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Please see attached memo

Energy Colleagues,

Please consider the attached advisory memo for a nascent "H2-Systems ..." research project, to be launched soo by a CA university. The Leighty Foundation is a modest co-funder. I am on the advisory board.
The memo suggests expanding the scale, scope, and horizon of the project so that we may thoroughly consider, and attempt to achieve by policy, the optimum allocation of markets and investment in CO2-emission-free, "green", energy systems based on hydrogen vis-a-vis electricity, i.e. "The Grid", as large and as smart as we may conceive and build it.

We should avoid over-dependence upon, and over-investment in, The Grid, as it may be a suboptimal technical and economic strategy for de-carbonizing and de-GHG-gassing the entire human enterprise, well beyond The Grid and the energy sector, as quickly as we prudently and profitably can:

Prudently: This transformation of the world's largest industry will be disruptive, but we don't want to cripple the CA, USA, or world economies.
Profitably: The very large amount of capital required will flow only to investment of attractive reward-to-risk ratio.

The attached memo may be useful in crafting the EPIC plans.

Thank you for your consideration.

Bill Leighty, co-director, Earth Protection Program, The Leighty Foundation
www.leightyfoundation.org/earth.php

Additional submitted attachment is included below.

"A Systems Analysis of the Future Role of Hydrogen in a Carbon-neutral California, before 2050 "

Dear Energy and Hydrogen Colleagues, 20 Oct 20 Juneau, AK

Humanity's urgent task is complete de-carbonization and de-GHG-emission of the entire human enterprise, before 2050. Some believe we can do this entirely by "the electrification of everything" via only the electricity Grid, at continental scale, supplied mostly by variable energy resources (VER) like wind and solar. This may be technically and economically suboptimal vis-a-vis hydrogen-based systems, presenting unacceptably-severe opportunity costs and large stranded Grid assets. Thus, we must think beyond electricity, the Grid, and energy systems, to total human enterprise scope and scale: Energy + Industrial Feedstocks [E+IF]. The Grid may be adjunct to the hydrogen system for totally de-carbonized [E+IF], rather than the reverse.

The renewable and hydrogen energy communities now urgently need new total systems analysis research, such as this memo suggests -- by several diverse, parallel, team projects -- to create a method, model, and discipline by which to continuously pursue the optimum allocation of CO2-emission-free [E+IF] markets and infrastructure capital investments, among electricity and hydrogen-based systems. Each of you should join at least one research collaborative, to think beyond Grid and energy, to whole-systems thinking, to rapidly achieve carbon-neutrality, then climate-neutrality, at California (CA), regional, USA, continental, global human enterprise scales. We minimize long-term total cost; quickly transform the world's largest industry.

Recent studies, roadmaps, and webinars enable and motivate this research (the Project), challenging the salient paradigm that the electricity system, the "Grid", is the primary, necessary, and optimum pathway and strategy for achieving total de-carbonization and de-GHG-emission for the entire human enterprise -- to be accomplished quickly, prudently, and profitably:

- Prudently: This will be "transformative and disruptive", but we must not cripple the CA, USA, nor global economies;
- Profitably: The very large amount of capital needed will flow only to high reward-to-risk ratio investments;

We will build on these studies to predict and track a new optimum strategy for a complex, "wicked problem " [1] , requiring great courage and intellectual resources to challenge the "Grid prevails" paradigm for total [E+IF]. Project outcomes:

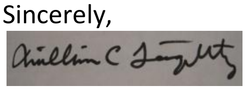
- Measure and calculate the complete benefit / cost merit of a mature CO2-emission-free (CEF) hydrogen system vis-a-vis an electricity-centric CEF system, before 2050, for total [E+IF], first in CA, and then beyond in continental context.
- Strategies to optimize allocation of market shares and capex investments among the Grid and nascent hydrogen-based systems, to prevent: over-dependence upon and over-investment in the Grid; stranded assets.
- Define "Inter-sector" and "cross-sector" coupling as a process by which to expand our perception of the scale, scope, and urgency for reaching carbon-neutrality and climate neutrality before year 2050; wisely craft and use optimization models for the huge, nascent, CEF [E+IF] economic sector; craft policies to allocate markets and capex.
- Change our language, for example, from "electric cars" to "battery and fuel cell vehicles", of all sizes; from Grid to [E+IF].
- Consider whether DHDRG geothermal energy proliferation will diminish hydrogen's role for transmission and storage.

The Project is based on hydrogen as an energy carrier, storage medium, fuel, and carbon-neutral and climate-neutral strategy for the entire CA enterprise, and beyond, to continental scale. The Leighty Foundation's Earth Protection program has granted modest funding, as one of many diverse sponsors of the Project. [www.leightyfoundation.org/earth.php] This memo is our suggested catalog of factors, features, and opportunities to consider including in the Project, to define it. The Project, which has not yet been announced by the CA university proposing to lead it, will require about two years.

Gia Brazil Vacin, from Gov Newsome's Go-Biz economic development office, asked, after her 10 September presentation to the California Hydrogen Business Council (CHBC) webinar, "German National Hydrogen Strategy": "What's next for CA? Do we need a Hydrogen Strategy like the EC and Germany have declared ? We cannot achieve CA's energy and climate goals without hydrogen." This Project transcends "Hydrogen Strategy" to achieve the total, CEF, [E+IF] system in CA, before 2050.

Thank you for your consideration. Please FWD this memo or use any part or all for your purposes. MSWord file by request.

Sincerely,



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[1] "Wicked problem: difficult or impossible to solve because of (a) incomplete or contradictory knowledge; (b) large number of people and / or opinions; (c) large economic consequences; (d) many interconnected aspects. TED: Tom Wujec, Edinburgh, 2013

Challenging the persistent incumbent Grid-centric world, to achieve this research Project objectives, is a "wicked problem". See: https://www.youtube.com/watch?v=O8FMBBVb71k See explorations below in:

- APPENDIX G "Wicked Problem" Dysfunction within a complex system or network
- (below, p. 11) 10. Compare Grid and Hydrogen-based Energy Systems.

Apprehending the wicked problem and beginning to solve it demands Whole-systems Thinking, "Systematology", and paradigm shifts that require great intellectual effort and the human and funding resources to enable that effort.
Total de-carbonization and de-GHG-emission for the entire human enterprise, to provide all Energy + Industrial Feedstocks [E+IF] , before year 2050, prudently and profitably, is a "Wicked Problem". Inertia discourages all of us from "thinking beyond electricity" -- beyond the Grid -- to confront and transcend it; "Green Grid" and "electric cars" persist.

This memo catalogs recommended features, topics, and outcomes to include in several instances of this Project, as many interdisciplinary teams collaborate to apply "Whole-systems Design" for a "wicked problem" solutions spectrum.

Figure 1. "Whole-systems Design" approach to the urgent "wicked problem" of total de-carbonization and de-GHG-emission of the entire human enterprise, before year 2050. CO2-emission-free (CEF) hydrogen is distributed for transportation and combined-heat-and-power (CHP) Energy, and for Industrial Feedstocks: [E+IF]

Project Scope, Scale, Horizon, and Policy Potential

CA, USA, and the world urgently need this Project in order to optimize our strategy and investments in the electricity and hydrogen systems by which to accelerate total de-GHG-emission, including total decarbonization, of the entire human enterprise. This begins with State of CA and its private enterprises, via CA's goals for years 2045 - 2050: achieve Carbon-neutrality, then Climate-neutrality, for the entire CA (E+IF] sector, as quickly as CA prudently and profitably can:

- Prudently: this will be transformative and disruptive, but we don't want to cripple the CA nor global economies;
- Profitably: the large amount of capital required will flow only to investments with attractive reward : risk ratios.

SIEMENS concept: Intersector Coupling, Power-to-X (PtX)
With Hydrogen as energy carrier, storage medium, fuel

Figure 2. "Whole-systems Design" approach to the "wicked problem". Appendix B. Hydrogen's role in "Inter-sector" and "Cross-sector" coupling: concepts for [E+IF] systems for the entire human enterprise, before year 2050. An unstructured, open-ended, multi-dimensional, wicked problem without prospect for a single solution. This Project begins the process of evolving a whole-systems-derived solutions suite. "Wickedness" is no excuse for not bravely apprehending the problem and beginning the urgent interdisciplinary creative process to yield a spectrum of solutions.

Now is the ideal time to launch this Project, to comprehensively address most of the scale and scope below. Figures 1, 2. This enterprise-scale optimization, as informed by this research Project, should recruit diverse CA and USA interests to:

1. Test the hypothesis of electricity system, i.e. "Grid", priority and supremacy as vector to C-neutral CA. [2, 3] Compose models and strategies for optimal allocation of market share(s) and capex among the electricity and the nascent Carbon-free fuels (hydrogen and ammonia) systems, in order to discover Grid + hydrogen system optimality:
    a. Avoid over-dependence upon, and over-investment in, the Grid; consider that the Grid might primarily support the hydrogen system, rather than the reverse;
    b. Show potentially-superior energy storage alternatives to batteries, in scale, technology, and economy;
    c. Transcend the energy sector to include all [energy + industrial feedstocks] [E+IF] required for decarbonization and de-GHG-emission of the entire human enterprise, in CA and beyond;
        i. Include all citizens and stakeholder groups as "customers";
        ii. Include anhydrous ammonia, NH_3, "the other hydrogen", and organic hydrides (MCH, C_7H_{14}) as energy carriers, storage media, fuels, and complete CO_2-emission-free (CEF) energy systems. [4]

[2] "The Hydrogen Transition" A NextSTEPS white paper by: Joan Ogden, Christopher Yang, Michael Nicholas, and Lew Fulton 29 Jul 14 https://steps.ucdavis.edu/files/08-13-2014-08-13-2014-NextSTEPS-White-Paper-Hydrogen-Transition-7.29.2014.pdf https://steps.ucdavis.edu/files/08-05-2014-NextSTEPS-White-Paper-Hydrogen-Transition-Executive-Summary.pdf

[3] UC Irvine, APEP, June 2020, Jeff Reed, et al, for CEC "Roadmap for the Deployment and Buildout of Renewable Hydrogen Production Plants in California"

   d. Fill the research void at this high level of scale, scope, and assumed year 2050 horizon;
   e. Develop draft models by which to roadmap the allocation of markets shares and capex among electricity and hydrogen complete energy systems, for a Carbon-neutral CA and world by 2050.
2. Think "beyond electricity", beyond the Grid and energy sectors, to total C-neutrality and de-GHG-emission;
3. Think beyond "Carbon-neutral" to "Climate-neutral": the Project's effect on long-term systems analysis, results;
4. Allow the CPUC to transcend depending upon natural-gas-fired generation to firm all renewables production;
5. Include DOE and NREL interests and major private enterprise(s) interests, especially discovering and analyzing the range of "at scale" options; demonstrate modeling pathways for their in-house studies and proposed policies;
6. Address the CA Go-Biz question articulated in the 10 Sept CHBC "German National Hydrogen Strategy" webinar by Gia Brazil Vacin, "Where does CA go from here ? Do we need a "Hydrogen Strategy" like Germany's ?"
7. Consider CA desire to collaborate with international partners, like Germany, on hydrogen R&D&D projects, especially for renewables-source, CO2-emission-free (CEF) hydrogen production;
8. Explore inter-sector and cross-sector coupling for total synergistic hydrogen [energy + feedstocks] [E+IF] supply, for the entire CA to global enterprise range of scale and scope: consider the conceptual options in Figures 2-4, 18-22.
9. Honor and incorporate and build upon the last few years' volume and spectrum of good research and publication on hydrogen systems and subsystems, throughout the Hydrogen Community;
   a. Interest in, and investment by, large private enterprises: over 90 Hydrogen Alliance members, for example;
   b. Increasing urgency for "climate change" response: mitigation and adaptation; so far avoiding geoengineering
   c. The COVID-driven example of consequences of, and responses to, very large problems.
10. Survey, evaluate, calibrate, and track several nascent enabling technologies in order to accurately include them in the technical evolution and economic models for Grid - hydrogen market and investment optimality:
   a. Linepipe for gaseous hydrogen (GH2) gathering, transmission, "packing" storage, and distribution, especially alternatives to steel; for example, polymer-metal hybrid, especially via in-field continuous manufacturing processes capable of minimizing joints and terminations; [5] Figures 7, 11.
   b. Components for GH2 pipeline systems: compressors, valves, meters, terminations, leak detection
   c. Simplified wind, PV, and [wind + PV] plants dedicated to hydrogen fuel production, with no connection to the electricity Grid: reduced plant capex, opex, and plant-gate and dispensed hydrogen production cost;
   d. Deep, high-pressure (~ 150 bar) salt cavern storage, especially in the domal salt of the Gulf Of Mexico (GOM), and perhaps in bedded salt; consider cost-reduction potential of multiple-cavern projects;
   e. Anhydrous ammonia (NH3) synthesis from CEF hydrogen via Haber-Bosch process, or via novel NH3 synthesis directly from RE-source electricity, water, and air, via the ARPA-E "REFUEL" project processes;
   f. Deep hot dry rock geothermal (DHDRG) energy capture, to achieve CEF, ubiquitous, low-cost, baseload heat, electricity, and hydrogen fuel production via DER micro- and mini-grids. From benign, inexhaustible sources, this minimizes the need for energy transmission and storage, including via hydrogen pipelines and caverns.
11. Include a variety of liquid hydrogen carriers, as transmission and storage media:
   a. Anhydrous ammonia (NH3)
   b. Organic hydrides, especially Toluene (C7H8) - Methylcyclohexane (C7H14) cycle (Chiyoda Chemical + HI)
   c. Formic acid (CH2O2); others
12. Consider the entire [energy + feedstocks] market, beyond Grid and energy sectors, at all scales, including enabling policies, including GH2 pipeline networks, pipeline "packing" , and salt cavern bulk energy storage, including NH3:
   a. Micro- and mini-grid, including [heat + electricity + hydrogen] systems driven by DHDRG
   b. Urban, regional, and ISO, RTO,
   c. National, continental, global
13. If this research Project's outcome is favorable to large-scale CEF [energy + feedstocks] systems based on hydrogen and other C-free energy carriers: Win the hearts and minds of the public and decision-makers to execute the optimization plan, by "selling" its diverse benefits. People buy benefits and services, not products, infrastructure.

