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New solicitations for Wind and Solar and Other in Alternative Fuel Production budget

The transmitted file in the Technical Volume from our company, Alaska Applied Sciences, Inc. Full Application for ARPA-E "OPEN" FOA funding to convert our Palm Springs windplant to deliver 100% of its energy capture as Hydrogen fuel for nearby markets, with no connection to the SCE electricity grid. It enhances the comment letter we also submitted today, recommending reallocating funding to Renewable Fuel Production from wind, solar, and other renewable sources.

Additional submitted attachment is included below.

Paralleled Self-Excited Induction Generators (SEIG's) for Optimized Hydrogen Fuel Production from Stranded, Multi-turbine Windplants: R&D and Demonstration at an Operating 13-turbine Windplant in Palm Springs, CA

Alaska Applied Sciences, Inc., Juneau, AK William C. Leighty

Total Project Cost: $ 4.10 M (27 % cost share)
Project Duration: 24 months

EXECUTIVE SUMMARY

This transformative project's success will reduce the cost of wind-generated hydrogen fuel and expand its geographic availability. We will design and build an off-grid wind-to-hydrogen system using an existing, stranded, 13-turbine windplant in Palm Springs, CA. Total windplant energy production will electrolyze water to produce hydrogen fuel for emerging nearby markets, for fuel cell buses and light duty vehicles, where large quantities of hydrogen fuel from diverse renewable energy resources will soon be required. This project is a fast path to production of hydrogen transportation fuel from a California windplant. This project will develop and demonstrate two novel technologies for lowering the cost of wind-generated hydrogen fuel:

1. Self-Excited Induction Generator (SEIG) system controller at each wind turbine, simplifying the generator system, using generic, robust, low-cost induction motors as generators, thereby lowering wind turbine capital and O&M costs
2. Windplant and electrolysis plant integrated control for maximum wind energy capture and hydrogen fuel production

The best wind resources are often stranded, with neither costly electricity grid transmission to distant markets nor firming storage for their time-varying output. Wind generation often peaks at night, when demand and price are low, and is minimum in summer, when demand and price peak. An alternative to electricity systems is required for a dispatchable supply of transportation and Combined Heat and Power (CHP) fuel, potentially a larger aggregate energy market than the electricity grid, in California and nationwide, as both "power-to-fuel" and "power-to-gas".

Converting the entire windplant output to hydrogen fuel, with no electricity grid connection, enables low-cost transmission and distribution via underground pipelines, and low-cost annual-scale firming energy storage in deep salt caverns and packed pipelines, at large scale. SEIG-equipped wind turbines and windplants may be located in any good wind area, their hydrogen fuel delivered by trucks and pipelines. Project success should proliferate SEIG-equipped wind-to-hydrogen investments; scaleup should be feasible as hydrogen fuel demand expands.

This project's transformative technologies are novel, intelligent controllers for (a) the SEIG on each wind turbine generator, and (b) combining the "wild DC" output of the turbines on a DC bus feeding the electrolyzer(s). Technology development assignments include:

- UCSJ EE Dept: implement SEIG system using off-shelf, three-phase, induction motors;
- NREL: electrolyzer system controller, integrating DC output from all 13 turbines;
- NREL: windplant system controller, integrating all controls and external communication
- Electrolyzer supplier: custom engineering and construction of electrolysis plant.

The complete system will be assembled and demonstrated at applicant's extant Palm Springs windplant, for at least two years. Annual production should exceed 11,000 kg of hydrogen.

1. INNOVATION AND IMPACT

1.1 Overall Description

Figures 1 - 3. This unique and disrupting project will reduce the cost of wind-generated hydrogen fuel and expand its geographic availability. It will transform the wind industry by disrupting its present near-total dependence on the electricity grid, providing new markets for wind-generated energy as a firm and dispatchable supply of hydrogen fuel, and of other fuels made from that hydrogen, for transportation, combined-heat-and-power (CHP), and all other energy markets. Multi-generator SEIG is applicable to all variable generation harvesters using rotating machines.

We will design and build an off-grid wind-to-hydrogen system using an existing, stranded, 13-turbine windplant in Palm Springs, CA. See video of windplant operation. [i] Total windplant electric energy production will electrolyze water to produce at least 11,000 kg of hydrogen fuel per year for nearby emerging markets, for fuel cell buses and light duty vehicles, where large quantities of hydrogen fuel from diverse renewable energy resources will soon be required.

This project is a fast path to production of hydrogen transportation fuel from a California windplant. This project will develop and demonstrate two novel, disruptive technologies for lowering the cost of wind-generated hydrogen fuel:

1. Self-Excited Induction Generator (SEIG) controller at each wind turbine, simplifying the generator system, thereby lowering wind turbine costs
2. Windplant and electrolysis plant integrated control for maximum wind energy capture and hydrogen fuel production

Figure 4. We have demonstrated stable SEIG-mode operation on one of the turbines at the Palm Springs windplant, with fixed shunt capacitance on the delta-connected generator stator. The research team will advance this finding by:

1. Designing an SEIG controller for installation on each wind turbine, by which optimum self-excitation is maintained, at startup and shutdown, and under varying wind and load; several topologies will be considered, featuring rectification of “wild AC” to “wild DC” at each wind turbine, for delivery to a common windplant DC bus
2. Designing a windplant controller to optimize impedance matching to the electrolysis plant, for:
    a. Maximum wind energy harvest
    b. Efficiency in conversion to hydrogen fuel
    c. Electrolysis plant operation, protection, and safety
3. Customizing the electrolysis plant design by eliminating the “transformer-rectifier” subsystem and by integrating the electrolysis plant controls with the windplant controller
4. Analyzing data from the windplant SCADA system to improve the wind-to-hydrogen plant design and operation, at every level

Contractors will build and install the equipment, including spares:

1. SEIG capacitors and control components on all wind turbines

2. Windplant control, SCADA, electric power, and external communication systems
3. Electrolysis plant, containerized, including all subsystems
4. Hydrogen fuel compressor, for loading tube trailer(s) at 250 bar
5. Civil engineering structures: concrete slabs, storage building

We expect that valuable IP will result from the successful project, in the form of control system hardware and software designs, which we intend to commercialize at multiple scales.

We intend to operate the wind-to-hydrogen plant profitably for several years after the project term, as a test bed, continuing to collect and publish operating data and improving system design. We will buy our own tube trailer, for hydrogen fuel transport and delivery.

1.2 Potential Impact

Figure 5. If BP's Year 2035 global energy system [ii] is humanity's future, we will not escape the five imminent, severe dangers of unrestrained fossil fuel combustion:

1. Rapid climate change, generally warming
2. Sea level rise
3. Ocean acidification
4. Species extinctions
5. Violent human conflict

Humanity must not accept this fate; we must and shall do better. Therefore, this is the problem to be solved, in part, by the proposed technology: Humanity needs to immediately accelerate its transformation of the world's largest industry from ~ 85% fossil to ~ 100% renewable energy sources. We cannot do that, and should not try, via electricity systems alone; they are probably technically and economically suboptimal for supplying all humanity's energy needs from renewable resources. We will also need carbon-emissions-free fuel systems to solve the three salient, chronic problems of time-varying renewable energy systems:

1. Gathering and transmission
2. Annual-scale firming storage, rendering renewables "dispatchable"
3. Distribution, integration, and end-use

Figures 12 – 17. Japan is leading the way toward transforming the world's largest industry, from ~ 85% fossil to ~ 100% renewable energy sources, as quickly as we prudently and profitably can. Japan is experimenting with three strategies for importing "liquid hydrogen" from non-carbon-emitting energy sources worldwide, in large volume, by ocean tankers.

The primary problem that SEIG, and multi-generator SEIG, may solve: Electricity systems can be adapted, at significant cost, with adjunct power electronics and energy storage and backup generation, to accommodate a large fraction of time-varying renewable energy input to the electricity sector. But electricity systems are probably a suboptimal technical and economic solution for the necessary transformation of the entire energy industry and its market segments, from fossil to renewable sources:

1. Figure 18. Overhead electric transmission lines are relatively expensive to build, per MW-km of transmission service, and are difficult to site.

2. O&M costs are high for overhead electric transmission and distribution lines vis-à-vis underground pipelines.
3. Without abundant storage and / or curtailment, electric line capacity factor is generally limited to the capacity factor of the sources.
4. Since the system operates in real time, at light speed, costly adjunct components and subsystems are required to maintain system stability and energy dispatchability.
5. Since annual-scale firming storage with “electricity” devices is not affordable, costly investment in backup generation, usually operating at low capacity factor, is required.

Thus, alternatives to electricity must be thoroughly considered, as complete renewable energy systems, from photons and moving air and water molecules to delivered energy services. Hydrogen, anhydrous ammonia (NH_3), and other “liquid hydrogen” fuels are attractive alternatives:

1. Generation, including conversion, may be less costly than for electricity systems
2. Transmission and storage are less costly than for electricity systems
3. Freedom from electricity grid connection greatly expands geographic harvest range
4. Complete renewables-source hydrogen and ammonia fuel systems may simultaneously solve renewable energy’s three salient problems: transmission, storage, integration.

The best wind resources are often stranded, with neither costly electricity grid transmission to distant markets nor firming storage for their time-varying output. Wind generation often peaks at night, when demand and price are low, and is minimum in summer, when demand and price peak. This project’s disruptive technologies are novel, intelligent controllers for (a) the SEIG on each wind turbine generator, and (b) combining the "wild DC" output of the turbines on a DC bus feeding the electrolyzer(s) to convert 100% of wind-generated electricity to hydrogen fuel, with no grid connection, for:

1. Transmission in underground pipelines
2. Storage in large, deep, salt caverns; in “packed” pipelines; in distributed vehicle tanks
3. Distribution for transportation and combined-heat-and-power (CHP) fuel

Wind and other turbines may consequently be equipped with simple, robust, low-cost, squirrel cage induction motors as generators, with minimal power electronics, and without field transformers and high voltage infrastructure, producing “wild AC” to “wild DC” to feed the electrolyzer stack(s). This results in:

1. Better mechanical load and electrical impedance matching between wind turbine and load
2. Lower cost of hydrogen fuel produced by wind and other variable-generation sources equipped with rotating-machine generators
3. The ability to combine the electric energy output of multiple wind turbines and other rotating renewable generation harvesters, on a common DC bus, to the electrolysis plant

Figure 25. The SEIG concept. SEIG-equipped wind turbines and windplants may consequently be located in any good wind area, their hydrogen fuel delivered by trucks and underground pipelines. Project success should proliferate profitable SEIG-equipped wind-to-hydrogen projects, especially in places with good wind resources and inadequate electricity transmission. In turn, this will hasten the adoption of hydrogen fuel for:

1. Transportation, in fuel cell cars, buses, and eventually, ships and aircraft

2. Stationary Combined Heat and Power (CHP) systems
3. Power-to-Gas, for direct injection into natural gas pipelines, to deliver mixed-gas fuel, with very low transmission and storage costs, to a hydrogen concentration limit

Project success will thus be disruptive:

1. Lowering the cost of hydrogen fuel produced by wind and other rotating-machine electricity generating systems; displacing DFIG and other more complex and costly systems on wind turbines
2. Expanding the geographic area over which wind energy may be profitably harvested

Figures 6 and 7. For an impact example, if 20% of California's 45 million light duty vehicles (LDV's) were hydrogen-fueled, fuel cell hybrid electric vehicles (FCHEV's), driven 15,000 miles per year at 68 miles per kg hydrogen fuel, they would consume ~ 1.7 million tons of hydrogen fuel per year. That would require the full output of ~ 23,000 MW nameplate wind, at 40% capacity factor (CF). Importing that amount into California would require 3 hydrogen transmission pipelines, of 1 meter diameter, at 100 bar. Firming that fuel supply at annual scale, rendering it "dispatchable", would require ~ 90 deep, solution-mined, salt storage caverns.

California recognizes that large investments in hydrogen pipeline systems will be needed. [iii] California cannot meet its goal of "80 x 50", an 80% reduction in Greenhouse Gas (GHG) emissions from transportation sources by Year 2050 with battery-electric vehicles, (BEV's) alone, [iv] without many FCHEV's operating on carbon-emissions-free hydrogen fuel.

Water feedstock consumption for electrolysis is an important impact in California. 9 kg of fresh water is required for each kg of hydrogen fuel. This project will therefore consume ~ 100,000 kg per year, about 26,300 gallons. The Palm Springs windplant site has municipal water supply, which will be available for this project. An equivalent amount of water will be generated at each hydrogen fuel point-of-use, but prospect for collection and re-use is unknown.

Figure 8. At USA national scale, this magnitude of hydrogen demand for transportation fuel alone, would justify a continental-scale infrastructure of pipelines and GH2 storage caverns dedicated to the gathering, transmission, firming storage, distribution, and end-use.

Figure 9. GH2 pipeline capacity, without midline compression, is large, enabled by the low viscosity of GH2. High-pressure-output electrolyzers may directly feed the transmission pipeline at 100 bar. Pipeline friction losses reduce city-gate delivery pressure to a convenient ~ 30 bar.

Figure 10. Project impact assessment must include SEIG propagation to complete wind-to-hydrogen systems. If low-cost salt cavern geologic storage is available, accessed by regional or continental GH2 transmission pipelines, wind-hydrogen systems are probably technically and economically superior to wind-electricity systems in delivering dispatchable energy services to end-users. GH2 storage at end-users enhances dispatchability. High-pressure-output electrolyzers may directly feed pipeline at 100 bar. Pipeline friction losses reduce city-gate delivery pressure to a convenient ~ 30 bar.

Figure 11. Windplants dedicated to hydrogen fuel production need no costly grid connection. Field transformers, substation, and transmission line are eliminated. Turbines are interconnected via pipes, not wires, except for low-power controls supply and comm.

1.2.1 Impact: Distributed Renewables – Wind and Other

As hydrogen fuel demand increases, now-stranded renewable resources that are harvested by rotating-machine generators – such as wind, tidal, ocean current, wave, and some solar – may become strategic and profitable, benefitting from the SEIG and multi-generator bus control systems to be developed by this project. These “distributed” generators vary from kW to MW.

Also, we do not now know in what proportions renewables-source energy will be “generated” as electricity or as hydrogen – the latter via biological, photochemical, thermochemical, artificial photosynthesis, nuclear, or other processes. Electrolysis from renewable-source electricity is only one path to hydrogen fuel, which should be synergistically integrated with other pathways, in optimized renewable energy systems at local, to continental, to global scales.

