DOCKETED

Docket Number:	17-IEPR-12
Project Title:	Distributed Energy Resources
TN #:	218058
Document Title:	Bill Leighty Comments Low-cost energy storage as Hydrogen DRAFT Narrative for CEC GFO-16-310
Description:	N/A
Filer:	System
Organization:	Bill Leighty
Submitter Role:	Public
Submission Date:	6/12/2017 5:27:11 PM
Docketed Date:	6/13/2017

Comment Received From: Bill Leighty
Submitted On: 6/12/2017
Docket Number: 17-IEPR-12

Low-cost energy storage as Hydrogen: DRAFT "Narrative" for CEC GFO-16-310

Additional submitted attachment is included below.

Low-cost Wind-source Hydrogen Transportation Fuel from Old and New California Windplants, Without Grid Connection, Prevents IOU Rate Burden and Expands Wind Market

1. Technical Merit and Need

California (CA) wishes to deeply decarbonize its entire energy economy, primarily by its RPS and "80 in 50" laws. If CA achieves both goals, in year 2050 it will require more CO_2-emission-free (CEF), renewable energy (RE) for transportation than for the electricity Grid's total non-transportation energy demand, assuming year 2017 transportation modal mix. Figures 1, 2, 3.

Attempting to supply CA's transportation energy via the electricity Grid will require very large investments (CAPEX) in upgrades and new gathering, transmission, storage, and distribution infrastructure, and its O&M costs, which must be recovered by higher electricity costs for IOU ratepayers:

- Gathering wiring and substations within windplants and solar PV plants
- Transmission lines and substations
- Grid energy storage, at several levels
- Backup generation, generally gas-fired and operating at low utilization factor (UF)
- "Smart" features: electricity quality, resilience, stability, metering, cyberattack defense
- Distributed Energy Resource (DER) generation acceptance on distribution feeders

The State of CA, several industries, and many companies, universities, and researchers have heavily invested funds and expertise in bringing Hydrogen-fueled, Fuel Cell Vehicles (FCV's) -- Light Duty Vehicles (LDV's), buses, and trucks of all sizes -- to market, and in the nascent Hydrogen production and fueling system to support them. The CA-funded retail Hydrogen fueling stations are required to dispense CEF-source Hydrogen fuel for > 1/3 of total fuel sales. That CEF Hydrogen is now made from "certified-green" landfill gas, methane metered and pipelined via extant natural gas infrastructure to large extant Steam Methane Reforming (SMR) plants for conversion to Hydrogen, for truck delivery to the new fueling stations.

A scenario published in 2014 by Institute of Transportation Studies, Sustainable Energy Pathways (ITS-STEPS), UC Davis, "The Hydrogen Transition", [i] assumes that in year 2050, given year 2014 modal mix, most transportation energy will be supplied via RE-source CEF Hydrogen fuel, gathered and transported ("transmission") via a new, underground, dedicated, high-purity Gaseous Hydrogen (GH2) pipeline system. Figures 2 and 3.

Figure 3. Thus, in CA in year 2050, ~ 256 GW of combined wind and solar nameplate generation will be dedicated to production of Hydrogen transportation fuel, at typical 30 - 40 % capacity factors, which is more than will be needed for non-transportation demand for the electricity Grid. Total wind + solar generating capacity, for transportation + established electricity markets will be > 400 GW. Total in CA in 2015 was ~ 18 GW. We will need ~ 20 times as much.

As Hydrogen fuel demand grows, the supply of "green" landfill gas to supply SMR plants will be exhausted, requiring new sources of CEF Hydrogen. RE electricity from old and new wind and solar plants may be converted to high-purity Hydrogen fuel by electrolysis of water. Older wind turbines equipped with squirrel cage induction motors, as generators, may be retrofitted with the new, integrated, Hydrogen production system to be designed and demonstrated in this project, based on the novel combination of Self Excited Induction Generator (SEIG) mode wind turbine operation and close-coupling to the electrolysis stacks, with no connection to the electricity Grid.

Both old and new Grid-independent turbine designs and new windplants, dedicated to Hydrogen production, equipped with low-cost, robust, induction motors as generators, will also help CA achieve most economically RPS and "80 in 50" goals, maximizing wind energy's contribution by:

- Simplifying and lowering the CAPEX and O&M cost of the wind-to-Hydrogen production system, thus reducing the plant-gate cost of Hydrogen fuel;
- Requiring no wind turbine components nor windplant infrastructure, dedicated at both turbine and windplant levels to delivering Grid-quality AC or DC to the Grid; Figures 8, 9;
- Freeing new windplants of costly infrastructure investments: underground gathering wiring, a transformer at every turbine tower base, and a Grid-interface substation;
- Improving the economic performance of windplants with expired PTC and / or PPA, by monetizing their wind-generated electric energy at ~ $ 0.08 / kWh by dedicated production of Hydrogen via electrolysis, which requires ~ 50 kWh of electric energy per kg Hydrogen. With wholesale CEF Hydrogen fuel price expected to be $ 4.00 to $ 5.00 per kg in years 2020 - 2035, the value of electric energy to produce it is ~ $ 0.08 / kWh. Figure 7; profitability is reduced by recovery of capital costs of the electrolysis system;
- Greatly reducing otherwise-curtailed wind and solar energy production, both "centralized" and "distributed", by providing alternative pathways for transmission, low-cost storage, distribution, and end-use as transportation and stationary CHP fuel; this includes GH2, Anhydrous Ammonia (NH_3), and "Power to Gas" -- the capture of otherwise-curtailed energy as GH2 injected into the natural gas pipeline network; [ii] Figures 8 and 9;
- Allowing the IOU's to develop new business models with less uncertainty about the amount of transportation energy they would be required to supply, where, and when;
- Enabling wind energy harvest from large, windy areas not served by electricity transmission, by both small and MW-scale turbines, by motivating construction of a new underground pipeline network dedicated to renewables-source, CEF, high-purity Hydrogen and / or Ammonia fuels; Figures 4, 5, and 12, a potential "lighthouse" project;
- Enabling synergistic combination of the output of both wind and solar PV generators at plants where both are co-located; both diurnal and seasonal synergy in most of CA;
- Enabling retrofit of older turbines and windplants, equipped with squirrel-cage induction motors as generators, by replacing only their control systems;
- Motivating the design of new turbines and windplants, dedicated to Hydrogen production, with no Grid connection, using the novel system this project demonstrates;
- Enabling very low-cost energy storage, < $ 1.00 / kWh CAPEX, as GH2 in deep, man-made, solution-mined salt caverns; Figure 6;
- Embracing both gaseous Hydrogen (GH2) and possibly also liquid NH_3 as complete, integrated, optimized, CEF energy systems supplied by wind and other renewable sources within, and from beyond, CA. Figures 8 and 9.
- Embracing "Blockchain" energy packet tracking and control; Energy Web Foundation;

This is a great policy, technology, and business opportunity for CA in the post-Paris-Agreement federal vacuum. CA should now invest in developing new technologies to improve technical and economic performance of old and new wind generation assets, dedicated to delivering 100% of their captured wind energy as high-purity Hydrogen and perhaps Ammonia fuels, with no connection to the electricity Grid. This project's success will do that, by addressing and achieving all of GFO-16-310's stated objectives.

Figures 4 and 12. Supplying most of CA's transportation energy as RE, CEF Hydrogen fuel will require a large, new infrastructure of underground GH2 pipelines dedicated to gathering, transmission, storage (by "packing" the pipelines at low cost), and distribution. When CEF Hydrogen fuel becomes accessible via such pipeline systems, in the future carbon-priced global energy economy, customers will buy it for stationary CHP as well as for transportation. But the pipeline infrastructure cost recovery will be paid by the transportation and CHP fuel users, not by IOU ratepayers. CA's example will propagate to USA and continental scales.

