Podcast #79 – Where will we use hydrogen?

Hello everyone and welcome to the HydrogenNowCast for December 29th, 2023. I'm your host Brian DeBruine, the Director of the non-profit Colorado Hydrogen Network. This is a podcast devoted to encouraging the deployment of hydrogen infrastructure throughout the world. Our intent is to encourage and motivate others to take charge, to help deploy hydrogen as a means to decarbonize the transportation other energy sectors and accelerate the movement to stop climate change.

On this podcast, I've talked many times about the fact of needing to develop a hydrogen market, where a market is defined as a constellation of multiple suppliers and users, so that anyone can enter the market and find buyers or sellers.

As I listen to people ponder how to start the hydrogen market, the one thing holding them back right now is confusion about what the role of hydrogen should be. Where are we likely to use it and why? This lack of understanding around why we need hydrogen and where to use it is really hurting the Energy Transition. As misdirected as it is, some environmentalists are actually fighting the use of hydrogen because they don't understand that to decarbonize some sectors, it will be impossible without hydrogen. These are sectors like transportation and industrial heat – and these two sectors alone make up almost 50% of total greenhouse gas emissions.

Now let's be clear from the start, that the world's use of hydrogen needs to emit zero greenhouse gases. After all, if it weren't for the need to eliminate greenhouse gas emissions from our energy sector, we wouldn't bother with hydrogen at all. Although in the past, the creation of hydrogen emitted CO_2, but so did electricity generation. But in the future, neither will.

So why do we even need hydrogen? Why isn't electricity alone enough to replace fossil fuels? To understand that, you have to first consider the characteristics of electrons and molecules.

There are three problems with electrons. First, they have to be generated and consumed at exactly the same time and in exactly the same quantity, otherwise you need storage, which is the second problem with electrons – they're difficult to store in large quantities and for very long. You need batteries which are expensive, heavy and bulky, and on top of that, all batteries self-discharge, which is to say that over time, all batteries lose their energy. And lastly, it takes WAY more time to transfer energy as electrons than as molecules. This is a huge issue for transportation. And it has nothing to do with the battery – it has to do with the vast amount of energy that we need to transfer quickly to vehicles and the practical limits to the Voltage and current we can apply to transfer that energy.

By contrast, **huge** amounts of energy can be transferred as molecules very quickly. When we fill the tank of a car with gasoline or hydrogen, in just 3 minutes we can transfer 400 kWh of energy or more. To do that in 3 minutes with electrons would require applying 8 million Watts to the car. Even if you could devise some huge wires and a connector to do that, having multiple vehicles at a charging station drawing that much power all at once, would require massive transmission lines plus a grid that could supply it.

Another reason we sometimes need molecules is that molecules can easily be stored. You can generate energy now and use it in the future. In some cases, molecules can be transported where electricity can't, for example across an ocean. Also, for the creation of high temperatures, it's far more practical to do this by burning molecules than using electrons. And lastly, and most importantly, large amounts of energy can be transferred as molecules far more quickly than as electrons. For example when fueling a vehicle.

And electrons and hydrogen are not the only answer either. As I'm going to discuss in this podcast, there may be some sectors that need biofuel to meet cost, performance and convenience expectations set by the current incumbent – petroleum. Those energy sectors that may need biofuels are shipping, long-distance air travel and existing home and building heating. Although biofuels do contain carbon, that carbon is pulled from the atmosphere by algae and plants, and some of that carbon can be diverted from use and sequestered, so the net result is actually somewhat carbon-negative. But more about that later.

So which functions of fossil fuels are best suited to be replaced by electricity, which by hydrogen and which by biofuels? Well, I'm not going to give you my opinion, and I'm not going to give you other people's opinions either. What I am going to do instead is set out an objective thought process to arrive at our own conclusions.

So let me guide us all through a thought process so we can have real clarity about which forms of clean energy are the most likely to replace fossil fuels for each application. We'll come up with a table showing the most likely form of clean energy for each sector. I've put that table in the show notes on the Colorado Hydrogen Network website at colorado-hydrogen.org/podcast.

Now, I think it goes without saying that to come up with the right answer, you've got to ask the right question. As the old adage goes, "You can tell whether someone is clever by their answers, but you can tell whether they're wise by their questions." So let's apply a bit of wisdom (or at least systems engineering) to our process.

