2013 DOE Hydrogen and Fuel Cells Program Review Presentation

Landfill Gas – to – Hydrogen

Validating the Business Case; Proving the Technology

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SCRA
15 May 2013

Project ID: MT007

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

Overview

Timeline:

- Project Start Date: 17 Jun 2011
- Project End Date: 31 Dec 2013
- Percent Complete: 70%

Budget:

- Total Project Funding: $1,045K
  - DOE Share: $575K
  - Contractor Share: $470K
- FY12 Funding Received: $575K

Notes:

- All project funding has been authorized, released and obligated
- $250K of FY12 DOE funds were not released to the project team until FY13

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:

- NREL (Project Phase 3)
- Plug Power (Project Phase 3)

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*

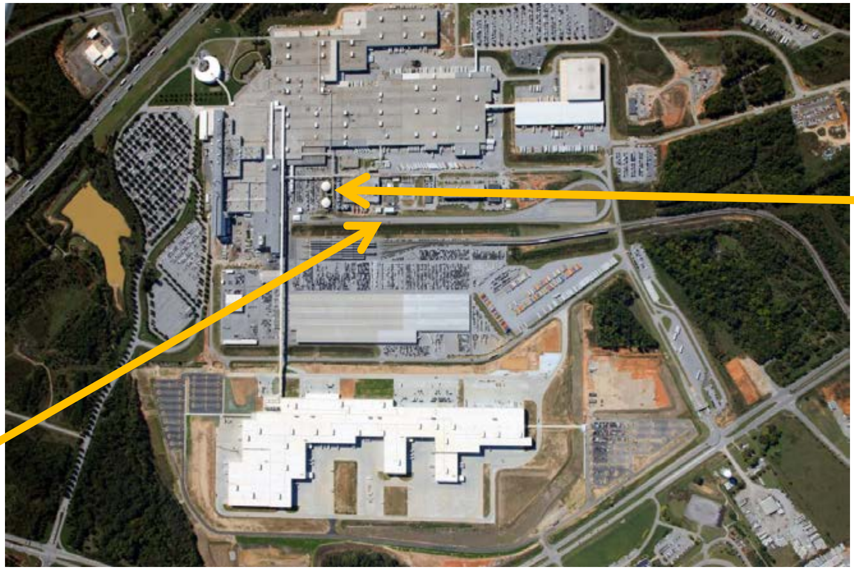
The BMW X3

In order to make one of these…

…BMW Starts Here

Palmetto Landfill, Wellford, SC

Pre-2010 "Baseline"

