DOCKETED	
Docket Number:	20-EPIC-01
Project Title:	Development of the California Energy Commission Electric Program Investment Charge Investment Plans 2021-2025
TN #:	240032
Document Title:	William C Leighty Comments - EPIC RDD Opportunities in Green Hydrogen from Off-Grid Wind + Solar
Description:	N/A
Filer:	System
Organization:	William C Leighty
Submitter Role:	Public
Submission Date:	10/9/2021 10:33:38 AM
Docketed Date:	10/9/2021

Comment Received From: William C Leighty
Submitted On: 10/9/2021
Docket Number: 20-EPIC-01

EPIC RDD Opportunities in Green Hydrogen from Off-Grid Wind + Solar

EPIC investments should fund Research, Development, and Demonstration (RDD) programs to invent and commercialize novel technologies by which to relieve the electricity Grid of the several costly burdens presented below , for which the Grid is probably a technically and economically suboptimal solution:

1. Transmission and firming storage from Variable Energy Resources (VER's) such as large, remote, wind and solar and wind + solar plants;

2. Profitably capturing and delivering otherwise-curtailed VER-source energy, now ~ 1,500 GWh / year in CA alone;

3. Supplying the very large amount of high-purity "green" hydrogen (H2) required in CA in year 2050, for only highway transportation rubber-tired vehicles of all sizes, from wind + PV, for example:
> http://www.leightyfoundation.org/wp-content/uploads/WP16-A-1.pdf
> http://www.leightyfoundation.org/wp-content/uploads/Poster-A-Backside-REV-7Jun16.pdf

4. Delivering the ultimate in Distributed Energy Resources (DER), Deep Hot Dry Rock Geothermal (DHDRG) energy, as summarized in these resources:
> http://www.leightyfoundation.org/wp-content/uploads/H2-SystemsStudy-20Oct20.pdf
> http://www.leightyfoundation.org/wp-content/uploads/Bill.Leighty.4Aug-Dilemma-13Jul21.pdf
> "Poster pitch" for the above: (4 min) https://vimeo.com/583485600

5. Solving California's present dilemma: (a) "Harden" the grid to prevent more forest fires; (b) Invest instead in underground pipeline systems for gathering, transmission, storage, and distribution of renewables-source energy; or (c) accelerate commercialization of the ultimate in DER -- DHDRG energy -- which requires no new transmission nor energy storage:
http://www.leightyfoundation.org/wp-content/uploads/Bill.Leighty.4Aug-Dilemma-13Jul21.pdf

Please see attachments. Our small company, Alaska Applied Sciences, Inc. (AASI) has applied for several GFO's, over the past six years, for which the important RDD project -- for which AASI is well-positioned to perform -- was not a good match, and consequently denied funding. Proceeding from the above rationale, AASI suggests at least one early GFO by which novel, proprietary, and profitable off-Grid wind, PV, and synergistic co-located and co-generating wind + PV plants, may be dedicated to

Complete System Solution for Low-cost Storage of Low-cost "Green Electrolytic H2"

Technical Merit

A Complete System approach is necessary to achieve the GFO goals and California (CA) C-free energy goals, and to realize the potential of "green electrolytic H2" for the IOU ratepayers, all CA energy users, and Earth.

We accelerate California's 2045 goal of 100% carbon-free electricity, simultaneously achieving :

1. New electric utility regulation to allow *virtual* H2 storage on customer side of meter, with low-cost *physical* H2 storage in "packed" pipelines and large remote salt caverns: UC Davis

2. Low-cost "green" H2 fuel from wind + PV co-located and co-generating, on- or off-grid, via an enabling novel power electronics and controls system, reducing capex and opex: Auburn Univ

3. New polymer-metal-hybrid linepipe, immune to H2 permeation and embrittlement, enabling underground pipeline H2 transmission with "free" energy storage -- both "free" power-to-gas "packing" of extant natural gas and of new, dedicated, pure H2 pipeline systems: Smart Pipe Co

4. Careful consideration of "the other hydrogen", anhydrous ammonia (NH3) as a low-cost, Carbon-free, energy carrier, storage medium, and fuel, of ARPA-E R&D: Clear Air Energy, LLC.

The Issue

"Green electrolytic H2", made from wind + PV electricity in California (CA) should not be *physically* stored on the electric utility customer's side of the meter, but may be *virtually* stored via new utility regulation policy. Green H2 may be stored at very low cost, or "free", by "packing" the pipelines to maximum pressure when wind and PV outputs are strong. But, new pipeline materials must be developed for safe transmission of this H2: 3, above. The customers' H2 may be returned to them for conversion to electricity, via CHP, for transport fuel, or sold to others.

Project Innovation + Advantages

Vast new land areas, without electricity transmission, will become open to wind + PV harvest, dedicated to H2 production, with no grid connection, with all captured electricity converted to "green H2", delivered to extant natural gas or new high-purity H2 pipelines, for "free" transmission and storage, connecting to low-cost annual-scale firming storage in salt caverns.

A large new market for "renewable H2", enabled by 3 and 2, above, will reduce capex by scale-up of all electrolysis and other H2 infrastructure, including dedicated hi-P H2 pipelines.

This project will develop novel power electronics and controls technology to allow wind turbines and PV arrays, dedicated to green H2 production, with no grid connection, to deliver their electrolytic H2 fuel directly to underground pipelines. This lowers the cost of green H2 by simplifying the wind turbines and windplants, and allowing PV to deliver electricity at DC to the electrolysis stacks arrays directly and efficiently. A pilot plant, designed and built at Auburn University, will be installed at the project's operating North Palm Springs wind + PV plant for technology proof-of-concept and demonstration, SCADA data validation of project objectives, pre-commercialization design advances, and prep for technology transfer via robust novel IP.

Anticipated Benefits for California Ratepayers

Electric utility customers will thus (1) be protected from rate increases required to build costly upgrades and expansion of the grid; (2) enticed to invest in new synergistic wind + PV plants dedicated to H2 production; (3) allowed, by new regulatory policy to be developed in this project, to store customers' and IOU's green H2 *virtually* on customer's side of meter. This will (1) accelerate green H2 production and decarbonization of the CA electricity and transportation sectors; (2) allow CA electric utilities to become "energy utilities", via a new green energy system and H2 and NH3 fuels for transportation, fixed CHP, and industrial uses.

"Green electrolytic H2" transmission and "packing" storage in extant "gas" grid, new H2 lines. CO2-emission-free wind + PV energy will have a safe, low-cost, pure H2 transmission and storage system available via the novel polymer-metal-hybrid linepipe developed by this project, with *virtual* access to this low-cost green H2 storage via the novel regulatory policy(ies) designed for this project by the Institute of Transportation Studies (ITS), UC Davis.

Specific Benefits

- Complete system solution for low-cost storage of low-cost "green electrolytic H2"
- Lower-cost, CO2-emission-free, green H2 from on- or off-grid wind, PV, and wind + PV plant
- New polymer-metal-hybrid linepipe developed for safe, green H2 transmission and storage
- Low-cost, even "free" green H2 storage by "packing" of natural gas and green H2 pipelines
- Attract investment in "green H2" production by enabling *virtual* H2 storage on customer side of meter, with low-cost, large-scale, safe *physical* storage in pipelines, salt cavern, NH3 tank
- Accelerate success of CA goal: 100% carbon-free electricity by 2045; all energy by 20??
- Accelerate "electrification of transportation" by reducing LCC of all sizes of fuel cell vehicles
- Enable CA IOU's to become energy companies, via profitable H2 sales for transport, CHP
- Energy security for CA, by harvesting more indigenous green energy and green H2
- Protect civilization from ravages of sea level rise and other "climate change" dangers

Table 1: Competition Matrix

Comparable Attribute	Applicant's Technology: now	Applicant's Technology: post-grant	Current Leading Technology / Competitor: today
Energy storage capex $ / kWh	Gaseous H2 pipeline $ 10 / kWh	Gaseous H2 pipeline $ 1 / kWh	Battery $ 200 - 300 / kWh
Plant gate cost, $ / kg H2, renewables-source H2	SEIG-mode wind + DC bus PV $ 5 / kg	SEIG-mode wind + DC bus PV $ 2 / kg	Wind, PV source $ 6 / kg
Utility regulatory policy for "green electrolytic H2 storage"	none	Provided to CA Gov and Legislature	none
H2 vs NH3 tech and econ compare	none	Credible comparison study	ARPA-E "REFUEL" program
Transmission capex, $ / GW-km	$ 2 million	$ 1 million	Electricity, HVDC: $ 3 million

Team Qualifications, Capabilities and Resources

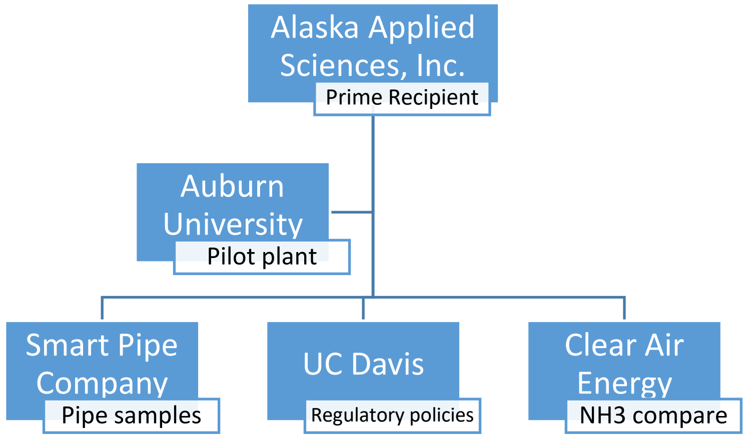


Figure 1: Organization Chart

Applicant, Alaska Applied Sciences, Inc., (AASI) owns the North Palm Springs wind + PV plant which is the test bed for the SEIG-mode proof-of-concept pilot plant to be designed and built by Auburn Univ. AASI owns the electrolysis plants, DI water plant, and PDC Machines H2 compressor to be used at the operating wind + PV plant test bed.