Figure 12. The Questar pipeline, now for sale, for example, if relined for 100 bar GH2 service with 12" diameter Hydrogen Embrittlement (HE) immune linepipe, would have a capacity of ~ 400,000 kg Hydrogen per day, without midline compression, based on hydraulic modeling. [iii] This brings a large quantity of San Gorgonio Pass wind and solar to LA Basin, Inland Empire.

The area in the "Pipeline" envelope in Figure 4 is ~ $ 50 - 60 billion, about the amount of new electricity Grid investment that would be required to supply year 2050 total transportation energy, from RE - CEF sources, as electricity via the Grid. [iv]

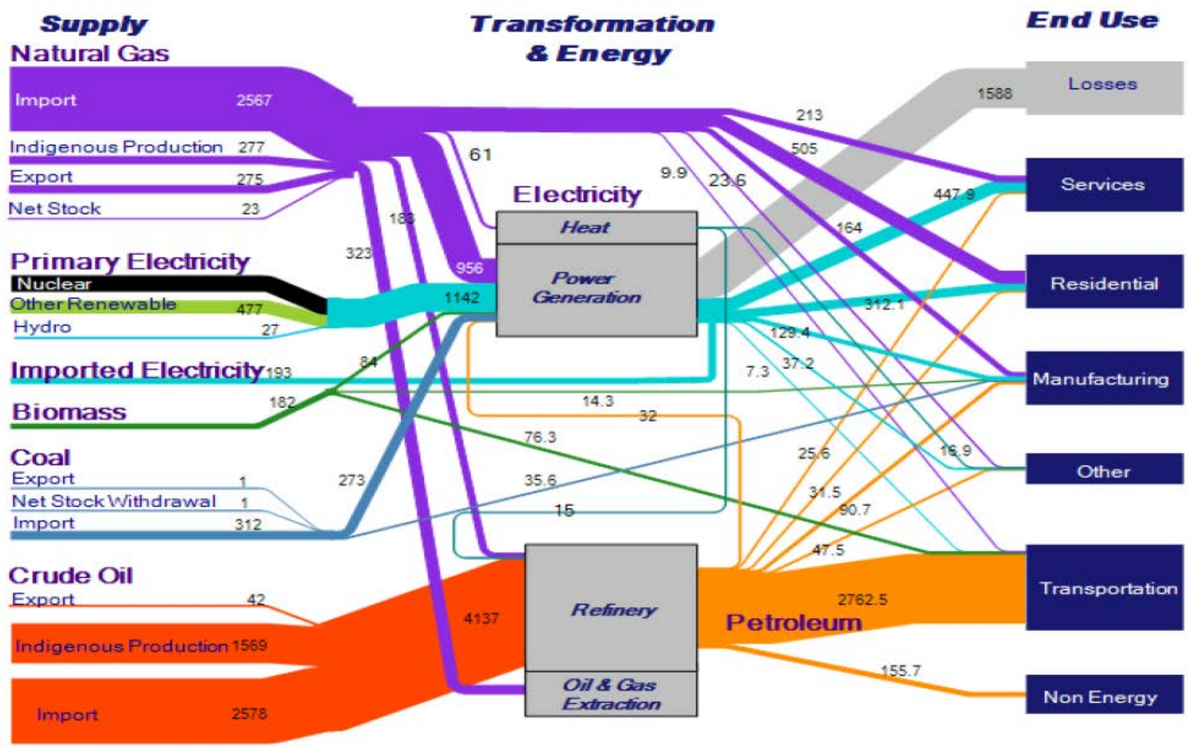


Figure 1. In CA in year 2000, transportation required more energy than electricity. This may persist to year 2050. Attempting to provide this much transportation energy via the electricity Grid will require very large Grid infrastructure investments in gathering, transmission, storage, distribution, and "fueling" (battery charging). Paying for these increases would burden the IOU ratepayers. [iv] Shifting transportation energy to wind + solar source Hydrogen fuel will spare the IOU ratepayers from capital recovery rate increases for capital recovery of new infrastructure.

Figure 5. Even with the new GH2 pipeline system, CA may not have enough land area, permissible for wind and solar and other RE, CEF generation, to provide the total amount of energy it will need in year 2050, and may need to import CEF energy from the Great Plains or from overseas, perhaps from Alaska. Therefore, CA should plan for its role in a continental-scale GH2 infrastructure, including pipelines accessing abundant Great Plains wind and solar,

and the low-cost, annual-scale, firming storage available in multiple arrays of solution-mined salt caverns in domal salt formations along the Gulf of Mexico coast, each storing ~ 90,000 MWh.

This continental-scale system maximizes synergy among multiple CEF energy types and regions, minimizing cost for an annually-firm, dispatchable energy supply, from all sources, for all uses, to nearly completely decarbonize the CA, USA, and North America energy economies.

These considerations profoundly affect, and would be affected by, the discussion and outcomes of R. 16-02-007 Integrated Resource Planning and SB 100 in CA, and by USA's withdrawal from the COP21 Paris Agreement.

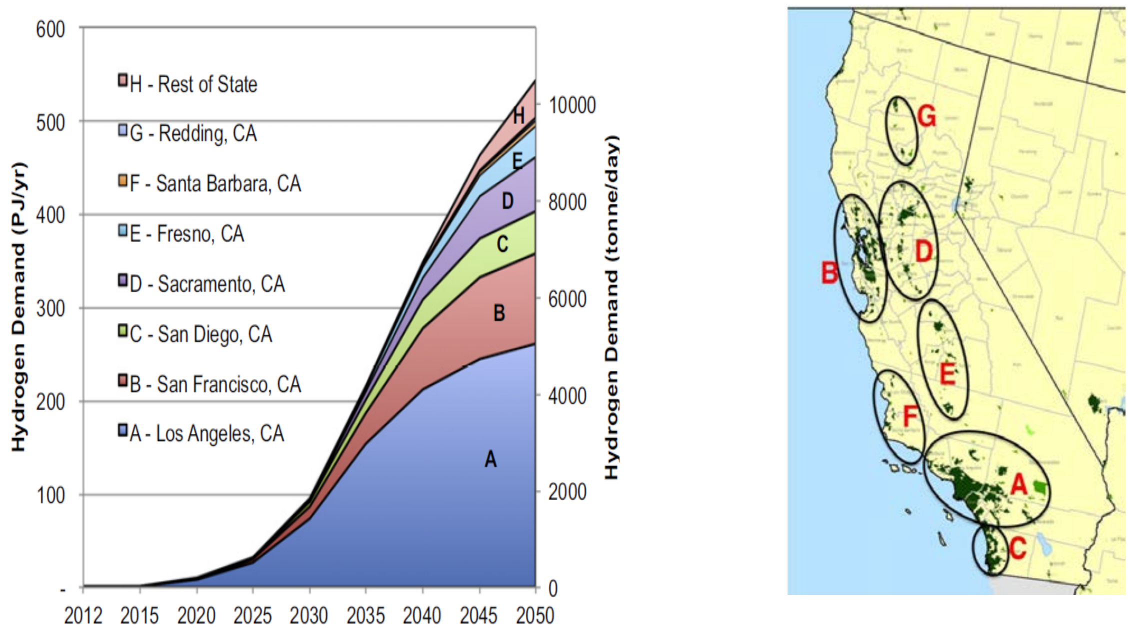


Figure 2. [v] Regional and total CA demand for Hydrogen fuel, for only light duty vehicles (LDV's). In year 2050, that is 10,000 tonne / day (tonne = metric ton, Mt) (Mt / day) = 3.65 million metric tons (MMt) per year, which would require the full energy output of ~ 100,000 MW nameplate combined wind and solar capacity. Total transportation Hydrogen fuel demand in year 2020 will be ~ 7.4 MMt, requiring the full energy output of ~ 250,000 MW combined wind and solar capacity. Figure 3. CA total installed wind + solar capacity in year 2016 was ~ 18,000 MW. By 2050, CA will require ~ 14 times as much capacity, just for total CEF transportation energy, mostly as Hydrogen fuel. That will require wind and solar PV harvest on large land areas without electricity transmission, both in CA and beyond.

