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Renewable H2: SBV-PalmSpringsWindplant-conversion-NREL

Sixth of 6 files

Additional submitted attachment is included below.

**Lower-cost Hydrogen (H₂) Fuel Production from Distributed Wind via Paralleled Self-Excited Induction Generators (SEIG's) at Multi-turbine Off-grid Windplants:
NREL R&D plus Demonstration at an Operating 13-turbine Windplant in Palm Springs, CA**

SBV project success at NREL will achieve TRL 6-7 in both SEIG and close-coupled electrolysis stack technologies, to enable:

- ➔ Reducing wind turbine, windplant, and electrolysis complexity, capex, and O&M costs, reducing wind-source H₂ cost ~ 20%
- ➔ Eliminating wind curtailment, via "free" storage in pipeline packing, salt cavern storage, and continental Hydrogen pipelines
- ➔ Greatly increasing "distributed" wind energy harvest area, delivering H₂ fuel, without grid connection, to a new pipeline net
- ➔ Wind turbines and plants dedicated to delivering 100% of captured energy as H₂ and/or NH₃ fuels, with or without grid tie
- ➔ DOE's "H₂@SCALE" concept. See RFI comments: <http://leightyfoundation.org/w/wp-content/uploads/RFI-H2@SCALE-Comments-DOE-0001655-2Nov16.pdf> <http://leightyfoundation.org/w/wp-content/uploads/RFI-Comments-POSTERS-5-2Nov16.pdf>

1. Alaska Applied Sciences, Inc. (AASI) delivered electric energy from its Palm Springs R&D windplant to the SCE grid for 21 years, until the PPA expired in 2012. We improved many aspects of the vintage-1985 turbine design to improve its durability, reliability, and energy capture. In 2005 AASI completed blade manufacturing R&D on DE-FG36-03GO13140 Final: www.osti.gov/servlets/purl/859303-oXetpM/ AASI is now ready to convert its Palm Springs windplant entirely to "distributed" H₂ fuel output, with no connection to the SCE grid. SBV project success enables wind deployment in a large new market. AASI's Full Application for ARPA-E 2015 "OPEN" FOA, for this RD&D technology, was not selected.

See video of the Palm Springs windplant in 2005, delivering electricity to the SCE grid at constant turbine RPM, with turbines' induction motors-as-generators locked at 60 Hz: <https://vimeo.com/86851009> These turbines are equipped with common, rugged, low-cost, three-phase, 60 hp induction motors as generators. This windplant is the perfect test bed and scale for R&D and demonstration of this novel, low-cost, high-efficiency technology system for producing high-purity H₂ fuel from wind-generated electricity, from single or multiple "distributed" turbines, with or without connection to the electricity grid. Modified for Self Excited Induction Generator (SEIG) mode, the turbines would be closely coupled, via simple, smart rectification on a DC bus, to the electrolyzer stacks, via a SCADA system integrating the complete wind-to-H₂ plant, to reduce system complexity and capital and O&M costs. This increases system reliability and maintainability, and reduces kWh per kg H₂, thus reducing plant gate H₂ fuel cost.

This has been AASI's mission and vision for fifteen years: urging the renewable energy (RE) industry to seriously consider alternatives to electricity systems for gathering and transmission, affordable annual-scale firming storage, and distribution and integration of CO₂-emissions-free (CEF) energy at small or large scales. H₂ and Anhydrous Ammonia (NH₃) are the attractive alternatives. See AASI Principal Bill Leighty's research papers, presentations, "H₂@SCALE" comment: www.leightyfoundation.org/earth.php

No other company has proposed demonstrating this technology of SEIG-equipped turbines, closely coupled to electrolysis stacks or Anhydrous Ammonia synthesis reactors, on an operating multi-turbine windplant. This project's success could be scaled to multi-MW turbines and windplants, to produce, for example, ~7 million tons per year of H₂ fuel required for the California (CA) transportation sector in year 2050 -- a larger market for CEF energy than electricity for the CA grid: AASI's vision. The project's H₂ fuel will be delivered to Sunline Transit, 15 miles east on I-10, and / or to other local markets.

