Comments on: RFI DE-FOA-0001655 https://eere-exchange.energy.gov/default.aspx#FoaId962c3a0a-3bd1-4331-af59-678214bb27d5
http://www.energy.gov/eere/fuelcells/downloads/h2-scale-potential-opportunity-webinar

H2@SCALE (HYDROGEN AT SCALE): DETERMINING RESEARCH, DEVELOPMENT, AND DEMONSTRATION (RD&D) NECESSARY FOR CLEAN HYDROGEN PRODUCTION TO ENABLE MULTISECTORAL DEEP DECARBONIZATION

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USDOE Hydrogen Colleagues, 2 Nov 16

Thank you for "H2@SCALE". I have been advocating this comprehensive study for over fifteen years, in research papers, posters, and podium talks at energy and other conferences, worldwide: www.leightyfoundation.org/earth.php I call this work "Alternatives to Electricity Systems for Running the World on Renewables". Assume "H2@SCALE..." means enabling and accelerating:

- Complete, optimized, renewable energy (RE) source, CO_2-emissions-free (CEF) energy systems based on gaseous hydrogen (GH2) and / or liquid anhydrous ammonia (NH_3) carbon-free fuels as energy carriers, low-cost annual-scale-firming storage media: RE-CEF systems;
- Transforming the world's largest industry from ~85% fossil to ~100% renewable, RE-CEF energy sources, as quickly as we prudently and profitably can: an IRHTDF via IPHE: http://leightyfoundation.org/w/wp-content/uploads/renewable_hydrogen_facility.pdf
- Alternatives to electricity systems for solving the challenges of variable renewables:
  - Gathering and transmission, from both large "centralized" and small "distributed";
  - Annual-scale firming storage: achieving dispatchability for both transport and CHP;
  - Distribution, integration, end-use, and energy services delivery from GH2 and NH_3 ;
- Thorough consideration of new, dedicated, high-purity, GH2 and / or NH_3 fuel pipeline systems for gathering, transmission, storage (by "packing" GH2 pipelines), and distribution of RE-CEF energy, at regional to continental scales, accessing large salt cavern GH2 storage;
- "Distributed" GH2 and NH_3 fuel production, without electricity grid connection.

See Figures 1-8, extracted from my panel presentation at the June, 2016, 21st World Hydrogen Energy Conference (WHEC), Zaragoza, ES: [video at https://vimeo.com/172485189]
http://leightyfoundation.org/w/wp-content/uploads/WHEC-2016-Zaragoza-C.pdf.pdf

Now, we need to simultaneously pursue the several projects and pathways below, because we:

a. Must deeply decarbonize Humanity's entire energy system quickly, prudently, and profitably, optimizing our investment strategy, avoiding overinvestment in electricity;
b. Don't know whether future RE-CEF energy will be most conveniently and economically harvested as electricity, as from wind and PV, or as GH2 directly from photo-, thermo-, or biochemical processes, splitting water molecules in both "central" and "distributed" sites;
c. Need both R&D and pilot plants by which to discover and demonstrate the technical and economic advantages -- if any -- of GH2 and NH_3 as complete RE-CEF energy systems vis-a-vis electricity systems, at local, regional, continental scales, for all energy services;
d. Must prevent suboptimal investments in enlarging and "Smartening" the electricity Grid, insuring that "electrifying transportation" includes GH2 and NH_3 as on-board, CEF fuels.

1. Complete RE-CEF energy systems. Conceive, design, build, and demonstrate complete RE-CEF energy systems optimized for capturing energy, in all ways, from incident photons and moving air and water molecules, from which to deliver an affordable, annually-firm, always-dispatchable supply of distributed energy services, for all purposes, to everyone on Earth. GH2 and NH_3 systems may be technically and economically superior to electricity systems at regional to continental scales. Attempts to upgrade, enlarge, and "smarten" the electricity Grid must be evaluated in this context, to avoid suboptimal investments in the Grid: http://energy.gov/eere/articles/revolutionnow-rewind-modernizing-grid-accelerate-solar- powered-future Collaborators in this major work should include: NREL Energy Systems Integration, with LBL and other DOE labs, EPRI, GTI, IGU, EEI, other industry groups, solar, wind, other energy OEM's, Oil & Gas industry, universities, and NGO's.