Reference: Year 2015	**GW**
Total installed nameplate wind generation in California (CA)	6
Total installed nameplate solar generation in California (CA)	12
ELECTRICITY: CA "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: CA renewables	**GW**
Equivalent nameplate wind generation capacity @ 40 % CF	85
Equivalent nameplate solar generation capacity @ 35 % CF	97
TRANSPORTATION Hydrogen Fuel in Year 2050: CA renewables	**GW**
Equivalent nameplate wind generation capacity @ 40 % CF	126
Equivalent nameplate solar generation capacity @ 35 % CF	130
TOTAL CA RENEWABLE ELECTRICITY + TRANSPORT ENERGY in Year 2050	**GW**
Equivalent nameplate wind + solar + other @ CF (varies)	438

Hydrogen transportation fuel demand, CA, year 2050: Million metric tons (MMt) per year

Light Duty Vehicles (LDV)	3.6
Trucking (goods movement)	1.6
Bus	1.4
Aviation, marine, other	0.8
Total	**7.4 MMt per year**

Figure 3. Year 2050 CA energy economy for only electricity and transportation energy, assuming that Hydrogen-fueled Fuel Cell Vehicles (FCV's) dominate, especially for large LDV's, buses, and trucks, with BEV's primarily for light-duty, short-distance use, and assuming year 2017 transportation modal mix. More RE-source CEF energy will be required for transportation Hydrogen fuel than for the electricity Grid: ~ 250,000 MW of combined solar and wind nameplate generating capacity, ~ 14 times total installed capacity in CA today.
This is derived from a scenario published in 2014 by ITS-STEPS, UC Davis. [i]
Source: http://leightyfoundation.org//wp-content/uploads/WP16-A-1.pdf

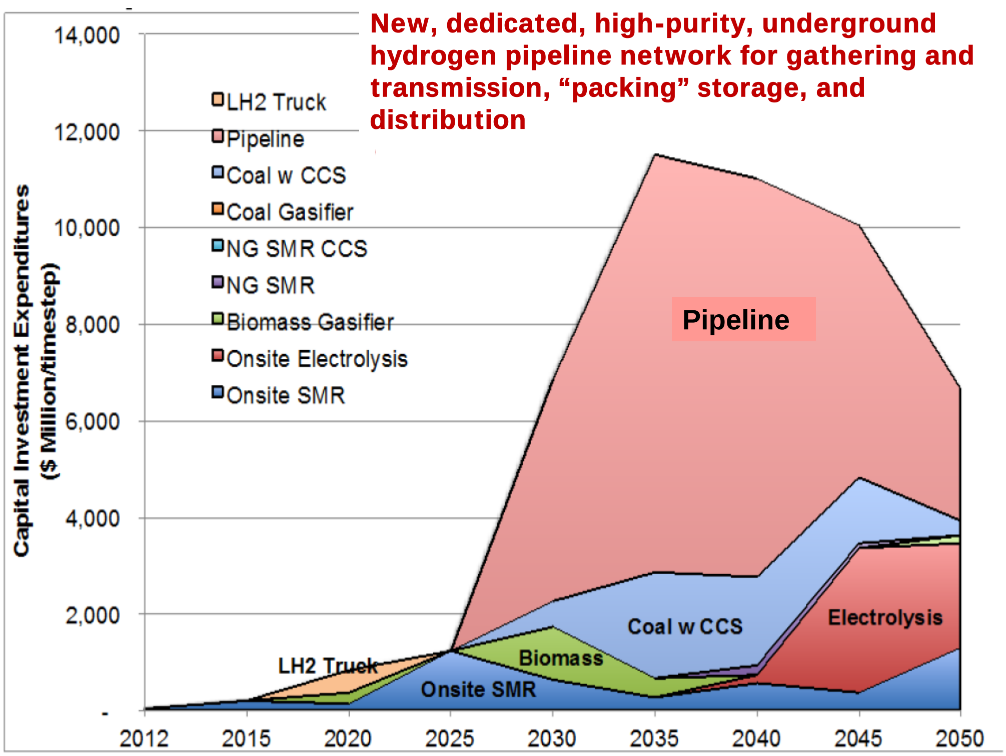
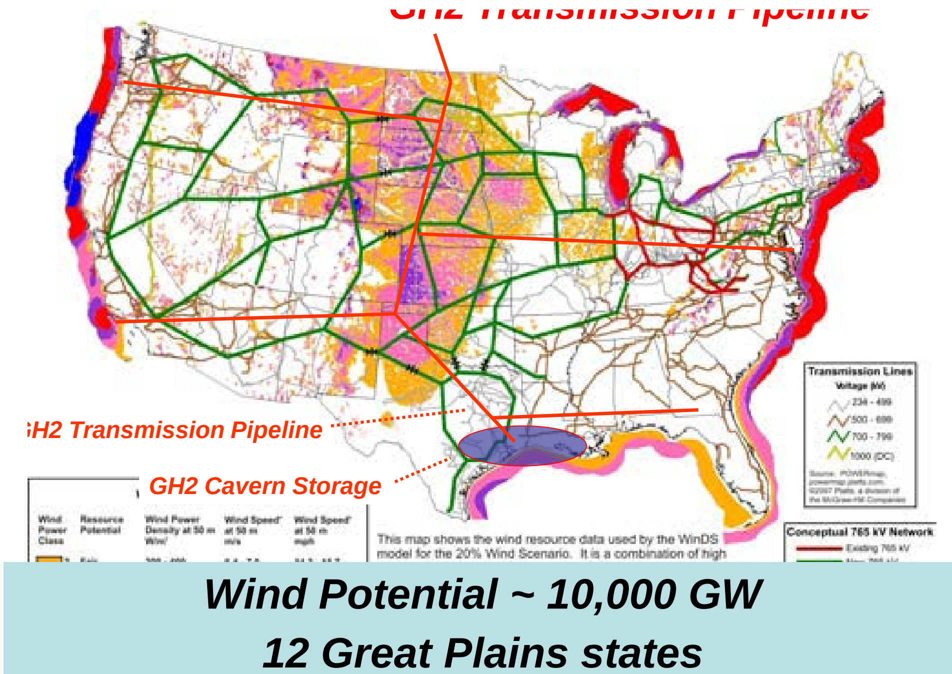


Figure 4. Producing any of CA's Hydrogen transportation fuel from Coal with CCS will be costly and undesirable; CCS is an uncertain technology. Therefore, CA must invest heavily in wind-source and solar-source CEF Hydrogen fuel production, both centralized and distributed, and in the new, dedicated, underground, high-purity, gaseous Hydrogen (GH2) pipeline infrastructure necessary to gather, transmit, store (by "packing" the pipelines, as the natural gas industry does, at no incremental capital cost, CAPEX), and distribute the Hydrogen fuel.
The area in the "Pipeline" envelope, aggregate investment from years 2025 - 2050, is about $ 50 - 60 billion, about equal to the incremental investments in electricity Grid infrastructure necessary to attempt to supply most of CA transportation energy as electricity.



