30, 2013	Oct 2014		Phase 2 on hold pending Go Decision
MS7	System #7 is commissioned	Jul 31, 2013	Oct 2014		Phase 2 on hold pending Go Decision
~~MS8~~	~~System #8 is commissioned~~	~~May 31, 2013~~			Deleted from Program

C. Gantt Chart - The revised Gantt Chart for Budget Period I is shown below, moving the Go/ No Go until Ulbrich demonstrates 2,500 kg.



9. Spending Progress

The tables below shows the costs incurred for Task A and the completion of Task 1 in 2Q2014.

A. Expenditures by Budget Category Update

Table 4: Expenditures by Budget Category

Budget Category	Approved Budget	Actual Expenditures	
		Current Quarter	Cumulative to Date
Personnel	$135,196	$9,773	$57,368
Fringe Benefits	$13,520	$978	$5,737
Travel	$23,963	$2,039	$6,239
Equipment	$402,132	$0	$278,813
Supplies	$0	$0	$0
Contractual	$30,575	$0	$30,575

Construction	$0	$0	$0
Other	$99,350	$5,161	$19,746
Total Direct	$704,734	$17,951	$398,478
Indirect	$362,078	$17,927	$178,501
Total	**$1,066,812**	**$35,878**	**$576,979**
DOE Share	$499,908	$16,812	$270,372
Cost Share	$566,904	$19,066	$306,607
Cost Share %	53.14%	53.14%	53.14%

B. Quarterly Spend Plan with Future Projections Update

Table 5: Quarterly Spend Plan with Future Projections

Federal Fiscal Year	Quarter Start Date	Quarter End Date	Past Quarters: Federal Share of Actual Expenditures	Past Quarters: Non-Federal Share of Actual Expenditures	Future Quarters: Projected Federal Share of Future Expenditures	Future Quarters: Projected Non-Federal Share of Future Expenditures	Actual (Past) and Projected (Future) Total Expenditures
2013	01/01/13	03/31/13	$203,822	$231,138			$434,960
2013	04/01/13	06/30/13	$23,691	$26,865			$50,556
2013	07/01/13	09/30/13	$0	$0			$0
2014	10/01/13	12/31/13	$0	$0			$0
2014	01/01/14	03/31/14	$0	$0			$0
2014	04/01/14	06/30/14	$26,048	$29,539			$55,587
2014	7/01/14	9/30/14	$16,811	$19,065			$35,876
2015	10/1/14	12/31/14			$40,091	$45,464	$85,555
2015	01/01/15	03/31/15			$17,182	$19,484	$36,666
2015	04/01/15	06/30/15			$125,918	$142,793	$268,712
2015	07/01/15	09/30/15			$19,864	$22,526	$42,390
2016	10/01/15	12/31/15			$13,537	$15,351	$28,888
2016	01/01/16	03/31/16			$7,764	$8,805	$16,569
2016	04/01/16	06/30/16			$5,179	$5,874	$11,053
Total Project Cost			**$270,372**	**$306,607**	**$229,536**	**$260,297**	**$ 1,066,812**

NYSERDA

Final Report

Prepared for

New York State Research and Energy Development Authority

Albany, NY

Miriam Pye

Project Manager

Prepared by

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Latham, NY

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Project Manager

Project Number 28782

Demonstration of Hydrogen Recycling Technology for use in Industrial Operations

NOTICE

Table of Contents

Executive Summary

H2Pump installed and demonstrated five Hydrogen Recycling Systems (HRS) at four industrial facilities across New York State. H2Pump and the project partners installed and operated recycling systems in a variety of applications in the metal heat treating and semi-conductor industries for over a year in some cases. The full-scale recycling systems were installed with partners Rome Strip Steel, two locations at the Pall Corporation, and one location at the College of Nanoscale Science and Engineering (CSNE) at the University at Albany. Commissioning Engineering support was provided by O'Brien and Gere, Hesnor Engineering Associates, Zeller Corporation and Edwards Vacuum. The project goals were to positively impact key metrics identified in the solicitation, i.e., energy usage, economics and emissions at each demonstration site.

Technical Learning

The hydrogen recycling four systems installed at Pall Corporation and Rome Strip Steel operated for over a year delivering the customer over 8,000 kg of recycled hydrogen saving an projected $30,000. The systems were able to be operated remotely which allowed for continuous operation when the furnace was in operation. As of the writing of this report the system installed with the MOCVD (semi- conductor tool) had only operated periodically, but it should be noted that this is the first operation of a hydrogen recycling system with a semi-conductor tool.

Process Implementation Learning

With the help of the commissioning engineers H2Pump, further developed its processes during the execution of this program. The processes include Site Evaluation, Site Preparation and Planning, and the Commissioning Procedure.

Project Background

Energy intensive industrial furnaces used for heat treating, brazing and sintering, use hydrogen for its oxygen scavenging properties. A well-controlled furnace atmosphere is required for process yield. Hydrogen is introduced to the furnace to react with any free oxygen preventing oxidation on the product surface. These types of manufacturing processes consume little of the hydrogen and the waste hydrogen is vented or flared. The project described in this report involves the installation and operation of hydrogen recycling technology developed by H2Pump LLC (H2Pump) integrated with different types of industrial operations. By recycling upwards of 90% of the process waste, the amount of fossil fuels required to generate and deliver the hydrogen feed stock will be substantially reduced. Figure 1 depicts the integrated arrangement of the Hydrogen Recycling System (HRS) with a common industrial furnace.