2. Wind and solar industries need to think "beyond electricity". "Transmission" now means to them only electric wires; "storage" generally means batteries. By 2050, hydrogen and ammonia fuels may be a bigger market for CEF energy than the electricity grid. http://leightyfoundation.org/w/wp-content/uploads/WP16-A-1.pdf OEM's and project developers shall embrace GH2 and NH_3 systems.

3. Pilot plants: RE-CEF pipeline-based GH2. Discover and demonstrate the technical and economic advantages -- if any -- of GH2 energy systems vis-a-vis electricity systems via pilot-scale demonstration of GH2 pipeline-based, complete, RE-CWG energy systems, including sharing byproduct O_2 with adjacent gasification plants. Working examples are priceless for education. Model continental scaleup. "Packing" GH2 pipelines is "free" storage. Low-viscosity H_2 allows 36" transmission pipeline, 800 km long, 8 GW capacity, without midline compression. Conference: https://www.youtube.com/watch?v=fND9S7Llvqk&list=UU_fKB5GeOPhfrEaNhjwZgvQ

4. Pilot plants: wind and solar dedicated to Hydrogen and Ammonia fuel production. Discover and demonstrate reduction in cost of wind-source and solar-source H2 and NH_3 fuels from plants with no Grid connection, simplified in design without transformers, underground wire, electronics, delivering only "wild DC" to electrolyzers and NH_3 synth reactors instead of Grid-quality electricity. Wind-to-H2 example: http://leightyfoundation.org/w/wp-content/uploads/WP16-B.pdf

5. Dedicated, new, high-purity, GH2 pipeline networks. If California achieves both its electricity RPS and "80in50" transportation CO_2-emissions-reduction goals by year 2050, it will need more RE-CEF energy for Hydrogen and Ammonia transportation fuels than for electricity for the Grid. This reduction must come primarily from the light duty vehicle (LDV), bus, and "goods movement" (trucking) transportation sectors; aviation and marine CO_2 emissions reduction will be more difficult. California's energy supply by 2050 will require about 7 million tons per year of CEF Hydrogen transportation fuel, requiring the full output of over 200,000 MW nameplate wind or solar at 40% CF. Much will be imported via new pipelines from Great Plains wind and solar. Several reports by the Institute of Transportation Studies, UC Davis, also predict that about $50 billion in new, underground, GH2 pipeline systems will be required in California, relieving wind's transmission, storage, and integration problems. Transmission capex cost per GW-km, and O&M costs per GWh, are less in underground pipelines than on wires. Vast, new land areas, not served by electricity systems, would open for low-cost gathering and transmission of RE in new pipelines.

6. H2-embrittlement-free Linepipe. Thousands of km of GH2 linepipe is in worldwide service, of low-alloy steel operating at relatively-low and constant pressure. Steel may be unacceptable or uneconomical for long transmission lines at 100 bar MAOP, suffering frequent, large pressure fluctuations -- the primary cause of HCC and embrittlement -- from variable-output renewables. Polymer-metal tubing, whereby a thin layer of Al or Cu is fabricated into the pipe wall, as a foil or by metal deposition, as the permeation barrier, has been researched at ORNL and licensed to Hydrogen Discoveries, Inc. http://patents.justia.com/assignee/hydrogen-discoveries-inc
Smart Pipe, Houston, fabricates polymer composite linepipe in a continuous process, in the field, eliminating joints except at necessary terminations. They have built a concept sample: Figure 4. More RD&D is needed, plus demonstration in pipeline pilot plants: 2, 3, 4, above.

7. GH2 annual-scale salt cavern energy storage. Fig. 5. Very large scale, low-cost energy storage is available via multiple, large, deep, solution-mined salt caverns, closely-spaced and manifolded together at the same pressure, sharing a surface facility for compression, drying, and metering, connected to a regional or continental-scale gathering and transmission pipeline network. Two successful GH2 caverns in domal salt in TX: Chevron-Phillips (30 years); Praxair (9 years).