Thus, we need to now develop the optimized hydrogen production technologies, including SEIG and multi-generator SEIG, to enable these synergistic, integrated, Distributed Energy Resources (DER) systems. [v]

1.2.2 Impact: Decarbonizing the Global Economy

“Today, for the first time ever, G7 leaders have rallied behind a long-term goal to decarbonize the global economy.” [8 June 15] [vi] As we accelerate our transformation of the world’s largest industry, from ~ 85% fossil to ~ 100% renewable sources, we will need renewable energy systems that supplement and transcend the electricity grid. We cannot, and should not try to, “decarbonizes the global economy” with electricity systems alone. We will need hydrogen, and perhaps other C-emissions-free fuel systems, to solve renewables’ three primary challenges: transmission, storage, and integration.

Japan is researching three strategies for transporting hydrogen from CO2-emissions-free sources, to Japan, as several liquid fuels, at very large scale, in commodity ocean tankers:

1. Liquid Hydrogen (LH2)	By:	Kawasaki Heavy Industry (HI) [vii]
2. Liquid anhydrous ammonia (NH_3)	By:	Sumitomo Chemical and HI [viii]
3. Methylcyclohexane (C_7H_{14}) (MCH)	By:	Chiyoda Chemical and HI [ix]

Therefore, we should expect increasing global demand for renewables-source hydrogen, and begin now to reduce the cost of producing it from wind and other rotating generators, in both distributed and centralized configurations, via this potentially transformative SEIG project. We should also now conceive, design, build, and operate proof-of-concept gaseous hydrogen pilot plants, whereby gaseous hydrogen (GH2) fuel is gathered from diverse sources in a generation corridor, transmitted to a destination community via underground pipeline at 100 bar, and distributed for transportation and CHP. [x], [xi]

Figure 12. The Kawasaki HI concept for large-scale seaborne LH2 transport of carbon-emissions-free hydrogen fuel from global sources. Liquefaction is energy-intensive.

Figures 13 – 15. Sumitomo's strategy for large-scale, global, seaborne NH_3 transport of carbon-emissions-free hydrogen. NH_3 contains more hydrogen atoms per liter than LH2.

Figures 16 and 17. Chiyoda Chemical and Heavy Industry, Japan, has built pilot plants for demonstrating global transport and long-term storage of "liquid" hydrogen from carbon-emissions-free sources in the carbon-emissions-free cycle of Toluene (C_7H_8) ←→ Methylcyclohexane (C_7H_{14}) (MCH).

1.2.3 Impact: Low-cost Transmission for Diverse Renewables

Figure 18. Compares capital costs per MW-km of transmission service. Underground pipelines are less costly to build and maintain, and are better protected from acts of God and man than overhead electric transmission and distribution lines. "Packing" GH2 pipelines provides large energy storage at low cost. Liquid anhydrous ammonia (NH_3) pipelines cannot be packed; they are made of low-cost carbon steel, operating at < 10 bar (150 psi).

Figure 9. GH2 pipelines, without midline compression, high very large capacity, enabled by the low viscosity of GH2.

Figure 19. A sample of polymer-metal tubing for GH2, researched at Oak Ridge NL, in which a thin foil of Al or Cu in the pipe wall provides the hydrogen permeation barrier without the hydrogen-embrittlement risk inherent in steel linepipe. Polymer-metal linepipe can be manufactured in continuous, unlimited length, in the field, by Smart Pipe Technologies, Houston, at up to 1 meter diameter, with GH2 transmission capacity of ~ 8 GW at 100 bar.

1.2.4 Impact: Low-cost, Annual-scale, Energy Storage for Diverse Renewables

Figures 20 and 21. Both GH2 and liquid NH_3 can be stored at > 100 GWh capacity at < \$ 1.00 / kWh capital cost. O&M costs are primarily compression, for GH2, and pumping, for NH_3 .

Each GH2 cavern stores ~ 2,500 metric tons (Mt) hydrogen at 150 bar: ~ 92,000 MWh. Caverns capital cost is ~ \$ 5 M plus ~ \$ 10 M "cushion gas" GH2, for total ~ \$ 0.16 / kWh. Caverns may be manifolded at common pressure, to share surface facility for compression, gas drying, metering, monitoring. Caverns are typically ~ 850,000 Nm^3 volume; top is ~ 700 m deep. Germany has good domal salt geology for caverns. Sandia NL has completed a recent study on GH2 storage in salt caverns. [xii]

Typical refrigerated (-30 C) "atmospheric" liquid NH_3 tank capacity is 30,000 – 60,000 Mt. A 35,000 Mt tank stores ~ 200,000 MWh as the chemical energy in the NH_3 molecules, at a capital cost of ~ \$ 0.08 / kWh. NH_3 is a C-free fuel, for ICE's, CT's, and direct NH_3 fuel cells, and may be easily reformed to high-purity hydrogen fuel at the end-user. The Nitrogen, N_2, byproduct is returned harmlessly to the atmosphere.

Figures 22 and 23. By any measures, GH2 and NH_3 energy storage are "off the charts". Optimized complete renewable energy systems, combining generation and conversion, gathering, transmission, storage, distribution, integration, and end-use, may be technically and economically superior with GH2 and / or NH_3 as the energy carrier(s), rather than electricity. This project prepares us for this comparison by investigating a multi-turbine windplant optimized for hydrogen fuel production and delivery.

1.2.5 Impact: Both "Power To Fuel" and "Power To Gas"

This project, and future larger renewable energy plants enabled by this project's disruptive technologies, will produce high-purity Hydrogen fuel and byproduct Oxygen, of at least "five nines" quality, via electrolysis of high-purity water. "Five nines" purity Hydrogen fuel is required for PEM fuel cells, for vehicles and for stationary plants. A dedicated, new infrastructure is required for gathering and transmission, storage, and distribution of this high-purity fuel, in tube trailers and eventually in new gaseous Hydrogen (GH2) pipeline systems, perhaps of polymer-metal construction, with annual-scale firming storage in "packing" GH2 pipelines and in large solution-mined salt caverns. This "Power To Fuel" system and strategy is shown in Figures 6, 8, 9, 18, 19, 20.

"Power To Gas" is an alternative strategy for GH2, whereby electrolytic Hydrogen, produced from otherwise-curtailed electricity generation from wind, solar, and other time-varying renewable, is injected directly into the natural gas transmission pipeline network, achieving "free" transmission, storage, and monetary value for "surplus" renewable energy for which the electricity grid market selling price is very low, or negative. However:

1. When the high-purity Hydrogen enters the natural gas pipeline it mixes with methane and other pipeline gases. Separating high-purity Hydrogen from the pipeline gas, suitable for PEM fuel cells, may be uneconomical;
2. If the electrolysis plant operates only when "surplus" renewable-source electricity is available, it suffers a low capacity factor (CF) and a poor return on capital investment;
3. The concentration of GH2 in the natural gas pipeline mix is probably limited to 5 – 20 %, by metallurgy (for steel pipelines) and by the lower volumetric energy content of the fuel delivered to end-users.

The "Power To Gas" technology is proven and commercially available, and is commercially valuable for renewable energy firming, as demonstrated in operating and planned installations, worldwide:

1. Southern California Gas Company demonstration plans; [xiii]
2. Falkenhagen, Germany, by Hydrogenics and E.ON; [xiv, xv], [xvi]
3. Enbridge, in Ontario, Canada; [xvii]
4. Siemens "SILYZER" electrolyzer product and system strategy. [xviii]

1.2.6 Impact: Solar-generated Electricity: Transmission and Storage

Photovoltaic (PV) generation produces direct current (DC), which electrolyzer "stacks" require. Consequently, PV is theoretically a better source for Hydrogen fuel production than wind turbines and other renewable energy harvesting equipment that depends on rotating generators. As California and other jurisdictions approach their ambitious RPS goals, this diurnal solar electricity generation, from both PV and from concentrating solar power (CSP) plants inflicts technical and economic costs on the electricity grid and electric utility industry. Hydrogen fuel systems, of GH2 pipelines and storage, at distributed generation (DG) and continental scales, may be technically and economically superior to electricity systems. Wind and solar sources could be synergistically combined, in Hydrogen fuel systems, since these sources are often complementary in their time-variability.

1.3 Innovativeness

Figure 25. This project's SEIG application and system integration and optimization has not been attempted on an operating multi-turbine windplant. For decades engineering literature has recommended the SEIG for wind generation, but only in the past decade has power and control electronics advanced enough to enable its stable, efficient, and economical variable-output operation. [xix], [xx], [xxi], [xxii] But, SEIG has not been deployed with commercial success, anywhere.

For a decade, engineering literature has reported wind-to-hydrogen systems research. [xxiii], [xxiv], [xxv], [xxvi], [xxvii], [xxviii], [xxix] However, few – if any – wind-to-hydrogen fuel plants have been built anywhere to supply merchant fuel, none in the USA, and none with:

1. SEIG rotating generation systems
2. Multiple turbines via optimization control, feeding a common DC bus, driving an electrolysis plant

Therefore, the project's disruptive innovation is the novel coupling of multiple SEIG-equipped wind turbines to an electrolysis plant with intelligent controls and minimum power electronics, resulting in:

1. Lower cost for hydrogen fuel than available from coupling off-the-shelf electrolyzers and wind turbines, of any size
2. Expanded geographic availability of wind-generated hydrogen fuel, by removing dependence on the electricity grid

Project performance goals:

1. Wind energy generation and energy conversion system capacity factor = 40%
2. Electricity-to-hydrogen energy conversion efficiency = 55 kWh / kg H_2
3. Hydrogen fuel cost < $ 3.50 / kg at the project windplant gate
4. Average annual production of 11,000 kg H_2, all sold at plant gate for > $5.00 / kg
5. Demonstrated probable MW-scale, wind-to-hydrogen system economics, assuming no connection to the electricity grid, with total energy production delivered as hydrogen fuel at the plant gate:
    a. Capital cost savings of ~ $ 130,000 / MW vis-à-vis electricity grid delivery
    b. Capital cost for electricity-to-hydrogen conversion system of ~ $ 1 M / MW

These performance goals are derived from industry experience and practice, from literature and industry and engineering conferences:

1. Wind turbine manufacturing
2. Windplant construction
3. Electrolysis plant manufacturing, although at low series-production volume
4. Electrolysis plant energy conversion efficiency
5. The nascent retail market for hydrogen fuel in Los Angeles: estimated at ~ $ 9.00 / kg; the wholesale market is estimated at $ 5.00 – 6.00 per kg

Figure 24. We estimate the hydrogen fuel production cost reduction from the SEIG-equipped multi-turbine windplant in Figures 1 and 2, when scaled to a 100 MW windplant of modern MW-class turbines, based on Figure 24 and total installed turbine cost of $ 2 M per MW nameplate: [xxx]

	Total Installed Cost [of windplant] (TIC)
2 MW wind turbine TIC	$ 2,000,000
Subtract from capital cost:	
1. Simpler generating system	$ 50,000
2. Field transformer at the tower base	$ 50,000
3. Field high voltage wiring	$ 10,000
4. 2 MW share of 100 MW substation, common to all turbines	$ 100,000
5. 2 MW share of transmission line to utility entry point	$ 50,000
TOTAL Subtract (13 % of $2 M per MW, TIC, windplant)	$ (260,000)
Add: 1.0 MW nameplate electrolysis plant @ $ 1,000 / kWe input	$ 1,000,000
SUBTOTAL add to or (subtract from) TIC	**$ 740,000**
Subtract: Present Value (PV) of future O&M savings, over 20 years	$ 740,000
Net present value (NPV) of capital + O&M cost differential	$ 0

The above calculation is speculative and optimistic. We have only the limited experience of NREL's wind-hydrogen program to guide us. [xvi]

Therefore, we assume the estimated capital cost saving in wind turbine and windplant are not now enough to pay for the electrolysis plant, but may be as the electrolysis industry matures and SEIG is adopted. At large scale, further capital and O&M cost savings and added value must be realized in order for wind-generated hydrogen fuel to be profitable, via:

1. The simpler SEIG generating system
2. Access to lower-cost hydrogen transmission and bulk energy storage
3. Access to more lucrative markets for the windplant's product hydrogen fuel

This project's purpose is to discover, demonstrate, and document the costs of converting the 13-turbine windplant to SEIG-driven hydrogen fuel production, and the windplant's operating energy conversion efficiency and O&M costs, so that we may correct the above calculation.

Other technical goals of the project:

1. Stable, safe, efficient operation of the SEIG and electrolysis subsystems, and of the whole system
2. Low system O&M costs
3. Energy conversion efficiency better than 55 kWh / kg hydrogen fuel
4. Extensive, quality SCADA data collection

2. PROPOSED WORK

2.1 Approach

Three R&D efforts are essential to project success:

1. Co-PI, Prof Ping Hsu, San Jose State University (SJSU): design SEIG system, of hardware and software, at wind turbine level, and integrate with windplant control system. Prof Hsu has many years' experience as a design consultant on wind turbine variable speed generation systems
2. Co-PI, Robert Preus, NREL: design the intelligent control systems, for DC bus combination of multiple wind turbine outputs, and for electrolysis plant drive. Assist electrolysis plant supplier to customize that plant's hardware and software to interface with the windplant's DC bus for optimum energy capture, generation, and conversion to hydrogen fuel. Ed Muljadi and Kevin Harrison, NREL research staff, will assist.
3. Electrolysis plant supplier: customize and simplify that plant's hardware and software, as above, to eliminate redundant controls and the transformer-rectifier subsystem. This effort must be coordinated with the SJSU and NREL efforts to insure overall windplant operational integrity and efficiency.

Three support activities are essential to project success:

1. Contract for fabrication of the system components designed by the R&D efforts, above. Applicant will be responsible for this contracting.
2. Contract for installation of all wind-to-hydrogen plant components at the Palm Springs windplant, including site preparation and infrastructure installation, SCADA and comm. An experienced candidate contractor has been identified, and wishes to do the work.
3. Prepare the 13 wind turbines, plus a spare, for reliable operation in SEIG configuration, for long service in the wind-to-hydrogen plant. Applicant is responsible for this work.

2.2 Technical Risk

The risks below are diverse; we have no plan for mitigating any of them, other than *ad hoc*, if and when problems occur, with good engineering practice. We doubt that mitigating any of these risks will require a scientific breakthrough or great expense. This is primarily a challenging pioneering engineering project.

