Grid Relief, Curtailed Energy Harvest, and Free Storage: Demonstrating Autonomous, Off-Grid, Lower-cost, Dedicated Hydrogen Production from Integrated Wind + PV via SEIG-mode Wind Turbines, Close-coupled Electrolysis Stack Arrays, and Single SCADA

CATEGORY 1, SUBCATEGORY F: Grid-Reliability

ARPA-E $ 480,000 Match, in-kind: $ 125,000 Total: $ 605,000 Duration: Two years

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H2 Hydrogen (H_2)
GH2 Gaseous Hydrogen (H2, H_2)
HE Hydrogen Embrittlement
NH_3 Anhydrous Ammonia, "the other hydrogen"
NG Natural Gas
DER Distributed Energy Resources
TEA Technical and Economic Analysis
CEF CO2-emission-free
GOM Gulf Of Mexico
AU Auburn University
VER Variable Energy Resources (wind, solar, etc.)
HCC Hydrogen Corrosion Cracking
SCADA Supervisory, Control, and Data Acquisition (system)
MAOP Maximum Allowed Operating Pressure
MMt Million metric tons
RD&D Research, Development, and Demonstration
LCC Life Cycle Cost
WECC Western Electric Coordinating Council

Partners:

- Auburn University, Auburn, AL: Prof Eduard Muljadi
- Nel Hydrogen, Wallingford, CT: Matthew Weaver, Commercial Manager, North America
- UC Irvine: Dr. Geoffrey Reed, Chief Scientist, Advanced Power and Energy Program
- NREL: Dr. Mark Ruth, Manager, Industrial Systems and Fuels | Strategic Energy Analysis Center
- Wintec Energy LLC, Palm Springs, CA: Fred Noble

A. Problem, Opportunity, Concept Total de-carbonization and de-GHG-emission of the entire human enterprise is our urgent goal. Attempting this entirely with a larger and smarter electricity Grid(s) will be technically and economically suboptimal, if primarily from variable energy resources (VER) like wind and solar. Transmission and annual-scale firming energy storage is too costly, relative to energy systems based on the C-free fuels, hydrogen (H_2) and ammonia (NH_3), whereby gathering, transmission, and distribution is via dedicated underground pipeline networks and very-low-cost (< $ 1.00 / kWh CAPEX) GWh-scale storage. "Packing" H_2 pipelines, as NG industry does, provides large no-cost energy storage.

California (CA) now curtails about 1 million MWh / year of wind and solar energy, which cannot be profitably harvested for lack of both electricity and H_2 or NH_3 infrastructure. In CA, year 2050, annual H_2 demand for road transportation fuel will be ~ 7 MMt, requiring the total energy production of (name plate) ~ 250,000 MW of an optimal mix of wind and solar generation. Marine, rail, and aviation, plus stationary CHP and H_2 industrial feedstocks demands, may double that, in CA, alone; H_2 net import from WECC is thus required. Years 2025 - 50 will also require a new, dedicated, high-purity, GH2 pipeline network, combining low-cost GH2 pipeline transmission and "packing" storage for profitable:

- Harvest and sale of otherwise-curtailed wind + solar energy as high-purity transport & CHP H_2 fuel;
- Production of H_2 and NH_3 fuels from both extant and new wind + PV plants, both on- and off-Grid;
- Continental-scale pipelines growth, to access big low-cost H_2 salt cavern storage in Utah and GOM.

Therefore, we now need this project's novel disruptive technology, applicable to both existing and new wind, solar, and wind + solar plants, to prevent over-dependence upon, and over-investment in, the Grid, to relieve it of responsibility for profitable harvest of curtailed, VER sources, as firm and dispatchable. We will embody this technology in a pilot plant tested on our off-Grid wind+PV plant in Palm Springs.

Impacts on Grid and entire energy system We prevent Grid instability, VER curtailment, long-term storage, and wildfire ignition stresses, by relieving the Grid of the responsibilities for (a) gathering and transmission and (b) seasonal-scale storage, from large, distant wind and solar plants, as disruptive events become more frequent. Now, at regional-to-continental scales, and at annual firming scales, Grid regions may interchange abundant "green" hydrogen via dedicated, high-purity GH2 pipelines. A 36" GH2 pipeline, 1,600 km long, stores ~120,000 MWh, at no cost, by "packing". Large, autonomous, off-Grid, wind, PV and co-located, co-generating wind+PV plants will deliver their entire output as GH2 to the new pipeline network, combining new pipelines and repurposed, relined, extant pipelines, all dedicated to high-purity, CEF, GH2 output. Grid relief, plus lower CAPEX & OPEX via simpler plants.

