Scalable Electrolytic Systems for Renewable Hydrogen Production

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DOE Hydrogen and Fuel Cells Program
2019 Annual Merit Review and Peer Evaluation Meeting

Project ID: H2001

Overview

Timeline and Budget

- Project start date: 02/26/18
- Project end date: 05/01/19
- Total project budget: $150k
  - Total recipient share: $25k
  - Total federal share: $25k
  - Total DOE funds spent*: $25k

* As of 3/01/19

Barriers

- Utilization of remote off-shore wind resources
- Capital cost reduction

Partners

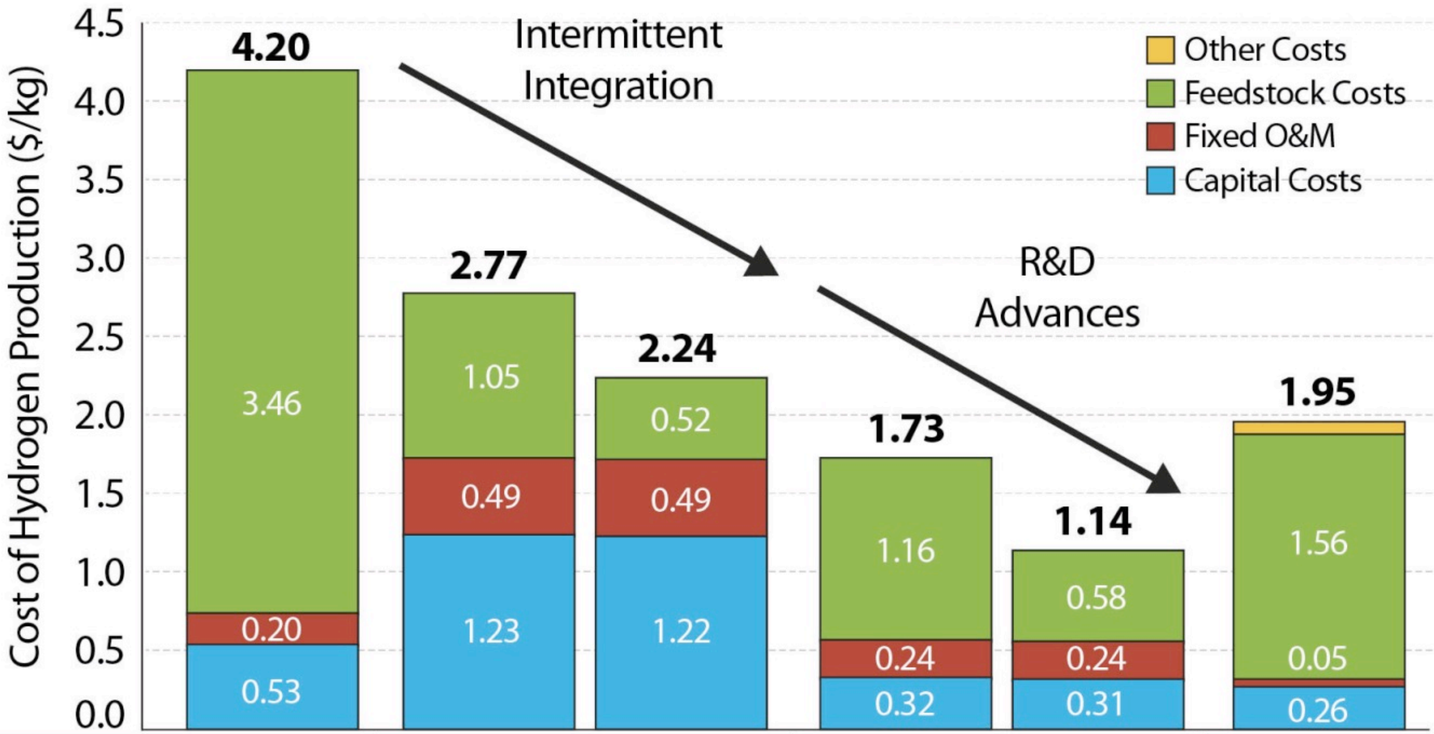
- GTA
- NREL

Relevance

- Relevance (H2@Scale CRADA call)
  – Support development of multi-MW (typically 10-12 MW) low temperature water electrolysis system that integrates with off-shore wind farm
- Objectives:
  – Verify technology at TRL4 level
  – Create input for advancement to TRL5 level