AASI has demonstrated SEIG mode operation on one of its stranded Palm Springs turbines, delivering rectified "wild AC", at variable speed, to a DC resistive load bank: Fig 1-2. <https://vimeo.com/160472532>

2. Problem: AASI needs help from NREL's unique resources team to design and dyno-test this novel, simple system of power electronics and controls, close-coupling multi-turbine SEIG generators via a common DC bus to the electrolysis stacks, preparing a prototype system for deployment for field testing for 6 - 12 months of SCADA data collection and design improvement at AASI's Palm Springs windplant:

- Kevin Harrison: wind-to-H₂ systems; windplant DC bus to electrolysis stacks drive PE; controls
- Robert Preus: distributed wind systems design and deployment; integration of H₂ fuel systems
- Ed Muljadi: rotating machine systems, dyno test, SEIG controls integration with electrolysis SCADA
- Woonki Na and Ping Hsu: (Fellows, Ed Muljadi) rotating machine systems, SEIG controls, dyno test

The above NREL team collaborated in this RFA preparation, partnered in AASI's unsuccessful \$ 3 M Full Application for the 2015 ARPA-E "OPEN" FOA, and is ready to employ several used electrolysis plant components and a spare motor from AASI to commence NREL's SEIG-to-H₂ design. Project success will be achieved, documented, and used for AASI's commercial purposes, to expand wind deployment, by:

- a. Design, assembly, and dyno test of a pilot-scale SEIG-based wind-to- H₂ system at NREL;
- b. Packaging the system with SCADA and comm in a CONEX at NREL, for transport to Palm Springs;
- c. 6 -12 months operation on 1- 3 AASI turbines; SCADA data analysis; system design improve; papers;



Video of operating windplant:
<https://vimeo.com/86851009>

Figure 1. AASI's 13-turbine Palm Springs windplant, ready for conversion to dedicated "distributed" Hydrogen fuel production, with no connection to the SCE grid. The SBV project will embrace 2 or 3 turbines; success will set the stage for attracting further funding to advance the SEIG-based electrolysis design and integrated controls. This will include acquisition of a MW-scale, custom-engineered electrolysis plant to embrace all 13 turbines, produce ~ 11,000 kg H₂ fuel per year, and prepare for system commercialization. Three leading electrolysis plant vendors partnered with AASI, NREL, Sunline Transit, and others on AASI's ARPA-E "OPEN" Full Application, and will be invited to propose plant + in-kind custom engineering contributions in future project phases. The NREL SBV will be proof-of-concept for the launch.

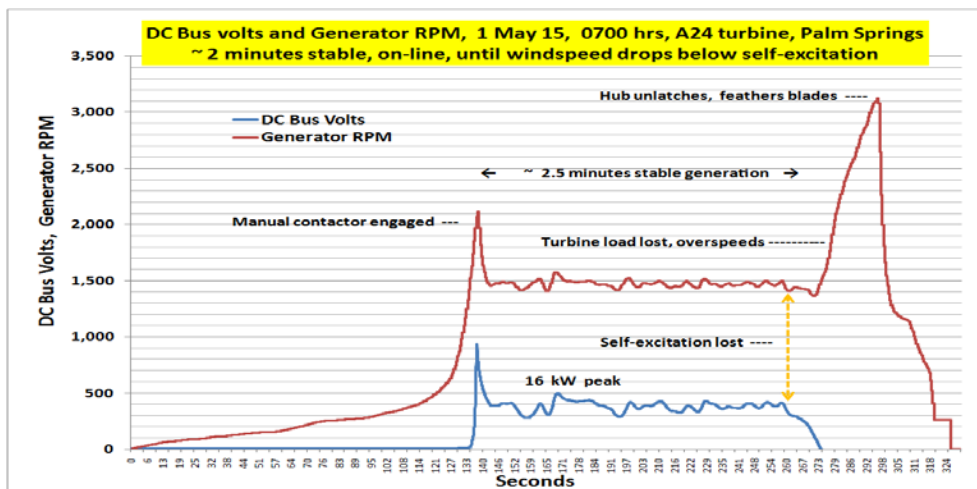


Figure 2. SEIG mode test on one of AASI's 13 Palm Springs 50 kW wind turbines, variable speed, "wild AC" to "wild DC" to resistive load. Self-excitation lost at low windspeed at 260 sec. No grid connection. Video: <https://vimeo.com/160472532>

