Scalable Electrolytic Systems for Renewable Hydrogen Production

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National Renewable Energy Laboratory
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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

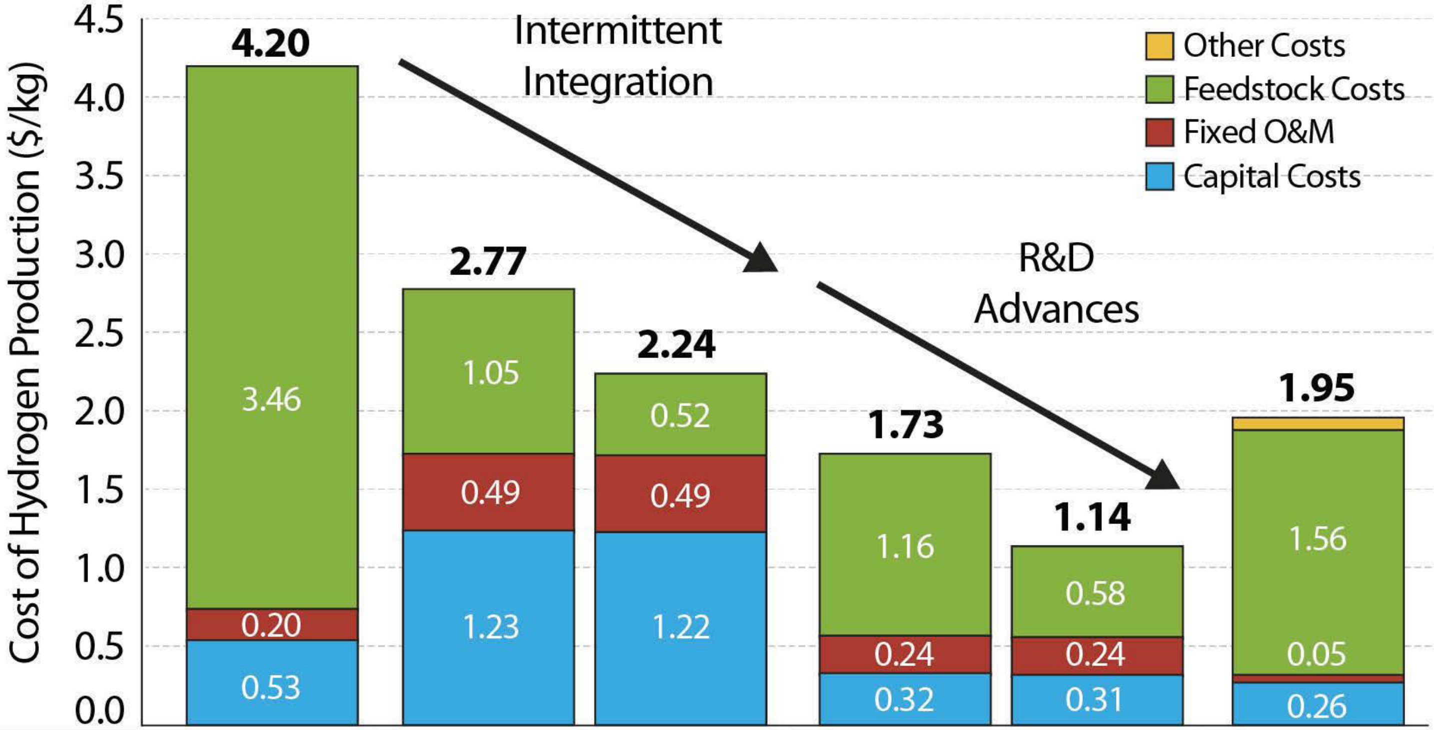
Partners

- 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

