2014 DOE Hydrogen and Fuel Cells Program Review Presentation

Landfill Gas – to – Hydrogen

Validating the Business Case; Proving the Technology

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Project ID: MT007

Overview

Timeline:

- **Project Start Date: 17 Jun 2011**
- **Project End Date: 30 Sep 2014**
- **Percent Complete: 85%**

Budget:

- **Total Project Funding: $1,402K**
  - **DOE Share: $650K**
  - **Contractor Share: $752K**

Barriers Addressed

- **Technology Validation Barrier 3.6.5.F** (Centralized Hydrogen Production from Fossil Resources)
- **Technology Validation Barrier 3.6.5.G** (Hydrogen from Renewable Resources)

Project Partners:

- **BMW**
- **Gas Technology Institute**
- **Ameresco, Inc.**
- **SC Hydrogen & Fuel Cell Alliance**

Additional Collaborators:

- **American Nitrogen Rejection, LLC**
- **Urban Renewable H2 (final phase)**

Project Lead: SCRA

Project Context: Relevance

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

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

Project Objectives: Relevance

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

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

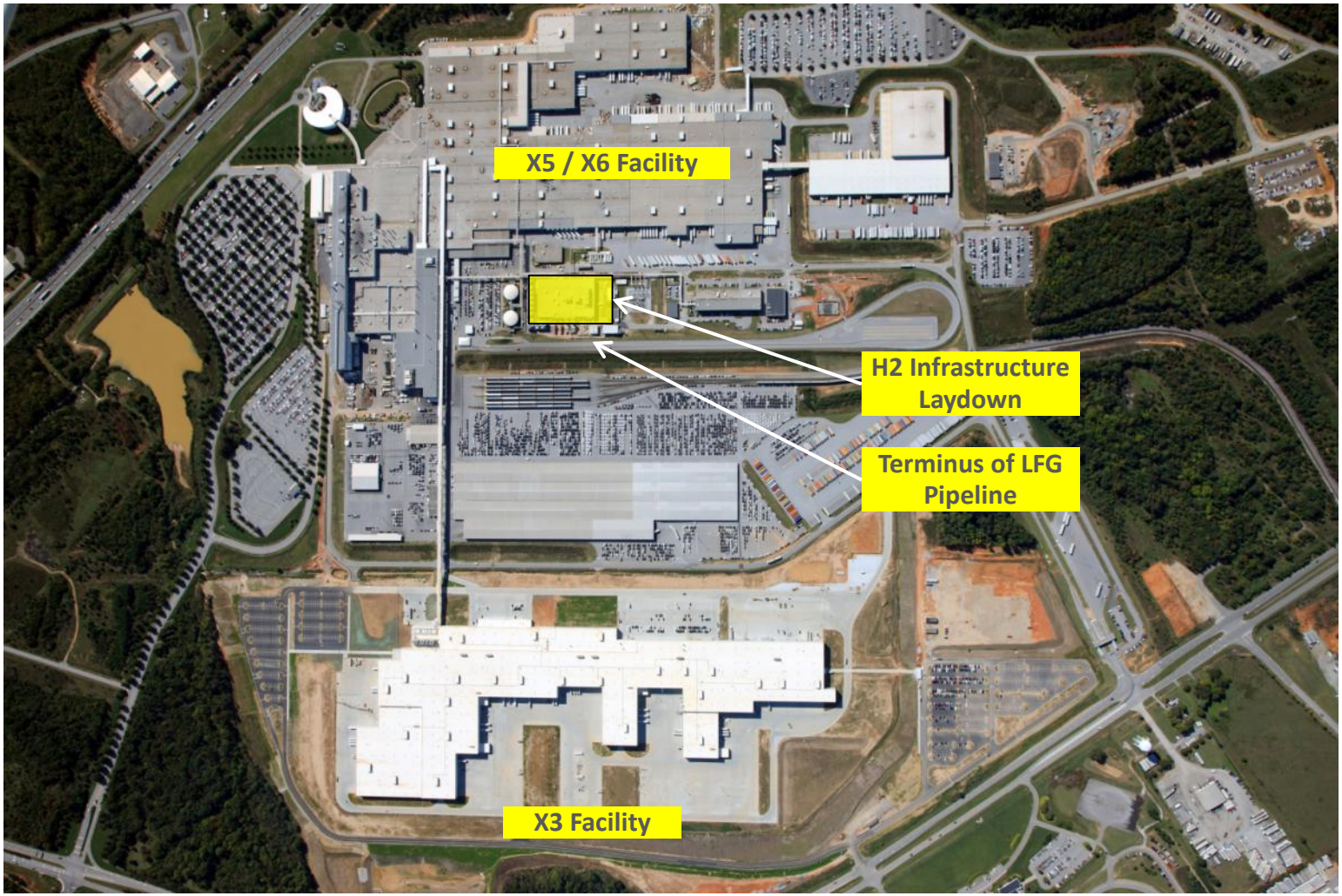
Technical Approach

- **Business Case Analysis**
  - BMW mandate: investigate only commercially-available equipment
  - Execute 2 separate data calls to industry seeking quotes for (1) gas cleanup equipment and (2) steam methane reformation (SMR) equipment
    - ❖ 2 iterations for hydrogen production capacity: 50 kg per day and 500 kg per day
  - Compare resultant 10-year costs with delivered hydrogen costs

- **Landfill Gas – to – Hydrogen Conversion**
  - Pilot-scale technology demonstration to be executed at the host site using host site's existing LFG source
  - Leverage previous partial DOE investment in "mobile hydrogen fueling station" having sufficient capacity (15 kg/hydrogen production per day) to support proof-of-principle
  - Construct flow-rate compatible front-end gas cleanup skid
  - Adapt the preceding systems to take a stream of on-site LFG (post-siloxane removal), remove non-methane constituents (e.g., CO_2, N_2, O_2, sulfur, trace contaminants, etc.) and produce fuel cell purity hydrogen via SMR and PSA