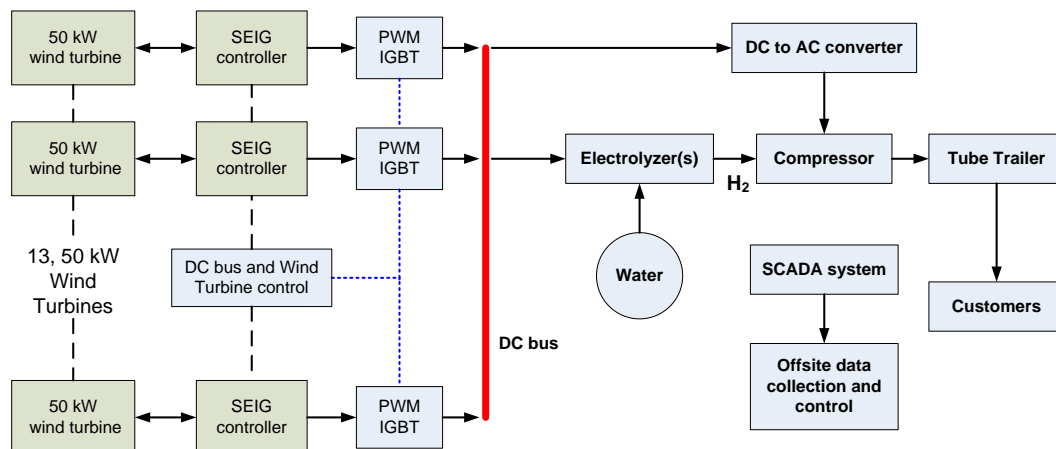


Figure 3. The novel technology to be developed at NREL by their wind-to-H₂ team using the small dyno for power electronics and controls engineering verification. Prototype hardware capable of 2 or 3 turbines will be deployed at AASI's Palm Springs windplant for 6 months' data collection, system design improvements, H₂ fuel delivery.

- d. Enabling AASI's SCADA analysis for hardware + software advance on the SEIG-electrolysis system;
- e. Long-term test and demo to attract customer interest, advancing system design to production-ready.

NREL's facilities and expertise are not globally elsewhere available and affordable to small business. The AASI Palm Springs windplant is the perfect test bed and demonstration site for the wind industry's first distributed wind-to- H₂, SEIG-driven, close-coupled electrolysis system with plantwide integrated controls. AASI depends upon the NREL partners team from our 2015 ARPA-E "OPEN" Full Application to design the SBV protocol and scope of work and to estimate the RFA cost, to best address the Problem.

3. Impact: SBV project proof-of-concept success will enable AASI to attract subsequent funding toward market readiness from one or several federal, State of California, and / or private enterprise sources to:

- a. Advance the SEIG-based electrolysis design and integrated SCADA, to improve stability, wind-to-H₂ energy conversion efficiency, and windplant energy capture: a major new energy capture innovation;
- b. Improve baseline: the SCADA system will calculate the power curve for the windplant-to-H₂ system in Palm Springs windplant operation, i.e. kg H₂ production as a function of windspeed, with appropriate sample time averaging. NREL lab testing will determine the kWh per kg H₂ power curve for optimized electrolysis and dyno-driven SEIG subsystems. SCADA analysis will guide SEIG-close-coupled-electrolysis hardware and software design advances to improve windplant power curve vis-a-vis baseline.
- c. Demonstrate how savings in capex and O&M costs for the simpler SEIG-driven windplant-to-H₂ system will allow extrapolation to MW and multi-MW scale reduction in the plant-gate cost of wind-generated H₂ fuel. We expect to demonstrate > 20% potential lower plant gate cost than H₂ fuel from wind systems delivering grid-quality electricity to AC or DC grid systems for distant H₂ conversion.
- d. Acquire a MW-scale, custom-engineered, electrolysis plant to embrace all 13 turbines, to produce ~ 11,000 kg H₂ fuel per year, improve the accuracy of (b), and prepare for system commercialization. Three electrolysis plant suppliers will propose a custom-engineered solution, collaborating with NREL research;
- e. Operate the full windplant for years, collecting data for NREL and others to establish the commercial value of this novel wind-to-H₂ generation technology, refine system hardware and software for preparing technical papers, and for commercialization. Long-term economic impact will be (a) lowering the cost of wind-source H₂ fuel; (b) eliminating curtailment; (c) greatly expanding wind's geographic harvest area, without costly expansion of the electricity grid, but assuming an extensive new, dedicated, high-purity, underground H₂ pipeline network of lower capex per MW-km than electricity lines as ITS proposed in Fig. 4; (d) enabling "H2@SCALE", deep decarbonization of the complete US and global energy system.

4. Use Results: The IP established by this SBV and sequentially-funded projects will enable AASI to promptly redesign, manufacture, and eventually license this technology, at small and large scales. The immediate market is hundreds of small, old, still-operating wind turbines in CA that could easily be retrofitted for SEIG-mode H₂ fuel production. The next market is new distributed wind turbines and MW windplants. Major wind OEM's will independently develop and adopt this technology, motivated by:

- Lower capex and O&M costs of dedicated H₂ and Ammonia energy production, transmission, and storage systems vis-a-vis electricity systems, at both distributed and continental scales;
- Higher value per wind-generated kWh for H₂ and NH₃ fuel production than for the grid;
- Eliminating curtailment by total output delivery as H₂ and NH₃ fuels to storage-backed pipelines;
- Wind deployment over far wider geographic areas, serving the H₂ fuel market via pipelines.

In CA in year 2050 the demand for CEF transportation fuel will probably exceed the demand for CEF grid electricity by > 30 %, a major new market for wind and other CEF energy sources. Fuel cell transportation will succeed only to the extent that abundant H₂ fuel is ubiquitously available at competitive prices. Distributed wind-source H₂ fuel production and a new pipeline network helps the EERE fuel cell program, and may motivate WWPTO to consider H₂ and Ammonia systems as alternatives to electricity systems, including for offshore wind. This could launch a very large impact, emulating Japan's interest in importing tanker loads of H₂-rich liquids from CEF sources worldwide -- perhaps especially from Alaska. Japan's NEDO assignments: Kawasaki, LH2. Sumitomo, NH₃. Chiyoda, Methylcyclohexane (C₇H₁₄) < > Toluene. Thus, we build a global energy "hydrogen sector".

Value: The H₂ fueling stations now being installed with State of California funding are required to acquire one-third of their dispensed H₂ from CEF sources. As fuel cell light duty vehicles (LDV's), buses, and trucks proliferate, the demand for CEF H₂ will rapidly increase. This SBV project success will enable proliferation of off-grid windplants equipped with the simpler SEIG-driven H₂ generation systems, producing high-purity H₂ fuel, over a large geographic area, feeding the new, dedicated, underground, high-purity gaseous H₂ (GH₂) pipeline network in Fig. 4, dispensing H₂ fuel at > 20 % lower cost than H₂ made from grid electricity sourced from windplants burdened by the generating systems and infrastructure required to deliver grid-quality AC or DC. This H₂ will bestow large beneficial impacts on CA's energy economy, and beyond, as the US and the world emulate the CA "lighthouse" transportation fuel and electricity systems, and the total CA energy system, pipelining in Great Plains wind and solar.

