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Comments on Renewable Hydrogen

Additional submitted attachment is included below.

General Comments

- Tri-Generation. Tri-Generation fuel cell systems can operate on biogas and other renewable fuels to generate renewable electricity, high quality waste heat, and hydrogen. The technology is based on a high-temperature fuel cell that internally reforms biogas (or natural gas) to hydrogen to support the generation of electricity at the stack and heat in the exhaust. By injecting more fuel, excess hydrogen is produced that can then be extracted as a transportation fuel (or other use). Due to the synergies captured by the process, Tri-Generation systems afford many economical, technical, and environmental benefits. For example, UCI researchers have calculated that Tri-Generation can produce hydrogen in a distributed fashion at costs below that of current methods (i.e., large-scale natural gas steam methane reformation).[1,2] Similarly, the high efficiency allows Tri-Generation systems to achieve the lowest emissions of greenhouse gasses (GHG) accounting for off-sets from energy stream utilization. Operating on biogas results in renewable, bio-hydrogen. The technology fits the growing California hydrogen fueling network and, due to these benefits, the use of Tri-Generation systems should be proactively pursued.

- Biogas Resources. In the near-term, production of hydrogen from biogas resources represents the most cost effective and technologically mature pathway for renewable hydrogen. While available biogas resources in California are limited, wastewater treatment plants, water resource recovery facilities, agricultural sources including dairies, and land-fills provide an immediate opportunity for meeting short and medium term sources for renewable hydrogen. While biogas pathways (e.g., Tri-Generation) are commercially viable, biomass-to-hydrogen pathways require further advancement prior to commercialization, but can contribute important amounts of renewable hydrogen in the mid- to long-term.

- Power-to-Gas. While biogas and biomass provide short-term resources, long-term renewable hydrogen must be produced in some capacity from power-to-gas (P2G), a strategy involving the electrolysis of water powered by renewable electricity. With the costs of renewable power decreasing dramatically in recent years and with the challenges of introducing very high levels of intermittent renewable power into the utility grid network and projected levels of otherwise curtailed generation, purpose-built renewable electricity to hydrogen portends the principal source for fueling the long-term population and diversity of hydrogen fuel cell vehicles. In the long term, dedicated hydrogen pipelines will serve as both a storage and distribution resource. In the short to medium term, the natural gas distribution system is an immediately available resource to serve this role.

  - Natural Gas Pipeline Injection. Integration of power-to-gas with the natural gas system provides a short to medium term solution to the storage and conveyance of the renewable hydrogen to the point of use. In particular, the inherent storage and transmission and distribution features of the natural gas system provide a highly valued resource for the widespread use of renewable gas to decarbonize the natural gas system while, at the same time, enabling (1) high penetrations of renewable power in the electric system, and (2) the ability of P2G to shift massive amounts of energy and to shift the energy over long periods of time (e.g., seasons).

[1] Leal and Brouwer, ASME Journal of Fuel Cell Science and Technology, Vol 3, pp. 137-143, 2006.
[2] Margalef, Brown, Brouwer, and Samuelsen, Journal of Power Sources, Vol 196, pp. 2055-2060, 2011.

Overall view of FCEV fueling with renewable hydrogen from a cost perspective

- Biogas and Biomass Resources. Renewable hydrogen costs more than hydrogen produced from current methods including steam methane reformation (SMR) of natural gas. Currently, renewable hydrogen produced from biogas via central SMR is the next lowest cost option. Hydrogen from electrolysis using renewable electricity is not currently cost competitive, but is likely to be cost competitive when renewable power in the future becomes ubiquitous or would otherwise be curtailed. To mitigate cost increases to consumers, biogas projects within and outside of California should be pursued. The potential of biomass-to-hydrogen pathways should also be considered since they potentially lie between electrolysis and biogas supply chain costs. Note that, while the CEC has recently released $36M (15-606: biofuels) and $23M (15-325: biomass to energy) plus federal cost share for biofuel projects, none of these projects include a hydrogen production pathway even though some of the considered technologies could be utilized in such a manner. Additionally, waste/residue biomass resources should be used to maximize the offset of GHG emissions, which would most likely occur from production of fuel for the transportation sector.

