Comment Received From: William C Leighty
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20 Megatons CO2-emissions-free Hydrogen transportation fuel required in Year 2050

Additional submitted attachment is included below.

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ARFVTP Colleagues, 9 Nov 15

Please accept my comments for the 6 Nov 15 meeting of the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP), which considered the staff draft of the "2016 - 17 Investment Plan Update … " I listened to most of the 6 Nov meeting via WebEx. I appreciate Brian Goldstein's interest in renewable-energy-source Hydrogen fuel. My presentation at Windpower 2015 [1] encouraged that industry to consider the large, nascent market for wind-source Hydrogen transportation fuel, especially in California (CA), where it may be larger than the electricity grid market, by 2050.

1. Figures 4, 5. Achieving CA's "80 x 50" and other statutory and regulatory goals will require ~ 20 million tons (MMT) per year of high-purity, zero-carbon-emissions, Hydrogen fuel for surface transportation (LDV, bus, goods movement), by Year 2050. Aviation Hydrogen fuel, if that market develops, would require additional Hydrogen fuel, supporting Gov Brown's ambition to reduce CA's petroleum-source transportation fuel use. "80 x 50" cannot be achieved with BEV's; attempting to is technically and economically suboptimal: Figure 4.

2. Supplying 20 million tons per year of Hydrogen fuel would require the full output of ~ 285 GW of nameplate wind generation at 40% capacity factor (CF), or its equivalent in solar or other non-CO2-emitting renewable energy generation. [2] Total wind generation now installed in CA is ~ 6 GW, all delivering electricity to the grid; we would also need ~ 47 times as much dedicated to transport fuel.

3. Therefore, CA needs, now, via its several state laws and energy project funding programs, to:

a. Consider the implications of trying to supply the very large quantity of ~ 20 million tons per year of CO2-emissions-free Hydrogen transportation fuel for CA, a "20 Megaton Scenario", Figures 1, 5:

(i) Has CA enough land and rooftops on which to harvest this amount of wind, solar, and other "green" Hydrogen fuel, in any transmission, annual-scale firming storage, and distribution scenario? What are the land use implications?

(ii) How can both "centralized" (large plants, usually far from demand centers, often without transmission) and "distributed" (connected to distribution lines for electricity or for fuels, often installed at point-of-use as rooftop solar often is) renewables generation best be accommodated ? As electricity, or as Hydrogen, Anhydrous Ammonia (NH3), or other fuels ?

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[1] https://vimeo.com/128484940

[2] One 1 MW nameplate wind turbine will produce 8,760 MWh of electric energy per year @ 100 % capacity factor (CF); 3,500 MWh at 40 % CF. Electrolyzer efficiency may approach 50 kWh / kg Hydrogen; each MW of nameplate wind @ 40 % CF thus produces 70,000 kg H2 per year = 70 metric tons (MT). 20 million MT (MMT) Hydrogen fuel / year thus requires the full output of 285 GW wind generation nameplate @ 40 % CF: 14 GW per MMT H2 per year.

(iii) Figures 2, 3. How should CA consider importing a significant fraction of its Hydrogen transportation fuel ? From diverse Great Plains resources via transmission in 1- meter- diameter pipelines of ~ 8 GW capacity each ? Via marine tankers as Hydrogen-rich liquids -- cryogenic Hydrogen (LH2), NH3, Toluene (C7H8)- Methylcyclohexane (C7H14) cycle, from Alaska or other global sources ?
Japan is considering all three.

(iv) Should CA consider changing its transportation modal mix, to require less total transportation fuel in 2050, when population growth and sea level rise will have greatly changed CA demographics and probably urban topologies ?

b. Encourage large wind and solar plants dedicated to Hydrogen fuel production, with no connection to, nor energy delivery to, the electricity grid;

c. Fund R&D and Demonstration programs to design and commercialize novel wind-to-Hydrogen and solar-to-Hydrogen systems optimized for Hydrogen fuel production, transmission, storage, delivery, and end-use. This R&D, Design, and Demonstration strategy would include:

(i) Simplifying the wind and solar generators by eliminating the costly components necessary to deliver grid-quality AC or DC to electricity transmission lines;

(ii) Further simplifying wind generator design by replacing complex variable-speed generator systems with the Self Excited Induction Generator (SEIG), using the simple, robust, low-cost induction motor ;

(iii) Simplifying the electrolysis (Hydrogen generation) plant by eliminating the costly transformer-rectifier subsystem, driving the electrolyzer stacks directly from the SEIG system;

(iv) Both centralized and distributed “green” Hydrogen generation.