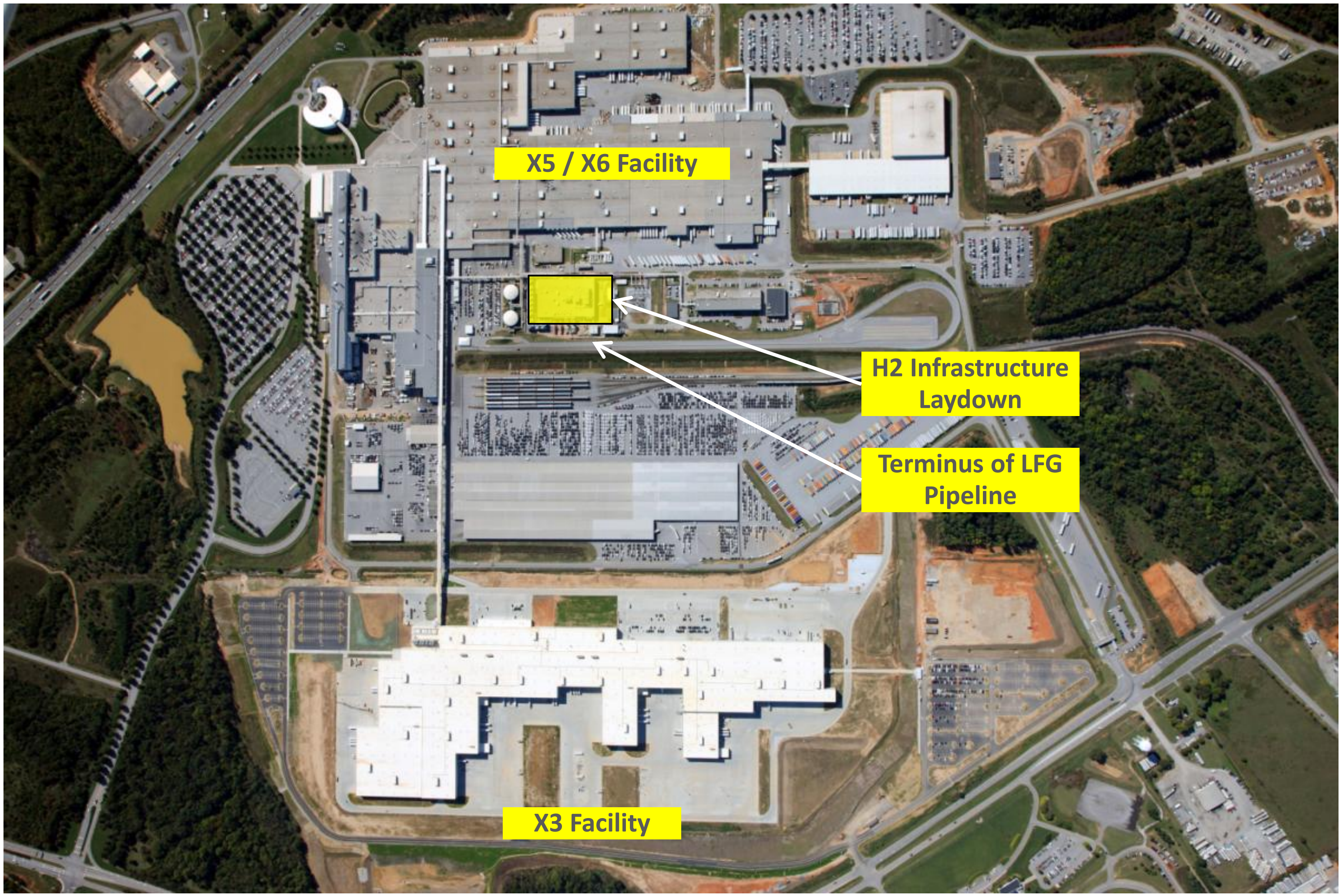


Gas Turbine Gen Sets

LFG Pipeline Terminus

The EPA Landfill Methane Outreach Program

Hydrogen and Fuel Cell Initiatives



2010 to Present

Site-Wide MHE Conversion

230 units to date; another 40 to go

SCRA

Transition to the Future

SC HYDROGEN & FUEL CELL ALLIANCE
www.SCHydrogen.org

An on-site, renewably-generated hydrogen production capability

Project Objectives: Relevance

- Validate there is a viable business case for full scale operation should the LFG-to-hydrogen conversion technology prove 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

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); May 2013 (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)
  - 6 months from satisfactory completion of monitoring portion of Phase 2
  - Target completion date: January 2013 (original); December 2013 (current estimate)
  - Critical milestones:
    - Operate test group of MHE to attain 25,000 run hours
    - Continue monitoring hydrogen purity of LFG-sourced hydrogen
- Project Completion – 31 December 2013

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, sulfur, trace contaminants, etc.) and produce hydrogen via SMR

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

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.

LFG-to-H_2 Conversion: FY13 Accomplishments

- BMW outfitted its X5/X6 assembly hall with fuel cell MHE
  - This removed some of the potential cost for the project (no need to run dedicated infrastructure into the assembly hall) and made it easier to orchestrate the side-by-side trial because the pieces of MHE involved in the trial now can actually operate side by side in the X5/X6 hall
  - However, lost the ability to run LFG-sourced hydrogen to indoor fueling site, which will cause greater impact to BMW during side-by-side trial

- 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 (only post-gas cleanup “contaminants” are excessive N_2 and O_2)

- Successfully produced hydrogen of sufficient purity to satisfy industrial standards for fuel cell use [subject to change prior to 13 May]

- Determined any daily/weekly/monthly changes in the composition of the incoming LFG stream could be accommodated by the cleanup equipment and not cause a change in the output hydrogen purity [subject to change prior to 13 May]

Schedule and Milestones: Progress

Project Element	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31
	JU11	JL11			OC11			JA12			AP12			JL12			OC12			JA13			AP13			JL13			OC13		DE13
Feasibility and Business Case Analysis	X	X	X																												
Go-No Go Decision (BMW)			X																												
LFG-to-Hydrogen Production and Testing				X	X	X	X	X	X																						
Identify Clean-up Eqpt Requirements																															
Determine Eqpt Pad Sizes and Locations																															
Design Clean-up Equipment																															
Refurbish Mobile Hydrogen Fueler																															
Connect to Existing Svcs (LFG, H2O, Power)																															
Commission and Start-up Equipment																															
Monitor and Test H2 Purity (2 months min)								X	X																						
Go-No Go Decision (Project Team)									X																						
Side-by-Side Testing										X	X	X	X	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	X	X	X	X	X	X													
Program Management and Reporting	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X													