- Power-to-Gas: Wholesale Electricity Market. To attain cost effectiveness for electrolysis produced hydrogen, a key step will be the allowance of access to the wholesale electricity market for electrolysis production of hydrogen. Research at APEP has recently shown that the levelized cost of returned energy of renewable electrolysis followed by injection into the natural gas system and conversion back to electricity in a legacy power plant is comparable to battery electricity storage. In addition, given the self-discharge feature of most battery systems, power-to-gas strategies could better enable seasonal shifting of renewable energy. In each case, batteries and power-to-gas, access to the wholesale electricity market (or reliable access to inexpensive power) is the key determining factor for the cost of hydrogen. The CEC should pursue means by which energy storage systems and renewable hydrogen production systems could reliably garner access to inexpensive wholesale power when installed in grid support applications (e.g., when taking renewable power that would otherwise be curtailed, or while providing ancillary services such as regulation or Volt/VAR support with their inverters).

- Economies of Scale. To address the current challenge of high cost for renewable hydrogen, strategies to significantly increase demand and thereby reduce costs via economies of scale should be pursued in California. This could be particularly important for reducing the cost of hydrogen produced from renewable electrolysis. This may require outside of the box thinking, i.e., not just a focus on increasing light duty vehicle FCEV demand, but also supporting and investigating the use of hydrogen as a fuel in heavy duty trucking, port operations, shipping, aircraft, and rail applications. Additionally, the CEC should consider encouraging the use of renewable hydrogen in various industrial applications. Examples for increasing the current demand for renewable hydrogen production and consumption include (1) petroleum refinery use of renewable hydrogen to meet some portion of their current demand (hydrogen is widely used by refineries to produce petroleum distillate fuels), and (2) industrial end-uses of renewable hydrogen, such as hydrogenation of food oils.

Environmental Concerns

- GHG and AQ Co-Benefits. Consideration of the environmental impacts of renewable hydrogen generation, transmission, and conversion in end-use sectors should consider both air quality (AQ) and GHG impacts in tandem. While many of the pathways associated with renewable hydrogen will result in significant reductions in emissions of GHG and criteria air pollutants, some may achieve reductions at the expense of the other (e.g., injecting renewable hydrogen into the natural gas grid can reduce the GHG intensity of gas supply but could increase emissions of criteria pollutant emissions from combustion end-use devices that are currently optimized for natural gas). Strategies should be identified and targeted that maximize GHG and AQ co-benefits from renewable hydrogen in California.

- Natural Gas Composition Impact. Injection of renewable hydrogen into pipeline natural gas is particularly attractive as a means of coupling very low to net-negative GHG emitting strategies in the stationary power generation, industrial, and transportation sectors. Blending renewable fuels into the natural gas system will certainly reduce GHG emissions by displacing the corresponding amount of fossil natural gas, and by other mechanisms, such as the direct offset of methane emissions from the natural gas system. However, the combustion performance, emissions, and AQ implications of using fuel blends in gas-consuming combustion devices (e.g., gas turbines, reciprocating engines, industrial boilers, household appliances) are not well understood, in particular those without control systems that can manage variation in fuel composition. End-use devices are optimized for operation on natural gas, and changing fuel composition may impact (increase or decrease) emission rates of criteria pollutants. In particular, the addition of hydrogen can alter the performance of legacy combustion devices including residential appliances, commercial and industrial sources, and electricity generators. Research should focus on quantifying the spatial and temporal distribution pollutant emission and associated AQ impacts of variable natural gas composition to better understand emission rates and overall impacts.

- Impact of Distribution Options for Renewable Hydrogen. Maximization of the environmental benefits of renewable hydrogen should prioritize pipeline or zero-emission truck transmission distribution as a potential source of environmental trade-off (e.g., reducing the GHG intensity of transportation fuel but increasing diesel particulate matter emissions from diesel truck delivery). This may require further research into dedicated hydrogen pipeline and heavy duty zero-emission trucking strategies.

Generation Pathway and Technology Research Needs

- Systems Analysis. Systems analysis to determine the life-cycle costs, energy and environmental impacts of hydrogen energy storage and renewable hydrogen fuel production in comparison to alternative zero emission pathways should be considered. Systems analyses should consider the various supply chains that industry is currently pursuing.

