Comment Received From: Bill Leighty
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Renewable H2: ESIF-NREL "HighImpact" proposal

Fifth of 6 files

Additional submitted attachment is included below.

Optimum relief for the electricity grid from the transmission, storage, and integration burdens of large variable renewable generation (VG): Gaseous hydrogen (GH2) and anhydrous ammonia (NH_3) energy systems based on pipelines and low-cost, GWh-scale storage

ABSTRACT This project's success will help achieve the goals of the Grid Modernization MYPP by preventing burdening the electricity system with technical tasks for which it is not optimally suited. At ESIF, and elsewhere, electrical and systems engineers are brilliantly succeeding in enhancing the electricity grid ("Grid") system design to accommodate the steadily-increasing fraction of variable generation (VG) and distributed energy resources (DER) inflicted upon the Grid, especially in California. http://leightyfoundation.org/w/wp-content/uploads/WP16-A-1.pdf

But, at ESIF and elsewhere, we may be pursuing a technically- and economically-suboptimal solution by expecting the Grid to accomplish seven challenges. Renewables-source (RE), CO2-emission-free (CEF) energy systems based on underground pipeline systems and low-cost (< $ 1.00 / kWh capex) energy storage, with gaseous hydrogen (GH2) and anhydrous ammonia (NH3) as energy carriers and storage media, may relieve the Grid of much of these demands, with improved long-term technical and economic performance. ESIF is ideally and uniquely conceived and equipped for testing this hypothesis and proposing follow-on studies and pilot systems, if we are encouraged by this preliminary study.

First, Prime Recipient (PR) and ESIF gather best-available information about costs and performance of GH2 and NH3 systems and components. Next, ESIF builds models for complete energy systems, at regional to continental scales. Finally, for a range of cases, PR+ESIF determine optimum technical and economic performance, including potential for relieving the Grid from economic and performance burdens of transforming the entire energy industry from fossil to CEF energy sources: an optimum mix range of electric, Hydrogen, and Ammonia harvest and dispatchable energy services delivery, minimizing LCCOE for each scenario.

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The Leighty Foundation, Prime Recipient, non-profit organization (NPO)
www.leightyfoundation.org/earth.php

ESIF Facility: Renewable electricity to Grid; Renewable energy to GH2 and NH3 fuels, pipelines, and low-cost (< $ 1.00 / kWh capex) GWh-scale energy storage

Budget:	Prime Recipient	$ 50,000 in-kind
	Cash	$ 0
	ESIF	$ 50,000
	Total	$ 100,000

Cost share value: 50 %

This project's success will help achieve the goals of the Grid Modernization MYPP by preventing burdening the electricity system with VG technical tasks for which it is not optimally suited:

> ***Vision:*** *The future grid will solve the challenges of seamlessly integrating conventional and renewable sources, storage, and central and distributed generation. It will provide a critical platform for U.S. prosperity, competitiveness, and innovation in a global clean energy economy. It will deliver resilient, reliable, flexible, secure, sustainable, and affordable electricity to consumers where they want it, when they want it, how they want it.*
>
> ***Six technical areas:*** *Modeling and Analysis (i.e., software): Develop and disseminate new and improved models for analysis, management and optimization of grid performance (e.g., solar and wind prediction)* ***[For this project: improving Grid performance by VG relief]***

Humanity's energy goal must be no less than transforming the world's largest industry from ~ 82 % fossil to ~ 100 % renewable, CEF energy sources, as quickly as we prudently and profitably can -- to "Run the World on Renewables". At ESIF, and elsewhere, electrical and systems engineers are brilliantly succeeding in enhancing the electricity grid system design -- toward yet-obscure technical and cost limits -- to accommodate these challenges:

1. A larger fraction of Grid's total energy transfer from diverse, VG, RE - CEF resources, to progressively and entirely decarbonize humanity's total energy economy;

2. A larger fraction of Grid's total RE energy transfer from DER, requiring curtailment + storage;

3. An expected large, nascent market demand for RE - CEF transportation energy;

4. Much larger total electric energy transfer per time period -- average and peak power, at time scales of seconds to seasons -- with larger power ramp rates, requiring large new investments in gathering, transmission, distribution, integration, and backup generation infrastructure;

5. Affordably storing GWh-scale quantities of electricity-source energy in order to deliver annually-firm, dispatchable electricity;

6. Excellent electricity -- and total energy system -- availability, reliability, security, power quality, resilience, affordability, and equity;

7. Becoming "smarter" , more interconnected and accessible and controllable, while more cybersecure; testing the hypothesis that "Smart Grid" will succeed at all system scales.