Analysis of Electrolyzer-Based Hydrogen Production Costs



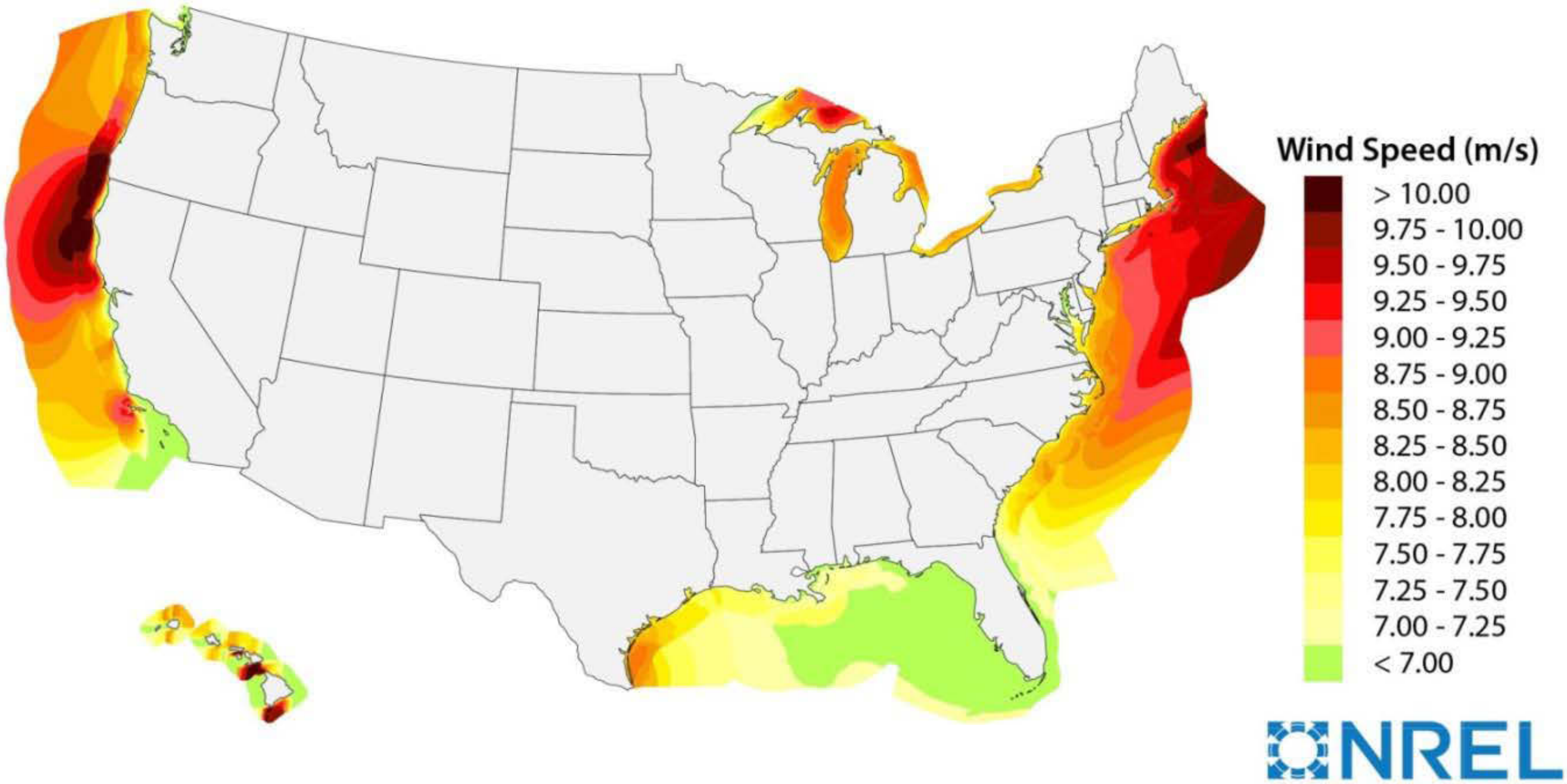
Capacity Factor	97%	40%		40%		0.9
Cost of Electricity	¢6.6/kWh	¢2/kWh	¢1/kWh	¢2/kWh	¢1/kWh	
Capital Cost	$400/kW	$400/kW		$100/kW		
Efficiency (LHV)	66%	66%		60%		
	Electrolyzer					**SMR**

$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.

