Fellow Delegates, Renewable Energy World: Orlando, FL 12-14 Nov 2013

Why the World Energy Community should now commit to:

Run the World on Renewables -- plus probably some degree of nuclear, now very difficult to predict

And therefore why we must now carefully consider:

Alternatives to Electricity for Gathering and Transmission, Annual-scale Firming Storage, and Integration of Diverse, Stranded, Renewable Energy (RE) Resources

1. We represent the world's companies, professional engineering societies, governments, and non-profit organizations responsible for transforming humanity's largest industry -- energy -- from primarily fossil-source to primarily renewables-source energy, to build a benign, equitable, affordable, profitable, sustainable global energy system, as rapidly as we prudently can do so.

2. Several dangers inflicted on Earth's systems, including humanity's, by our present energy system, have become emergencies, although we humans are very slow to recognize this and react:
   a. Rapid climate change, generally warming
   b. Ocean acidification
   c. Rapid sea level rise
   d. Species extinctions

These dangers apparently result from increasing concentrations of greenhouse gases (GHG's) in Earth's atmosphere, including CO_2 from fossil fuel combustion.

3. Our present energy system also inflicts several socio-economic challenges upon humanity:
   a. Depletion of non-renewable energy resources, depriving future generations of hydrocarbons
   b. Lack of access to any affordable, high-quality energy, for many people
   c. Competition for fresh water
   d. Costly resource wars

Public opinion and governments are drifting in inadequate response, wasting precious time. Engineers need to lead with a compelling and encouraging vision, strategy, and plan for a benign, equitable, and affordable energy future for humanity's total energy needs. IEEE, ASME, and others professionals should lead, now.

4. The renewable energy (RE) community's vision and ambition is inadequate. Our goal must be nothing less than "running the world on renewables" -- plus probably some degree of nuclear, now very hard to predict. This will require a combination of "distributed" and "centralized" generation and other infrastructure. We cannot do this -- and should not try to -- with electricity systems alone, because the necessary total energy system resilience, reliability, and dispatchability will be too costly to achieve thereby. NREL's "Renewable Electricity Futures Study (RE Futures)" embraces only the electricity sector's one-third; we need to supply ALL energy from renewables. http://www.nrel.gov/analysis/re_futures/

Therefore, we must think beyond:
   a. Advocating PTC preservation and a few hundred GW of new electricity transmission;
   b. Electric wires as "transmission";
   c. "Power", to include all energy, for all purposes, from all sources.

Our modeling must also anticipate carbon taxes, eventually global.

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5. Hermann Scheer (1944-2010), Bundestag, published in 2010 "Der Energethische Imperativ" (energy ethics), subtitled "100% Now: How the Complete Switch to Renewable Energies Can Be Realised": his passionate conviction that it is technically and economically feasible for renewable energy to fully replace fossil and nuclear energy within just a few years, if the political will existed, essentially "running the world on renewables." http://www.theguardian.com/world/2010/oct/18/hermann-scheer-obituary

6. This conversion of the world's largest industry is a very large technical, economic, and social task and opportunity, requiring conceiving and optimizing complete RE systems -- from photons and moving air and water molecules and biologic processes to delivered energy services. This will synergistically affect all RE system components, including the generators. Electricity systems will always serve us, even as we advance their design, but may be inadequate to or suboptimal for this task because:

a. Earth's richest RE resources -- of high intensity and large geographic extent -- are stranded, far from markets with inadequate transmission of any kind;

b. Most RE resources are time-varying in output, at scales of seconds to seasons;

c. Expanding and enhancing the electricity grid to "run the world on renewables" will be costly.

Distributed generation (DG) requires on-site RE resources and conversion equipment and / or a firm and dispatchable supply of fuel; in this "run the world on renewables" scenario, that must be RE-source, C-free or C-neutral fuel.

7. Progress toward "running the world on renewables" presents three grand challenges:

a. Gathering and transmission

b. Annual-scale firming storage, rendering "dispatchable" the time-varying output, at scales of seconds to seasons, of many RE resources

c. Integration: distribution, end-use, and synergy with other energy systems

As RE generation equipment advances in technology, lower long-term cost of energy (COE), and in public and industry acceptance and desirability, these challenges become severe constraints.