What we're going to develop here is the most likely fuel-for-use scenario based on normal market forces. But admittedly, non-market forces such as the inability to deploy new transmission lines, or regulations and tax incentives could skew this prediction somewhat.

Now, I worked during my career for a defense contractor, Honeywell Aerospace, and we often had to develop specifications for the military. As any of you with direct experience know, the military has great rigor and discipline around their documentation. And one of the principal mantras around writing specifications is NOT to say HOW something should be done, but instead define the result you want. If you specify how to do something, you may be ignorant of a better way of doing it that those "skilled in the art" are aware of. For example, I'm continually annoyed by the habit of some to define "green hydrogen" only as hydrogen produced by electrolysis – which is totally oblivious to the fact that there are other ways of producing green hydrogen. For example, hydrogen from geological wells. The true definition of green hydrogen is: that it is renewable and that it produces no greenhouse gas in its production.

Another huge mistake that's often made is saying we need to eliminate the use of all fossil fuels. The right definition is that we need to eliminate the atmospheric release of greenhouse gases from the use of fossil fuels. There's a big difference. Fossil fuels can be used with zero release of any greenhouse gases. For example, underground generation of hydrogen in old petroleum wells. Only pure hydrogen is brought out of the ground through a palladium filter. So there's no chance of methane leaks and no carbon to sequester. We covered this a year ago on the December 23, 2022 podcast.

So what IS our process to determine the likely forms of clean alternatives to fossil fuels? We could make mistakes if we simply guess at one-to-one replacements. A far better way **is** to think about the functions that fossil fuels provide and then come up with clean alternatives those functions. The best example I can give of this is energy for vehicles. If you just think about some equivalent-energy clean-alternative (like a battery), you'll miss the FUNCTIONS that the fossil fuel provided. Functions like fast energy transfer to the vehicle, or long driving range.

So here's our process. Let's examine all the major uses of fossil fuels. Next, we'll look at the functions that those uses of fossil fuels provide, and lastly let's find the best clean alternative replacement that will provide those same functions.

Regarding the fossil fuel uses, the US Environmental Protection Agency or EPA publishes a pie chart showing the greenhouse gas emission from major energy sectors. The three big ones, that each account for around a quarter of emissions, are vehicles, the electric grid and industrial uses. The next-biggest emitter is building heating at around 13%. Aviation is 3%, shipping is 1%. Agriculture does account for 10% of emissions, but not all of this greenhouse gas is from energy usage. Much comes from improper farming practices like tilling the soil and chemical use such as nitrogen fertilizer – both of which kill the soil life that could be sequestering carbon in the soil.

So let's focus our attention on just six sectors – **the electric grid, transportation, heating for homes and buildings, industrial processes, aviation and shipping**.

Now, some of these sectors subdivide into functions. For example, the energy grid features energy generation, energy storage and transmission. Transportation subdivides into light-, medium- and heavy duty plus the associated use-cases for each of those sizes. Aviation divides into short-haul and long-haul. Building heat subdivides into new-build and existing buildings. And shipping divides into short haul like ferries and long haul like transoceanic tankers and container ships.

Now one more thing before we start. The clean energy solutions that we propose must pass a test meeting 3 criteria – they must be technically feasible, have the same or lower cost, and have the same or better performance and convenience as the fossil energy they replace. We can think of technical feasibility, cost and performance & convenience as three legs of a stool. If any one is missing, the stool falls over.

Grid

Alright. So let's dig in. Let's first consider the energy grid. Notice I didn't say electric grid. While we'll certainly continue to have an electric grid, transporting energy isn't the sole domain of electricity. Energy can be transported as either molecules or electrons. In fact, energy can be sent by hydrogen in pipelines more cheaply and more securely and (very importantly) more acceptable to the public via underground hydrogen pipelines because they're out of sight. Pipelines have the added advantage that by varying the pressure, hydrogen can also be stored.

As the pressure is increased, more hydrogen is present in the pipeline. That hydrogen can then be used which decreases the pressure.

