Bigger Market than Electricity Grid ? Wind-source Hydrogen Fuel for California Transportation and Combined Heat and Power (CHP)

Bill Leighty, The Leighty Foundation, Juneau, AK wleighty@earthlink.net Poster download: http://leightyfoundation.org/w/wp-content/uploads/WP16-A.pdf

Hydrogen Transportation Fuel Demand California, year 2050 Million metric tons per year:

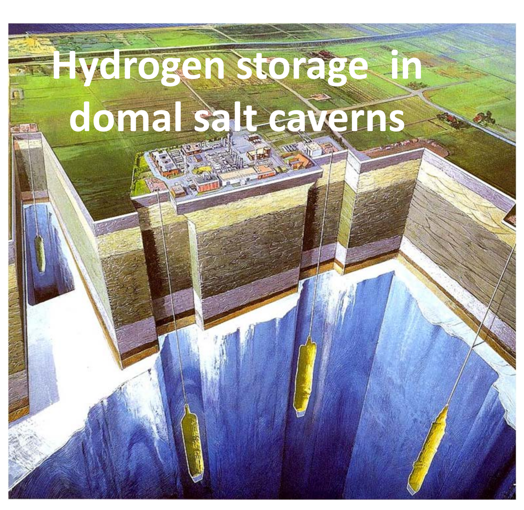
Light Duty Vehicles (LDV)	3.6
Trucking	1.6
Bus	1.4
Aviation and Other	0.8
Total	**7.4**

Source: interpret and extrapolate from several papers by ITS-STEPS, UC Davis

Reference: Year 2015	GW
Total installed nameplate wind generation in California (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

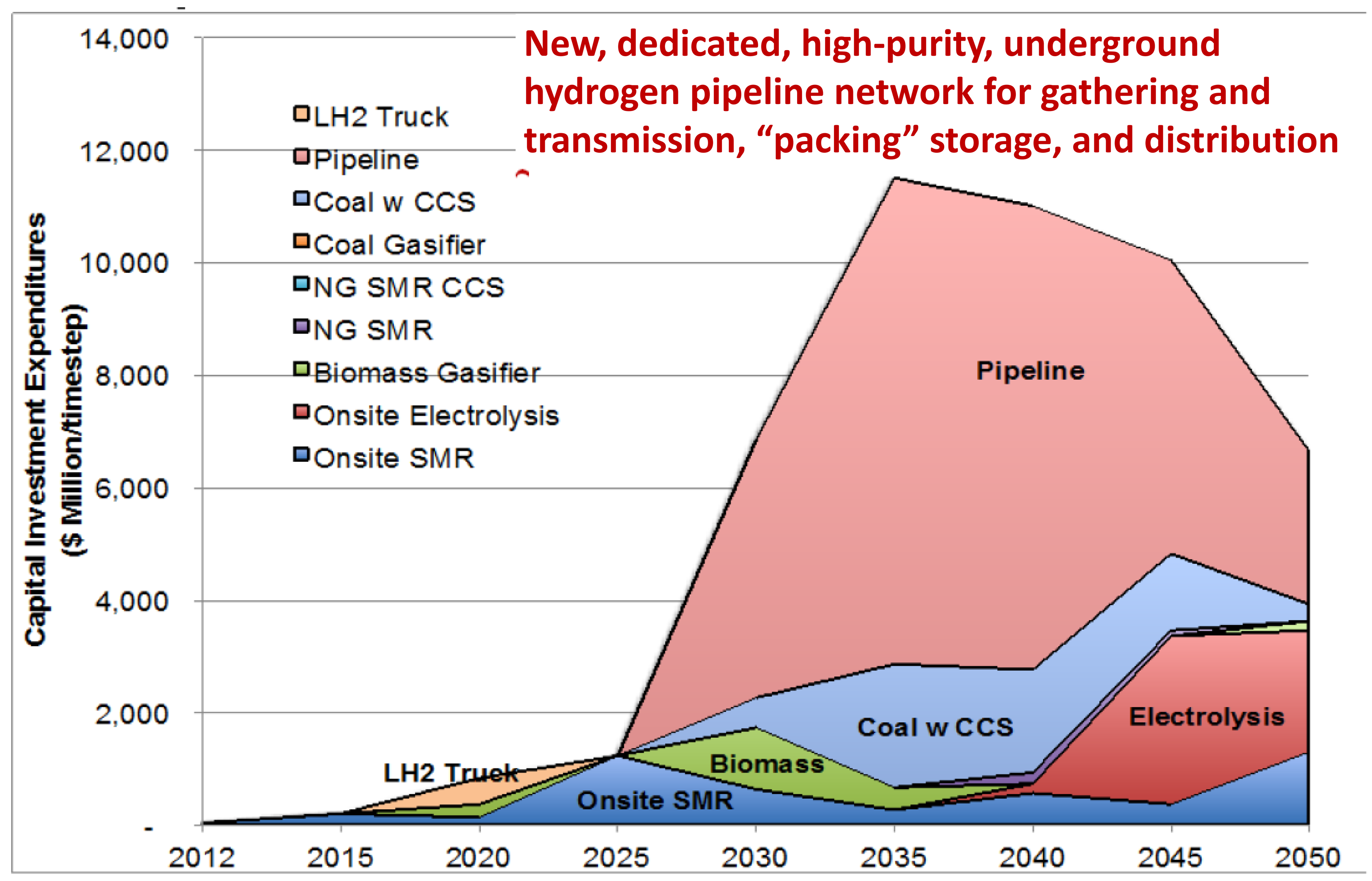
For Year 2050 Electricity + Hydrogen Transportation Fuel, California will need about:

- 210 GW = 35 times Year 2015 installed wind capacity in CA, *PLUS*
- 230 GW = 19 times Year 2015 installed solar electricity capacity in CA



Annual-scale firming storage for < $ 1.00 / kWh capex
Each domal salt cavern:

- Stores ~ 92,000 MWh as ~ 2,500 Mt "working" Hydrogen
- "Full" at 150 bar = 2,250 psi
- Cavern top ~ 700m below ground
- 860,000 cubic meters each cavern physical volume
- $ 15 M average capex per cavern
- Capex = $160 / MWh = $0.16 / kWh



New, dedicated, high-purity, underground hydrogen pipeline network for gathering and transmission, "packing" storage, and distribution

Capital Investment for Hydrogen Fuel Infrastructure in California
$ 50 Billion cumulative investment : Transition to "green" Hydrogen for "80 in 50"
80 % reduction in CO2 emissions from California transportation sector by year 2050
Source: Institute of Transportation Studies (ITS), STEPS program, UC Davis

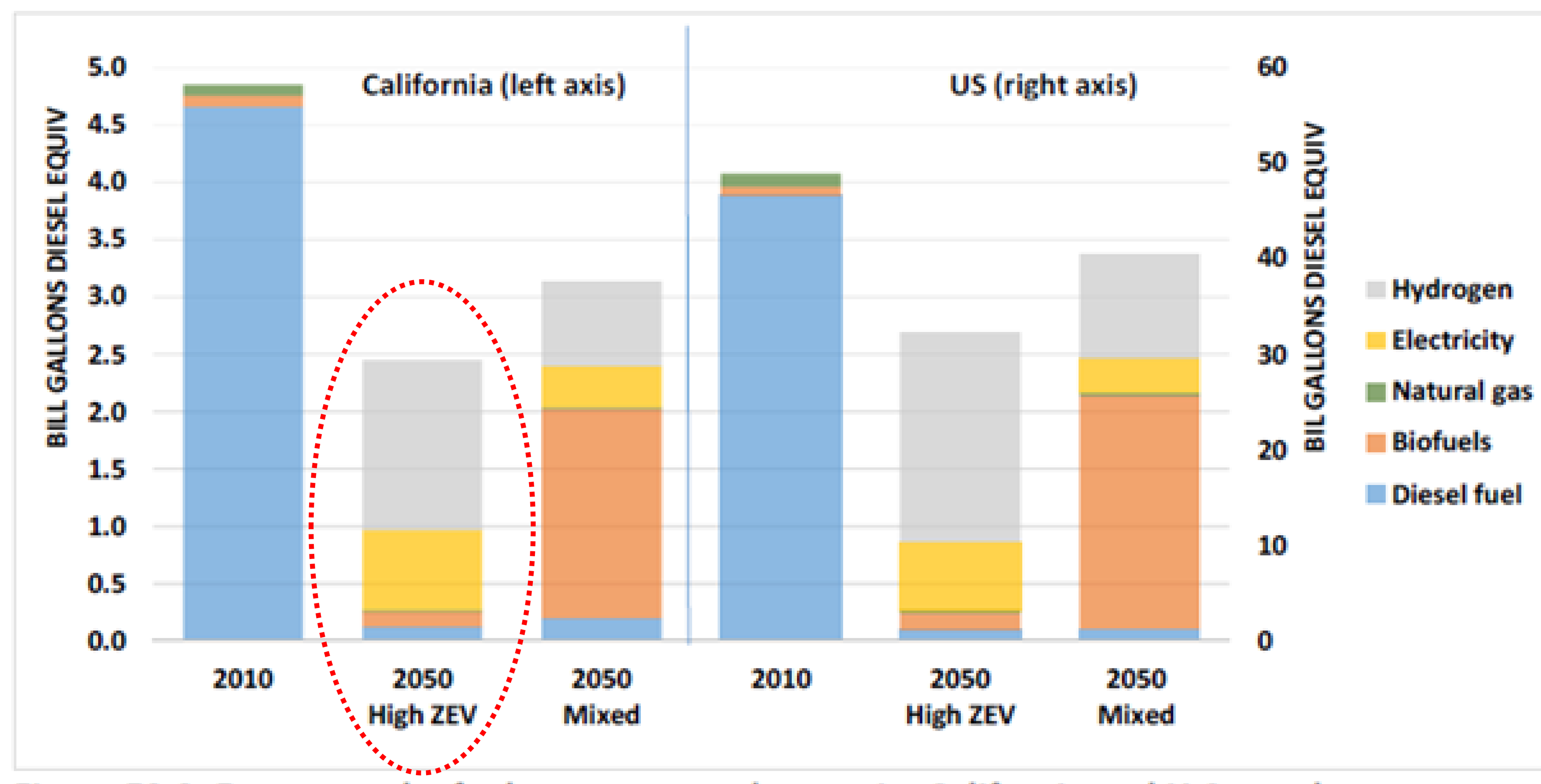
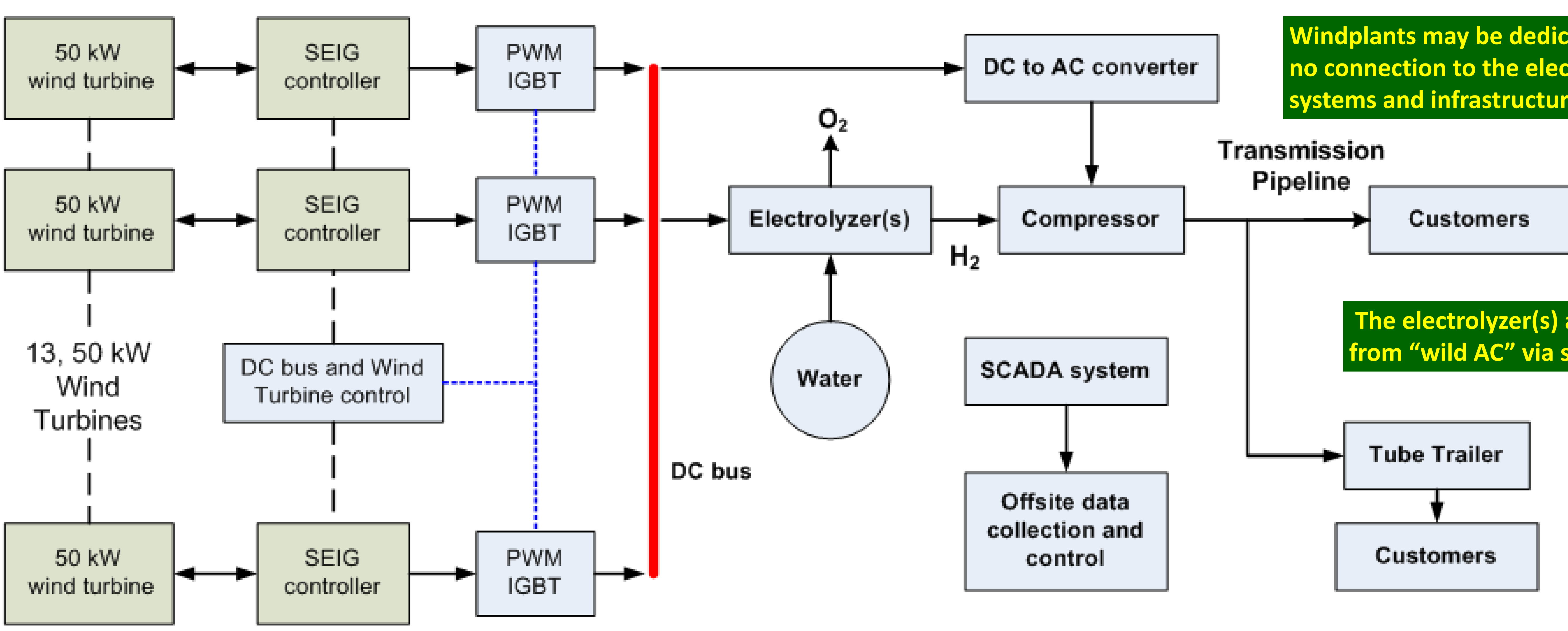