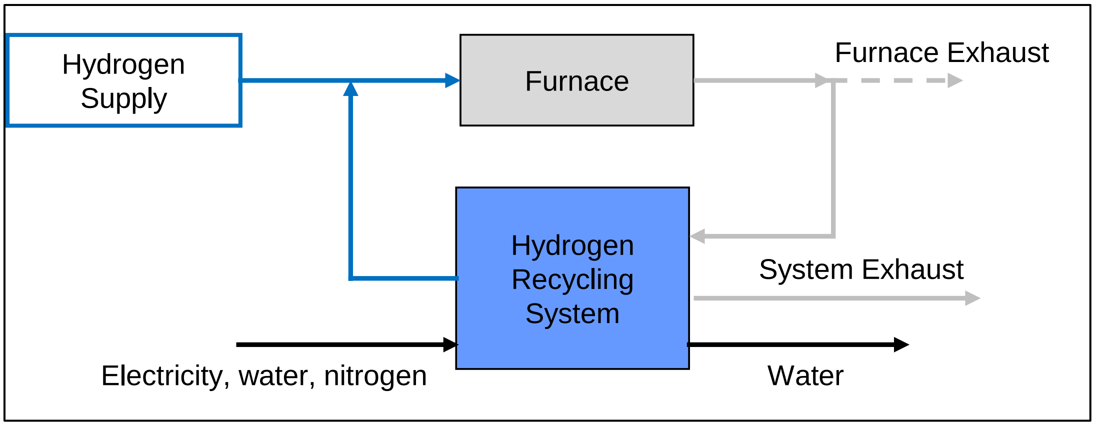


Figure 1: Hydrogen Recycling System Integrated with Furnace Operations

The two year project, as reported here, highlights the potential for the reduction of manufacturing costs and the associated greenhouse gas emissions from hydrogen usage. Eaton manufactures VIs for the power industry. Eaton's VI technology uses vacuum as opposed to sulfur hexafluoride gas (SF6) which is classified as a greenhouse gas. Given that Eaton's VI products have an inherent environmental benefit; H2Pump's HRS-100 was to provide further benefit by reducing the greenhouse gas associated with the production of the VI devices. Initially, H2Pump projected a 50% reduction in the CO_2 generated from the creation and delivery of hydrogen and a reduction of the hydrogen cost by 20%.

Hydrogen Pumping Technology

The heart of the HRS system is the electrochemical pump (EHP). The electrochemical process involves the extraction of hydrogen from a gas stream containing hydrogen followed by the formation of "new" hydrogen. This transformational approach is accomplished without mechanical compression. As shown in Figure 2, the gas passes over a catalyzed membrane where the hydrogen is oxidized to protons and electrons, the electrons are driven from the anode to the cathode via a power supply, and finally, the protons and electrons recombine to form a "new" hydrogen stream at the cathode. The electrochemical reactions are fast, the membrane separator is highly (proton) conductive and electrical resistance is minimal. Since the proton conducting separator only processes hydrogen, impurities in the original waste gas stream are rejected (except for a small diffusion component). There are no moving parts and this technology can inherently pressurize the "new" hydrogen electrochemically. The technology is scalable by adjusting the number of pumping cells, size of pumping cells, and magnitude of electrical current.

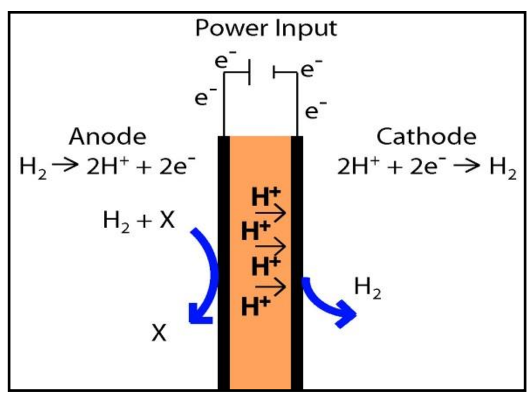


Figure 2: Electrochemical hydrogen pumping technology

Project Partners

The following sections summarize the site and application and performance of the systems for each installation.

