What's the deal with electrolyzers?

A conversation with Raffi Garabedian of Electric Hydrogen.
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David Roberts

Hey everybody, this is Volts for February 1, 2023. What's the deal with electrolyzers? I'm your host, David Roberts. You Volts subscribers are likely well aware of the fact that a fully decarbonized energy system is going to require an enormous amount of hydrogen to fill in the gaps left by wind and solar. What's more, you're probably aware that hydrogen comes in a dazzling variety of colors, from blue to gray to brown, depending on the carbon intensity of the production. In the end, though, only one such color matters: green. That is to say, a fully decarbonized energy system is going to require lots and lots of hydrogen made with renewable energy with no carbon emissions.

The way to do that is to run water and electrical current through an electrolyzer, which splits the hydrogen off from the oxygen. Currently, about 95% of the world's hydrogen is made using fossil fuels. Green hydrogen—hydrogen made with renewable energy—and electrolyzers comprises only a sliver of the remaining 5%. Yet, it's going to have to scale up to 100% in the next several decades, even as demand for hydrogen rises. This is all a familiar story, at least to energy nerds. But if you're anything like me, the more you think about it, the more you realize that despite the key role they play in that story, you don't actually know very much about electrolyzers themselves.

What are they exactly? What do they look like? How can they be improved? What policy is supporting them? To talk through these questions, I

contacted Raffi Garabedian, the CEO of Electric Hydrogen, a startup that has set out to rapidly drive down the cost of green hydrogen. Garabedian, who was previously Chief Technology Officer at First Solar, believes that the market for green hydrogen today is roughly where the solar market was in 2008, with all the attendant risks and opportunities. Garbadian, quite patiently, walked me through the basics of electrolyzers, the current state of the market and the technology, the kind of cost improvements he believes are possible within the next five years, the increasingly supportive policy environment and the future of green hydrogen.

David Roberts

With no further ado, Raffi Garabedian. Welcome to Volts. Thank you so much for coming.

Raffi Garabedian

It's great to be here, David.

David Roberts

I'm excited to talk today about electrolyzers because I think I am, and I think probably most of my listeners are already convinced that hydrogen is going to play an important role in a decarbonized electricity system. I think we can just assume that. And I already think, and I think my listeners probably already know this too, that in a true decarbonized system, it's going to have to be so called "green hydrogen," hydrogen made without greenhouse gases. I know there are 50 other colors made from different other things with varying levels of greenhouse gas production. But, I think—and obviously you think, since you've predicated your business on it—that we got to make green hydrogen work.

And green hydrogen is hydrogen made with renewable electricity and electrolyzers. So, we know all that. But I find that when I think about the technologies involved, I have a pretty good understanding of all the pieces

of that puzzle, except for electrolyzers. They're just kind of this thing that plugs into a certain spot in the diagram. But I find that when I actually focus in on it and think about it, I turn out to know very little about electrolyzers. So I'm very excited to have you on the pod today because I suspect I'm not the only one who has that sort of gap in my knowledge. So maybe we can just start with: what is an electrolyzer?

Raffi Garabedian

Yeah, let's start there. Let's first start by just exploring and defining the problem that we're trying to solve, right? So we're trying to make hydrogen, which is both a feedstock and a fuel, and we're trying to make it using renewable energy. So how does that work? Well, it all starts with the water molecule. So everybody knows water is... what's the chemical formula for water? It's H2O. So think of that as oxidized hydrogen. Hydrogen, the word, actually is derived from hydro: water, gen: produces. So when you burn hydrogen yeah, interesting, right? When you burn hydrogen, you get water as a result.

So burning is oxidation. So what an electrolyzer does is the opposite of that. It's the reverse of oxidation, which is called reduction. But it does so electrochemically. Now, what does that mean? Electrochemistry is a whole field of science and technology that involves the interaction between chemical reactions and electricity. And generally the kinds of electrochemical systems that are used in industry involve things like membranes and electrodes. But the function of these devices is to drive some sort of a chemical reaction that requires energy towards a desired end state. Now, in this case, what we're trying to do is drive water, which is burned hydrogen, oxidized hydrogen, back to its original state, right back to hydrogen's original state, which is H2, which is just the diatom of the element hydrogen.

David Roberts

You're unoxidizing it.

Raffi Garabedian

Yeah, you're unoxidizing it and and to do—you're unburning it. And to do so requires a tremendous amount of energy. That's because the reaction of hydrogen plus oxygen equals water, releases a lot of energy in the first place. It's, as they say, energetically downhill. So to go the other direction, we have to pump a lot of energy into it. Now, that's the good news. It's not bad news in this case. The good news is: we are able to store a lot of electrical energy as chemical potential energy in the form of hydrogen. And then we're able to extract that either as heat by literally burning it like you would any other fuel or through other mechanisms. For example, you can run hydrogen through a fuel cell and you can get electricity back out again round trip, just like a battery.

David Roberts

So all that energy you're using to break up the water is effectively stored in the hydrogen, and you're getting all that energy back out when you...

Raffi Garabedian

You got it. I've heard people say, "Oh, well, electrolysis is bad because it's so energy hungry." Well, that's exactly the point. It's energy hungry because you're trying to convert, transform that electrical energy from electrical potential into chemical potential, right? That's what an electrolyzer does. So an electrolyzer is the machine that does that, and it's generally got a bunch of parts to it. The heart of the machine is this thing called an electrochemical stack, typically. And that's a bunch of plates, layers of plates, and they're literally stacked on top of each other, which is why we use that term in the art.

But you flow water through this thing, you pass electricity through it, and what comes out is oxygen on one side in one pipe and hydrogen on the other side in another pipe. It's got an anode and a cathode. And that's where you get the two gases are produced on either side of that cell. Now there's a bunch more to it. There's a power converter that delivers the electric power to the device and controls it. And then there's a bunch of piping, plumbing, valves, control systems, gas, water, separators, whole bunch of things wrapped around it, which we usually call like the balance of plant. Electrolyzers, historically... they've been around for a long time.