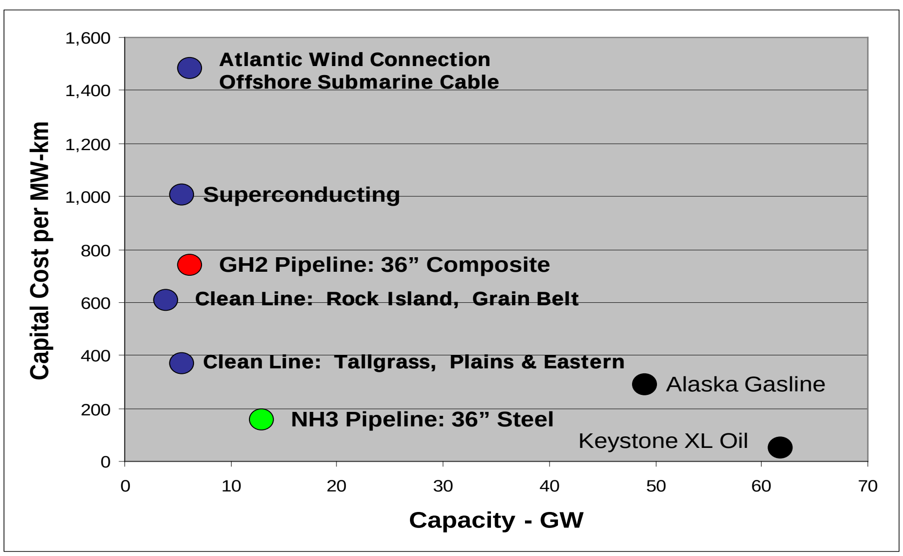


Figure 5. CA may not have adequate land area, permissible for wind and solar energy production, on which to generate its total energy demand, so will need to import RE-source, CEF Hydrogen fuel from the Great Plains via Gaseous Hydrogen (GH2) pipelines. As other states and regions emulate CA's RE regulatory experience, a nascent continental market will require an extensive GH2 pipeline network allowing accessing Great Plains energy and low-cost energy storage in deep salt caverns in the Gulf of Mexico region. GH2 transmission pipelines are lower in CAPEX per GW-km of transmission service capacity than electricity transmission lines, and require less right-of-way (ROW) width. Generally, pipeline O&M cost is lower, because they are underground, relatively safe from acts of God and man.

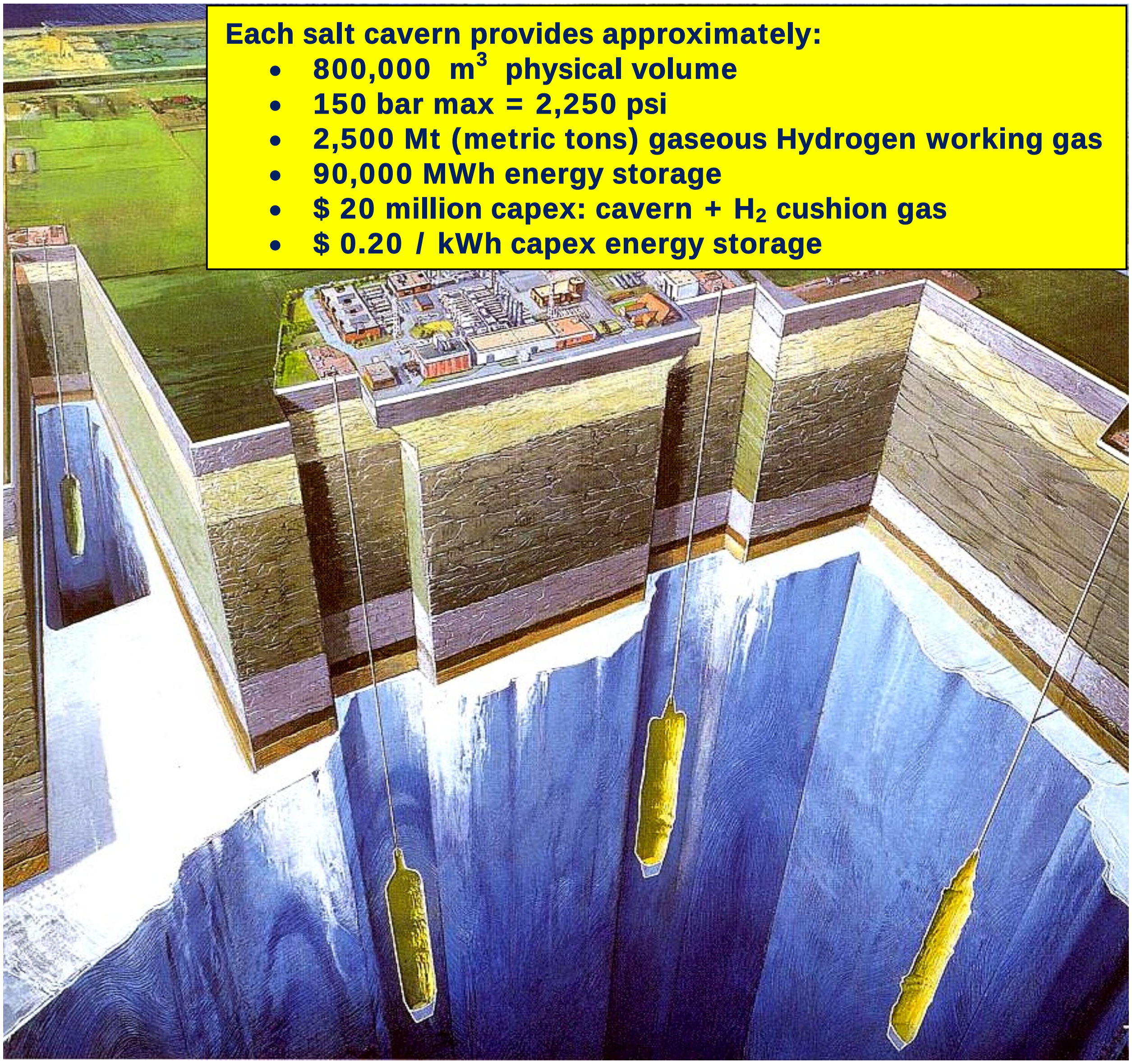


Figure 6. Energy may be stored as compressed Gaseous Hydrogen (GH2) in deep, man-made, solution-mined salt caverns, where domal salt geology is available and abundant -- along the Gulf of Mexico coast -- for ~ $ 0.20 / kWh capital cost (CAPEX). Annual-scale firming storage for USA's total energy supply from wind and solar is affordable, at continental scale.

Each cavern stores ~ 90,000 MWh as the chemical energy in Hydrogen (H_2) , in ~ 2,500 tons (Mt) of "working gas" in addition to ~ 1,000 Mt of permanent "cushion gas". The surface facility, which provides compression, metering, gas drying, and pipeline termination, may be shared by several caverns manifolded together at the same pressure.

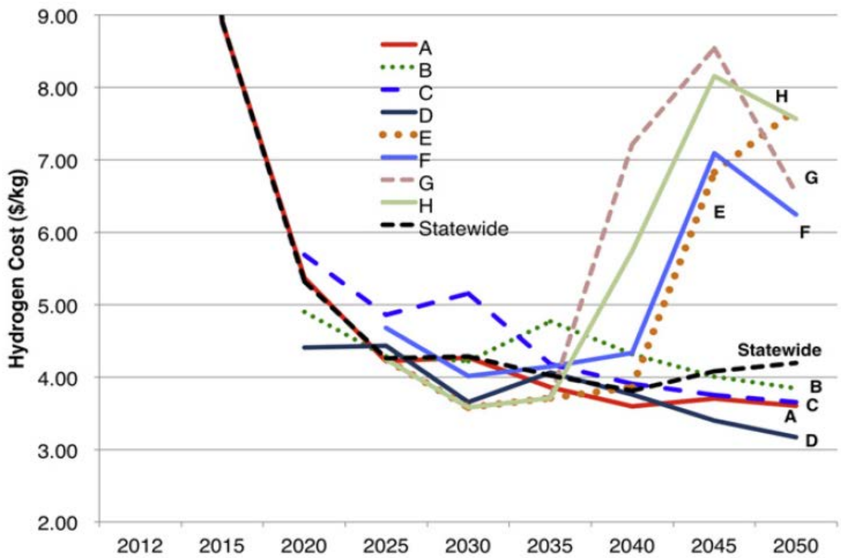


Figure 7. [vi] In years 2020 - 2035, if the wholesale Hydrogen fuel price in CA is $ 4.00 / kg, at 50 kWh / kg for Hydrogen production by water electrolysis, wind and solar energy is worth $ 0.08 / kWh at the turbine, PV array, or plant gate, with no necessary connection to, nor energy delivery to or from the electricity Grid. The CAPEX cost recovery for the electrolysis plant is offset by the CAPEX and O&M cost savings at the wind turbine and windplant by eliminating the electricity Grid connection infrastructure and the complex controls necessary to deliver grid-quality electricity to AC or DC gathering, transmission, and storage systems.