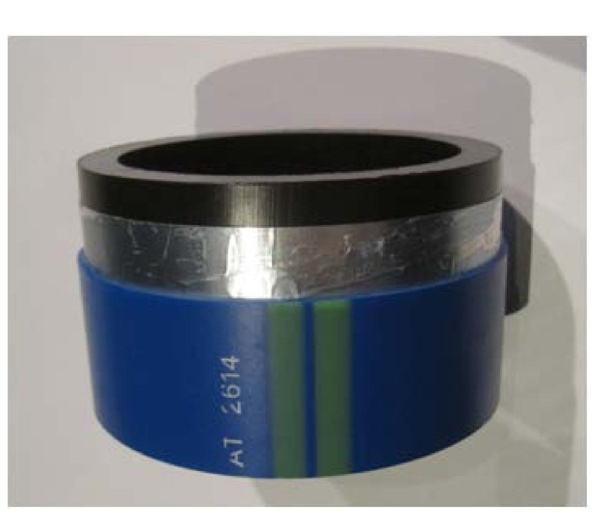
Figure ES-2. Energy use by fuel type, year and scenario, California and U.S. results

"Goods movement" trucking diesel fuel demand in Year 2050
California (left, red circle) and USA (right), High Zero Emissions Vehicle (ZEV) case
This is included in the "Hydrogen Fuel Demand" estimates on the poster's right side.
Source: Institute of Transportation Studies (ITS), STEPS program, UC Davis



Windplants may be dedicated to Hydrogen fuel production, with no connection to the electricity grid, without costly generating systems and infrastructure to deliver grid-quality AC or DC.

The electrolyzer(s) are a dumb DC load, fed "wild DC" from "wild AC" via simple power electronics and controls



Gaseous Hydrogen (GH2) transmission pipelines
Polymer-metal hybrid tubing concept sample, from Smart Pipe, Houston, www.smart-pipe.com May be made up to I meter diam for transmission; smaller for gathering and distribution lines. Fabricated in an on-site, trenchside factory in continuous, unlimited lengths, without splices. Has not been tested for 100 bar GH2 service. Probably immune to Hydrogen embrittlement.

Turbines with simple, low-cost induction motors are modified for Self Excited Induction Generator (SEIG) mode and closely coupled via simple, smart rectification on a DC bus to the electrolyzer stacks, via a SCADA system integrating the complete wind-to-Hydrogen plant, to reduce system complexity and capital and O&M costs.
This will reduce kWhe per kg Hydrogen and boost energy conversion efficiency, reducing plant gate Hydrogen fuel cost in several ways.

- **This poster download:** http://leightyfoundation.org/w/wp-content/uploads/WP16-A.pdf [Windpower 2016]
- Videos: Windpower 2015: "Alternatives to Electricity for Transmission ... " https://vimeo.com/128484940
  PowerGen International 2017: "Bigger Market for Renewables ... " https://vimeo.com/251251415
  https://vimeo.com/126045160 https://vimeo.com/86851009 https://vimeo.com/160472532
  https://vimeo.com/148190671 https://vimeo.com/148049904 https://vimeo.com/172485189

A Bigger Market than the Electricity Grid ? Wind-source Hydrogen Fuel for California Transportation and Combined Heat and Power (CHP)

Bill Leighty, The Leighty Foundation, Juneau, Alaska, USA wleighty@earthlink.net 206-719-5554
Renewable energy papers, posters, presentations: www.leightyfoundation.org/earth.php