David Roberts

The metal that the plates are made of is something reactive, right? Such that when you introduce electrical current to it and water to it, it causes the chemical reaction in question, like what do we have other than water and electricity?

Raffi Garabedian

Right. There are different technologies for electrolysis, but they all involve a thing called a catalyst

David Roberts

Right.

Raffi Garabedian

And a catalyst is typically, in these cases, metals or metal oxides, which, well, like the word implies, catalyze the reaction. So they sit there, they don't get consumed, but they play a critical role in facilitating the reaction to occur. You can make water break into hydrogen and oxygen without a catalyst. Some of your listeners might remember high school chemistry class, right? You have like a little beaker of water. You put some stuff in the water to make it conduct electricity. You put two wires in it, connect it to a battery, and you see bubbles. Well, bubbles on one wire, oxygen. The other wire is hydrogen. And you can collect those gases. But that's a very inefficient way to electrolyze water. To electrolyze water efficiently, you need a very special kind of a catalyst. So those are the metals you're referring to. So they sit there, they're part of the construction of the device. They don't get consumed in the process, but they play a critical role in the process.

David Roberts

Right, so the catalyst is the same, whatever, after a year of production as it was at the beginning. This is not something that is breaking apart in any way or declining in any way.

Raffi Garabedian

Well, ideally, that's the case. Now, with any practical device, there are breakdown mechanisms, degradations, all sorts of practical things we technologists and scientists think about. And nothing works forever. Everything in the world breaks down. But, yeah, the first order, what you said is generally true. They're participants in the reaction, but they're not consumed in the process.

David Roberts

Okay, so you got these basic parts. What is the scale of this thing? Like, what is the smallest electrolyzer you could build? Or the biggest one? Or what is the typical one look like? Is it bigger than a breadbox? Like, what am I looking at if I'm looking at an electrolyzer?

Raffi Garabedian

Yeah, let's go back in history a little bit, okay? So I think... forgive me, my dates are probably off a little bit, but I think the first electrolyzers were built in Norway, I believe. And they were built to utilize hydroelectricity to make hydrogen. And those were built using a technology called alkaline electrolysis, where caustic soda, or lye, is used as the working fluid, which is water-based. It's an aqueous solution. And those units are extremely physically large. Think of an object the size of a school bus, and they operate at pretty low power levels for their physical size.

Think about something on the order of hundreds of kilowatts to a megawatt kind of scale for an object the size of a school bus. On the other extreme is this more advanced, I would say, technology called proton exchange membrane electrolysis. And that was invented... gee, I don't know the exact inventor, but I think it might have been Westinghouse back in the... fifties? And it was invented to make oxygen, interestingly, for submarines, for nuclear power subs. So these were relatively small devices operating in the kilowatts to 100 kilowatt regime, literally platinum- and gold-plated, super expensive things. They made it from submarines to the International Space Station to spaceflight again for oxygen.

David Roberts

And this is more like breadbox size.

Raffi Garabedian

Yeah, that's right. But they've been adapted and have been scaled up over the years for the production of hydrogen. They typically go from, again, from that small scale breadbox scale to objects the size of a small refrigerator, shall we say, that could be as big as a megawatt in power capacity. So electrolyzers these days, the largest electrochemical stacks you can get are on that order, about a megawatt. They're physically very different in size depending on the technology.

David Roberts

So it's not crazy to think that electrolyzers could be used in places where they need to sort of tuck into a relatively small space. Like, they vary widely in size. They could be made custom-sized for custom tasks.

Raffi Garabedian

Yeah, they've been used industrially for years. They've been used in laboratory settings for years and years. They've been used for on-site production of extremely high purity hydrogen for things like semiconductor applications, for metal processing applications, whatnot. There's kind of a history of using these devices, but generally at relatively small scales. Now, when we think about the energy transition, which is the topic of your podcast and certainly my topic of interest, we are starting to now speak about a much, much different regime of scale.

David Roberts

Right. So this leads to my next question, which is: currently, I think it's 5%, something like that, of the world's hydrogen is made with electrolyzers. 95% still comes basically from fossil fuels. So those of us who are interested in decarbonization are expecting or asking this technology to scale up super big, super rapidly, relatively speaking, like this is like we're knocking on the door like, "Hey, can you like 2000 x in the next decade or whatever." So my question is just about... is the technology itself ready to scale up that big? Is it mature in the sense that efficiencies have been wrung out? Like we have it down as well as we can? Or do you feel like there's basic tech work to be done before we're prepared for that sort of explosion?

Raffi Garabedian

That is a great question and a great framing of it. There's all sorts of really interesting technology in the laboratory today that promises to ultimately allow electrolysis to expand up in scale and down in cost. But, our problem is clear and present and urgent and so waiting for technology to emerge from the lab, which can take a decade or more because most of these devices are...first of all, electric chemistry is notoriously difficult to transition from the laboratory to reality.

David Roberts

When you say in lab, do you mean something fundamentally than what you described to me, the proton exchange membrane? You mean like fundamentally different kinds of electronics?

Raffi Garabedian

That's right. There are different chemical cycles that people are experimenting with, different membranes, new catalysts, all sorts of really great science.

David Roberts

There was something biological...capillary?

Raffi Garabedian

All sorts of stuff.

David Roberts

We can table that. Maybe we could mention that later.

Raffi Garabedian

Yeah, all sorts of stuff that's out there. Electric Hydrogen, my company, we of course are aware of all of these kind of more advanced scientific developments. We've chosen a very different path because of the time horizon of the industry. So we are clearly focused on largescale decarbonization and both the market fundamentals, the secular trends and the policy frameworks are now in place to facilitate this industry to expand and become meaningful in the next five years. And that time horizon doesn't really support basic new technology development. And so we have opted to take a very well-developed mature technology, proton exchange membrane electrolysis, and adapted to our new needs.