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[4] https://www.bloomberg.com/news/articles/2020-10-05/orsted-aims-to-make-green-ammonia-for-fertilizer-with-wind?srnd=premium

[5] For example, Smart Pipe Company, Houston

Timing and Strategy for this Research Project

This Project launch timing is good because it fills a research void: Bill Leighty's brief Aug - Sept survey of people at DOE HFTO, NREL, and UC Irvine -- and other observations from the hydrogen and energy industries -- supports the above research needs, because no one apparently plans to soon address salient Scope topics 1 and 2 on Page 3:

- Neha Rustagi, DOE, EERE, Hydrogen and Fuel Cell Technology Office (HFTO)
- Maggie Mann and Chad Hunter, NREL
- Jeff Reed, UC Irvine, APEP [6]
- State of CA: CEC, CPUC, Governor's Go-Biz office
- Diane Moss, Policy Director, California Hydrogen Business Council

This research Project design and good launch timing was informed by Bill Leighty's attendance at these events:

- CA Hydrogen Business Council (CHBC) annual Summit, Sacramento, 6-8 March 20
- CHBC webinar. 10 September 2020 Topic: " German National Hydrogen Strategy "
- ICEPAG conf, UC Irvine, 14-18 September
- Pivot2020, https://www.texasgeo.org/pivot2020 "Kicking Off the Geothermal Decade"

The research Project timing is also fortuitous because: (See Figures 3, 4, 23, 24)

1. CA needs to decide whether to invest billions in "hardening" its electricity infrastructure, to attempt to prevent future fires, or to consider an alternative for [energy + feedstocks]: C-free energy carriers via underground pipelines.
2. TED Talks: Urgent need for 50% GHG reduction by 2030 https://www.youtube.com/watch?v=5dVcn8NjbwY https://blogs.shell.com/2020/10/16/the-short-term-climate-ambition/
3. Arresting the multiple aspects of "Climate Change" is urgent, and within our technical and economic grasp;
4. The past several years' research, by USA federal, State of California (CA), and European programs, has prepared the renewables and other components of the energy industry to "think beyond electricity" to human enterprise scale;
5. The nascent concepts of Inter-sector Coupling and Cross-sector Coupling need modeling exploration and definition; see Figures 2-4 and 18-22 for candidate concepts, for (5). Hypothesis Testing, below. See Hydrogen Council: https://hydrogencouncil.com/en/study-hydrogen-scaling-up/
6. The Hydrogen Council has expanded Hydrogen's scope from transportation fuel to decarbonizing and de-GHG-emission of the entire human enterprise, far beyond the electricity and energy sectors, to include industrial and other feedstocks;
7. Private enterprise is investing in R&D for commercializing hydrogen-based, complete, integrated, CEF energy systems;
8. We may soon be able to profitably access ubiquitous Deep Hot Dry Rock Geothermal (DHDRG) energy: Figures 7 - 9. This may allow providing all [E+IF] from this local, autonomous, DER source, via proliferating micro- and mini-grids. This greatly reduces the need for importing CEF energy from distant, large, VER wind and solar plants. Storage is free: leave the heat in the ground until needed. This transformative disruption would reduce hydrogen's utility as transmission energy carrier and storage medium; reduce the need for pipelines and salt storage caverns. The "wicked problem" process would track the enabling deep-boring technology: https://www.texasgeo.org/pivot2020, 15 July, 1145 hrs: "The Future of Drilling: Non-conventional Concepts"

[6] Ibid, Reed-2020, p. 39: " The analysis does not consider long-distance hydrogen pipelines delivering hydrogen from out of state. Moreover, it does not analyze the potential role of in-state dedicated hydrogen pipelines that might be developed beyond 2030, at which time hydrogen demand may justify the construction of such facilities ... "

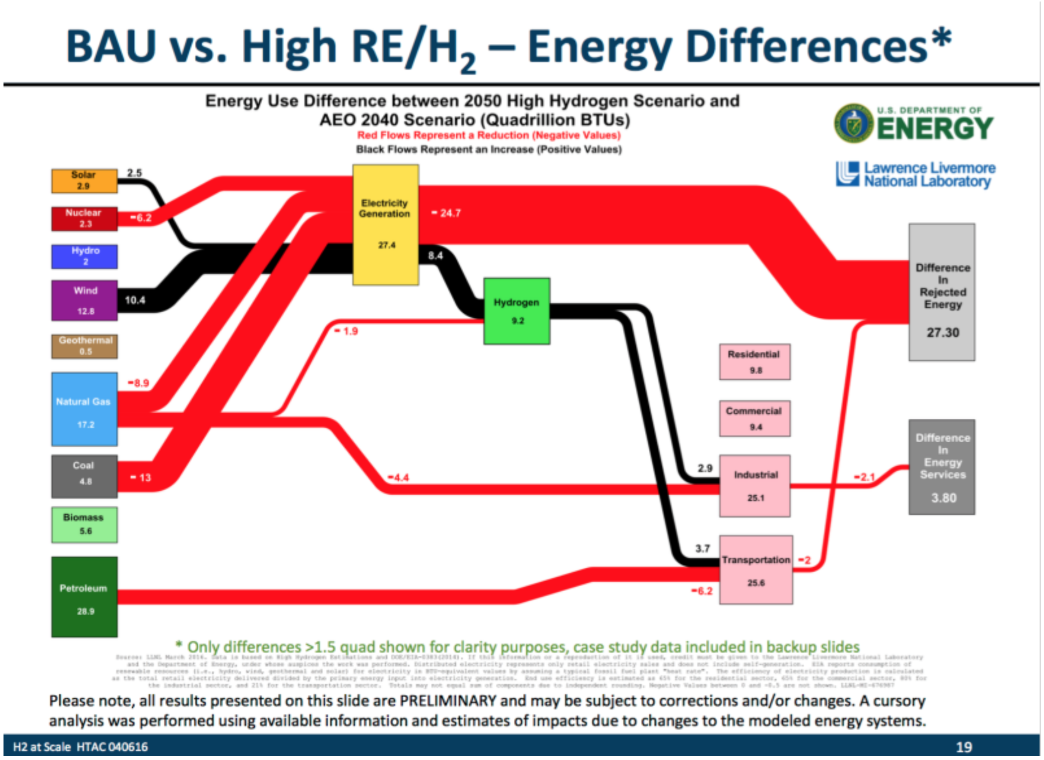

Figure 3. "Whole-systems Design" approach to the "wicked problem". Hydrogen's role in "Inter-sector" or "Cross-sector" coupling, for total decarbonization and de-GHG-emission for the entire California enterprise, and global enterprise, before 2050. "High RE / H2" is not nearly high enough. "Differences" only; no Industrial Feedstocks (IF).

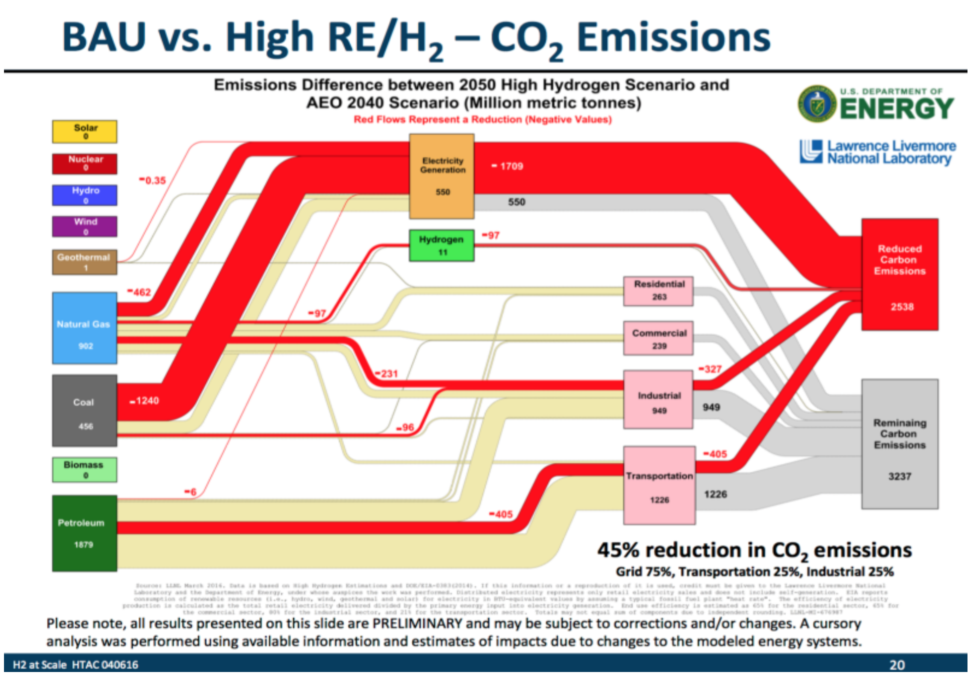

Figure 4. Hydrogen's role in "Inter-sector" or "Cross-sector" coupling, for total decarbonization and de-GHG-emission for the entire California enterprise, and global enterprise, before 2050. "High RE / H2" is not nearly high enough. Chart doesn't include Industrial Feedstocks (IF). "Differences" only. 45% CO2 reduction by 2050 misses CA's 2045 goals.

This memo's suggestions are on the research Project scale, scope, time horizon, and potential for novel CA policy. They proceed from The Leighty Foundation Earth Protection program's interest in accelerating humanity's progress toward decarbonizing the entire human enterprise, beyond electricity and energy, to embrace all [energy + industrial feedstocks], [E+IF]. Therefore, we now need to question in detail our assumptions about how to most wisely and economically do that, before year 2050, for CA and beyond:

1. Is the electricity system, i.e. Grid, the optimum, or necessary, vector for gathering, transmission, storage, distribution, and end-use of CO2-emission-free (CEF) energy for this total decarbonization ? Shall we consider avoiding Grid buildout, the present default as the obvious option; the dominant, even exclusive strategy ?
2. Might electricity assets be limited to approximately the first-and-last km, or few km, of the regional and continental [E+IF] system(s), with the Carbon-free fuels, H2 and NH3, via underground pipelines, with low-cost energy storage (salt caverns and pipeline "packing" for GH2, and liquid surface tanks for NH3) everywhere between ? Figures 7, 11.
3. What is the optimum continental-scale system for supplying total [E+IF] to all economic sectors at minimum long-term COE, including all externalities ? The optimum mix of electricity and fuels ?
4. What is the optimum market allocation and optimum capital allocation among electricity and hydrogen systems -- and perhaps other energy carriers -- to supply CO2-emission-free [E+IF] ?
5. Shall the energy and [E+IF]sectors now pause their investments in advancing the Grid to be larger, smarter, more firm and dispatchable, harder and more "fireproof" ? Need we first resolve these questions, to prevent over-commitment to, and over-investment in, the Grid, resulting in large stranded capital assets and high cost-of-capital ?
6. Shall we now pursue the research strategy proposed below ? Who should lead and fund ? Participate ?
7. Shall we include the potentially "disruptive and transformative" effects of potentially-profitable DHDRG, below ?
   See: ELECTRIC POWER webinar, 22 July 20, " Ultimate Distributed Energy Resource (DER): Deep (6-10 km), Hot Dry Rock Geothermal (DHDRG) without Transmission or Storage "
   https://www.youtube.com/watch?v=fr1QlIcprFc&t=81s

   Bill Leighty presentation starts: 26:00 min Ends; Q&A begins: 42:03 min Presentation time = 16 min

   Also see Pivot2020 webinar on DHDRG energy: https://www.texasgeo.org/pivot2020
   15 July, 1145 hrs: "The Future of Drilling: Non-conventional Concepts"

1. Project Scale and scope.

At what scale, by what measures, does CEF H2 become strategically and economically important ? For CA statutory goals; for extant policies and by new policies to be proposed by the Project ? How do we discover that critical scale ? Is this a "wicked problem" ? If so, how shall we organize to address it ? What long-term commitment does it require ?

Project is CA-centric, but is regional or USA or continental scale required for economy and annual-scale firming and dispatchability ? For access to GOM coast salt cavern storage, transmission pipelines are needed; they can be fed by gathering pipelines from VER in Great Plains and Southwest; also backfed from CA . Extending the CEF-source GH2 pipeline system east may favorably affect CA economics as it evolves to a continental "Hydrogen Economy" sector.

a. Think beyond electricity, to total energy systems (now energy + feedstocks, a la Hydrogen Council); to total decarbonization of entire human enterprise;
b. Define system, subsystems, components; define systems boundaries
c. Gather basic performance and cost estimates for extant and nascent technologies, and likely trajectories to 2050 for them, for system components. Feed this to the technology-driven economic models.
d. Emphasize good policies as well as well-executed model building and modeling results.

e. Build on, without duplicating:
   i. A 2014 white paper by the Institute for Transportation Studies (ITS)-Sustainable Transportation Energy Pathways (STEPS) "The Hydrogen Transition ..." "ITS-2014" [7]
   ii. Jeff Reed, UC Irvine, "Roadmap ..." https://cafcp.org/sites/default/files/Roadmap-for-Deployment-and-Buildout-of-RH2-UCI-CEC-June-2020.pdf "Reed-2020" [8]

f. Add value to ITS-2014 and Reed-2020: gaseous hydrogen (GH2) pipelines
   i. Enlarge upon pipeline systems treatment in Reed-2020 [9]
   ii. Build upon ITS-2014. Figures 1, 2, 5, 6.
   iii. Develop a CA-specific model that can be emulated by other states and extrapolated to regional and continental scales. Figure 6.
   iv. Assume extensive GH2 underground pipeline network(s) will be needed:
      a. Throughout CA
      b. Beyond CA: Interstate, regional, continental, GOM salt cavern geology access; Figure 7.
      c. Gathering, transmission, "packing" storage, distribution Figures 7, 11.
      d. Repurpose and re-line extant pipelines-as-conduits; compose a CA inventory:
         1) Out-of-service oil, nat gas, water
         2) In-service oil + nat gas, becoming available as HC fuels are displaced
         3) Abandoned, but suitable for rehab and repurpose by re-lining with (e, below)
      e. HE, HCC immune linepipe: R&D&D path to materials and pipe manufacture & installation; consider flexible polymer-metal hybrid linepipe, such as that by Smart Pipe Co., Houston
      f. Higher pressure that extant nat gas pipelines, including > 700 bar (NREL research)
      g. Novel safety system concepts: valves, meters, detectors, fiber optics; scavenge leaked GH2
      h. Hydraulic modeling for compression, propagation loss; eliminate mid-line compression
      i. "Packing" storage capacity to MAOP (Maximum Allowed Operating Pressure) Figures 7, 11.
   v. Extend the CA system to regional and continental scales. Figure 7.
   vi. Build a case for value of accessing salt cavern storage via CA-to-GOM (Gulf Of Mexico) Gaseous Hydrogen (GH2) transmission pipelines
   vii. Survey linepipe materials, designs, manufacturing and installation methods. Include:
      a. "Composite Reinforced LinePipe" (CRLP) by Tanscanada (~2005);
      b. Polymer-metal hybrid tubing by Smart Pipe Company, Houston
      c. WireTough LLC process for high-P GH2 storage cylinders, adapted to pipelines

g. Add value to ITS-2014 and Reed-2020: Salt cavern storage: general
   i. Budget for and contract with Solution Mining Research Institute (SMRI) for estimates for capex and opex of TWh-scale GH2 salt cavern storage, including in multi-cavern arrays, in several candidate geologies and regions: GOM "domal" salt; TX and NM "bedded" salt. Total GH2 cavern storage potential in GOM coast, onshore and offshore. Define, fund, and contract for a comprehensive research paper for salt cavern storage necessary for continental-scale, annually-firm, GH2 energy storage.

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[7] "The Hydrogen Transition" A NextSTEPS white paper by: Joan Ogden, Christopher Yang, Michael Nicholas, and Lew Fulton 29 Jul 14 https://steps.ucdavis.edu/files/08-13-2014-08-13-2014-NextSTEPS-White-Paper-Hydrogen-Transition-7.29.2014.pdf https://steps.ucdavis.edu/files/08-05-2014-NextSTEPS-White-Paper-Hydrogen-Transition-Executive-Summary.pdf

[8] UC Irvine, APEP, June 2020, Jeff Reed, et al, for CEC "Roadmap for the Deployment and Buildout of Renewable Hydrogen Production Plants in California"

[9] Reed-2020, p. 39: " The analysis does not consider long-distance hydrogen pipelines delivering hydrogen from out of state. Moreover, it does not analyze the potential role of in-state dedicated hydrogen pipelines that might be developed beyond 2030, at which time hydrogen demand may justify the construction of such facilities ... "

ii. Get capex, opex estimates from Magnum, for UT salt dome: single cavern; multi-cavern arrays
iii. Try to get capex, opex for two extant GH2 caverns near Moss Bluff, TX: Chevron-Phillips; Praxair
iv. Model marginal cost and value of cavern storage as function of VER (Variable Energy Resource: wind, PV, etc.) size, AEP, variability
v. Consider attending annual conference of the Solution Mining Research Institute, probably in 2021: https://www.solutionmining.org/assets/docs/Fall2020/SMRI%20Conference%20Announcement_Fall%202020.pdf

h. Add value to ITS-2014 and Reed-2020: Salt cavern storage: specifically investigate Magnum salt dome in UT:
   i. Can they provide the expert tech and econ advice that SMRI might ? Verify and complement ?
   ii. What's maximum Mt or GWh of energy storage, and likely capex and opex therefor, assuming the salt dome is geographically well situated for CA hydrogen CEF energy strategy. Figure 8.
   iii. May multiple caverns be constructed ("washed") simultaneously, in typical 2-year process ? How many ?
   iv. How many caverns may be manifolded together, if operated at the same pressure, to eliminate lateral forces on the caverns, so that they may be spaced close together, to reduce capex per MWh storage capacity ? Danger: a single cavern problem affects all manifolded caverns. How to isolate failed cavern ?
   v. Could a multiple-cavern array share a single surface facility (compression, GH2 drying, metering, pipeline(s) management) to reduce capex per MWh storage capacity ? Figure 8.
   vi. What would be capex and opex for a dedicated GH2 transmission pipeline(s) system bringing CO2-emission-free (CEF) energy to CA and other markets from Great Plains wind + solar ? Figures 5 - 10.
   vii. How is GH2 storage at ~ 2,000 - 3000 Mt / cavern compatible with other uses of this salt dome ?
      - https://ieefa.org/conversion-of-1800mw-intermountain-coal-plant-in-utah-to-840mw-gas-hydrogen-facility-moving-forward/
      - https://magnumdev.com/

2. Horizon. What should be horizon for this Project ? Important to look to at least 2045 - 2050; specify "before 2050" in Project title: ambitious, and urgent. Include several cases and / or scenarios necessary beyond 2030; beyond 2050.