AASI completed a DOE-funded R&D project in 2005:

> Proof-of-Concept Manufacturing and Testing of Composite Wind Generator Blades Made by HCBMP (High Compression Bladder Molded Prepreg)
> Final Technical Report for the U.S. Department of Energy
> Grant Number DE-FG36-03GO13140

Auburn University and UC Davis are research universities with many successful projects.

Smart Pipe Company has designed and commercialized a polymer-composite linepipe manufacturing process over the past decade, which is now successful and ready for the R&D innovation proposed here, at their plant in Houston.

TRL

- Pilot plant for Palm Springs wind + PV plant test and demo: SEIG mode wind + DC bus PV integration, design and build by Auburn Univ: TRL 4 --> TRL 6-7

  SEIG-mode pilot plant: power electronics and controls technology is mature. This is a novel combination to be demonstrated at AASI, applicant, wind + PV plant in North Palm Springs, CA

- Polymer-metal-hybrid linepipe for high pressure GH2 service, with low H2 permeability and immune to H2-embrittlement : TRL 4 --> TRL 6-7

  Polymer-metal-hybrid linepipe: Smart Pipe Company pipe manufacturing process is mature, but no pipe with integral metal H2 permeation barrier has been produced and tested for H2 permeation.

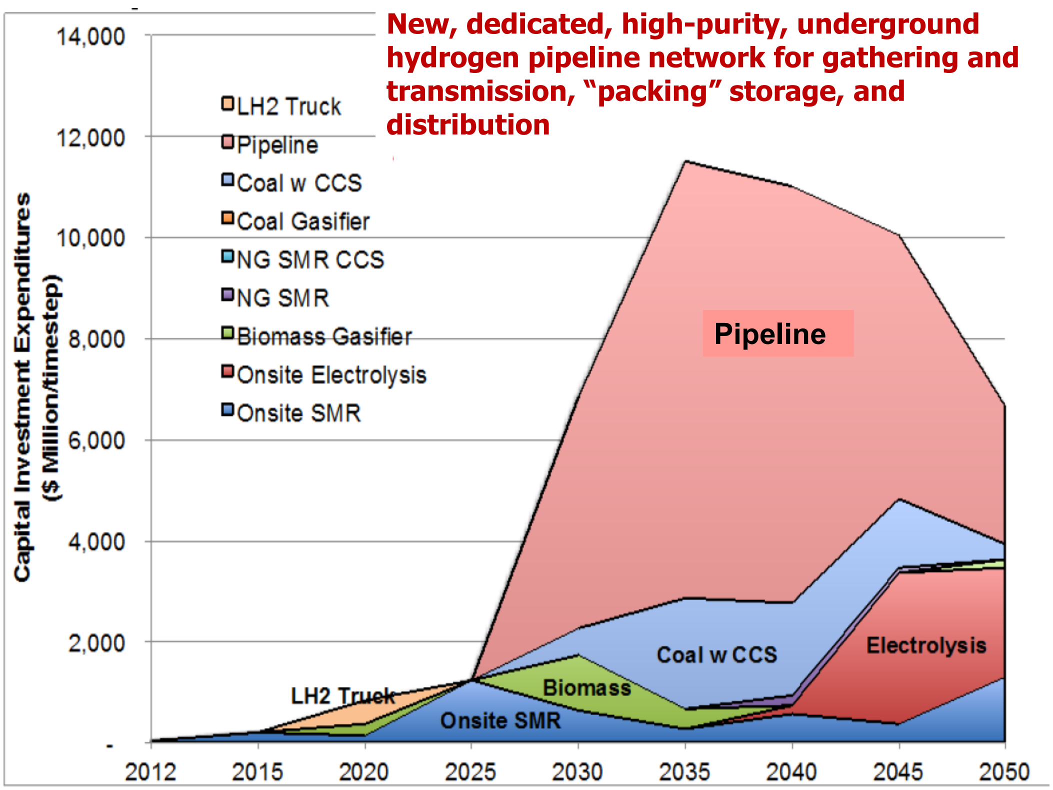


Figure 2: In 2050 CA will need ~7 million tons of high-purity "green H2" per year for transportation fuel, which will require ~ 250 GW of nameplate wind + PV capacity, in addition to ~ 200 GW of wind + PV nameplate for electricity demand. And, a very large, new, high-purity H2 pipeline network, with very large "free" annual-scale firming electricity or H2 energy storage capacity by "packing" pipelines. IOU customers participate, reducing rates and CO2 emission via new regs.

Budget and Cost Effectiveness

Table X: Task Budget

Task (by major task)	Energy Commission Funds	Match Share	Total
Task 1: General Project Tasks	$ 657,335	$ 188,966	$ 846,301
Task 2:			
Task [TBD-1]: Evaluation of Project Benefits			
Task [TBD-2]: Technology/ Knowledge Transfer Activities *			

*** Requires 5% of total CEC funds**

Funds Spent in California

This project proposes to spend $ 471,650 of Energy Commission funds in California.

Disadvantaged Communities

All Californians will benefit from the several components of this project, especially disadvantaged people and communities for whom energy is a cost burden and the effects of fossil fuel consumption comprise a health burden. An annually-firm, dispatchable, affordable, price-stable, supply of "green", CO2-emission-free electricity and H2 fuel, as enabled by this projects diverse successes, will benefit persons, communities, all of California, and the world. California employment at all levels will benefit from production and export of products to be advanced by this project.

Reference: Year 2015	**GW**
Total installed nameplate wind generation in California	6
Total installed nameplate solar generation in California	12
ELECTRICITY: California "Power Mix"	**GWh**
2014: Total electricity consumed	296,843
2050: Total electricity demand "Power Mix" is 130 % of 2014	385,896
ELECTRICITY in Year 2050	**GW**
Equivalent nameplate wind generation capacity @ 40 % CF	85
Equivalent nameplate solar generation capacity @ 35 % CF	97
TRANSPORTATION Hydrogen Fuel in Year 2050	**GW**
Equivalent nameplate wind generation capacity @ 40 % CF	126
Equivalent nameplate solar generation capacity @ 35 % CF	130

Figure 3. In CA in 2050 the market for CO2-emission-free (CEF) transportation fuel energy will exceed the market for CEF grid electric energy. Large, new, dedicated, high-purity Hydrogen pipeline systems in CA will accelerate distributed wind and PV deployment, providing a lower-cost transmission, storage, and distribution alternative to electricity systems, opening large windy and high-solar-irradiance land areas now without electricity transmission.

Project goals, within and beyond California

This integrated Whole System will approach TRL 6-7:

1. Reduce the cost of wind-source energy delivered as high-purity H_2 fuel by reducing the capex and opex of wind turbines and windplants, by simplifying both, by dedicating windplant production to H_2 fuel with no connection to the Grid; measure and demonstrate novel system on operating Palm Springs windplant; demonstrate potential for ~ 20% lower COE at windplant gate, as GH2 vis-a-vis as MWh.

2. Provide a new market for wind energy, aside from the PTC-driven Grid: H_2 and NH_3 C-free fuels for transportation and stationary CHP, via GH2 and NH_3 pipeline networks, low-cost storage.

3. Design, build, test, demonstrate, and improve a novel system of integrated [SEIG + close-coupled electrolysis + SCADA], on an operating windplant, to emphasize optimization of complete

C-free renewables-to-fuel systems, including wind capture and conversion, pipeline gathering, transmission, and storage, integration with other energy sources and systems, and efficient end-use as both transportation and CHP fuels. Demonstrate potential for ~ 10% increase in energy conversion efficiency.

4. Advance SEIG and electrolysis technology via an integrated system, potentially optimized by Machine Learning AI (ML-AI), to pre-commercialization, to produce both H_2 and NH_3 fuels at minimum cost from electric energy from wind, solar, and other sources, centralized and distributed. Demonstrate stable, autonomous, safe, efficient wind energy capture and conversion at all windspeed.

5. Prove new linepipe materials for safe, economical, underground, continental scale GH2 pipeline systems. Fig 15. Reduce the cost of HE-immune, corrosion-free pipeline for GH2 service, for gathering, transmission, "free" packing storage, and distribution of VG-source (wind, solar, other) H_2 fuel.