Now, that is done through some very core technical innovations. But the fundamental outcome of those innovations is to dramatically increase the productivity of that physical object. So that refrigerator-sized electrochemical stack we're talking about? Think about a five times increase in both the amount of power that we can run through it and the amount of hydrogen we can get out of it. The same physical-sized object. Now we can talk a little bit about how that's done. I'll be cagey about how we do it.

David Roberts

Yes, this is exactly my set of questions right here. I figured you would be a little bit cagey about it, but maybe you can tell us some general things because we're talking about both kind of the electrolyzer itself, the core, the electrodes, the membrane. And then, as you said, there's all this "balance of plant" stuff. It's a big complex process which suggests that there are lots of places within that process to tweak things and tighten things up and make things more efficient, et cetera, et cetera.

Can you tell us a little bit about in that whole big messy process where you are going in and tightening the screws and finding these efficiencies?

Raffi Garabedian

The pat answer to your question is "everywhere," but let's peel that onion apart a little bit and explore it. So, let's start with the product we're building. The biggest electrolyzer that one can buy today is roughly, I think, a 20-megawatt plant.

David Roberts

What does that look like? What does a 20-megawatt electrolyzer plant look like? Is that a factory?

Raffi Garabedian

It's a huge building that looks like a small chemical plant. And it has, you know, maybe 15 or 20 electrochemical stacks in it...

David Roberts

Got it.

Raffi Garabedian

...with a lot of plumbing and pipes and pumps and all sorts of things. And it's extremely expensive. That's the key, right? The key isn't actually how big it is. The key is the cost. Now, those things are related because the cost of plumbing, piping, valves, pumps, all of those things scales kind of with size. So to make it smaller is a good thing for cost, but also to keep it large in terms of its production capacity is extremely important.

Let's talk about the application for a second before we go into the guts of the plant, because I think it's useful to have a frame of reference for scale. So you mentioned the current use cases for hydrogen, of which 95% is supplied using steam methane, reformation of natural gas. So those use cases are roughly 50-50 split between refineries. So hydrogen is a chemical input to the petrochemical refining process. And the other half goes to the production of ammonia, which is fertilizer.

David Roberts

That's the current hydrogen market?

Raffi Garabedian

That's the current hydrogen market, yeah. Now let's just talk for a second about an ammonia plant. There are dozens and dozens of these around the world. A typical ammonia plant, if you wanted to run it off of renewable green electrolyzed hydrogen would require rough numbers on the order of a gigawatt of renewable capacity and electrolysis. So that's a big number. And remember, we're talking about these electrochemical units which are at their fundamental building block level. They're one megawatt in scale. So it would be a thousand of these things. That's a problem.

David Roberts

A thousand of these stacks?

Raffi Garabedian

Yeah, that's right.

David Roberts

Per ammonia plant?

Raffi Garabedian

Per single ammonia plant. World scale ammonia plant. Of which there are many, many. And that's just scratching the surface of what we want to do with hydrogen. Because, look, cleaning up ammonia production for fertilizer. That's great. That's some single digit percentage of global CO2 emissions right there. But the world is not interested in green hydrogen just for that reason. The world is interested in green hydrogen as an energy vector for moving energy from where renewables are abundant to where people are abundant and need the energy, for example, right? But also as an input to numerous industrial processes which cannot be electrified directly with renewables.

For example, the DRI primary steel production process, which converts iron ore to metallic iron.

David Roberts

Right. Industrial fuel, airplane fuel...

Raffi Garabedian

Ship fuel. So synthetic fuels is generally a broad category of applications so.

David Roberts

Seasonal energy storage is another...

Raffi Garabedian

You got it.

David Roberts

...big one. Really, hydrogen can do literally anything. So you could go down the list.

Raffi Garabedian

Yeah. And when you add up all those things that are very hard to decarbonize directly, you end up with about 50% of global emissions. I think the IEA's official number is something like 30%. But that skips over a very important factor you mentioned, which is the long duration storage of energy for the electric system. And when you add that back in, you get to about 50% of global emissions. So it's a massive, massive problem, requiring ultimately terawatts of capacity to be built and installed.

David Roberts

Because I know some people have lots of weird hangups about hydrogen. I know there are some people out there who are skeptical about some of these larger uses of hydrogen. But I think it's worth saying that even if that estimate is off by several percent in either side, it's still many, many, many, many, many times the current production. Like, at a certain point, it hardly matters. The target is so far distant.

Raffi Garabedian

That's right. You could be ten times over ambitious about what hydrogen could do for the world and still have an immense scaling opportunity and challenge ahead of you. Because again, we're talking about terawatts of ultimate available or necessary capacity to decarbonize all of these sectors. A tenth of that is 100 gigawatts. So big numbers here that we're talking about. So how do we address the scale of the opportunities and the scale of the plants that have to be built with technology that's at a fundamentally different scale today?

David Roberts

Right. We cannot meet that scale we need with current technology.

Raffi Garabedian

Exactly. So we can just try to make more of them. But the issue with that is that they're too expensive when they're that small. So the other thing we can try to do is make them more productive. And the word I use is: "higher throughput." So again, take those same physical-sized objects and get a lot more value out of them. The name of the game in all of this is to make green hydrogen cheap. Let's not lose sight of that. Some of the applications you mentioned for example, shipping fuel. The economic parity point for shipping fuel is almost impossible to reach with anything other than what's currently being burned, which is bunker fuel.