Relevance

Analysis of Electrolyzer-Based Hydrogen Production Costs



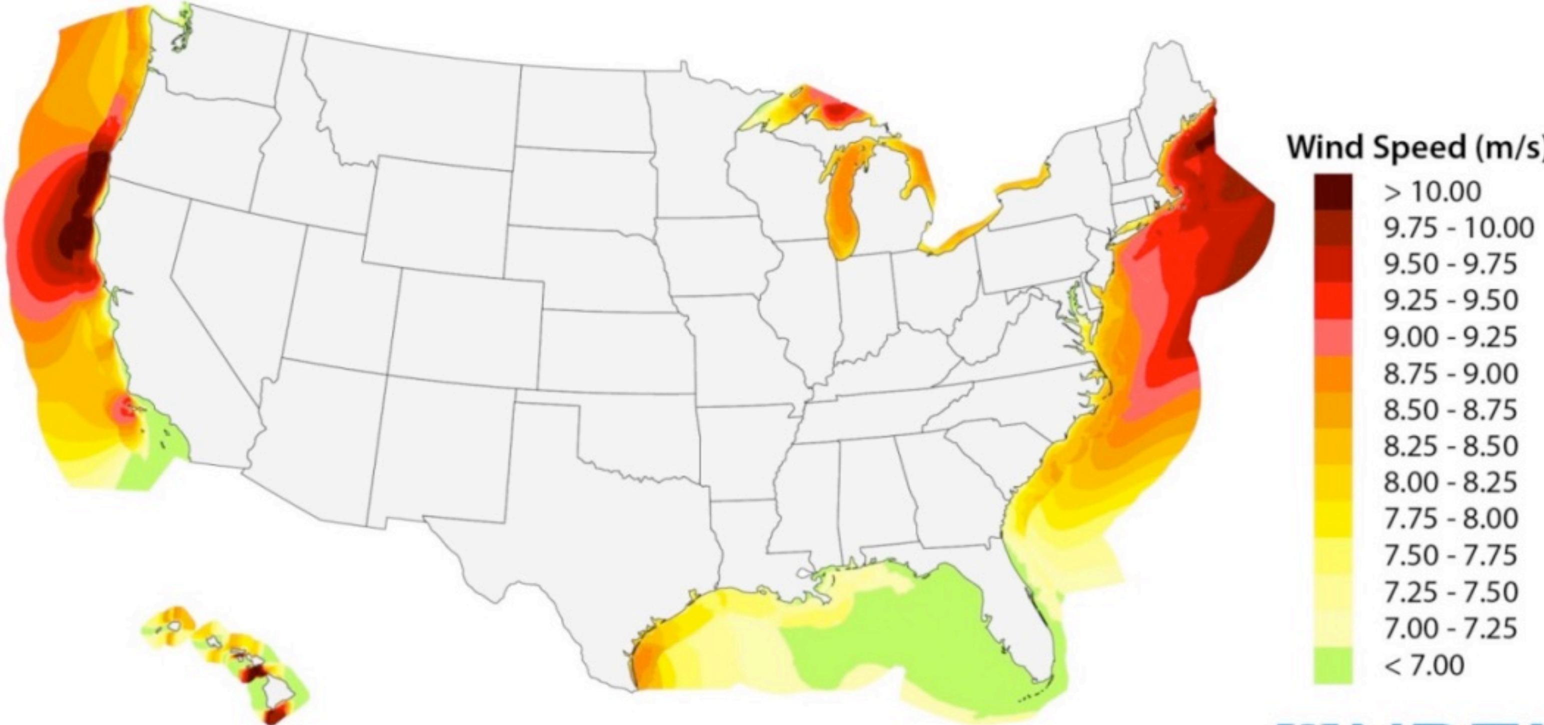
Capacity Factor	97%	40%		40%		0.9
Cost of Electricity	¢6.6/kWh	¢2/kWh	¢1/kWh	¢2/kWh	¢1/kWh	
Capital Cost	$400/kW	$400/kW		$100/kW		
Efficiency (LHV)	66%	66%		60%		
	Electrolyzer					SMR

$100/kW = $100,000/MW

B. Pivovar, N. Rustagi, and S. Satyapal, "Hydrogen at Scale (H2@Scale) Key to a Clean, Economic, and Sustainable Energy System", The Electrochemical Society *Interface,* Spring 2018, pp. 67 – 72.