In CA in 2050, transport H₂ fuel alone will require ~20 times today's installed wind capacity or ~ 25 times today's installed solar capacity, or equivalent combinations with other CEF sources:

Hydrogen fuel demand, CA, year 2050, Million metric tons per year:	
Light Duty Vehicles (LDV)	3.6
Trucking	1.6
Bus	1.4
Aviation and Other	0.8
Total	7.4
Source: interpret and extrapolate from several papers by ITS-STEPS, UC Davis	

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

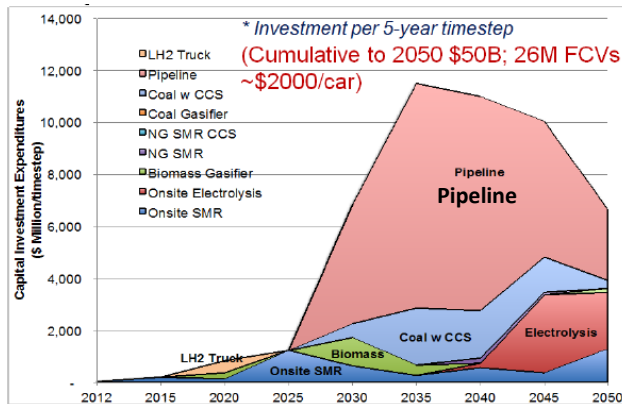


Figure 4. Large, new, dedicated, high-purity Hydrogen pipeline systems in CA will accelerate distributed wind deployment, providing lower-cost transmission, storage, and distribution alternative to electricity systems, opening large windy land areas now without electricity transmission, as in DOE "H₂@SCALE". Gaseous Hydrogen pipelines may be "packed" for free storage. Underground pipelines cost less per MW-km than electric lines. In CA in 2050 the market for CEF transportation fuel energy will exceed the market for CEF grid electric energy. Source: ITS-STEPS, UC Davis

5. Three NREL and two adjunct research staff teamed with AASI for this project. Resumes in Appendix. Contract help, per need: UC Riverside (CE-CERT, Bourns Engrg); John Cornish, EPC, Lakewood, CO

6. AASI cost share includes used equipment for the Palm Springs prototype test and cash for materials:

- In-kind, Used: (2) ProtonOnsite H6m electrolyzers (~ \$ 200 K each, new) \$ 40 K
 - In-kind, Used: ELGA water deionizer (~ \$ 12 K, new) \$ 3 K
 - In-kind, Used: PDC Machines H₂ compressor (~ \$ 50 K, new) \$ 3 K
 - In-kind, Palm Springs windplant: use 2 or 3 turbines for 6 - 12 months prototype system testing \$ 10 K
 - In-kind, Palm Springs windplant site free use: by owner D&E Land Company, 6 - 12 months \$ 1 K
 - Cash: AASI share of \$ 300 K NREL CRADA: SBV funds request therefore = \$ 250 K \$ 50 K
 - Cash: 20 ft CONEX and misc components for prototype system deployment \$ 10 K
 - Cash: Palm Springs windplant: transport and install CONEX-contained prototype system \$ 6 K
 - Cash + in-kind, AASI project management, 2 or 3 turbines maintenance, travel by Bill Leighty \$ 10 K
- Total \$ 133 K**

APPENDIX: Team resumes and support letters. The NREL team was assembled for partnering on AASI's ARPA-E "OPEN" FOA application, has helped compose this SBV RFA, and will execute it.

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

BS Electrical Engineering, Stanford, 1965 MBA, Stanford, 1971
 1990 - present Principal, Alaska Applied Sciences, Inc. (AASI), Juneau, AK. Energy R&D, consulting
 1989 - present Director, The Leighty Foundation www.leightyfoundation.org/earth.php
 Co-authored and presented over 20 papers on H₂ and Ammonia energy systems as alternatives to electricity systems for large + small distributed renewable energy sources, at: www.leightyfoundation.org/earth.php
 1971 - 1990 Small business owner and consultant, Juneau, AK
 1966 - 1969 Collins Radio Company: Assistant Product Line Manager; Field Engineer in Thailand, Vietnam

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

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

BS Mechanical Engineering, University of Washington. Licensed PE. Certified for OSHA-10, NFPA70e, First Aid Basic and CPR, Tower Climbing, Suspended Scaffold Safety and Self Rescue, Up Tower Assisted Rescue. Extensive experience in project management including: design, prototype development, testing, certification, manufacturing, installation, onsite inspection and repair for multiple renewable energy products and projects. Provided project commissioning inspections, maintainability and availability analysis, forensic analysis, repair cost review, lost revenue calculations, and retrofit design oversight for renewable energy products and projects. Led the successful development of five wind powered generators, three of which went into commercial production.