Grid relief success requires both lower plant-gate H_2 cost and a ubiquitous GH2 pipeline network. This project's success, confirmed by field test data on an operating, H_2 plant of co-located wind+PV, will:

1. Enable progress toward year 2050 scale, by reducing the plant-gate cost of wind+PV source H_2, by decreasing CAPEX and OPEX, by eliminating costly electricity infrastructure, both in-plant, beyond;
2. Open a large new market for wind and PV energy, perhaps larger than for the electricity Grid;
3. Open large windy land areas, without electricity transmission, to wind+PV harvest as C-free fuels, H_2, for underground pipeline transmission as GH2, and perhaps also as liquid Anhydrous Ammonia (NH_3);
4. Simplify wind turbine electric generating systems, reducing CAPEX, OPEX, and H_2 COE; Figs 1, 2
5. Simplify electrolysis plant, reduce cost: eliminate AC-DC power supply, redundant controls; Figs 1, 2
6. Allow autonomous and optimum wind turbine, windplant, and PV operation on internal DC bus, off-Grid, reducing costs of electrolysis system, thus reducing H_2 COE at the windplant gate; Figs 1,2
7. Free congested electric transmission lines from the burden of VER wind+PV energy; allow profitable capture of otherwise-curtailed "green" energy; provide large zero-cost GH2 pipeline "packing" storage.
8. Develop and protect novel IP, perhaps justifying developing a product line for both retrofit & OEM;
9. Discover, prove, novel wind+PV system optimization via Machine Learning AI (ML-AI) SCADA;
10. Enable H2@Scale: all above scalable from 100 kW (this project) to multi-MW, DER to continental.

B. High-risk Innovation Auburn University develops the novel enabling power electronics and single SCADA system to optimize Grid relief: wind+PV energy capture, conversion efficiency, safety, and profitable harvest of energy now curtailed. Both extant and new wind, PV, and wind+PV plants, with or without Grid connection, can relieve tech and econ stress on the Grid by operating the turbines in Self Excited Induction Generator (SEIG) mode, producing "wild DC" directly coupled to electrolysis stacks arrays, producing high-purity hydrogen fuel at > 20% lower cost than Grid-delivery plants. Co-located, co-generating, PV "wild DC" strings also directly feed electrolysis stacks arrays; no AC-DC supplies.

Project success will disrupt and transform both the electricity and H_2 industries, relieving the Grid of large, perhaps suboptimal and futile, capital investments attempting to achieve stability, reliability, and economy, in order to supply most of humanity's energy from CEF, VER sources. Electricity will not be replaced, but may be restricted to "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, high-purity, GH2 underground pipeline infrastructure is required: we must discover whether it would be a better investment than Grid expansion, capacity, and storage increases:

1. Enables 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 wind+PV plant DC bus to the electrolysis stacks, and a single SCADA, as invented and lab-tested by Auburn University (AU), and field-proven and design-improved, on applicant AASI's operating wind+PV plant in Palm Springs, CA;
2. Reduces wind turbine, windplant, PV, and electrolysis integrated system complexity: CAPEX, OPEX, by eliminating electricity Grid tie, thus reducing wind-source H_2 cost ~ 20% at turbine and at windplant;
3. Replaces costly wind+PV plant electrical medium-voltage (MV) infrastructure -- many km of cable, turbine transformers, switchgear, substation, transmission line to HV interface -- with lower-cost piping. This includes whole system: GH2 gathering to transmission pipeline delivery --without Grid connection.
4. Eliminates costly, delaying PPA's and "system impact studies" required by utilities, RTO's, ISO's;
5. Greatly increases "distributed" wind energy harvest area, delivering high-purity H_2 and NH_3 fuels, without Grid presence or connection, to these new GH2 and / or liquid NH_3 pipeline network(s) for both stranded and distributed (DER) wind and synergistic PV, and perhaps also for other "green" DER.