Relevance

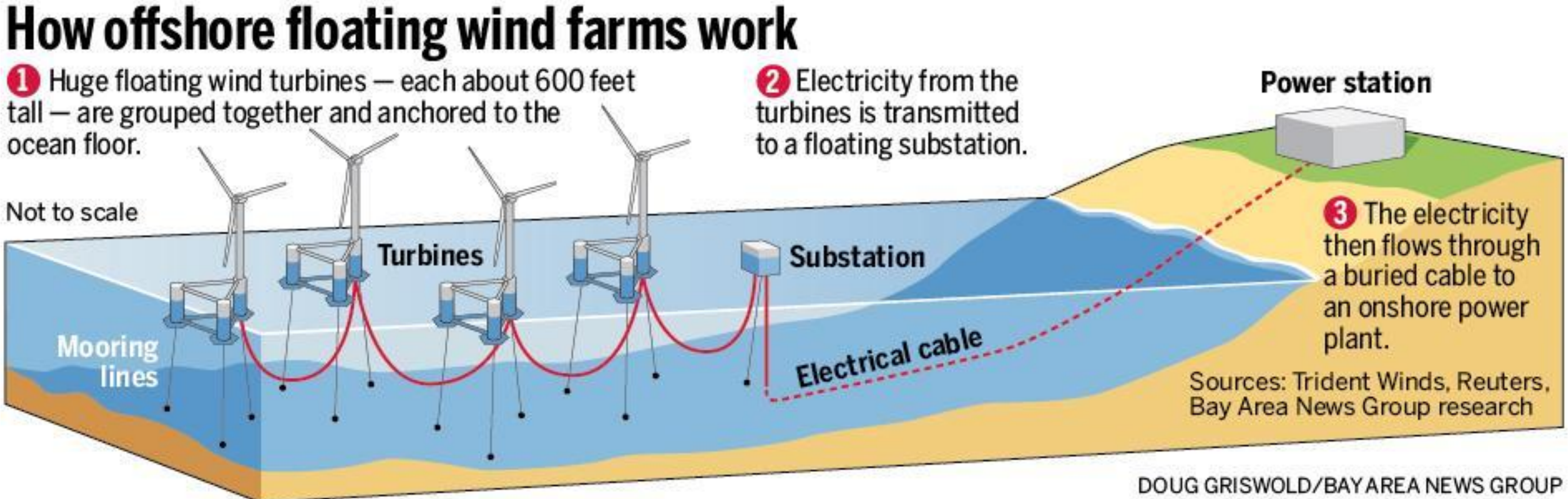
- **In one H2@scale future scenario 12.8 quad of wind electrical power is added**
  (B. Pivovar, DOE FCTO webinar, “H2@scale: Deeply Decarbonizing Our Energy System”, July 28th 2016)
- **12.8 quad = 58 million metric tons H_2/year @ 60% conversion efficiency**
- **Red square area needed for 12.8 quad/year of electrical power offshore wind energy**
- **12.8 quad/year require for example 94,800 wind turbines at 10 MW each; capacity factor = 0.45**



NREL
NATIONAL RENEWABLE ENERGY LABORATORY

- **Adapted from W. Musial, D. Heimiller, P. Beiter, G. Scott, and C. Draxl, *2016 Offshore Wind Energy Resource Assessment for the United States*, Technical Report, NREL/TP-5000-66599, September 2016.**
- **1 quad = 10^{15} BTU**
- **341,000 wind turbines world-wide as of 2017. Anmar Frangoul Freelance Digital Reporter, CNBC.com, 8 September 2017.**

Approach - Technology



ECOSSE Subsea Systems — Cost of Cable Damage

- Niels Kragelund - Head of Wind Energy at Danish Insurers Codan says…..