But, to satisfy this very large looming demand for "green" Hydrogen fuel, we probably do not want to:

- Build new electricity transmission, storage, and distribution infrastructure to gather, transmit, and deliver this large amount of energy from diverse, dispersed renewable resources, within and / or from beyond CA;
- Inflict on those renewable energy sources the cost of generating and delivering grid-quality AC or DC to the electricity "grid", if it is to be converted back to Hydrogen fuel at point-of-use, at considerable capital and energy conversion loss cost.

4. Figure 2. ARFVTP should recognize the Hydrogen fuel system opportunity embraced in the 2014 paper by J. Ogden, C. Yang, L. Fulton, "The Hydrogen Transition" by NEXTSteps, ITS, UC Davis, Figure 1. Source: Fig 17. A $ 50 - 60 B investment, in CA, in Years 2025 - 2050, in new pipeline systems for gathering, transmission, storage, and distribution of high-purity Hydrogen fuel. [3]

[3] http://steps.ucdavis.edu/files/08-13-2014-08-13-2014-NextSTEPS-White-Paper-Hydrogen-Transition-7.29.2014.pdf

5. Therefore, ARFVTP should begin now to encourage and fund R&D & Demonstration projects to discover and showcase paths to large-scale commercialization of high-purity Hydrogen fuel production from wind, solar, and other CO2-emissions-free energy sources to achieve:

- Lower-cost Hydrogen fuel, at the plant gate or other source terminals, and at the end-user's fueling station. At large scale, a 20 - 50 % cost reduction may be possible.
- Much larger geographic areas over which renewable energy (RE) can be harvested, without expansion of the electricity grid, assuming availability of new Gaseous Hydrogen (GH2) fuel pipeline systems. Novel polymer-metal tubing linepipe material, developed at Oak Ridge National Lab, with IP owned by Hydrogen Discoveries Inc., and with potential manufacture by Smart Pipe, Houston, may solve the hydrogen embrittlement problem of steel Hydrogen transmission pipelines at 100 bar Maximum Allowed Operating Pressure (MAOP) and frequent pressure fluctuation characteristic of production from renewables. Figure 3. [4]
- "Free" energy storage in the GH2 pipeline system by "packing" the pipelines to MAOP when RE-source Hydrogen is available and surplus to demand, then drawing down pipeline pressure as customers withdraw Hydrogen fuel when RE-source energy production is reduced; this emulates the natural gas industry's routine pipeline "packing" storage practice which adds great value to their product and service.
- "The Hydrogen Transition" vision from ITS, UC Davis, above.

6. Therefore, the ARFVTP "2016 - 17 Investment Plan Update ..." should shift a significant fraction of the $ 20 M "Biofuel Production and Supply" in "Alternative Fuel Production" to a new solicitation for "transforming" the RE-source Hydrogen fuel supply to achieve the above goals. The new "Hydrogen Fuel Production from Wind and Solar Sources" solicitation would specifically fund R&D and Demonstrations:

- Plants and generators dedicated solely to Hydrogen fuel production, with no connection to, nor energy delivery to, the electricity grid.
- Feeding the future network of dedicated, high-purity, GH2 pipelines.
- Reducing Hydrogen fuel cost at the generator terminals, and at the plant gate, and at the end-user's fueling station.
- Increasing the geographic area in which Hydrogen fuel may be generated from diverse, rich (high intensity; large geographic area) RE resources.
- Especially synergistic public-private and other collaborations and partnerships.
- Projects that promised early production (< 12 months) of RE-source Hydrogen fuel for delivery and sale to nearby customers.
- Projects that optimize RE-source Hydrogen fuel system designs that relieve the wind and solar generators, especially, from the technical and cost burdens of delivering grid-quality AC to the electricity grid, instead optimizing the RE-to-Hydrogen system design to simplify the electrolysis system and its integration with the wind and solar generators.