Now what about grid energy storage? Electrons or molecules? Batteries will certainly play a role, especially lower cost batteries like iron-air. Hydrogen can be used for storage by converting electricity to hydrogen in electrolyzers and then back to electricity using fuel cells. The round-trip efficiency of hydrogen storage is about 50% which is similar to iron-air batteries. But the choices for each application will come down to cost and local assets – like underground caverns for hydrogen storage.

Currently, we think of clean grid-energy-generation as coming only from wind and solar. But, in major parts of the US, geothermal energy is available and the cost per watt is equivalent to wind or solar. But geothermal has a big advantage in that it generates continuously. I covered geothermal on the October 28, 2022 podcast.

Another source of energy for the grid is geological hydrogen from wells. This hydrogen could be a low-cost way to power utility turbines. Finally, clean hydrogen can be generated underground using old petroleum wells. Since the carbon never comes out of the ground, these are truly clean ways to generate very low cost hydrogen for electric generation. We covered clean underground hydrogen generation on the December 23, 2022 podcast.

So to summarize hydrogen uses for the energy grid, hydrogen can be a <u>source</u> of energy, it can be used to generate grid electricity in hydrogen turbines, transmit energy in pipelines and to store energy. And of course electricity will continue to play a role.

Alright. Next let's move to transportation.

Transportation

The answer here is fairly complex for two reasons. First, there are a huge range of vehicle sizes and uses – from small family sedans to large consumer vehicles such as large pick-up trucks, sport utility vehicles and recreational vehicles plus the need to tow things like camping trailers, boats, snow mobiles and the like. Then in the commercial realm we have delivery vans, box trucks, bucket trucks, flat-bed tow trucks and various utility vehicles that also have to provide power for the equipment they carry like overhead buckets, pumps, trash compaction and more.

Secondly, complexity comes from the way the vehicle is driven. Is it used just a few minutes each day, or is it driven continuously all day long and used to carry or tow heavy loads? For each of these various conditions, we need zero-emission solutions that provide the same performance and convenience as petroleum vehicles if the users are going to accept them.

So what are our choices for zero emissions vehicles? Do we change the engine or change the fuel, or some combination of the two?

When it comes to the engine, there are really only two choices – an internal combustion engine or an electric motor. Either of those can provide the motive force we need.

Next it becomes a question of the source of zero-emission energy to drive the engine. Internal Combustion Engines can be run on hydrogen, but for light- and medium-duty applications, a fuel-cell is more efficient than an internal combustion engine. But for heavy-duty applications where the engine is run at nearly full power much of the time, an internal combustion engine powered by hydrogen fuel can make economic sense. Now, because the engine is burning air which contains 70% nitrogen, some nitrogen oxides or NO_X are produced. But by the use of sophisticated turbo-superchargers to control the fuel-air mixture, and the use of catalytic converters to treat the exhaust, the NO_X can be kept to extremely low levels. I covered this on the January 7, 2022 podcast with SuperTurbo.

Cummins, Caterpillar, JCB and others are in the process of rolling-out internal combustion engines running on hydrogen and we can expect to see those on the road by 2027 or before.

But the best motor-choice for light and medium-duty vehicles is an electric motor or motors. But we need a source of energy, what are our choices? Should we use electrons or molecules? When you look at the numbers, it takes a huge amount of energy to propel a vehicle – especially a heavy vehicle – down the road, up hills and carrying or towing cargo. We have to store this huge amount of energy on the vehicle and then when it runs out, we need to transfer this large amount of energy to the vehicle in just a few minutes as we do now with gasoline or diesel if we're going to meet the same performance and convenience that users experience now.

Batteries are much more limited than hydrogen in the amount of energy they can store. This is especially an issue with larger, heavier vehicles. Additionally, moving electrons to the vehicle is a very slow process compared to moving molecules. And this energy transfer rate has nothing to do with the battery, it has to do with the practical limit on the Voltage and current that can be realistically applied to the vehicle which affects the charge rate. This means that battery vehicles can never be charged as fast as hydrogen or petroleum vehicles can be fueled.

The simple fact is that battery vehicles are, and will remain, different from petroleum or hydrogen vehicles in their performance and convenience. For light vehicles used short distances and charged at home or work, a battery vehicle is superior to hydrogen or petroleum because you don't have to go somewhere to buy fuel. However, for the other cases of long trips, heavy vehicles and heavy loads, and towing – hydrogen is superior.