- **Conduct "side-by-side trial" in actual fuel cell MHE (to be funded)**

Project Environment: Approach



BMW Manufacturing Company
Greer, SC

Timeline and Milestones: Approach

- **Project Kickoff – 17 June 2011**

- **Phase 1: Feasibility Study**
  - Completed 26 October 2011
  - Approved by BMW 21 November 2011; project team authorized to proceed to Phase 2

- **Phase 2: LFG-to-Hydrogen Conversion**
  - 8 months nominal; target completion date: July 2012 (original); January 2014 (actual)
  - Critical milestones:
    - ❖ **Prepare site and extend landfill gas supply and utilities**
    - ❖ **Land, interconnect, start up and test equipment**
    - ❖ **Monitor hydrogen purity for at least 2 months**

- **Phase 3: Side-by-Side Trial (to be funded)**
  - 3-6 months from satisfactory completion of monitoring portion of Phase 2
  - Target completion date: January 2013 (original); September 2014 (current estimate)
  - Critical milestones:
    - ❖ **Operate test group of MHE to demonstrate end-to-end solution**
    - ❖ **Continue monitoring hydrogen purity of LFG-sourced hydrogen**

- **Project Completion – 30 September 2014**

Study Conclusions: FY12 Accomplishments

- Technologies exist and are commercially available to achieve the expected level of clean-up required to meet specifications of hydrogen generation system providers. These technologies are very mature.
  - Large scale industrial hydrogen production by SMR in the oil refining and petrochemical industry is very mature.
  - Applications for smaller scale SMR equipment (< 800 kg/day) are less mature.

- **"Bottom Line" Conclusion:** At the 500 kg/day level, with the existing landfill gas (LFG) supply and equipment at the host facility, onsite production of hydrogen using LFG as the hydrocarbon feedstock appears to be cost competitive, if not advantageous, over hydrogen sourced from vendors, produced offsite and transported to the facility.

- Implication for DOE Fuel Cell Technology Program: Although the analysis presented within the feasibility study are specific to the LFG equipment and constituents at the host facility, the basic principles of hydrocarbon feedstock clean-up and reformation to hydrogen should apply to agricultural waste streams, wastewater systems, digester gases and other process off-gases.