3. Curtailed energy. Can H2 systems profitably harvest, recover, and save the presently-curtailed CEF VER (wind + solar, now salient in CA) ? How, given geographically-distributed sources and likely low CF of the electrolysis plants ? Is the business case improved if wind and PV are co-located in the primary CA wind resource areas, for enhanced synergy ? Will GH2 pipeline network(s) systems be required ? Over what time interval ? Should pipeline-based proof-of-concept pilot plants be built in CA, or perhaps in jurisdictions with likely easier and faster permitting ? Figure 24.

4. Deep Hot Dry Rock Geothermal (DHDRG) energy access. Consider the effects, upon hydrogen systems and markets, of potential [E+IF]-wide disruptive competition from DHDRG as a Distributed Energy Resources (DER): See 14-17 July 20 "Pivot2020" webinar: https://www.texasgeo.org/pivot2020 Click on any panel to play video. Figures 14 - 17.

a. Ubiquitous production of electricity, heat, and Hydrogen (from produced electric energy)
b. The ultimate DER (Distributed Energy Resource): install almost anywhere
c. Provides baseload, firm, dispatchable energy, to nameplate capacity
d. Storage is free: leave heat in ground until needed
e. All [energy+ feedstocks], [E+IF], delivered within micro- and mini-grids; minimize "transmission" needed
f. Hydrogen's role, as well as electricity's role, for transmission and energy storage is diminished
g. DHDRG requires novel, low-cost, very deep (6-10 km) boring technology. Not available, yet, for profitable systems. One technology is "ready for field trial soon". Big technical challenges: Temp, HDD, ROP, mudflow.

From ELECTRIC POWER webinar, 22 July 20.
" Ultimate Distributed Energy Resource (DER): Deep (6-10 km), Hot Dry Rock (HDR) Geothermal, without Transmission or Storage " **https://www.youtube.com/watch?v=fr1QlIcprFc&t=81s**
Bill Leighty presentation starts: 26:00 min Ends; Q&A begins: 42:03 min Bill's presentation time = 16 min

5. Hypothesis testing; developing modeling cases. Based on the results of the above research and modeling, stretch the research Project scope and scale to articulate and test six hypotheses: (CEF = CO2-emission-free)

a. Electricity, as energy and infrastructure, should be generally restricted to the first and last km, or few km, of local, regional, and continental energy systems; all infrastructure between should be C-free fuels (hydrogen and NH3) in underground pipelines (both new and repurposed extant pipelines) with bulk energy storage as:
   I. Compressed GH2 "packed" in pipelines, as the natural gas industry routinely does;
   II. Compressed GH2 in large, deep, solution-mined salt caverns, where suitable geology is available;
   III. Liquid NH3 in large (typically 30,000 to 60,000 Mt each), double-walled, insulated, refrigerated, "atmospheric", on-grade tanks of up to 200,000 MWh (200 GWh) each;
   IV. Liquid NH3 in small (200 to 20,000 gallon), dispersed, mild steel, inexpensive, readily-available, on-grade tanks at ~ 10 bar (150 psi).

b. In the year 2045 - 50: mature CA energy system, the electricity Grid will support the hydrogen and / or ammonia system(s), not vice versa. Hydrogen and / or ammonia pipelines are the primary gathering, transmission, and distribution infrastructure. Large, annual-scale, low-cost, firming storage is inherent.

c. In the year 2045 - 50: mature CA hydrogen and / or ammonia system(s) will be supplying a significant amount of product(s), made from CEF energy, as chemical and industrial feedstocks, improving economies-of-scale, advancing decarbonization of entire human enterprise, as envisioned by the Hydrogen Council.

d. In the year 2045 - 50: DHDRG systems produce most of CA electricity and heat energy, and chemical and industrial feedstocks from electrolytic Hydrogen, so that much less hydrogen and / or ammonia pipeline and storage infrastructure is needed; hydrogen and / or ammonia are less useful and valuable as energy carriers and storage media; pipeline systems may be unnecessary and / or unprofitable.
https://www.texasgeo.org/pivot2020, 15 July, 1145 hrs: "The Future of Drilling: Non-conventional Concepts"

e. In the year 2050: if CA achieves its present statutory decarbonization goals, hydrogen transportation fuel will require more energy from CEF sources than will the electricity Grid for electric energy demand. [10] Figure 6. The renewables energy industry should be planning for this. Novel State of CA and federal policies should be crafted and introduced to facilitate this trajectory. The transportation fuel market will probably require some underground GH2 pipelines systems, which will also require novel policies.

f. Value the costs to CA of continuing to depend upon electricity infrastructure as the primary vector, system, and strategy for total decarbonization: attempting to "harden" and "fireproof" the Grid while enlarging it.

g. Goal is long-term optimized allocation of markets and capex among electricity and hydrogen systems.

6. Electricity Grid over-commitment tests. From (5) and other topics above, state that a major objective of this research Project is to prevent over-commitment to, and over-investment in, the electricity system, i.e. "Grid", as the presently-supposed default CA and USA energy and feedstocks backbone through 2045 - 50.

7. C-pricing. How will the Project include C-pricing, in the interaction of economic analyses, policy, scale, and ramp-up trajectory ? How does that interact with the electricity - hydrogen total [E+IF] total systems optimization ?

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[10] The Leighty Foundation, Windpower 2016 poster, "Bigger Market than the Electricity Grid ..."
http://www.leightyfoundation.org/wp-content/uploads/WP16-A-1.pdf

8. Build on extant research. A large volume of excellent pioneering research has appeared, from diverse sources and collaborations, in 2016 - 2020. For example, confirm and expand upon the research in Figures 12 - 13, apparently unpublished: " Relative Cost of Long-Distance Energy Transmission by Electricity vs. Gaseous and Liquid Fuels" [11]

9. Catalog available pipelines for repurpose. Survey NG pipelines and ROW (right-of-way) in SO CA for availability, suitability for high-purity GH2 service, including by relining: in-service, out-of-service, abandoned:

- Natural gas
- Liquid HC's (hydrocarbons): crude oil; refined fuels and products
- Water; other

Survey results may have a large impact on aggregate capex in the "Hydrogen Pipeline" envelope, years 2025-2050; Fig 5.

10. Compare Grid and Hydrogen-based Energy Systems. All technical and Economic aspects, for entire CA enterprise, supplying all [energy + feedstocks]; optimized reward-to-risk ratios and net present value (NPV);

- CO2-emission-free (CEF); GHG-emission-free (GEF); sources and systems
- Complete, synergistic, optimized, long-term: beyond 2045 - 2050
- At adequate scale to achieve (a) all CA goals: Carbon-neutral; climate-neutral; (b) hydrogen systems economies-of-scale, especially GH2 pipeline + salt storage cavern systems
- Novel

a. Electricity systems, i.e. the "Grid": Technical + Economic Strengths and Advantages; constraints + difficulties
    i. Micro- and minigrid compatibility: autonomy, resilience, dispatchability; many sources, services;
    ii. Legacy: incumbents in place; proven and accepted;
    iii. Sources and services: fundamentally electric, but hydrogen infrastructure may be attractive for gathering, transmission, storage, distribution, end use for FCV and CT powered transportation;
    iv. Consider: Limit electricity to first-and-last km, several km, several m; BOS is C-free fuels (5, above).

b. Electricity systems, i.e. the "Grid": Technical and Economic Risks and Disadvantages
    i. Operates at light speed: time constants in milliseconds, to maintain balance and stability; autorecovery from faults is essential and adds system cost, especially at sources: example - wind + PV plants;
    ii. "Grid Quality AC" required: frequency, voltage, power, impedance, phase and power factor, harmonics, overload tolerance, faults tolerance;
    iii. Grid-quality HVDC is also required: long-distance point-to-point only; interface to AC infrastructure;
    iv. "Grid compatibility": high voltage and low voltage ridethrough (HLVRT); firm; dispatchable; geographically availability limited; new transmission required;
    v. Transmission and distribution energy losses;
    vi. Vulnerable to cyberattack; increasing complexity, "Smart Grid", more nodes, induces increased risk;
    vii. Storage high cost, limited availability: capex, opex; firm, dispatchable at annual-scale; geography;
    viii. Regulatory burden: complex, uncertain markets; higher admin and ratepayer costs: ISO, RTO, PUC;
    ix. Market complexity: regulations to manipulate customer behavior -- ISO's, RTO's, PUC's;
    x. Complex Demand Side Managment (DSM) is required to improve asset capacity factor (CF);
    xi. Transmission (and to some extent gathering and distribution) more costly than pipelines [12] ;
    xii. Energy storage for "firm and dispatchable" is unaffordable beyond hours, in most storage systems; we need low-cost, very large seasonal-to-annual scale storage for VER sources; much less for geothermal.

[11] " Relative Cost of Long-Distance Energy Transmission by Electricity vs. Gaseous and Liquid Fuels"
Daniel DeSantis, Brian D. James, Cassidy Houchins, Genevieve Saur, and Maxim Lyubovsky , 2019

[12] Ibid

xiii. Infrastructure:
  a) Costly to build, maintain: capex, opex
  b) Wide ROW required: obtrusive, offensive, NIMBY delays + costs
  c) Vulnerable to acts of God and man: how to "harden"; limits and costs
    1. O&M costs: Overhead infrastructure costly to maintain, especially after severe weather
    2. Physical: guns, explosives
    3. Cyberattack at many levels and nodes; scale and "Smart Grid" complexity exacerbates
    4. EMP: electromagnetic pulse from high-altitude nuclear explosion
    5. CME: coronal mass ejection from Sun
  d) Wires cause fires: PG&E bankrupt; costs to "harden"; outages costly to all ratepayers
  e) California, USA dilemma: Repair, replace, harden, fireproof, upgrade, renew, or abandon ?
  f) Underground wires capex ~ 6x overhead; opex lower than overhead

xiv. Micro- and minigrid incompatibility: autonomy, resilience, dispatchability; many sources, services;

xv. If supplying deep hot dry rock geothermal (DHDRG)-source [heat + electricity + hydrogen] for all [energy + feedstocks] [E+IF] via DHS for total-enterprise decarb and de-GHG, to achieve "Climate-neutrality"

xvi. Extant USA "Grid" :
  a) Many components and systems are old, near end of service life
  b) Repair, Replace, Renew, repurpose, upgrade ? Or, consider alternative systems; hydrogen ?
  c) Expand; make it more "smart" ; how much smarter ? Assets Capacity Factor (CF) ? Cost ?
  d) Danger: electrocution, electromagnetic field, falling infrastructure, starting fires

c. Carbon-free fuels (hydrogen and ammonia) systems: Technical and Economic Strengths and Advantages
  i. Bulk energy, annual-scale storage at low cost: GH2 salt caverns; liquid NH3 surface tanks;
  ii. Bulk energy, annual-scale storage at no cost: "pack" GH2 pipeline networks and caverns as systems;
  iii. Carbon-free; CEF at end use
  iv. Water recovery from end-use; consider C-free fuels pipelines as water demand and delivery

d. Carbon-free fuels (hydrogen and ammonia) systems: Technical and Economic Risks and Disadvantages
  i. Feedwater source for electrolysis and synthesis; new pipelines required; seawater source electrolysis ?
  ii. Capex and opex (efficiency, maintenance) of conversion equipment

Conclusion: We need this comparative study research Project now.

a. Accelerate urgent California and global de-carbonization and de-GHG-emission of the entire human enterprise, Energy + Industrial Feedstocks [E+IF].
b. Engage the "wicked problem" with long-term (2050; beyond) whole-systems thinking, multiple interdisciplinary and international teams funded by industry, governments, and philanthropy.
c. Avoid misallocation of markets and capex via either Grid or hydrogen systems over-investment, -commitment:
  i. Stranded investments;
  ii. Delay achievement of CA and global goals for de-carb and de-GHG-emission;
  iii. Discover what scales and values are tipping points ? Tip to what ?
d. Geothermal energy storage, a virtual Earth "battery", can greatly reduce the need for costly battery storage.
e. Landscape monitor: what likely and potential technical breakthroughs will transform and disrupt ?
f. Optimize use of intellectual resources and R&D&D funding from all sources.
g. Internalize external costs; include case(s) for global carbon pricing schemes and their consequences.
h. Design and plan demonstrations and pilot plants; prepare RFP and RFQ for each for DBO contracts;
i. Scale-up planning to discover optimum scale for whole-systems design and subsystem designs; establish R&D processes and protocols for future scale-up efforts;
j. Much research and technical and economic analysis must be started, orchestrated, and presented for policy;

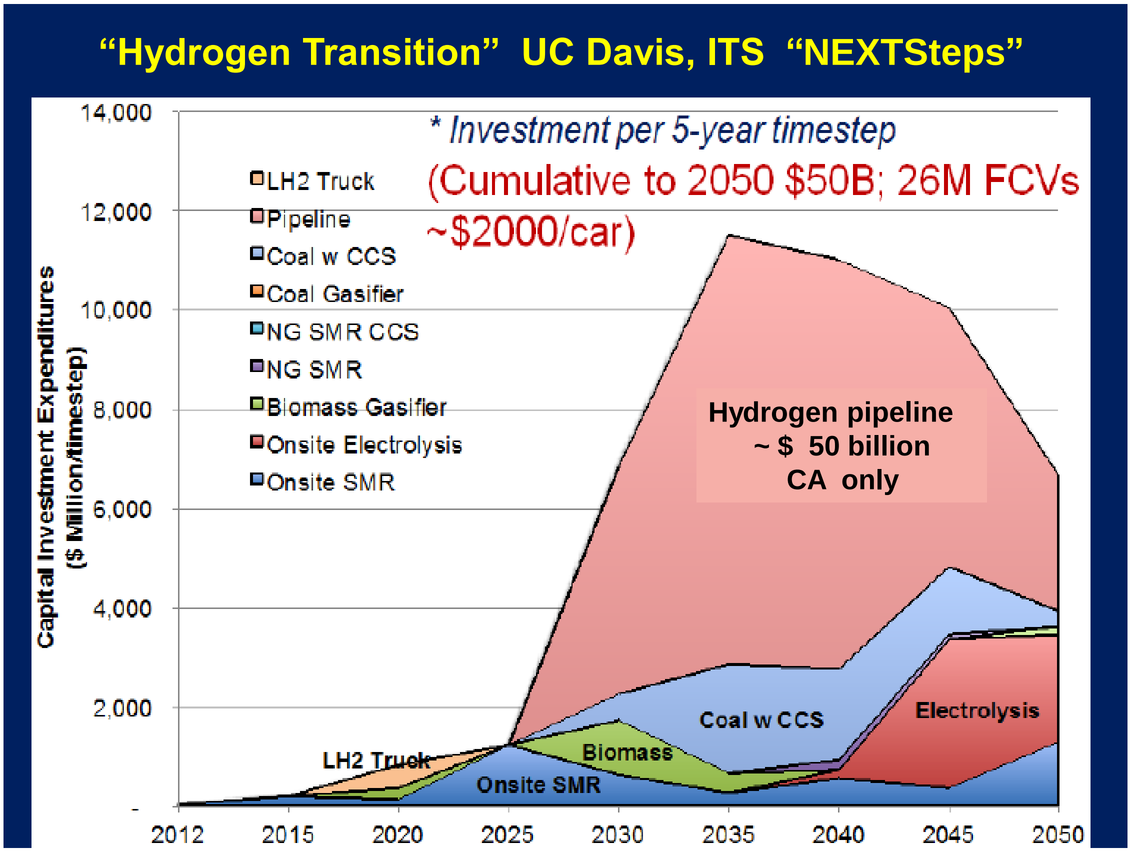


Figure 5. From "The Hydrogen Transition", ITS-STEPS, 2014 [1] Large cumulative capex for "Hydrogen Pipeline" if building a new, dedicated, high-purity, underground GH2 pipeline system ; less capex if diverse extant pipelines are repurposed .

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

Figure 6. Derived from "The Hydrogen Transition". [1] Bill Leighty, The Leighty Foundation, interpretation for an AWEA 2016 poster. By 2050 in CA, CEF hydrogen transportation fuel requires more energy than CEF electricity for Grid.