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[4] www.smart-pipe.com

Or, the ARFVTP "2016 - 17 Investment Plan Update ..." should shift funds from elsewhere in its $100 M budget, to prepare to meet the very large, looming demand for Hydrogen transportation fuel in CA. “Emerging Opportunities” may be a good vector.

7. For example, our company, Alaska Applied Sciences, Inc. (AASI) has owned a small, 13-turbine windplant in North Palm Springs for over 20 years, reliably delivering electric energy to the SCE grid, until the PPA terminated in June 2012. This would be an ideal test bed for an R&D and Demonstration project consistent with (5) and (6), above. Therefore, AASI has proposed a project, to ARPA-E, to the NREL Small Business Voucher Pilot Program, and to the State of CA -- CEC, CARB, SCAQMD -- to produce Hydrogen fuel from the entire energy harvest of our windplant, with no connection to the SCE grid. (See five application files submitted with this letter).

AASI’s ARPA-E "Full Application" for $ 3 million, responded to the 2015 "OPEN" FOA. In October ARPA-E advised AASI that its proposed project would not be funded. The three salient application files are attached submitted with this letter. This full-scope $ 3 million project would have included all 13 wind turbines, operating in Self Excited induction Generator (SEIG) mode, feeding a state-of-art, custom-engineered, MW-scale electrolysis plant from a major supplier: Hydrogenics, Proton OnSite, ITM Power were partners in the ARPA-E application. NREL would have done the system engineering, integrating innovative SEIG operation of the turbines using low-cost, rugged induction motors as generators, with the electrolysis plant, to reduce capital and O&M costs in a simpler wind-to-Hydrogen system which would have produced about 11,000 kg of Hydrogen fuel per year.

AASI submitted a reduced-scale, proof-of-concept, lab-based engineering project via a $ 300 K Small Business Voucher Project application at NREL via their new Voucher Pilot Project. This would prepare for the full-scale, 13-turbine project. With matching resources from AASI, and perhaps from State of CA, we may be able to deploy a small wind-to-Hydrogen system at the Palm Springs windplant to demonstrate Hydrogen fuel production from one or two turbines, paving the way to full-project funding.

Catherine Dunwoody invited me to prepare a reduced-scale, proof-of-concept, lab-based engineering project , via a $ 350 K proposal to State of CA programs -- CARB, CEC, SCAQMD -- similar to our application for the NREL Voucher Pilot Program. Catherine advised me that our wind-to Hydrogen project may be valuable, but that no State of CA funding vehicle is apparent, and the $ 3 M ARPA-E budget is too large for CA programs. But, she thought that a $ 350 K proposal might be useful for discussion and for potential future funding vectors. Jim McKinney and several of his staff invited me to present and discuss this $ 350 K project plan at CEC on 2 Oct 15, leading to this comment letter.

AASI would propose this, or a similar project, if the "2016 - 17 Investment Plan“ included an appropriate solicitation. We imagine many others would also propose innovative and valuable projects.

8. Sunline Transit, Thousand Palms, CA, partnered with AASI on the ARPA-E application because they will need a large quantity of Hydrogen fuel when their fleet expands to about 7 fuel cell buses. They will need still more, if their public retail fueling station is upgraded and FCV’s proliferate.

Sunline is 15 miles from AASI's Palm Springs windplant. Sunline agreed to consider buying our wind-source Hydrogen fuel if we could deliver it to their site at acceptable purity, pressure, schedule, and price. Tube trailer transport from AASI windplant to Sunline would be required; ITX Group proposed to provide that service on contract.