Rome Strip Steel

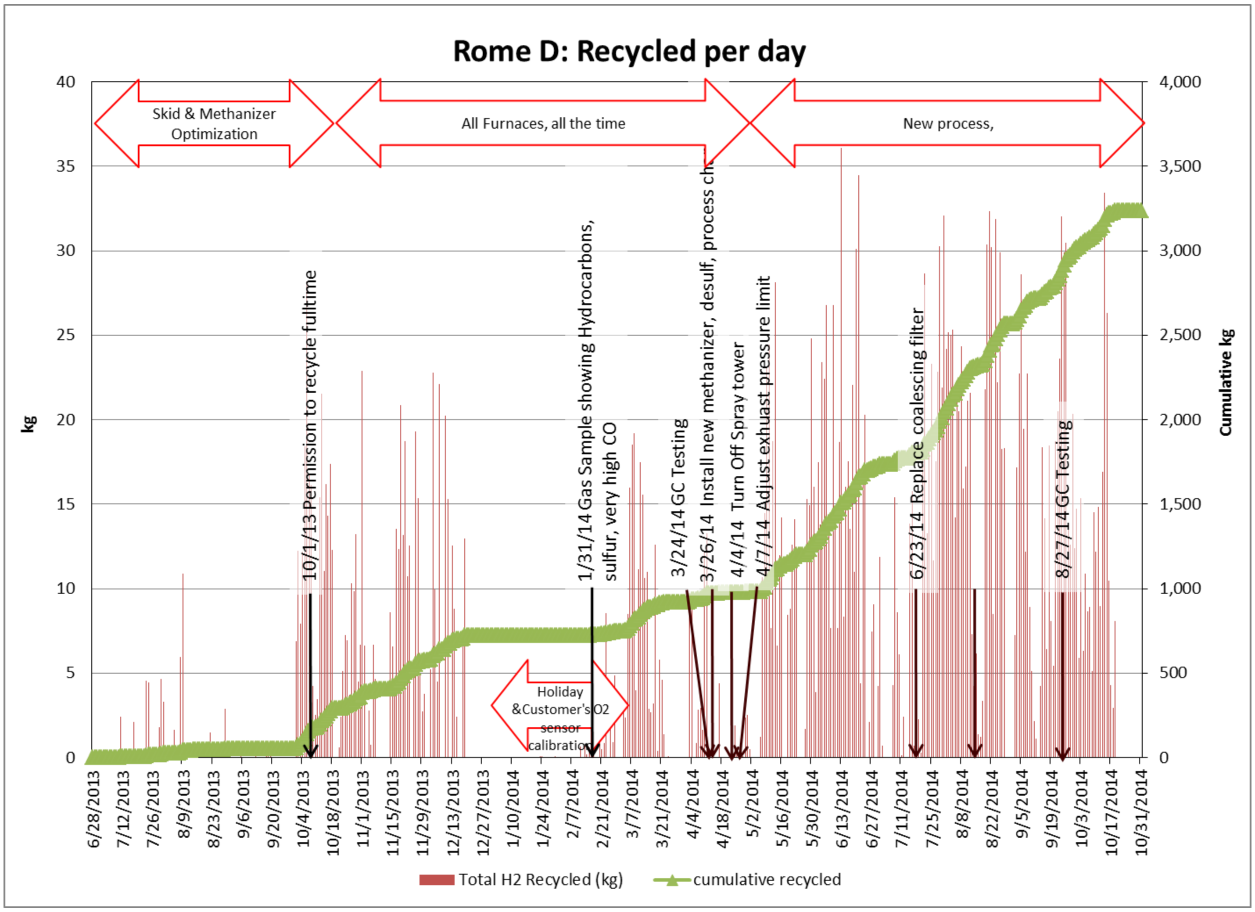
The Rome Strip Steel (RSS) site has unique process elements that are attractive from a value proposition perspective but technically challenging from an installation and operation perspective. RSS uses an abundance of hydrogen, operating a total of 16 bell furnaces in an operation running 24 hours a day, 7 days a week. H2Pump's assessment was that two HRS systems installed in tandem would address the very large recycling opportunity but the technical challenges at the site including oil vapor in the furnace exhaust and more CO than expected proved to be a challenge. While these technical challenges created operational difficulties, the lessons learned by H2Pump as well as RSS helped both companies improve their processes. H2Pump performed in depth testing of the furnace exhaust that provided RSS with key information while benefitting H2Pump in understanding the gas being supplied to the HRS-100™.

H2Pump developed a full scale methanizer and spray tower solution to implement at RSS. The clean-up skid could not be fully integrated and tested with the HRS prior to installation, several integration issues were found while commissioning onsite. While some of the issues took months to uncover and understand the team gained valuable experience with managing oil and CO. The table below summarizes the performance of the system for the entire installation period.

Metric	July 2013	Aug 2013	Sept 2013	Oct 2013	Nov 2013	Dec 2013	Jan 2014	Feb 2014
Availability	36.1%	39%	32%	59.9%	40.0%	46.3 %	19%	51.3%
H2 Recycled	34.9 kg*	50.5 kg*	89.3 kg*	307.6 kg	202 kg	150.3 kg	41.0 kg*	27.1 kg
% Recycled	3 %*	4 %*	5 %*	7.9 %	6.1 %	9%	0%	4 %
$ Savings		($267)	($85)	$1,138	$642	$222	($64)	($198)
	Mar 2014	Apr 2014	May 2014	June 2014	July 2014	Aug 2014	Sept 2014	Oct 2014
Availability	68.3%	26.3 %	44.6 %	69%	46.8%	77.2%	78%	54%
H2 Recycled	170.8 kg	64 kg	290 kg	450kg	321kg	524kg	437kg	229kg
% Recycled	11%	4 %	14 %	22%	16%	26%	22%	12%
$ Savings	$408	$42	$1,136	$2,163	$1,479	$2,572	$2,097	$1,078

*Not recycling, data is for pumping mode

The following graph indicates the trend of the performance over time. It is obvious that the changes to the CO and oil mitigation in March of 2014 clearly impacted the systems performance.