It's the sludge that comes out of the bottom of a distillation column and a petrol... super gross. Bunker fuel, because it's so gross, is super cheap. Now we know we can't compete economically against bunker fuel. Nothing can. However, the alternative of continuing to burn bunker fuel is less and less tractable. And so, both by legal restriction and through other economic means, the cost of the conventional approach, the bunker fuel approach, is gradually rising and we see it rising at an accelerated pace as time goes forward. So what we have to do if we want to change that

industry, just as an example, right? We have to drive down the cost of green hydrogen-derived fuels very rapidly to intersect as soon as possible with the rising cost of burning bunker in ships.

David Roberts

And we're all presuming and we'll maybe discuss this in a little bit more detail in a minute. But the assumption behind all this is that policy is going to help do this. Like policy is going to be pushing up the price of fossil fuels—one hopes—even as technology and scale are pushing down the cost of hydrogen.

Raffi Garabedian

It's happening as we speak. Okay, let's go back to the machine. So the machine has got to be big.

David Roberts

Yes.

Raffi Garabedian

And let me just say the product that we are building at Electric Hydrogen, it's about an acre in size. It's funny to think of that as a product, but that's our product.

David Roberts

And that's multiple... stacks within that?

Raffi Garabedian

It's multiple stacks, but not nearly as many as you might think. And it's comprised of modular process units. So think about kind of tractor trailer-sized frames like you might see in an oil field or a gas field. These are fluid processing units, heat exchangers, tanks, pumping skids, water treatment units and power conversion equipment, right? So we modularize all this equipment so that it can be easily put in place at a project site interconnected to produce a large-scale hydrogen plant. When I say large-scale, our product, that one acre size thing, that is 100 megawatt plant.

David Roberts

What is 100 megawatt referring to? 100 megawatts worth of hydrogen coming out or energy going in?

Raffi Garabedian

That's the energy going in to the electrolyzer. And if you want to get geeky, that's about 50 tons per day of hydrogen output at full nameplate capacity. Now, a green hydrogen electrolyzer should almost never run at full capacity all day long.

David Roberts

Oh, really?

Raffi Garabedian

The only scenario in which you should be able to do that is if you're connected to a hydroelectric power plant.

David Roberts

Are you talking about because of renewables coming and going?

Raffi Garabedian

Exactly.

David Roberts

Being variable.

Raffi Garabedian

Which is kind of the point of the architecture of our product as well. Is to be able to follow and track those renewables without firming the energy. And it has significant bearing on the choice of technology and the design of both the electrolyzer itself and also the whole plant that's put around it.

David Roberts

And to what extent are you improving the electrolyzer itself? From what I understand, the electrodes are made from fairly specialized metals? Like, are you looking for cheaper electrodes? Are you trying to improve the actual physical electrolyzing process itself?

Raffi Garabedian

The latter. So there are really two approaches to making electrolysis more cost effective to making the equipment cheaper, which goes directly to making the gas cheaper. The two approaches, broadly speaking are: make the existing hardware for less money, find cheaper materials to make it out of, reduce the labor content of the manufacturing, et cetera, et cetera. The other approach is: get more out of the same hardware, the same kind of hardware. Now, when we analyzed these two approaches when we were starting the company, we kind of looked at the scenarios and what we thought could be done.

What's the entitlement for the two approaches? Our conclusion was there might be 30-40% cost to find in the existing technologies if one can thrift

the materials, find cheaper materials, lower labor, all that, right? And frankly, we're not all that good at that. I mean, we're good at it, but it's not our forte. What we're actually really good at is driving a technology roadmap around performance. And when we thought that through and really analyzed the entitlement, we found numerous opportunities to get multiples higher performance out of what is essentially existing technology, materials and components that are well developed.

David Roberts

And this is the balance of plant stuff you're talking about, like, stuff outside the elec...?

Raffi Garabedian

No, this is in the very, very guts of the electrolyzer cell itself. So, we take a device physics approach to the problem. For those of your listeners who don't know my background, I was Chief Technology Officer at First Solar for many years. My co-founder at Electric Hydrogen was also Chief Technology Officer at First Solar. Before that, he was with Bell Labs running their device physics department. Long career in electrical and electrochemical devices.

David Roberts

Yeah, I guess I'm a little baffled how you get more out of the same materials, so please.

Raffi Garabedian

Yeah. And the way you do it is by understanding the physics of the device, deconvolving the various contributors to both performance losses and efficiency losses, and designing solutions to those material science and interfacial and transport problems. So it's all around interfaces, material choices, and the physics of how the device operates. And so with that kind of device physics approach, we've been able to quintuple essentially, like, dramatically improve the performance of the electrolyzer cell itself. Now, that gives us the ability to, without changing the size or materially changing the cost of that refrigerator thing, it allows us to get a lot more power into it and a lot more hydrogen out of it, and that's the secret trick. Right, so our hydrogen production is extremely physically dense.

Now, when you sell an electrolyzer, what does the customer care about? The customer is typically a project developer or industrial owner. They care about the hydrogen production cost. Ideally, about half of that cost is the cost of capital that's involved with the purchase of the plant.

David Roberts

Right.

Raffi Garabedian

So when you buy a plant like this, you price it in terms of dollars per watt or dollars per ton of hydrogen per day produced. So the more you can get into and out of that thing, the lower its price proportionately on a dollar per watt basis. So if I make that refrigerator size box and I can get a megawatt out of it, its price is a dollar, right? If it costs a million dollars to make or to sell, it's a dollar. If I can get just make up a number 10 megawatts out of it, wow. That same thing costs ten cents a watt.

David Roberts

So those are your biggest gains you're making. Or is it in the electrolyzer?

Raffi Garabedian

Absolutely. And the electrolyzer then has knock on effects and ramifications for the rest of the balance of the plant that's around it. If you look at our plant architecture, at first flush, it looks like others. But on more detailed inspection, one finds a lot of very critical differences. Some of them actually add cost to the plant relative to a conventional approach in order to support this really fancy, super high energy electrolyzer stack. But on average, in some total, the cost is greatly reduced even at the plant scale.