9. Conclusion: AASI suggests that the ARFVTP "2016 - 17 Investment Plan Update ..." should shift $ 5 - 10 M from elsewhere in its $ 100 M annual budget, to prepare to meet the very large, looming demand for Hydrogen transportation fuel in CA, via the strategy in (5) , (6), and (7), above. “Emerging Opportunities” seems also a good place for the wind-to-Hydrogen project described in the enclosed funding applications. This may also apply to CA’s “Integrated Energy Policy Report”, which should include investigation of the “20 Megaton Scenario”: potential CA annual demand for up to 20 million metric tons (MMT) (Megaton) of CO2-emissions-free “green” Hydrogen transportation fuel per year by Year 2050. 20 MMT of Hydrogen fuel per year requires the full output of ~ 285 GW of wind generation nameplate @ 40 % CF: 14 GW per MMT of Hydrogen fuel per year.

CA is making great progress in Hydrogen fuel delivery. Now, CA needs to invest in CO2-emissions-free Hydrogen fuel production to achieve optimum system synergy with the large, new, necessary, Hydrogen pipeline infrastructure proposed by ITS, NEXTSteps, UC Davis. Figure 3. [3]

CA laws, regulations, and Gov Brown’s ambitions will require extraordinary commitments of technology innovation, capital, and probably urban reconfiguration. CEC, CARB, and the ARFVTP Advisory Committee need to recalibrate now, before committing to the 2016-17 Investment Plan.

We will advise ARFVTP if AASI’s application for a $ 300 K NREL Voucher for SEIG-driven wind-to-Hydrogen R&D & Demonstration succeeds. In that case, State of CA funding would greatly enhance the project, probably enabling significant Hydrogen fuel production at, and sale of fuel from, AASI's Palm Springs windplant. [5]

Thank you for your consideration.

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[5] AASI Palm Springs windplant operation video: https://vimeo.com/86851009