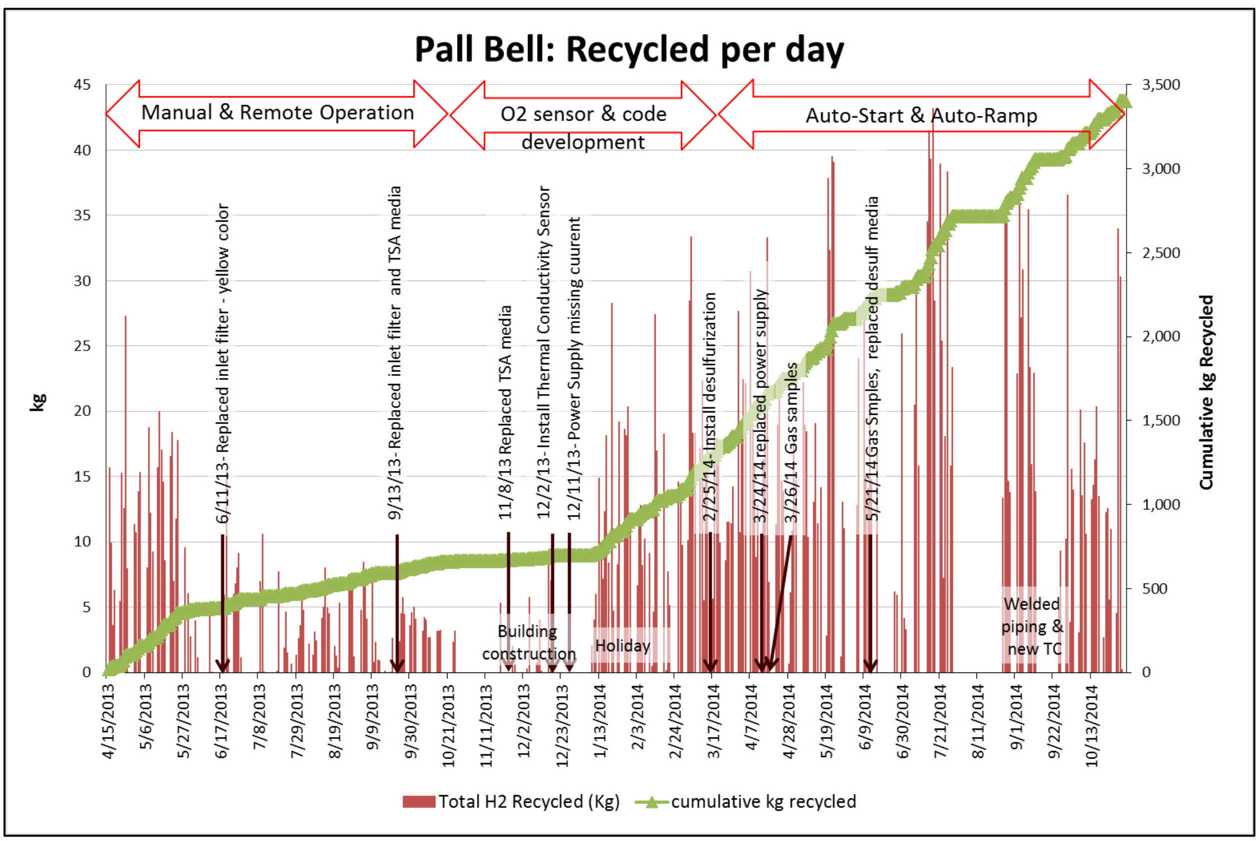
Pall Corporation- Bell Furnaces

Site Summary: A batch-operated heat-treatment furnace in which material is heated inside a retractable dome, Bell Furnaces are utilized for heat treatment of products in a controlled, gaseous environment. The gaseous medium of interest with respect to H2Pump's HRS-100™ unit is hydrogen. This hydrogen atmosphere, when combined with a high-convection recirculation fan, promotes optimum temperature uniformity, yielding a higher-quality crystalline structure, reduced decarburization and homogeneous physical properties of the annealed material.

The performance track is shown in the following table. The HRS recycled over 3,000 kg at this site.

Metric	July 2013	Aug 2013	Sept 2013	Oct 2013	Nov 2013	Dec 2013	Jan 2014	Feb 2014
Availability	45.8%	55.6%	52%	33.7%	6%	23%	53%	66.5%
H2 Recycled	41.7 kg	78.7 kg	62.8 kg	45.4 kg	8 kg	27.8 kg	211kg	178 kg
% Recycled	56.5%	69.4%	71 %	87.8 %	62 %	63.8%	95%	94%
% Pumped	10%	16%	12%	8.3%	3 %	7.0%	24%	26%
$ Savings	$15.61	$234.38	($106.81)	($108.85)	($314.40)	($125.39)	$854	$690
	March 2014	April 2014	May 2014	Jun 2014	Jul 2014	Aug 2014	Sept 2014	Oct 2014
Availability	70.5%	65%	44%	23%	47%	13%	54%	84%
H2 Recycled	344 kg	336 kg	337kg	182kg	427kg	113kg	290kg	289kg
% Recycled	95%	96%	85%	76%	98%	99%	98%	98%
% Pumped	24%	35 %	35%	29%	48%	50%	41%	41%
$ Savings	$1,552	$1,529	$1,647	$542	$1,993	$522	$1,470	$1,340

The performance trend is shown in the following table. The most significant contribution to performance improvement was the development of controls along with the implementation of a oxygen sensing scheme in the exhaust. This enabled an automatic start-up algorithm to be developed and the ability for the system to respond if both bells were running at the same time.