  "cables account for 90% of the number of offshore wind claims"
  "cables account for 70% of the actual cost of claims"

- Tim Halperin-Smith - Director at Global Insurance brokers Willis says …..

  "of all of the offshore wind claims his firm receives, most incidents occur during installation, half of them due to human error'



High-Voltage Export Cables Cost

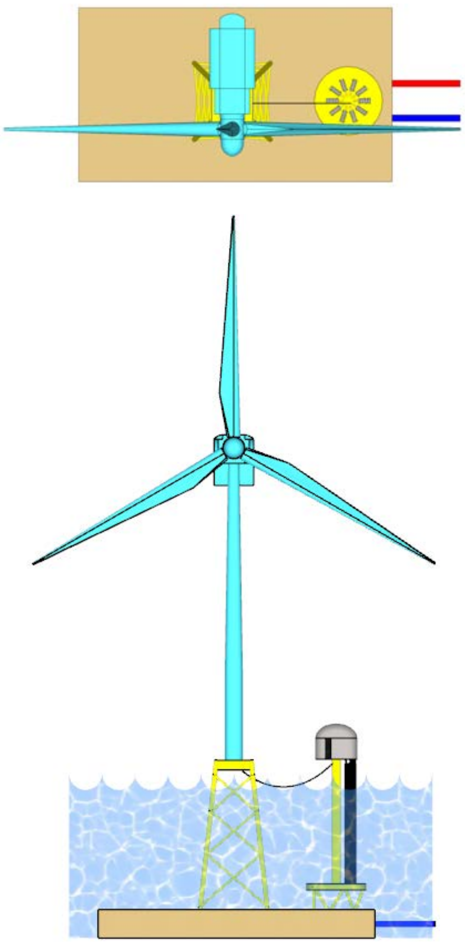
- **25% CAPEX**
- **30% of OPEX are cable related liability insurance premiums :**
  - **90% legal challenges**
  - **70% of those are actual cash settlements**

Wind turbine operating models

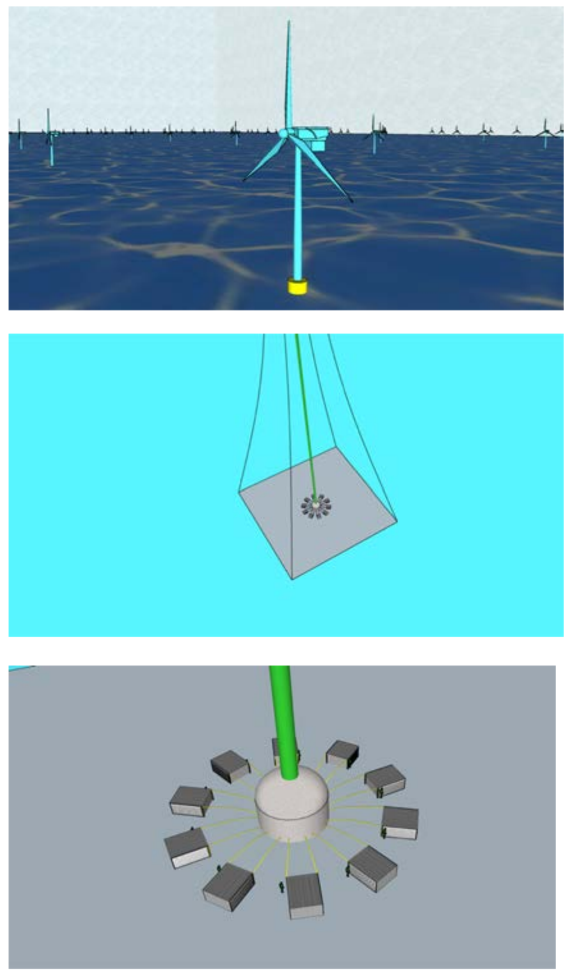
- **Electricity single product**
- **Demand vs. supply challenge**
- **Typically one customer**
- **Benefits from value-added H2**

Approach - Technology

Fixed Base Turbines



Floating Turbines



- **Offshore wind turbine options:**
  - **Fixed platform**
  - **Floating spar buoy**
- **Hydrogen production at wind turbine site**
- **Minimal electrical power transfer loss from turbine to electrolyzer**
- **Hydrogen delivery via gas pipelines**