By year 2050, to achieve its statutory RPS and "80 in 50" (80% reduction in CO2 emissions from transport sector, below 1990, by 2050) energy goals, California must procure the full output of about 438 GW of combined nameplate wind and solar energy or its equivalent -- about 20 x the 2015 total installed capacity in CA. ~ 58% of that will be Hydrogen transportation fuel, if ITS-STEPS at UC Davis is correct: in 2050 fuel cell vehicles will predominate in personal, bus, and truck service; BEV's are limited to short-distance, light-duty service. In 2050, Hydrogen fuel will be a bigger market for renewable energy than the electricity grid.

Therefore, we should now think "beyond electricity", to capture a larger market for wind energy than the electricity grid, to carefully consider using underground pipeline networks, for transmission, storage, and distribution of the Carbon-free fuels -- Gaseous Hydrogen (GH2) and liquid anhydrous ammonia (NH_3) -- for solving renewable energy's (RE) Big Three technical and economic problems, at lower capital and O&M costs than we can achieve with electricity systems:

1. Gathering and Transmission: from diverse, stranded, remote, and rich RE resources
2. Annual-scale Firming Storage: so that variable RE becomes annually firm and dispatchable
3. Distribution, Integration, and End-use: for an annually-firm supply of quality, CO2-emissions-free energy for all uses and sectors

We should now design and optimize complete RE fuel systems, based on GH2 and NH3, at local to continental scales, from sunlight, wind, and water resources, to dispatchable energy services delivered for ALL energy uses:

- Conversion, Transmission, Combined-heat-and-power (CHP): for both stationary and transportable uses
- Generation, Gathering, Firming storage, and end use: transportable and CHP Carbon-free fuels, as well as electricity

This enables very low cost energy storage: less than $ 1.00 / kWh capital cost:

- Gaseous Hydrogen (GH2) in large, deep, solution-mined salt caverns, where the salt geology is available: Gulf of Mexico coast
- Liquid Anhydrous Ammonia (NH_3) in large, refrigerated, "atmospheric", carbon steel surface tanks, extant in the Corn Belt
- Interconnected via continental underground pipelines, adding "free" storage by packing the GH2 pipelines (not liquid NH3 lines)
- At lower cost than any contemplated “electricity” storage technology, components, or systems

Pipelined GH2 and NH_3 fuels free those wind and solar PV plants, which would be dedicated to delivering all their captured RE as GH2 and NH_3 fuels to pipelines, from the capital and O&M costs of generating and delivering grid-quality AC or DC electricity: the required complex generators and power electronics, field transformers, cables and substations, transmission lines.

To achieve this goal, we must overcome these obstacles:

- Earth’s richest RE resources are often stranded, far from markets with no transmission
- Markets and infrastructure for the C-free fuels -- Hydrogen and Ammonia -- do not exist for GH2, are inadequate for RE - NH3
- We cannot achieve this entirely via electricity, and should not try to do so; “Smart Grid” is primarily demand side management (DSM); it adds no inherent or physical new transmission nor energy storage capacity , and only slight effective new capacity.

Therefore, we should now design and build pilot plants for both GH2 and NH_3 as complete, optimized, RE systems, by which to:

- Discover and demonstrate scalable technical proof-of-concept and economic advantages
- Explore optimum system topologies for sources, components, infrastructure, and fuels end-uses
- Motivate private-public collaboration to conceive RFP’s and RFQ’s for these pilot plants
- Capture the very large nascent market for CO2-emissions-free transportation fuel, in California and beyond

Humanity’s urgent goal is to transform the world's largest industry from ~ 85 % fossil to ~ 100 % renewable, greenhouse gas (GHG) - emissions - free energy sources, as quickly as we prudently and profitably can: to "Run the World on Renewables", perhaps including some nuclear fission or fusion. Therefore, we should now design these alternatives to, and adjuncts to, the electricity grid:

- Wind and solar PV plants converting all RE, at their sources, with no grid connection, to GH2 or NH_3 fuels
- Deliver these C-free fuels via underground pipelines for transportation and CHP, accessing very-low-cost energy storage

RE-source NH_3 : http://www.siemens.co.uk/en/insights/potential-of-green-ammonia-as-fertiliser-and-electricity-storage.htm
http://www.ammoniaenergy.org/