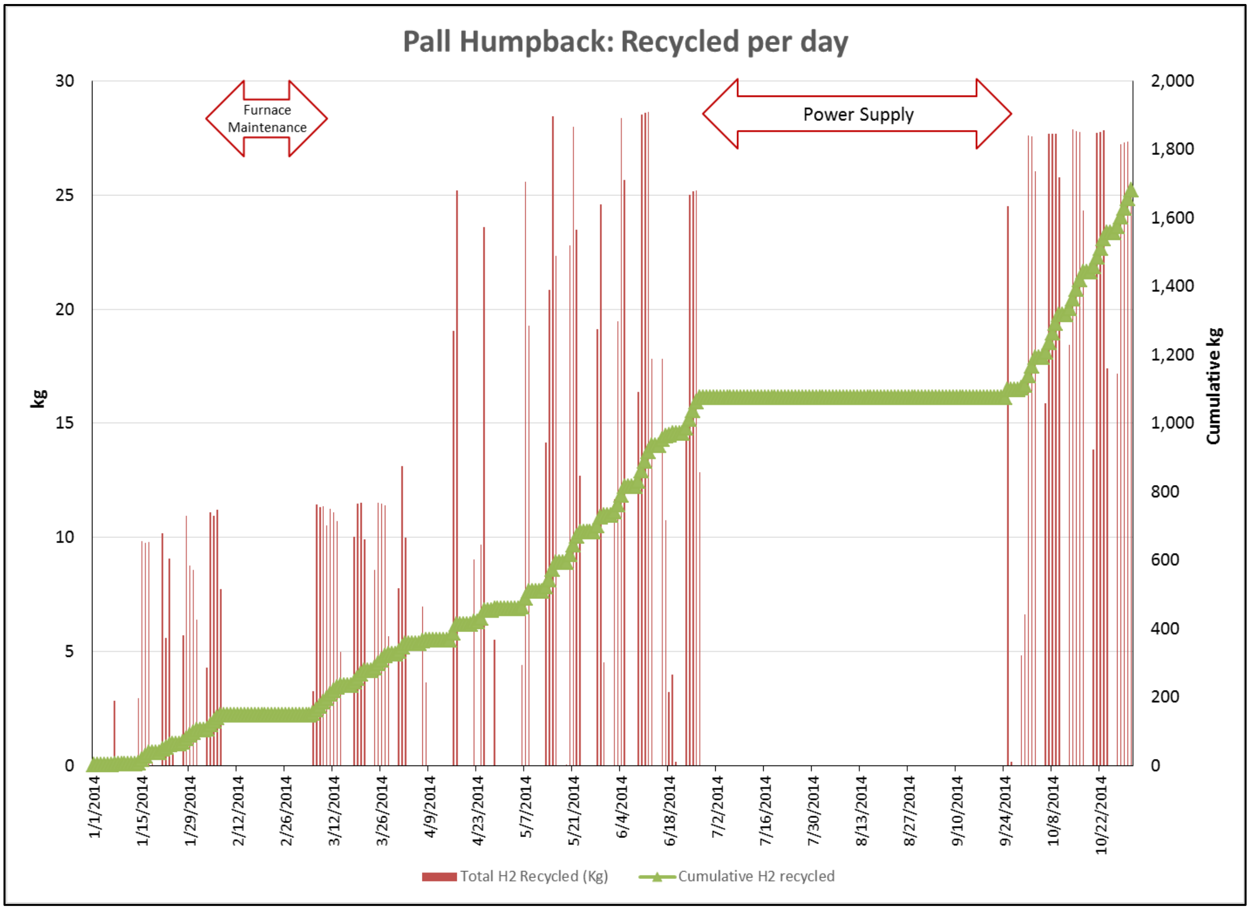
Pall Corporation- Humpback Furnace

Site Summary: A continuously operated furnace open to atmosphere posed a new challenge for adapting the HRS. A humpback furnace with its elevated center takes advantage of the density differences between air and hydrogen to create a controlled environment with dew points upwards of -70 degrees C while allowing continuous product flow to increase production. A flame curtain is also used between the entrances and the exhaust to effectively "close" the system and ensure no oxygen can enter the furnace.

The installation with the Humpback was nearly flawless. The install had the advantage of the previous installs process improvements. The table below summarizes the performance of the system for the entire installation period.

Metrics	Jan 2014	Feb 2014	March 2014	April 2014	May 2014	Jun 2014	Jul 2014	Aug 2014
Availability	87%	83%	91%	45%	74%	88%	0	0
H2 Recycled	100 kg	51.7 kg	185.3 kg	126 kg	270 kg	344 kg	0	0
% Recycled	5.6 %	5.5 %	6.5 %	6%	11%	14%	0	0
Savings	$130.99	$137.93	$628	$286	$1,012	$1,402	0	0
Metrics	**Sept 2014**	**Oct 2014**						
Availability	8%	98%						
H2 Recycled	36 kg	571						
% Recycled	9 %	17 %						
Savings	$115	$2528						

As seen in the table and the following trend chart, the system was not operational for a period of two months after the system power supply failed. The power supply was returned to the vendor in Germany and it took over two months for the repair to take place. H2Pump has since changed to an alternative supplier. Once the power supply was replace the system performance resumed on a similar track.



CNSE- MOCVD

Site Summary: The College of Nanoscale Science and Engineering (CNSE) is a leading edge research foundation partnered with State University of New York (SUNY). The CNSE facility represents over $20 billion in investments from private industry, government, scholastic, and green industry. The Albany, NY facility is comprised of 1.3 million square feet, including 135,000 square feet of Class 1 cleanroom. More than 3,100 scientists, researchers, engineers, students, and faculty currently work there, from companies including IBM, Intel, Global Foundries, SEMATECH, Samsung, TSMC, Toshiba, Applied Materials, Tokyo Electron, ASML, Lam Research and Edwards Vacuum. The collective goal is to prepare the next generation of scientists and researchers utilizing advanced semiconductor processes and equipment.