Approach - Project

- Project leveraged NREL in-situ testing capabilities
- GTA provided prototype electrolysis cell of ≤700W and other specific laboratory equipment as needed
- NREL integrated and commissioned test equipment
- NREL conducted a series of performance tests
- NREL conducted trace gas analysis on the product hydrogen
- GTA utilized information from exchange into next development step

Accomplishments and Progress

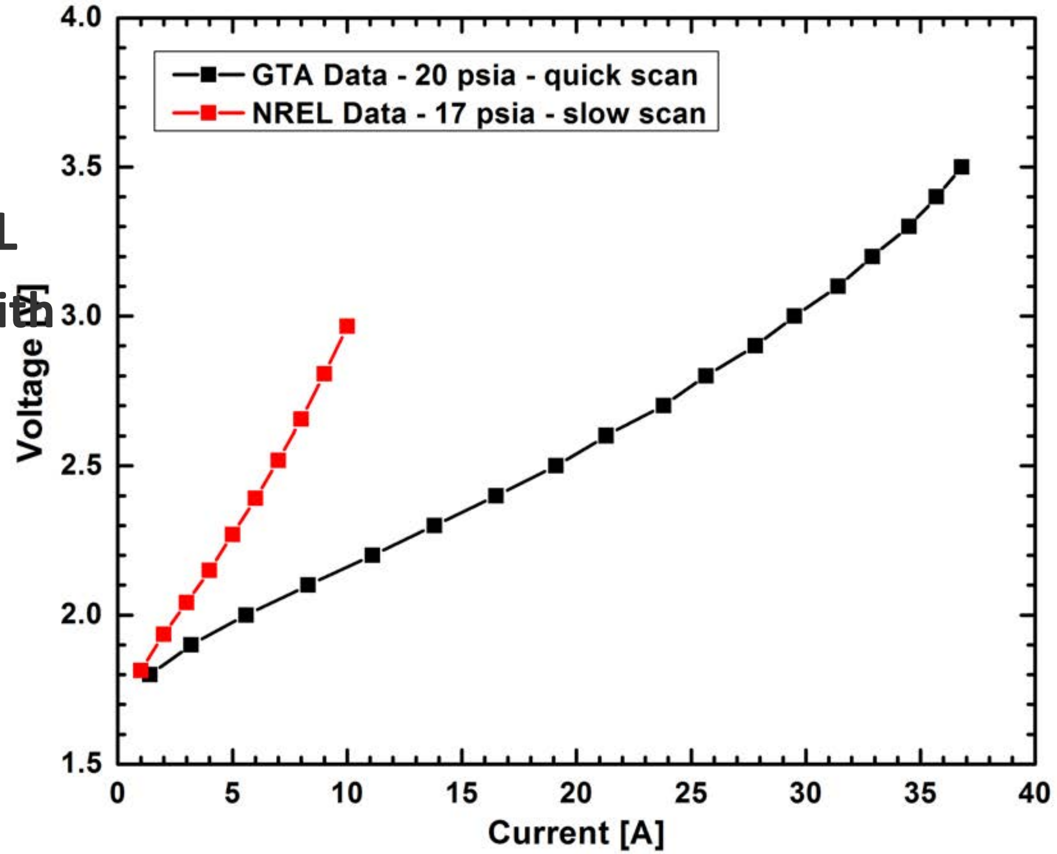
<u>**Test setup**</u>

- **Received, assembled and commissioned at NREL**
- **Integrated into NREL's laboratory environment**
- **Refined with**
  - **Thermocouple testing**
  - **Automated performance experiments**
  - **Automated data collection**
  - **Backpressure control**

Accomplishments and Progress

Verification of Operation

- Electrolyzer performance measured with and without oxygen scrubber
- Performance difference observed between GTA & NREL
  - Assigned to NREL elevation with ambient pressure of 12 psia
  - Bubble size effect expected
  - Only 5 psi gauge pressure operation was available with hardware
- Pressure adjusted to sea level ambient pressures and slightly elevated pressure for fuel quality experiments