8. Embrace Anhydrous Ammonia, NH_3, as "the other Hydrogen". ARPA-E's 2016 "REFUEL" FOA includes NH_3 because of its high Hydrogen volumetric energy density, ease of transportation and handling, and low-cost energy storage. It is a C-free fuel for the ICE, CT, and direct ammonia fuel cell (DAFC); we need more R&D to improve energy conversion efficiency, in both NH_3 synthesis and energy recovery, and to prevent NOx. Pipelining and storage in low-cost carbon steel, at ~10 bar and in large, refrigerated "atmospheric" storage, are well known. Siemens has embraced "Green Ammonia": http://www.siemens.co.uk/en/insights/potential-of-green-ammonia-as-fertiliser-and-electricity-storage.htm Japan includes Ammonia in its "Strategic Innovation Promotion" (SIP) program, "Energy Carriers": http://www.jst.go.jp/sip/pdf/SIP_energycarriers2015_en.pdf Fig. 6.

9. Dedicated "distributed" GH2 and NH3 fuel plants. With no connection to, nor energy delivery to, the electricity grid, wind and solar plants are simplified, eliminating field transformers, power wiring, substations necessary to deliver grid-quality electricity. Turbine and PV output is "wild DC" close-coupled to electrolysis stacks and / or to NH_3 synthesis reactors. Capex and O&M cost savings may pay for electrolysis and NH_3 plants and for some energy conversion losses. These tradeoffs must be engineered, field-tested, and quantified at GW scale. Fig. 1.

10. Electricity or hydrogen RE-CEF energy harvest? We cannot now predict whether the most technically-attractive and economical sources of harvested RE-CEF energy will be as electricity -- at the terminals of wind turbines and PV panels, for example -- or as GH2, via photochemical, biochemical, or thermochemical processes. Therefore, we should apply immediate public and private investments to the pathways and projects described herein, so that we will be prepared to design, invest in, and deploy the many large-scale integrated, optimized, complete RE-CEF systems necessary to transform Humanity's largest industry from ~ 85% fossil to ~ 100% RE-CEF energy sources, as quickly as we prudently and profitably can, for all energy demand, from all sources.

11. Power-to-gas. Otherwise-curtailed, variable, solar and wind and other RE-CEF electric energy may be converted to GH2 for injection into the natural gas transmission pipeline network -- even at residential scale -- achieving "free" transmission and storage, for delivery as mixed-gas fuel. But the high-purity, electrolytic-grade, hydrogen cannot be economically recovered from the pipeline gas for PEM fuel cells. If solar and wind plants are designed primarily for electric energy delivery to Grid:

- They are burdened by the high capex and O&M costs of grid-quality delivery and of infrastructure: inverter, field transformer, copper wiring, substation, transmission feeder;
- Capacity factor of the electrolysis plant is relatively low; capital recovery cost high.

12. Export diverse, abundant, stranded RE-CEF resources. Alaska, for example, has abundant, diverse, RE-CEF resources that could perhaps be profitably harvested and exported as H-rich liquids to Japan and other global markets. Western Australia has a vast area of high insolation that could also be harvested and exported in this way; an NH_3 export plan is in progress.

13. Emulate the natural gas infrastructure. The gas industry operates on very long time constants, enjoying seasonal-scale, low-cost storage and low-cost pipeline systems. RE-CEF systems could, too, packing GH2 pipelines for "free" storage, for ubiquitous distribution of high-purity fuel. http://leightyfoundation.org/w/wp-content/uploads/worldenergycongresssydney.pdf

14. GH2, NH_3 energy systems replace electricity ? These C-free fuel systems may displace, then replace, much of electricity infrastructure, avoiding large global investments in "Smart Grid" and Grid expansion to accommodate deep carbonization of Humanity's total energy supply.

15. New urban configurations and GHG mitigation require less fuel. Reducing anthropogenic GHG emissions and accommodating millions of people displaced by rapid sea level rise may require far less transportation fuel, if cities become higher-density, served by compact, electric-powered fixed-guideway transit systems, with far fewer LDV's per capita. "Uber"-style and autonomous on-demand LDV modes will exacerbate this. GH2 and NH_3 energy systems may become less important.

16. EMP threat. GH2 and NH_3 infrastructures could be built with simpler controls than electricity Grid's, for better resilience as we face more probable threats from aerial nuclear explosions.