- Proton Exchange Membrane Electrolysis. Proton exchange membrane (PEM) electrolysis systems should be advanced to better support and prove the grid support functions (e.g., provision of fast ramping, regulation and spinning reserve ancillary services) that they should be able to provide. The dynamic operation of PEM electrolyzers in direct complement to otherwise curtailed solar and wind power should be explored. Part-load conditions impact performance and control system modifications and alternative successful start-up, shut-down, and part-load operating parameters that allow better capture of the dynamics of otherwise curtailed renewable power should be pursued.

- Solid Oxide Electrolysis. Solid oxide electrolysis (SOE) is an emerging technology that offers significantly higher electricity-to-hydrogen conversion efficiency and can use heat as an input for hydrogen production. These features may make SOE technology attractive as a key technology in capturing the benefits of power-to-gas and hydrogen energy storage. However, SOE systems require research, development, and demonstration (electrolysis stack plus the complete balance of plant) to advance such systems and demonstrate the ability to control and maintain operating temperature (and other attributes) during dynamic operation, and start-up and shut-down as a complement to intermittent solar and wind power generation.

- Reversible Solid Oxide Fuel Cells. Reversible solid oxide fuel cell (RSOFC) systems operate at high temperature in both electrolysis and fuel cell modes, and may offer electricity energy storage efficiencies (electricity in, electricity out) that are unprecedented for hydrogen energy storage. These features make RSOFC systems attractive as a key technology in capturing the benefits of power-to-gas. RSOFC systems are capable of producing renewable hydrogen and oxygen during periods of available solar power and electricity during periods of high electrical demand. As is the case for SOE systems, RSOFC systems require research, development, and demonstration (reversible solid oxide electrolysis and fuel cell stack plus the complete balance of plant) in order to control and maintain operating temperature and other attributes during dynamic operation, and start-up and shut-down.

- Emerging Technologies. The following emerging technologies or processes are recommended for further study and/or advancement to support renewable hydrogen production:
  - Anaerobic digester technology improvements and demonstration for high solid content waste streams to hydrogen pathways
  - Solar thermal technology to increase the efficiencies of SMR and/or SOE processes
  - The use of nuclear waste heat to support hydrogen production pathways (e.g., gasification, SMR, thermal hydrolysis, SOE, etc.)

- Hydrogen Injection Impact on Natural Gas Combined Cycle Plants. Exploration of the impacts that hydrogen production and blending have on current electric power generation technologies should be explored. For example, UCI is currently injecting small amounts of renewable hydrogen into the natural gas line that feeds a natural gas combined cycle (NGCC) plant. Such plants are currently providing the majority of power to California. Research and development that considers increasingly higher levels of renewable hydrogen delivery and conversion in NGCC plants should be considered. Such NGCC plants should be evaluated for their potential to operate on mixtures of hydrogen and natural gas considering the energy efficiency, combustion temperature and other characteristics, and criteria pollutant and GHG emissions impacts of hydrogen natural gas mixtures.

Natural Gas System as a means of Storing/Transporting Renewable Hydrogen

- Hydrogen Injection into the Natural Gas Pipeline. The use of the natural gas system as a means of storing and transporting renewable hydrogen has many advantages and represents an important opportunity in California to support renewable power generation, maximize environmental and economic benefits of an existing resource, and address a key barrier associated with a hydrogen future (i.e., lack of current infrastructure). The following issues, however, require consideration and further research:

  – Potential for increased gas leakage from the natural gas system when hydrogen is injected. In recent studies at UCI, hydrogen, hydrogen natural gas blends, and pure natural gas were found to leak at the same rate in existing customer-side natural gas infrastructure. Further experimental investigation and physical simulation of these phenomena are recommended.

  – Potential leak mitigation strategies.
  In recent work at UCI, a copper epoxy leak mitigation strategy was found to significantly suppress leakage of pure hydrogen, hydrogen natural gas mixtures, and pure natural gas. Further experimental investigation of this and other mitigation measures is recommended to evaluate their potential for eliminating leakage from customer-side natural gas infrastructure

  – Natural gas system pipeline integrity when exposed to hydrogen.
  A paucity of experimental data exists for hydrogen-induced fatigue crack growth behavior in natural gas line pipe steels in the presence of hydrogen over long durations and under realistic pressure dynamics. Additional data are needed in low hydrogen pressures, and also in welds and in gas containing impurities. Studies on the effect of impurities such as oxygen or carbon dioxide in the mixture of hydrogen and natural gas can help to ascertain the extent to which these impurities can mitigate the hydrogen effect should be considered and explored both experimentally and theoretically.