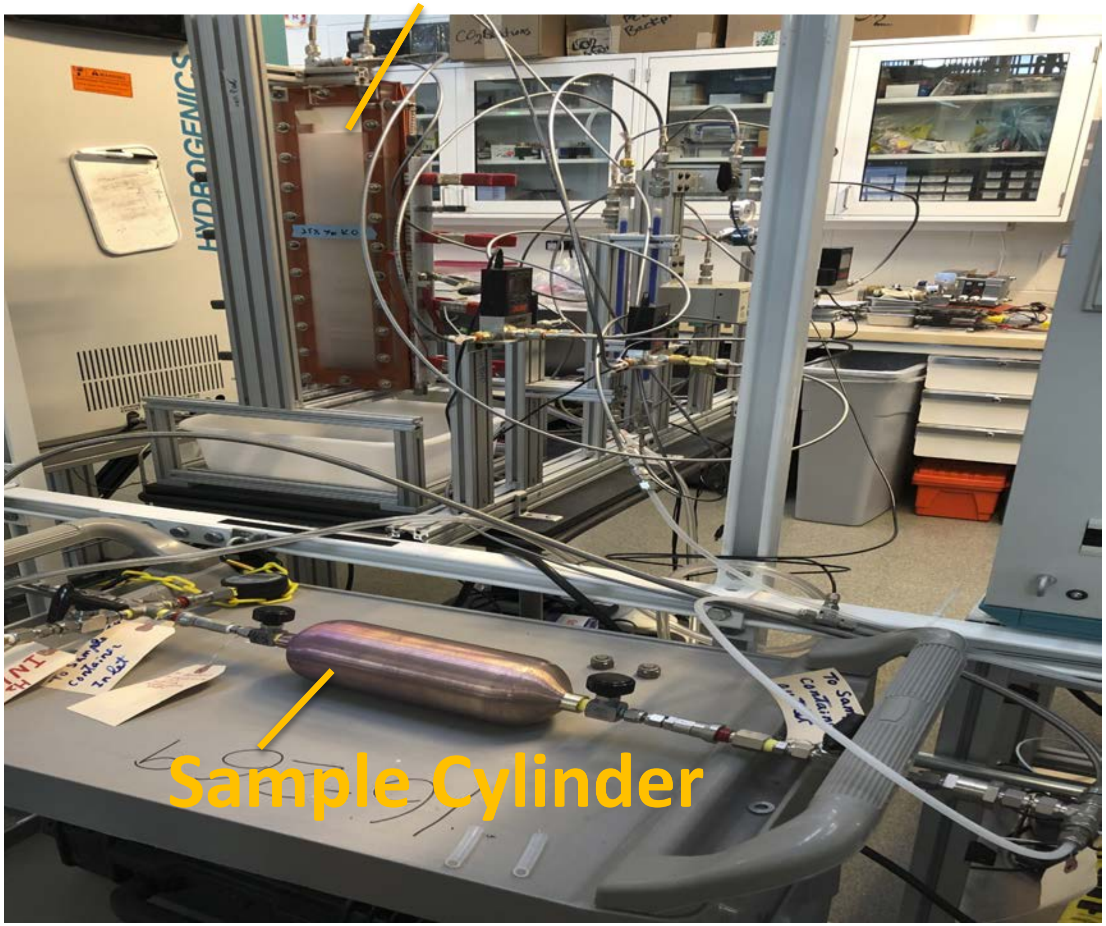


Accomplishments and Progress

Trace Gas Analysis

- Electrolyzer operated with sample cylinder collecting gas samples with and without oxygen scrubber
- Gas analyzed towards SAE J2719 fuels purity standard
- Hydrogen fuel purity reported by GTA verified at NREL

Electrolyzer Stack



Accomplishments & Progress

Characterization of H_2 purity

- Gas collection with custom containers for Hydrogen fuels purity characterization from Smart Chemistry
- Hydrogen purity as measured = 99.96681%
- H_2O, O_2, and CO_2 as measured are above the stringent SAE J2719 fueling standards
- Gas purity met the expectations and are sufficient for many hydrogen applications for H2@scale objectives
- Simple upgrades could be implemented to meet the SAE J2719 fueling standard
- Removing the H_2O, O_2, and N_2, the hydrogen purity would increase to be above 99.999%