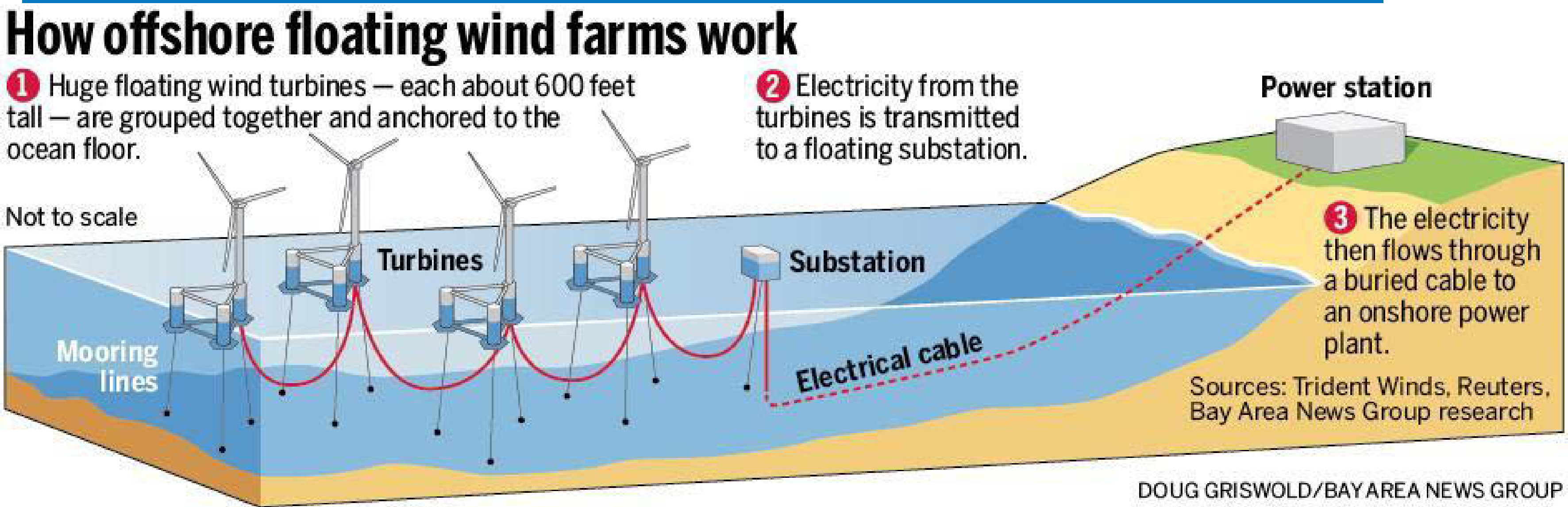
Relevance

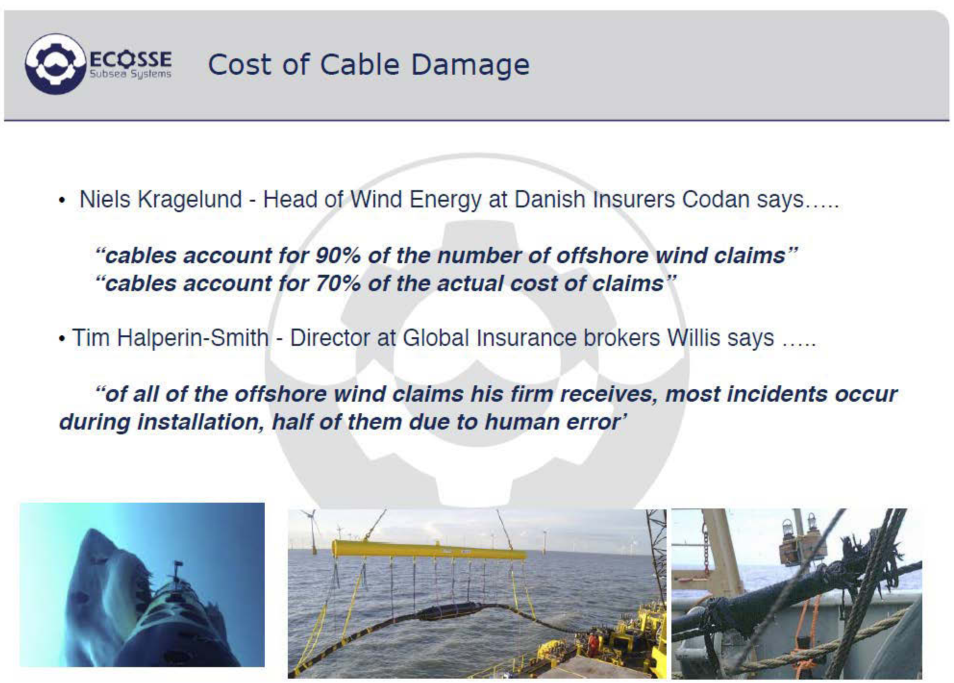
- **In one H2@scale future scenario 12.8 quad of wind electrical power is added**
  (B. Pivovar, DOE FCTO webinar, "H2@scale: Deeply Decarbonizing Our Energy System", July 28th 2016)
- **12.8 quad = 58 million metric tons H_2/year @ 60% conversion efficiency**
- **Red square area needed for 12.8 quad/year 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**



- **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





High-Voltage Export Cables Cost

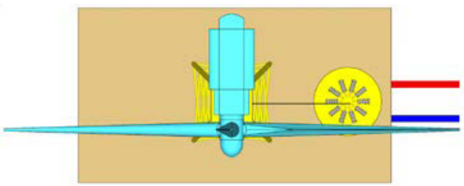
- **25% CAPEX**
- **30% of OPEX are cable related liability insurance premiums :**
  - **90% legal challenges**
  - **70% of those are actual cash settlements**

