Why Hydrogen? Can Anything Better Come Along?

Some introductory thoughts for the

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About the future, we never know everything but we always know something. And for some things we can often project the deep future better than tomorrow. These observations are especially relevant to our energy system when that "something" is energy *currencies*. Then, relatively predictable of currencies can be used to at least deduce patterns in a few other components of energy system infrastructures.

These ideas can help focus this symposium, because it's prudent to distinguish between those things which are impossible to project and those that are pretty damn certain (at least, if civilization survives).

Focusing on *energy currencies* leads to the logic that, a century from now, the staple energy currencies will be hydrogen and electricity. This robust tether of longer-view predictability can help us leap the tangles of today's vested mantras, ill-found hopes and conventional *wishdoms* – to better anticipate future infrastructures, a little about future sources, but much less about future service technologies.

To put this last in context, we need the idea of the energy system's architecture. After a brief discussion ot the architecture, we can go on to "Why Hydrogen?" and "Can Anything Better Come Along?"

Architecture of the Energy Systems

The unfortunate thing about the energy system is that few people think of it as a system. Instead most think about its bits-and-pieces—about electricity networks or oil cartels, about how the latest geopolitics will influence prices — but little about the integrated system. We need a concept of systemic architecture to see how the bits and pieces fit together, what they do themselves and do for each other.

At its simplest, the system may be represented by a five-link chain that starts with energy services, moves to technologies (that deliver the services), then to energy currencies (that feed the service technologies), then transformer technologies (that produce the currencies) and finally the sources that the transformer technologies harvest. This figure shows where things fit.

To appreciate how the system functions, it's *essential* to remember that people want energy *services*; they don't much care about energy itself. Energy is a means to ends. Services are the ends.

Why Hydrogen?

As we embark upon the 21st century, two specters threaten civilization. One is the prospect of economic disarray and incitement to war caused by the local depletion and global mal-distribution of high-quality fossil fuels, especially oil. The second is the prospect of almost unimaginable environmental, economic and cultural disruption caused by climate volatility and triggered, primarily, by our energy system's carbon dioxide (CO_2) emissions.

If we remain tethered to fossil fuels it is merely a question of when, not if, one or both specters become reality. Today we're seeing the precursors of both. From the viewpoint of Earth's physiology, climate volatility is much the more critical. Yet at any moment flaring geopolitics could suddenly destroy international fossil-energy supply.

Happily, a straightforward pathway can steer us clear of both specters. First, we must rapidly adopt sustainable energy sources that don't emit CO_2. Such sources include solar, wind and next-generation nuclear power. Second – and perhaps more critical because it's so poorly understood – we must rapidly adopt the twin energy currencies, hydrogen and electricity. Alone among currencies, both can (a) be manufactured from any energy source, (b) neither emits carbon dioxide and, (c) together, they can provide the full menu of energy services, from flying airplanes to running computers.

Depletion rationale:

Today's transportation fuels are harvested exclusively from fossil energy sources. But because fossil sources are threatened by regional depletion and are a sure cause of international conflict, civilization must move to sustainable, regionally available, non-fossil sources. We must harvest sustainable sources to manufacture chemical fuels in general and transportation fuels in particular. Realistically, the only way sustainable sources can manufacture transportation fuels is via hydrogen. (How else, for example, can we use the energy from wind, solar or nuclear to fly an airplane?) Therefore, a significant move from fossil to sustainable sources can only begin with the increased use of hydrogen in transportation, and can only be completed with the supremacy of hydrogen among chemical fuels.

Climate disruption rationale:

Today our energy system's CO_2 emissions are pushing the planet towards climate destabilization that, if unabated, will be catastrophic. To eliminate these emissions we need *both* non-carbon emitting *sources* and non-carbon *currencies*. Many non-C sources are available or can be developed, including hydraulic power, sunlight, wind, nuclear fission and perhaps (much later) nuclear fusion. By contrast, there are only two non-C currencies that can, together, power the full menu of civilization's energy services: electricity and hydrogen. Electricity is already established — but of course electricity can't fly airplanes. Therefore, anthropogenic CO_2 can only be slowed by the extensive use of hydrogen and can only be stopped by the supremacy of hydrogen among chemical fuels.

The Hydrogen – Electricity Age

To anticipate how hydrogen and electricity will (a) share markets and (b) have different infrastructure roles it helps to see the ways hydrogen and electricity are both *similar* and *synergistic*.

Similarities:

Hydrogen and electricity share many properties, of which the most important may be:

- Both can be manufactured from any energy source.
- Both are intra-convertible. (Electricity can be made from hydrogen, hydrogen from electricity.)
- Both are renewable.

We know electricity can be generated from any energy source. Of course so can hydrogen — illustrated, if you like, because we can produce hydrogen from electricity via electrolysis. Of course, there are many ways to harvest hydrogen without using electrolysis, such as SMR, the most common route today.

Both currencies are intra-convertible. Electrolyzers convert electricity to hydrogen. Fuelcells convert hydrogen to electricity. Other chemical fuels are not mutually interchangeable with electricity. Gasoline, for example, can be converted to electricity, but electricity cannot be converted to gasoline. Today, the energy system is severely restricted by this electricity-gasoline one-way street.

The third similarity speaks to our hankering for renewables. I've heard some say, "The good thing about hydrogen is we have so much water that we'll never run out of water to make hydrogen." That misses the point. It's like saying "The good thing about electricity is we'll never run out of electrons.