A. Figure 4. We have demonstrated that the 13 wind turbines are suited for this project. We have demonstrated stable operation of one windplant turbine in SEIG mode, feeding a resistive load bank on the DC bus, for several episodes, in light-to-moderate windspeed. Figure 4 shows a typical interval of ~ 2.5 minutes, while power varies with windspeed. Peak = 16 kW. The high-voltage peaks occur when the SEIG generator is unloaded, pre- and post- stable SEIG mode region. R load = 15.4 Ohms. Generator is wired for 480 v, 3-phase, delta. Total shunt self-excitation capacitance is 100 kVAR, which may be unnecessarily large. Turbine compatibility with the project is not a risk. The next test will rewire generator for 240 v, lower R load.

B. These turbines have operated almost continuously in San Gorgonio Pass, CA, delivering electricity to the SCE grid, for ~ 20 years and thus do not represent a technical risk. The turbines are equipped with a passive centrifugal governor in the hub, which changes blade pitch via full span pitch control in overspeed events. We do not think the wind turbine- tower system is a risk.

C. SEIG mode has been demonstrated in the lab, documented in research papers, many times over many years. The self-excitation phenomenon is well understood, but the power electronics and intelligent controllers necessary to implement it affordably were not available until the past decade. Stable and efficient SEIG mode requires continuously adjusting the shunt capacitance on the induction motor (generator) windings, and adjusting the generator load, to properly startup and shut down each turbine, and to optimally impedance match each turbine to the DC bus common to all turbines. And, the DC bus must be matched to electrolyzer load. This multi-turbine control and operating mode has not been demonstrated; it is a significant project risk.

D. Electrolyzer stacks and electrolysis systems have not been widely and successfully operated with a stranded wind turbine as their only energy supply. The electrolysis subsystem components require a quality electricity supply, while the electrolyzer stacks may be more tolerant of a time-varying DC electricity supply. The project windplant is stranded, with no connection to the SCE grid, so must make its own electricity, from:

1. Battery storage and an inverter capable of operating the electrolysis plant subsystems. A PV array, or windplant electricity during operation, or both, will charge the battery.
2. A DC-to-AC converter operating from the windplant DC bus, when the windplant is generating, producing the voltage, frequency, and phase required by the subsystems

This electrolysis plant electricity system is a moderate risk, because the project is a novel system. Fortunately, the total power required is small, and off-shelf equipment is available.

E. The electrolyzer stacks will need to be configured to accept electric energy input from the windplant DC bus, instead of from the usual transformer-rectifier subsystem. The windplant DC bus may be at a higher voltage than the stack is designed to accept. Perhaps two or more stacks will need to be connected in series. This is a design challenge and project risk.

The electrolyzer stacks must operate well – safely and efficiently, with stability – with the time-varying power available from the windplant output DC bus. Stack tolerance for this variability may be uncertain and unproven, so is a major project risk.

F. The Palm Springs windplant site is very hot in summer, when the wind is strongest, usually at night. Daytime summer ambient temperature may be > 45 C. This may present a risk to power electronics and electrolysis systems and the cooling systems that serve them. The wind turbines have endured this climate for > 20 years, so are probably not at risk.

2.3 Schedule

Windplant equipment and site preparation may begin immediately upon receipt of contract and funds: primarily servicing the turbines for reliable and long service life, and beginning wiring and capacitor installation for SEIG mode operation.

NREL tasks scheduling will depend on their staff availability. Priority will be collaborating with:

- Prof Ping Hsu, San Jose State University, EE Department, so that he may begin the SEIG controller system design, with controls compatible with the windplant controller
- Electrolysis plant supplier candidates, and with the chosen supplier.

Supplier negotiations for the 650 kW electrolysis plant may begin immediately upon receipt of contract and funds. We list three “Partners” in the project; we have not selected the supplier because:

1. Our Feb 2015 RFP process returned essentially-identical proposals from three of the major suppliers: Hydrogenics, Proton OnSite, and ITM Power. Each will supply the complete, containerized, transportable electrolysis plant of ~ 650 – 1,000 kW nameplate rating for $ 1.5 million, plus an in-kind contribution of ~ $ 375,000 of engineering necessary to customize the design, in hardware and software, for this project.
2. The supplier must work closely with the NREL team to integrate their two design efforts, to result in a windplant control system that optimizes the complete system of wind turbines, power electronics, electrolyzer stacks, controls, SCADA, and communications – both within the wind-to-hydrogen plant and with the external world. Therefore, we will welcome NREL staff advice in choosing the electrolysis plant supplier.
3. The candidate suppliers are relatively small companies, where resource scheduling and technology advances change quickly. We cannot predict the situation at each candidate at the time we will be ready to contract with one for the tasks on the Schedule, below. Therefore, the project will benefit from maximum flexibility in supplier selection.
4. We don't know when project funding might be available from ARPA-E and / or from other sources for which we will apply.

We will immediately supply a spare generator (three phase induction motor) to Prof Ping Hsu, San Jose State University, EE Department, so that he may begin the SEIG controller system design.

We will begin selection of other contractors immediately upon receipt of contract and funds.

2.4 Task Descriptions: refer to 2.3 Schedule Chart, page 16

This is primarily an advanced engineering project. The identified tasks and their scheduling is good engineering practice. The tasks are generally pursued simultaneously and synergistically, so that no particular task reduces technological uncertainty. The key technical milestone is task 5, below, which will help validate the design approaches by the electrolysis plant supplier and NREL teams.

1. SEIG controller design. We will immediately supply a spare generator (three phase induction motor) to Prof Ping Hsu, San Jose State University (SJSU), EE Department, so that he may begin the SEIG controller system design. This task includes using the measured motor electrical characteristics to calculate the shunt capacitance required for the expected operating range of the motor, as an SEIG on the wind turbine, over the expected range of rpm and torque applied to the SEIG by the turbine and gearbox which drive it. Then, power electronics is designed, in hardware and software, to ideally control the SEIG system, including startup, shut down, and protection. The power electronics must also supply passive or controlled rectification, by which to deliver "wild DC" to the common windplant DC bus. The controller software must integrate perfectly with the windplant controller developed by NREL.

2. Windplant DC bus and turbine dispatch controller design. A collaboration among Prof Ping, SJSU, electrolysis plant supplier, and NREL team of Robert Preus, Ed Muljadi, and Kevin Harrison. Power electronics and controls will match impedance and mechanical and electrical power flow from the wind turbine rotors to the electrolysis plant hydrogen output, maximizing wind energy harvest. The controller will also startup and shut down individual turbines, monitor system health, protect components, feed the SCADA system, and communicate with the outside

world. All windplant components are included; they must communicate perfectly. Primary design responsibility is NREL.

3. Electrolysis plant custom design. The three candidate electrolysis plant suppliers have agreed to supply the same, adequate, in-kind-contribution engineering to customize the plant to:

- Eliminate the “transformer-rectifier” subsystem; replaced by the controlled DC bus
- Integrate primary control functions via windplant control software developed by NREL
- Operate BOS components on an electric supply system, fed by PV-charged or windplant-charged battery, to supply the required voltage, frequency, and phase to these components.
- Collaborate with NREL on all aspects of integrating wind turbines, common DC bus, electrolysis, compression, and SCADA subsystems.

4. SEIG system build, test, and commission. Select contractor to build and install the SEIG system at each wind turbine, for energy delivery to the common windplant DC bus. This is primarily power electronics, shunt capacitors, a custom controller board with display, and comm.

5. 50 kW electrolysis plant with custom controls. This is an early-stage proof-of-concept pilot plant, a test bed to be installed briefly on one to three turbines at the Palm Springs windplant. It will be built of small, low-cost components and operated only briefly. NREL and electrolysis plant supplier responsible for design; applicant responsible for installation, operation, and data collection. Technical milestone: success here will validate windplant and electrolysis system design approaches, in 2 and 3, above.

6. SCADA system install. This system will be an integral part of the SEIG and windplant controller design tasks. It will be installed at the windplant with the other system components, by a contractor, and connected to the outside world via cellphone network.

7. Compressor. A contractor will install the selected hydrogen compressor and its power supply, probably an inverter connected to the windplant control system power supply storage battery.

8. Hydrogen fuel storage and delivery. Hydrogen fuel delivery will probably be managed by IGX Group or another contractor who will spot a tube trailer on-site while the project’s electrolysis plant and compressor fill it. Contractor will replace the trailer when it is full. Or, the project may but its own tube trailer, for this storage and delivery.

9. 650 kWe input (nominal) electrolysis plant. The electrolysis plant must be custom-designed by the manufacturer, primarily to:

- Replace transformer-rectifier subsystem with the windplant controlled DC common bus
- Integrate electrolysis plant and windplant controls into one system

The electrolysis plant supplier is primarily responsible for this task, and must work closely with NREL for successful system integration. 650 kW electrolysis plant supplier negotiations may begin immediately upon receipt of contract and funds: we have not selected the supplier because:

a. We have essentially-identical proposals from three of the major suppliers: Hydrogenics, Proton OnSite, ITM Power. Each will supply the complete, containerized, transportable electrolysis plant of ~ 1 MW nameplate rating for $ 1.5 million, plus an in-kind contribution of ~ $ 375,000 of engineering necessary to customize the design, in hardware and software, for this project.
b. The supplier must work closely with the NREL team to integrate their two design efforts, to result in a windplant control system that optimizes the complete system of wind turbines, power electronics, electrolyzer stacks, controls, SCADA, and communications – both within the wind-to-hydrogen plant and with the external world. We will welcome NREL staff advice in choosing electrolysis plant supplier.
c. The candidate suppliers are relatively small companies, where resource scheduling and technology advances change quickly. We cannot predict the situation at each candidate at the time we will be ready to contract with one for the tasks on this Schedule. Therefore, the project will benefit from maximum flexibility, and from NREL staff advice, in supplier selection.
d. We don't know when project funding might be available from ARPA-E and / or from other sources for which we will apply.

10. NREL tasks. Scheduling will depend on their staff availability. Priority will be collaborating with:

- Prof Ping Hsu, San Jose State University, EE Department, so that he may begin the SEIG controller system design, with controls compatible with the windplant controller;
- Electrolysis plant supplier candidates, and the chosen supplier.

11. Windplant equipment and site preparation. This may begin immediately upon receipt of contract and funds: primarily servicing the turbines and beginning wiring and capacitor installation for SEIG mode operation. Applicant will directly supervise this because it requires both on-site work at the Palm Springs windplant and contractor in-shop work.

3. TEAM ORGANIZATION AND CAPABILITIES

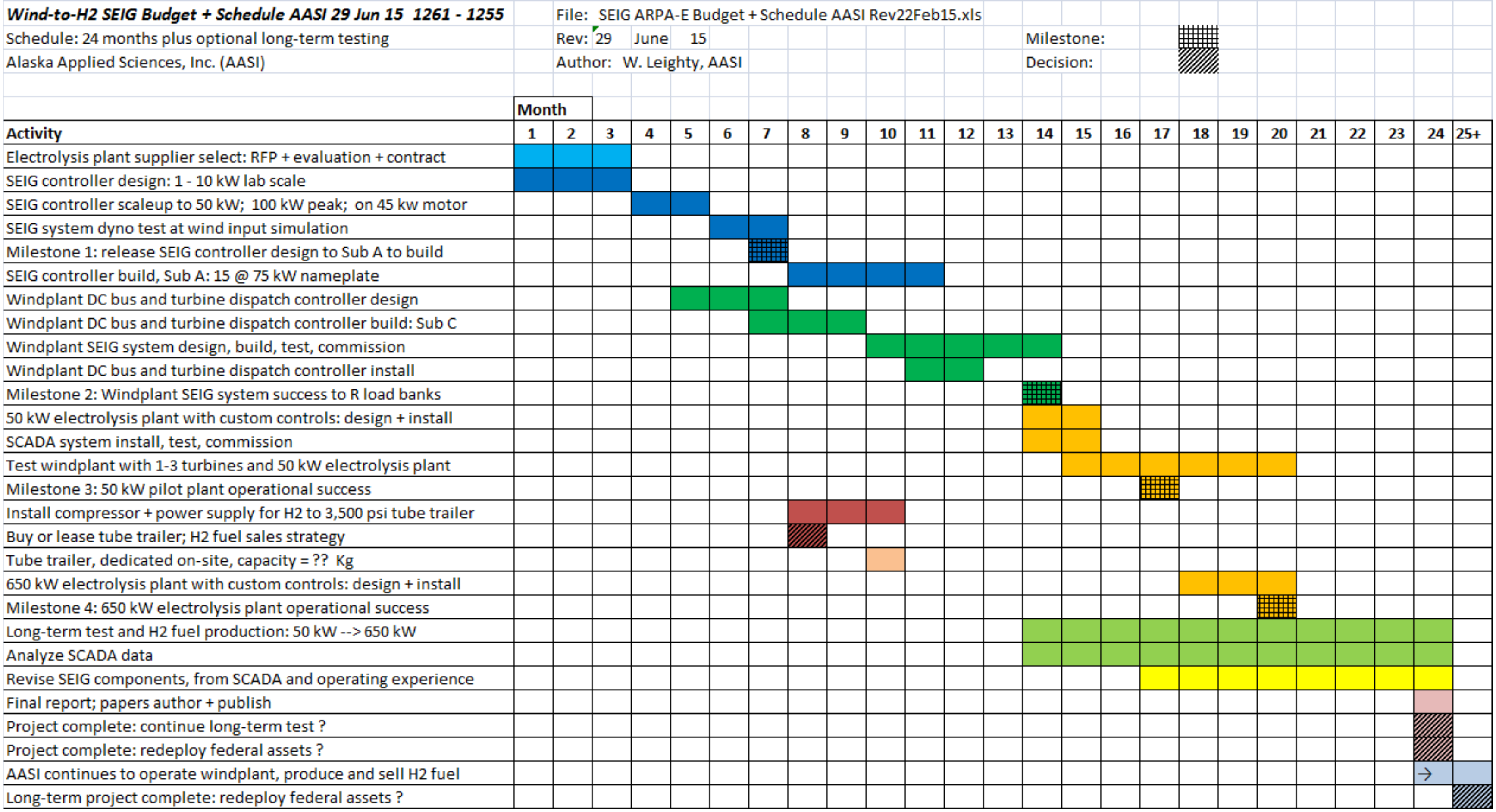
3.1 Organization

Previous collaborations:

- Prof Ping Hsu was a Fellow in Eduard Muljadi's lab at NREL, for many months
- NREL hydrogen research staff has collaborated with, and worked on contract for, the major electrolysis plant suppliers.