Technical Approach

Auburn University: Assessment of Technical Concept Feasibility Figures 4-8

1. Analyze and characterize the renewable energy (RE) + H_2 Electrolyzer system pilot plant, both at the AU Laboratory and at the AASI Palm Springs wind + PV plant test site. 2. Analyze the optimal “right-sizing” of both wind and solar generation nameplate capacity when paired with a single H_2 electrolyzer for integration with a microgrid system. 3. Analyze how the co-generation value-added byproduct system performs under different contingencies in the power system throughout the day. How can we balance supply (PV during the day, wind during the night) and demand (loads variations) during cloudy days and low wind periods? How shall we benefit from wind and solar forecasting? 4. Assess compression technology and options for shipment of the H_2 produced at the generating site to the customer, probably Sunline Transit, 15 miles away. 5. Evaluate how the RE-source H_2 generated can be used as input for fuel cells, thus enabling inherent energy storage within the system.

Smart Pipe Company: Design and manufacture pipe samples Figures 9-11

Smart Pipe (SP), Houston. SP invented a proprietary continuous process for delivering safe, self-monitoring, custom-design polymer hybrid linepipe, from a mobile factory at the jobsite, in significantly-longer lengths (tens of miles per section), without joints. SP has worked with both Savannah River NL (SRNL) and NREL to develop test methods for measuring H_2 permeation rate through pipe wall, for pipe samples to be made of various hybrids of polymers and possibly of polymer-metal, then tested for H_2 permeation rates at NREL or SRNL. Fig 11.

Figs 9, 10. SP made a sample with a thin aluminum foil in the pipe wall, as an H_2 permeation barrier, demonstrating the flexibility of their onsite manufacturing process, but this sample was not tested for H_2 permeation. In this project, several pipe samples of different material hybrids will be tested at NREL or SRNL or other national laboratory for H_2 permeation, and perhaps also for durability in frequent pressure cycling, if time and budget allow.

Independently, Smart Pipe (SP) will fabricate short sections of 6" diam multi-polymer plastic and / or polymer-metal hybrid pipe for measuring pipe wall H_2 permeation under pressure test at NREL or SRNL. This SP- NREL or SRNL effort is motivated by the potential in Figs 15-17.

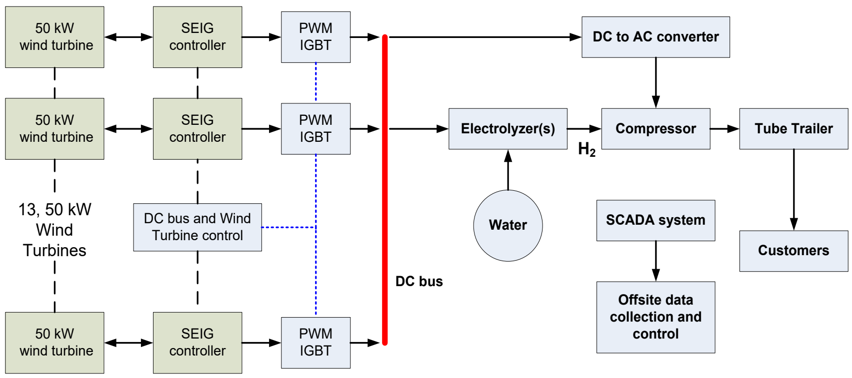


Figure 4. Complete, integrated, multi-turbine, autonomous wind-to-H_2 system to be designed by Auburn Univ and NREL and field tested at AASI's multi-turbine Palm Springs windplant, with no connection to the utility Grid. Single SCADA for all components, uploads ops data to all Team partners for design improvements, and optimizes energy capture by (ML-AI) "tuning", for Z-matching all components of the total system.

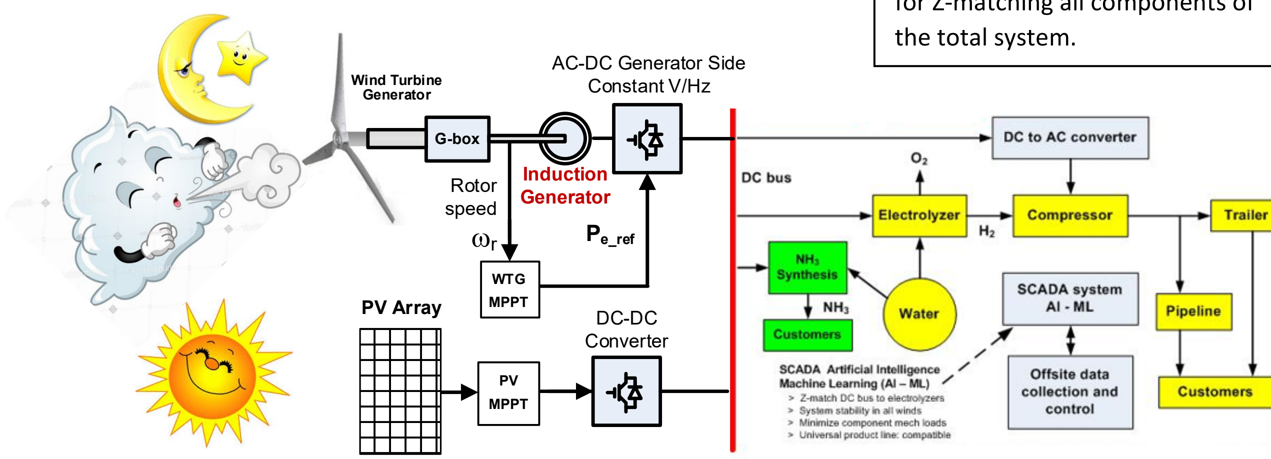


Figure 5. Prof. Eduard Muljadi, Auburn University (AU), will expand this wind-+PV-to-H_2 project by, to integrate PV for both H_2 and perhaps for NH_3 production, via nascent ARPA-E "REFUEL" technologies. Autonomous, SEIG-mode windplants and solar PV plants could synergistically deliver CO2-emission-free (CEF) GH2 and liquid NH_3 fuels via both repurposed and new natural gas (NG) and new, dedicated, high-purity GH2 underground pipelines, with no Grid connection.

Figure 6. AASI multi-turbine windplant in Palm Springs, CA, which will be used for field test of the integrated wind-to-H2 system to guide system design improvement. This is the ideal test bed for this project: high-energy wind regime, off-shelf 50 kW nameplate squirrel cage induction motors as generators, simple turbine controls, accessible site, easy scale-up of experimental results to multi-turbine and multi-MW windplants, with windplant owned and maintained by applicant. These 13 turbines have operated for over 20 years with acceptable availability in the severe San Gorgonio Pass wind regime, and are in serviceable condition for this project, which will utilize three of them, at most. In-kind.
Windplant operating:
https://vimeo.com/86851009

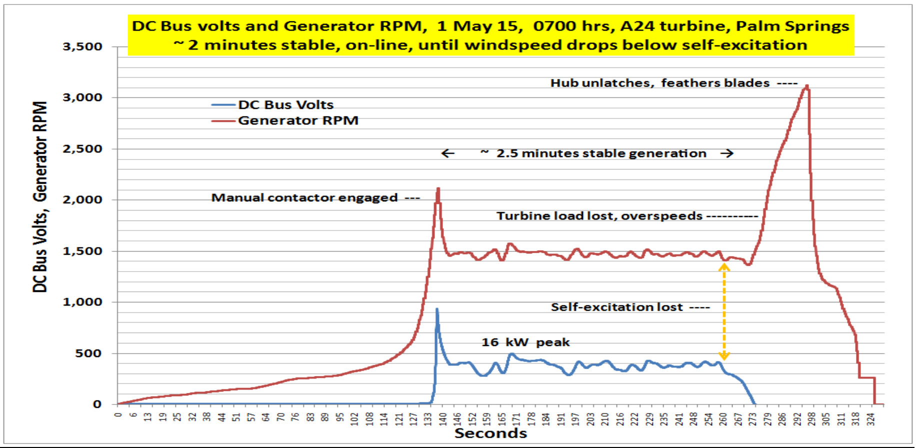
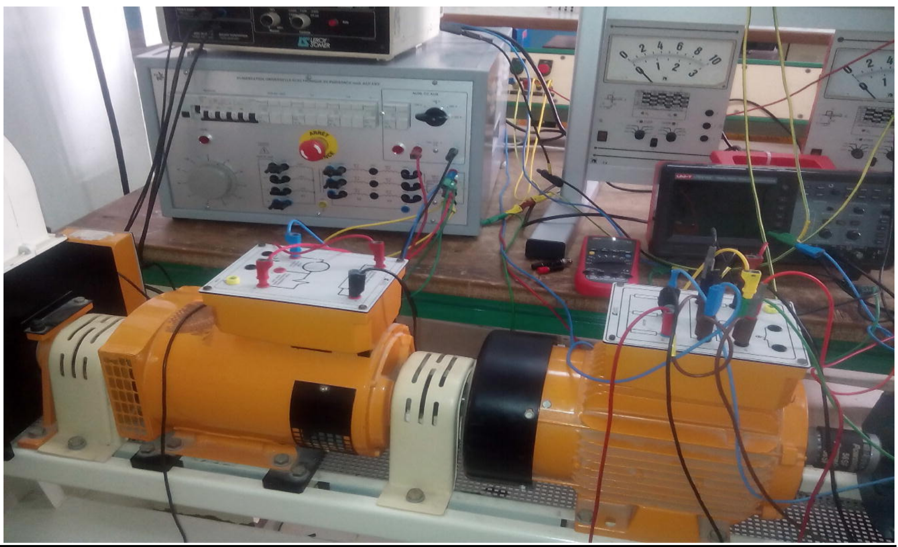