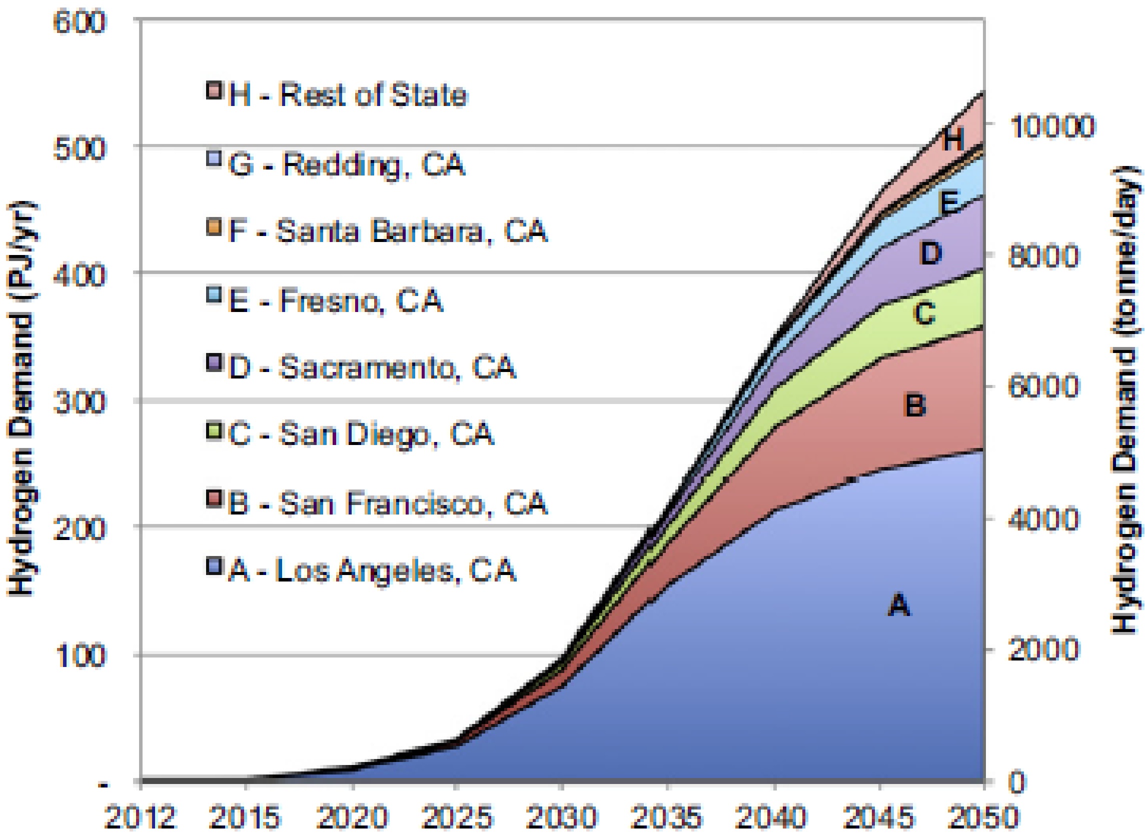

Figure 1. Exogenously specified California hydrogen demand (PJ/yr) to 2050 broken out by regional cluster (1 PJ H2/yr [19.3 tonnes H2/day]). Source: Figure 3, "Renewable and low carbon hydrogen for California: Modeling the long term evolution of fuel infrastructure using a quasi-spatial TIMES model ". 10,000 metric tons (MT) per day is ~ 3.65 million MT (MMT, i.e. Megaton) per year.