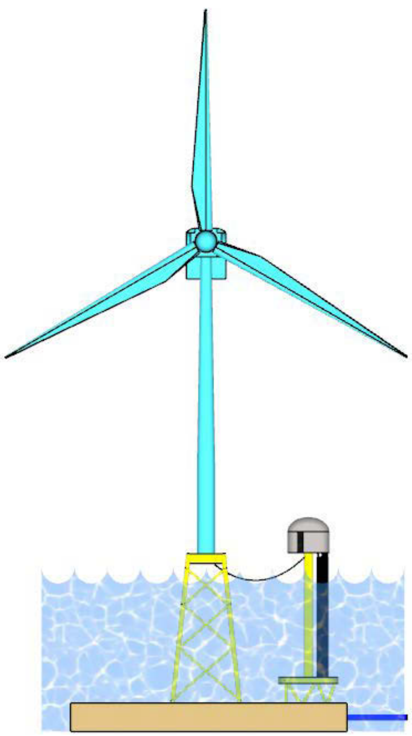
Wind turbine operating models

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

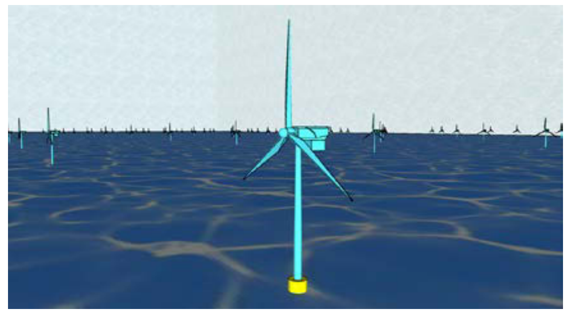
Approach - Technology

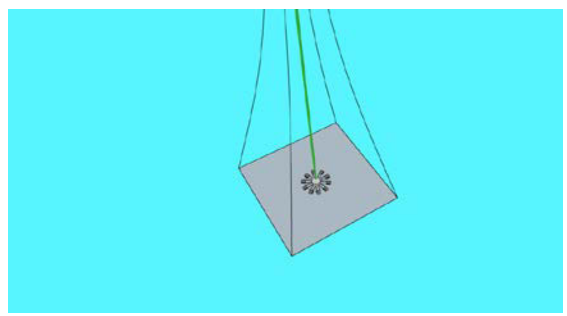
Fixed Base Turbines

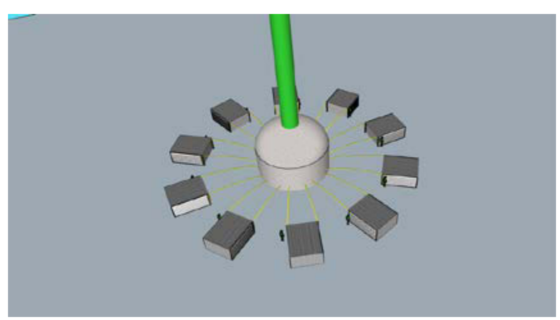




Floating Turbines







- **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

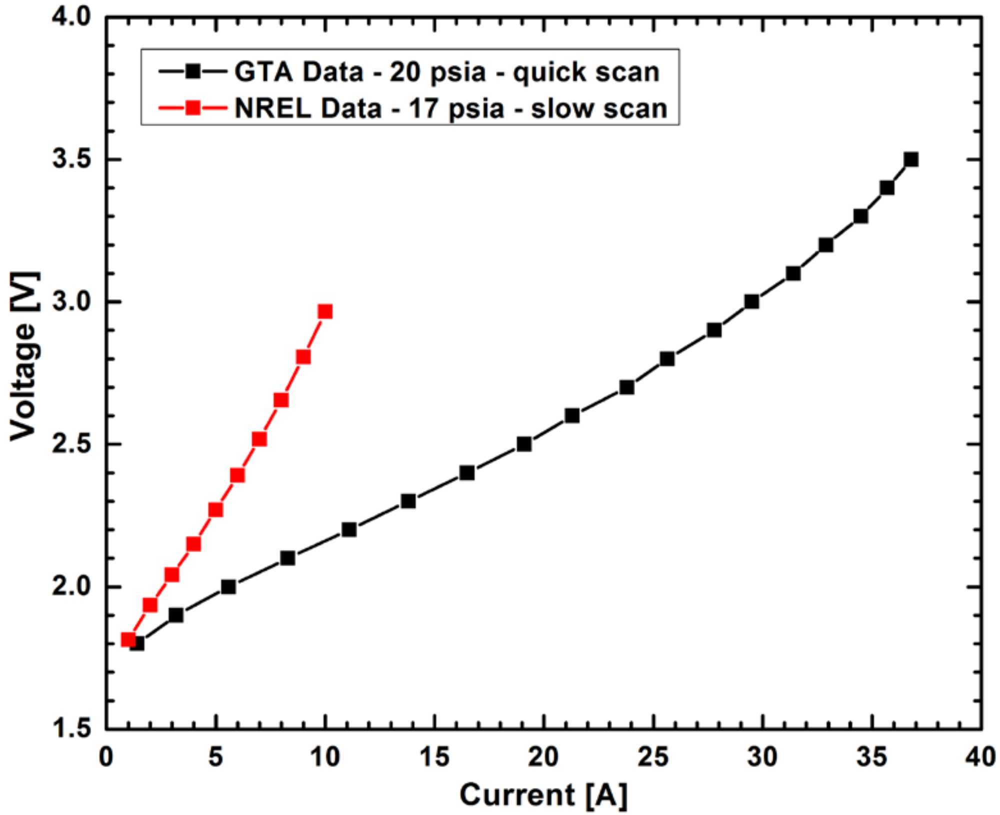
Test setup