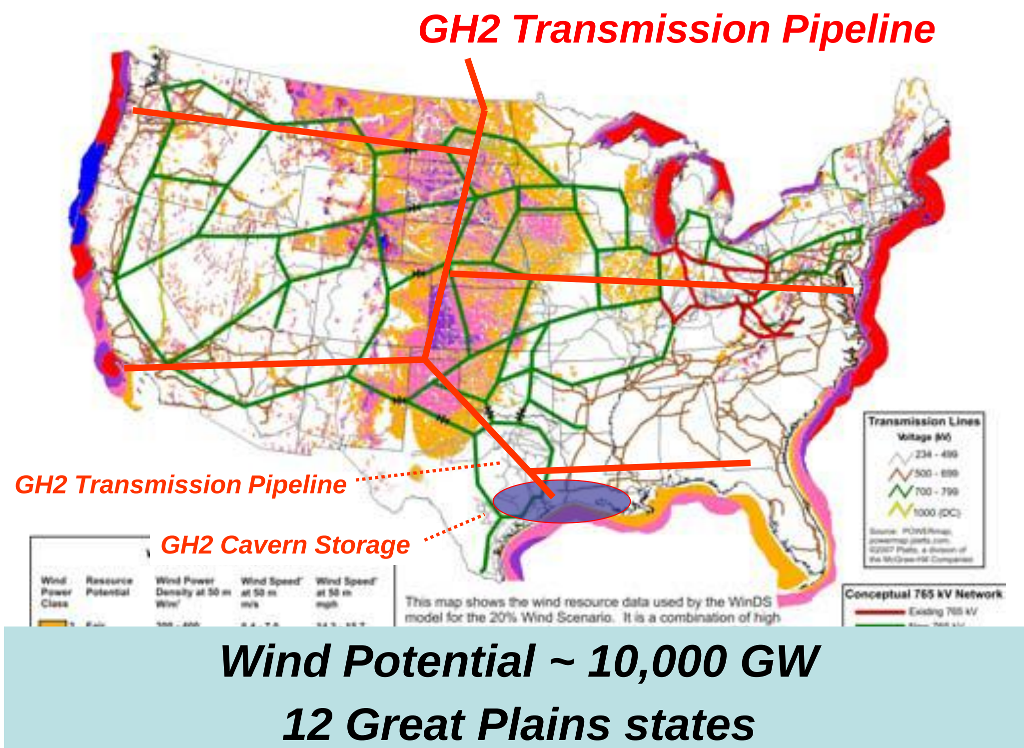


Figure 7. Scale dominates. The research Project may need to invoke a continental scale CEF VER-driven GH2 system to achieve CA's Carbon-neutral goal(s) for total energy supply. Then, add feedstocks for total firm demand for the entire [energy + feedstocks] enterprise Carbon-neutrality, then Climate-neutrality, first in CA, then USA and global.

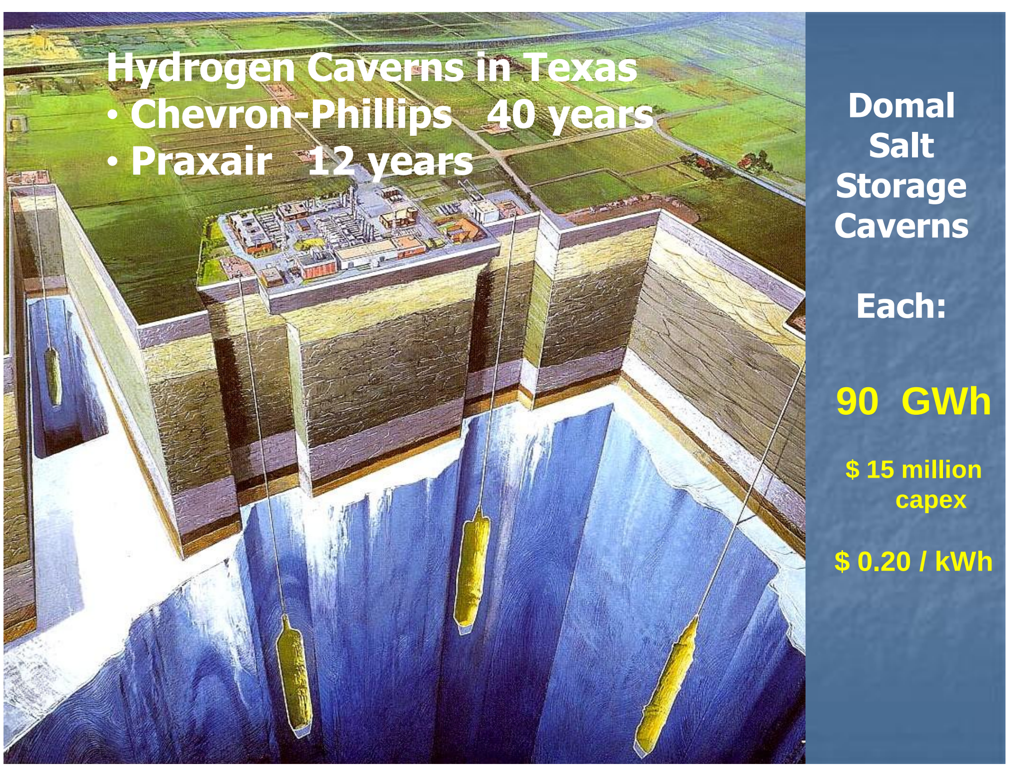
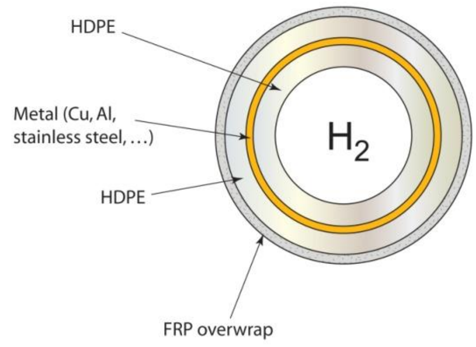


Figure 8. Multi-cavern arrays, sharing a common surface facility (compression, gas drying, metering), probably in GOM domal salt, onshore and / or offshore, reduce cost of energy storage as compressed GH2 to < $ 1.00 / kWh capex.



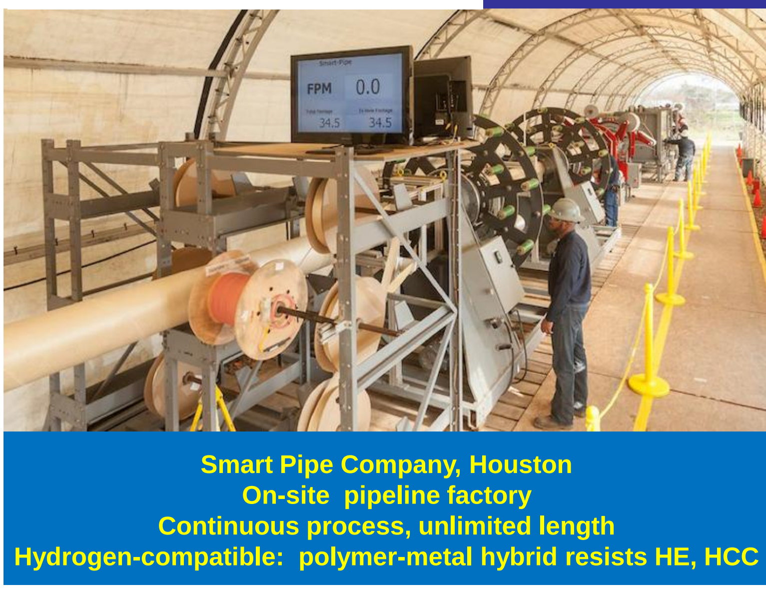
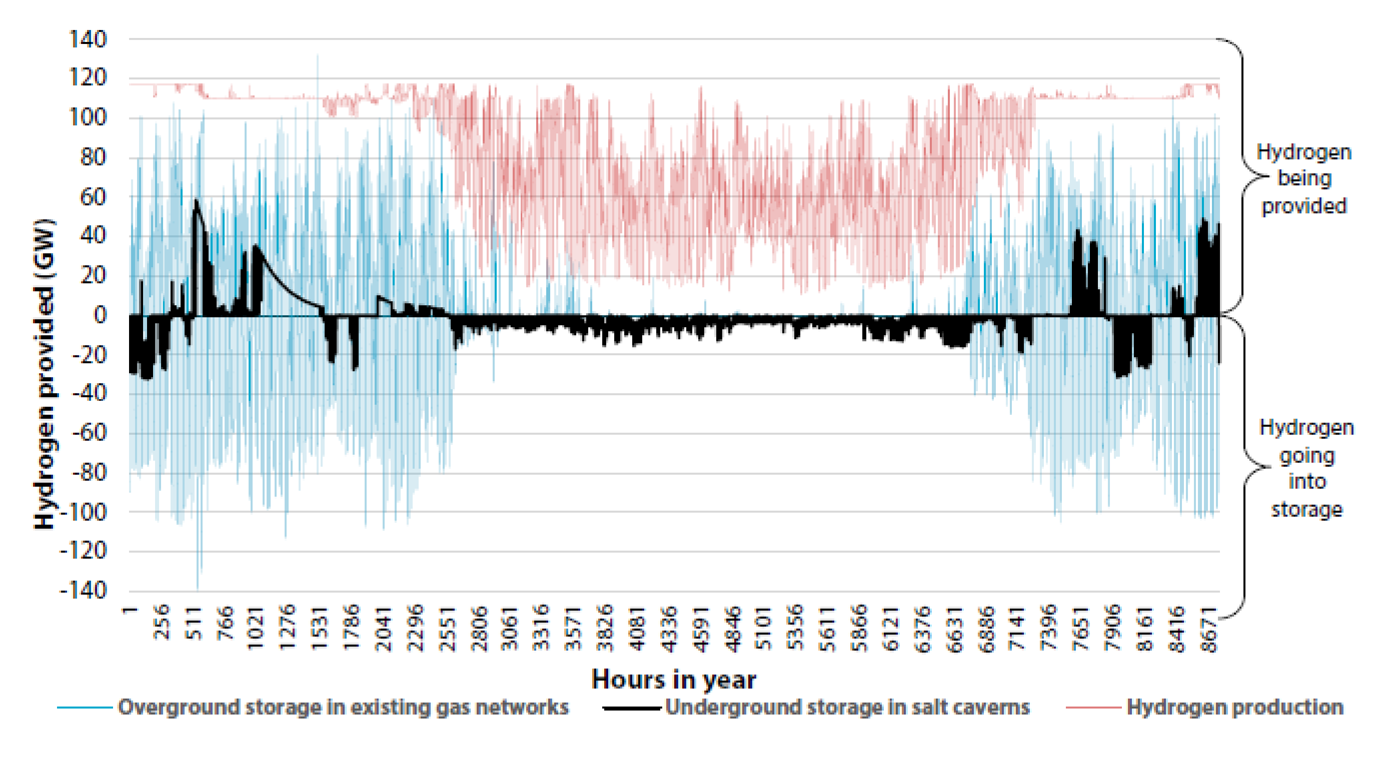


Figure 9. Hydrogen-embrittlement-resistant linepipe option: polymer-metal hybrid linepipe, experimental capability by Smart Pipe Co., Houston. A continuous copper or aluminum foil in the pipe wall is the hydrogen permeation barrier. Linepipe is manufactured in the field in a continuous process, for pipe of unlimited length, minimizing splices and terminations. The continuous flexible linepipe may be pulled into extant pipelines to repurpose them for gaseous hydrogen (GH2) service.

Figure 10. Trans Canada Pipeline test. Hydrogen-embrittlement-resistant linepipe option: Fiberglass overwrap constrains mild steel core radial flexing with renewables-source hydrogen energy input pressure fluctuations, for hydrogen embrittlement prevention. Has not been tested for renewables hydrogen service.

Fiber Reinforced Plastic (FRP) ("fiberglass") over mild steel core pipe provides tension strength for hoop stress, minimizing steel radial flexure.

Figure B3.3a. 'Linepack' storage in existing networks can provide 90% of hydrogen storage needs across the year



Source: Imperial College (2018) *Analysis of alternative UK heat decarbonisation pathways*.
Notes: Peak demand for hydrogen is 261 GW in hour 594, equivalent to 6pm on a January weekday evening. Hour 1 is midnight to 1am on January 1st.

Figure 11. "Free" energy storage by "packing" a dedicated, high-purity, underground, gaseous hydrogen (GH2) pipeline system, to "firm" and render dispatchable the electrolytic hydrogen production from variable energy resources (VER) such as wind and solar (PV or other). Compressors at the VER sources deliver GH2 to the gathering pipelines at up to maximum allowed operating pressure (MAOP), packing the system. When VER generation is low, customers withdraw GH2 fuel from the distribution pipelines. The entire GH2 pipeline system must be built of linepipe immune to hydrogen embrittlement (HE), aka hydrogen corrosion cracking (HCC): probably polymer-metal hybrid tubing. Figures 9, 10. This GH2 pipeline system could be created by relining, thus repurposing, extant hydrocarbon or other pipelines, with the Figure 9 technology. Source: Hydrogen in a Low-carbon Economy, UK Committee on Climate Change, Nov 2018.

For example, a 36" GH2 transmission pipeline 1,600 km long, packed to 100 bar, unpacked to 30 bar, stores ~ 120 GWh as chemical energy in the H2 molecules, at only the cost of compression at VER delivery points to gathering pipelines.

Transmission CAPEX per MW – mile, over 1,000 miles

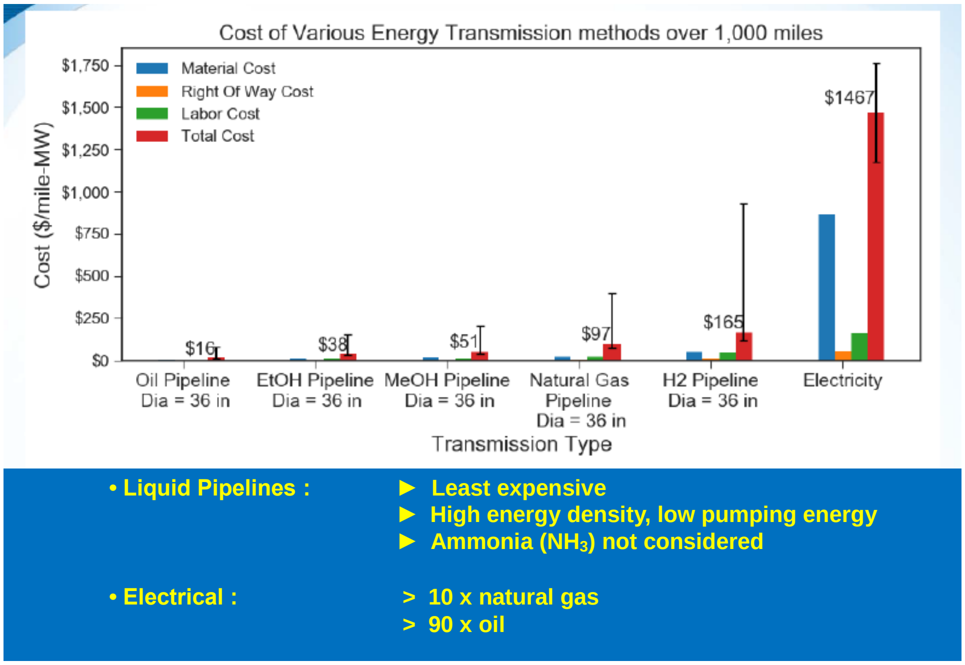


Figure 12. From research supported by an award from the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy under Award Number DE- EE0007602 and by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. (Unpublished at 17 Aug 20, but submitted to one or more journals by the authors)

Figure 12. From "Relative Cost of Long-Distance Energy Transmission by Electricity vs. Gaseous and Liquid Fuels" Daniel DeSantis, Brian D. James, Cassidy Houchins, Genevieve Saur, and Maxim Lyubovsky , 2019