2. Technical Approach

Figures 10 and 11. The AASI Palm Springs windplant is the ideal test bed for this project:

- Turbines are equipped with 50 kW squirrel cage induction motors, as generators;
- SEIG-mode operation has been demonstrated on one turbine; Figure 11, with video link;
- 50 kW turbines allow this low-cost testing project, at valid size for scaleup to multi-MW;
- The wind regime is both strong and variable;
- Customers for the produced Hydrogen fuel are nearby.

AASI will commission NREL and / or Auburn University EE Department ("Auburn") to design, test, build, and deliver a proof-of-concept system implementing the Self Excited Induction Generator (SEIG) + Close-coupled electrolysis + SCADA system in Figure 8, for installation, test operations, Hydrogen fuel production, and data collection at its Palm Springs windplant, Figure 10, to achieve ~ TRL 6. This novel system could also produce CEF, carbon-free Ammonia fuel, as in Figure 9, which the International Energy Agency (IEA) considers a credible strategy. [vii]

Figure 11. SEIG mode has been used for decades as an EE teaching tool, but has not been commercialized, for lack of low-cost power electronics and digital control hardware and software: this applied R&D project, proposed by AASI for GFO-16-310, is now enabled by lower-cost components, by demand for Hydrogen fuel production without the costly Grid connection, and by the body of SEIG research, including by the project's NREL design team. [viii] This project will advance a novel commercialization of SEIG, in an integrated system for wind-to-Hydrogen production, advancing from ~ TRL 2 to ~ TRL 6.

AASI has achieved ~ TRL 2 by operating one of its Palm Springs windplant turbines in SEIG mode, delivering "wild DC" to a resistive dummy load. Figure 11.
Video of this test: https://vimeo.com/160472532
Video of the complete AASI windplant operation: https://vimeo.com/86851009

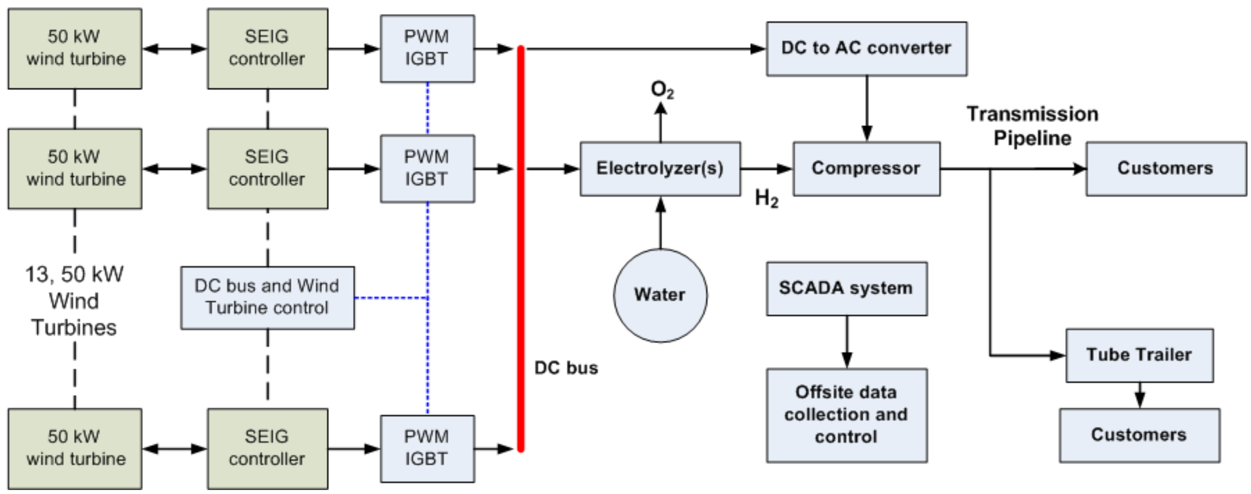


Figure 8. The SEIG + Close-coupled electrolysis + SCADA system to be designed, tested, and built at NREL and / or at Auburn, then to be installed at AASI's Palm Springs windplant for evaluating total system performance at an operating windplant, in an energetic wind regime, combining the outputs of two or three turbines. SCADA data will guide integrated system design improvements, and enable and document evaluation of commercialization potential.

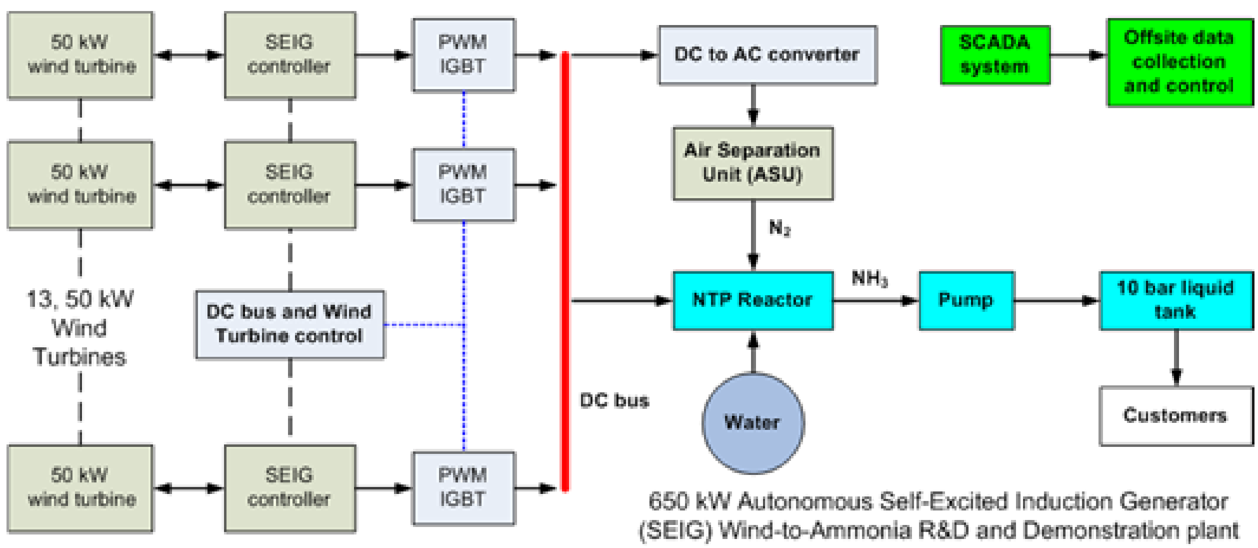


Figure 9. This project's SEIG technology may also be coupled via the "wild DC" bus, to novel Anhydrous Ammonia (NH_3) fuel synthesis reactor systems being researched via the ARPA-E "REFUEL" program [ix], and by Siemens, and others. [x]

Figure 10. AASI's windplant of 13, 50 kW nameplate, downwind, free-yaw turbines in A-row, at 62450 Dillon Rd, North Palm Springs, CA 92258. This windplant of vintage-1985 turbines delivered electricity to the SCE grid from 1991- 2012, when the PPA expired. AASI intends to reconfigure this windplant to deliver 100 % of its captured energy as Hydrogen transportation fuel, with no connection to the grid, for fuel cell cars, buses, trucks. Hydrogen delivery will be via tube trailer in the short term, then via a new, dedicated, high-purity, underground Hydrogen pipeline system for gathering and transmission, firming storage, and distribution. An attractive Hydrogen fuel customer is Sunline Transit, 15 miles east on I-10, at Thousand Palms, which operates fuel cell buses.
Video: https://vimeo.com/86851009