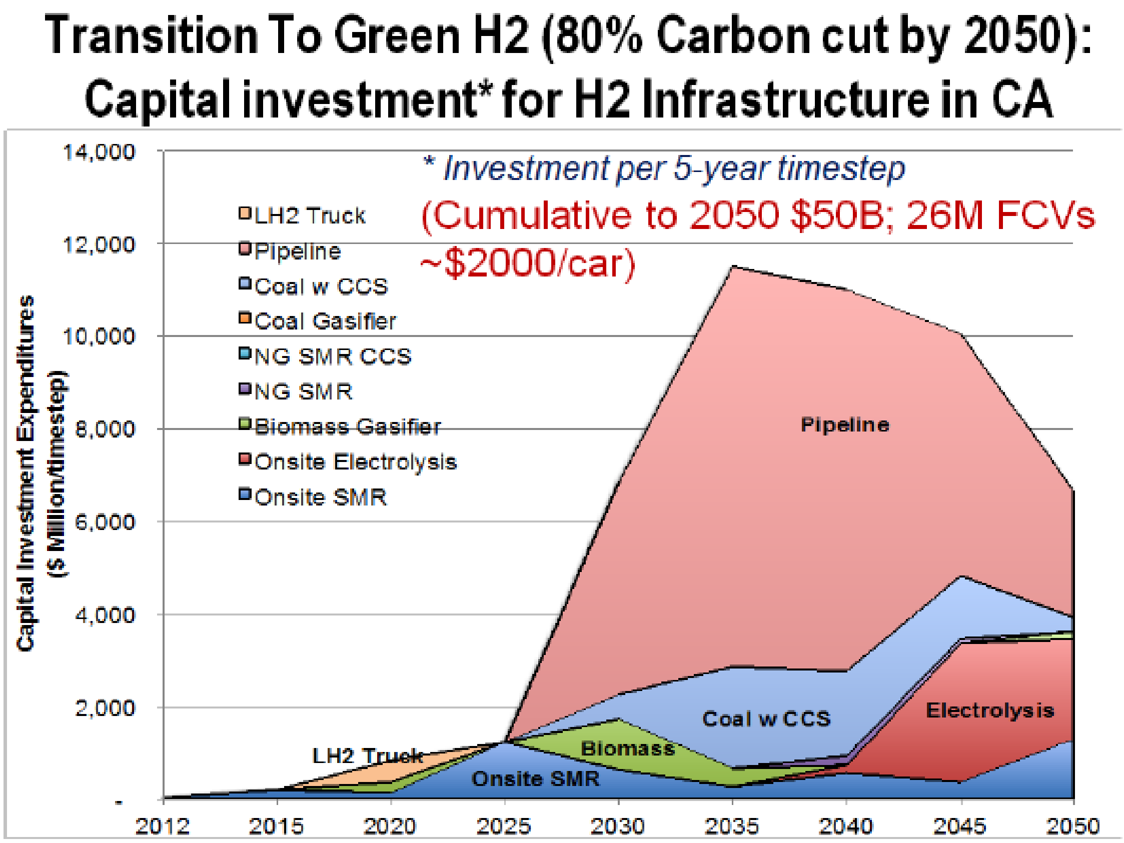

Figure 2. A possible mix for hydrogen supply over time to reduce vehicle GHG emissions by 80% compared to a gasoline reference vehicle. Source: Fig 17, "The Hydrogen Transition", ITS, UC Davis [2]

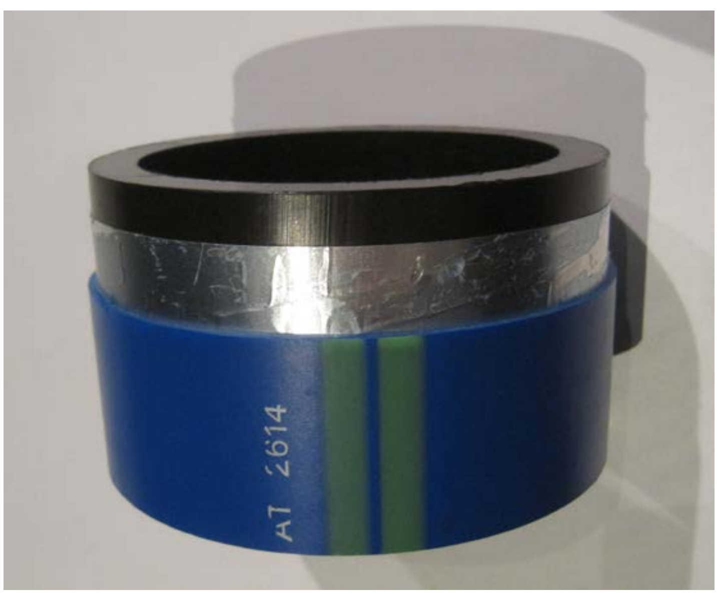

Figure 3. Polymer-metal hybrid tubing concept sample, from Smart Pipe, Houston, www.smart-pipe.com May be made up to I meter diam for GH2 transmission pipelines; smaller for gathering and distribution lines. Has not been tested for 100 bar GH2 service. Fabricated in an on-site, trenchside factory in continuous, unlimited lengths without splices.