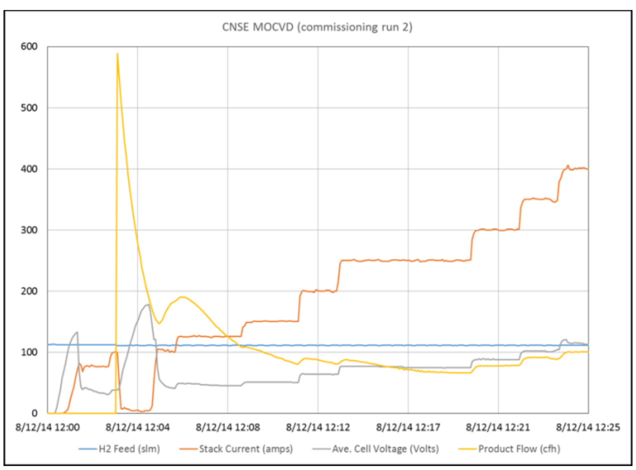
Edwards has undertaken a project to demonstrate the feasibility of Hydrogen (H2) recycling for semiconductor manufacturing applications. The Metal Organic Chemical Vapor Deposition (MOCVD) process is an ideal candidate application for this investigation as a significant amount of high purity hydrogen is consumed.

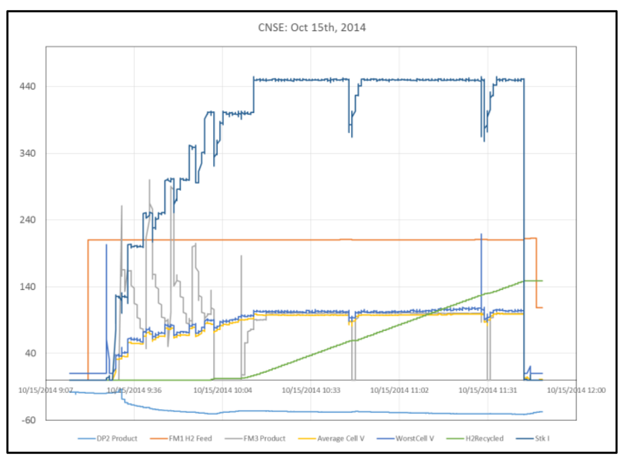
The MOCVD system uses Ultra High Purity H2 as both a carrier gas to deliver the metal organic source material into the process reactor in a useable form, and also as a purge gas to protect various internal parts of the reactor from the extremely high temperatures required during process.

The chemistry within the reactor during process breaks down all materials present and recombines certain portions into a crystal lattice structure, designed to produce particular electrical properties. Specific properties depend upon the particular crystal layer being grown. Any impurities present within the source material (in this case, H2) will usually become integrated into the lattice. These impurities will negatively impact the desired electrical properties.

The full flow of H2 on a standard MOCVD reactor will vary based on reactor design, size, and the particular processes required for the individual growth run. It is extremely common to see H2 flows in the range of 80 LPM and higher. Therefore, the ability to recover and re-use flows of this magnitude are significant opportunities for any company looking to promote an effective "Green Initiative," through waste and operating cost reduction. The most difficult aspect if the installation turned out to be the lack of required product safety certifications called Semi-S2 for the prototype piece of equipment. By executing intensive safety reviews with CNSE, Edwards and Sematech, the system was cleared for installation. These challenges illustrate that the HRS-100™ system was originally designed for use outside of the semiconductor industry. However, collaborative efforts resulted in the successful adaptation and deployment of the hydrogen recovery system, meeting unique and stringent semiconductor industry requirements.

As previously mentioned the system was never put into continuous duty given the hazardous gases associated with the manufacturing process. H2Pump staff began attended operation and the graph below shows the commissioning run and the attended operation run in October.