Figure 7. Manual SEIG mode test on one of AASI's Palm Springs 50 kW nameplate wind turbines, at variable speed, "wild AC" to "wild DC" to resistive load. Self-excitation lost at low windspeed. No grid connection. Manual control, modest windspeed. Video of episode: **https://vimeo.com/160472532**



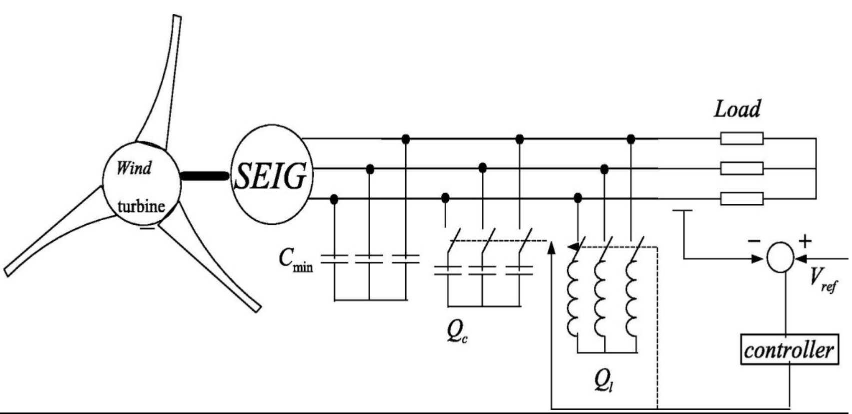


Figure 8. SEIG has been lab demonstrated for decades, without commercial success on a wind turbine, nor close-coupled to electrolysis stacks in a SCADA-integrated, system optimized for H_2 and / or NH_3 production, with no Grid connection -- which is this project's purpose and goal. Only recently enabled by low-cost power electronics and Machine Learning Artificial Intelligence (ML-AI) now ready for nascent H_2 fuel market.

Photo: 3 kW lab demo: variable speed motor drives induction motor in SEIG mode, simulating VG windspeed. Auburn Univ lab will achieve 100 kW for pre-commercialization design of [SEIG + electrolysis + SCADA], then to testing on 1 - 3 turbines at a Palm Springs operating windplant for Z-matching of wind turbine to electrolysis subsystem and ops data driven design improvements.

Figure 9. Two used Proton OnSite H6m electrolysis plants; their six electrolysis stacks dedicated to this project. Owned by AASI; in-kind contribution.

Figure 10. Smart Pipe Company fabricates flexible pipe onsite, in a continuous process, of any length, without joints. Multiple non-ferrous layers may provide adequate H2 permeation barrier without embrittlement; polymer-metal hybrids may be necessary, as in Fig 10. NREL will test H2 permeation and burst; may have time for P cycling.

Figure 11. Sample of polymer-metal hybrid linepipe for gathering, transmission, free "packing" storage, and distribution. Non-ferrous; prevents Hydrogen Embrittlement (HE), Hydrogen Corrosion Cracking (HCC) and other corrosion. Thin layer of Cu or Al in pipe wall is the H_2 permeation barrier. Made on-site in unlimited length to 24" diam by Smart Pipe, Houston. NREL will test several Smart Pipe designs for H2 permeation, and perhaps for P cycling, and then correlate back to benchmark burst strength. Fig 14.

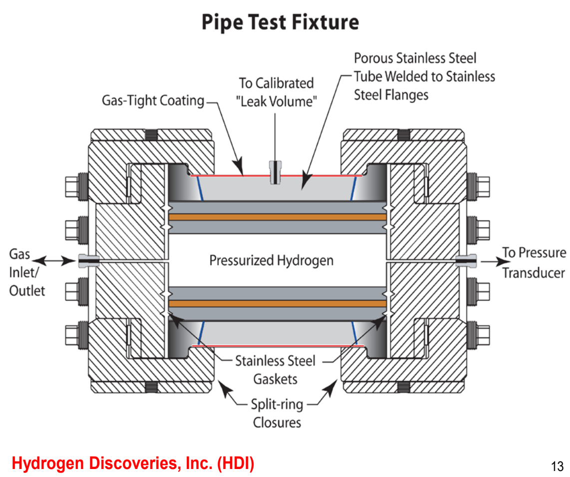


Figure 12. NREL, SRNL, or other national laboratory will use a test fixture similar to one invented by Hydrogen Discoveries, Inc. to measure H_2 permeation through the pipe wall,

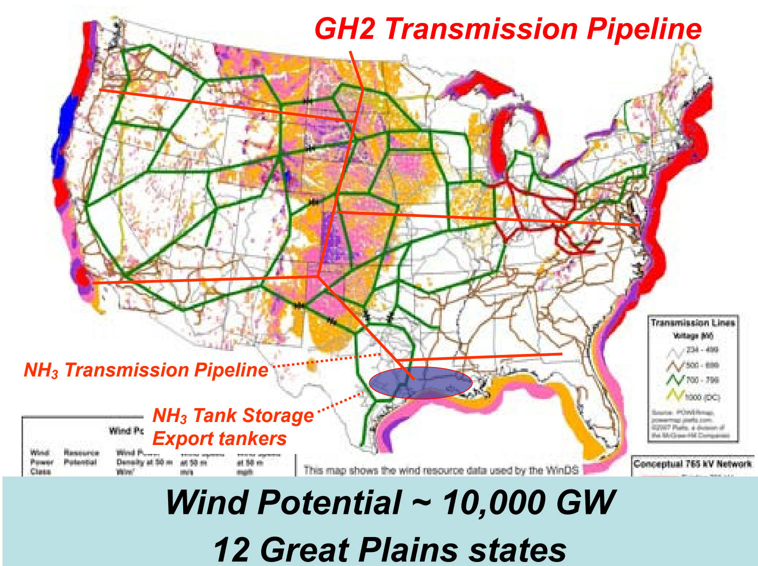


Figure 13. "H2@Scale" will allow and require importing RE-source H_2 fuel from dedicated Great Plains wind and solar plants without Grid connection. As other states and regions emulate California's RE regulatory and GH2 pipeline network construction experience, a nascent continental H_2 fuel market will require an extensive GH2 gathering, transmission, storage, and distribution pipeline network allowing accessing and interconnecting Great Plains energy and low-cost, TWh-scale and annual-scale energy storage in deep salt caverns near the Gulf of Mexico. Each cavern stores ~ 90,000 MWh @ 150 bar as the chemical energy in H_2.
Source: Conceptual transmission plan for 400 GW of new wind energy (AEP 2007), "20% Wind Energy by 2030", EERE, 2008. (Red GH2 overlay added.)

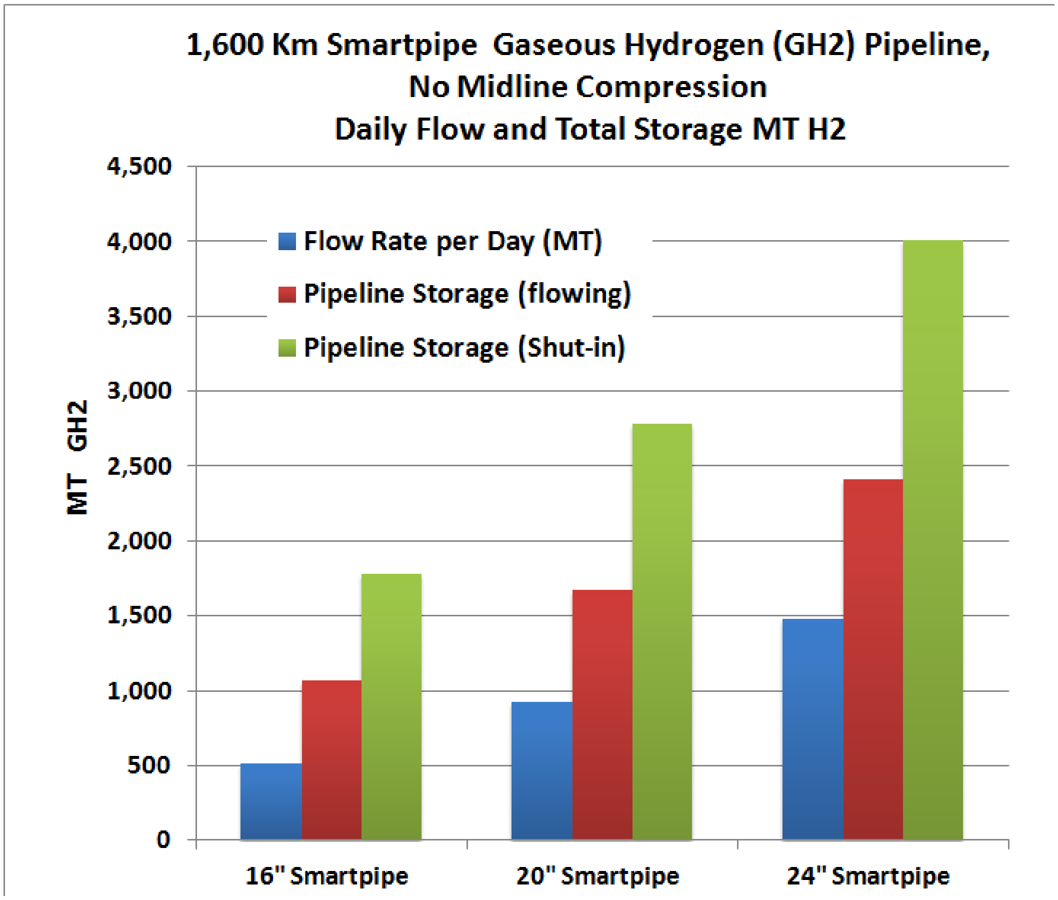


Figure 14. H2@Scale: Smart Pipe GH2 capacity, HE- and HCC-free linepipe for transmission and "packing" storage 24" GH2 pipeline capacity ~ 1,500 MT H_2 / day = 2.2 GW