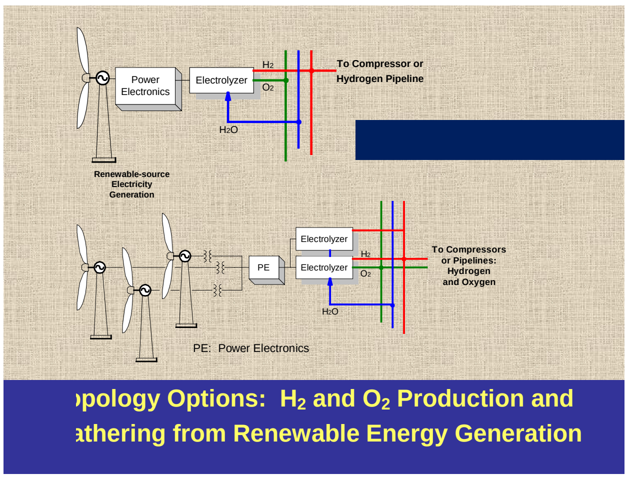

Figure 1. Example of a wind-source RE-CEF system optimized for "distributed" GH2 and NH_3; minimum electricity infrastructure cost.

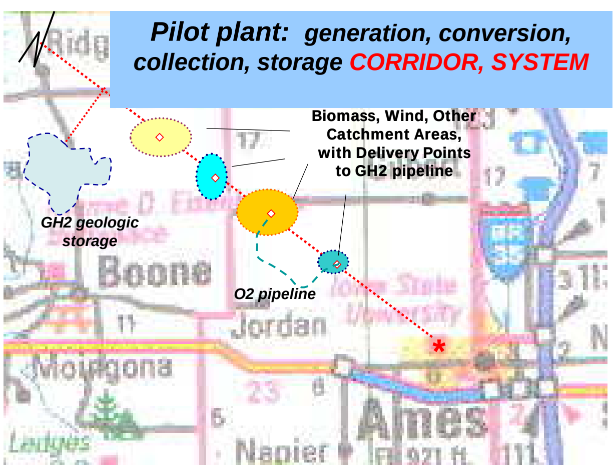

Figure 2. An early RE-CEF GH2 underground pipeline pilot plant might be built in central IA more readily than in CA. Destination Ames: Iowa State University campus, retail GH2 fuel.

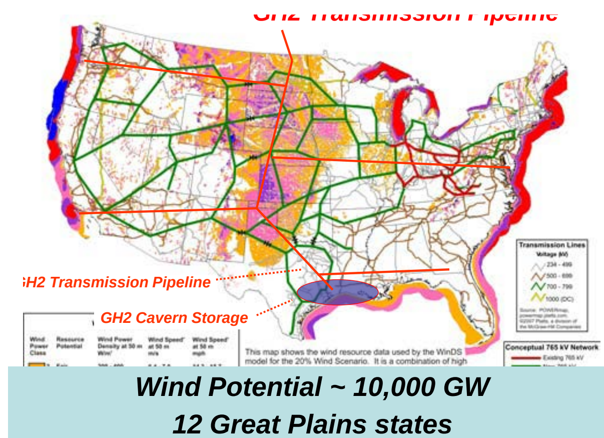

Figure 3. Continental-scale GH2 gathering, transmission, and storage system capable of supplying all USA energy for all purposes from high-intensity, widespread RE-CEF sources.

Figure 4. Polymer-metal hybrid linepipe for GH2. Thin Al or Cu foil H_2 perm barrier. Sample by Smart Pipe, Houston. Not tested for GH2 service: ORNL origin; more R&D required.

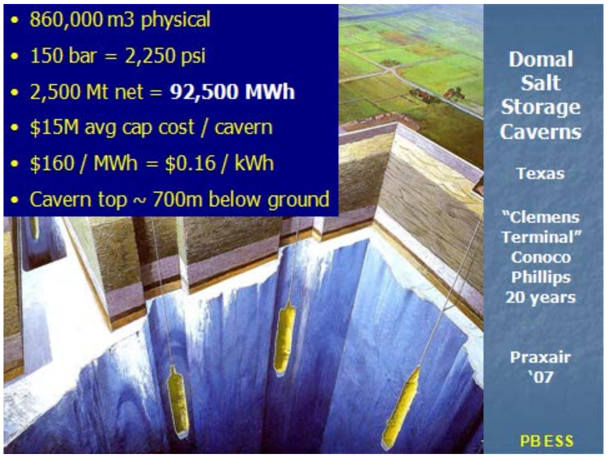

Figure 5. GH2 low-cost, annual-scale firm storage. Multiple caverns manifolded at same pressure for high-density array.