SmartChemistry

SAE J2719 — Sample Receipt Date 11/30/2018 — NREL Electrolyzer H_2

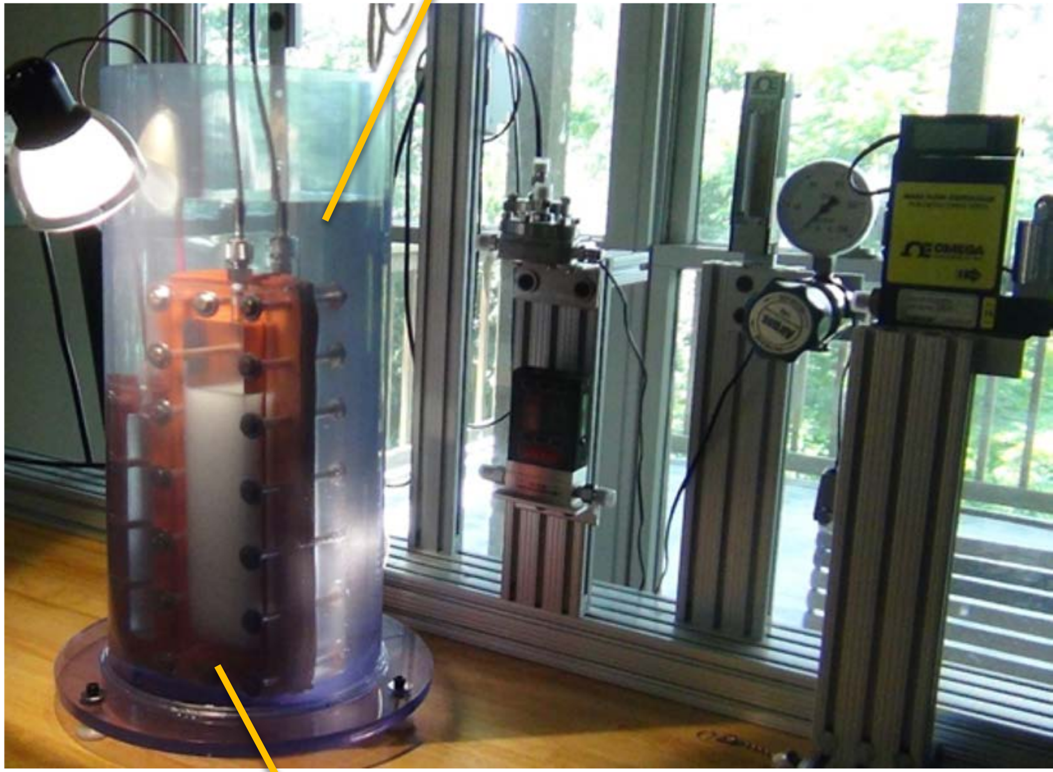
SUMMARY	SAE J2719 Limits (µmol/mol)	Smart Chemistry Detection Limits (µmol/mol)	Concentration (µmol/mol)
H_2O	[illegible]	[illegible]	279
Total Hydrocarbons -C_1 Basis	[illegible]		0.48
Methane			0.15
Acetone			0.039
Benzene			0.008
Ethane			0.21
Ethanol			0.022
Isopropyl Alcohol			0.011
Toluene			0.025
Hexanal			0.010
Octane			0.009
O_2 NREL Electrolyzer H_2	[illegible]	[illegible]	9.4
O_2 NREL Electrolyzer H_2 WITHOUT OXYGEN TRAP			3472
He	[illegible]	[illegible]	< 10
N_2 & Ar	[illegible]		
N_2		[illegible]	40
Ar		[illegible]	1.4
CO_2	[illegible]	[illegible]	2.3
CO	[illegible]	[illegible]	0.023
Total S	[illegible]		0.00082
Hydrogen Sulfide		[illegible]	0.000015
Carbonyl Sulfide		[illegible]	0.00060
Methyl Mercaptan		[illegible]	< 0.00001
Ethyl Mercaptan		[illegible]	< 0.00001
Dimethyl Sulfide		[illegible]	0.0000085
Carbon Disulfide		[illegible]	0.000066
Isopropyl Mercaptan		[illegible]	< 0.00001
Tert-Butyl Mercaptan		[illegible]	< 0.00001
n-Propyl Mercaptan		[illegible]	< 0.00001
Thiophene		[illegible]	0.0000098
Diethyl Sulfide		[illegible]	< 0.00001
n-Butyl Mercaptan		[illegible]	< 0.00001
Dimethyl Disulfide		[illegible]	0.000056
Tetrahydrothiophene		[illegible]	0.000056
Formaldehyde	[illegible]	[illegible]	0.0012
Formic Acid	[illegible]	[illegible]	< 0.003
Ammonia	[illegible]	[illegible]	< 0.03
Total Halogenates	[illegible]		0.015
Cl_2		[illegible]	< 0.003
HCl		[illegible]	< 0.014
HBr		[illegible]	< 0.008
Total Organic Halides (32 compounds in red and bold listed in "Non-Methane Hydrocarbons") (ASTM D7892, Smart Chemistry limit is for each individual organic halide)		[illegible]	0.015
Ethene, chlorotrifluoro-			0.0026
Hexane, 1,1,1,2,2,3,3,4,4,5,5,6,6-tridecafluoro-			0.0012
1-Butene, 4,4-dichloro-1,1,2,3,3,4-hexafluoro-			0.0064
1-Propene, 3-chloro-1,1,2,3,3-pentafluoro-			0.0048
Particulate Concentration	[illegible]		Not Required
Particulates Found & Size			Not Required
Hydrogen Fuel Index	[illegible]		99.96681%