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

A.A.S., Computer Technology, Monroe Community College, 1992
 B.S., Electrical Engineering, University of Rochester, 1995
 M.S., Electrical Engineering, University of North Dakota, 2002
 Ph.D., Energy Engineering, University of North Dakota, 2006

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

- Responsible for all R&D activities surrounding integrated renewable electrolysis hydrogen production, compression, and dispensing system.
- Equipment work includes maintaining low-temperature hydrogen production equipment, rebuilding diaphragm compressors, fuel cells, cooling systems, water purification, and related support equipment < 10,000 psi.
- Design, build, and program data acquisition systems to monitor and control remote hydrogen-based equipment
- Design, build, and test power converters from wind and solar electricity sources to hydrogen-producing stacks of commercial electrolyzer systems.
- Co-PI for renewable electrolysis projects, including budget, annual operating plan, personnel development, and reporting results to DOE/NREL management.

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

Ph.D., Electrical Engineering, University of Wisconsin-Madison, 1987
 M.S., Electrical Engineering, University of Wisconsin-Madison, 1984
 B.Sc., Electrical Engineering, Sepuluh Nopember Institute of Technology, 1981
 1992-Present National Renewable Energy Laboratory, Golden, CO, Electrical Systems Engineer
 1988-1992 Electrical Engineering, California State University, Fresno, CA, Asst. Professor
 1983-1987 Electrical Engineering Dept., University of Wisconsin-Madison, Research and Teaching

- Awarded IEEE Prize Paper (1994) for a paper entitled: "Series Compensated PWM Inverter with Battery Supply Applied to an Isolated Induction Generator", IEEE Transactions on Industry Applications Vol. 30, No. 4, 1994
- Graduate with High Distinction from Surabaya Institute of Technology.
- Inducted to Fellow of the IEEE in 2010
- 200+ publications (complete list: www.nrel.gov/publications); 4,200+ citations (scholar.google.com)

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

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

Director of General Engineering, Professor, Department of Electrical Engineering,
Charles W. Davidson College of Engineering, San Jose State University, San Jose, CA 95192-0080

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

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

Dr. Sadrul Ula sula@cert.ucr.edu Office: 951-781-5791

Manager, Winston Chung Global Energy Center, UC Riverside, CE-CERT, SC-RISE. Prof, Bourns Engineering
Generator parameter test. Student access to windplant site and SCADA data; improve equip and experiment design.

John Cornish JCornish@epc4h2.com Office: 720-974-1709

Principal, EPC, Lakewood, CO Hydrogen system permitting and installation at Palm Springs windplant test site.



Bill Leighty
Principal, Alaska Applied Sciences, Inc. (AASI)
Box 20993, Juneau, AK 99802-0993

3 April 2016

Dear Bill,

I am writing to support your Small Business Voucher Request for Assistance, for the Palm Springs wind-to-H₂ project. The application of PEM electrolysis technology for renewable energy storage has always been a primary vision of Proton OnSite. We have made a major financial commitment to bring a product to market that will enable that vision. The kind of research described in this SBV RFA for the NREL-led team will provide an important capability for a new SEIG-based technology path to optimize the design of our M-Series platform for off-grid wind applications. This SEIG-based wind-to-H₂ research has never been done before, and could be a breakthrough approach for reducing both system capital cost and improving electrical efficiency. Although Proton OnSite would not be directly involved in the SBV effort, we would be pleased to provide technical input to NREL to enhance the value of the AASI project.