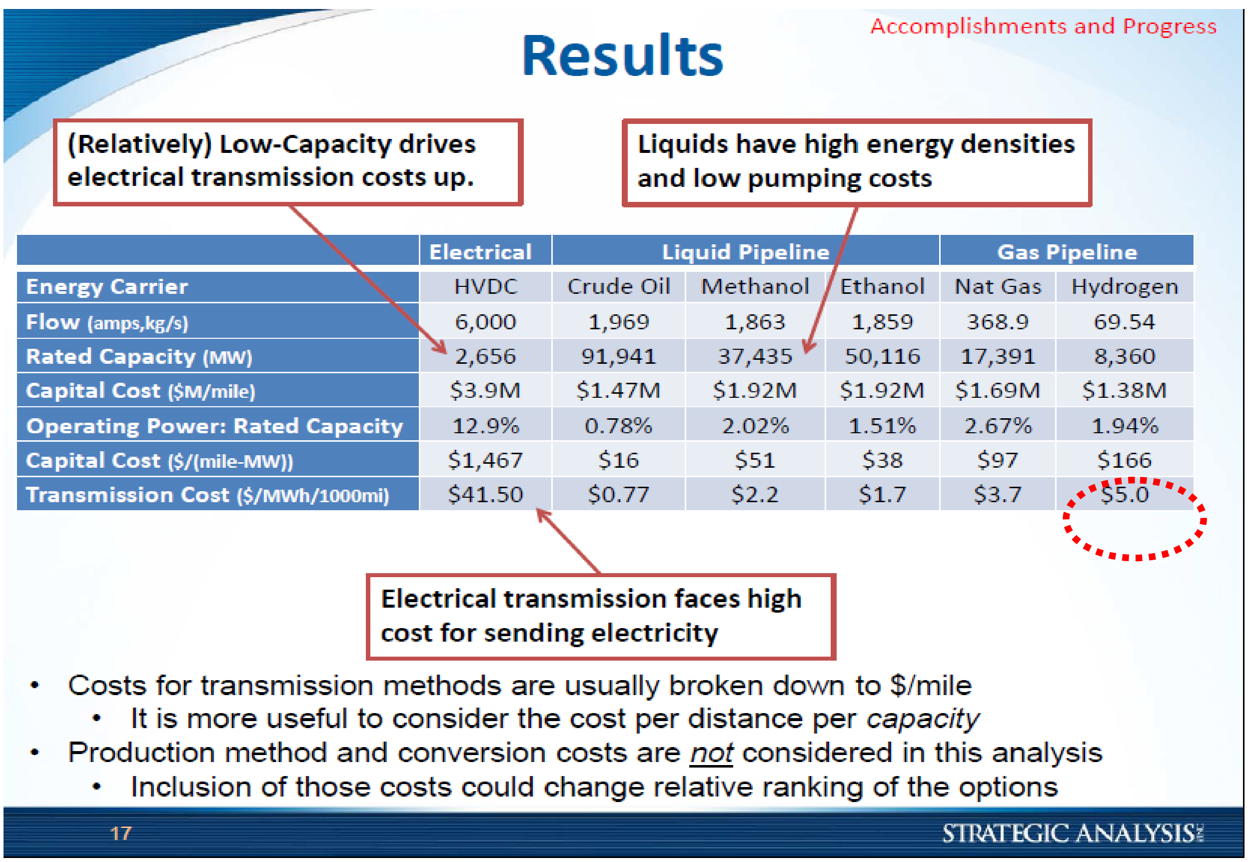


Figure 13. From" Analysis of Advanced H2 Production & Delivery Pathways " , June 2018, by Strategic Analysis
See slides 11 - 20 in: https://www.hydrogen.energy.gov/pdfs/review18/pd102_james_2018_p.pdf

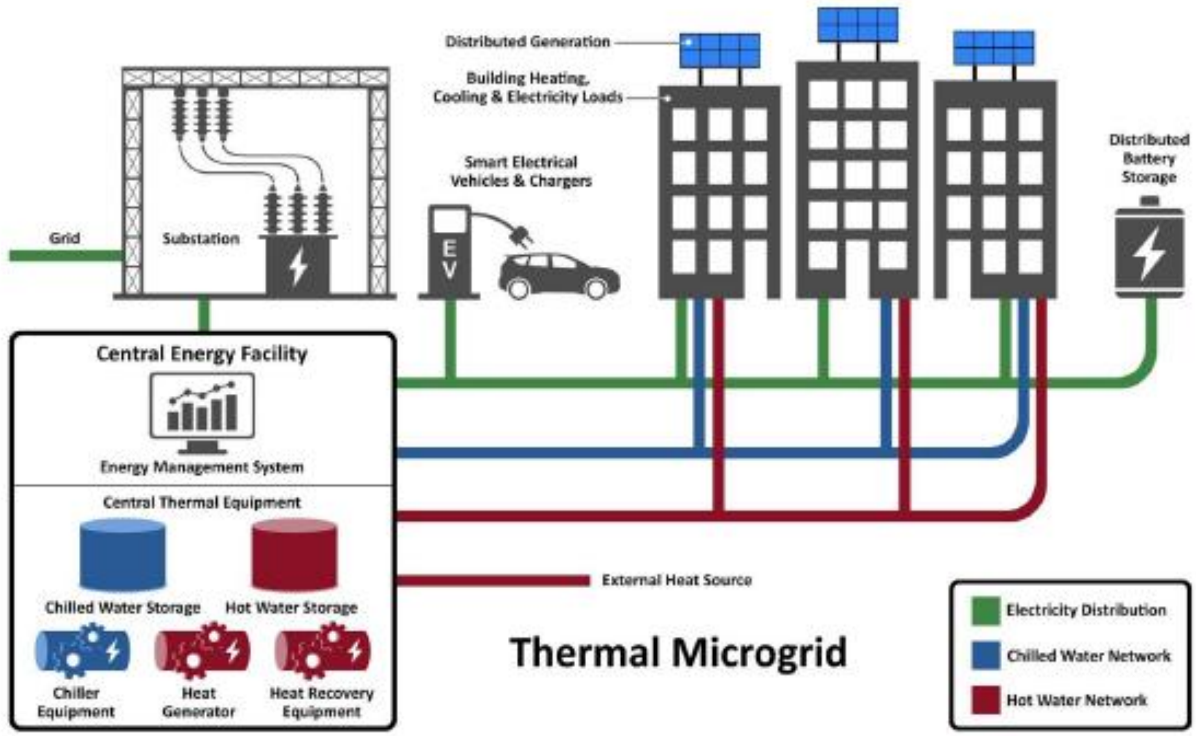


Figure 14. Basic thermal microgrid, with unspecified external heat source. From EDF Innovation Lab presentation at EPICBuildings, California Energy Commission (CEC), 2 Sep 20, webinar, by Sonika Choudhary, Principal Energy Analyst

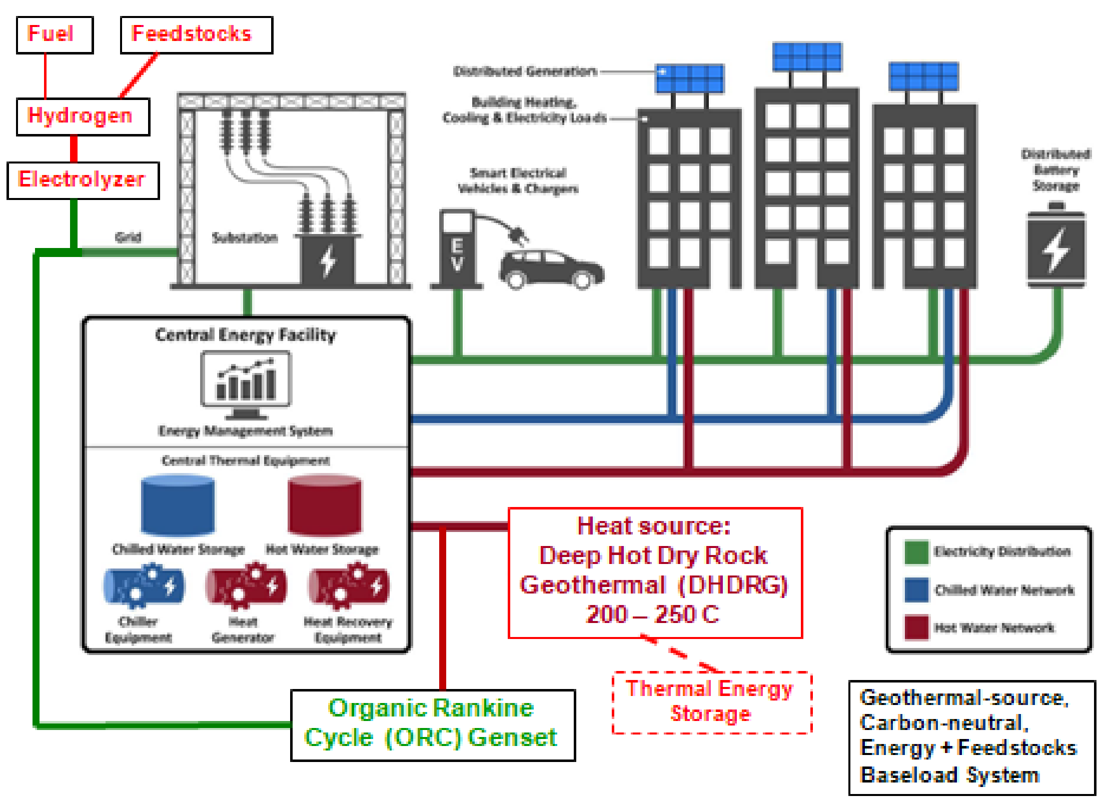


Figure 15. Micro- or Mini-grid driven by baseload DHDRG energy, delivers heat, electricity, hydrogen fuel, Industrial feedstocks [E+IF] , minimizing transmission and storage. Energy storage is free: leave heat in the ground until needed.

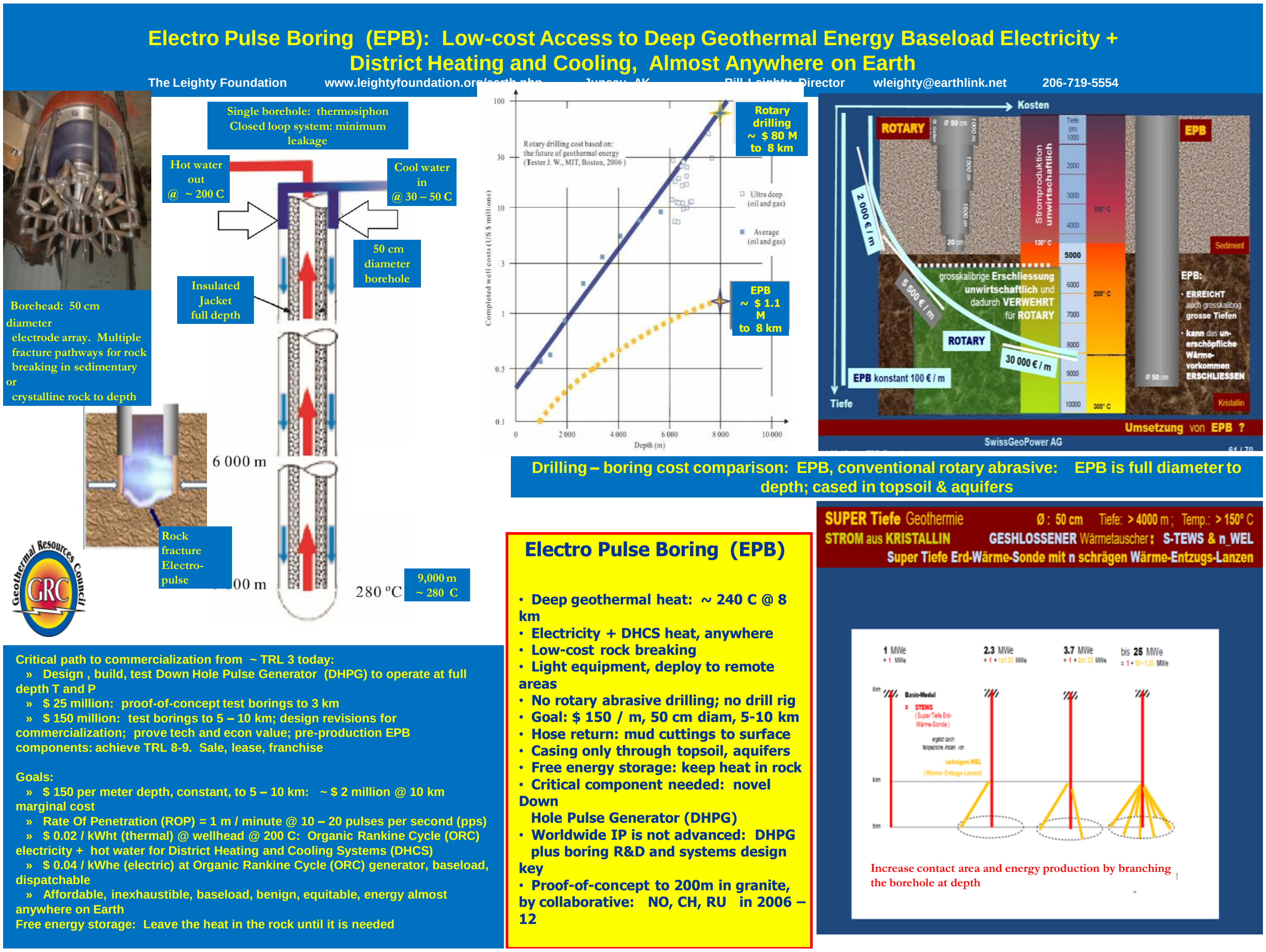


Figure 16. A candidate enabling technology for Deep Hot Dry Rock Geothermal (DHDRG) (6 - 10 km depth) energy, to supply the thermal microgrid concept in Figures 14 - 17. The human enterprise could thus provide all its global [E+IF], i.e. [electricity + heat +Industrial Feedstocks] via a proliferation of autonomous, loosely-interconnected, micro- and mini-grids: the ultimate in distributed energy resources (DER). Energy storage is free: leave the heat in the ground until needed.

But, the energy industry must be able to bore "deep enough, cheap enough" to profitably access DHDRG energy, delivering it as electricity, heat, and hydrogen within each micro- or mini-grid at competitive prices. See "The Future of Drilling: Non-conventional Concepts", 15 July 20, 1145 hrs https://www.texasgeo.org/pivot2020

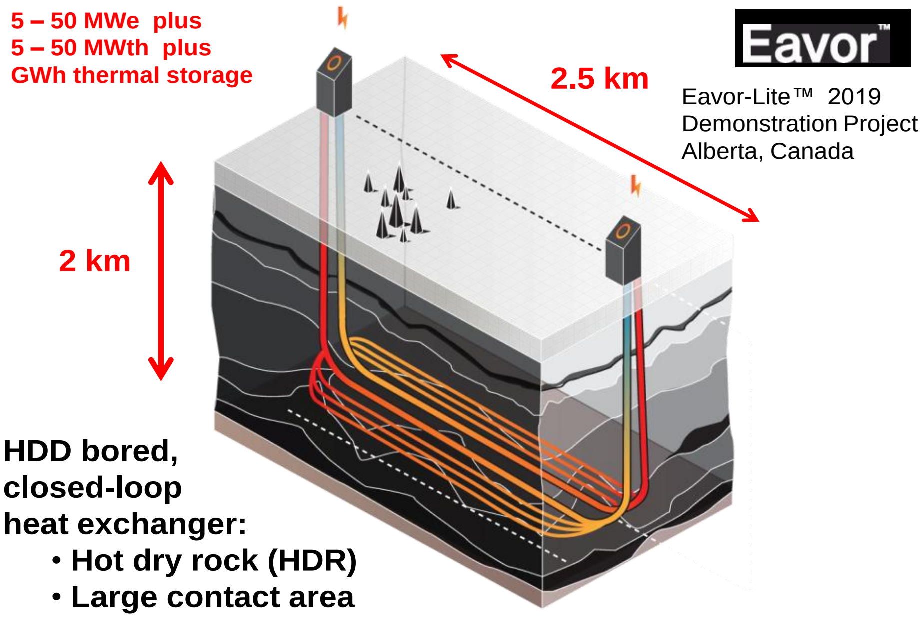


Figure 17. Deep Hot Dry Rock Geothermal (DHDRG) energy system. The proof-of-concept, operating, demonstration energy plant near Calgary, AB, Canada. Graphic from www.Eavor.com Precision horizontal directional drilling (HDD) at depth enables this Advanced Geothermal System (AGS). High-T materials and novel boring technology should enable profitable harvesting of deep (6 - 10 km) heat for electricity generation, district heating and cooling systems (DHCS),and electrolytic hydrogen production. Energy storage is free: leave the heat in the ground until needed. Hydrogen's value for storage and transmission is thus reduced by ubiquitous DHDRG, the ultimate in distributed energy resource (DER).