David Roberts

Oh, that's... sort of counter my intuitions. I sort of figured that with nobody having really tried to scale these things up to the point you're scaling up, I would think that all the stuff outside the electrolyzer all that plumbing and structure of the plan itself and.... I figured there's lots of efficiencies in that stuff that just nobody's thought to look at yet or squeeze out of yet.

Raffi Garabedian

Yeah, I think that's also true. Maybe there's about 500 megawatts of electrolysis installed in the world today. I think the vast majority of those plants are custom engineered and designed and built—stick built by EPCs—for a site, right. So there's not a whole lot of economy of scale or learning yet in this industry.

David Roberts

And your acre-size plant is a set thing. It's the same every time you build it?

Raffi Garabedian

Yeah, that's why I call it a product. It's not a project, it's not engineered for a site. You can buy any size and shape electrolyzer you want from us as long as it's this one. It's like the old black Model T.

David Roberts

Well, theoretically you could build two if you had two acres. Right?

Raffi Garabedian

Yeah.

David Roberts

Modular in that sense.

Raffi Garabedian

That's right. And that modular approach is actually really interesting in the market as well because we're at the early stages of this industry's growth and so project finance is a major constraint. Of course, people who are building a gigawatt-scale plant. They don't want to take the risk on building that whole gigawatt all at once.

David Roberts

Right.

Raffi Garabedian

They want to build it in small modules. So it does also serve a market need in that regard.

David Roberts

A couple of other questions about cost. How big a factor is the cost of the energy you're buying, the cost of the renewable energy. Like, if renewable energy continues to get cheaper or for whatever reason, you're able to just find cheaper energy, does that make a major difference or is that marginal?

Raffi Garabedian

Yeah, it's a huge difference. So let's talk about some numbers here, okay? So hydrogen produced from steam methane reforming of natural gas in Texas and Louisiana today, which is kind of the lowest cost region of production in the world, save maybe a few places in the Middle East—which are comparable. That hydrogen costs about a $1.50 to $2 a kilogram to produce and buy. And it's directly proportional almost to the price of natural gas. Okay, so that's the bogey. If you can beat a $1.50 a kilo or lower, the world is your oyster because you're at so called fossil parity hydrogen.

David Roberts

Right.

Raffi Garabedian

That's—and by the way, that's the dirtiest hydrogen. That...well, not quite. Hydrogen from coal is dirtier, but that's dirty hydrogen, that's so called gray hydrogen, right. Where the CO2 is emitted. If you try to capture the CO2, that price only goes up. Now, when you talk about electrolysis, the energy input to the production of hydrogen for most electrolyzers equates to about, well, every $10 a megawatt hour of electricity price contributes about $0.60 roughly per kilogram of hydrogen production cost.

David Roberts

So really makes the difference whether you're competing with that cheap stuff or not.

Raffi Garabedian

That's right. So the best in class solar energy power purchase agreement that I've seen is just under $10 a megawatt hour in the Middle East. We also see in the US, new build wind in the wind belt that's on that order, below $10 a megawatt hour, is possible. But if your energy is $30 a megawatt hour, you're already going to be north of a $1.50 a kilogram hydrogen production cost just with the energy input, not even counting the cost of capital to build the electrolyzer plant.

David Roberts

Right. And you have limited control over that. I mean, in some sense, you're subject to what energy is available.

Raffi Garabedian

Yes and no. So here's what we know. We know that renewable power all around the world where the resource is rich is extremely inexpensive as long as you don't try to firm it, as long as you can take it when it's produced. Anything you do to try to firm that power adds substantial cost, right? Because batteries are expensive.

David Roberts

Yes.

Raffi Garabedian

So the key for making low cost hydrogen is to take the renewable energy intermittently is to take it when the wind's blowing, when the sun's shining.

David Roberts

I mean, I'm sure you get this question all the time. One of the, you know, I sort of threw this out on Twitter, and I got many versions of this question, which is: how is it economic to run a hydrogen-making plant where the capacity factor is, whatever, 40% or 50% or lower? How do you pencil out the economics when your energy supply is variable?

Raffi Garabedian

Well, your Twitter followers are brilliant.

David Roberts

I could not agree more.

Raffi Garabedian

That is exactly why we have been working so hard towards this singular goal of making a large-scale electrolyzer plant that's really cheap. Not cheap on a dollars per unit basis, but cheap on a dollars per watt or dollars per ton of hydrogen produced per day basis, right? That's the key. If your capital plant, your electrolyzer, is too expensive, you can't afford to run it at a low capacity factor.

David Roberts

Right.

Raffi Garabedian

If it's cheap enough, now you can afford to use really cheap energy and run your electrolyzer intermittently. That is the secret. That is the way you get to low cost hydrogen production. That's also completely green hydrogen production. The other thing we should note here is that if you try to firm the energy input to an electrolyzer using the grid, what you're literally doing is in the hours when the wind isn't blowing or the sun isn't shining, you are ramping up a fossil generator somewhere to power that electrolyzer. And that is a terrible outcome!

David Roberts

And you no longer have green hydrogen!

Raffi Garabedian

You have the worst possible thing. You're burning a fossil fuel, which you could have converted directly into hydrogen to make electricity and then convert back into hydrogen right through an electrolyzer. That's a terrible thing to do. By the way, there's a policy...I don't know, maybe I'll call it a food fight going on in the US right now around the rulemaking that results from the IRA. I go back to policy.

David Roberts

We'll get there. So accommodating intermittent energy input is not so much a specific technological thing as just a price thing. If you can get your plant cheap enough, then you can make it work with intermittent energy.

Raffi Garabedian

Yeah, it's a bunch of things. We have to make the plant cheap enough so that it can work with intermittent energy. That's the only scalable kind of clean energy in the first place. There's a lot of hydro in the world, but not enough to solve a terawatt-scale problem.