- 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

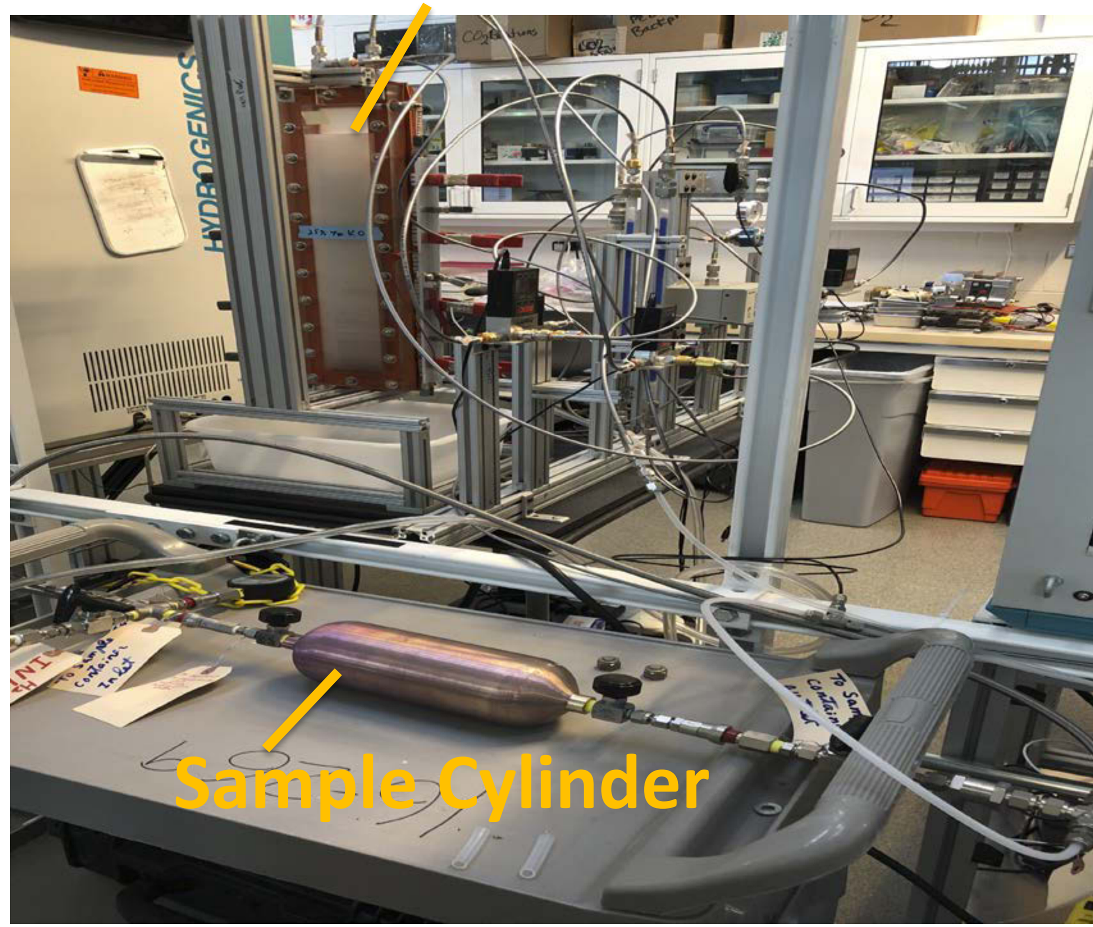
- Electrolyzer performance measured with and without oxygen scrubber
- Performance difference observed between GTA & NREL
  - Assigned to NREL elevation with ambient pressure of 12 psia
  - Bubble size effect expected
  - Only 5 psi gauge pressure operation was available with hardware
- Pressure adjusted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