8. Two alternatives to electricity systems seem especially attractive, whereby the costly connection of RE generation to deliver quality electricity to the grid is replaced by conversion of all the RE, within the plant gate, to:

a. Gaseous hydrogen (GH_2) for transmission in underground pipelines, with low-cost bulk storage in deep, solution-mined salt caverns, and / or

b. Liquid anhydrous ammonia (NH_3) for transmission in underground pipelines, with low-cost bulk storage in small and large carbon-steel tanks,

with distribution of GH_2 and NH_3 fuels at market centers for C-free stationary combined-heat-and-power (CHP) and transportation fuels.

These alternatives must be considered as complete, integrated, optimized RE systems, not as adjuncts to the electricity system, or "grid", as we know it or as we may advance it. Both hydrogen and ammonia systems and fuels have unique advantages, disadvantages, and dangers -- as all fuels and electricity have. Other energy carriers and systems have been proposed and should also be considered in the context presented in this paper. NH_3 Fuel Association: http://nh3fuelassociation.org/events-conferences/

Hydrogen (H_2) from biological and quasi-biological sources may complement or exceed hydrogen from RE-source electricity, synergistically feeding gaseous hydrogen (GH_2) gathering and transmission pipelines.

Bio H_2 : http://web.mit.edu/newsoffice/2011/artificial-leaf-0930.html
http://www.guardian.co.uk/science/blog/2013/jul/19/sweet-hydrogen-sugar-energy-needs

9. We must expand our definition of "transmission" from electric wires, and of "storage" from adjuncts to the electricity system, as we may advance it, in order to conceive and optimize complete RE systems. Systems other than hydrogen and ammonia may also be attractive or superior.

10. We cannot now say that either hydrogen or ammonia RE systems will be advantageous, at any scale. But, given the urgent energy system challenges and dangers before us, these alternatives deserve investment now in thorough, competent, and unbiased technical and economic systems analysis as complete, integrated, optimized systems. We should now begin this process, necessary to test this "alternatives to electricity systems" hypothesis. If we find these alternatives limited, or unattractive, we may confidently set them aside for demonstrated good cause, refocusing our systems engineering where it is most promising. We will need resources for this analysis, which has never been adequately done.

11. "Smart Grid" is primarily a demand side management (DSM) strategy, with limited value to "running the world on renewables", because making the electricity grid only "smarter":

a. Results in no increase in physical transmission and storage capacity and only marginal increase in these virtual and effective capacities;
b. Will require large capital investments;
c. Diverts resources from potentially superior investments in other RE systems;
d. May make the electricity grid more vulnerable to cyberattack;
e. Probably does not adequately lengthen the time constants of the electricity system to accommodate diverse, time-varying-output RE resources as our total energy supply.

12. Energy storage, as adjuncts to the electricity grid, is too costly to deploy at adequate scale to approach our goal of "running the world on renewables". We haven't enough valleys to dam for pumped hydro. Batteries remain too costly. But, we have enough deep salt formations in the Gulf of Mexico coast and northern Germany to firm at least North America's and Europe's total energy supply as GH_2. We can afford to buy enough large, above-ground, mild steel, "atmospheric" NH_3 storage tanks to firm the global energy supply. The capital cost of this chemical energy storage is about:

- $ 0.10 per kWh for liquid NH_3 in typical 30,000 ton steel tanks ubiquitous in the Corn Belt;
- $ 0.20 per kWh for GH_2 storage in large salt caverns; two such caverns operate now in Texas.

Round trip efficiency is relevant only to electricity systems. This concept delivers RE-source fuel(s), not electricity, intended for applications capturing and using the byproduct heat from CHP and transport.