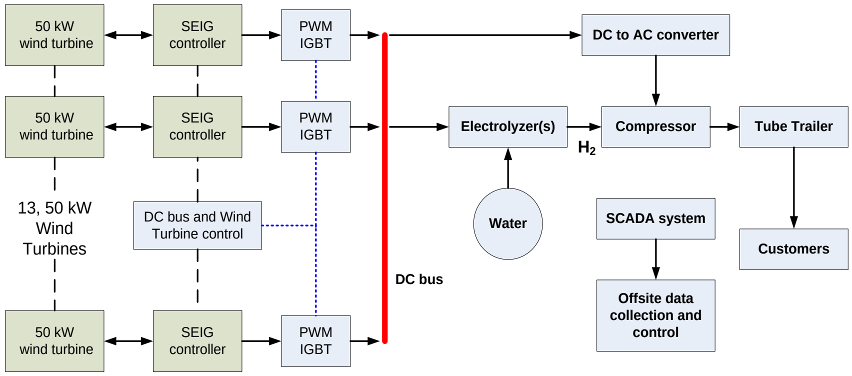

Figure 1. Complete, integrated, SEIG multi-turbine, autonomous wind-to-H_2 system to be designed by Auburn University and field tested at AASI's multi-turbine, off-Grid, Palm Springs windplant. Single SCADA for all components, uploads ops data to all Team partners for (a) design improvements, (b) optimizing energy capture by (ML-AI) "tuning", for Z-matching all components of the total system, (c) TEA: techno-economic whole-system analyses.

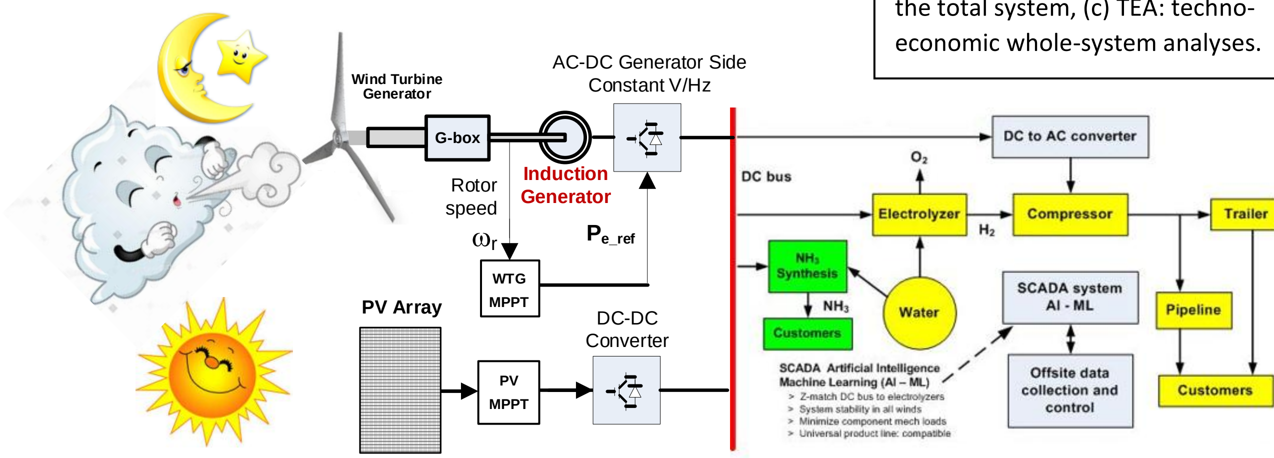

Figure 2. Auburn University (AU) will combine PV DC strings with SEIG-mode wind turbines at the applicant's synergistic, off-Grid, autonomous, operating wind+PV H_2 production pilot plant in Palm Springs, CA, to provide credible data for the comprehensive techno-economic analysis. This enables H_2 vis-a-vis Grid systems comparison, scaling to multi-GW, and to GWh and TWh, to avoid over-dependence on, and over-investment in, the electricity Grid.

Figure 3. AASI multi-turbine windplant in Palm Springs, CA, for operational field test of novel-technology integrated wind+PV-to-H_2 system, to guide system design improvement and produce data for techno-economic analyses. Ideal test bed for this project: high-energy wind, 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-GW windplants. 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; in serviceable condition; project will utilize at most three of them; follow-on project for all 13. PV array to be added. Windplant operating video: https://vimeo.com/86851009

Figure 4. Two Proton OnSite H6m electrolysis plants; six electrolysis stacks from them, for use in RD&D project to generate data for the techno-economic analyses to guide commercialization, H2@Scale policy, and future HFTO R&D menu.