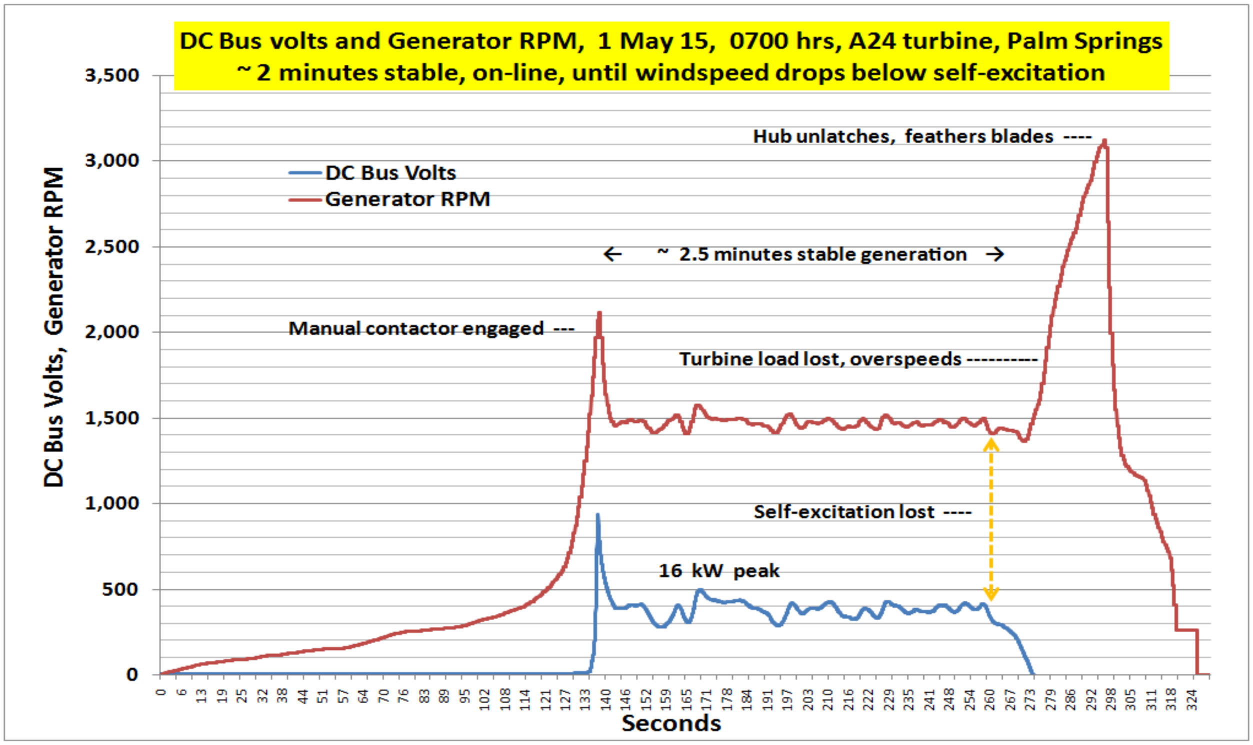


Figure 11. AASI achieved TRL 2 by operating one of the turbines at its North Palm Springs, CA windplant in variable-speed Self Excited Induction Generator (SEIG) mode, delivering "wild DC" energy to a resistive dummy load.
Video: https://vimeo.com/160472532

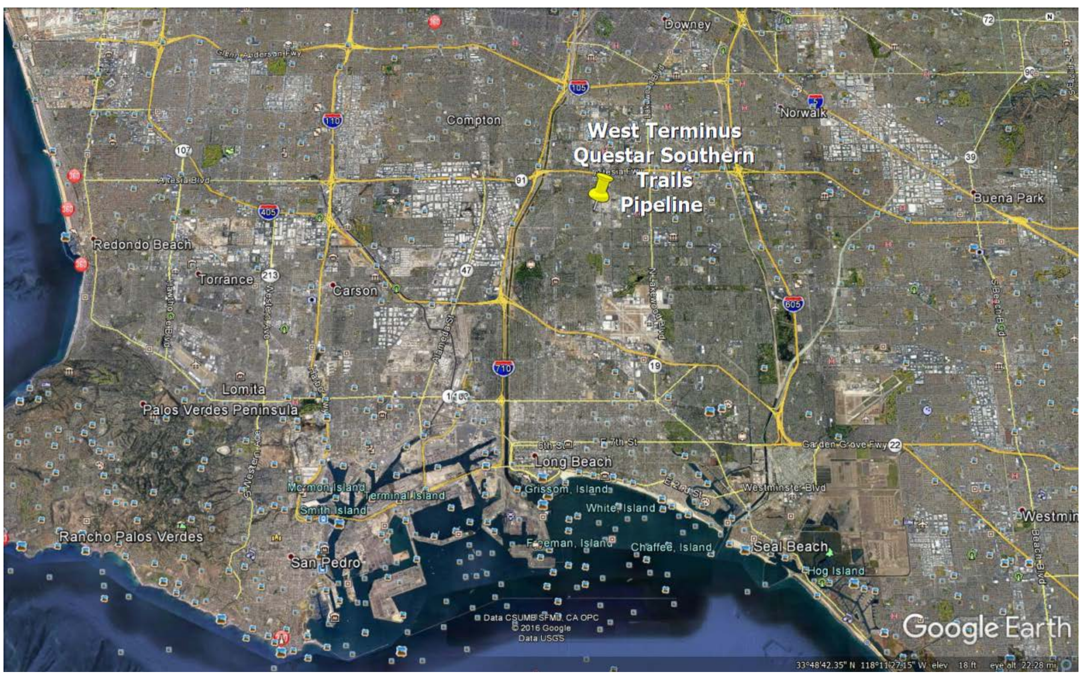


Figure 12. Western Section, Southern Trails Pipeline, east and west terminals. This pipeline is for sale by Questar. Former crude oil pipeline, now out of service: 16" diameter, 96 miles long, without compression or other midline components. It might be repurposed for low-pressure, low-capacity, gaseous Hydrogen (GH2) service as a "lighthouse" project, in the short term. If relined to 12" diameter, MAOP = 100 bar, pipeline capacity would be ~ 900 MW = ~ 400 metric tons (Mt) of Hydrogen fuel per day = 40,000 kg / day. Contact: Lori.Creer@questar.com

Figure 13. Hydrogen delivery, from windplants equipped with the technology this project's success will enable, is by compressed Hydrogen in "tube trailers" [xi] in the short term, and in the longer term by pipelines designed for RE-source Hydrogen transmission service. The time-varying output of wind and solar sources, and "packing" the pipeline to maximum allowed operating pressure (MAOP) will probably require new linepipe materials such as polymer-metal tubing with a thin layer of Cu or Al as the Hydrogen permeation barrier. Concept sample. [xii]

3. Impacts and Benefits to California Ratepayers

This project's success and subsequent commercialization will primarily benefit CA IOU ratepayers by:

- Preventing large investments in Grid infrastructure, attempting to supply CA's transportation energy from wind and other CEF sources, to achieve RPS and "80 in 50" goals; preventing higher electricity rates required for Grid investment cost recovery;
- Greatly reducing curtailed wind energy by providing alternatives to the Grid in markets and pathways, proceeding from wind-source Hydrogen: GH2 and NH_3 fuels, Power-to-Gas. This will allow new wind production for primarily Grid delivery at lower PPA prices;
- Eliminating costly connection of wind turbines and windplants, dedicated to Hydrogen fuel production, to the electricity Grid.

