FCEB Webinar Series 2024: #2 – Fuel Cell Electric Bus Training & Support

Question & Answer Session:

Q. To what extent is Ballard ready to compete with, or join forces with, huge corporate fuel cell suppliers, such as Toyota, which will likely offer a higher value due to leveraging a vaster manufacturing infrastructure?
A. There are currently some impressive efforts from the likes Toyota, particularly in passenger cars, however Ballard has invested over $1.5B USD in developing hydrogen fuel cells specifically for heavy-duty applications, and no one in the industry can match us for lifetime and performance. As for many engine drive system components, the specialized expertise required to make long-lived fuel cells is very different to assembling trucks, and our benefits as a supplier continue to be proven with growing deployments.

Q. How many years can the fuel cell operate before reaching its end-of-life?
A. Our fuel cell modules match the service life of diesel engines and are designed to last 12-15 years. After 20,000-25,000 hours or six years of service the stacks are due for refurbishing – in which the stack is returned, the plates are inspected and re-used multiple times, and the precious metal catalyst recovered from the membranes (>97% recovery). The refurbished stack then costs a fraction of the cost of a new stack and can have the same warranty protection as a new stack. Some of the balance of plant components of the fuel cell engines will have to be replaced during the lifetime of the product.

Q. *Can you discuss any pros/cons between battery-dominant vs. fuel cell dominant architectures?*
A. The size of the battery relative to the fuel cell has a few design factors, including relative price of the components, and the amount of time the vehicle needs to use maximum power from both items. If the battery is too small, you may be limited in the time you can drive at max power. If it is too big then

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space, weight and range become an issue. It really requires deep experience to get this balance right, as you can see in the New Flyer drive evolution.

Q. Any OPEX savings comparison using hydrogen vs diesel?
A. You're going to see the price for maintaining both are about the same. Some of the parts on the fuel cell bus are more expensive now – simply because of low volume production, but as there are fewer moving parts less maintenance operation is required. With time we expect the maintenance cost of a fuel cell powertrain to be less than diesel. In a diesel bus there are roughly 10,000 parts, compared to around 5,000 for a fuel cell bus – so having half the number of parts will eventually positively impact the cost of maintenance.

Q. Can you give any estimated cost benefit using the fuel cell vs diesel?
A. Where you will save money is in the long-term in repairs. Fewer number of parts means fewer things to do, you don't have fluids that have to be replaced, it's a much cleaner environment, much easier to work on, and will be cheaper for your service. Once we get to hydrogen that is $5-7/kg, which will hopefully be very soon, your fuel costs will be cheaper as well. We look to see our capital costs for a fuel cell bus, we expect the price of the bus to continue to be lower as production scales up. Remember that diesel and hybrid buses are anticipated to get more expensive and some of those engines may even be discontinued, so it's going to be difficult to stay on the ICE route for several reasons.

Q. Do you currently use or plan to use hydrogen tanks with 700bar pressure in your fuel cell electric buses?
A. Our customers have so far found 350bar pressure provides sufficient fuel for the range they need (350+ miles). There is a version of the New Flyer bus being made with additional 350bar fuel storage for Humboldt Transit, which should take them over 400 miles of range. Going to 700bar will increase the price of the tank storage, per kilogram of hydrogen, and the fueling station becomes a bit more expensive, with pre-cooling of the fuel being required. So, we are not considering 700bar for 40ft or 60ft transit buses, but we may see it in upcoming fuel cell motor coaches.

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Q. What is the expected cost for future fuel cells? Do you think that SOFC can substitute PEMFC?
A. Fuel cell prices will continue to drop as production scales up. Ballard just announced our new factory coming to Rockwall, Texas that will produce 3GW and 20,000 modules per year. SOFC is interesting for large scale stationary, but we have not seen a system with the weight and size that would fit mobility requirements due to high-temperature operation and limited cycling capability.

Q. Is it only necessary to have detection systems for hydrogen, or are there other gases that need to be detected, e.g. carbon monoxide?
A. The fuel cell drive system produces no gases other than water vapor and trace amounts of hydrogen - there are no other gases produced or use that require detection. We have found some lower-cost hydrogen sensors cannot discriminate between hydrogen and carbon dioxide and should be verified with the manufacturer.

Q. How long is Tier 3 training?
A. Tier 3 training is one week.

Q. *How do we access these trainings?*
A. Ballard usually interacts with participants and the bus manufacturer to establish a training schedule. Once the training has been completed, that is when participants gain access to all documentation. Training is always completed with Ballard for our customers and is done in conjunction with the initial start-up of a FCEB fleet.

Q. Do you offer any training in the UK?
A. Yes! Ballard's division in Denmark provides the base for where our trainers come from and their support for interested parties and customers is Europe-wide.

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Q. How much time is required for the rebuilding of the fuel cell stack?
A. For a mid-life rebuild, the module would be replaced with one that was already refurbished, and the old module sent back to Ballard where we would re-build the stack and module in-house.

Q. What do you suggest about retrofit running buses?
A. It has been done - one such company to talk to is Complete Coach Works. There is not a "commercial" retrofit package today, but more and more people are interested in the process.