Synergies:

The patterns in synergies are:

- Hydrogen can be a transportation fuel or material feedstock. Electricity cannot.
- Electricity can be used to transmit, process and store information. Hydrogen cannot.
- Hydrogen can be stored in enormous quantities. Electricity cannot.
- Electricity can transport energy without transporting material. Hydrogen cannot.
- On Earth, hydrogen will be best for long distance energy transport. In space electromagnetic radiation (an electricity proxy) wins.

That hydrogen can be stored in enormous quantities confers its future as both (a) the staple transportation fuel and (b) the system's energy storage sponge. Storage is needed to improve the reliability and efficiency of the system and is especially important for renewable sources — like when we harvest solar during the day but need its energy at night. Of course, we also need energy storage for national security. Electricity cannot fill these roles.

One way or another, material is always the root of environmental intrusion. Delivering energy via electricity requires no material movement. Hydrogen systems do involve material transport; however hydrogen carries more energy per unit mass than does any other common currency.

These synergies can help us predict how these currencies will share markets. Hydrogen will fuel free-range surface vehicles. Electricity will "fuel" computers. By applying our template we can anticipate whether hydrogen or electricity will be used for any particular service — or if both will have a shot.

Can Anything Better Come Along?

Many now realize that, by the early decades of the 22nd century, hydrogen and electricity (both derived from sustainable sources) will dominate our energy system. Yet, of these, some might add, "But only until something better comes along."

Yet I propose that solid arguments show: Nothing better will come along.

Keep in mind I'm claiming immortality for two *currencies*, electricity and hydrogen, *not* for a technology. It's not a claim for the permanence of computers, telephones or fuelcells — or any technology that might sprout in the future.

To cover the full menu of energy services, we need at least one electronic and one chemical currency.

The electronic currency is electricity, whose corpuscular bits and pieces are charge carriers — normally electrons.[1] Moving charges carry exergy when not in equilibrium with their environment or, said another way, when they are within an electromagnetic potential different from their environment. Ions — atoms or molecules with a net electronic charge due to a surplus or deficit of electrons — can also be charge carriers. Ions are important in batteries and fuelcells, and in some industrial processes.[2]

Chemical currencies are made of material "stuff" — like today's gasoline, diesel, coal and natural gas, and yesterday's wood and dung. I often call them "protonic" currencies because protons determine the chemistry of atoms that, in turn, establish the currency's characteristics. Analogous to electricity, a protonic currency carries exergy when its corpuscular bits, its molecules, are not in equilibrium with the environment, or — drawing on the electrical potential analogy — when its molecules have a different chemical potential than their environment.

[1] In a transistor, an equivalent but inverse unit of charge is called a "hole"—it represents the absence of an electron that, if there, would provide charge neutrality.

[2] I include electromagnetic radiation (EMR) as part of the electricity family.

If we hope to find a still better protonic currency we must work within two constraints.

First, we're restricted to the elements Nature gave us. We're not going to find more elements.[3]

Second, an overriding criterion for environmental gentility is that the amount of waste product material be insignificant compared with the environmental background level of the same material. This means, environmental gentility can only be achieved by using chemical currencies composed of elements that are environmentally abundant. If a universal currency were composed of trace elements, its waste products would impose an unequivocal environmental burden.

Of course, a protonic currency needn't be a single element; almost all today's chemical fuels are molecular combinations of at least two, commonly hydrogen and carbon. Nitrogen and oxygen are the two other abundant elements in both our atmosphere and lithosphere. So we seem restricted to combinations of C, H, N and O – which means we're pretty much back to currencies we already know, like gasoline and diesel, supplemented by less common currencies such as ammonia (that uses H and N) or the alcohols, methanol and ethanol (that use H, C and O) and molecular hydrogen (H_2).

We know the menu. Nothing else will come along.

That's *not* something we can say about technologies. We're used to rapid technological evolution . . . from the invention of hay, to water wheels . . . Eventually, undreamed-of new technologies will challenge the most advanced of today's technologies. We'd be fools to think we can predict tomorrow's wonderful widgets.

In contrast, once wedded, the bond twixt civilization and the hydrogen-electricity pair will be "until (civilization's) death do us part." The vital components—the corpuscles—of these forever currencies will be a single electron and a single proton.

The challenge is to get civilization to hydrogen, not to stay there once we get there.

<u>A subset: "Imbedded currencies"</u>

Of course there will always be "*imbedded* currencies" — currencies employed over short distances *within* transformer and service technologies. To illustrate, consider one of today's familiar technology chains: coal-fired electricity generation flowing up-stream to services. Coal is the *currency* input to a combustor that manufactures the *imbedded currency*, heat. Heat is the input to the boiler that manufactures the imbedded currency, steam. Steam is the input to turbines that deliver work via rotating shafts. A rotating shaft is the currency that powers an alternator, which, in turn, delivers medium voltage electricity. Medium voltage electricity is the embedded currency input to a transformer delivering high voltage electricity to the transmission lines — and so on — until low voltage electricity is the input currency to your oven that delivers the final currency, heat, which cooks your pot pie.

Conclusion:

The further we look ahead, the fuzzier our knowledge of technologies, but the clearer our knowledge of currencies. We're lucky to have such a firm tether of predictability stretching ahead to the deep future. It's not technological predictability, nor is it source predictability and certainly it's not predictability of the now unimaginable and yet surely wonderful new ways services will be delivered. Rather it is the knowledge that, about a century from now and forever after, hydrogen and electricity will sit plunk in the middle of our five-link systemic chain.

Mixed with a modicum of wit, that information can be very useful.

[3] We can't rule out synthetically manufactured unstable elements having even more protons than, say, Lawrencium with its 103. But no such element could ever be a practical currency—or part of a chemical compound that could fulfill the role of a currency.