13. Transportation fuel is a very big market for RE: the ICE, CT, and fuel cell operate well on GH_2 and NH_3 fuels, with only H_2O and N_2 (in the NH_3 case) emissions:

a. Battery electric vehicles (BEV's) are no panacea, and have significant disadvantages: http://spectrum.ieee.org/energy/renewables/unclean-at-any-speed
b. The world's major automakers plan to introduce series-production hydrogen fueled, fuel cell hybrid electric vehicles (FCHEV's) in about 2015, if adequate fueling is available, in competition with the BEV's they are introducing now
c. NH_3 is easily reformed to H2 on-board a vehicle; NH_3 costs less to store on-board than GH_2

14. Net metering and high-penetration distributed generation (DG) force the electric utility to supply firming storage and dispatchability for which it may not be technically competent nor adequately financially compensated. GH_2 and NH_3 systems may better accommodate a large percentage of total large-scale energy supply from RE, from DG backfeed, via their distribution pipelines. The "utility of the future" must respond wisely to the DG challenge via new technology and business models.

15. "Power To Gas": On 13 June 13, Hydrogenics, Toronto, activated the world's largest (2 MW) electrolysis plant converting otherwise-curtailed wind-generated electricity to GH_2 for direct injection into the E.ON natural gas transmission pipeline system at Falkenhagen, Germany, receiving only the natural gas wholesale energy value, but enjoying free storage and avoiding generation curtailment. Germany now allows 5% H_2 in pipeline gas.
http://www.hydrogenics.com/products-solutions/energy-storage-fueling-solutions/power-to-gas

Enbridge Pipelines intends to do the same in Canada.
http://www.enbridge.com/DeliveringEnergy/AlternativeTechnologies.aspx

EU's "NaturalHY" project studied metallurgical and other implications of up to ~ 20% (volume) concentration of H_2 in pipeline gas, concluding that ~ 10% is safe, but requires volumetric price adjustment to customers for H_2 concentration. http://www.naturalhy.net/

EU's "HyUnder" project studies RE storage as GH_2 in deep salt caverns.
http://www.iphe.net/docs/Events/Seville_11-12/Workshop/Posters/IPHE%20workshop_HyUnder_poster.pdf

This presages increased transmission and storage of stranded and DG RE as GH_2 in pipelines and caverns, perhaps eventually in RE systems optimized for 100% high-purity GH_2 fuel, via dedicated national-scale and continental-scale GH_2 pipeline networks connecting RE sources -- both centralized and distributed -- with cavern storage and widespread markets.

16. A "Power To Ammonia" limited infrastructure is already in place, via ~ 3,000 miles of liquid ammonia pipelines and storage terminals, from New Orleans to and throughout the Corn Belt, moving ~ 12 million tons of NH_3 per year as nitrogen fertilizer, ~ 60% of which is imported. With the owners' agreement, this infrastructure could distribute "green" NH_3 made from RE, mixed with "brown" NH_3 made from fossil fuels, as we now mix "green" and "brown" electrons in electricity systems, with comparable economic incentives for customers buying the green products. Presentations from nine years of Ammonia Fuel Association conferences are at: http://nh3fuelassociation.org/events-conferences/

17. "Packing" GH_2 pipelines, compressing to store and decompressing to deliver, as the natural gas industry does, provides low-cost storage. A 1 m diameter GH_2 pipeline, 1,600 km long, packed to 100 bar and unpacked to 35 bar, stores ~ 190,000 MWh as the chemical energy in H2. GH_2 viscosity is low, so that optimized transmission pipelines might be built with no midline compression; transmission loss is thus low. Liquid NH_3 pipelines cannot be packed. NH_3 pumping energy is significant, but low.

18. Capital cost of GH_2 and NH_3 transmission pipelines, and HVDC electric lines, per GW-km of transmission service capacity, is comparable; pipelines may cost less. Underground pipeline O&M cost is generally lower than for overhead electric transmission lines. Polymer-metal composite linepipe may solve the hydrogen embrittlement (HE) problem for GH_2 systems.

19. Fresh water use: Supplying all 100 Quads of total annual energy used in USA today, from all sources for all purposes, requires ~ 17,000 billion liters (about 1.7 trillion gallons) of fresh water per year. Some is "withdrawn", returned to the source water body, usually warmer. Some is "consumed", usually evaporated, and lost by the host water body. If all 100 Quads were generated as RE-source electricity, converted to GH_2 and / or NH_3 fuels at the source, for pipeline transmission and delivery as C-free fuels, total annual fresh water consumption would be ~ 7,000 billion liters. The H_2O would be dissociated; H becomes the energy carrier; the O_2 byproduct is released to Earth's atmosphere or sold to adjacent gasification plant markets.