FY13 Reviewer Comments: Approach

- **Weakness:** This project can still be successful. An extension will need to be put in place for the project to complete all of the goals laid out. They will probably not be able to meet the current timeline.
  - **Response: Original project period of performance sunset on 31 July 2013. Project team self-funded troubleshooting and recovery actions (>$100K in unplanned/unbudgeted cash). Clean-up system performance and subsequent hydrogen production purity goals achieved in January 2014; awaiting DOE contract action to complete final phase.**
- **Recommendation:** This project should consider third-party evaluation/an alternate vendor for gas separations
  - **Response: Immediately after AMR 2013 presentation, SCRA reached out to gas separations experts at ANL; GTI subsequently identified and then retained a nitrogen removal vendor, whose technology led directly to correcting the existing separation challenges.**
- **Recommendation:** A post-project debrief should be considered in which lessons learned are discussed and then amended in this report. The lessons learned may facilitate similar projects.
  - **Response: Absolutely agree. The technical challenges and solutions (and the process used) provide useful "lessons learned;" significant factors that bear on the financial / business case have arisen since the feasibility study completed in 2011 and warrant updating.**

Overcoming FY13 Challenges: Approach

- **Challenge:** Uncharacteristically high nitrogen and oxygen content in BMW's LFG source (nearly twice the concentration of "typical" LFG sources) resulted in poor performance from original gas cleanup equipment vendor's solution in separating/removing nitrogen and oxygen from the purified methane stream
- **Solution:**
  - **Installed a self-contained nitrogen removal unit supplied by American Nitrogen Rejection, LLC. ANR's system uses commonly available, non-patented activated carbon in the towers as adsorption media, which preferentially adsorbed hydrocarbons under pressure while rejecting the entrained nitrogen. The unadsorbed nitrogen-rich gas was vented from the tower, and then the hydrocarbons adsorbed on the charcoal were recovered under vacuum.**
  - **Installed an additional compressor in series with the original compressor so that a deeper vacuum could be drawn on the CO_2 removal beds. This improved the performance of the ANR pressure swing adsorber system.**
  - **Installed a dedicated deoxygenation unit downstream of the original clean up skid equipment to correct the widely varying system output oxygen concentration.**

Overcoming FY13 Challenges: Approach

FY14 Key Takeaway: Accomplishments

- Successfully proved the technical viability of producing fuel cell industry specification (SAE J2719) hydrogen from BMW's landfill gas source and the project's equipment laydown

Constituent	Specification	17 Oct 2013	14 Jan 2014
	(umol/mol)		
Total Hydrocarbons	2	1.4	1.2
Oxygen	5	<5	<5
Helium	300	<10	<10
Nitrogen	100	<5	<5
Argon	1	<1	<1
Carbon Dioxide	2	<0.4	<0.4
Carbon Monoxide	0.2	0.011	0.047
Total Sulfur	0.004	0.00072	0.0002
Hydrogen Fuel Index		99.99985%	99.99988%

LFG-to-H_2 Conversion: FY14 Accomplishments

- Successfully proved the technical ability to recover sufficiently pure methane from an incoming stream of LFG to permit follow-on hydrogen recovery using traditional steam methane reformation technology

- Successfully produced hydrogen of sufficient purity to satisfy industrial standards for fuel cell use

- Successfully demonstrated repeatability of results in accommodating daily/weekly/monthly changes in the composition of the incoming LFG stream without causing a change in the output hydrogen purity

  - However, lost the ability to run the integrated pilot-scale system remotely based upon additional equipment installed to correct original performance deficiencies. This required re-evaluation and re-scoping of the number of run-hours achievable in the final phase of the project

Schedule and Milestones: Accomplishments

Project Element	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
	JS11	OD11	JM12	AJ12	JS12	OD12	JM13	AJ13	JS13	OD13	JM14	AJ14	JS14
Feasibility and Business Case Analysis	X	X											
Go-No Go Decision (BMW)		X											
LFG-to-Hydrogen Production and Testing		X	X	X									
Identify Clean-up Eqpt Requirements		X											
Determine Eqpt Pad Sizes and Locations		X											
Design Clean-up Equipment			X										
Refurbish Mobile Hydrogen Fueler			X										
Connect to Existing Svcs (LFG, H2O, Power)				X									
Commission and Start-up Equipment				X									
Monitor and Test H2 Purity (2 months min)				X									
Go-No Go Decision (Project Team)				X									
Side-by-Side Testing					X	X							
Identify Test Group (3-5 pieces MHE)													
Identify Control Group (3-5 Pieces of MHE)													
Operate Trial MHE in Normal Duties													
Collect Data / Compare Performance													
Go-No Go Decision (BMW)							X						
Confirm Value Proposition													
Collect Info on Daily Operations				X	X	X							
Program Management and Reporting	X	X	X	X	X	X							