But, at ESIF and elsewhere, we may be pursuing a technically- and economically-suboptimal solution by expecting the electricity "Grid" to accomplish all of the above, essentially attempting to stuff a square peg into a round hole. RE - CEF energy systems based on underground pipeline systems and low-cost (< $ 1.00 / kWh capex) energy storage, with gaseous hydrogen (GH2) and anhydrous ammonia (NH3) as energy carriers and storage media, may relieve the Grid of much impact of these demands, with improved long-term technical and economic performance. ESIF is ideally and uniquely conceived and equipped for testing the "Smart grid" hypothesis and for proposing follow-on study and pilot systems by which to:

1. Compose a roadmap toward an optimum mix of electricity, GH2, and NH3 complete energy systems for RE-CEF sources, at DER to continental scales;
2. Prevent excess investment in the Grid, both in R&D and in deployment;
3. Optimize global energy system rapid decarbonization and propagation to the energy-underserved;
4. Consider investing in an International Renewable Hydrogen Transmission Demonstration Facility (IRHTDF), perhaps via IPHE, as a pilot plant system of GH2 production and GH2 pipeline gathering, transmission, storage (by pipeline "packing"), and end-use -- to test the ESIF models. https://www.youtube.com/watch?v=fND9S7Llvqk&list=UU_fKB5GeOPhfrEaNhjwZgvQ

This modest, preliminary ESIF R&D project should commence, soon, while EISF resources are still available during the current Administration; success may attract interest and funding from philanthropy and industry, to replace or enhance EISF's present funding and other support.

This project satisfies the five "High Impact" criteria of the Call. Recent global energy trends and nascent interest by industry, USDOE, and others suggest this study is timely, as a demonstration of ESIF's ability to model continental-scale energy systems "beyond electricity", including:

- USDOE "H2@SCALE" RFI, 2016: deep decarbonization of the total USA energy system;
- ARPA-E "REFUEL" FOA, 2016: renewables-source liquid fuels, including NH3;
- Hydrogen Alliance paper "How hydrogen empowers the energy transition", 17 Jan 17;
- The "Breakthrough Energy" collaborative, including Bill & Melinda Gates Foundation, which advocates CEF NH3 production, for fertilizer, low-cost energy storage, and fuel;
- Rollout of GH2 fueling infrastructure and FCHEV's in California (CA); 1/3 as RE-CEF fuel;
- NREL capability in wind-to-Hydrogen, and in other Hydrogen system applications, to model large increases in rich wind and solar resource land, not served by electricity transmission, which could be served with new GH2 and NH3 transmission pipelines;
- Growing realization that battery electric vehicles (BEV's) will likely remain suboptimal for heavy-duty, long-distance transportation and for full-size LDV's; FCHEV's will prevail;
- Thirteen annual conferences of the Ammonia Fuel Association, primarily from RE-CEF sources. https://nh3fuelassociation.org/
- The Siemens business and technical case for renewables-source NH3 as an energy vector and complete system: synthesis, transport, storage, delivery of energy services:
    - http://www.energy.ox.ac.uk/wordpress/wp-content/uploads/2016/03/Green-Ammonia-Hughes-8.3.16.pdf
    - https://www.siemens.co.uk/en/insights/potential-of-green-ammonia-as-fertiliser-and-electricity-storage.htm
    - http://www.bloomberg.com/news/articles/2016-04-20/green-ammonia-made-with-wind-is-future-of-fertilizer-at-siemens
    - https://www.siemens.co.uk/pool/insights/siemens-green-ammonia.pdf

BUDGET SOURCES

The Leighty Foundation: W. Leighty, PI, in-kind 250 hours @ $ 200 / hour	$ 50,000
Other in-kind	$ 0
EISF	$ 50,000
Cash	$ 0
Total	$100,000

BUDGET USES

EISF internal modeling study	$100,000
Consulting studies, to the extent cash funding is available	$ 0
Total	$100,000

SCOPE OF WORK This is a preliminary, best effort study with limited resources. If selected for negotiation and award, we may be able to gather other collaborators and resources, pre-CRADA, to enhance the project. Project success will motivate follow-on ESIF study. SOW steps:

A. Estimate, from best available sources:

1. Capacity (MW) of GH2 pipelines, with and without midline compression, at assumed MAOP;
2. Capex and O&M cost: GH2 and liquid NH3 pipelines for gathering, transmission, distribution;
3. Capex and O&M cost: large, deep, solution-mined salt caverns for GH2 storage, including multiple-cavern arrays sharing a surface facility; costs for GH2 pipelines to access the caverns;
4. Capex and O&M cost of GH2 pipeline infrastructure required in State of CA to supply ~ 7 million tons per year of high-purity, GH2 fuel, from in-state and/or out-of-state RE-CEF sources;
5. Reduction in capex and O&M cost for wind, solar, and other RE-CEF systems, from single wind turbines and PV arrays > 100 kW, dedicated to GH2 and / or NH3 fuel production, with no connection to nor energy delivery to the Grid, vis-a-vis costs of these fuels produced from Grid-connected systems; include a range of CF for the conversion from RE-source electricity to fuels;
6. Range of GH2 fuel demand 2018 - 2050 for CA and USA; implications for CA integration;
7. Range of combined-heat-and-power (CHP) fuel demand 2018 - 2050 for CA and USA, assuming GH2 and / or NH3 CEF fuels are widely available via pipeline systems.

B. Model construction: ESIF lead; Prime assist

1. CA-scale and USA-scale total energy systems, with / without GH2 and NH3 pipeline systems, under several scenarios and input variables assumptions, including C-pricing, 2020 - 2050;
2. Continental-scale total energy systems, from all sources for all uses, years 2035 - 2050, of varying degrees of energy capture and transfer as electricity, GH2, and NH3 systems.

C. Modeling outcomes:

1. Optimum mix range of electric, Hydrogen, and Ammonia RE-CEF energy harvest and delivery, and LCCOE for each; estimate economic and intangibles relief to the electricity Grid;
2. Decide whether and how to advance this energy systems options modeling study; SOW and budget and likely collaborators for several scenarios; focus on deep decarbonization and Grid relief, including nearly eliminating curtailment ;
3. Decide whether and how to propose building R&D&D pipeline pilot plants, driven by various RE-CEF energy sources, to discover and demo tech and econ feasibility of GH2, NH3 systems.

SCHEDULE Continuous collaborative work among ESIF and Prime Recipient for ~ 12 months. No milestones or benchmarks proposed.

FIGURES

Year 2050 Electricity + Hydrogen Transportation Fuel, California will need :

Reference: Year 2015	GW
Total installed nameplate wind generation in California (CA)	6
Total installed nameplate solar generation in California (CA)	12
ELECTRICITY: CA "Power Mix"	**GWh**
2014: Total electricity consumed	296,843
2050: Total electricity demand "Power Mix" is 130 % of 2014	385,896
ELECTRICITY in Year 2050: CA renewables	**GW**
Equivalent nameplate wind generation capacity @ 40 % CF	85
Equivalent nameplate solar generation capacity @ 35 % CF	97
TRANSPORTATION Hydrogen Fuel in Year 2050: CA renewables	**GW**
Equivalent nameplate wind generation capacity @ 40 % CF	126
Equivalent nameplate solar generation capacity @ 35 % CF	130
TOTAL CA RENEWABLE ELECTRICITY + TRANSPORT ENERGY in Year 2050	**GW**
Equivalent nameplate wind + solar + other @ CF (varies)	438

Fig 1. If CA succeeds in both its RPS and "80 in 50" transportation energy goals, it will need the full output of over 400 GW of combined wind and solar energy at 30-40% CF. Transportation energy will be primarily Hydrogen, demanding more RE-CEF energy than electricity for the Grid, in year 2050. Combined "distributed" and "centralized" sources will be needed, interconnected with storage via GH2 and/or NH3 pipelines. http://leightyfoundation.org/w/wp-content/uploads/WP16-A-1.pdf