Projections as of 29 March

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 (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 $70K 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 $30K in-kind cost share in Phase 2
- Ameresco (industry)
  - Subcontractor to SCRA
  - Providing lead for business case analysis and on site engineering support for technical validation portion of the project

Next Steps: Proposed Future Work

- Execute remaining Phase 2 tasks (target completion May 2013)
  - Complete post-commissioning "run-in" of equipment (nominally 2 months), sampling output hydrogen purity frequently to ensure conformance with fuel cell MHE hydrogen quality input specifications
    [may need to address alternative pathways]
- Phase 3 activities (to be funded; nominal 6-month effort)
  - Conduct side-by-side trial comparing fuel cell performance and durability when using LFG-sourced hydrogen compared with hydrogen sourced from industrial gas delivery company
  - Provide fuel cell performance data to NREL to expand sample size in national database
  - In concert with NREL, reassess and refine feasibility study based upon actual results
- "Beyond the scope" of this project
  - BMW makes a business case decision regarding scale-up of the LFG-to-hydrogen process to accommodate site-wide hydrogen fuel needs

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 currently in progress
- **Collaborations:** Current partnership with SCHFCA, BMW, GTI and Ameresco, Inc.
- **Future Work:** Complete technical proof-of-principle; secure follow-on funding for side-by-side trial / data gathering phase

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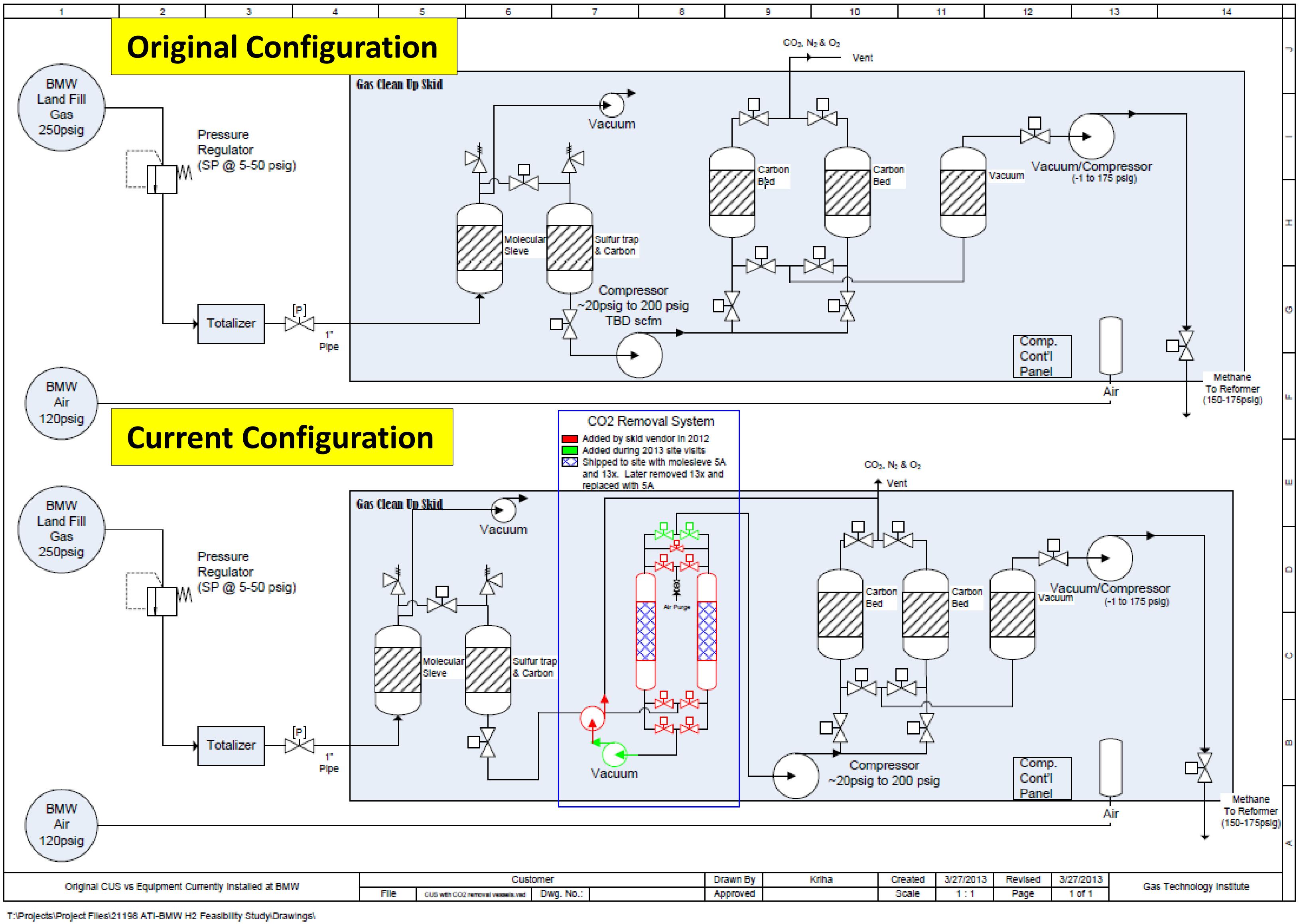
Technical Back-up Slides