David Roberts

Right. Well, people talk about building nuclear energy plants specifically to make hydrogen. People talk about using offshore wind energy specifically to make hydrogen, that way you wouldn't have to string a power wire out to the offshore wind. Is any of that stuff on your radar or you think that's mostly distraction?

Raffi Garabedian

Well, the energy problem is extremely localized. It's regional. So if you're in a place where natural gas is super expensive and in short supply for geopolitical reasons, whatever, your fossil parity price for hydrogen might be a lot higher than the numbers I threw out, right? So if you're in Northern Europe and you're concerned about Russian gas supply, you might be willing to spend a lot more for your hydrogen production. And in those scenarios, things like offshore wind could make a lot of sense.

Nuclear is a tough one for me to understand, quite frankly, because, look, I mean, the best use of a flexible nuclear plant, I think, is to continue to clean up the electric system first and foremost. So if we're able to figure out how to build and scale more nuclear, wow, let's go do that. I'm not sure making hydrogen out of it is the right answer. Also, the price of that power is quite high.

David Roberts

Yes. I can just tell you, Raffi, out there in the world, out there on Twitter world, people really just want nuclear. They want it to be useful for something, and so they propose it for everything. So one more question about the physical thing here, which is: where are these things currently manufactured? Because one of the big arguments going on around all the rest of clean energy is who's making it and who should make it, and is it worth trying to onshore manufacturing? Who makes electrolyzers today?

Raffi Garabedian

Today... I mentioned I spent over a decade in the solar industry. When I started in 2008, the solar industry felt a lot like the electrolyzer industry is today. So we had really strong industrials in the electrolyzers today, just like in solar back then. We had really strong industrial players in the US and Europe, who kind of had the core technology and sold the bulk of the equipment. But we're seeing China emerging. They're doubling down on electrolysis, and they're coming up in capacity. I think there's probably more electrolyzer manufacturing capacity in China today than anywhere else in the world. Though, it's a different kind of business than solar. And I think exporting these very, very large units from China to the rest of the world is going to be a different kind of challenge. I'm not sure it rolls the same way.

David Roberts

Right, so the plants you're building in the US are manufactured in the US? All your parts and pieces?

Raffi Garabedian

Yeah, we'll be manufacturing in the US

David Roberts

One of the things we've been talking a lot about on the pod recently are learning curves and what kinds of technologies do and don't get on learning curves. And this work out of Oxford last year made such a big splash—claimed that electrolyzers are on a learning curve. So what's your take on that? Is there an answer about the percentage that the cost falls per doubling of deployment? Or is it still, do you feel, like, too nascent to have an answer to that question?

Raffi Garabedian

Yes, I think we are too nascent. Look, I mean, learning curves are an analysts' way of explaining the trajectory of a whole industry's work in an area. The goal of any given company, technology company, is to be a nonlinear force in going down that curve. Right, so, I don't want to be on a learning curve at Electric Hydrogen. I want to disrupt that learning curve and put it in a new direction. And, you know, the analyst learning curve is simply the aggregate, the average, of a whole bunch of companies trying to do the same thing, which has come out on top with the best solution to the problem. So I don't put a lot of stock in learning curves. I understand why they exist. They're useful, particularly on the buy side, to kind of try to understand and predict the future.

David Roberts

Well, they're good descriptive. The question is whether they're predictive at all, right?

Raffi Garabedian

Yeah. And predicting the future is notoriously difficult, right, so.

David Roberts

But do you think, based on your experience, that costs are headed down? You're confident that costs are headed toward that target they need to hit, and that target is reachable?

Raffi Garabedian

I am. And our explicit goal at our company, at Electric Hydrogen, is to accelerate that cost down curve. So it's not that electrolysis isn't going to be scaled without us. It's not that it's not going to get to the price point it needs to without us. We think our role in this industry, at least with the role we're going to try to play, is to be an accelerant, a catalyst.

David Roberts

Pardon the pun. But it's odd, given what a central role electrolyzers play in this sort of vision of a decarbonized future. I find it odd, I guess, that I just haven't heard of more people doing what you're doing, trying to squeeze costs out of this juncture of the whole system. Do you have a lot of competitors? Do people coming to this...like who's solar? You could name five zillion companies, five zillion research labs. Is there comparable brain power going toward this right now?

Raffi Garabedian

There's a lot of research. So if you look at companies involved in electrolysis, it's kind of bimodal. On the one extreme, you have a group, a mode of companies who are large established players. I'm talking about thyssenkrupp, Siemens, Cummins, folks like that, right? And then on the other extreme, you have a large number of very small companies who are at that low technology readiness level stage. So kind of in the lab playing with new membrane materials or new catalyst chemistries or whatnot. Now, the large industrial players, they tend to be very conservative and slow moving in their technology, road mapping. They tend to be risk averse because they have massive businesses and their reputation is contingent on every piece of that business performing as advertised. So they don't like to take risks. And then on the other hand, you've got the small companies, the material science-y companies, who might be a decade from the market. There are relatively few companies, you could name a small handful today in kind of the middle ground, which is where we are.

David Roberts

Right, right.

Raffi Garabedian

Where we're rapidly developing and commercializing technology that has relatively low risk profile.

David Roberts

Right. And part of what you could do if you succeed, and tell me if I'm wrong about this, is de-risk this a little bit and lure some of those bigger players into devoting more resources to this.

Raffi Garabedian

Absolutely. Now, I don't know, history is sometimes a good teacher. And again, if we go back to solar, the big industrials all got out.

David Roberts

Yeah, I remember BP bailing.

Raffi Garabedian

Oh, yeah, everybody bailed. And whether... you could list the litany of names who no longer exist in the solar industry, who really wilted under very, very rapid technology innovation cycles.