Figure 15. 100 kW off-shelf Yaskawa U1000 Matrix VFD drive, to be reconfigured in hardware and software for R&D for SEIG mode operation of the AASI windplant turbines. Project goals include pre-commercialization of custom-design product line optimized for integrated wind-to-H2 production as ML-AI enabled [SEIG + Close-coupled electrolysis + SCADA] system, to avoid the high cost of OEM general-purpose VFD drives.

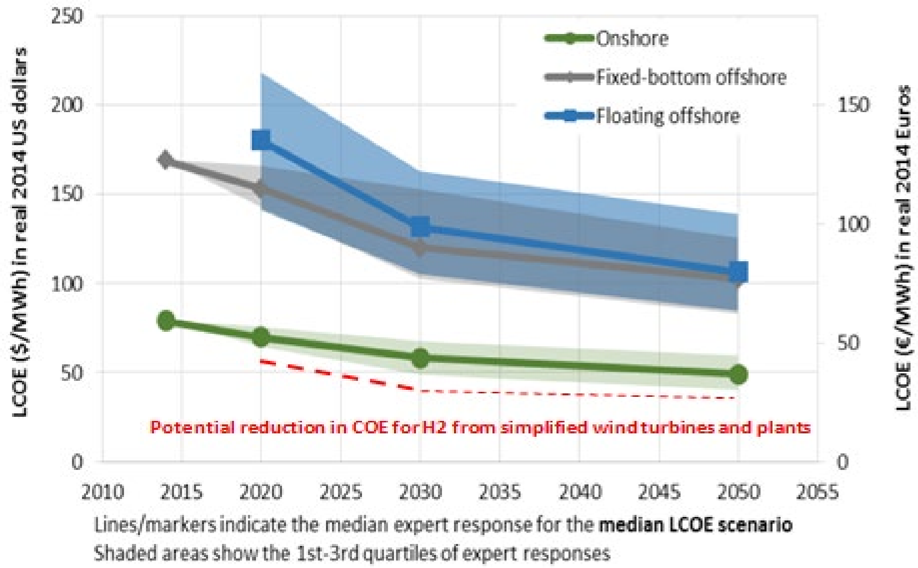


Figure 16. Wind turbines and windplants dedicated to H_2 fuel production, with no Grid connection, are simpler, with lower capex and opex, but require a new underground GH2 pipeline infrastructure. Project goal is evidence of potential 20% COE reduction for H_2 from sum of both windplant capex and opex.

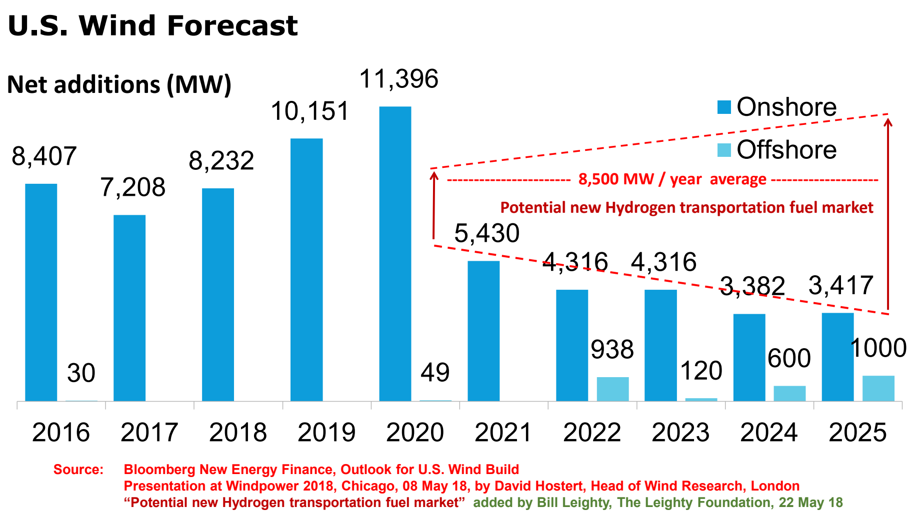


Figure 17. Wind energy needs a new market, as PTC-driven electricity Grid market wanes: H2 transportation fuel demand may exceed Grid demand in CA, in year 2050.

Windpower 2018 panel presentation by David Hostert, Head of Wind Research, Bloomberg New Energy Finance, London. (Leighty edits)

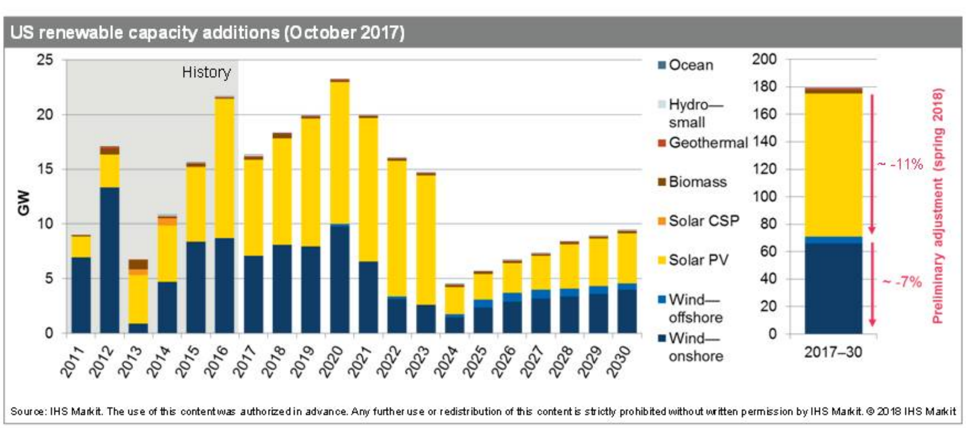


Figure 18. Wind energy must be synergistic with solar PV for H2@Scale, to decarbonize entire energy economy. Windpower 2018 presentation by Max Cohen, IHS Markit, Cambridge, MA

With permission

Complete System Solution for Low-cost Storage of Low-cost "Green Electrolytic H2"

All aspects of this project must succeed in order to fully realize the potential contribution of "Green Electrolytic H2" to achieving the California year 2045 goal of 100% C-free electricity, and well beyond electricity to all energy sectors and markets, to decarbonize and de-GHG the entire human enterprise:

1. Novel IOU regulatory policy(ies) facilitating *virtual* storage of "green electrolytic H2" on the customer side of meter with *physical* storage where it belongs, expeditiously and at much lower cost, in "packed" pipelines and in large salt caverns.

2. Enable wind turbines and windplants equipped with simple, robust, low-cost induction motors, as generators, to deliver 100% of captured energy as H_2 or NH_3 fuels, without electricity Grid connection, via the integrated system of novel SEIG power electronics, close-coupling of windplant DC bus to the electrolysis stacks, and a single SCADA, invented and field-proven by Auburn University (AU) and NREL, and tested and design-improved on applicant, AASI, operating windplant in Palm Springs, CA;

3. Reduce wind turbine, windplant, and electrolysis integrated system complexity, capex and opex, by eliminating electricity Grid tie, thus reducing wind-source H_2 cost ~ 20% at turbine and at windplant, and by close-coupling the electrolysis stacks to the SEIG DC bus;

4. Replace costly windplant electrical infrastructure - turbine MV transformers, many km of MV cable, MV switchgear, substation, transmission line to HV interface -- with lower-cost piping, including GH2;

5. Eliminate time-consuming, costly "system impact studies" required by utilities, RTO's, and ISO's;

6. Nearly eliminate wind curtailment, via "free" energy storage by "packing" GH2 in a continental-scale pipeline network, and at very low cost, in large, deep, salt caverns. This includes storing H2 via "power-to-gas" systems in the extant natural gas pipeline system, for essentially "free" transmission and storage, until the CA renewables-source H2 market is ~ 1,000 times it present size.