Technical Challenge: Gas Cleanup System

- **Key project team decisions, errors in execution and "real world" constraints that have impacted progress**
  - Membrane vs. Pressure Swing Adsorption design
    - Large-scale system (BMW size) preference is PSA; small-scale (pilot size) system preference is membrane separation
    - Selected PSA based upon cost and to demonstrate direct scale-up potential for BMW
    - Result: challenges with scaling DOWN from commercial-scale PSA system (50X)
  - Vendor "test gas" standard did not conform to BMW LFG composition
    - Vendor's initial system build met all specifications using the test gas mix blended at the Vendor site……but that mix deviated significantly from BMW's **actual** LFG composition
    - Subsequent testing against actual BMW LFG composition revealed failure to meet specifications
  - Divergence between BMW's actual LFG composition and other LFG sources
    - BMW LFG stream has unusually high levels of O_2 and N_2
    - This made the "traditional" adsorbent recipe less effective for the unique BMW LFG composition
  - Geography and sample-to-results time delays
    - Vendor in OK; GTI in IL; BMW in SC. Cost driver in on-site troubleshooting
    - Sample turnaround takes several days; becomes significant when multiple iterative cycles of corrections/re-sampling are required

Technical Challenge: Gas Cleanup System



Technical Challenge: Gas Cleanup System

- **Chronology**
  - Jan 2012: Commence design
  - May 2012: Vendor delivers gas cleanup skid to GTI for testing / acceptance
    - Testing fails; CO_2, N_2 and O_2 concentrations too high
    - GTI determines vendor had tested the system prior to shipment with incorrect "simulated LFG" gas composition (system had met required specs using wrong gas composition; when using actual BMW LFG proportions, the system failed to meet specs)
  - Aug 2012: Cleanup skid returned to Vendor for corrective action
    - Vendor installed additional adsorbent to remove CO_2 and N_2, which required installing two new vessels, blower and associated valves, and modifications to the control logic/strategy for the system.
    - Retest showed high CO_2 problem corrected, but high N_2 and O_2 levels remained
    - Purge system modified to recycle a portion of the clean methane product gas to purge the CO_2 adsorbent / vessels (rather than using clean air)
    - The preceding fix also required changing some logic within the control scheme of the system.
  - Nov 2012: Cleanup skid delivered to the BMW site
    - Cleanup skid married to SMR equipment and connected to BMW LFG source, electricity, water
    - During startup sequence, operators identified several component failures (one solenoid control valve and two check valves in the CO_2 removal subsystem), timing/control problems involving the purge subsystem, and an under-sized vacuum pump that was limiting CO_2 removal.
  - Feb 2013: Material repairs complete; cleanup skid restarted and tested using BMW LFG source
    - CO_2 back in spec; N_2 and O_2 remained high out of spec
    - Purge system adjusted to use larger percentage of product gas / smaller percentage of clean air. Additional purge line installed to increase available purge flowrate.
    - Vendor recommended significant reduction in pressure and cycle times for the molesieve CO_2 adsorbent beds, and change-out of adsorbents to those better tailored to N_2 removal.