There is currently quite a bitter debate raging by battery enthusiasts questioning the need for hydrogen-powered vehicles. This is easily resolved by simply asking the public what they're willing to buy, and a number of polling agencies such as Consumer Reports, JD Power, Pew Research Center and Gallup Polls have done just that. The results of all these polls show that only 20 to 40% of people say they would be willing to buy a battery-powered vehicle. Yet we have **got** to replace 100% of internal combustion vehicles with zero emission vehicles. And these polls are just regarding light-duty vehicles. The energy needs of commercial vehicles is even greater where all-day driving, heavy loads and towing trailers are commonplace. So there can be no question that hydrogen is critical and essential to decarbonize transportation – heavy, medium and light-duty and any position to the contrary ignores public opinion. We almost always have more than one choice in <u>everything</u> else we buy – why should vehicles be any different? Especially since we need to replace every vehicle out there with zero emissions – and as fast as possible.

So hydrogen for transportation definitely meets the performance and convenience requirement of our 3-legged stool and the technology to make and use hydrogen is sufficiently mature. But what about the last leg, cost? Well, the cost of fuel cell vehicles will be less than gasoline or diesel when this technology is produced at scale because the fuel cells and electric motors are so much simpler than internal combustion engines. Hydrogen internal combustion engines will be the same as gasoline or diesel.

But what about the creation of clean hydrogen? Well, the sources are electrolysis of water, and geological hydrogen – either natural hydrogen wells or generating hydrogen underground from old petroleum wells. Remember that this last process is clean because no carbon comes out of the ground – so there can be no methane leaks and no carbon to sequester.

But how do we compare the price per gallon of petroleum to the price per kg of hydrogen? Although coincidentally a gallon of gasoline and a kg of hydrogen contain around the same amount of energy, we have to consider the efficiency of a hydrogen vehicle versus a petroleum vehicle to determine what the hydrogen must cost to provide the same cost-per-mile of the two fuels for the user.

The California Air Resources Board or CARB has provided us with data on vehicle efficiency. They publish an **Energy Economy Ratio** or EER. This CARB EER is the fuel efficiency ratio between a vehicle using hydrogen and the same vehicle using either gasoline or diesel. For light and medium duty vehicles, the ratio is 2.5 for gasoline and 1.9 for diesel. In other words, a light duty fuel cell vehicle will go 2.5 times farther on a kg of hydrogen than a gallon of gasoline or 1.9 times farther on hydrogen than diesel. This gives us a way to calculate what hydrogen needs to cost so that the user experiences the same cost per mile with their hydrogen vehicle as they did with gasoline or diesel. So in other words, hydrogen can cost 2.5 times the price of gasoline or 1.9 times the cost of diesel and the cost per mile to the user is the same.

So . . . can we make hydrogen via water electrolysis at a price competitive with petroleum? Well let's look at the numbers. In the US, right now the average price of a gallon of premium gasoline is around $4. So hydrogen can cost 2.5 times that or $10 per kg, and the user will experience the same cost per mile as gasoline. The cost of the electricity needed to generate, store and dispense a kg of hydrogen using grid commercial electricity-rates is around $4.25 per kg. So that leaves a margin $5.75 for other operating expenses and a return on investment. And that's without any of the tax credits and incentives currently available.

But that's light and medium duty vehicles. For heavy-duty vehicles, the Energy Economy Ratio or EER isn't as good at just over 1. With the average price of diesel fuel in the US also at around $4 per gallon and the cost for electricity per kg again at $4.25, for that class of vehicle, hydrogen from electrolysis using grid electricity can't compete with diesel.

But what other sources of electricity? For example, on-site electricity generation from a modular geothermal plant. Dry-rock geothermal is an abundant resource in the western US. Current CAPEX prices for geothermal are at around $3,500 per kW. I won't go through all the calculations and assumptions about return on investment, but the cost for electricity from geothermal would allow on-site hydrogen generation at around $3 per kg. But this would qualify for the full $3, 45V Production Tax Credit. So that takes the electricity cost to zero. You can learn more about modular geothermal electricity generation from the October 28, 2022 podcast.