7. Greatly increase "distributed" wind energy harvest area, delivering high-purity H_2 and NH_3 fuels, without Grid connection, to these new, dedicated, high-purity, underground, GH2 and / or liquid NH_3 pipeline network(s) for gathering, transmission, storage, distribution, and integration of both stranded and distributed (DER) wind and synergistic solar, and perhaps other DER;

8. Test novel low-H_2-permeability, H_2-embrittlement-free, polymer-metal hybrid pipe samples to develop safe, affordable, self-monitoring linepipe systems by which to build the GH2 infrastructure for H2@Scale. See Smart Pipe in-field continuous fabrication process: http://smart-pipe.com/

We include Smart Pipe Company's production, and NREL or SRNL testing, of novel, low-H2-permeability, affordable, self-monitoring, durable, composite linepipe designs optimized for new, underground, GH2 infrastructure -- pipelines, cavern, and tank storage. GH2 and liquid NH_3 pipelines may be new or relined extant pipelines, of many kinds, many of them out-of-service, using Smart Pipe technology to be explored in this project.

Project success will disrupt and transform both the electricity and H_2 industries, relieving the Grid of large, perhaps futile, capital investments attempting to achieve stability, reliability, and economy, in order to supply most of humanity's energy from CEF, VG sources. Electricity will not be replaced, but may be restricted to the "last meter" or "last km" in optimized systems of renewable sources and uses, to avoid the peak transmission limits inherent with electricity. But, a large, new, costly "H2@Scale" pipeline infrastructure will be required, with welcomed but not necessary DOE EERE FCTO assistance: perhaps a better investment than Grid expansion.

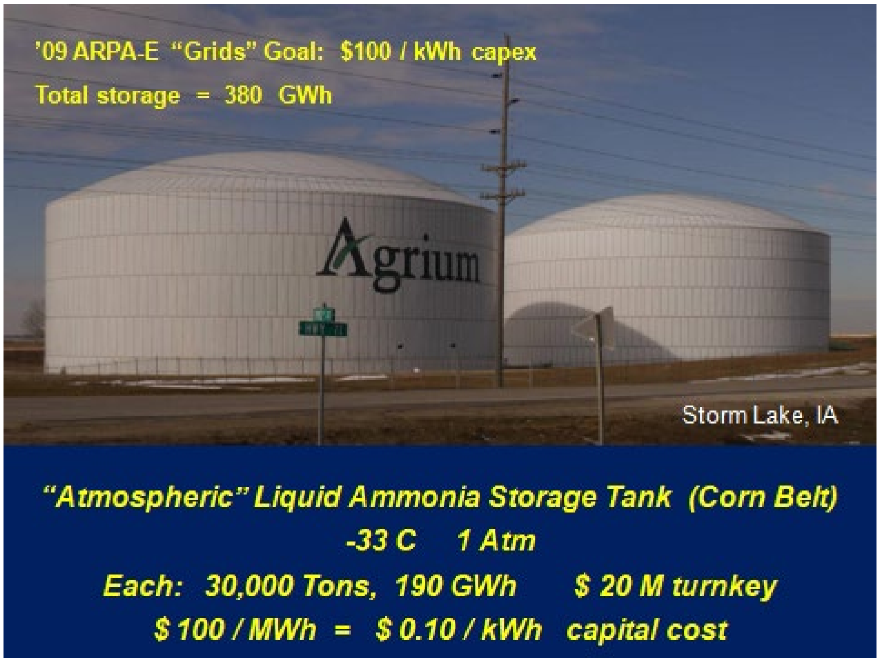


Figure 19. Very large, very-low-cost energy storage as liquid Anhydrous Ammonia (NH_3) in large, refrigerated, double-wall steel "atmospheric" tanks, ubiquitous in the Corn Belt, storing N-fertilizer. Each tanks stores ~ 200,000 MWh as chemical energy in NH_3 molecules, which may be burned in SOFC, ICE, and CT "Carnot" heat engines or easily "cracked" to recover high-purity H2 for mobile and stationary fuel cells and heat engines, to decarbonize and de-GHG entire human enterprise.

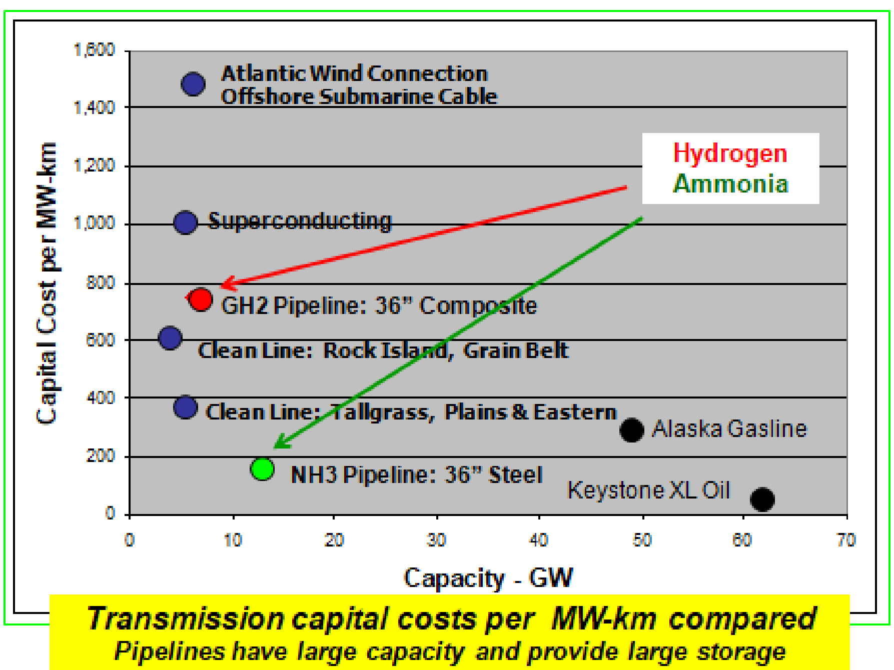
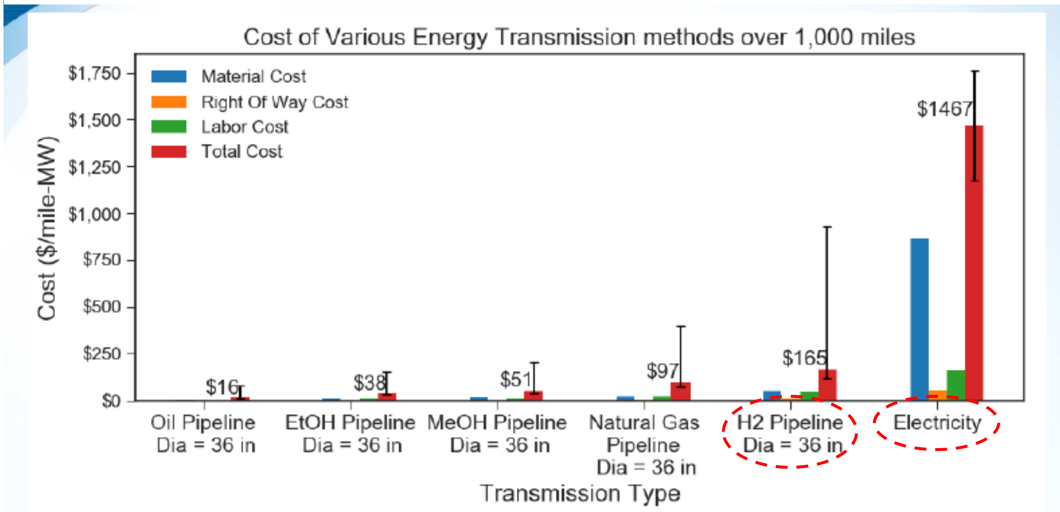


Figure 20. Capex for Gaseous Hydrogen pipelines are comparable, and provide free "packing" storage, plus low-cost cavern storage. Capex of liquid Ammonia transmission pipelines, which cannot be "packed", per MW-km, is lower than for HVDC electricity lines; storage < $ 1.00 / kWh.

Transmission CAPEX per MW – mile, over 1,000 miles



- **Liquid Pipelines :**
  - ► **Least expensive**
  - ► **High energy density, low pumping energy**
  - ► **Ammonia (NH_3) not considered**
- **Electrical :**
  - **> 10 x natural gas**
  - **> 90 x oil**

Figure 21. This unpublished paper from DOE, EERE, Fuel Cells Technology Office, shows that