20. While the Institute of Electrical and Electronic Engineers (IEEE) Utility Variable-Generation Integration Group (UVIG) and others have bravely and brilliantly enhanced and modified the electricity system to accommodate an increasing fraction of RE-source energy on the "grid", this may be a technically and economically suboptimal strategy as we proceed to "run the world on renewables".
http://variablegen.org/newsroom/

Electricity systems, with inherent short time constants, are fundamentally not well suited to gathering and delivering the time-varying output -- at scales of seconds to seasons -- of most RE sources, as annually "firm" and "dispatchable" energy for services. System economics and capital component design suffer as we attempt to "stuff a square peg into a round hole". As RE penetration, to supply all energy for all purposes, increases, we may simply be "barking up the wrong tree" to expect electricity systems to perform optimally and exclusively.

21. FERC, NIMBY, and transmission permitting: FERC has jurisdiction over interstate oil and natural gas pipelines and perhaps over interstate GH_2 and NH_3 energy transmission pipelines. Siting and construction of electricity transmission facilities is not within FERC's public utility related statutory authority under FPA Parts II and III. http://www.ferc.gov/about/ferc-does/ferc101.pdf (slide 12)
NIMBY may always be a problem for new overhead electric transmission lines, while historically it has been less impeding for underground transmission pipelines.

22. Resources: Complete and competent exploration, discussion, and presentation of the comparative systems analysis topic proposed herein will require both in-kind and funded effort. The work may be embraced by established budgets and work plans in many established organizations: NREL and other national labs, EPRI, IEEE, ASME, UCS, NRDC, for example, in USA. Consultants will require cash funding. Organizing and leading this effort will require talent and sponsors' imprimatur.

23. The World Energy Council's (WEC) goal and role should be motivating and recruiting interest in pursuing this topic as a collaboration of diverse interests, perhaps under continued WEC patronage, and / or perhaps as a separate entity with a budget to enable professional consulting contracts. The collaboration should be global. The collaboration should include at least these RE interests in USA and many others internationally:

Professional associations:	IEEE, ASME, et al
Industry groups:	ACORE, AWEA, ASES, EPRI, UVIG, CHBC, CHFCP, et al
Federal government:	DOE and its National Laboratories; DOT; DOD; EPA

Universities and their Institutes	Charitable foundations
Manufacturers	Consultants
Research Institutes and Advocacy Organizations	Others:

The collaboration should include at least these RE interests outside USA:

International Energy Agency (IEA) http://www.iea.org
Canadian Hydrogen and Fuel Cell Association http://www.chfca.ca/
World Energy Council
METI and NEDO, Japan

APPENDIX

Corrections, comments, and revisions are welcome: I offer this draft as an MSWord file, for your convenience in critique and comment, in revision and propagation. Please request it via email. Thank you for your consideration. wleighty@earthlink.net

Distribution: I will widely distribute this, within and beyond the Renewable Energy World 2013, Orlando, requesting comments and corrections and interest in collaboration. Please FWD this, as you wish.

Power and Energy industry embrace: I don't know in which energy forum or conference this work belongs, because it requires embracing complete renewable energy systems, from photons and moving air and water molecules to delivered energy services.

Alternative titles for future RE World committee, working group, conference, or conference topic:

- Integrated, Optimized, GW-scale Renewable Energy Systems: Alternatives to Electricity for Transmission, Storage, and Integration to Supply Humanity's Total Energy Demand
- Running the World on Renewables -- and Perhaps Some Nuclear: Can We Do It Entirely with Electricity Systems? Should we try?
- Renewable Energy Storage at < $1.00 / kWh Capital Cost Requires Integrated Renewables-source Energy Systems Beyond Electricity

Other resources: Please consider my co-authored work on this subject at:
http://www.leightyfoundation.org/earth.php
See especially: http://www.leightyfoundation.org/files/ASME-IMECE-12-87097-FINAL-30Jul12-C.pdf
http://www.leightyfoundation.org/files/ASME-IMECE-2012-A.pdf
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http://www.nytimes.com/2013/08/02/opinion/a-republican-case-for-climate-action.html?hp&_r=0