Sincerely,

Stephen Szymanski
Director – Business Development



ITM Power supports the proposed project. Many of the R&D activities around the world are focused on grid tied hydrogen energy storage and this project provides a potential to increase efficiency of the process and reduce cost. ITM has a number of projects where we are either injecting hydrogen directly into a natural gas grid or using the hydrogen to fuel vehicles; all are grid tied. The development of controller and power supplied to work with the SEIG technology within this project would be a very exciting addition to our product portfolio and allow of grid renewables to be integrated with ease.

Sincerely,
Stephen Jones, Managing Director, ITM Power Inc.

LISA MURKOWSKI
ALASKA

COMMITTEES:
ENERGY AND NATURAL RESOURCES
CHAIRMAN
APPROPRIATIONS
SUBCOMMITTEE ON INTERIOR,
ENVIRONMENT, AND RELATED AGENCIES
CHAIRMAN
HEALTH, EDUCATION, LABOR,
AND PENSIONS
INDIAN AFFAIRS

United States Senate

WASHINGTON, DC 20510-0203
(202) 224-6605
(202) 224-5301 FAX

April 5, 2016

510 L STREET, SUITE 600
ANCHORAGE, AK 99501-1956
(907) 271-3735

101 12TH AVENUE, ROOM 329
FAIRBANKS, AK 99701-6278
(907) 456-0233

800 GLACIER AVENUE, SUITE 101
JUNEAU, AK 99801
(907) 586-7277

805 FRONTAGE ROAD, SUITE 105
KENAI, AK 99611-9104
(907) 283-6808

1900 FIRST AVENUE, SUITE 225
KETCHIKAN, AK 99901-6059
(907) 225-6880

851 EAST WESTPOINT DRIVE, SUITE 307
WASILLA, AK 99554-7142
(907) 376-7665

Mr. Mark Higgins, Operations Supervisor
U.S. Department of Energy, Energy Efficiency & Renewable Energy
Office of Wind and Power Technologies Office
1000 Independence Ave., SW
Washington, DC 20585

Re. Solicitation for Small Business Voucher Grant for Wind-source Hydrogen Fuels

Dear Mr. Higgins:

I am writing to ask that the Department of Energy's National Renewable Energy Laboratory consider granting a Small Business Voucher for research and prototype design for using the technology developed by Alaska Applied Sciences Inc. (AASI), to reduce the cost of Hydrogen and Anhydrous Ammonia carbon-free fuels made from wind turbines using specific technologies.

I have known the principal of AASI, Bill Leighty for more than two decades. He has published more than 20 professional papers and is recognized as an expert in developing renewables-source Hydrogen and ammonia energy systems. I am particularly interested in seeing this technology advance because of its potential applications to reducing the high-cost of energy in rural Alaska. Alaska's small, isolated communities could benefit greatly by reducing the cost of using seasonally produced renewable energy to produce carbon-free fuels.

My understanding is that AASI is seeking a \$300,000 Small Business Voucher to prove the economic feasibility of using wind power from a 13-turbine wind farm at Palm Springs, CA to produce Hydrogen fuel by using low-cost, three-phase induction motors as generators, operating in Self Excited Induction Generator (SEIG) mode. Proof of this process would lower the cost of hydrogen fuel made from electricity generated by rotating machines, could increase the geographical area in which wind energy can be harvested, and simplify wind turbine and wind-to Hydrogen fuel productions systems nationwide.

This process could prove extremely useful to reducing energy costs in rural Alaska, where much of coastal and rural Alaska enjoy Class 6 and 7 wind conditions, and at windy sites without electricity transmission access nationwide. Consistent with all relevant rules, laws, and regulations, I respectfully request that all due consideration be given to funding this feasibility study, an outgrowth of AASI's unsuccessful Full Application for a \$3 million grant from the ARPA-E "OPEN" solicitation last year, for a more complete version of this SBV project. I thank you for your consideration of this request.

Sincerely,



Lisa Murkowski
United States Senator