Attempting to supply CA's transportation energy via the electricity Grid will require very large investments (CAPEX) in upgrades and new gathering, transmission, storage, and distribution infrastructure, and its O&M costs, which must be recovered by higher electricity costs for IOU ratepayers:

- Gathering wiring and substations within windplants and solar PV plants
- Transmission lines and substations
- Grid energy storage, at several levels
- Backup generation, generally gas-fired and operating at low utilization factor (UF)
- "Smart" features: electricity quality, resilience, stability, metering, cyberattack defense
- Distributed Energy Resource (DER) generation acceptance on distribution feeders

The State of CA, several industries, and many companies, universities, and researchers have heavily invested funds and expertise in bringing Hydrogen-fueled, Fuel Cell Vehicles (FCV's) -- Light Duty Vehicles (LDV's), buses, and trucks of all sizes -- to market, and in the nascent Hydrogen production and fueling system to support them. The CA-funded retail Hydrogen fueling stations are required to dispense CEF-source Hydrogen fuel for > 1/3 of total fuel sales. That CEF Hydrogen is now made from "certified-green" landfill gas, methane metered and pipelined via extant natural gas infrastructure to large extant Steam Methane Reforming (SMR) plants for conversion to Hydrogen, for truck delivery to the new fueling stations.

As Hydrogen fuel demand grows, the supply of "green" landfill gas to supply SMR plants will be exhausted, requiring new sources of CEF Hydrogen. RE electricity from old and new wind and solar plants may be converted to high-purity Hydrogen fuel by electrolysis of water. Older wind turbines equipped with squirrel cage induction motors, as generators, may be retrofitted with the new, integrated, Hydrogen production system to be designed and demonstrated in this project, based on the novel combination of Self Excited Induction Generator (SEIG) mode wind turbine operation and close-coupling to the electrolysis stacks, with no connection to the electricity Grid.

Both old and new Grid-independent turbine designs and new windplants, dedicated to Hydrogen production, equipped with low-cost, robust, induction motors as generators, will also help CA achieve most economically RPS and "80 in 50" goals, maximizing wind energy's contribution by:

- Simplifying and lowering the CAPEX and O&M cost of the wind-to-Hydrogen production system, thus reducing the plant-gate cost of Hydrogen fuel;
- Requiring no wind turbine components nor windplant infrastructure, dedicated at both turbine and windplant levels to delivering Grid-quality AC or DC to the Grid; Figures 8, 9;
- Freeing new windplants of costly infrastructure investments: underground gathering wiring, a transformer at every turbine tower base, and a Grid-interface substation;
- Improving the economic performance of windplants with expired PTC and / or PPA, by monetizing their wind-generated electric energy at ~ $ 0.08 / kWh by dedicated production of Hydrogen via electrolysis, which requires ~ 50 kWh of electric energy per kg Hydrogen. With wholesale CEF Hydrogen fuel price expected to be $ 4.00 to $ 5.00 per kg in years 2020 - 2035, the value of electric energy to produce it is ~ $ 0.08 / kWh. Figure 7; profitability is reduced by recovery of capital costs of the electrolysis system;
- Greatly reducing otherwise-curtailed wind and solar energy production, both "centralized" and "distributed", by providing alternative pathways for transmission, low-cost storage, distribution, and end-use as transportation and stationary CHP fuel; this includes GH2, Anhydrous Ammonia (NH_3), and "Power to Gas" -- the capture of otherwise-curtailed energy as GH2 injected into the natural gas pipeline network; [xiii] Figures 8, 9, and 13;
- Allowing the IOU's to develop new business models with less uncertainty about the amount of transportation energy they would be required to supply, where, and when;
- Enabling wind energy harvest from large, windy areas not served by electricity transmission, by both small and MW-scale turbines, by motivating construction of a new underground pipeline network dedicated to renewables-source, CEF, high-purity Hydrogen and / or Ammonia fuels; Figures 4, 5, 12, 13, a potential "lighthouse" project;
- Enabling synergistic combination of the output of both wind and solar PV generators at plants where both are co-located; both diurnal and seasonal synergy in most of CA;
- Enabling retrofit of older turbines and windplants, equipped with squirrel-cage induction motors as generators, by replacing only their control systems;
- Motivating the design of new turbines and windplants, dedicated to Hydrogen production, with no Grid connection, using the novel system this project demonstrates;
- Enabling very low-cost energy storage, < $ 1.00 / kWh CAPEX, as GH2 in deep, man-made, solution-mined salt caverns; Figure 6;

- Embracing both gaseous Hydrogen (GH2) and possibly also liquid NH_3 as complete, integrated, optimized, CEF energy systems supplied by wind and other renewable sources within, and from beyond, CA. Figures 8 and 9.
- Embracing "Blockchain" energy packet tracking and control; Energy Web Foundation;

We estimate that commercializing this project's SEIG + Close-coupled electrolysis + SCADA system, on older wind turbines equipped with squirrel cage induction motors-as-generators, and on new turbines and windplants, optimized for and dedicated to wind-source Hydrogen fuel production, with no connection to the Grid, the long-term plant-gate wholesale cost of Hydrogen fuel may be reduced by 25 - 40 % with significant consequential improvements in system reliability and resilience, vis-a-vis Grid-connected wind generation systems.

4. Team Qualifications, Capabilities and Resources

The NREL team, below, was assembled for partnering on AASI's 2015 unsuccessful ARPA-E "OPEN" FOA Full Application. The team helped compose AASI's unsuccessful Small Business Voucher (SBV.org) applications; it helped prepare this CEC GFO-16-310 application, and will execute it, if funded.

William C. Leighty (PI) wleighty@earthlink.net 907-586-1426 (w) 206-719-5554 (m)

BS Electrical Engineering, Stanford, 1965 MBA, Stanford, 1971

1990 - present	Principal, Alaska Applied Sciences, Inc. (AASI), Juneau, AK. Energy R&D, consulting
1989 - present	Director, The Leighty Foundation www.leightyfoundation.org/earth.php
	Co-authored and presented over 20 papers on H2 and Ammonia energy systems as alternatives to electricity systems for large + small distributed renewable energy sources, at: www.leightyfoundation.org/earth.php
1971 - 1990	Small business owner and consultant, Juneau, AK
1966 - 1969	Collins Radio Company: Assistant Product Line Manager; Field Engineer in Thailand, Vietnam

Robert W. Preus, PE (NREL POC and PI) Robert.preus@nrel.gov 303-384-7284 office 720-302-3476 mobile

Professional Engineer and Project Manager. Technical Lead for Distributed Wind Energy Systems. Responsible for projects at National Renewable Energy Laboratories that are for the development of distributed wind (DW) tech.

BS Mechanical Engineering, University of Washington. Licensed PE. Certified for OSHA-10, NFPA70e, First Aid Basic and CPR, Tower Climbing, Suspended Scaffold Safety and Self Rescue, Up Tower Assisted Rescue.

Extensive experience in project management including: design, prototype development, testing, certification, manufacturing, installation, onsite inspection and repair for multiple renewable energy products and projects. Provided project commissioning inspections, maintainability and availability analysis, forensic analysis, repair cost review, lost revenue calculations, and retrofit design oversight for renewable energy products and projects.

Led the successful development of five wind powered generators, three of which went into commercial production.

Kevin W. Harrison, PhD Senior Engineer Kevin.Harrison@nrel.gov 303-815-3721

A.A.S., Computer Technology, Monroe Community College, 1992

B.S., Electrical Engineering, University of Rochester, 1995

M.S., Electrical Engineering, University of North Dakota, 2002

Ph.D., Energy Engineering, University of North Dakota, 2006

2006 – Present Senior Engineer, NREL, Hydrogen Technologies & Systems Center

• Responsible for all R&D activities surrounding integrated renewable electrolysis hydrogen production, compression, and dispensing system.

• Equipment work includes maintaining low-temperature hydrogen production equipment, rebuilding diaphragm compressors, fuel cells, cooling systems, water purification, and related support equipment < 10,000 psi.

• Design, build, and program data acquisition systems to monitor and control remote hydrogen-based equipment Design, build, and test power converters from wind and solar electricity sources to hydrogen-producing stacks of commercial electrolyzer systems.

• Co-PI for renewable electrolysis projects, including budget, annual operating plan, personnel development, and reporting results to DOE/NREL management.