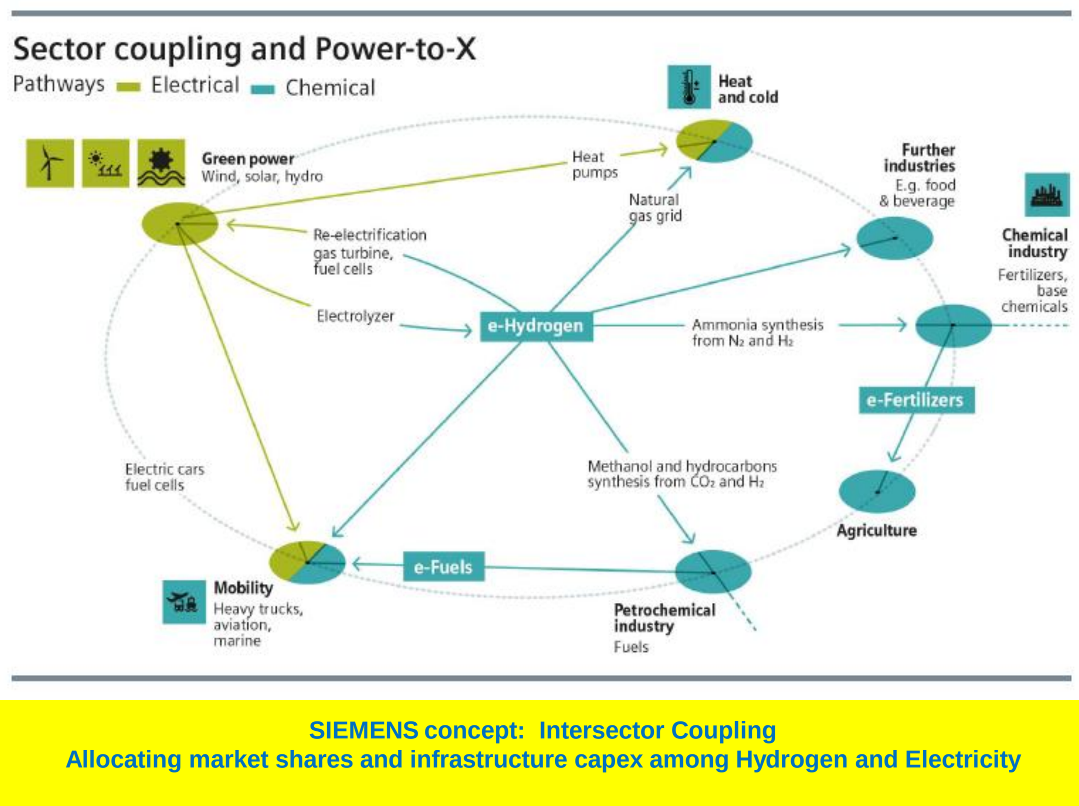
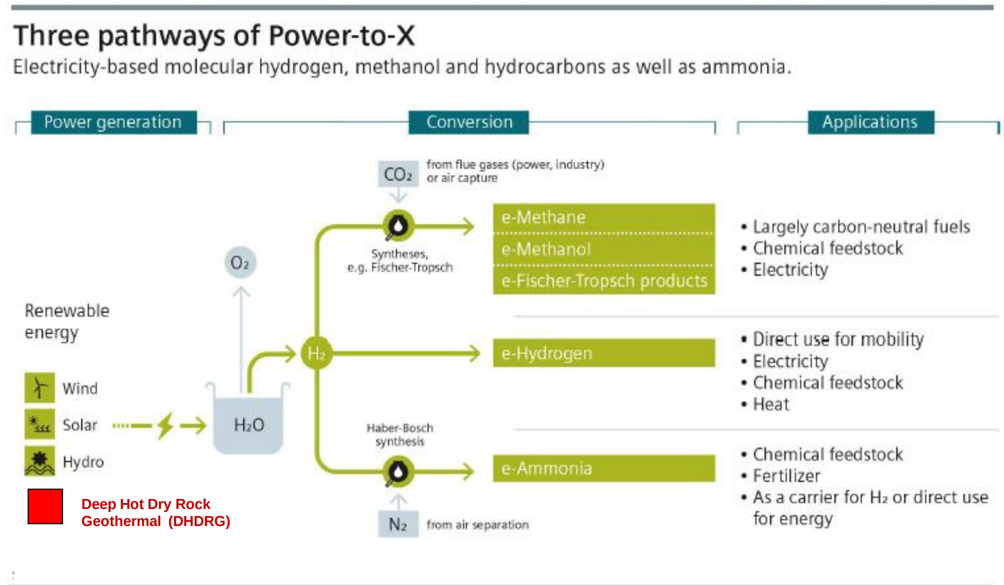
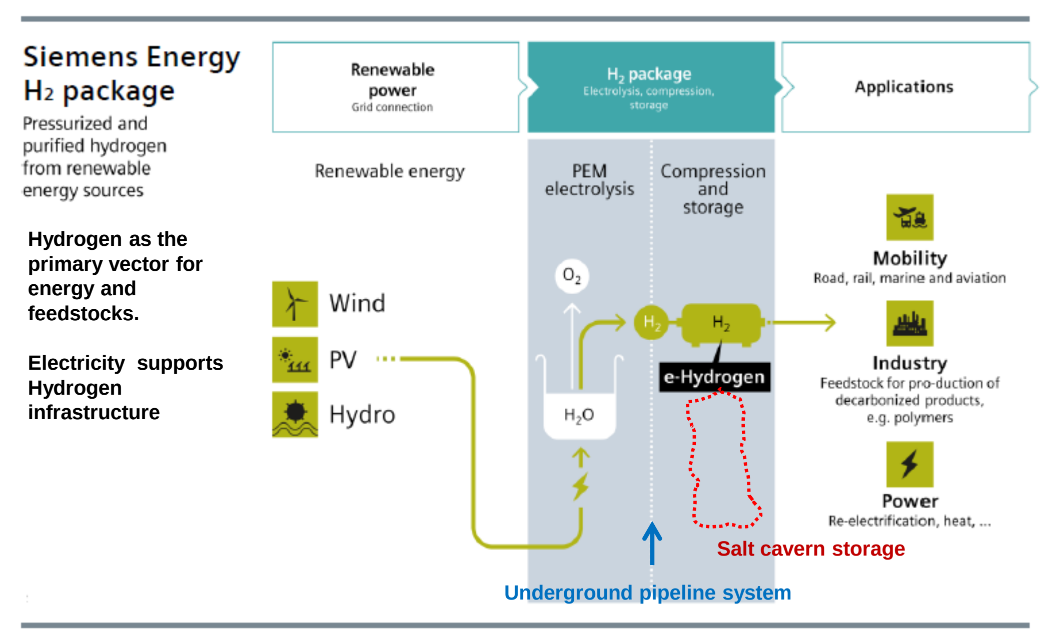


Figure 18. Hydrogen's role in "Inter-sector" or "Cross-sector" coupling: concepts for exploring [energy + feedstocks] systems definitions to optimize pathways to de-carb and de-GHG the entire human enterprise, before year 2050



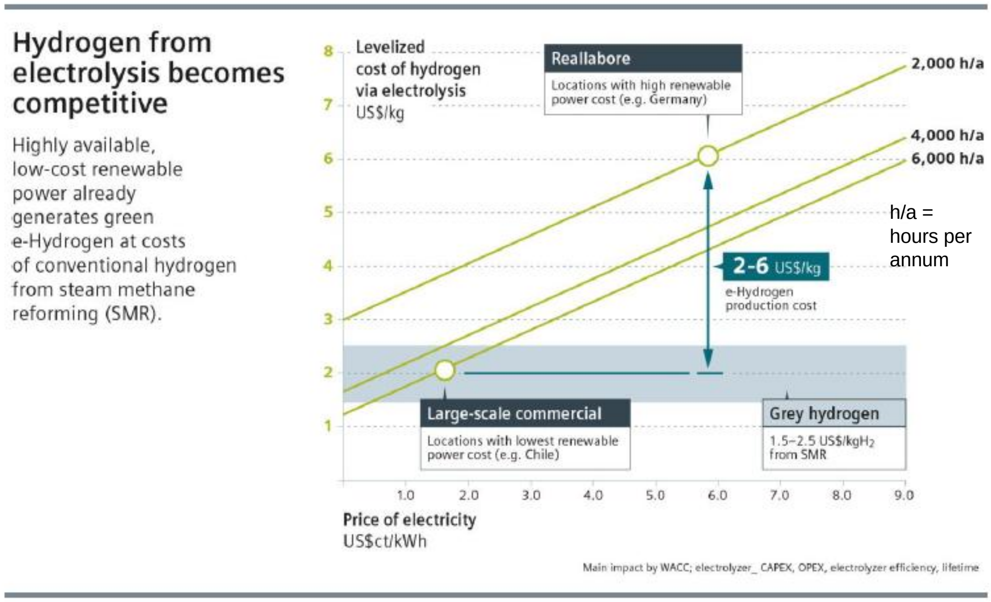
SIEMENS concept: Intersector Coupling
Allocating market shares and infrastructure capex among Hydrogen and Electricity

Figure 19. Hydrogen's role in "Inter-sector" or "Cross-sector" coupling: concepts for exploring definitions for [energy + feedstocks] systems for the entire human enterprise, before year 2050. Save otherwise-curtailed wind and PV in CA ?



SIEMENS concept: Intersector Coupling
Allocating market shares and infrastructure capex among Hydrogen and Electricity

Figure 20. Hydrogen's role in "Inter-sector" or "Cross-sector" coupling: concepts for exploring definitions for [energy + feedstocks] systems for entire human enterprise, before year 2050. Whole-systems analysis, design is essential.



The capacity factor (CF) of electrolysis is as important as the levelized cost of electricity. It defines the capital efficiency of the electrolysis plant.

Baseload renewable electricity from Deep Hot Dry Rock Geothermal (DHDRG) energy would achieve a high CF: [hours per annum (h/a) / hours per year (8,760)]

Figure 21. Hydrogen's role in "Inter-sector" or "Cross-sector" coupling: prospects for profitably harvesting otherwise-curtailed wind and solar energy, in CA and beyond, because of low CF of electrolysis and hydrogen gathering assets.

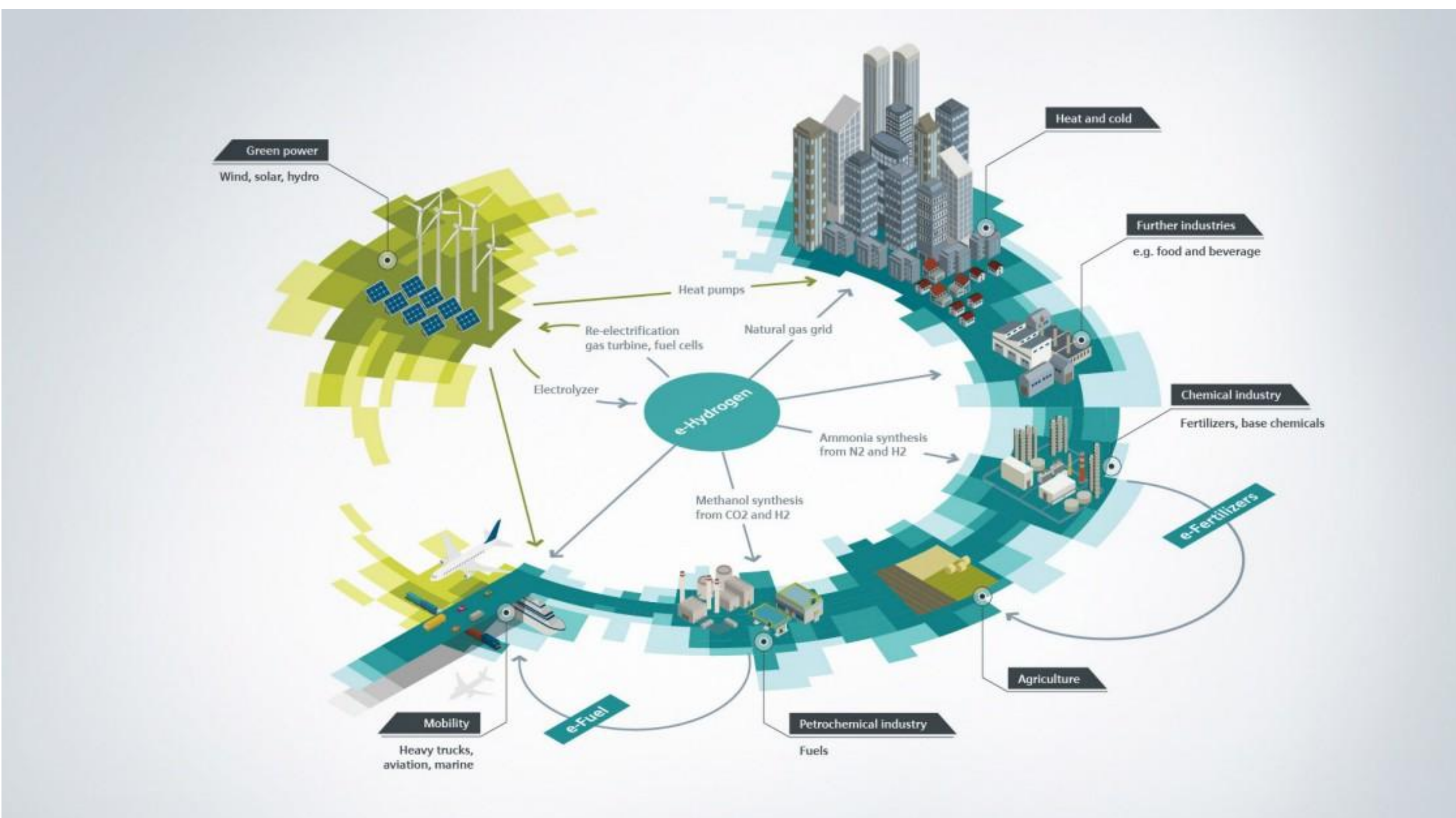


Figure 22. SIEMENS concept: Hydrogen's role in "Inter-sector" or "Cross-sector" coupling: exploring optimized roles for [energy + feedstocks] systems, beyond electricity Grid and energy, for the entire human enterprise, before year 2050.