2.3 SCHEDULE

SEIG: Self-Excited Induction Generator
AASI: Alaska Applied Sciences, Inc.
SCADA: Supervisory Control And Data Acquisition



Wind-to-H2 SEIG Budget + Schedule AASI 29 Jun 15 1261 - 1255
Schedule: 24 months plus optional long-term testing
Alaska Applied Sciences, Inc. (AASI)

File: SEIG ARPA-E Budget + Schedule AASI Rev22Feb15.xls
Rev: 29 June 15
Author: W. Leighty, AASI

Milestone: ▦
Decision: ▨

	Month																								
Activity	**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+**
Electrolysis plant supplier select: RFP + evaluation + contract	🟦	🟦	🟦																						
SEIG controller design: 1 - 10 kW lab scale	🟦	🟦	🟦																						
SEIG controller scaleup to 50 kW; 100 kW peak; on 45 kw motor				🟦	🟦																				
SEIG system dyno test at wind input simulation						🟦	🟦																		
Milestone 1: release SEIG controller design to Sub A to build							▦																		
SEIG controller build, Sub A: 15 @ 75 kW nameplate								🟦	🟦	🟦	🟦														
Windplant DC bus and turbine dispatch controller design					🟩	🟩	🟩																		
Windplant DC bus and turbine dispatch controller build: Sub C							🟩	🟩	🟩																
Windplant SEIG system design, build, test, commission										🟩	🟩	🟩	🟩	🟩											
Windplant DC bus and turbine dispatch controller install											🟩	🟩													
Milestone 2: Windplant SEIG system success to R load banks														▦											
50 kW electrolysis plant with custom controls: design + install														🟧	🟧										
SCADA system install, test, commission														🟧	🟧										
Test windplant with 1-3 turbines and 50 kW electrolysis plant															🟧	🟧	🟧	🟧	🟧	🟧					
Milestone 3: 50 kW pilot plant operational success																	▦								
Install compressor + power supply for H2 to 3,500 psi tube trailer								🟥	🟥	🟥															
Buy or lease tube trailer; H2 fuel sales strategy								▨																	
Tube trailer, dedicated on-site, capacity = ?? Kg										🟧															
650 kW electrolysis plant with custom controls: design + install																		🟧	🟧	🟧					
Milestone 4: 650 kW electrolysis plant operational success																				▦					
Long-term test and H2 fuel production: 50 kW --> 650 kW														🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Analyze SCADA data														🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Revise SEIG components, from SCADA and operating experience																	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
Final report; papers author + publish																								🟥	
Project complete: continue long-term test ?																								▨	
Project complete: redeploy federal assets ?																								▨	
AASI continues to operate windplant, produce and sell H2 fuel																								→	🟦
Long-term project complete: redeploy federal assets ?																									▨

Lead: Alaska Applied Sciences, Inc. C-Corp
Founded 1990 No employees; all work by contractors
William C. Leighty, Principal BSEE, Stanford ’65 MBA, Stanford ‘71
2005: USDOE R&D grant successfully completed DE-FG36-03GO13140
www.osti.gov/servlets/purl/859303-oXetpM/ Jun 30, 2005
http://www.osti.gov/bridge/purl.cover.jsp;jsessionid=2668D60E7416C4B65E40EF1F55353C51?purl=/859303-oXetpM/
Roles: Project manager, business manager; Site prep and operations

Contractor: San Jose State University, Department of Electrical Engineering,
Charles W. Davidson College of Engineering

Co-PI: Professor Ping Hsu, PhD, has many years experience as design consultant for variable-speed wind turbine generating systems. He will be responsible for designing the SEIG system for the 13 windplant turbines, in collaboration with the NREL team

Contractor: NREL, Golden, CO

Co-PI: Robert W. Preus, PE Technical Lead, Distributed Wind Technologies
Joined NREL in 2013. More than 27 years' experience in wind energy. Founder of Advanced Renewable Technology: provided training, engineering, and certification support to small wind manufacturers. Led successful development of 2.5kW to 300kW wind generators. Extensive experience in wind energy systems design.

Eduard Muljadi, PhD Senior Engineer, Wind Research Staff
Ph.D. Electrical Engineering, University of Wisconsin-Madison
M.S., Electrical Engineering, University of Wisconsin-Madison
B.Sc., Electrical Engineering, Surabaya Institute of Technology
Joined NREL in 1992. Member of the Transmission Grid Integration Group. Research projects are in the fields of electric machines, power electronics, and power systems with emphasis on renewable energy applications, including variable speed wind turbine development, electric machine design and optimization, isolated operations (battery charging, self-excitation, and water pumping), and wind power plant design (collector system equivalent), operation, dynamic model development, and system integration.

Kevin Harrison Principal Researcher at NREL's hydrogen production cost analysis, renewable electrolysis research, and the wind-to-hydrogen project, at the Energy Systems Integration Facility and Distributed Energy Resources Test Facility

Electrolysis plant supplier candidates:

Hydrogenics	Daryl Wilson, Rob DelCore
Proton OnSite	Rob Friedland, Steve Szymanski
ITM Power	Geoff Budd, Stephen Jones

These are three of the world’s leading electrolysis system providers. They have proposed essentially identical equipment, cost, and in-kind contributions of engineering time to customize the electrolysis plant for the project’s unique purpose. All three have excellent technical staff, and have promised to make them available for this project. We have not selected an electrolysis plant supplier, for the reasons given in 2.4, above. Selection now would be unnecessary, unwise, and might compromise the prospects for this project's best possible outcome. We wish to benefit from NREL staff's selection advice.

3.2 Capabilities, Facilities, Equipment, and Information

Alaska Applied Sciences, Inc. owns the 13-turbine windplant in North Palm Springs, CA. It is now stranded from the SCE grid, and is available for dedication to this project. The low voltage wiring (originally 480 V, 3-phase) is in the ground, to two central circuit breaker cabinets on concrete slabs, where the SEIG components could be located. The project Budget includes repair and refurbishing of the wind turbines, equipment, and buildings to prepare them for the project.

San Jose State University, EE Department, has adequate laboratory space and equipment for its role in the project.

NREL has adequate laboratory space and equipment for its role in the project.

The candidate electrolysis plant suppliers all have adequate laboratory space and equipment for the selected supplier's role in the project.

We do not expect to purchase a significant amount of test equipment.

Fabricated and purchased parts:

- 650 – 1,000 kWe input electrolysis plant, customized
- Hydrogen compressor
- Hydrogen tube trailer for storage and delivery of fuel to customer(s)
- SEIG control system for each of 13 turbines, plus spares
- Windplant control system
- SCADA system

Wintec Energy, Ltd., Palm Springs, CA, owns the land at the project windplant site, and has offered free site rent for at least two years of project operation.

4. TECHNOLOGY TO MARKET

4.1 Technology to Market Strategy

The technology market depends on the hydrogen fuel market. Sunline Transit, 15 miles from the project site, has agreed to buy our project's fuel for their fleet of fuel cell buses, when they need it, if we can deliver it at convenient quantity and pressure, at a competitive price. IGX Group said they might buy our hydrogen fuel for their various customers, supplying the tube trailers.

As discussed in Impact, above, we are in the early stages of supplying large quantities of carbon-emissions-free hydrogen fuel for nascent markets which, in aggregate, may exceed the potential demand for energy from diverse renewable resources, which is now provided for wind and solar generators exclusively by the electricity industry via its transmission and distribution grid.

This project will help us discover whether the SEIG system, applied to wind turbines, single or in windplant arrays, with no connection to the electricity grid, offers:

- A significant reduction in the cost of wind-generated hydrogen fuel at the plant gate
- Markets for wind energy from wider geographic areas, where transmission access or the price paid for energy is poor

If this project succeeds, we can promptly advance the SEIG and windplant-to-hydrogen electrolysis plant controller design to commercialization, beginning with retrofits for the smaller, older, wind turbines still operating in San Gorgonio Pass. At the same site as the project windplant, another 18 turbines, 65 kW each, are similarly stranded from the SCE grid, and would be good candidates for conversion to SEIG for hydrogen fuel production for the Southern California market.

Elsewhere in San Gorgonio Pass, probably 200 more 65 – 100 kW-class wind turbines are also still operating, delivering to the SCE grid, but perhaps not on lucrative PPA terms. They might be near-term candidates for conversion to SEIG for more profitable hydrogen fuel production.

Securing IP: The project will produce novel system hardware and software designs, for the SEIG system and the windplant-to-electrolysis plant controllers, for which IP protection may be available at modest cost to the applicant; we cannot predict that, now. Adequate IP may emerge from the project so that the applicant would own value, at least for early adopters, which may have market value.

In the longer term, we could license or sell this project's technology to designers and manufacturers of small and medium-size wind turbines for distributed service, especially where transmission access or the price paid for energy is poor and a market for hydrogen fuel is nascent. Alaska Applied Sciences, Inc. would lead the marketing effort. We do not expect that others on the team would be inclined to this marketing effort, although the Co-PI's are experienced in technical paper writing, which is an important first marketing step.

The manufacturing, cost, and scalability risks are low, if the SEIG wind-to-hydrogen plant works well. No exotic components or processes are required. The electrolysis industry continues to make slow and steady progress. The "power-to-gas" market will probably give the electrolysis industry the sales volume it needs to advance its products' designs and achieve profitability, while lowering the capital and operating costs of electrolysis plants.

"Energy islands", including over 150 Alaska villages, have no grid connection, and rely on expensive diesel generation. Low-pressure hydrogen storage, or conversion of hydrogen to anhydrous ammonia, NH_3, for low-cost storage, may be a solution for their energy problem.

Project success may motivate the major wind turbine OEM's to embrace SEIG for hydrogen production without electricity grid connection. They are capable of repeating our SEIG and electrolysis plant impedance matching, probably without procuring any IP from our project team.

This great value of this project's success will be its demonstration, supported by SCADA system operating data, of SEIG operating efficiency on an operating, multi-turbine windplant.

The wind and other renewable industries are apparently not pursuing SEIG and hydrogen fuel production now, because of:

- The hydrogen fuel market's small size, and the lingering skepticism about the "hydrogen economy" from the early 2000's.
- Electrolysis plant high capital cost and modest energy conversion efficiency
- Belief that "Smart Grid", electricity storage, new gas-fired peaker plants, and other technologies will solve renewables' time-varying output and integration problems
- Belief that new, high-capacity, long-distance electricity transmission lines will be built
- Only recently have curtailments and occasional negative energy prices become problems
- Belief that the federal PTC will be renewed for long enough to keep the present wind-to-grid business model alive
- "Paradigm paralysis": if your only tool is a hammer, the world looks like nails; if your only product is electricity, the world looks like wires. Imagining otherwise is difficult

The team will describe the project's success or failure in co-authored papers and in technical presentations at energy conferences. This will help sell the SEIG and windplant controller concepts, as the market for hydrogen fuel increases, and as concern about the dangers of unrestrained combustion of fossil fuels increases.

Products based on this project's technologies:

1. Will add value to wind and other rotating-generator renewable systems by lowering the cost of Hydrogen fuel production and by greatly expanding the geographic area for renewable generation, by eliminating the need for an electricity grid connection.
2. Will enjoy a brief path to commercialization: no fundamental scientific research path is required, but several years' extensive field testing will be required.
3. May be scaled-up to MW in nameplate capacity, and in large manufacturing volume, because no novel components are required. Capacity and production volume will reduce Hydrogen fuel cost at the plant gate, as well as at the individual generating device.
4. May be easily outsourced for manufacturing, worldwide.

Team skills: This team is unexcelled, in the world, for this project, as a synergy of academic, national lab, and industry experience and attitude. The applicant has decades of business success, with particular strength in promotion of new concepts. The technical team each have decades of ideally-relevant research and industrial experience.

Post-ARPA-E funding: If the project succeeds, technically and economically, with a clear path to scaleup in kWe nameplate capacity for individual and aggregate generation, and if large markets develop for both power-to-fuel and power-to-gas, follow-on funding will not be an immediate problem:

1. The technology maturation path is not long nor risky;
2. Demand for equipment will be adequate for at least modest private enterprise growth;
3. Technology licensing is a well-established business strategy;
4. Emulation and imitation by others will grow the market for all;
5. In the short term, public subsidy for renewable-source fuel will aid business plans.

4.2 Intellectual Property

We believe no relevant IP, to which we must have access, exists, to assist or impede the project. Adequate IP may emerge from the project so that we would own access to value, at least for early adopters, which may have market value. The IP would be the hardware and software components of the SEIG and windplant-to-electrolysis plant controllers. The applicant would own that IP, by which we could enable others to commercialize the technology at broad scale.

Project success may motivate the major wind turbine OEM's to embrace SEIG for hydrogen production without electricity grid connection. They are capable of repeating our SEIG and electrolysis plant impedance matching, probably without procuring any IP from our project team.

This great value of this project's success will be its demonstration, supported by SCADA system operating data, of SEIG operating efficiency on an operating, multi-turbine windplant.

5. BUDGET

5.1 Budget Breakdown

See Budget Breakdown sheet, on separate page. All budget cash will flow to contractors to Alaska Applied Sciences, Inc. None is directly for personnel.

5.2 Budget Summary

Of the total $ 4,095,000 budget, cash + in-kind:

- 81 % is for contractual services and equipment
- 16 % is for other direct costs
- 3 % is for supplies

5.3 Cost Share

Of the total $ 4,095,000 budget, cash + in-kind, 27 % is in-kind.
See 5.1, Budget Breakdown, chart on separate page

6. BIBLIOGRAPHIC REFERENCES

See Pages 31 - 32, after Figures.

7. PERSONAL QUALIFICATION SUMMARIES

Continued on Pages 33 – 46, after Figures

Lead: Alaska Applied Sciences, Inc. C-Corp
Founded 1990 No employees; all work by contractors
William C. Leighty, Principal BSEE, Stanford '65 MBA, Stanford '71
2005: USDOE R&D grant successfully completed DE-FG36-03GO13140
www.osti.gov/servlets/purl/859303-oXetpM/ Jun 30, 2005
Roles: Project manager and business manager
Site preparation and operations

Windplant operation and non-SCADA data collection

Contractor: San Jose State University, Department of Electrical Engineering,
Charles W. Davidson College of Engineering

Co-PI: Professor Ping Hsu, PhD, has many years experience as design consultant for variable-speed wind turbine generating systems. He will be responsible for designing the SEIG system for the 13 windplant turbines, in collaboration with the NREL team

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Eduard Muljadi, PhD Senior Engineer, Wind Research Staff
Ph.D. Electrical Engineering, University of Wisconsin-Madison
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B.Sc., Electrical Engineering, Surabaya Institute of Technology
Joined NREL in 1992. Member of the Transmission Grid Integration Group. Research projects are in the fields of electric machines, power electronics, and power systems with emphasis on renewable energy applications, including variable speed wind turbine development, electric machine design and optimization, isolated operations (battery charging, self-excitation, and water pumping), and wind power plant design (collector system equivalent), operation, dynamic model development, and system integration.