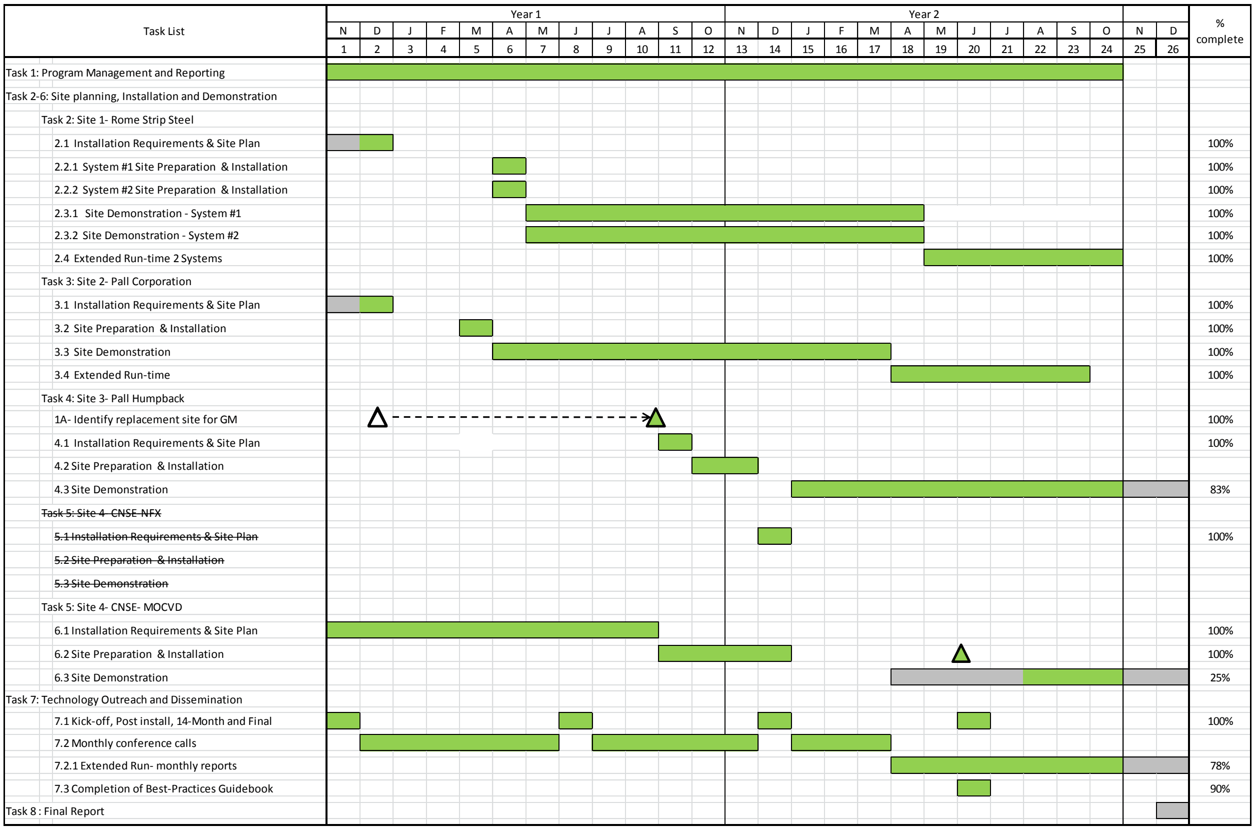




Work Performed

Gantt Chart

The following Gantt chart shows the planned order of the activities and the actual completion dates for the program. Originally the program was expected to be 18 months but was extended to 24 months.



Budget

The following table summarizes the milestone payments as agreed to at the contract modification in March 2014. The total program funding was $1,848,638.

Task	Description	Month	Milestone Payment
Task 1	Program Management and Reporting	On-going	
Task 2	Site #1 Rome Strip Steel		
2.1	Installation Requirements & Site Plan Completed	3	$ 130,000
2.2.1	System #1 Site Preparation & Installation Completed	4	$ 75,000
2.2.2	System #2 Site Preparation & Installation Completed	5	$ 75,000
2.3.1	Monthly test-report documenting the demonstration test results and metr	5 to 16	$ 95,000
2.3.2	Monthly test-report documenting the demonstration test results and metr	6 to 17	$ 95,000
2.4.1	Extended Run time- monthly test report- System #1	19-24	$ 30,000
2.4.2	Extended Run time- monthly test report- System #2	19-24	$ 30,000
Task 3	Site #2 Pall Bell		
3.1	Installation Requirements & Site Plan Completed	2	$ 65,000
3.2	Site Preparation & Installation Completed	3	$ 75,000
3.3	Monthly test-report documenting the demonstration test results and metr	4 to 15	$ 95,000
3.4	Extended Run time- monthly test report	18-23	$ 30,000
Task 4	Site #3- Pall Humpback		
4.1	Installation Requirements & Site Plan Completed	5	$ 65,000
4.2	Site Preparation & Installation Completed	6	$ 75,000
4.3	Monthly test-report documenting the demonstration test results and metr	7 to 18	$ 95,000
Task 5	Site #4- EUV		
5.1	Installation Requirements & Site Plan Completed	4	$ 65,000
~~5.2~~	~~Site Preparation & Installation Completed~~	~~7~~	
~~5.3~~	~~Monthly test-report documenting the demonstration test results and metr~~	~~8 to 18~~	
Task 6	Site #5- MOCVD		
6.1	Installation Requirements & Site Plan Completed	6	$ 65,000
6.2	Site Preparation & Installation Completed	8	$ 75,000
6.2.1	Installation preparation Completed	18	$ 45,000
6.3	Monthly test-report documenting the demonstration test results and metr	9 to 18	$ 85,000
Task 7	Technology Out Reach and Dissemination		
7.1	Commissioning Engineer Meeting 1 Report	1	$ 50,000
	Commissioning Engineer Meeting 2 Report	8	$ 50,000
	Commissioning Engineer Meeting 3 Report	14	$ 50,000
	Commissioning Engineer Meeting 4 Report	18	$ 50,000
7.2	Commissioning Engineer Monthly Reports	16-Feb	$ 140,000
7.2	Extended Run Monthly Report	19,22,24	$ 30,000
7.3	Completion of Best Practices Guidebook	18	$ 75,000
Task 8	Final Version of Final Written Document	18	$ 38,638
	NYSERDA Contribution		$ 1,848,638

Technology Outreach and Dissemination

A major deliverable for the program was the Best Practices Guidebook which documents the lessons learned by the commissioning engineers who contributed to the project. The guidebook was completed in July 2014. In addition to the guidebook, our sales and marketing representative attend the following tradeshows.

FNA2014- October 6-8, 2014, Nashville, TN

PowderMet Show- June 25 & 26, 2013, Chicago, Illinois. This is a large industrial tradeshow with hundreds of companies in attendance. H2Pump had a dedicated booth in the exhibitor hall. This show generated about 18 new leads that resulted in several site visits. Three leads have been presented with contracts and one of those is still actively engaged.