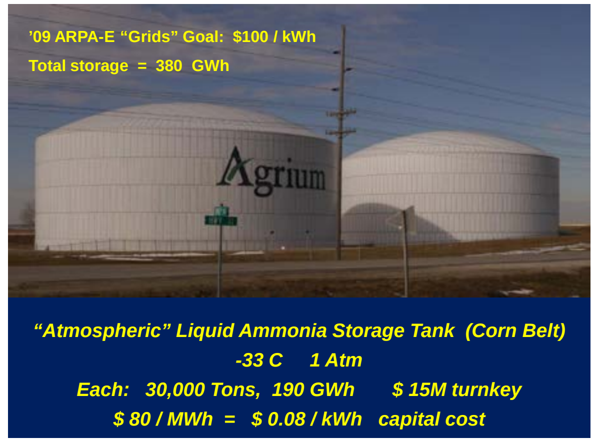

Figure 6. Liquid NH_3 low-cost, annual-scale firm storage. Large extant pipeline and tank N-fertilizer infrastructure in Corn Belt.

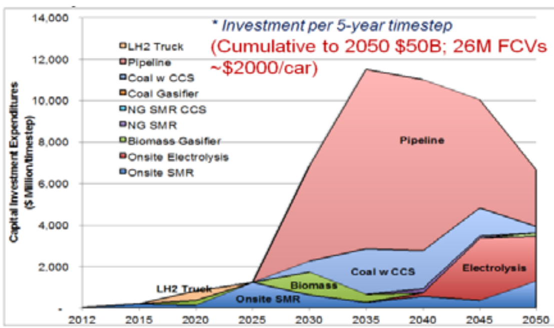

Figure 7. In California, year 2050, the demand for CEF transportation energy will exceed demand for electricity for the Grid. Source: UC Davis, ITS scenario. Total 2025-2050 pipeline investment ~ $50-60 billion.

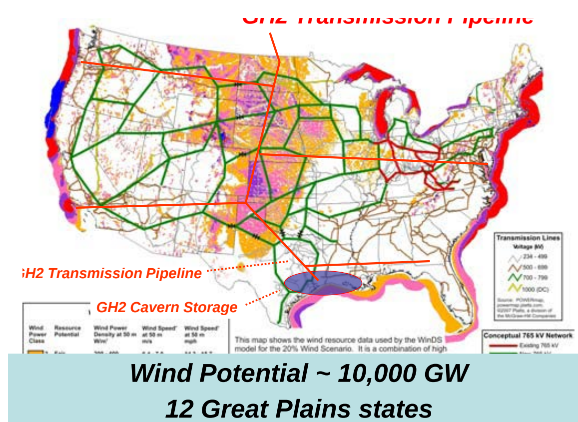

Figure 8. "H2@SCALE": continental, to achieve necessary economy. 36" GH2 pipeline is 8 GW; "pack" for "free" storage.

CONCLUSION

We must adequately decarbonize Humanity's entire energy system quickly, to avoid the feared consequences of our unrestrained combustion of fossil fuels. Attempting this entirely, or principally, via electricity systems may be suboptimal. To strategize our urgent investments, we must also RD&D attractive alternatives, GH2 and NH_3 as complete energy systems for RE-CEF sources, at distributed to continental scales, via pipelines and GWh-scale storage: thus "H2@SCALE".

Therefore, we now need investment in a grand collaboration of public and private interests and expertise to compare these several strategies for quickly and profitably designing and building a sustainable global energy system which is ubiquitous, benign, affordable, equitable, annually-firm, and dispatchable, for all services. Pilot plants must follow, to confirm. Very large capital will be required to transform the world's largest industry; capital is limited; it must not be misallocated; we haven't a second chance.