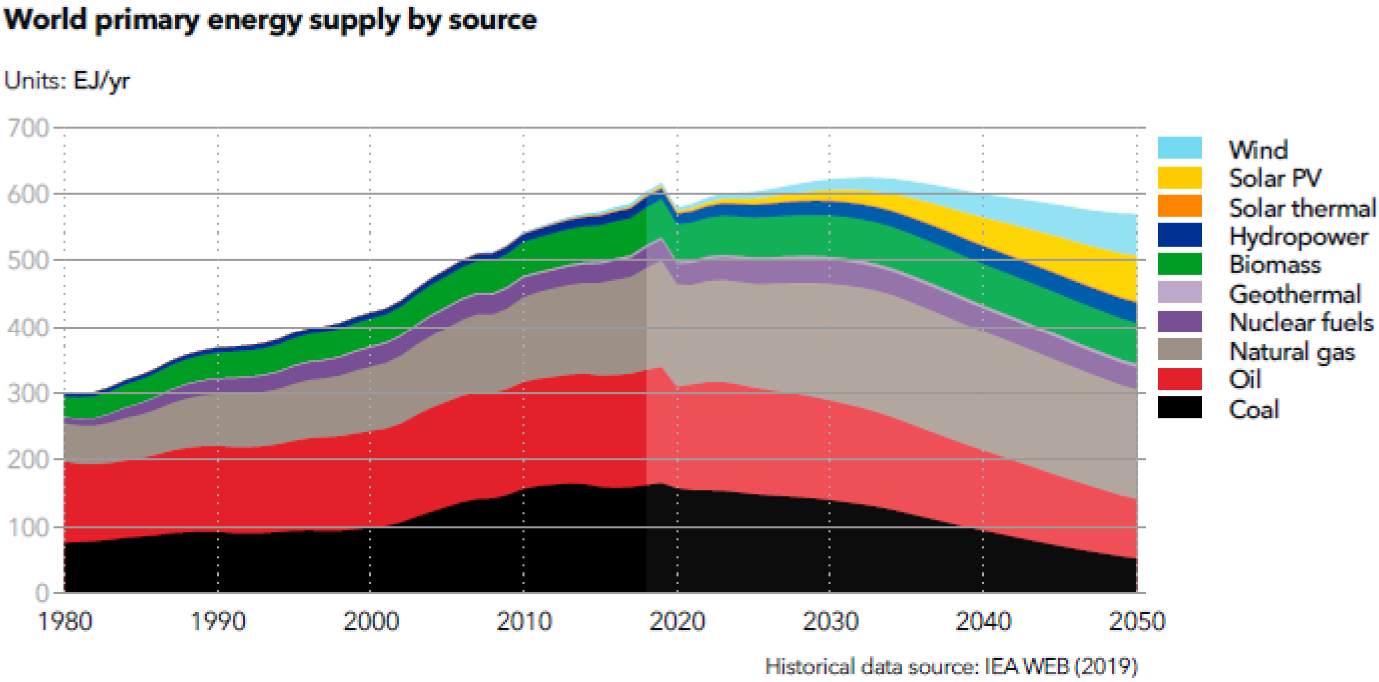


Figure 23. Conclusion: In year 2050 humanity's total energy supply is still estimated at > 50% fossil fuel, as reported by DNV GL from the International Energy Association (IEA, 2019). This is unacceptable: we will not prevent the catastrophic spectrum of "climate change": global warming, sea level rise, ocean acidification, species extinction, and violent conflict. How may hydrogen-based "Whole-systems" reverse this bleak prospect, accelerating climate-neutrality and climate change reversal ? How shall we optimize our investments in electricity and hydrogen infrastructure, and by policy allocate market shares to supply all humanity's [energy + feedstocks] from CO2-emission-free (CEF) sources ? This research Project should help us steward our precious capital while avoiding stranded assets, engaging this "wicked problem". Graphic source: Energy Transition Outlook 2020, DNV GL: https://bit.ly/32sbFz2 "Heading For Hydrogen"

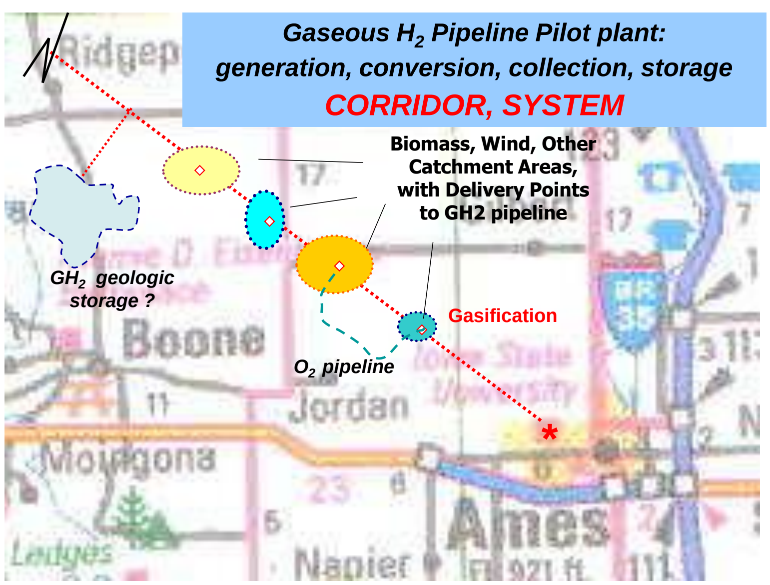


Figure 24. A proof-of-concept CEF GH2 pipeline pilot plant demonstration project in the Great Plains, perhaps destination Iowa State University and DOE Ames Laboratory. Whole-systems engineering research: a pipeline-based International Renewable Hydrogen Transmission Demonstration Facility (IRHTDF), perhaps via the IPHE.

APPENDIX A Recent Hydrogen systems studies, strategies, roadmaps, and webinars

Hydrogen Council https://hydrogencouncil.com/en/category/studies/ APPENDIX B

World Hydrogen Conference 22-24 Sept 20 https://www.worldhydrogencongress.com/Agenda

A hydrogen strategy for a climate-neutral Europe European Commission, 7 August 2020
https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

Fuel Cell and Hydrogen Energy Association (FCHEA)
http://www.fchea.org/us-hydrogen-study http://www.ushydrogenstudy.org/

World Energy Council https://www.worldenergy.org/publications/entry/innovation-insights-brief-new-hydrogen-economy-hype-or-hope

Hydrogen: A renewable energy perspective IRENA, Sept 2019
https://irena.org/publications/2019/Sep/Hydrogen-A-renewable-energy-perspective

UK: Hydrogen in a Lo-carbon Economy, Nov 2018; "H21"
https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf

UK: HyNET Northwest https://hynet.co.uk/ https://hydeploy.co.uk/
https://hydeploy.co.uk/about/document-library/

Renewable Hydrogen Production Roadmap for California, UC Irvine, APEP, June 2020
http://www.apep.uci.edu/White_Papers_Renewable_Hydrogen_Production_Roadmap_For_California_June_2020.html

California Hydrogen Business Council (CHBC), 10 Sep 20, " German National Hydrogen Strategy " APPENDIX D.

ICEPAG 2020, UC Irvine, Advanced Power and Energy Program, 14-16 Sept http://www.apep.uci.edu/ICEPAG2020/

NREL: Novel boring technology for DHDRG access https://www.nrel.gov/news/program/2020/new-high-rate-drilling-system-could-revolutionize-high-temperature-power-electronics-for-geothermal-industry-and-beyond.html

DNV GL: Heading For Hydrogen
https://www.dnvgl.com/oilgas/Hydrogen/Heading-for-hydrogen.html?utm_campaign=OG_GLOB_20Q2_NURT_Hydrogen%20whitepaper%20-%20download-follow-up%2001&utm_medium=email&utm_source=Eloqua

The Hsue-Shen Tsien Think Tank: Systems Science Approach to Complex Problems. ["Systematology"]
AAAS, 4 October 2019 China Aerospace Laboratory of Social System Engineering (CALSSE)

Project GERI, BP, AUS, H_2 + NH_3
https://arena.gov.au/projects/project-geri-feasibility-study/
https://arena.gov.au/news/bp-australia-study-looks-to-scale-up-renewable-hydrogen-for-export/

Ammonia Energy Network
https://www.ammoniaenergy.org/articles/wartsila-repsol-and-knutsen-to-test-ammonia-four-stroke-engine/
https://www.ammoniaenergy.org/articles/hydrogen-stands-out-in-bps-new-strategy/?mc_cid=6da26c5f4e&mc_eid=003e56e4d4

Saudi export
https://www.ammoniaenergy.org/articles/saudi-arabia-to-export-renewable-energy-using-green-ammonia/

Rocky Mountain Institute (RMI)
https://rmi.org/why-nexteras-green-hydrogen-investment-is-a-big-deal/

CO Mines H2 & NH3
https://arpa-e.energy.gov/?q=slick-sheet-project/efficient-hydrogen-and-ammonia-production-process-intensification-and

Great Plains Institute (GPI) + World Resources Institute (WRI), 23 July 2020 release
Industrial Innovation Initiative (I^3)
https://www.wri.org/news/2020/07/release-industrial-initiative-releases-federal-policy-recommendations-us-economic
https://www.betterenergy.org/wp-content/uploads/2020/07/i3-Economic-Recovery-Recommendations-2.pdf

Pivot2020: Kicking Off the Geothermal Decade Pivot2020 was hosted by the Geothermal Entrepreneurship Organization (GEO) at the University of Texas at Austin, and the International Geothermal Association (IGA), along with NREL, other DOE labs, industry and organizational partners and friends. https://www.texasgeo.org/pivot2020

APPENDIX B Hydrogen Council https://hydrogencouncil.com/en/category/studies/

Relevant website excerpts:

The Hydrogen Council, a global coalition of 90+ CEOs working to enable the energy transition through hydrogen, calls on governments around the world to invest in hydrogen as part of their COVID-19 recovery plans. Hydrogen technologies can empower a more robust, resilient and sustainable economy; however, urgent action and global collaboration is required to deliver on their unique potential.

... for hydrogen to foster the energy transition ... acknowledge the contribution and potential of hydrogen as a key element of the energy transition ... define and implement a specific action plan with appropriate supporting tools that will help accelerate major investment into large-scale commercialization of hydrogen solutions across industries world-wide ... we need long-term thinking and massive investments in game-changing, systemic solutions such as hydrogen.

- Path to Hydrogen Competitiveness: A Cost Perspective, 20 Jan 20 https://hydrogencouncil.com/en/path-to-hydrogen-competitiveness-a-cost-perspective/
- Hydrogen, Scaling Up, 13 Nov 17 https://hydrogencouncil.com/en/study-hydrogen-scaling-up/
- How Hydrogen Empowers the Energy Transition, 15 Jan 17 https://hydrogencouncil.com/en/study-how-hydrogen-empowers/
- Position paper: Invest in Hydrogen for Robust, Resilient and Sustainable Growth as a Response to the COVID-19 Pandemic, 28 Jul 20 https://hydrogencouncil.com/en/invest-in-hydrogen-for-a-robust-resilient-and-sustainable-growth-as-a-response-to-the-covid-19-pandemic/
- Hydrogen cost to fall sharply and sooner than expected, 20 Jan 20 https://hydrogencouncil.com/en/cost-reduction-study-announcement/

APPENDIX C DOE EERE HFTO H2@Scale 2020 Annual Merit Review (AMR) selected presentations from:
https://www.hydrogen.energy.gov/annual_review20_h2fuel.html
https://www.hydrogen.energy.gov/annual_review20_infrastructure_systems.html#infrastructure

P102 Advanced H2 Production and Delivery Pathways Brian James, Strategic Analysis
https://www.hydrogen.energy.gov/pdfs/review20/p102_james_2020_o.pdf

ST001 System Level Analysis of H2 Storage Options R. Ahluwalia, ANL
https://www.hydrogen.energy.gov/pdfs/review20/st001_ahluwalia_2020_o.pdf

ST100 H2 Storage Cost Analysis C. Houchins, Strategic Analysis
https://www.hydrogen.energy.gov/pdfs/review20/st100_houchins_2020_o.pdf

ST204 HyMARC: H2 Carriers for Bulk Storage & Transport T. Autrey, PNNL
https://www.hydrogen.energy.gov/pdfs/review20/st204_autrey_2020_o.pdf

SA172 H2 Demand Analysis for H2@Scale A. Algowainy, ANL
https://www.hydrogen.energy.gov/pdfs/review20/sa172_elgowainy_2020_o.pdf

SA171 H2@Scale Analysis M. Ruth, NREL
https://www.hydrogen.energy.gov/pdfs/review20/sa171_ruth_2020_o.pdf

SA173 Energy Storage Analysis C. Hunter, NREL
https://www.hydrogen.energy.gov/pdfs/review20/sa173_hunter_2020_o.pdf

SA175 Regional Hybrid Energy SystemsTechnoecon Analysis R. Boardman, INL
https://www.hydrogen.energy.gov/pdfs/review20/sa175_boardman_2020_p.pdf

TA037 Demo & Framework: H2@Scale in TX and beyond N. Bouwkamp, Frontier Energy
https://www.hydrogen.energy.gov/pdfs/review20/ta037_bouwkamp_2020_p.pdf

H2000 H2@Scale Overview Bryan Pivovar, NREL
https://www.hydrogen.energy.gov/pdfs/review20/h2000_pivovar_2020_p.pdf

H2041 CA H2 Research Infrastructure Research Consortium Sam Sprik, NREL
https://www.hydrogen.energy.gov/pdfs/review20/h2041_sprik_2020_p.pdf

H2058 Toluene - MCH as 2-way carrier for H2 Transmiss + Stor R. Ahluwalia, ANL
https://www.hydrogen.energy.gov/pdfs/review20/h2058_ahluwalia_2020_p.pdf

H2059 CRADA: Electrolytic Renewable Fuel Production Optimal Ops J. Eichman, NREL
https://www.hydrogen.energy.gov/pdfs/review20/h2059_eichman_2020_p.pdf

NE01 Integrated Energy Systems: H2 & Chemicals Production S. Bragg-Sitton, R. Boardman, INL
https://www.hydrogen.energy.gov/pdfs/review20/ne01_bragg-sitton_boardman_2020_o.pdf

IA002B SCAQMD Program Overview J. Impullitti, SCAQMD
https://www.hydrogen.energy.gov/pdfs/review20/ia002b_impullitti_2020_o.pdf

Long-duration storage: J. Eichman, NREL
https://www.energy.gov/sites/prod/files/2020/01/f70/fcto-fcs-h2-scale-2019-workshop-8-eichman.pdf

APPENDIX D CA Hydrogen Business Council (CHBC) webinar. 10 September 2020 Topic:
" German National Hydrogen Strategy " [DE = Germany] [Bill Leighty comment, insertion]
https://vimeo.com/456676232
Also: https://www.bmbf.de/files/bmwi_Nationale%20Wasserstoffstrategie_Eng_s01.pdf

Speakers: Dr. Cyriac Massue, Dr. Toni Glaser, German Federal Ministry of Economic Affairs and Energy
Gia Brazil Vacin, Go-Biz, California (CA) Governor Newsome's office; Tyson Eckerle, Go-Biz backup

Summary: This webinar covers Germany's €9 billion plan that will fund green hydrogen production, of which €2 billion are earmarked for projects outside of Germany (DE).

NOTES from presentations: Video: https://vimeo.com/456676232 Time log of webinar video (minutes):

08:00 (Begin DE presentation) Other actors and Ministries considered. See many uses. New value chains: Mobility, aviation, chemicals, decarb some industrial processes. Green or climate-friendly. Electrolyzers, transport H2, heat. Important, convenient, useful, versatile energy carrier, storage medium. Power-to-x, sector coupling (vector, system)
11:40 DE status: Production = 55 TWh / yr consumed = 1.5 MMT / yr = 50% refineries, 50% chem industry (NH3, MeOH, other). 3.85 TWh = electrolysis (byproduct of chlor-alkali process) + (high-purity for chems); balance SMR.
13:30 Demand growth to total H2 = ~ 90 -110 TWh mostly industry + transport.
Add 5 GW in 2030 + 5+ GW in 2040: not enough renewable energy (RE) in DE for 110 TWh H2, so DE imports H2 carriers (green + ??)
14:30 DE will need green H2 imports, from EU + beyond, but DE will export H2 tech equipment: essence of the "Strategy" (where find in brochure?)
15:30 Green H2 must compete with coal (coke) for steelmaking; with coal & gas for other industrial. Need infrastructure = chicken - egg. Need secure supply via pipelines. [probably dedicated GH2: see below] 7 "strategic objectives" in H2 strategy (slide 6)
Want int'l coop, projects, for that green H2 supply (for H2@Scale big picture, below, as in USA DOE HFTO ?).
17:00 Want to see whole market, see how whole value chain of H2 will work out, how bricks can interlink, in heavily-industrialized DE. From production + transport H2, to mobility applic (+industry ?)
18:10 Action Plan = 6 measures (slide 7) Integrated approach: balance, not subsidy focus. Elec source too costly in DE: RE adopt charges. So, affordable elec for elecrolysis how ? R&D offensive: "H2 Technologies 2030"
19:40 How implement EU energy directive ? (not interesting to USA)
20:30 How can "grreen" steel be competitive with "gray" steel? Blast furnaces. Need state subsidy aid? polit proj's
21:15 CO2 certificates prices increasing.
21:40 Heat not attractive: last phase; elec heat pumps very good.
22:20 Reuse, Convert extant NG pipelines, esp decommissioned, is priority. (Smart Pipe?)
22:50 Now window of opportunity for steel mfrs to convert: DRI with H2
23:10 Big "H2 Tech 2030" program. Big, applied, close to full scale
23:30 Steel "Integrated approach"(slide 8):
28:10 2 billion Euros to stimulate int'l coop on demo projects, EU + international. Interest from CA, so where next ?
29:10 How produce + transport "green" H2 ? Which forms, derivatives ? NH3, fuels, etc.
30:24 Need standards, so can ramp up global production, for DE imports, global trade. Green H2 must be competitive
31:00 collaborate: ongoing projects in CA, might interest us.
31:15 END DE presentation

Gia Brazil Vacin: (slides presentation)

32:15 START. 6 sectors in Go-Biz. ZEV mkt develop group. CA policy context: CEC. CARB, CPUC, DGS. Capital grants. LCFS. Capacity credits. Infras grants = H2 stations.
35:45 42 public stations open; 16 in progress; 8,600 KDV FCV's ; 48 buses; 3 HD truck stations, in construction. Cars lineup for fuel, now. 4 Sep CEC announces new stations awards. 120 stations; start with 36.
38:20 Industry brings $ 288 M to stations.