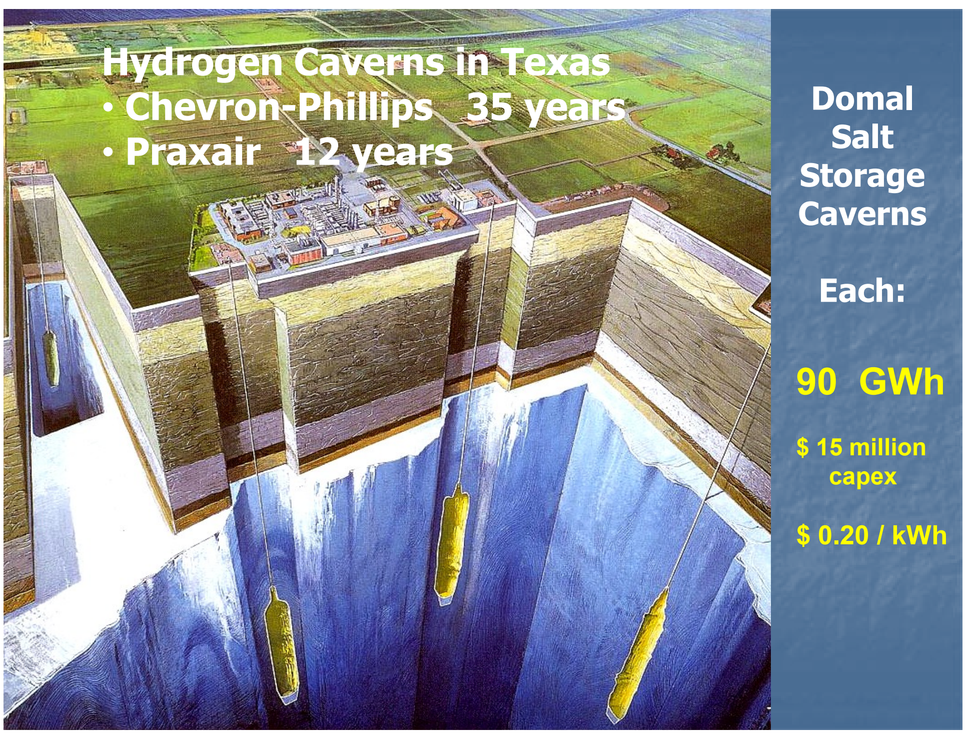


Figure 22. Each solution-mined, man-made salt cavern stores ~ 90,000 MW where domal salt geology is available, especially along Gulf Of Mexico (GOM) coast, at capex < $ 1.00 / kWh. Caverns may be clustered, manifolded at the same pressure, for even lower energy storage cost.

Project goals: This integrated system will approach TRL 6-7, advancing H2 scale-up to:

1. Reduce the cost of wind-source energy delivered as high-purity H_2 fuel by reducing the capex and opex of wind turbines and windplants, by simplifying both, by dedicating windplant production to H_2 fuel with no connection to the Grid; measure and demonstrate novel system on operating Palm Springs windplant; demonstrate potential for ~ 20% lower COE at windplant gate, as GH2 vis-a-vis as MWh.

2. Provide a new market for wind energy, aside from the PTC-driven Grid: H_2 and NH_3 C-free fuels for transportation and stationary CHP, via GH2 and NH_3 pipeline networks, low-cost storage.

Goal: market for Mt (metric tons / year) "green electrolytic H2" in 2030 is > 1,000 x year 2020

3. Design, build, test, demonstrate, and improve a novel system of integrated [SEIG + close-coupled electrolysis + SCADA], on an operating windplant, to emphasize optimization of complete C-free renewables-to-fuel systems, including wind capture and conversion, pipeline gathering, transmission, and storage, integration with other energy sources and systems, and efficient end-use as both transportation and CHP fuels. Goals: (1) Demonstrate potential for ~ 10% increase in energy conversion efficiency; (2) plant gate cost of GH2 or NH3 fuel > 15% less than in conventional wind and PV plants.

4. Advance SEIG and electrolysis technology via an integrated system, potentially optimized by Machine Learning AI (ML-AI), to pre-commercialization, to produce both H_2 and NH_3 fuels at minimum cost from electric energy from wind, solar, and other sources, centralized and distributed. Demonstrate stable, autonomous, safe, efficient wind and PV energy capture and conversion at all windspeeds and insolar conditions.

5. Prove new linepipe materials for safe, economical, underground, continental scale GH2 pipeline systems. Fig 15. Reduce the cost of HE-immune, corrosion-free pipeline for GH2 service, for gathering, transmission, "free" packing storage, and distribution of VG-source (wind, solar, other) H2 fuel to < 20% more than steel alloy pipelines.

Agreement Goals The goal of this Agreement is to deliver these essential components:

1. Novel, peer-reviewed policy(ies) enabling virtual storage of "green electrolytic H2" energy storage on customer side of meter with large-scale, low-cost, physical energy storage in "packed" pipelines, salt caverns, and perhaps as liquid NH3 in steel surface tanks. Policy(ies) are ready for proposal to Governor and Legislature. UC Davis, ITS STEPS program

2. Successful design, deployment, and test of the novel power electronics + controls proof-of-concept pilot plant, at AASI's operating Palm Springs wind + PV plant, with SCADA data analysis indicating a profitable path to advanced design, scale-up, commercialization.

From SCADA analysis: demonstrate a predicted reduction in multi-MW-scale, wind + PV source H2 production cost, at plant gate for delivery to NG or H2 pipelines, of > 15%. Auburn U

3. Several 6" diam pipe samples, made of polymer-metal-hybrid H2-embrittlement immune materials, tested for very low H2 permeability. Demonstrate a probable technology pathway to economical linepipe materials and production method for GH2 pipelines immune to H2 embrittlement, with very low through-wall H2 permeation, at < 20% greater cost than steel pipelines of the same transmission capacity (GW-km and MAOP). Smart Pipe Company

4. Technical and economic report comparing H2 and liquid ammonia (NH3) as alternative complete systems for "green electrolytic H2" storage, per ARPA-E "REFUEL". Define under what conditions liquid NH3 may be superior to GH2 for "green electrolytic H2" transmission and energy storage. Clear Air Energy, LLC

5. Demonstrate pathways to protect IOU ratepayers and IOU's from higher energy costs and rates.

Agreement Objectives

The objectives of this Agreement are success to:

1. Achieve consensus on, and support for, the IOU regulatory policy(ies) described above; release the policy(ies) for consideration for law. UC Davis ITS - STEPS

2. Measure the energy capture and conversion efficiency, and control effectiveness and stability, of the novel wind + PV electrolysis pilot plant described above. Confirm a profitable path to advanced design to higher TRL, scale-up, and commercialization. Harvest quality operations data from the pilot plant SCADA system. By Auburn University

3. Achieve very low measured H2 permeation for the pipe samples produced by Smart Pipe Company. Estimate installed cost per unit of transmission (GW-km) and storage (GWh) for pipelines built of the novel polymer-metal-hybrid design and manufacturing process. Conceive a profitable scale-up, technology transfer and commercialization pathway. Measurements by NREL, SRNL, or other national laboratory.

Technical details discussion for project goals and objectives

1. Enable wind turbines and windplants equipped with simple, robust, low-cost induction motors, as generators, to deliver 100% of captured energy as H_2 or NH_3 fuels, without electricity Grid connection, via the integrated system of novel SEIG power electronics, close-coupling of windplant DC bus to the electrolysis stacks, and a single SCADA, invented and field-proven by Auburn University (AU) and NREL, and tested and design-improved on applicant, AASI, operating windplant in Palm Springs, CA;

2. Reduce wind turbine, windplant, and electrolysis integrated system complexity, capex and opex, by eliminating electricity Grid tie, thus reducing wind-source H_2 cost ~ 20% at turbine and at windplant, and by close-coupling the electrolysis stacks to the SEIG DC bus;

3. Replace costly windplant electrical infrastructure - turbine MV transformers, many km of MV cable, MV switchgear, substation, transmission line to HV interface -- with lower-cost piping, including GH2;

4. Eliminate time-consuming, costly "system impact studies" required by utilities, RTO's, and ISO's;

5. Nearly eliminate wind curtailment, via "free" energy storage by "packing" GH2 in a continental-scale pipeline network, and at very low cost, in large, deep, salt caverns;

6. Greatly increase "distributed" wind energy harvest area, delivering high-purity H_2 and NH_3 fuels, without Grid connection, to these new, dedicated, high-purity, underground, GH2 and / or liquid NH_3 pipeline network(s) for gathering, transmission, storage, distribution, and integration of both stranded and distributed (DER) wind and synergistic solar, and perhaps other DER;

7. Test novel low-H_2-permeability, H_2-embrittlement-free, polymer-metal hybrid pipe samples to develop safe, affordable, self-monitoring linepipe systems by which to build the GH2 infrastructure for H2@Scale. See Smart Pipe in-field continuous fabrication process: http://smart-pipe.com/

Novel, low-H2-permeability, affordable, self-monitoring, durable, composite linepipe designs optimized for new, underground, GH2 infrastructure -- pipelines, cavern, and tank storage. GH2 and liquid NH_3 pipelines may be new or relined extant pipelines, of many kinds, many of them out-of-service, using Smart Pipe technology to be explored in this project.

Project success will disrupt and transform both the electricity and H_2 industries, relieving the Grid of large, perhaps futile, capital investments attempting to achieve stability, reliability, and economy, in order to supply most of humanity's energy from CEF, VG sources. Electricity will not be replaced, but may be restricted to the "last meter" or "last km" in optimized systems of renewable sources and uses, to avoid the peak transmission limits inherent with electricity. But, a large, new, costly "H2@Scale" California-wide, then continental-scale, pipeline infrastructure will be required: perhaps a better investment than electricity Grid expansion.