Kevin Harrison Principal Researcher at NREL's hydrogen production cost analysis, renewable electrolysis research, and the wind-to-hydrogen project, Energy Systems Integration Facility and Distributed Energy Resources Test Facility

5.1 BUDGET BREAKDOWN: two-year project

Rev: 28 June 15 CFDA Number: 81.135

AASI: Alaska Applied Sciences, Inc.
NREL: National Renewable Energy Laboratory
SJSU: San Jose State University

Task, Equipment, or Activity	Supplier	Cash Cost x $1,000	In Kind Value x $1,000	Total Cost x $1,000
Prepare 13-turbine windplant: repairs, site improvement	AASI	85	26	111
SEIG controller design: 1 - 10 kW lab, assist NREL scaleup to 50 kW	SJSU	130	60	190
SEIG controller scaleup to 50 kW, 100 kW peak: on 45 kw machine	NREL	300	0	300
SEIG system dyno test at wind input simulation	NREL	60	0	60
Windplant DC bus and turbine dispatch controller design	SJSU	40	0	40
Windplant DC bus and turbine dispatch controller design	NREL + SJSU	20	0	20
50 kW electrolysis plant with custom controls: design + install + test	NREL + Sub B	0	20	20
SEIG controller build: 15 @ 75 kW nameplate, 100 kW peak	Sub A	75	0	75
Windplant DC bus and turbine dispatch controller design	Sub B (Electrolysis plant supplier)	10	10	20
Windplant DC bus and turbine dispatch controller build	Sub C	50	0	50
Windplant SEIG system design, build, test, commission	Sub D	280	50	330
Windplant DC bus and turbine dispatch controller install	Sub D	20	0	20
650 kW electrolysis plant with custom controls: design + install	Sub B (Electrolysis plant supplier)	1,500	355	1,855
Windplant, Palm Springs, CA 13 turbines @ 50 kW = 650 kW	AASI	0	520	520
Windplant land rent + common area + insurance, Palm Springs, CA	Wintec Energy Ltd	0	24	24
Compressor for H2 to 3,500 psi to tube trailer	Sub E	100	0	100
Compressor power supply: elec generator or DC-AC converter	Sub E	20	0	20
Tube trailer, dedicated on-site, capacity = 500 kg	Sub F	200	0	200
Project management	AASI	30	60	90
Project TT&O	AASI	30	0	30
Travel	AASI	17	0	17
Site liability insurance	AASI	3	0	3
	TOTAL	**$2,970**	**$1,125**	**$4,095**

SJSU + NREL subtotal	$ 550	$ 60	$ 610

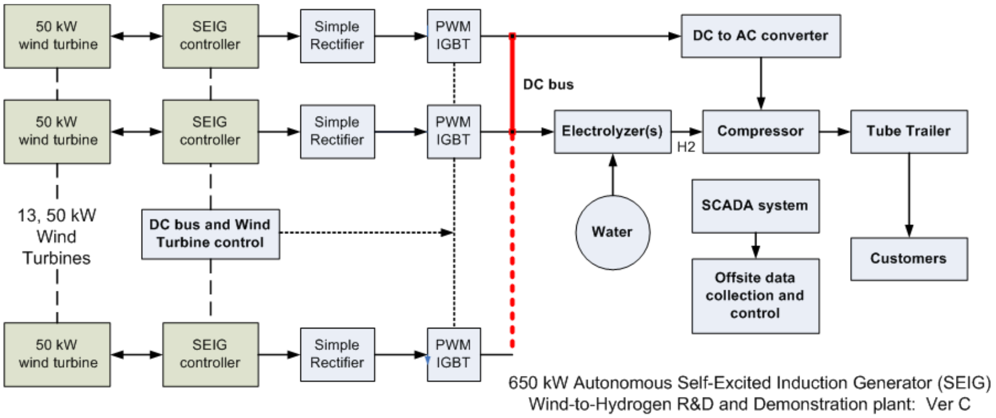


Figure 1. 650 kW Wind-to-hydrogen fuel project using 13 paralleled SEIG wind turbines in the existing AASI stranded, windplant in Palm Springs, CA: it has no connection to the SCE electricity grid. The “SEIG controller” is a novel, proprietary combination of shunt capacitors, power electronics, and software. The “DC bus and Wind Turbine control” is a novel, proprietary power electronics system replacing the costly “transformer-rectifier” subsystem in electrolysis systems. Together, they will transform the wind turbine generation system from the complexity required for electricity grid delivery to a simpler one using the squirrel cage induction generator.

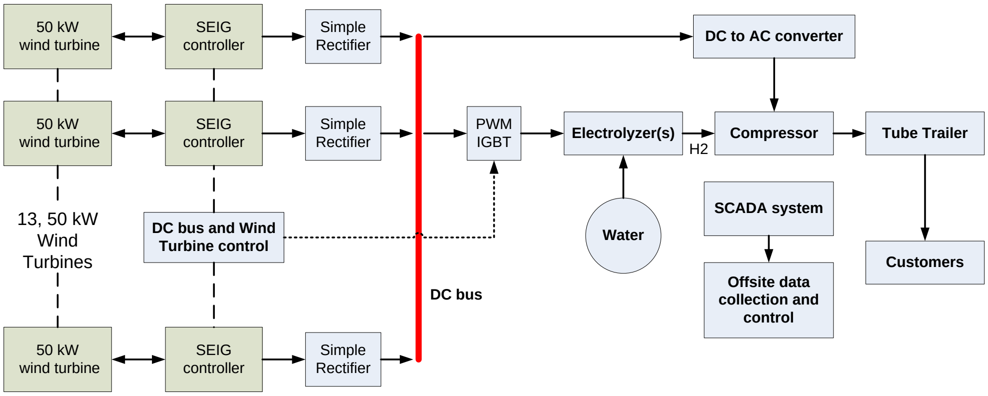


Figure 2. One topology alternative to Figure 1. The project will explore alternatives and select one for installation at all 13 turbines in the project windplant.

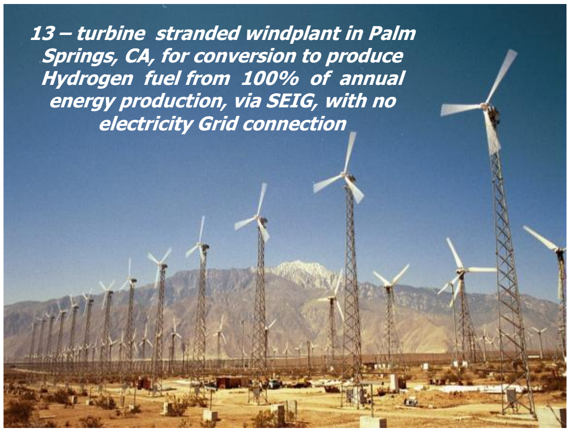


Figure 3. The applicant’s 13-turbine windplant in Palm Springs, CA, in San Gorgonio Pass, equipped with 50 kW squirrel cage induction motors, ideal for SEIG R&D and demonstration.

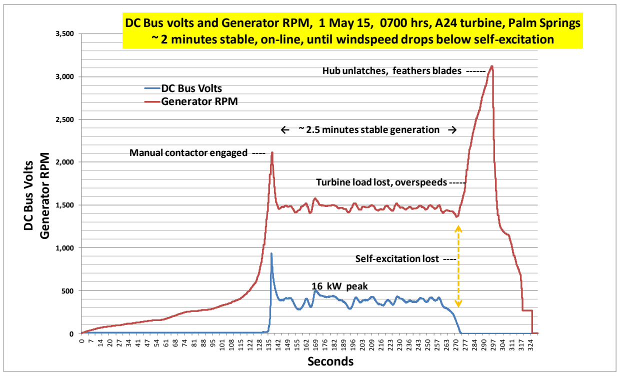


Figure 4. Stable operation of one windplant turbine in SEIG mode feeding resistive load bank on DC bus for 2.5 minutes, while power varies with windspeed. Peak = 16 kW. High-voltage peaks are SEIG generator unloaded, pre- and post- stable SEIG mode region. R load = 15.4 Ohms. Total shunt self-excitation capacitance is 100 kVAR, which may be unnecessarily large.

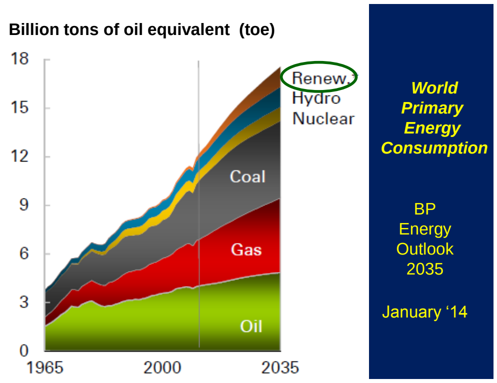


Figure 5. BP's prediction of Humanity's energy economy in 2035. "Renew" includes wind, solar, biomass, and all other renewables except hydro. This is dangerous and unacceptable. We must accelerate our conversion of the world's largest industry from fossil to renewable sources.

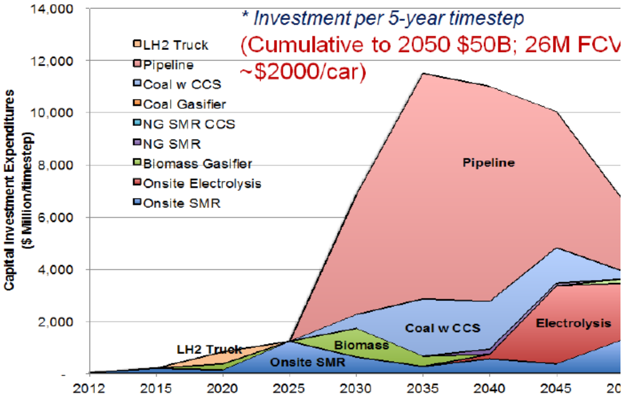


Figure 6. Large investment in dedicated GH2 pipelines begins ~ 2025. Source: UC Davis, ITS, NextSTEPS, *The Hydrogen Transition*, J. Ogden, et al, July 2014. Figure 17. California requires RE-source H2 for one-third of the fuel supply for new state-funded H2 fuel stations.

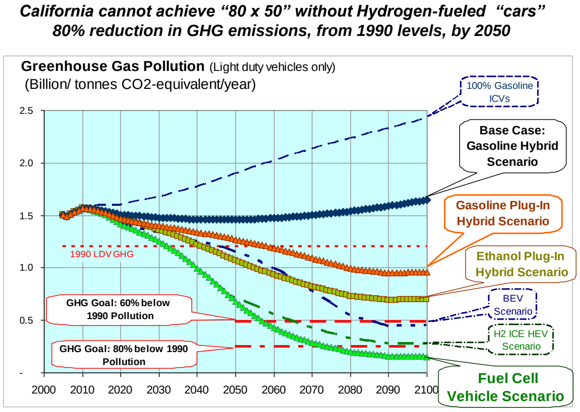


Figure 7. Hydrogen-fueled, fuel cell hybrid vehicles (FCHEV's) are necessary. [xxxi], [xxxii]

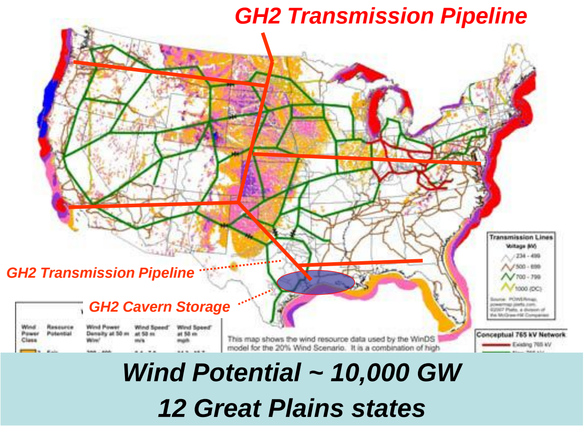


Figure 8. A continental network of gaseous hydrogen (GH2) transmission pipelines enables low-cost gathering, annual-scale firming storage, distribution, and end-use of diverse renewable.

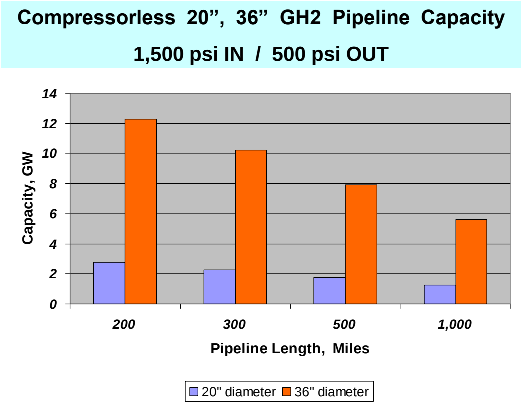


Figure 9. GH2 pipeline capacity, without midline compression, is large, enabled by the low viscosity of GH2. High-pressure-output electrolyzers directly feed the transmission pipeline at 100 bar. Pipeline friction losses reduce city-gate delivery pressure to a convenient ~ 30 bar.

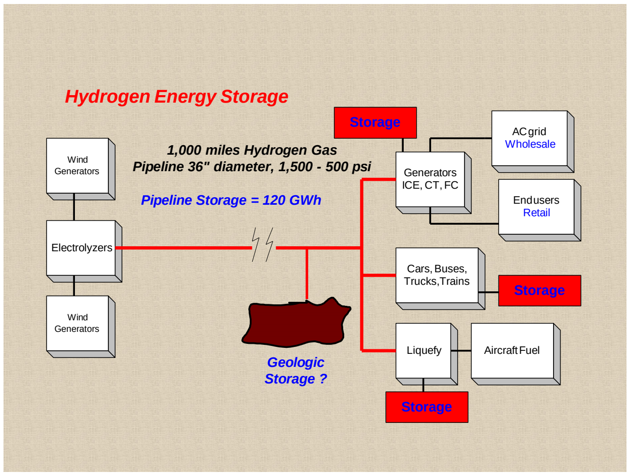


Figure 10. Project impact assessment must include SEIG propagation to complete wind-to-hydrogen systems. If low-cost salt cavern geologic storage is available, accessed by regional or continental GH2 transmission pipelines, wind-hydrogen systems are probably technically and economically superior to wind-electricity systems in delivering dispatchable energy services. GH2 storage at end-users enhances dispatchability. High-pressure-output electrolyzers directly feed pipeline at 100 bar. Pipeline friction losses reduce city-gate delivery pressure to a convenient ~ 30 bar.