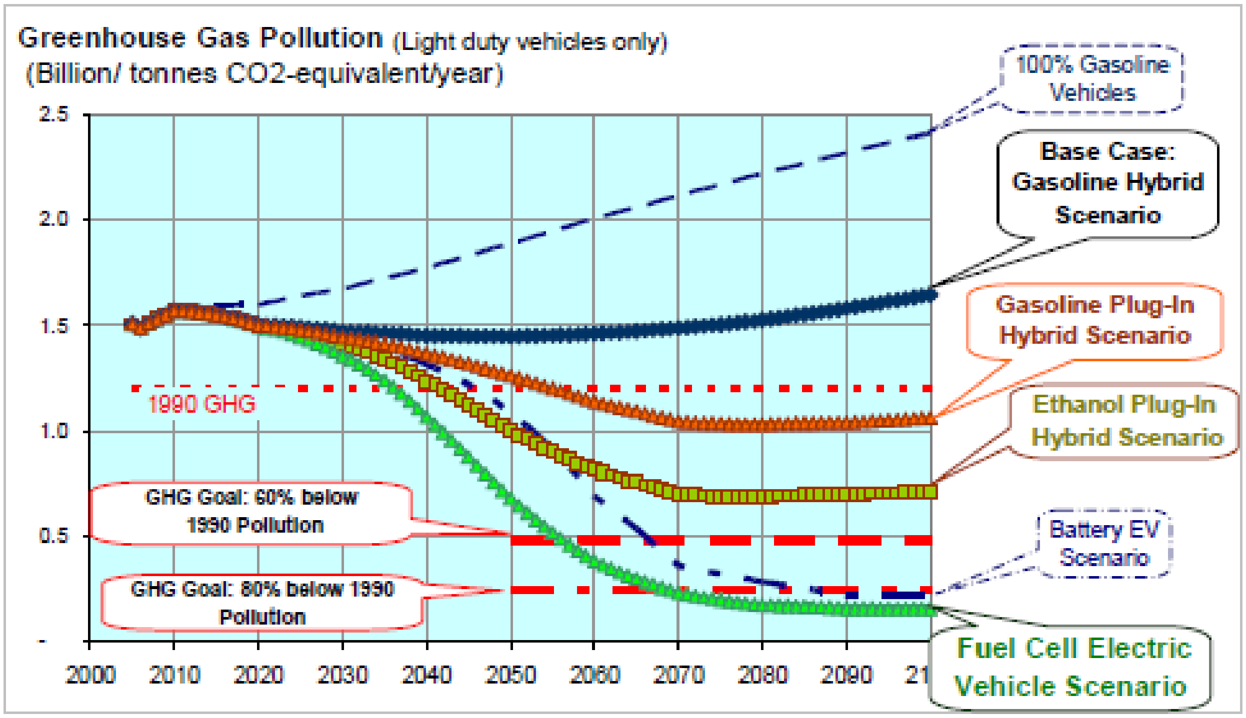

Figure 4. CA's "80 x 50" goal of 80% reduction in CO2 emissions from transportation below 1990 level by 2050 cannot be achieved for LDV's by BEV's alone. FCV's will be required. Source: Sandy Thomas, 2009, IJHE

Here are two ways to achieve an 80% reduction by 2050 in GHG in trucking…both are very challenging

- Mixed case would require a doubling of current US biofuels use for all purposes and must provide at least 80% reductions in GHG compared to base fuel
- Hydrogen use in the ZEV case would be about twice U.S. production for all purposes and must be deeply decarbonized, e.g. from “waste” wind/solar power

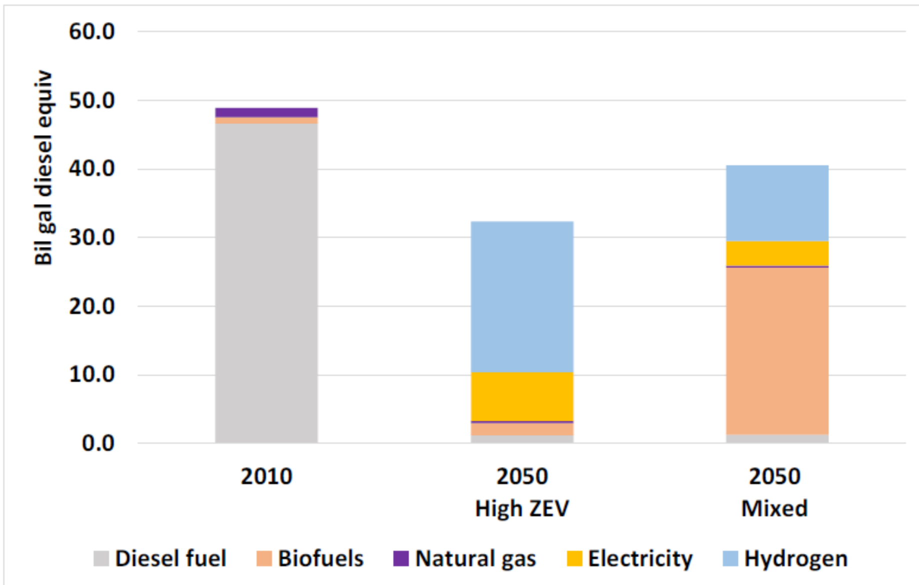

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Figure 5. The “High ZEV” scenario requires Hydrogen fuel equivalent to ~ 20 billion gallons of diesel fuel for the “trucking” sector: ~ 10 million tons of CO2-emissions-free Hydrogen fuel, since diesel has higher energy content by volume than gasoline. Source: Slide 10, Lew Fulton presentation at Asilomar Conference, 19 Aug 15