BUDGET

Participant	CEC cash	In-kind	Total
AASI + PV DC string	207,000	116,000	323,000
Auburn University (AU)	249,775	29,966	279,741
Smart Pipe	80,560	0	80,560
Smart Pipe samples test: NREL, SRNL	50,000	0	50,000
UC Davis	50,000	25,000	75,000
Clear Air Energy (CAE) NH3 analysis	20,000	0	20,000
D&E Land	0	8,000	8,000
Nel Hydrogen	0	10,000	10,000
TOTAL	657,335	188,966	846,301
In-kind %	29%		
Funds to be spent in CA			
AASI	207,000		
UC Davis	50,000		
Smart Pipe	80,560		
CAE	20,000		
SUBTOTAL	357,560		
AU: all except personal services	114,125		
Total	471,685		
AU CEC cash	249,775		
Less: Total labor	135,650		
Net in CA	114,125		

REFERENCES

1. *Self-Excited Induction Generator for Variable-speed Wind Turbine Generation*, E. Muljadi, B. Gregory, D. Broad, 1996, NREL https://www.nrel.gov/docs/legosti/old/21436.pdf NREL/CP-440-21436 • UC Category: 1213 • DE97000057
2. "Stand-alone self-excited induction generator driven by a wind turbine" https://www.sciencedirect.com/science/article/pii/S111001681730011X, Elsevier
3. Institute of Transportation Studies (ITS), UC Davis, "The Hydrogen Transition" Ogden, Fulton, Yang, et al, 2014
   https://its.ucdavis.edu/research/publications/?frame=https%3A%2F%2Fitspubs.ucdavis.edu%2Findex.php%2Fresearch%2Fpublications%2Fpublication-detail%2F%3Fpub_id%3D2312
4. IEEE "Electrification" magazine, May 2018 https://ieeexplore.ieee.org/document/8369455/
   "The Future Is Present in California: Delivering on the Promise of Fuel Cell-Powered Transportation"

Project schedule: 24 months

Schedule-AASI-GFO-19-305: Hardware engineering tasks only
Schedule: 24 months plus optional long-term testing
Alaska Applied Sciences, Inc. (AASI)
Design, Build, Test wind-to-H2 pilot plant; test on operating AASI Palm Springs windplant
Pilot plant: [SEIG + close-coupled electrolysis stacks + SCADA] integrated system, by AU
Polymer-metal-hybrid pipe samples manufacture and test for H2-permeability

File: Schedule-1874-1599-AASI-26May18.xlsx
Rev: 28 May 18
Author: W. Leighty, AASI

Milestone:
Decision:

AASI	Alaska Applied Sciences, Inc.
AU	Auburn University
SP	Smart Pipe Company, Houston
UCD	UC Davis
NREL SRNL	Nationa Laboratories, Pipe testing

Activity	Task	By	Month 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25+
Negotiate & Execute contracts: AU, SP, CAE, UCD	1	AASI																									
AU purchase & install special lab equipment for SEIG, SCADA	2	AU																									
SEIG controller design: 1 - 10 kW lab scale	3	AU																									
Implement SEIG in SCADA	4	AU																									
SEIG control scaleup 50 kW; 100 kW peak; 45 kw motor, Yaskawa VFD	5	AU																									
SEIG system dyno test at 50-100 kW wind input simulation	6	AU																									
Achieve autonomous, stable SEIG across wind spectrum	7	AU																									
Milestone 1: SEIG design done: Level A		AU																									
Windplant DC bus and turbine dispatch control design in SCADA	8	AU																									
Windplant complete system design, build, test, commission	9	AU																									
Milestone 2: Windplant complete system success to R load: Level B		AU																									
Decision 1: Objectives achieved ? Continue or redefine project ?		AU,AASI																									
Repair, refurbish stacks, PDC compressor, DI, if required	11	AASI																									
Milestone 3: Deliver all electrolysis components to AU		AASI																									
Assemble electrolysis plant & test on Grid power: H2 production	13	AU																									
Electrolysis plant benchmark performance documented; T variable	14	AU																									
Integrate electrolysis plant with SEIG, safety check, dyno test	15	AU																									
Milestone 4: SEIG & electrolysis plant + SCADA integrated		AU																									
Decision 2: Objectives achieved ? Continue or redefine project ?		AU,AASI																									
	16																										
Optimize complete system hardware, software; finish test	17	AU																									
Prepare AASI Palm Springs windplant for pilot plant installation	18	AASI																									
Milestone 5: Deliver pilot plant to AASI; accept test		AU,AASI																									
Decision 3: Ship pilot plant to Palm springs windplant ?		AU,AASI																									
Complete pilot plant installation, test, commission, verify SCADA data	20	AASI																									
Verify valid SCADA data export to AU, NREL, CA	21	AASI																									
Milestone 6: Pilot plant installed, operating, valid SCADA data		AASI																									
Test windplant: 1-3 turbines and pilot plant: 60 kWE, 100 kWe peak	22	AASI																									
Install compressor + power supply for H2 to 3,500 psi tube trailer	23	AASI																									
Analyze SCADA data from windplant ops: Primary responsibility	25	AU																									
Analyze SCADA data from windplant ops: Secondary responsibility	26	CA																									
Recommend pilot plant revisions: hardware, software	27	[all]																									
Revise SEIG components, from SCADA and operating experience	28	AU,AASI																									
Revise system components, from SCADA and operating experience	29	AU,AASI																									
Milestone 8: Decide whether to commercialize; product line		AU,AASI																									
Decision 4: Launch business plan to commercialize ?		AASI																									
Design & fab H2 pipe samples for test	30	SP																									
Milestone 9: All, or most, pipe sampled delivered to NREL		SP																									
Pipe samples test at NREL: H2 permeation	31	NREL, SRNL																									
Milestone 10: All pipe samples tested at NREL; report		NREL, SRNL																									
Project complete: continue long-term test of pilot plant at windplant	32	AASI																									
Decision 5: Project complete: redeploy federal assets ?		AASI																									
Milestone 11: Project complete; final report; papers author + publish		[all]																									
AASI continues to operate windplant, produce and sell H2 fuel	33	AASI																									

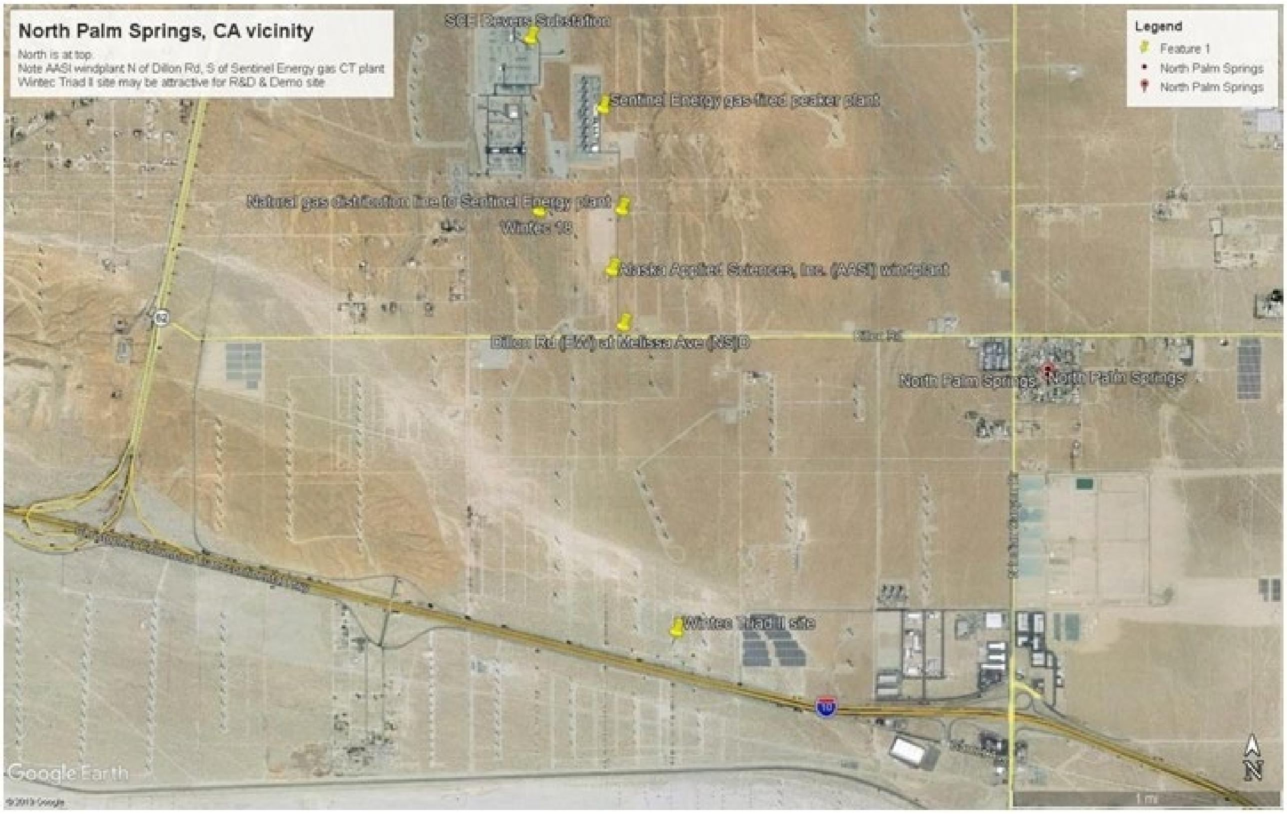


Figure 23. ABOVE: The AASI windplant is now at upper center, marked with several yellow pins. About 1 km south is a potential alternate site, marked with a single yellow pin, near a PV plant.

BELOW: Closeup of the southerly, potential alternate wind + PV plant site, north of I-10 freeway.