David Roberts

Yeah.

Raffi Garabedian

And resulting steep cost reduction curves. So the learning curve in solar was just brutal and fast and hard. And if you weren't willing to run with it, you weren't going to survive in it. Electrolyzers very well could go that way. They also could go the way of wind, right? So wind power has really been a game that's been dominated by large industrials because wind has scaled the other direction. It hasn't scaled in the volume axis, it's scaled on the size axis. So frankly, the physical size of those units makes them very hard to innovate rapidly.

David Roberts

Right. Fairly curious where EVs fall and that sort of... maybe it's too early to tell.

Raffi Garabedian

I think it might be.

David Roberts

Whether the big players will be able to pivot fast enough.

Raffi Garabedian

Yeah, I'll hold my opinions on that.

David Roberts

Alright, so at long last, let's talk about policy. Because one of the questions I got about this, which I think is a very good question, is the danger, it seems to me, of being in the green hydrogen business is that the danger is getting out ahead of policy such that you start producing on a greater scale than there is demand. Generally, the market will opt for the cheapest hydrogen until forced not to by some sort of policy. So is there enough policy support for green hydrogen now that you're confident demand will exist for whatever amount you can produce?

Raffi Garabedian

Yeah, I think in the long term, absolutely. Yes both...

David Roberts

Long term is, we're all dead in the long term, or whatever the phrase is.

Raffi Garabedian

Yeah. Well, let's frame it more carefully. So five plus years out.

David Roberts

Right.

Raffi Garabedian

I think the answer is yes. There is still a big question mark around the two to five year time frame. There are gigawatts and gigawatts of announcements globally of companies who are building—air quotes building—fossil-free hydrogen production plants for industrial uses, for energy uses, for grid firm, all sorts of applications that we've talked about and mentioned. But what does it take for those to get to a financial investment decision and for ground to be broken and for electrolyzers to be installed? That's the question, right.

And I think there is a lot of risk in that. It comes down to understanding, from our point of view as a company in the business of making and selling electrolyzers, we do as much diligence on our customers as they do on us. So our customers are worried about our technology. "It's a new technology. We haven't seen it before, and you guys haven't really built one before. How do we know it's going to work? Okay, great." That's our customers diligence on us. The other side of that coin is, "Hey, we want to understand... who's your offtaker for hydrogen? Why do they want the gas?"

David Roberts

Alright.

Raffi Garabedian

"Why is it economical today? What policies are supporting it? What's the end use segment and application? And how does all that work? Why does your project actually make sense?" Because if we believe it actually makes sense, then we can have much, much higher confidence that it will go through, that it will get built.

David Roberts

A little wariness on both sides then, at this point, like the supply side and the demand side.

Raffi Garabedian

Absolutely. I would say the reality-to-hype ratio is about one to ten right now.

David Roberts

Yes, it is right there in that cycle. But, presumably your business thesis, the way you're raising money, is by saying demand is on the rise.

Raffi Garabedian

Demand is on the horizon. And we look really carefully and thoughtfully, at least we try to, at the leading indicators that predict demand. Because, look, I mean, this is an industry that essentially doesn't exist and has never existed before, so we can't use past performance to predict the future, right? So we've got to look at leading indicators. We've got to look a layer or two underneath what's being built today to understand what's driving that behavior. And we think the fundamentals are there. So a number of things come together. Certainly the European policy framework has firmed up, continues to firm up, and is driving bona fide, like, verifiable activity on the European subcontinent.

David Roberts

Is that just the cap and trade? Is that just the general squeezing of carbon? Or there's the hydrogen-specific stuff you're talking about.

Raffi Garabedian

There's hydrogen-specific stuff in Europe as well, but there's also a lot of secondary, "Hey, it can only be solved. We can only meet these requirements with hydrogen we don't know how else to do it" kind of things. And then when we look at the US, again the IRA, which I mentioned, that makes fossil-free hydrogen an economic viability, like with the snap of a finger.

David Roberts

And that's just a big tax credit. That's like a per production tax credit. What exactly is the structure of the...?

Raffi Garabedian

That's right, it's framed as a production tax credit. So for each kilogram of hydrogen you produce, you get a certain number of dollars in tax credit back, which goes to the bottom line of a project.

David Roberts

And does it have any stuff about the other colors of hydrogen, or is this a black and white, sort of like, "We'll give you money if you do green."?

Raffi Garabedian

Well, it's thoughtfully framed, actually, in terms of the greenhouse gas intensity of the hydrogen that's produced. It's technology agnostic, it's greenhouse gas indexed, so you can get anywhere from $0 to $3 a kilogram tax credit, depending on your carbon intensity. I mentioned a little while ago there's a bit of a food fight going on around the rules for that because the quality of the electricity going into an electrolyzer is what's being fought over.

David Roberts

Oh, interesting.

Raffi Garabedian

Yeah. Some of us in the industry kind of want to take a long view, and the long view says, "Gee, that electricity really needs to be directly fed from a renewal plant." Not on one wire, but at least time-synchronized and locationally matched.

David Roberts

As opposed to just sort of using grid electricity and then buying wrecks or whatever.

Raffi Garabedian

You got it. That's exactly the fight that's going on.

David Roberts

This is, again, Volts listeners will find this whole discussion familiar from the distinction between going 100% renewable and going 24/7 renewable, matching on an hour-to-hour level.

Raffi Garabedian

It is the same exact thing being fought out right now against this $3 potential tax credit.

David Roberts

So you're advocating for, "we need to be doing this hour-by-hour so we know...not just that we're offsetting, but that we're using clean energy."

Raffi Garabedian

I will unabashedly say we're advocating to do it right, for God's sake.

David Roberts

And this is ambiguous in the language of the law. So this will be...who's making this decision in the end?