Another option for cost effective hydrogen for heavy-duty vehicles is geological hydrogen from hydrogen wells or underground hydrogen generation using old oil wells. At the well head, this hydrogen would cost around 50¢ per kg, but transporting the hydrogen would add to cost to that, with the amount depending on distance.

So to summarize, both hydrogen and batteries have a place in providing energy for vehicles. And I'll add that probably both in the same vehicle as in fuel-cell-plug-in-hybrids just as Honda, Stelantis and others are doing. Hydrogen will meet all three criteria of technical feasibility, cost and performance and convenience. However, batteries only meet the performance and convenience criteria in limited cases such as light-duty vehicles where the user drives short distances.

Building heating

Moving on to building heating – for new homes and buildings, electric heat pumps are a practical and cost-effective solution. The rules and regulations mandating heat pumps for new construction make sense. But for existing homes and buildings, replacing existing furnaces is highly problematic because it's very costly to retrofit entire heating systems in hundreds of millions of homes and businesses. Add to that the fact that many people may refuse the conversion. For these reasons, I think we'll need to consider converting the fuel not the equipment for existing home and building heating.

Although theoretically, gas or oil-fired furnaces could burn hydrogen, a number of practical obstacles exist. The most difficult is how to get hydrogen to the buildings? We can't use existing gas piping systems which would prove too leaky for the tiny hydrogen molecules, and the materials will degrade in the presence of hydrogen.

So assuming we'll need to retain the heating equipment in existing homes and buildings, what alternative fuel could we use? It would have to be something that can be delivered to the building using existing pipes or tankers. That means, it would have to contain significant energy at low pressure and not react with the pipes or tankers. The two choices are ammonia or some form of hydrocarbon. Ammonia is an irritant and is also incompatible with copper and brass which are both found in natural gas systems. So that leaves hydrocarbons. But of course hydrocarbons emit carbon dioxide when burned. But what if the carbon to produce the fuel was pulled from the atmosphere? That would mean that at least the fuel is carbon neutral. Algae and plants pull carbon from the air. We could grow algae specifically for fuel production or use biomass discarded from other uses, such as garbage, sewage and agricultural waste.

I mentioned that this process is carbon neutral, but we could make this cycle carbon negative if we decide to sequester some of the carbon from the biomass.

As I covered in the April 29, 2022 and February 10, 2023 podcasts, using algae for biofuels can be very cost effective, since the algae can be made into not only biofuel, but animal feed and industrial chemicals. Algae is an extremely attractive way to perform direct air carbon capture since the entire plant is devoted to photosynthesis, there is no bark, wood or stems. The other advantages are that algae grows quickly and is easily processed.

Industrial Processes

So moving on to the industrial sector, there are a whole variety of industrial processes that need high temperatures. Examples include heat for cement making, heat to melt and process glass and of course steel making. But there are others, for example heat for commercial cooking and baking, steel treating and forming and the list goes on.

Although electricity can-and-is used to create some of this heat (for example in the smelting of bauxite ore to make aluminum), in most cases either the temperatures or amount of heat needed are impractical to attain with electricity. These are cases where hydrogen is necessary. Because of the high volumes and low prices needed, this directs us to use geological hydrogen – either from hydrogen wells or underground hydrogen generation from petroleum.

Aviation

Turning to the aviation sector, hydrogen is already starting to be used for aircraft, either as compressed gas or in liquid form. Although liquid hydrogen provides higher energy density, liquid hydrogen is somewhat perishable in that it does boil-off. So time-on-aircraft is a consideration. Hysky society (their website is hysky.org) is a non-profit organization helping to promote hydrogen for aviation. I covered Hysky society on the July 28, 2023 podcast. Aircraft manufacturers are considering two ways of bringing the hydrogen to the aircraft. Either filling fixed tanks as is done today with jet fuel, or with interchangeable canisters, where the fuel tanks are changed out, much like you would do with propane tanks on your backyard grill.

Although both gaseous and liquid hydrogen are technically feasible, it remains to be seen whether hydrogen for aviation – especially for the long-range jumbo-jets – can be done cost-competitively with petroleum.