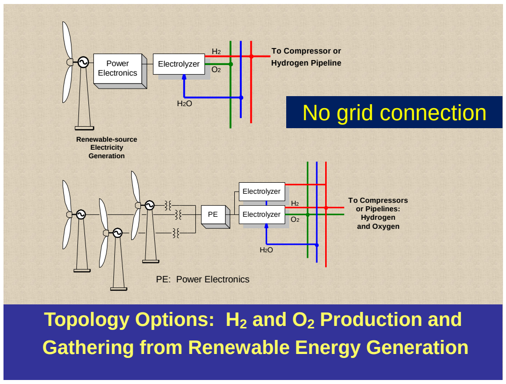


Figure 11. Windplants dedicated to hydrogen fuel production need no costly grid connection. Field transformers, substation, and transmission line are eliminated. Turbines are interconnected via pipes, not wires, except for low-power controls supply and comm.

Figure 12. Kawasaki Heavy Industry concept for large-scale seaborne LH2 transport of carbon-emissions-free hydrogen fuel from global sources.

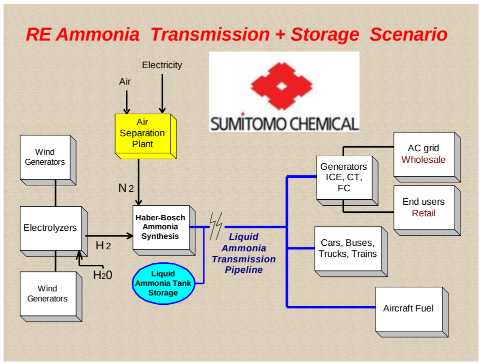


Figure 13. Sumitomo Chemical and Heavy Industry is researching anhydrous ammonia, NH_3 , as a “liquid hydrogen” renewable energy carrier and storage medium.

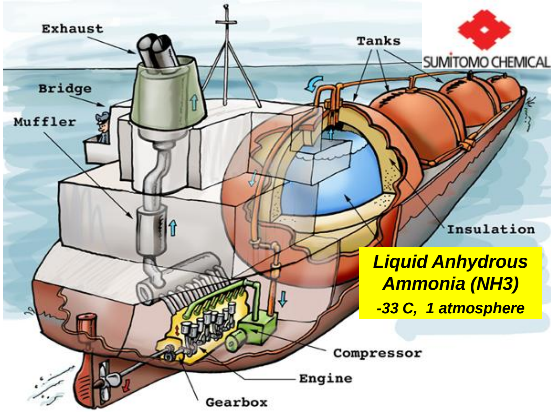


Figure 14. About 130 million Mt of liquid NH_3 is transported per year in commodity tankers in global trade, primarily for Nitrogen fertilizer. Sumitomo is investigating NH_3 as a high-hydrogen-density energy carrier and storage medium for renewables from C-emissions-free sources. A liter of NH_3 contains more hydrogen atoms than a liter of liquid hydrogen (LH2).

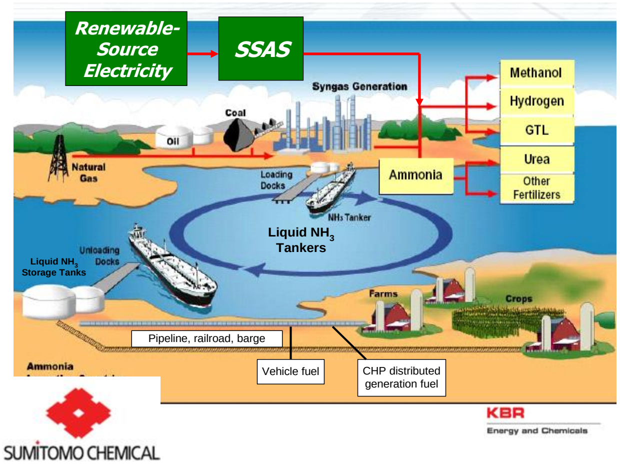


Figure 15. Global liquid NH_3 trade may include Ammonia fuel from carbon-emissions-free sources via hydrogen plus Haber-Bosch or a Simple Solid Ammonia Synthesis (SSAS) process.

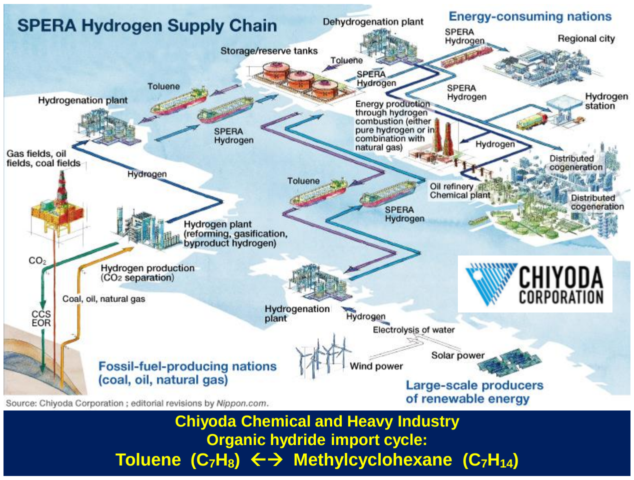
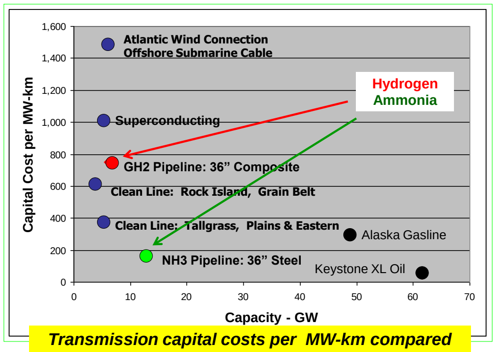


Figure 16. Chiyoda Chemical and Heavy Industry, Japan, has built pilot plants for demonstrating global transport and long-term storage of "liquid" hydrogen from carbon-emissions-free sources in the carbon-emissions-free cycle of Toluene (C_7H_8) ←→ Methylcyclohexane (C_7H_{14}) (MCH).

Figure 17. Chiyoda has built pilot plants to develop its trademarked "Spera Hydrogen" scheme for hydrogen transmission as the cycle of Toluene (C_7H_8) ←→ Methylcyclohexane (C_7H_{14}) (MCH). [xxxiii] This "liquid hydrogen" is stable for long-distance transport and low-cost, long-term storage. The necessary hydrogenation and dehydrogenation processes are apparently economical.



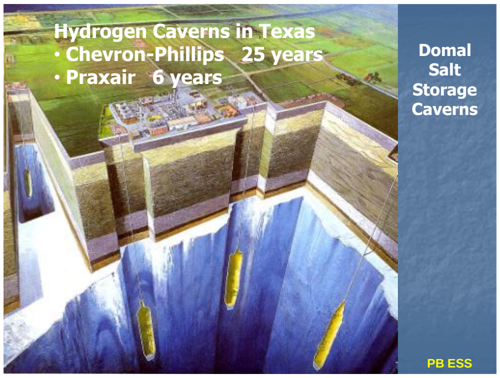
Transmission capital costs per MW-km compared
Pipelines have large capacity and provide large storage

Figure 18. MW-km is the best measure of transmission service. Underground pipelines have lower O&M costs than overhead electric lines, and are protected from acts of God and man.

36" = 8 GW gaseous Hydrogen @ 100 bar

Smart Pipe Technologies, Houston
Polymer-metal linepipe avoids hydrogen embrittlement

Figure 19. Transmission and distribution pipe: a thin Al or Cu foil provides the hydrogen permeation barrier, avoiding the hydrogen embrittlement danger inherent in steel linepipe.

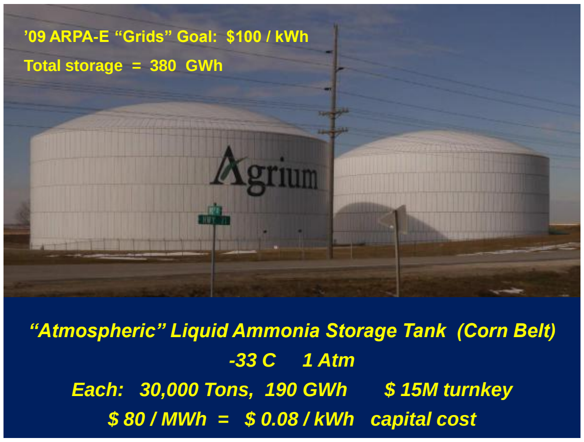


Hydrogen Caverns in Texas
- **Chevron-Phillips 25 years**
- **Praxair 6 years**

Domal Salt Storage Caverns

PB ESS

Figure 20. GH2 storage in large, deep caverns in domal salt geology. Each cavern stores ~ 2,500 metric tons (Mt) hydrogen at 150 bar: ~ 92,000 MWh. Caverns capital cost is ~ $ 5 M plus ~ $10 M "cushion gas" GH2, for total ~ $ 0.16 / kWh. Caverns may be manifolded at common pressure, to share surface facility for compression, gas drying, metering, monitoring.



'09 ARPA-E "Grids" Goal: $100 / kWh
Total storage = 380 GWh

"Atmospheric" Liquid Ammonia Storage Tank (Corn Belt)
-33 C 1 Atm
Each: 30,000 Tons, 190 GWh $ 15M turnkey
$ 80 / MWh = $ 0.08 / kWh capital cost

Figure 21. Nitrogen liquid fertilizer tanks, ubiquitous in the Corn Belt, are fed by a 3,000 mile underground pipeline network; low-cost carbon steel, at < 150 psi.

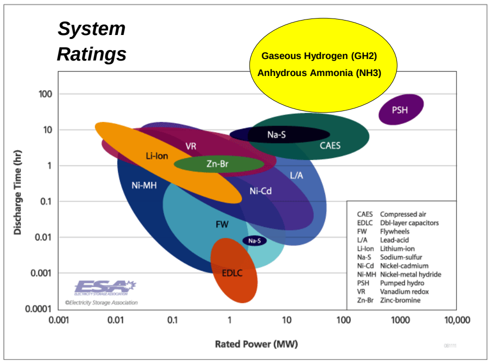


Figure 22. By total energy storage capacity, hydrogen and ammonia energy storage systems are "off the chart" because multiple GH2 caverns and NH_3 tanks may be manifolded together and interconnected via transmission pipelines.

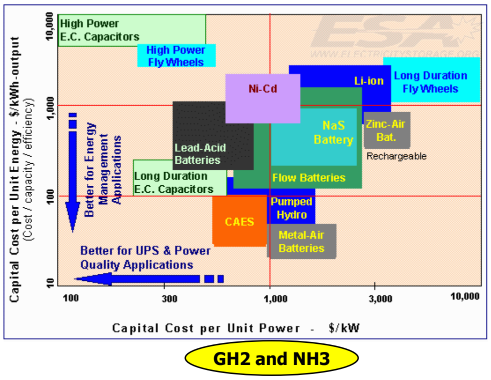


Figure 23. The low capital cost of gaseous hydrogen (GH2) and anhydrous ammonia (NH_3) energy storage are "off the chart".

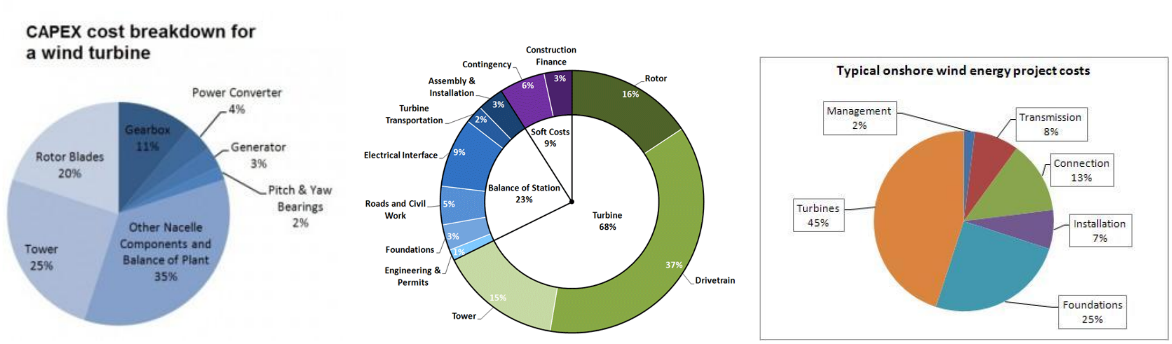


Figure 24. Land-based windplant capital cost components: 3 charts. Source: NREL, RESCO

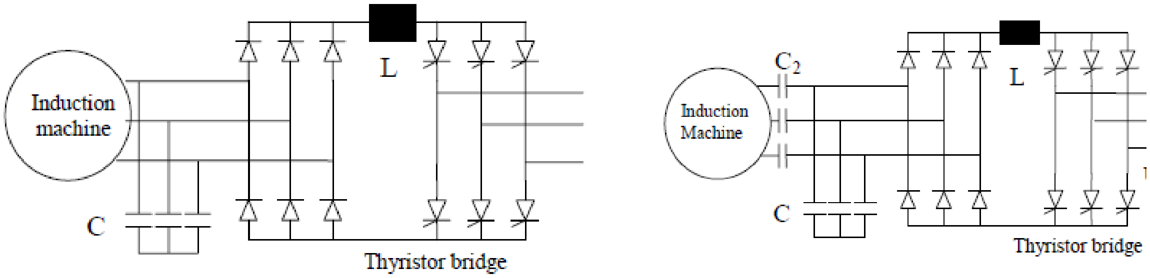


Figure 25. Candidate configurations for Self-Excited Induction Generator (SEIG): with and without series capacitors. This project will substitute an electrolyzer stack, or stack array, for the "Thyristor bridge" DC-input load shown connected to the single-turbine DC bus. [xiii]

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7. PERSONAL QUALIFICATION SUMMARIES

Eduard Muljadi

National Renewable Energy Laboratory

Education/Training

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

Employment History

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 Assistant/Lab. Instructor
Summer 84	Allen Bradley, Milwaukee, WI, Internship Worked with a Finite Element Analysis Package for electric machines
1978-1981	Energy Conversion Lab, S.I.T., Teaching Assistant/Lab Instructor
Summer 80	P.L.N. Electric Utility Co., Surabaya, Internship
1977-1981	HAKA Engineering, Electrical Contractor, Field Engineer.