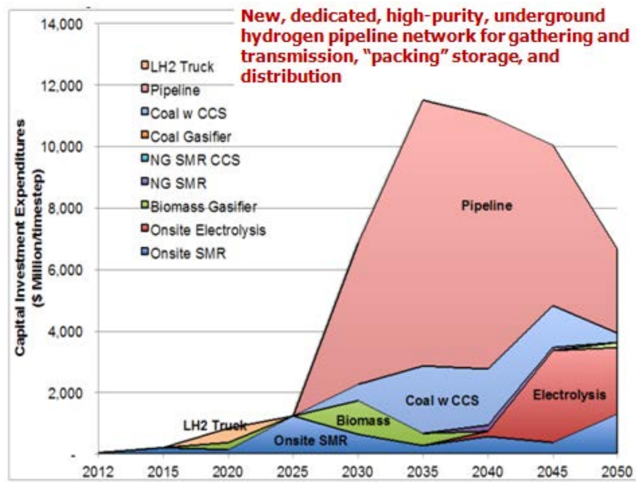

Fig 2. A new, dedicated, high-purity, underground, GH2 pipeline network will be needed to supply ~ 7 million tons per year of GH2 transportation fuel. Source: THE HYDROGEN TRANSITION, J. Ogden, C. Yang, M. Nicholas, L. Fulton. UC Davis Institute of Transportation Studies, NextSTEPS, 29 July 2014. http://steps.ucdavis.edu/files/08-13-2014-08-13-2014-NextSTEPS-White-Paper-Hydrogen-Transition-7.29.2014.pdf

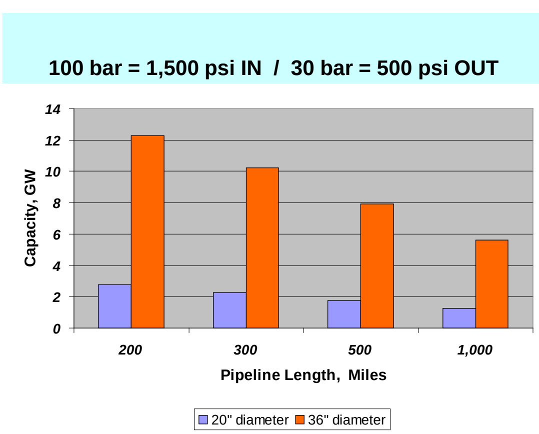

Fig 3. GH2 pipelines have high capacity, without midline compression: 36" diam, 800 km long, 100 bar input, 30 bar out is ~ 8 GW, including acceptable friction loss as the tradeoff for eliminating midline compressors. "Packing" this pipeline to 100 bar MAOP, unpacking to 30 bar, stores 30 GWh as the chemical energy in H2. This relieves the Grid of the substantial burden of low-CF gathering and transmission of VG resources.

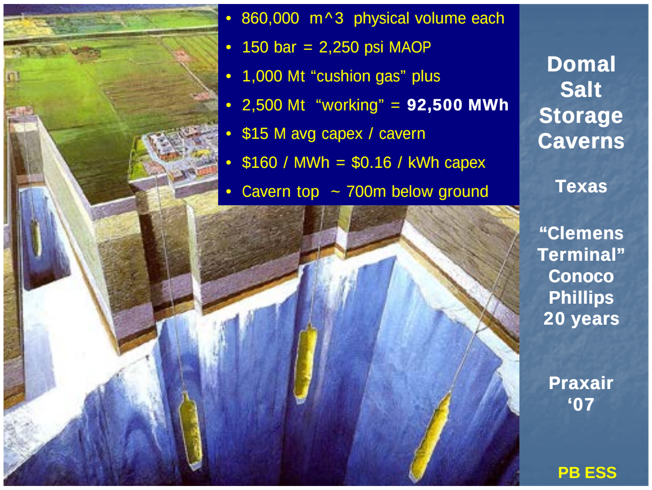

Fig 4. Large, deep, solution-mined salt caverns are tight for GH2 in the domal salt abundant on US GOM coast and northern Germany. Each cavern stores ~ 90,000 MWh as the chemical energy in H2. Multiple caverns may be closely-spaced if manifolded together, to share a surface facility. Three GH2 storage caverns in TX now. "ChevronPhillips" cavern > 30 years old; negligible H2 loss. Praxair 6 years. ~ 12,000 caverns would annually-firm enough Great Plains wind to supply all USA energy, for all purposes, as dispatchable.