Key:	
Progressing toward Milestones	
System Failure Occurred	
Troubleshooting/Corrective Action	
Successful Milestone Completion	
Milestone Decision Pending	

Projections as of 15 April 2014

Project Team Members: Collaboration

- **South Carolina Hydrogen and Fuel Cell Alliance** (private, not-for-profit)
  - Prime contractor with DOE
  - Providing education and public outreach
- **BMW** (private industry)
  - Host site
  - Providing on-site engineering and services support and $250K cash cost share
- **SCRA** (private, not-for-profit)
  - Subcontractor to SCHFCA
  - Providing overall program management; financial management; subcontracts administration; compliance and reporting to sponsors and $180K cash cost share
- **Gas Technology Institute** (private, not-for-profit)
  - Subcontractor to SCRA
  - Principal equipment provider for technical validation portion of the project; providing support for business case analysis and $110K in-kind cost share
- **Ameresco** (private industry)
  - Subcontractor to SCRA
  - Providing lead for business case analysis and on site engineering support for technical validation portion of the project
- **American Nitrogen Rejection, LLC** (private industry)
  - Subcontractor to GTI
  - Technology provider for clean-up system modifications made in the summer of 2013
- **Urban Renewable H2** (private industry)
  - Potential “next adopter”
  - Contributing $50K cash cost share toward final phase of the project

Remaining Challenges and Barriers

- **Technical**
  - **Install hydrogen fueling "fill post" at outlet of mobile hydrogen fueling unit**
    (low risk)
  - **Operate project equipment continuously for 8 10-hour shifts per weekly trial period (Goal: 2-3 weekly trials before mid-August)**
    (low-to-moderate risk based upon limited prior experience with operating the project equipment continuously for this length of time)
- **Non-technical**
  - **Timeline (must be off of BMW site NLT 31 August 2014)**
    (need 2 weeks to decommission, disconnect, pack up and ship project equipment off the BMW site)
  - **Train BMW MHE operators on fueling from the project equipment**
    (low risk, but potentially high negative impact if procedures not followed/accomplished properly)

Next Steps: Proposed Future Work

- **Execute Phase 3 activities (to be funded; nominal 3-6 month effort)**
  - Operate 3 or more pieces of fuel cell MHE at the BMW site on LFG-sourced hydrogen; evaluate any indicators of performance that differ from that expected from MHE units fueled by hydrogen sourced from industrial gas provider
  - 2 or 3 one-week trial periods.
  - Provide performance data to NREL to begin populating a national database
  - **Project team must be off of the BMW site NLT 31 August 2014.**

- **"Beyond the scope" of this project**
  - BMW makes a business case decision regarding scale-up of the LFG-to-hydrogen process to accommodate its site-wide hydrogen fuel needs
  - In concert with NREL, reassess and refine the 2011 feasibility study based upon actual results, newer clean-up and hydrogen production equipment information, and the potential financial benefit that could arise were LFG-sourced hydrogen to be classified as a "renewable transportation fuel" by EPA.

Project Summary

- **Relevance:** Validate the business case and technical feasibility of using landfill gas as a "distributed generation" option for hydrogen production; transfer "lessons learned" that may be applicable for other candidate waste streams
- **Approach:** Survey commercially-available equipment to draw conclusions regarding economic viability of LFG-to-hydrogen approach for potential end-users; actually demonstrate the technical viability of current systems to produce sufficiently pure hydrogen for use in motive or other applications; confirm no adverse impact on fuel cell systems that operate on LFG-sourced hydrogen
- **Technical Accomplishments and Progress:** Economic feasibility study concluded a viable business case can be made; technical proof of principle validated SAE J2719 specifications for hydrogen purity can be achieved using LFG source
- **Collaborations:** Current partnership with SCHFCA, BMW, GTI, Ameresco and ANR
- **Future Work:** Secure follow-on funding and demonstrate fueling operations with LFG-sourced hydrogen at the project site. Host makes scale-up decision

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Technical Back-up Slides

Overcoming FY13 Challenges: Approach