C. Work 1. AU will design, build, and demonstrate a 100 kWe nameplate, novel, integrated, efficient, lower-cost, wind+PV-to-H_2 capture and production system on AASI's operating off-Grid windplant, based on Self Excited Induction Generator (SEIG) turbines, several DC PV strings, close-coupled via the common DC bus to electrolysis stacks array, with a single SCADA optimizing the complete system;

2. Operating data from the novel power electronics and single-SCADA-controls pilot plant, at applicant AASI's off-Grid Palm Springs wind+PV plant, will guide and enable future DOE Grid and H_2 R&D:

- By what percentage will this novel H_2 production technology, in concert with the GH2 pipeline systems it enables and requires, lower the plant-gate and dispensed costs of "green" H_2, anywhere ?
- How may this project's success influence the energy industry's relative dependence upon, and investment in, H_2-based vis-a-vis Grid-based systems for de-carbonizing entire human enterprise?

3. Advance the project's novel system design from ~ TRL 3 to TRL 6: pre-commercialization, for profit;

4. Relevance: Pilot plant ops data must show performance targets > 20% lower plant-gate, > 30% lower dispensed, H_2 cost than as H_2 from Grid-connected new wind+PV plants. High confidence in techno-economic analyses, based on operational pilot plant data, scalable to multi-MW, regional-to-continental.

5. Validate project's novel technologies; install and test hardware and software design improvements revealed by Palm Springs wind+PV plant field test data. Extrapolate: TEA to estimate lower plant-gate & dispensed LCC for wind+PV-source H_2 for goals achievement and advancements toward TRL 6.

6. Risks: This on- or off-Grid RD&D system novel technology development may fail to produce goal improved wind+PV plant operation, or lower expected plant-gate H_2 cost, or get valid data for analyses. Integrating wind+PV on same DC bus to electrolyzer stacks may fail; system instability may result. Partners will assist with novel "wild DC" bus-to-electrolysis stacks Z-matching and controls interface.

7. Funds: $ 480,000 ARPA-E + $ 125,000 in-kind from applicant and partners, for pilot plant + field test

D. Team organization and capabilities

Alaska Applied Sciences, Inc. PI: William C Leighty, BSEE, MBA, Stanford, Principal. Founded ' 90. Director, The Leighty Foundation: 20 years co-authoring papers on complete renewables-H_2 systems. Owns 13-turbine Palm Springs, CA windplant & 2 electrolysis plants & H_2 compressor & water DI set. Successful DOE-funded research project, 2005: https://www.osti.gov/biblio/859303
Auburn University PI: Dr. Eduard Muljadi. SEIG-mode custom power electronics and controls for off-Grid wind+PV H_2 production. NREL, 1990-2017. Principal Engineer, wind turbine generating systems and power electronics; retired in 2017 to join the EE Dept faculty at AU. Fellow of the IEEE (2010).
Dr. Bruce Tatarchuk. Professor, Department of Chemical Engineering. Close-coupling wind+PV DC bus to electrolysis stacks array; feedwater supply, system cooling. 1996-Present.
Dr. Robert Nelms. Department Head, Electrical Engineering. Power electronics and SCADA system architecture design and test; dynamometer lab supervision; graduate student management; resources.

Nel Hydrogen Wallingford, CT. Matthew Weaver, Commercial Manager -- North America. TEA for simplified electrolysis plant design, close-coupling "wild DC" VER sources to electrolysis stacks.
NREL Dr. Mark Ruth, Manager, Industrial Systems and Fuels | Strategic Energy Analysis Center. TEA for project effect on total H_2 systems design, relevant to "H2@Scale" for C-neutrality in year 2050.
UC Irvine, APEP (Advanced Power and Energy Program) Dr. Jeff Reed, Chief Scientist, Renewable Fuels and Energy Storage. Board chair, California Hydrogen Business Council. Former Sempra Utilities
Wintec Energy Ltd Palm Springs, CA. Fred Noble, President. No-cost test site use.

Equipment and facilities Auburn University EE and Chemical Engineering Departments are well equipped for this work. The AASI windplant in Palm Springs, CA will need refurbishing and modification for operation as the operating test and data collection site for the novel technology pilot plant to be delivered by AU. Wintec Energy donates use of the site. AASI will contract for and supervise this work, PV installation, wind+PV plant operation, maintenance, and data collection.

Teaming on prior projects AASI, AU, Nel Hydrogen, UCI APEP, and Wintec Energy LLC have teamed on prior unsuccessful Full Applications for DOE (via FOA) and CEC (via GFO) project funding.