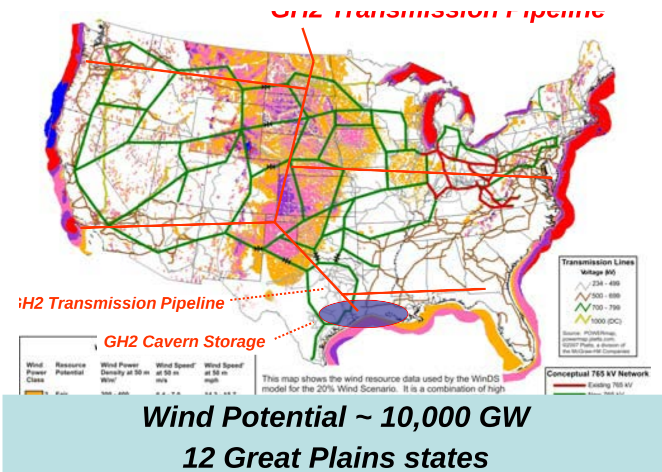

Fig 5. At continental scale, diverse RE-CEF energy resources are gathered, transmitted, and distributed via a new, dedicated, high-purity, GH2 pipeline system. "Packing" pipe-lines to MAOP, unpacking as RE-CEF input declines, provides substantial free energy storage. GH2's low viscosity allows low-cost pipeline transmission, enabling continental storage concentration in high-quality domal salt caverns and in pipeline storage. This relieves the Grid of substantial energy storage tech and econ burdens.

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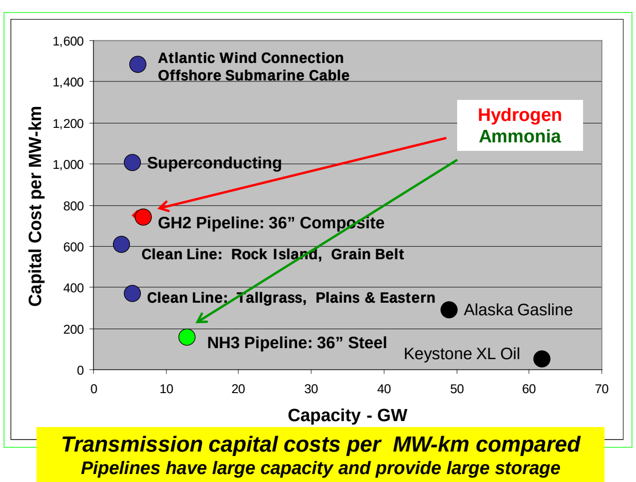
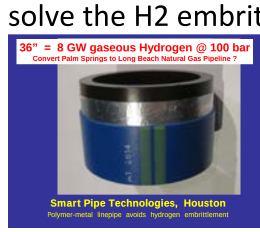


Fig 6. GH2 and NH3 pipelines are comparable to electricity transmission systems in GW capacity, and capex per MW-km of transmission service capacity. O&M costs are probably lower for GH2, higher for NH3 pipelines (liquid NH3 pumping cost). Underground infrastructure is protected from acts of God and man. Polymer-metal composite linepipe may solve the H2 embrittlement problem.



SHORT BIOGRAPHY

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West High School, Waterloo, 1961

BS Electrical Engineering, Stanford, 1966 (class of 1965)

MBA, Stanford, 1971

Principal, Alaska Applied Sciences, Inc. (AASI)
R&D in wind generation and science education. Renewable energy consulting. Owns a fourteen-turbine, 700 kW windplant in Palm Springs, CA, delivering energy to the Southern California Edison (SCE) grid. In '05 AASI completed a USDOE R&D contract # DE- FG36-03-GO-13140 for wind generator blade manufacturing innovation and demonstration.

Director, The Leighty Foundation (TLF)
www.leightyfoundation.org/earth.php
A small, charitable, family foundation, founded by my father in 1985, in our home town, Waterloo, Iowa. One of eight on TLF Board of Directors.
www.leightyfoundation.org/earth.php

2000 – 2016: Pro bono for TLF, co-author of over twenty research papers exploring transmission and firming energy storage alternatives to electricity, for diverse, large-scale, stranded renewable energy resources, especially as gaseous hydrogen and / or as liquid anhydrous ammonia via underground pipelines, with hydrogen storage in deep salt caverns and ammonia storage in refrigerated surface tanks.
Papers presented at USA and international energy conferences.
See resources at: www.leightyfoundation.org/earth.php

2007 – 2016: Board of Trustees, Alaska Conservation Foundation, Alaska
www.alaskaconservation.org

1972 – 1990: Owned Gold Creek Salmon Bake summertime outdoor restaurant and visitor attraction, Juneau, AK. Sold business in 1990.

1971 – 1974: Program budget analyst, contractor to State of Alaska.

1966 – 1969: Collins Radio Company, Cedar Rapids, Assistant Product Line Manager. Field Engineer, Thailand and Vietnam, 1968-69.