Fuels of the Future: Chemical Energy Carriers for a Decarbonized Economy

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Summary

Lower carbon intensity energy sources have grown dramatically, placing climate change targets tantalizingly within reach. RD&D Prioritization should now be given to the required infrastructure transition to move, store, and use this energy. What should the energy carriers and supporting infrastructure of a decarbonized society look like? We believe that that research funding emphasis should be given to flexible options that minimize large scale infrastructure turnover. Given this point, this whitepaper argues that a diverse and robust funding support should be made available for a variety of such future fuels, including hydrogen, natural gas, liquid fuels, and ammonia. However, we also argue that significant increases, and special funding priority, be given to fuels that can "drop in" to existing infrastructures and be incrementally deployable.

Introduction

Major transformations in the US energy system are driving important questions about societal investments in supporting infrastructure. For example, what prioritization should be given to transforming to a hydrogen economy, developing large scale carbon capture, and/or aggressively promoting electrification? While the associated cost and efficiency considerations are important, politics and historical inertia will be equally, if not more, significant in how this transition will unfold.

Energy: Sources, Consumers, and Carriers

Today's energy system includes three major subsystems: (A) *energy sources* (oil, solar, etc.), (B) *infrastructure and carriers for moving/storing these energy sources*, and (C) *energy consumers*. It is the movement and storage of energy which is the focus of this whitepaper. We must think carefully about the energy carriers associated with large-scale decarbonization due to the enormous construction costs, land use, and right-of-way issues that will be required in building out the associated infrastructure. Currently, the energy system is dominated by two largely independent, multi-trillion dollar carrier systems: (A) *electricity,* and (B) *hydrocarbon fuels.*

There are three options for decarbonizing energy carriers – electric power, carbon capture, or renewable chemical energy carriers, often termed renewable *synthetic fuels*. Synthetic fuels are an energy storage medium like fossil fuels, but are manufactured. A variety of synthetic fuel options are possible, including hydrogen, methane, ammonia, or synthetic gasoline. A convenient way to distinguish these candidate fuels is whether they (a) can or cannot "drop-in", without requiring changes to the existing distribution infrastructure and users (e.g., do you need to change out your home furnace or get a new car?), and (b) contain a carbon atom or not.

Consider some representative examples. Hydrogen, H_2, is the most commonly proposed option, and so is worthy of special attention. It contains no carbon atom, and, outside of the 1000 miles of hydrogen pipelines in the US, it cannot "drop-in" to existing gas pipelines at appreciable levels. It is one of the lowest cost synthetic fuels to be generated on an energy basis. A second example of a carbon-free energy carrier is ammonia. Ammonia production for fertilizer is one of the largest chemical industries globally but, broad-based infrastructure is relatively limited.

Examples of synthetic fuels that contain carbon atoms could include ethanol, methane, or a gasoline or aviation gas substitute. If they are "drop-in" substitutes, such energy carriers would use the existing hydrocarbons infrastructure, which in the U.S. alone includes 115,000 gasoline stations, 2.4 million miles of pipeline, and 275 million vehicles and involves hundreds of thousands of well-paying jobs. We term these "renewable hydrocarbons" as they are powered by renewable energy.

Priorities for Energy Carrier RD&D Funding

What should the energy carriers of a decarbonized society be and how should we prioritize research allocations? We recommend a diverse funding portfolio that addresses all of these candidate energy carriers. However, while an "all the above" *research* strategy makes a lot of sense, such an approach on actually *deploying* energy carrier infrastructure does not, due to the significant requirements in constructing energy distribution systems' infrastructure, and ensuring compatibility with end users. In other words, once deployment decisions are made, we will need to pick, and pick a probably very small number of energy carriers. Economic and engineering considerations around production costs and efficiencies are key to these decisions. Indeed, if were developing our energy systems from scratch, these considerations might drive the decisions. However, the enormous built out infrastructure and associated political considerations will be equally significant. We argue that federal research programs should prioritize the following considerations:

1. *Minimize overall social costs*. The challenges to transitioning to new energy carriers goes beyond arguments of dollars per kilogram of fuel production costs. The social displacement and costs seen in the demise of the coal industry should serve as a warning to those seeking to end the hydrocarbon industry, which is a substantially larger component of the US economy. Furthermore, the resistance of users to changing existing buildings and vehicles could render top-down fiats irrelevant at best and alienating at worst.
2. *Incrementally deployable*. The path to decarbonization will involve gradual transitions and renewal of pipelines and electric transmission lines, potentially over multiple decades. Stated differently, we hypothesize that society will not unify around the multi-trillion dollar expenditures needed for a one-off/short term, large scale infrastructure turnover. Thus, any solution must work when deployed incrementally, and it should be capable of obtaining reasonable adoption levels even while it is partially deployed; i.e., it should not require large economies of scale to ensure uptake, as is typically the case in, for example, telecom networks or e-commerce platforms.

Hydrogen or ammonia, or any other non-drop-in fuel in high concentrations do not currently satisfy either criteria. Indeed, while hydrogen production is possibly the lowest cost/highest efficiency relative to other potential chemical energy carriers, its deployment suffers from the lack of a substantive user base and distribution network. Simply put, evolving to a hydrogen economy would require getting a new car and major investments in hydrogen transmission and distribution systems. Research and development around hydrogen should focus not only on reducing production costs, but enabling incremental deployment and minimizing disruptions to users.

Renewable hydrocarbons (i.e., synthetic gasoline or natural gas) satisfy both criteria. They can plug into the nation's existing distribution infrastructure and adoption requires no changes to the user base, such as cement manufacturing, automobiles, or home water heaters. The underlying technology can be developed in modular form and deployed incrementally, reducing capital risk and leveraging learning curves to reduce unit costs. Moreover, no large-scale buildouts of electricity distribution infrastructure are needed to ensure uptake. A major ancillary benefit would be facilitating the transition of chemicals and plastics production from its current primary fossil fuel feedstock. Finally, from a purely political standpoint, such an approach minimizes disruption to a number of vested political interests. The key challenge for synthetic drop-ins is that they are more expensive to manufacture and, for related reasons, their production is less efficient than, say, hydrogen production. Major funding increases should be put in place to drive down production costs for drop-in synthetic fuels.