Awards and Honors

- 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, July/August 1994, pp. 1073-82
- Graduate with High Distinction from Surabaya Institute of Technology.
- Member of Honor Society Eta Kappa Nu
- Member of Honor Society Sigma Xi
- Inducted to Fellow of the IEEE in 2010
- 200+ publications (complete list: www.nrel.gov/publications)
- 4200+ citations (scholar.google.com)

Relevant Peer-Reviewed Publications

1. Muljadi, E.; Butterfield, C.; Parsons, B.; Ellis, A. (2007). Effect of Variable Speed Wind Turbine Generator on Stability of a Weak Grid. IEEE Transactions on Energy Conversion. Vol. 22(1), March 2007; pp. 29-36; NREL Report No. JA-500-40175. doi:10.1109/TEC.2006.889602

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1. Wenzhong Gao, Xiaoyu Wang, Eduard Muljadi, "Power Capacity Specification for Energy Storage in Wind Application Using Probability-Based Method" presented at the IEEE ECCE 2011, September 19-22, 2011, Phoenix, AZ.

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3. E. Muljadi, V. Gevorgian, "Short Circuit Modeling of a Wind Power Plant," Invited Panel Session presented at the IEEE Power and Energy Society, General Meeting, July 24-28, 2011, Detroit, MI

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5. Coauthor: Renewable-energy Power-systems Modular Simulation (RPMSim) 1998 software package for renewable energy power system dynamic analysis in Hybrid Power System applications.

6. Member of IEEE Standard Project P1100 Working Group: Emerald Book (IEEE Std.1100-1992 Recommended Practice for Powering and Grounding Sensitive Equipments). The standard (IEEE Std 1100-1999), "IEEE Recommended Practice for Powering and Grounding Electronic Equipment," was published in September 1999 by the IEEE

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9. Patent #1. Peak Power Tracker for Photovoltaic Application (NREL IR# 93-51 issued on May 5, 1998 as U.S. Patent No. 5,747,967)

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Robert W. Preus, PE

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Professional Engineer and Project Manager

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.

Awarded a BS in Mechanical Engineering from the 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 and advanced residential PV system design and installation.

Career Highlights

Technical Lead for Distributed Wind Energy Systems. Responsible for projects at National Renewable Energy Laboratories that are for the development of distributed wind (DW) energy technology. Manages the annual operating plan for DOE funded DW projects and Requests for Proposals. Monitors DW subcontracts for technology development.

On Site Manager for a tower weld and blade repair projects on 2MW wind generators. Responsible for supervision of subcontractors, meeting schedule and budget targets, tracking progress and expenses, and coordinating with site manager. Acted as the safety officer onsite for the project. Conducted daily safety meetings and saw to the development and approval of new procedures for inside weld repairs. Managed the project to assure that critical flaw repairs were completed before the scheduled project winter downtime.

Led the successful development of five wind powered generators, three of which went into commercial production. Recruited and managed the design teams, selected and coordinated with suppliers, built prototypes, performed prototype testing, and developed manufacturing capability. Built sales and distribution network for small wind generators. Developed installation and maintenance training and manuals.

Provided oversight and due diligence, on behalf of insurance companies, on engineering redesign work by several wind generator manufacturers. Managed the review of insurance claims and litigation issues relating to product performance and reliability including on-site inspections and investigation. Supervised failure analysis and loss evaluation. Acted as an expert witness in several lawsuits.

Contributed renewable energy industry leadership. Co-chaired the committee that wrote the new section for small wind (694) in the 2011 National Electric Code (NEC). Currently serving on NEC code panel 4, which covers solar, wind, and fuel cell sections of the code. This keeps me current on PV safety requirements and issues, along with new technology such as arc fault detection. Currently serving on the panel writing a UL standard for Listing small wind generators. Received the Small Wind Advocacy Award in 2010.

Career History

From 2013 to present, as Distributed Wind Technical Lead for National Renewable Energy Laboratories, I manage all DW related technical development projects.

From 2011 to 2012, as project manager for Wind Solutions, LLC, I managed tower weld and blade repair projects on 2 MW wind generators. My responsibilities included supervision of suspended platform, welding and QA testing subcontractors, project safety and maintenance of project timeline and budget.

From 2010 to 2013, I have provided renewable energy consulting services through my company Advanced Renewable Technology, LLC. I also have led small wind installation workshops.

From 1998 to 2010, I led Abundant Renewable Ene**rgy** (ARE) in the design, manufacturing and distribution of small wind turbines. Intellectual property and designs were sold in February 2010 to Xzeres Wind Corp., which I worked for during the ownership transition.

In 1997 and 1998 I was the Sales Engineer for CleanPak Enterprise in Penang, Malaysia. I assisted the managing director in the start-up and opening of the sales office. Managed the construction of a demonstration Cleanroom. Arranged local (Malaysia) production of Cleanroom ceiling grid. In addition, I responded to customer requests for proposals and technical assistance.

During 1995 and 1996 as Design Manager for Synergy Power In**c**., I led a team that designed wind generators, constructed prototypes, implemented a test program, and produced wind turbines for overseas customers.

From 1991 to 1994 as Lead Mechanical Designer/ Senior Engineer for R. Lynette & Associates, I participated in all aspects of the design of a utility-grade wind generator and led the design of mechanical systems and component interface control. From 1985 to 1989 as Project Manager, I oversaw programs to monitor wind generator and PV system maintenance for EPRI. I also supervised insurance investigations, acted as an expert witness, and provided redesign program oversight for wind generators.

Kevin W. Harrison, Ph.D.

Senior Engineer

National Renewable Energy Laboratory

Education and Training

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

Professional Experience

2006 – Present Senior Engineer, National Renewable Energy Laboratory,
Hydrogen Technologies & Systems Center, Golden, CO

- 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 up to 10,000 psi.
- Design, build, and program data acquisition systems to monitor and control remote hydrogen-based equipment (wired and wireless).
- Design, build, and test power converters from wind and solar electricity sources to hydrogen-producing stacks of commercial electrolyzer systems.
- Design, build, and operate Class I, Division 2 hydrogen production, compression, and dispensing systems and facilities.
- Co-PI for renewable electrolysis projects, including budget, annual operating plan, personnel development, and reporting results to DOE/NREL management.

1996 – 2002 Engineering Manager, Xerox Corporation, Canandaigua, NY

- **Managed multi-disciplined group of 20 technicians and engineers across 3 shifts.**
- **Designed and installed high-volume/high-precision automated manufacturing. systems containing embedded controls, motor controls, PLC systems, digital circuits,** high-speed precision vision-guided robotics, and ultrasonic welding systems.
- Initiated and led projects that reduced manufacturing costs by integrating innovative and leading-edge technologies.
- Championed and secured internal capital funding that enabled a broad range of product and process improvements.

1991 – 1996 Electrical Engineer, Laboratory for Laser Energetics, University of Rochester, NY

- Provided cross-disciplinary engineering support and assisted scientists in one-of-a-kind equipment design, testing, deployment, and maintenance to support laser operations.

- Programmed in Fortran, C, and Assembly.
- **Developed software and gained experience in high-voltage, high-speed electronics, computer controls, PLCs, and computerized data acquisition.**
- Designed electronic system, including circuitry that incorporates sensors, digital electronic, microprocessor, and motor control subsystems. Troubleshot optical, electrical, and mechanical systems to verify laser performance.

Select Publications

1. Eichman, J.; Harrison, K.; Peters, M. (2014). Novel Electrolyzer Applications: Providing More Than Just Hydrogen. 35 pp.; NREL Report No. TP-5400-61758.
2. Harrison, K. (2014). Fueling Robot Automates Hydrogen Hose Reliability Testing (Fact Sheet). Highlights in Research & Development, NREL (National Renewable Energy Laboratory). 1 pg.; NREL Report No. FS-5D00-61091.
3. Harrison, K.W.; Remick, R.; Hoskin, A.; Martin, G.D. (2010). "Hydrogen Production: Fundamentals and Case Study Summaries." NREL /CP-550-47302, 21 pp., http://www.nrel.gov/docs/fy10osti/47302.pdf
4. Ramsden, T.; Harrison, K.; Steward, D. (2009). "NREL Wind to Hydrogen Project: Renewable Hydrogen Production for Energy Storage & Transportation." (Presentation), NREL/PR-560-47432, 26 pp., http://www.nrel.gov/docs/fy10osti/47432.pdf
5. Harrison, K.W.; Martin, G.D.; Ramsden, T.G.; Kramer, W.E.; Novachek, F.J.(2009). *Wind-To-Hydrogen Project: Operational Experience, Performance Testing, and Systems Integration*. NREL/TP-550-44082, 95 pp., http://www.nrel.gov/docs/fy09osti/44082.pdf
6. Harrison, K.W.; Martin, G.D. (2008). "Renewable Hydrogen: Integration, Validation, and Demonstration." NREL/CP-581-43114, 13pp., http://www.nrel.gov/docs/fy08osti/43114.pdf
7. Rajeshwar, K.; McConnell, R.; Harrison, K.; Licht, S. (2008). "Chapter 1: Renewable Energy and the Hydrogen Economy." *Solar Hydrogen Generation*: *Toward a Renewable Energy Future*. New York, NY: Springer. NREL/CH-581-44203, 1–18.
8. Dale, N.V.; Harrison, K.W.; Han, T.; Mann, M.D.; Salehfar, H.; Dhirde, A.M. (2008). "Hydrogen Dew Point Control in Renewable Energy Systems Using Thermoelectric Coolers." *Proceedings of the IEEE Power & Energy Society* General Meeting, 20–24 July 2008, Pittsburgh, PA. Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE) NREL/CP-581-44138. doi:10.1109/PES.2008.4596026, 6 pp., http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4596026
9. Harrison, K.; Levene, J.I. (2008). "Chapter 3: Electrolysis of Water." *Solar Hydrogen Generation: Toward a Renewable Energy Future*. New York, NY: Springer. NREL/CH-581-44204, 41-63.
10. Duffy, M.; Harrison, K.; Sheahen, T. (2007). *Measurement of Hydrogen Production Rate Based on Dew Point Temperatures: Independent Review*.NREL/MP-150-42237, 24 pp., http://www.nrel.gov/docs/fy08osti/42237.pdf
11. Harrison, K. (2007). "Renewable Electrolysis Integrated System Development and Testing" (Presentation) NREL/PR-581-41613, 30 pp., http://www.nrel.gov/docs/fy07osti/41613.pdf
12. Kroposki, B.; Levene, J.; Harrison, K.; Sen, P.K.; Novachek, F. (2006). "Electrolysis: Opportunities for Electric Power Utilities in a Hydrogen Economy." *38th Annual North American Power Symposium: NAPS-2006 Proceedings*, 17-19 September 2006, Carbondale, IL. Piscataway, NJ: Institute of Electrical and Electronics Engineers, Inc. (IEEE) NREL/CP-581-40198, 567-576.
13. Eichman, J.; Harrison, K.; Peters, M. (2014). Novel Electrolyzer Applications: Providing More Than Just Hydrogen. 35 pp.; NREL Report No. TP-5400-61758.
14. Harrison, K. (2014). Fueling Robot Automates Hydrogen Hose Reliability Testing (Fact Sheet). Highlights in Research & Development, NREL (National Renewable Energy Laboratory). 1 pg.; NREL Report No. FS-5D00-61091.

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15. Harrison, K.W.; Remick, R.; Hoskin, A.; Martin, G.D. (2010). “Hydrogen Production: Fundamentals and Case Study Summaries.” NREL /CP-550-47302, 21 pp., http://www.nrel.gov/docs/fy10osti/47302.pdf
16. Ramsden, T.; Harrison, K.; Steward, D. (2009). “NREL Wind to Hydrogen Project: Renewable Hydrogen Production for Energy Storage & Transportation.” (Presentation), NREL/PR-560-47432, 26 pp., http://www.nrel.gov/docs/fy10osti/47432.pdf
17. Harrison, K.W.; Martin, G.D.; Ramsden, T.G.; Kramer, W.E.; Novachek, F.J.(2009). *Wind-To-Hydrogen Project: Operational Experience, Performance Testing, and Systems Integration*. NREL/TP-550-44082, 95 pp., http://www.nrel.gov/docs/fy09osti/44082.pdf
18. Harrison, K.W.; Martin, G.D. (2008). “Renewable Hydrogen: Integration, Validation, and Demonstration.” NREL/CP-581-43114, 13pp., http://www.nrel.gov/docs/fy08osti/43114.pdf
19. Rajeshwar, K.; McConnell, R.; Harrison, K.; Licht, S. (2008). “Chapter 1: Renewable Energy and the Hydrogen Economy.” *Solar Hydrogen Generation*: *Toward a Renewable Energy Future*. New York, NY: Springer. NREL/CH-581-44203, 1–18.
20. Dale, N.V.; Harrison, K.W.; Han, T.; Mann, M.D.; Salehfar, H.; Dhirde, A.M. (2008). “Hydrogen Dew Point Control in Renewable Energy Systems Using Thermoelectric Coolers.” *Proceedings of the IEEE Power & Energy Society* General Meeting, 20–24 July 2008, Pittsburgh, PA. Piscataway, NJ: Institute of Electrical and Electronics Engineers (IEEE) NREL/CP-581-44138. doi:10.1109/PES.2008.4596026, 6 pp., http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4596026
21. Harrison, K.; Levene, J.I. (2008). “Chapter 3: Electrolysis of Water.” *Solar Hydrogen Generation: Toward a Renewable Energy Future*. New York, NY: Springer. NREL/CH-581-44204, 41-63.
22. Duffy, M.; Harrison, K.; Sheahen, T. (2007). *Measurement of Hydrogen Production Rate Based on Dew Point Temperatures: Independent Review*.NREL/MP-150-42237, 24 pp., http://www.nrel.gov/docs/fy08osti/42237.pdf
23. Harrison, K. (2007). “Renewable Electrolysis Integrated System Development and Testing” (Presentation) NREL/PR-581-41613, 30 pp., http://www.nrel.gov/docs/fy07osti/41613.pdf
24. Kroposki, B.; Levene, J.; Harrison, K.; Sen, P.K.; Novachek, F. (2006). “Electrolysis: Opportunities for Electric Power Utilities in a Hydrogen Economy.” *38th Annual North American Power Symposium: NAPS-2006 Proceedings*, 17-19 September 2006, Carbondale, IL. Piscataway, NJ: Institute of Electrical and Electronics Engineers, Inc. (IEEE) NREL/CP-581-40198, 567-576.