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

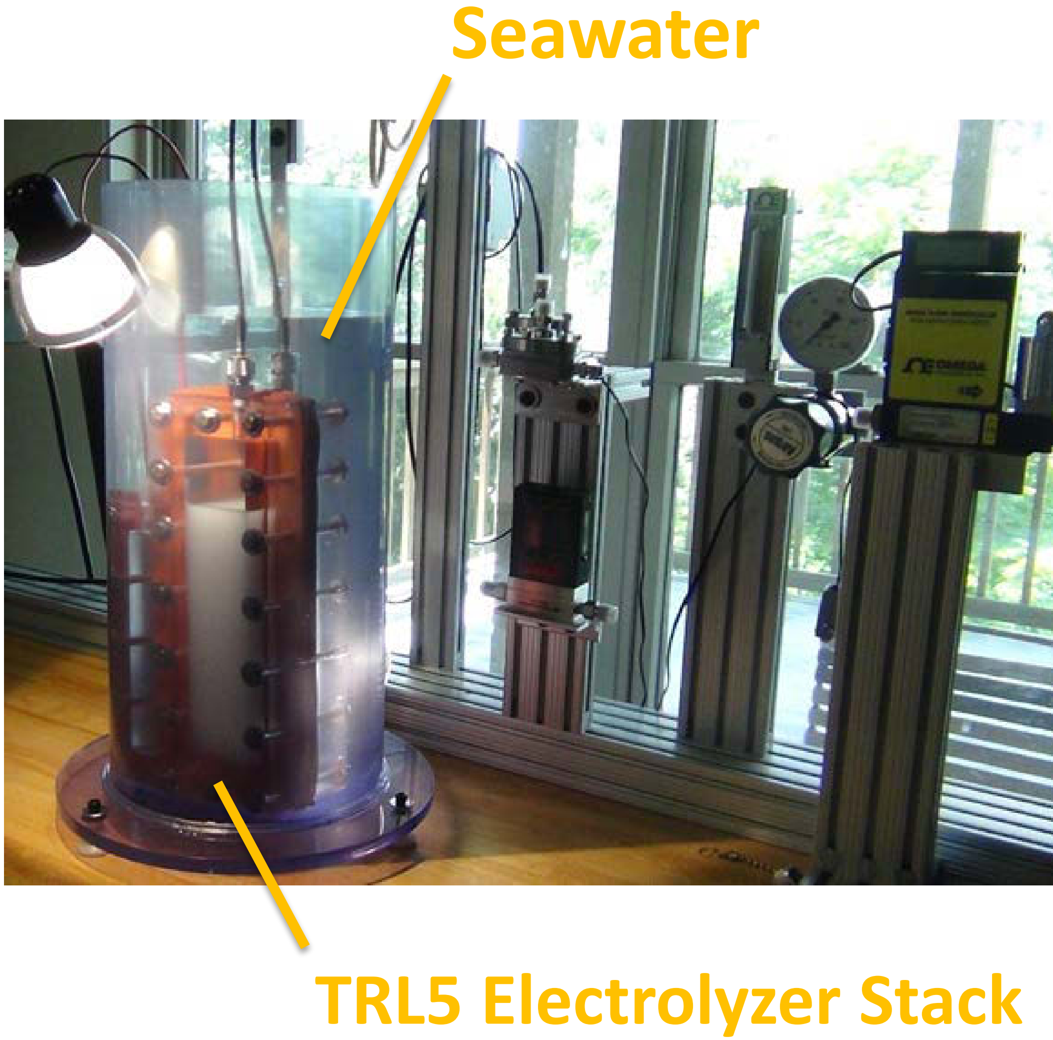
SAE J2719 — Sample Receipt Date 11/30/2018 — NREL Electrolyzer H_2

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		0.4	1.4
CO_2	[illegible]	[illegible]	2.3
CO	0.2	[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	0.2	[illegible]	< 0.003
Ammonia	0.1	[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**



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

- **Matthew Post, system integration sub-lead**

Thank You

www.nrel.gov

NREL/PR-5900-73493

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