Eduard Muljadi, PhD Eduard.Muljadi@nrel.gov 303-384-6904 303-275-3760

Ph.D., Electrical Engineering, University of Wisconsin-Madison, 1987

M.S., Electrical Engineering, University of Wisconsin-Madison, 1984

B.Sc., Electrical Engineering, Sepuluh Nopember Institute of Technology, 1981

1992-Present National Renewable Energy Laboratory, Golden, CO, Electrical Systems Engineer

1988-1992 Electrical Engineering, California State University, Fresno, CA, Asst. Professor

1983-1987 Electrical Engineering Dept., University. of Wisconsin-Madison, Research and Teaching

• Awarded IEEE Prize Paper (1994) for a paper entitled: "Series Compensated PWM Inverter with Battery Supply

Applied to an Isolated Induction Generator", IEEE Transactions on Industry Applications Vol. 30, No. 4, 1994

• Graduate with High Distinction from Surabaya Institute of Technology.

• Inducted to Fellow of the IEEE in 2010

• 200+ publications (complete list: www.nrel.gov/publications); 4,200+ citations (scholar.google.com)

Ping Hsu, PhD ping.hsu@sjsu.edu 408-924-3902

Former NREL Fellow, with Ed Muljadi. Potential adjunct role in this SBV project

Director of General Engineering, Professor, Department of Electrical Engineering,

Charles W. Davidson College of Engineering, San Jose State University, San Jose, CA 95192-0080

Woonki Na, PhD wkna@csufresno.edu Office: 559-278-4824

NREL Fellow, with Ed Muljadi. Potential adjunct role. 2320 E. San Ramon Ave, MS EE 94 Fresno 93740-8030 Assistant Professor, Department of Electrical and Computer Engineering, California State University, Fresno

Dr. Sadrul Ula sula@cert.ucr.edu Office: 951-781-5791
Manager, Winston Chung Global Energy Center, UC Riverside, CE-CERT, SC-RISE. Prof, Bourns Engineering
Generator parameter test. Student access to windplant site and SCADA data; improve equipment and experiment design.

John Cornish JCornish@epc4h2.com Office: 720-974-1709
Principal, EPC, Lakewood, CO Hydrogen system permitting and installation at Palm Springs windplant test site.

5. Budget and Cost Effectiveness: Return on Investment (ROI, IRR from NCF)

This project's success, and subsequent commercialization of the proprietary technology developed thereby, has three significant cash consequences:

- Stable and lower electricity rates for all CA IOU ratepayers;
- Lower cost for wind-source Hydrogen fuel for CA transportation and CHP markets, from both old and new Grid-independent windplants;
- Profitable operation of CA windplants, their developers and construction companies, and the enterprises making and selling the SEIG-based wind-to-Hydrogen control systems, as older turbines and windplants are kept in service and new windplants are attracted to the profitable wind-to-Hydrogen market .

Since the project technology is at ~ TRL 2, numerical estimates for the ROI above are risky. However:

- The cost of wind-source Hydrogen fuel from dedicated, Grid-independent windplants using the SEIG-based controls system should be 25 - 40 % lower than for Grid-connected windplants.
- The aggregate CAPEX for CA Grid expansion, to provide CA transportation energy as electric energy from Grid-connected RE plants, would probably exceed $ 60 billion. This is the aggregate amount that CA IOU ratepayers would save over ~ 10 years: it will not be needed if Hydrogen-fueled FCV's prevail for all vehicle sizes and uses.
- ~ 250 GW of new wind + solar plants to provide Hydrogen transportation fuel will require ~ $ 400 - 500 billion in CAPEX, although not all of them will be in CA. Annual O&M contracts for the new plants will be several billion.

5. Budget and Cost Effectiveness: Budget $ Thousands

MajorTask	CEC Funds	Match Value Share	Total
Design SEIG subsystem	100		100
Design Close-coupled electrolysis subsystem	150		150
Design, integrate SCADA subsystem	100		100
Integrate, test, build, deliver pilot plant system for windplant test	110		150

Install pilot plant at AASI windplant	20		
Long-term test, data collection & analysis, hardware & software mods	20		
AASI supplied equipment		60	60
AASI supplied windplant test site windplant + infras		30	30
Site owner supplies test site, at no cost		4	4
AASI travel		4	4
AASI project mgmt.		20	20
TOTALS	500	118	618

AASI and NREL have agreed on scope of work (SOW), budget, and schedule for our application for USDOE Small Business Voucher (SBV), for NREL. Their hours for each task are appropriate; their hourly rate and overhead & administration are established internally. NREL is the intended principal subcontractor. The same principles will apply for work, if any, at Auburn.

6. Funds Spent in California Although the test site is in North Palm Springs, CA, AASI does not expect to spend enough funds in CA to qualify for bonus points for doing so.

7. Ratio of Direct Labor and Fringe Benefits Rates to Loaded Labor Rates AASI does not expect to hire employees anywhere for this project. All work will be done by subcontractors. We assume their labor and fringe benefits loading are appropriate and acceptable; we will so require of them

.

8. Match Funding See 5. Budget, above

Estimated cash value of matching effort by AASI and the test site owner, $ Thousands:

AASI supplied equipment	60
AASI supplied windplant test site windplant + infras	30
Site owner supplies test site, at no cost	4
AASI travel	4
AASI project management	20
TOTAL	118

9. Disadvantaged Communities The test site in North Palm Springs, CA 92258 is in a designated low income area (51 - 60%) but not in an Environmentally Disadvantaged community. The project's benefits will apply to all CA IOU ratepayers. AASI does not expect bonus points for this project aspect.

REFERENCES

[i] https://its.ucdavis.edu/research/publications/?frame=https%3A%2F%2Fitspubs.ucdavis.edu%2Findex.php%2Fresearch%2Fpublications%2Fpublication-detail%2F%3Fpub_id%3D2312

[ii] http://www.energy.ca.gov/2017publications/CEC-200-2017-001/CEC-200-2017-001.pdf

[iii] http://leightyfoundation.org/new/wp-content/uploads/whec16-lyon/WHEC16-Ref022.pdf

[iv] CALIFORNIA ENERGY BALANCE UPDATE AND DECOMPOSITION ANALYSIS FOR THE INDUSTRY AND BUILDING SECTORS, LBNL, 2013 APRIL 2013 CEC-500-2013-023

[v] Fig. 3 Exogenously specified California hydrogen demand (PJ/yr) to 2050 broken out by regional cluster (1 PJ H2 / yr = 19.3 tonnes H2 / day = 7,044 tonnes / year). SOURCE: Renewable and low carbon hydrogen for California -- Modeling the long term evolution of fuel infrastructure using a quasi-spatial TIMES model
Christopher Yang*, Joan M. Ogden, Institute of Transportation Studies, One Shields Avenue, University of California, Davis, Davis, CA 95616, USA international journal of hydrogen energy (IJHE) 38 (2013) 4250 - 4265

[vi] ibid

[vii] http://www.iea.org/newsroom/news/2017/april/producing-industrial-hydrogen-from-renewable-energy.html

[viii] Self-Excited Induction Generator for Variable-Speed Wind Turbine Generation, E. Muljadi, B. Gregory, D. Broad, National Renewable Energy Laboratory (NREL)
Prepared for POWERSYSTEMS WORLD '96 Conference, Ventura, California, September 7-13, 1996
http://www.nrel.gov/docs/legosti/old/21436.pdf

[ix] https://arpa-e.energy.gov/?q=arpa-e-programs/refuel

[x] https://www.siemens.co.uk/en/insights/potential-of-green-ammonia-as-fertiliser-and-electricity-storage.htm

[xi] GTM-1350 tube trailer by Luxfer-GTM Technologies http://www.luxfergtm.com/index.php/our-products-2/

[xii] Polymer-metal linepipe concept sample by Smartpipe Technologies, Houston. www.smart-pipe.com An R&D and Demonstration program would be required to design and certify the manufacturing process

[xiii] http://www.energy.ca.gov/2017publications/CEC-200-2017-001/CEC-200-2017-001.pdf