39:15 CA global leader; FC aviation. Intermountain project, LADWP, UT salt cavern, H2 CT's with NG mix. Magnum.
39:40 Very large curtailed renewables;
40:00 No way to get to 100% without H2.
40:15 Now CA not doing much beyond transport; start to dip toes. Mostly local, regional
40:20 Example: LADWP, from coal to gas, open in 2025. 20% RE-H2 by 2030; 100% RE-H2 by 2045
40:30 What's next, needed ? CA state H2 Plan ?
40:40 City of Lancaster: largest RE- H2 facility in world. 11 MMT / day. Muni waste streams, save $. Full on: 2023.
41:30 Get serious: shift from myopic think about ZEV choice,
41:50 Focus more on H2 systems. Important Q for State: " Are we committed to H2 systems ? " Make decisions from this perspective.
42.15 We have SB-100 + EO's, so that helps. Much to learn from DE. Think holistically across value chain.
42:45 END Gia gia.vacin@gobiz@ca.gov
44:10 Q (DE): DE driven much by need to decarb by 2050, especially some sectors very hard to do w/o H2; industrial processes. What are CA goals ? From same top down as DE, EU. Gia:

> 45:40 CA goal total decarb by 2045 - 50 (?), so same drive as DE.
>
> 45:50 CA recognizes importance of scale; acceleration of H2 outside transport; it's growing;
>
> 46:30 CA can't get fully decarbonized without H2; we don't have another solution set. Hard to decarbonize by sectors. Need both bottom-up and top-down.
>
> 46:50 Very little going on at that level. We're asking, "What's next ?" at state level. Do we need to have a "H2 state plan" ?

47:30 (DE): We are realizing that industrial sectors and heavy transport are hardest to decarbonize. LDV's are not a priority. BEV's are fine for short distances. Don't know the likely mix for LDV FCV and BEV, but we're sure that FC will be better in HD.
48:50 (Gia): Good points. CA has been grappling with this quite a bit. Here's where we've landed, so far: Talking with industry: synergy with LDV, HDV, at least in transport. LD drives down cost of components [through volume], while HD drives down cost of molecule(s). Need both LD, HD. For CA it's getting to scale, driving down costs.
50:30 Q: (Gia) How are you getting German government support ?
A: (DE) All ministries agree that renewable electricity will not be enough, so H2 will be key. There's a huge consensus within fed government and among the states. The only controversy: Shall we focus only on "green" H2, or shall we accept "blue" or other H2 colors for interim, for transition. Nuclear is more difficult, and varies among the EU countries. FR has much nuclear; DE is phasing it out.
53:00 (DE) We want to subsidize only the production of green H2. Germany won't have enough green electricity for the total H2 demand. One steel plant will require a great amount of H2 for DRI (Direct Reduction of Iron).
54:00 Transportation H2 fuel is easier than H2 for industry.
55:20 Q: (Gia) Outside gov't, has DE bottom-up support for H2 from people and NGO's ?
55:50 A: (DE) It's more difficult when you go into the details; understand what the options are all about. Shall we use H2 for heating ? We often confuse CCU and CCS.
57:20 Other member states are about same. Must avoid seeing H2 as a panacea.
58:30 DE is densely populated. Will need many more wind turbines + PV plants. Where to put them; allocate their output to electricity or to H2 ?
1:00:00 Q: (Emanuel) How is the 2 B Euro collab investment fund being managed ? How does CA access it ?
1:00:50 A: (DE) We're now drafting guidelines, criteris, for project choice, who can apply, then a "Call for Projects". Now finding projects to produce green H2. Subsidize what ? Capex, opex ? Criteria: green, low-cost, transportable to DE, DE companies able to participate, fit EU regulations.
1:03:50 Q: (Emanuel) Will cost share be required ? Are you encouraging private enterprise investment ?
1:04:00 A: (DE) Definitely want to use our funding to leverage others'. Demo projects to trigger private investments. DRI steel plants example: DE gov't may subsidize opex, but expect private enterprise will do capex.
1:05:00 Q: (Emanuel): Gaseous hydrogen (GH2) pipelines. Part of the "Strategy" ? Dedicated or converted extant pipelines ? Plans + strategies for blending H2 + NatGas , or prefer dedicated high-purity H2 infrastructure ? DE agree with the "backbone study", by "other" [EU, elec] transmission operators, released in July '20 ?

1:05:45 A: (DE) Important: Blending good for phasing-out NatGas, use extant infrastructure. But, DE not emphasizing blending for three reasons: (1) [blended gas used for] heating; not a priority, in early phases, for scarce + expensive H2; (2) big DE chem industry uses pipeline NatGas; H2 is a contaminant; must remove H2, which is costly. EC "H2 Strategy" released in July, agrees: blending not priority; don't expect much of it. Small, rural, and distribution networks, but they have small effect. We're now dedicated to large, dedicated, distribution pipelines, from production centers to big industrial users. (3) Mobility sector: only two options: (a) H2 from centralized production to fueling stations via dedicated pipelines; (b) H2 production at stations via electrolyzers.
1:08:00 So, we don't see now an opportunity for blending; see that as going in wrong direction for our objective.
1:08:30 Q: (Emanuel): How was DE leadership convinced that H2 is necessary, for future of renewable energy (RE) in Europe ? Was modeling used to derive DE's H2 Strategy; how ?
1:08:52 A: (DE) H2 not seen as a replacement for RE; if we use Green H2 extensively, we need even more RE. Strategy clear on that. Elec goal is 65% renewables by 2030; Green H2 must not interfere with that. Many models and studies available. Our approach: "Action Plan" goes through 2023, then assessment, because so many unknowns & conflicting data, now. Depends on assumptions. Review in 2023; adapt our strategy to evolving conditions.
1:10:00 LDV sector: cases exist for wide variety of assumptions, outcomes. We don't know yet. Must watch launching markets to see directions.
1:11:00 Q: (Emanuel): Have any DE states shown special interest in H2 ? For Gia: Where's H2 growth, interest growth, likely outside CA, in USA ?
1:11:45 A: (DE) Much like USA, some DE states have own budget and industry. Independent H2 Strategies. Eastern DE states are still behind, so see new way to move ahead, new innovation parks, industries, etc. Example: Tesla building factory in Brandenburg, E DE. Econ advantages granted for settling there.
1:13:30 A: (Tyson E) CA has long been leader, but now interest from CO, WA, UT, some in NE. People just starting to get interested. Noticing sea change, but much work to do: get word out; ask right questions; what H2 can do. No USA state has, yet, an H2 strategy. [CA first, now ? Gia suggested so]
1:14:40 Emanuel: Webinar over. CHBC will collect questions [publish where?]. Thanks to all.
Try: https://www.californiahydrogen.org/resources/webinars/
NOTE: CA - DE H2 conference, 26 Oct. Time ?

Questions from audience:

- Q: How shall CA strategize optimum investment mix in electricity and H2 infrastructure, and market shares for energy and feedstocks, to (1) accelerate total CA decarbonization; (2) minimize long-term costs; (3) prevent over-investment in electricity "Grid" ?
- Q: Who in CA is, or should be, investigating the prospects for H2 underground pipeline infrastructure for gathering, transmission, "packing" storage, and distribution for the large amount of CO2-emission-free H2 needed to meet expected total demand ? Figures 7, 11.
- Q: What's status of Germany's interest in (1) dedicated high-purity gaseous underground H2 pipeline networks; (2) large-scale gaseous H2 storage in deep, solution-mined salt caverns (HYUnder ?) ?

APPENDIX E Key concepts from EC "Hydrogen Strategy for a Climate-neutral Europe", July 2020

1. Need a strategic approach: bridge electricity-hydrogen gap for RE storage; transportation; long-distance transmission, to become totally decarbonized and free of all GHG emissions
2. Repurpose or re-use parts of natural gas sector; don't build whole new hydrogen infrastructure (pipelines, etc.)
3. Define Hydrogen " Society", "Economy", "Ecosystem" via European Clean Hydrogen Alliance as Hydrogen Initiative
4. Provide solutions for hard-to-abate sectors: several transportation; steel, chemicals, cement; N-fertilizers
5. We are probably past tipping point(s): urgent action and opportunities now require:
    a. Critical mass in investment
    b. Enabling regulatory framework

APPENDIX F Hydrogen systems potential: CEF hydrogen fuel for CHP in buildings, perhaps via GH2 pipeline networks. Webinar notes: EPIC-Buildings-2 Sep 20 AM California Energy Commission (CEC)

- "Reimagining Buildings for a Carbon-neutral Future"
- Lightning Talks: (videos)
- Microgrid & Solar Solutions https://forum.meetatepic.com/agenda/session/336188
- Building Material Solutions https://forum.meetatepic.com/agenda/session/336182
- Grid & Energy Storage Solutions https://forum.meetatepic.com/agenda/session/336184
- Heat, Cool, Total Energy Effic https://forum.meetatepic.com/agenda/session/336201

Solutions in Planning Process https://forum.meetatepic.com/agenda/session/303114

APPENDIX G "Wicked Problem" Total de-carbonization and de-GHG-emission for the entire human enterprise, to provide all [Energy + Industrial Feedstocks] [E+IF], before year 2050, prudently and profitably, is a "Wicked Problem", which discourages everyone from "thinking beyond electricity" -- beyond the Grid -- to confront and transcend it.
Exploring "wicked": These resources sound familiar and relevant in this Project's hydrogen systems context:

- https://www.youtube.com/watch?v=O8FMBBVb71k
- https://www.ted.com/talks/tom_wujec_got_a_wicked_problem_first_tell_me_how_you_make_toast?language=en

Some aspects of "wicked problems" and how to engage them:

- Dysfunction within a complex system or network
- Unstructured: lacks shape, layers, hierarchy, order
- Open-ended
- Interconnected
- Interdependent
- Multi-dimensional
- Unbounded (in space and time)
- Crosses disciplines, borders, departments
- Difficult to contain or structure; pulling any part affects the whole
- Many deep and unknown interconnections and interdependencies; nodes and links
- Many possible solutions; no right answer
- Evolutionary; dynamic
- Problem and solutions are intertwined
- People responses: overwhelmed, denial, resignation, attempt to oversimplify (to "tame")
- Result: inertia, default to status quo without challenging the problem
- Required for success: recontextualize; whole systems thinking; challenge and break assumptions; paradigm shifts; integrate many aspects
- Never solve; only change; process is the product; collaboration in the design process is key; willing to produce model drawings *en charette*

APPENDIX H Miscellaneous opportunities

Energy storage: little new GH2 infrastructure may be needed, if we repurpose extant natural gas infrastructure. Need survey of operating, out-of-service, and abandoned pipeline assets, of all kinds, in CA and elsewhere, to estimate. Consider higher MAOP. NatGas pipeline injection vs. a dedicated high-purity GH2 pipeline system.
UK: "system betterment" 500 page report. Distribution via used low-P or refurbished pipelines at modest cost.

Challenge: Many organizations need help to "think beyond electricity" while they persist encouraging Grid investment:

- Example: American Council on Renewable Energy (ACORE) Grid Forum: Maximizing Renewables Integration through Grid Modernization Nov 17-18 (virtual)

"Explore the business opportunities, policy and regulatory issues, and technology challenges associated with integrating increasingly high penetrations of renewable electricity on the grid. Uniting dealmakers, policymakers and systems experts, to advance efforts to build a modernized grid that values flexibility, reliability and resilience. Examine the role of regulators, grid operators, electric service providers, corporate buyers and the renewables sector as states make progress toward 100% clean energy goals." [apparently confusing "energy" with "electricity"]

- Example: American Wind Energy Association (AWEA) Demand Committees:
  - Wholesale Electricity Markets & Transmission Committee
  - Electricity Policy Committee

CALIFORNIA

• California passed their state budget on 22 June 2020, including small amounts of funding for hydrogen infrastructure.
• California Air Resource Board (CARB) to approve Advanced Clean Truck (ACT) rule with ZEV mandates for 2024 on Thursday, 25 June to promote H2 fuel cell truck adoption.
• Funding shortfalls from Cap and Trade revenue at the state level will greatly reduce capital available for purchase incentives and infrastructure investments for H2 and Fuel Cell technology.

See also recent energy conference presentations from Bill Leighty: More at: www.leightyfoundation.org/earth.php

- https://vimeo.com/301111544 Deep Decarbonization of Total Global Energy: Hydrogen and Ammonia C-free Fuels as Integrated Energy Systems
- https://vimeo.com/209160500 Begin Now: Design and Build a Renewables-Source Hydrogen Transmission Pipeline Pilot Plant
- https://vimeo.com/203829095 Bigger Market for Renewables than the Electricity Grid ? Hydrogen and Ammonia Carbon-free Fuels for Transportation and CHP
- https://vimeo.com/128484940 Alternatives to Electricity for Transmission, Firming Storage, and Integration of GW-scale Wind and Solar via Hydrogen and Ammonia Pipelines

GLOSSARY

Grey hydrogen	Made from any HC: today mostly via the steam reforming of natural gas.
Blue hydrogen	Made from HC with carbon capture and storage (CCS); carbon-neutral if 100% CO2 capture
Green hydrogen	Produced via electrolysis of water; the electricity used for the electrolysis must be CEF; the Hydrogen is thus zero-carbon
Turquoise hydrogen	Produced via the thermal splitting of methane (methane pyrolysis). Byproduct is solid carbon rather than CO2. Carbon-neutral if the heat for the high-temperature reactor is produced from CEF or carbon-neutral energy sources, and permanently binds the carbon.
Pink Hydrogen	Obtained from nuclear energy, usually by heat-assisted electrolysis of nuclear offpeak electricity
Feedstock	Hydrogen or PtX, PtG, PtL product made from Hydrogen of any "color", used in manufacturing
Downstream Product	Anything made from Feedstock
Wicked problem	See Appendix G

ABBREVIATIONS

AEP	Annual Energy Production
AGS	Advanced geothermal System Access deep (4-10 km) heat via two vertical boreholes with HDD between to create heat exchanger via multiple parallel laterals at depth
CEF	CO2-emission-free, typically renewables-source
CF	Capacity Factor, %; also UF = Utilization Factor. % of time asset operates at nameplate rating
CHBC	California Hydrogen Business Council www.californiahydrogen.org
DER	Distributed Energy Resources
DHDRG	Deep Hot Dry Rock Geothermal Deep = 6-10 km Includes EGS and AGS. Distributed production of electricity, heat, an Hydrogen and / or Ammonia C-free and CEF fuels
DRI	Direct Reduction of Iron (by H2, rather than via carbon, from coke, made from coal)
[E+IF]	Energy + Industrial Feedstocks: the total energy-derived inputs to the human enterprise
EGS	Enhanced Geothermal System Access deep (4-10 km) heat via two vertical boreholes with fracking between them, at depth, to create heat exchanger. May cause earthquakes; pumping loss
GH2	Gaseous Hydrogen
GOM	Gulf Of Mexico
HC	Hydrocarbon; hydrocarbon fuels
HDD	Horizontal Directional Drilling; from O&G industry, for AGS
HE, HCC	Hydrogen Embrittlement, Hydrogen Corrosion Cracking. Dangerous weakening and failure of steel when exposed to high-purity Hydrogen, especially as pipelines experiencing large and frequent pressure variations, as they would in VER service.
MAOP	Maximum Allowed Operating Pressure, for gaseous pipelines
Mt	Metric ton
NH3, NH_3	Anhydrous ammonia, gaseous or liquid. Carbon-free energy carrier and storage medium and fuel
PtG	"Power to gas" Any gaseous product made from "green" Hydrogen; usually methane (CH4, natural gas)
PtL	"Power to Liquid" Any liquid product made from "green" Hydrogen
PtX	"Power to X" Any product(s) made from "green" Hydrogen, which is made from CEF electric energy
ROP	Rate Of Penetration, of a rock boring bit; m or ft per minute
TWh	Terawatt-hour
VER	Variable energy resource(s) (example: wind + solar)