Accomplishments and Progress

TRL4 to TRL5 Transition

- Component validation in relevant environment
- Simulated off-shore operation by submersion of electrolysis stack in seawater
- Redesign of stack for TRL5 demonstration
- Successful operation of submerged system
- **Screening test of various diaphragm materials underway**

Seawater



TRL5 Electrolyzer Stack

Collaboration and Coordination

- **Industry partner: GTA**
  - **Defined objectives**
  - **Defined operating conditions**
  - **Provided information about specific operating procedures**
  - **Provided specialized equipment**
  - **Provided data measured at GTA**
- **National lab partner: NREL**
  - **Performed system setup in NREL lab for ≤700W cell**
  - **Performed refinements to experimental setup**
  - **Confirmed GTA performance**
  - **Characterized hydrogen quality via trace gas analysis for GTA**

Remaining Challenges and Barriers

- **Scope of project completed**
- **No challenges remain within the scope of the project**

Proposed Future Work

- **Project completed**
- **No future work planned within this project**

- **Future work outside this project**
  - **Demonstrate functionality in various scenarios:**
    - **Simulated ocean floor pressure submersed in seawater**
    - **Actual off-shore environment**
  - **Investigate performance improvement through**
    - **Pressure operation**
    - **Electrode optimization**

Technology Transfer Activities

- **This project did not result in any technology transfer**

Responses to Previous Year Reviewer's Comments

- Project was not reviewed last year

Summary

- **NREL and GTA successfully collaborated on verification and characterization of GTA's submersible electrolyzer technology for off-shore operation**
- **Verification of performance data at NREL**
- **Successful characterization of hydrogen fuels purity**
  - **Hydrogen purity as measured = 99.97%**
  - **Theoretical purity above 99.999% after removal of H_2O, O_2, and N_2**

Acknowledgements

GTA

- **Elias Greenbaum, Industry Partner PI**

NREL

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Thank You

www.nrel.gov

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Project Task Details

- **Task 1:**

  GTA will send to NREL prototype electrolysis cells of less than 700W total power. To facilitate the collaboration and optimize resources, GTA will also send to NREL ancillary equipment such as pumps, dryers, programmable DC 750 W power supply, and catalytic O2 cleanup of the hydrogen. NREL will prepare the KOH electrolyte solution in distilled water.
- **Task 2:**

  NREL will run a series of steady-state hydrogen and oxygen producing polarization (IV) tests on the stack, and measure the output quantity and quality of the hydrogen. Oxygen will be vented. NREL will run a trace gas analysis on the product hydrogen. Once the system is set up, NREL may run an initial ~100 hour durability test to look for early signs of degradation.
- **Task 3:**

  NREL will prepare a report for GTA, and return all GTA equipment at the end of the project.