Raffi Garabedian

Yeah, like any law, right. There's a of lot rules associated with it. So yeah, the decision is being effectively litigated at this point.

David Roberts

And does the IRA tax credit sort of add a stroke, make your current product viable? Is it enough in and of itself?

Raffi Garabedian

Yeah, frankly it does. But I will also tell you that, again, based on experience in solar and the resulting scar tissue, I'm extremely wary of subsidies. I value them highly. They're necessary to get a nascent industry like this off the ground in the face of a much cheaper but dirty alternative, which is fossil fuels.

David Roberts

It's the iconic case for subsidies.

Raffi Garabedian

Absolutely. But having said all that, our goal as a business is to enable subsidy-free fossil parity hydrogen production as soon as possible because the subsidies are always at risk. They're expensive, right.

David Roberts

But the ones in IRA are not capped or time as an expiration date or?

Raffi Garabedian

I believe it's a ten-year.

David Roberts

So that's a pretty good runway. It's a great runway assuming it stays in place, right.

Raffi Garabedian

Assuming it stays in place. And of course, these things are political at the end of the day.

David Roberts

Yeah.

Raffi Garabedian

So for a lot of reasons, both fundamental reasons and also political reasons, our goal is to be subsidy-free to enable subsidy-free fossil parity pricing as soon as possible. And we think we can do that in under five years.

David Roberts

Really? That's pretty tight. Like, have you built a plant yet? Where where are you at in deployment? Have you got a demonstration plant? Where...what's going on?

Raffi Garabedian

We have a small scale prototype here in California. We'll be building a pilot towards the end of this year. So the answer to your question is no.

David Roberts

The pilot is the full-acre plant?

Raffi Garabedian

It's the indivisible unit of that full-acre thing. It's not the full-acre thing, but that'll be coming in 2024.

David Roberts

And background policy. I know that the IRA is a big, huge deal. I know there are supports in Europe. What about procurement rules? I think, like, the federal government now has some sort of like, rules about the cleanliness of the hydrogen can buy, or big institutions basically saying, "We'll be a market for this, we'll be guaranteed offtakers." Is there much of that, or is it mostly the IRA you're banking on?

Raffi Garabedian

Well, right now in the US, it's mostly the IRA that's driving adoption. Well, it's the IRA coupled to corporate procurement and decarbonisation strategies. And just like you see in the world of renewable energy procurement, the same is going on now in renewable fuels, clean fuels, and hydrogen writ large as an element of various industries.

David Roberts

Right, well, like steel and stuff like that, too. If you want green steel, you're basically saying you want hydrogen. Green hydrogen.

Raffi Garabedian

That's right. And if you survey the steel industry, you'll find a spectrum of opinions from company to company as to how seriously these producers are approaching decarbonization. Some are extremely committed to decarbonizing rapidly, and others, I guess I would say, are making moderate moves, grudgingly in that direction. So you see that in every sector that we work in. You see it in ammonia production, you see it in fuels, you see it in steel. There's a spectrum of opinions.

David Roberts

Well, as you said, specifically in the hydrogen market, there's this sort of like, "You go first. No, you go first." between the buyers and the sellers. It's a very specific moment in the market.

Raffi Garabedian

It is. You could say it's a high risk moment. It is. It's also a high opportunity moment.

David Roberts

Exactly.

Raffi Garabedian

One of the things about this industry that I think will track in a similar direction as both wind and solar did, there's going to be a large wave of adoption. And if you're not a participant in that first wave of adoption as a technology provider, I think it could become very, very difficult to get down the learning curve and to scale at a future date.

David Roberts

So you think early movers have a big advantage here?

Raffi Garabedian

I do think so. I do think so.

David Roberts

But it's worth saying, you seem confident that these efficiencies exist, that the technological possibility exists. So even if, God forbid, your company doesn't make it, you think this is going to happen, these electrolyzers are going to get cheaper and cheaper until green hydrogen is cost competitive? You think that's more or less inevitable?

Raffi Garabedian

I do. I think that's inevitable. I also think the continued reduction in renewable power costs is inevitable. Despite there are short-term disruptions in that market kind of supply, demand, balance thing. But in the longer term, again, it only gets cheaper. It doesn't get more expensive.

David Roberts

Awesome. I've kept you a long time, but I guess just by way of a final question, is you're, as you say, specifically not messing with the stuff on the lab right now. You are trying to economize and bring down the cost of existing technology. Is your sort of like business plan open to the idea that if one of these capillary things come along or one of these sort of fundamentally new...because this is a question about storage...that I often ask people in the storage industry. Like, lithium ion is so established and so far ahead that if you want to compete with lithium ion, at the very least, you need to be able to slip stream in to basically the same manufacturing process because otherwise you're just starting from nothing and you'll never catch up.

Is this the sort of thing where if a fundamentally new kind of electrolyzer comes along that you could just slot it in? Or just how modular is this and how open is your business plan to sort of big advances in the technology like that?

Raffi Garabedian

Oh, we're not only open to it, we're eager for it. And we expend some of our R&D effort on just those kinds of directions as well as talking to other companies who are more in the lab than we are. So, yeah, we're absolutely open to it. It's early days in this industry and there are very few examples in the world of technology where the solution today is the solution 20 years from now, right? So this is a long game. We're going to be doing this for a while, and the technology will shift and will adapt with it, but not at the expense of losing focus. Again, I think we have an opportunity that's three to five years in front of us to scale this industry from a glimmer in our eyes to something that actually matters at the scale of the global energy system. That's what we're laser focused on.

David Roberts

Well, thank you so much for coming. This is hugely clarifying for me now. I feel like I have a little bit something in that electrolyzer bucket in my head now, and I know our listeners will appreciate that too. Thanks so much for coming on.

Raffi Garabedian

This has been a great conversation. Thanks for all the awesome questions and thanks for having me on the show.

David Roberts

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