But there is another alternative. The market may eventually determine that biofuel – which can be used somewhat carbon-negatively – is the best compromise to meet our 3 criteria of technical feasibility, performance-convenience and cost. Any biowaste such as garbage and sewage can be used, but possibly the best way to do this will be to use algae to pull carbon from the air. Since algae can produce 3 products: animal feed, industrial chemicals and biocrude, it can be profitable. The biocrude is processed into jet fuel using conventional refining techniques. But with the positive economics of this process, some of the biocrude could be sequestered – almost like a carbon "tax" – to make this process slightly carbon-negative. As I mentioned earlier, I produced two podcasts about algae – April 29, 2022 and February 10, 2023. I strongly encourage you to listen to these very important podcasts if you haven't already.

Shipping

So biofuel may play an important role as a compromise fuel for aviation and existing building heating. The third place that biofuel may be the only practical choice is in shipping. Hydrogen and batteries are already being deployed for short haul shipping, like ferries around metropolitan areas. But for large ships and long distances, like transoceanic shipping, a much more energy-dense fuel is needed. Ammonia (which is NH_3) could be used. It's fairly energy dense, it can be burned directly in engines or blended with some hydrogen which is made by converting some of the ammonia to hydrogen. It can be stored at ambient temperature at just 150 pounds per square inch or around 10 bar, but because it's a tissue irritant and can be lethal at high enough concentrations, it would probably not be used on passenger ships.

Biofuel, made from algae, garbage or sewage may be the only practical answer. Again, some of the biofuel could be sequestered to make the biofuel somewhat carbon-negative.

Another advantage to deploying algae to make biofuels is that it starts a whole industry to perform direct air capture of carbon dioxide. As this industry scales, costs drop. Then the cost to pay this industry to simply capture carbon dioxide and sequester the biofuel becomes more practical. Plus adding regulations requiring biofuel manufacturers to sequester percentage of their product – effectively a carbon tax – performs some removal of CO_2 from the atmosphere.

The giant shipping company Maersk has ordered six ships that'll be powered by methanol (CH_3OH). Methanol could be refined from algae biocrude, but it may be simpler to refine the algae biocrude to other hydrocarbons which would still have the same benefits.

Summary

So that's the gamut of where electricity, hydrogen and biofuels are likely to replace petroleum. Again, I'll put a table showing our results in the show notes on the Colorado Hydrogen Network website at colorado-hydrogen.org/podcast. But here's a summary, organized by energy sector.

Electricity

The electric grid
A minority of light and medium-duty transportation but probably as fuel cell plug-in hybrid
Building heating using heat pumps but only in new construction
Short-range shipping like ferries

Hydrogen

The majority of transportation energy
Energy grid for transmission in parallel with the electric grid, some energy storage and as a fuel for electric utility generators
Industrial heat and processes
Short-range aviation
Short-range shipping like ferries

Biofuel

Long-range aviation
Existing building heating
Long-range shipping

So that's a summary of the likely replacements for petroleum in our energy sectors. I encourage all of you to view this as a table in the show notes at Colorado-hydrogen.org/podcast.

So listeners, if you enjoy listening to the HydrogenNowCast, consider subscribing to the podcast and also give us a rating in your podcast app. A good rating helps us be discovered by other people. And of course, word-of-mouth recommendations are really important, so consider letting people in your own Network know about the HydrogenNowCast.

If you'd like to contact me, I'd love to hear from you. You can reach me through the website at colorado-hydrogen.org or on Linked-In.

So until next time, this is Brian DeBruine wishing you health and prosperity, good bye.

Use	Electricity	Hydrogen	Biofuel	Key Discriminator
Energy Grid Generation Transmission Storage	 ✓ ✓ ✓	 ✓ ✓ ✓		Cost
Transportation Light-duty Medium Heavy	 ✓ ✓ 	 ✓ ✓ ✓		Performance & Convenience
Industrial Heat		✓		Technical
Aviation		✓ (Short)	✓ (Long)	Technical
Building Heat	✓ (New build)		✓ (Existing)	Cost
Maritime	✓ (short)	✓ (short)	✓ (long)	Technical

Link to IRENA "Renewable Power Generation Costs in 2022". See page 167 for information on geothermal systems:
https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Aug/IRENA_Renewable_power_generation_costs_in_2022.pdf?rev=cccb713bf8294cc5bec3f870e1fa15c2