CURRICULUM VITAE

PING HSU, San Jose State University
ping.hsu@sjsu.edu Summer 2015

EDUCATION:

University of California, Berkeley; Dept. of EECS. Ph.D. in Electrical Eng., graduated: 12/88
Thesis title: Control of Mechanical Manipulators
Minor areas: Mechanics and Mathematics

Southern Methodist University, Dallas, Texas
M.S. in Electrical Eng., graduated: 12/79
Major area: Computer Hardware and Digital System
Minor area: Computer software.

St. John's Unversity, Taiwan (formerly, St. John's & St. Mary's Institute of Technology) Major area: Electronics
Diploma, graduated: 6/77

EXPERIENCE:

1/14-present	San Jose State University Research Foundation Position: Board member	
8/13-present	San Jose State University, Department of Electrical Engineering, College of Engineering	Position: Professor
8/12-2/13	San Jose State University, College of Engineering	Position: Interim Dean
8/08 – 8/12	San Jose State University, Department of Electrical Engineering	Position: Professor
10/01 – 8/08	San Jose State University, College of Engineering	Position: Associate Dean
8/00 – 9/01	San Jose State University, Department of Electrical Engineering	Position: Associate Chair
8/90-7/00	San Jose State University, Department of Electrical Engineering, College of Engineering Position: Assistant Professor ('90), Associate Professor ('93), and Professor ('00)	
1/89-7/90	University of Illinois at Urbana-Champaign Department of Mechanical and Industrial Engineering	Position: Assistant Prof.

INDUSTRY PROJECTS Kenetech Windpower

- Developed a real-time rotor resistance identification scheme for a Field Oriented Controlled (FOC) induction generator. The objective of the study was to evaluate the potential performance improvement provided by such an identification scheme.

- Studied the dynamic interaction between a FOC based controller with the dynamics of the generator, the gear box, and the main turbine shaft. An analytic model and a computer model of the overall system were developed. The purpose of the study was to identify potential excessive stress on the gears due to the dynamic interaction between the control algorithm and the structure dynamics of the gear box and the turbine shaft.

- Studied the transient torque produced by an induction generator during an electrical failure due to phase-to-phase or phase-to-neutral cable short or inverter component failure.

- Developed a control algorithm for inverters for unbalanced loading condition. The control scheme adaptively adjust both the positive and negative sequence components of the output current so as to keep the voltage balanced under unbalanced loading condition.

- Studied and proposed a way to detect speed measurement error (tachometer failure) by power measurement.

- Studied the relationship between the flux level and the overall power loss (including the inverter and the generator loss).

Trace Technologies

- Studied a high efficient grid-tied photovoltaic inverter system and proposed an optimum peak-power-tracking algorithm.

- Developed a 3-level PWM control scheme for a grid-tied inverter. This scheme substantially reduced the switching loss and the transformer core loss. This resulted in a substantial improvement of the overall system efficiency.

- Developed a control scheme including necessary analog circuitries for data acquisition for a micro- turbine driven DC brushless generator. The speed of operation of this system can reach up to 100krpm.

- Developed a Field Oriented Control (FOC) program for a wind turbine driven, grid-tied, doubly fed wound-rotor 750kW generator. This wind turbine is currently a major production model by a major energy/electic equipment company in the US. The control program is based on a DSP digital control system and it is capable of controlling both the real and the reactive output power. This work included the development of the control program, a computer model, an analytic model, and the evaluation and field testing of the system.

GE Nuclear

- Developed an experimental FOC based induction motor driven positioning system. The system is for the control of nuclear reaction control rods. The experimental system has the potential of replacing the existing stepper-motor based system. This work include the development of a fully functional system and the design and development of a custom induction motor.

- Evaluation of the stability of a voltage regulator for a variable speed induction motor. This motor is used in a recalculation system in nuclear reactors.

United Defenses

- Involvoed in the development of a field-oriented control based induction motor/generator control system for special purpose diesel-electric vehicles.

- Developed computer models for permanent magnet machines and induction machine and their control systems for the next generation diesel-electric vehicles.

BAE Systems

- Providing advices and guidelines for power electronics and their control for various special purpose hybrid vehicles.

RECENT PUBLICATIONS:

[1] "Adaptive Control of Mechanical Manipulators"; John J. Craig, Ping Hsu, and S.
[36] “Optimal Aerodynamic Energy Capture Strategies for Hydrostatic Transmission Wind Turbine' D. Rajabhandharaks and P. Hsu; 2014 2nd IEEE Conference on Technologies for Sustainability. July, 2014.

[2] " Synchronous Generators and Its Application in a Multi-turbine System.," P. Hsu and E. Muljadi, Australasian Universities Power Engineering Conference, AUPEC,
2014.

[3] "Damping Control for Permanent Magnet Synchronous Condenser with Solid State Excitation and." P. Hsu, E. Muljadi, Z. Wu, W. Gao. IEEE PES General Meeting. Denver, July 2015

[4] " Permanent Magnet Synchronous Condenser for Wind Power Plant Grid Connection Support." P. Hsu, E. Muljadi. 9th International Conf. on Power Electronics -ECCE Asia, June, Seoul, Korea, 2015.

[5] " Stand Alone Control of DFIGs in a Multiple Wind Turbine System with Load
Sharing." D. Kwon, S. Mattson, P. Hsu, E.; IEEE Energy Conversion Congress & Expo
– Montreal, Canada, ECCE, Sept. 2015.

WILLIAM C. LEIGHTY

Alaska Applied Sciences, Inc. 25 June 15

Box 20993, Juneau, Alaska 99802-0993 wleighty@earthlink.net
907-586-1426 (business and home) 907-586-1423 (fax) cell: 206-719-5554
Birth date: 18 June 43 Boyhood home: Waterloo, Iowa, USA

ACADEMIC BACKGROUND

MBA, Stanford, 1971
BS Electrical Engineering, Stanford, 1966

PROFESSIONAL EXPERIENCE

CURRENT: Principal and Secretary-Treasurer, Alaska Applied Sciences, Inc. Founded 1990. Innovation in science education, renewable energy production, energy and materials conservation, and planning for sustainability. Consulting. Owns a 700 kW wind-electric generation plant in California. USDOE-funded R+D project completed 2005, below.

Director and Trustee, pro bono, The Leighty Foundation, a small charitable family foundation, investing in several non-profit organizations for sustainable energy policy study and advocacy, among other interests; speaking in support of these investments. Co-author of a major wind energy transmission study, co-funded with The Energy Foundation, consequent followon studies and papers.

1990-98: Vice President, board member, and stockholder, Engineered Products Company, Waterloo, IA. Designed and manufactured the “Filter Minder” gauge product family, to reduce filter element consumption and maintenance costs on internal combustion engines. Sold business to employees in ’98.
1980-90: Proprietor, Maui Wind Electric: wind-electric energy generation and R+D, Hawaii
1972-90: Proprietor, Gold Creek Salmon Bake (summertime outdoor restaurant, Juneau, Alaska). Sold business March in '90.
1975-80: Proprietor, W.C. Leighty Co., insulation contractor, Juneau, Alaska
1972-75: Seasonal consultant, program budget analysis, State of Alaska
1972: City of Juneau, Model Cities Program, Evaluation Specialist; six months; resigned to open new business
1971: State of Alaska: Program Budget Analyst contractor
1968-69: Collins Radio Company (commercial and military electronic equipment): Field Engineer, Thailand five months, Vietnam ten months
1966-67: Collins Radio Company, Cedar Rapids, IA: Product Line Manager, marketing division, avionics: HF and VHF comm and nav

USDOE R&D CONTRACT

2003-05: Completed R&D contract for new composite blade manufacturing process. Final report *http://www.osti.gov/bridge/purl.cover.jsp;jsessionid=E8FBF940D2969C184E6E2FA7C77096B1?purl=/859303-oXetpM/*

PROFESSIONAL MEMBERSHIPS

American Society of Mechanical Engineers (ASME)
Institute of Electrical and Electronic Engineers (IEEE)
American Association for the Advancement of Science (AAAS)
International Solar Energy Society (ISES)

HONORS AND AWARDS

Best Paper, 22nd World Gas Conference, 1-5 June 2003, Tokyo. Leighty, W., Hirata, M., O'Hashi, K., Asahi, H., Benoit, J., Keith, G. "Large Renewables – Hydrogen Energy Systems: Gathering and Transmission Pipelines for Windpower and other Diffuse, Dispersed Sources". Proceedings of the 22nd World Gas Conference, International Gas Union, Tokyo, 1-5 June 03

Fourth Place, Physical Science, National Science Fair, April 1961

PUBLIC SERVICE

Current	Board of Trustees, Alaska Conservation Foundation
Current	Board of Directors, The Leighty Foundation
Current	Advisory Board, ISER, University of Alaska Anchorage (UAA)
Current	Co-chair, Renewable Energy Cluster Industry Working Group, Juneau, AK
1996-98	Juneau Energy Advisory Committee, Juneau, Alaska. Local government.
1992-96	Capitol City High School Science Fair: founding and organizing committee
1992-96	Juneau Sustainable Community Roundtable: organizing committee
1985-88	Juneau World Affairs Council: board member
1988-95	Juneau Planetarium: founding and organizing committee
1984-91	Beyond War: international educational movement
1978-81	Alaska Solar Advisory Group, of Western Solar Utilization Network (SUN)

CONSULTING

Various, in fields of renewable-source energy, large-scale energy transmission and storage, Hydrogen and Anhydrous Ammonia energy systems, and energy policy, as Alaska Applied Sciences, Inc.

SELECT PUBLICATIONS: www.leightyfoundation.org/earth.php

2015 Leighty, B. "Alternatives to Electricity for Transmission, Storage and Integration of Renewable Energy", WindTech International. 1 June 2015, http://www.windtech-international.com/editorial-features/features/articles/alternatives-to-electricity-for-transmission-storage-and-integration-of-renewable-energy

2013 Leighty, W., Memo to Delegates, 22nd World Energy Congress, Daegu, Korea, 13-17 Oct 2013 "Running the World on Renewables: Alternatives to Electricity for Gathering and Transmission, Annual-scale Firming Storage, and Integration of Diverse, Stranded, Renewable Energy (RE) Resources", http://leightyfoundation.org/w/wp-content/uploads/MEMO-to-Delegates-Tokyo-JREF-WSEW-Feb-23-2014.pdf

Leighty, W. ASME Power, Boston, 29 Jun – 1 Jul
Paper: POWER2013-98294 Renewable Energy Bulk Storage for < $1.00 / kWh Capital Cost as Gaseous Hydrogen (GH2) and Liquid Anhydrous Ammonia (NH3) C-free Fuels
http://leightyfoundation.org/w/wp-content/uploads/ASME-Power-98294-Jul13-FINAL.pdf

Leighty, W. ASME Power, Boston, 29 Jun – 1 Jul
Paper: POWER2013-98290 Alaska's Renewable-source Fuel Energy Storage Pilot Plant: Toward Community Energy Independence via Solid State Ammonia Synthesis (SSAS)
http://leightyfoundation.org/w/wp-content/uploads/ASME-Power-98290-Jul13-FINAL.pdf

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2012 Leighty, W., Holbrook, J., "Beyond Smart Grid: Alternatives for Transmission and Low-cost Firming Storage of Stranded Renewables as Hydrogen and Ammonia Fuels via Underground Pipelines", World Hydrogen Energy Conference, Toronto, 3-8 June 212.

2011 Leighty, W., Holbrook, J., "Alternatives to Electricity for Transmission and Low-cost Firming Storage of Large-scale, Stranded, Renewable Energy as Pipelined Hydrogen and Ammonia Carbon-free Fuels". International Gas Union Research Conference 2011, Seoul, Korea, 19-21 Oct

Leighty, W., Holbrook, J., "Beyond Smart Grid: Alternatives for Transmission and Low-cost Firming Storage of Stranded Renewables as Hydrogen and Ammonia Fuels via Underground Pipelines" ASME Power 2011, Denver, CO, 12-14 July 11

2010 Leighty, W., Holbrook, J., Blencoe, J., "Alternatives to Electricity for GW-scale Transmission and Firming Storage for Diverse, Stranded Renewables: Hydrogen and Ammonia". Presented at ASME 4th International Conference on Energy Sustainability, Phoenix, AZ, 17-22 May 10. Proceedings of ES2010: ES2010-90341

Leighty, W., Holbrook, J., "Transmission and Annual-scale Firming Storage Alternatives to Electricity for GW-scale Stranded Renewables: Gaseous Hydrogen and Anhydrous Ammonia via Underground Pipeline". Presented at ASME 2010 Power Conference, Chicago, IL, 13-15 Jul 10. Proceedings of POWER2010: POWER2010-27120

Leighty, W., "Transmission and Annual-scale Firming Storage Alternatives to Electricity: Gaseous Hydrogen and Anhydrous Ammonia". Presented at ASME International Colloquium on Environmentally Preferred Advanced Power Generation, Costa Mesa, CA, 9-11 Feb 10. Proceedings: ICEPAG2010-3416

2009 Leighty, W., "Alaska Village Survival: Affordable Energy Independence via Renewables Firmed as Hydrogen Stored in Liquid Anhydrous Ammonia". Presented at National Hydrogen Association Conference, Columbia, SC, 30 Mar – 3 Apr 09. Published in conf. proceedings.

VIDEOS OF CONFERENCE AND OTHER PRESENTATIONS

Windpower 2015, Orlando, FL 18-21 May 2015, Session 8B: The "Mostly Wind" Grid–Implications for Reliability, Markets, and Storage. "Alternatives to Electricity for Transmission, Firming Storage, and Integration of GW-scale Wind and Solar via Hydrogen and Ammonia Pipelines" https://vimeo.com/128484940 20 minutes

Juneau World Affairs Council, Juneau, AK, 12 May 2015
"Arresting Climate Change: Transforming the World's Largest Industry"
https://vimeo.com/127890670 50 minutes

ASME-IMECE – American Society of Mechanical Engineers, International Mechanical Engineering Congress and Exposition, Houston, TX, 9–15 November 2012
"Running the World on Renewables: Alternatives for Transmission and Low-cost Firming Storage of Stranded Renewables as Hydrogen and Ammonia Fuels via Underground Pipelines"
https://www.youtube.com/watch?v=0w-1oLXXlqk&index=1&list=UU_fKB5GeOPhfrEaNhjwZgvQ

National Hydrogen Association (NHA) annual conference, Long Beach, CA, 4-6 May 2010
"Begin Now: Design and Build a Renewables-Source Hydrogen Transmission Pipeline Pilot Plant" https://www.youtube.com/watch?v=fND9S7Llvqk&list=UU_fKB5GeOPhfrEaNhjwZgvQ