Heat Treat 2013- September 17 & 18, 2013, Indianapolis, Indiana. This is a large industrial show largely attended by members of the Association of Heat Treaters. H2Pump had a booth in the exhibit hall. Over 73 companies visited H2Pump's booth and 17 were added to the sales prospect list. This was also an excellent opportunity to meet with potential strategic partners such as gas suppliers and furnace manufacturers.

These outreach activities listed here above while not necessarily funded by the program, the ability to reference the program and the support from NYSERDA was beneficial.

Economic and Environmental Impact

The following table summarizes the actual results of the project through June 30, 2014 and is published in the Best Practices Guidebook.

ACTUAL

Site Name	Total recycled Kg or SCF	Savings $	CO2 Reduction Metric Tones	Diesel saved gallons
Pall Bell	2,286/964,692	$6,497	20	155
Rome #1 &2	1,723/727,106	$5,137	15	117
Pall Humpback*	1,076/454,072	$3,597	9	73
MOCVD**	TBD	TBD	TBD	TBD

*Humpback has only operated for 6 months

Original value proposition indicated that savings would have been much more however the actual site operation characteristics were not well defined and the system availability was lower than expected during the program due learning and problem solving. A conservative projection based on the site characteristics (24/7 or 10/5) as they are known today is shown. The following table shows the anticipated results under an HRA arrangement and with a sustained level of performance after 12 months of operation.

12 Month Prediction

Site Name	Projected recycled kg or SCF	Savings including HRA $	CO2 Reduction Metric Tones	Diesel saved gallons
Pall Bell	9,360/3,949,920	$11,700	81	636
Rome #1 &2	15,768/6,654,096	$19,710	137	1072
Pall Humpback	7,200/3,038,400	$9,000	63	489
MOCVD	TBD	TBD	TBD	TBD

*savings assuming merchant cost of $5.50/kg and $1.00/kg for electricity

Lessons Learned

Besides the technical challenges and problem solving that provided a very rich set of lessons learned which resulted in numerous design changes that will be implemented in the next design revision, the NYSERDA program identified key business process improvements that will increase the efficiency of H2Pump's engagement with the customer. The following section describes some of the important lessons learned and the resulting Best Practice that has been implemented.

The Site Champion

The site champion plays a pivotal role in making things happen at the site. Whether it's scheduling the installation work or getting H2Pump access to the system, the site champion is essential to a successful site. The site champion will help navigate the customer's internal processes such as safety and quality control. The site champion will also provide internal visibility to the project and keep their management informed of progress, both good and bad, so the site champion has to be informed on a weekly basis as to the status of the system. The recently implemented H2Pump online database will be an essential tool for our customers and site champions, providing them with detailed data and analysis at the tip of their fingers. Site Champions may be an individual tasked with environmental issues, the facilities manager may assign a person, the H2Pump Engineers or Commissioning Engineers may also have recommendations as to who would be the appropriate person. The best way to find the best site champion is to have that person assigned by the person who "owns" the problem or who stands to benefit from the project succeeding.

Time to Install and Commission

One of the major business issues that we discussed after the installations at Pall and Rome was the time from delivery to installation and commissioning. For H2Pump's business purpose, the commissioning of the system triggers the start of billing for the recycled hydrogen. Likewise, this is when the customer will start to experience savings in their cost of hydrogen. At the beginning of the program the Pall- Bell delivery to commissioning took nearly three months. By the time H2Pump installed the system at Pall- Humpback, it only took five weeks.

The primary enabler for the timing improvement was the communication with the customer and confirming that the site was 90% ready when the unit was delivered. H2Pump and Pall still struggled with getting the internet connected, but the delay was minimal compared to the Pall-Bell installation since H2Pump already knew the contacts and could easily implement it at Pall-Humpback. Frequent communication (at least every three weeks if not every two weeks) with all stakeholders is essential in the months leading up to an install. There needs to be a "project owner" at both the customer site and at H2Pump. The project owner is responsible for ensuring that the process continues to move forward, that milestones are met, etc.

Value Proposition

Creating a compelling value proposition is essential to H2Pump's business. Clearly understanding the operational characteristics of a site is important. Additionally, observing the operation will help clarify specifics such as hours of operation and hydrogen usage. Many customers state that their operation is 24/7. We have found that belief is often incorrect as it relates to the actual running of the furnaces. It is critical to understand what the profiles of the furnaces are that are to be involved in the recycling effort.

Gas Sampling Before Install

As noted across all of the sites, there were many unknowns in the exhaust gas composition that were detrimental to the system performance over time. At the beginning of the program H2Pump's approach was to either perform single cell testing for a few days and sample the furnace exhaust with Draeger tubes. In order to better identify possible contaminants, H2Pump is now employing gas chromatography (GC) and analysis of gas samples by an external laboratory. Because of the significant cost, many customers have not invested in a GC. Customers have found it very helpful to learn what is actually in their gas. As stated earlier by both Pall and Rome, the ability to analyze their gas compositions have enabled them to modify their production runs and greatly reduce their product rejection rate. Rome has saved "hundreds of thousands of dollars" in eliminating rejects.

H2Pump has also learned to observe and discuss with site operators the furnace temperature cycles to identify when the highest level of contaminants may be present and what different types of materials are run in each furnace.

H2Pump has implemented many internal processes and problem fixes during this program that are reflected in the current fielded systems. Partner cooperation and feedback throughout the program increased H2Pumps understanding of applications and the issues involved in integrating our HRS technology.