Q. *Where do you see Ballard in 10 years?*
A. Ballard's ambition is to be the leading high-volume global supplier of fuel cell engines across multiple heavy-duty mobility applications.

Q. How does an on-board hydrogen storage tank compare in terms of weight/capacity to CNG tanks we are using today?
A. Design-wise the cylinders themselves are very similar – sometimes identical cylinders are used for both gases. In terms of overall capacity and distance for the engine, that varies from design to design, but we know OEMs try to target the 300–400-mile range, some even greater. So, there are differences, but they try to keep it close to parity.

Q. Does the refurbished fuel cell engine have the same 20-30k hour, six-year life as the original or is it diminished somewhat?
A. Yes, 20-25,000 hours and six years – whether it's new or refurbished.

Q. Do the Ballard fuel cell engines use graphite or steel bipolar plates?
A. We use graphite plates on our fuel cells as they last longer. Since the early days, our stacks have gotten smaller, longer lasting and higher efficiency – everything we needed to do in order to be competitive with and actually exceed combustion engine performance.

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Q. How (or) has this fuel cell stack evolved from the stack used in the 1990s stack evolved from the stack used by the FTA program from the PNGV program?
A. Ballard has advanced almost every aspect of fuel cells since the 1990s to increase performance and lifetime while reducing costs. Platinum use has been reduced so much that the amount of platinum in a fuel cell car's fuel cell stack is about the same as in a gasoline car's catalytic converter. Advances in seals and coating have greatly increased lifetime durability as well as electrical performance, and high-speed roll-to-roll manufacturing has drastically reduced costs.

Q. What voltages do the FCEV buses run at in comparison to the fully electric buses? Is there any specific PPE that is needed purely for the hydrogen side or just the same PPE as electric buses for high voltage?
A. The fuel cell module voltage is 280VDC-560VDC, which is boosted up to battery voltage by a DCDC converter. The battery bus voltage is the same as the battery electric bus equivalent, and so the high voltage PPE is the same.

Q. Have you considered future implementation of hydrogen combustion engine propulsive technology?
A. Many in the industry are looking at it. There are currently a few manufacturers that are trying it out – we think it might be an interim solution, but there are a few issues with combustion. One is that the high temperatures are always going to create knots and particulates, so you'll always have to have some kind of after-treatment; and if you're going to have a combustion engine, you're still going to want to take up your braking energy, so that means you're going to hybridize it – and so 10,000 parts suddenly becomes even more, because you also throw in a transmission that is probably going to have a lot of gears to get to that very narrow high-efficiency power band. So, it may be compelling to look at the combustion of hydrogen, but when you look at the technical issues you have to deal with on the engine, it starts to become expensive, lifetime gets challenged again, and you've got emissions and the after-treatments to deal with. It's interesting, but we think that fuel cells are still going to win in the end for cost, lifetime, and performance. Fuel cells will always be more efficient than hydrogen internal combustion engines by at least

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15%. So, when you look at your operating cost, fuel cell is the best option moving forward.

Q. I think the best solution is green hydrogen by fuel cells for minimum carbon footprint, what do you think?
A. We do try to get away from specific colors, but electrolysis hydrogen from wind or solar is fantastic – but what it brings along with it is that intermittency. So, either you're going to have to overbuild your electrolyser so that you can take up all the peaks and valleys and not just the average amount of sun and wind, or you're going to have to have a very large battery bank to buffer that. There are downsides with going just with solar and wind that mean you need to build more infrastructure – there are people looking very seriously at hydrogen from nuclear because it can help with the variability on the grid where they can run those things at constant output. If you look at renewable natural gas, you can get to carbon negative situations, and there are people looking at pyrolyzing methane to get solid carbon out and hydrogen. As you say, 'green' hydrogen is great, but it's worth looking at all of those alternatives, and that's where a lot of the tax incentive discussions are today.

Q. What is the price to be considered for green hydrogen today?
A. In California, transit agencies are procuring zero carbon liquid hydrogen for about $10/kg, while passenger cars and specialty projects are paying double or triple that price. The price will begin to drop when the first pure-play clean hydrogen production facilities come online. It is only the lack of competition keeping the price as high today - otherwise the math is simple: estimate 50kWh of electricity to produce one kilogram of hydrogen from electrolysis, and at $0.10/kWh you get $5/kg, on which you add amortization of the capital, O&M and transportation.
For transport within 200 miles of gaseous hydrogen production, the transportation should not cost more than $1/kg. The O&M should be a fraction of this, and if the capital is mostly funding by federal grants, this should be an easy price to hit. Renewable natural gas and pyrolysis producers may be able to produce zero carbon or carbon-negative hydrogen even cheaper, at scale. The key for cheaper clean hydrogen is to ensure healthy competition by applying

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federal incentives to <u>all</u> clean forms of hydrogen. Tell your Congressional representative today!

Q. How are Certarus' hydrogen trailers delivered, and how does that fit into the "carbon balance" or "climate change" benefits otherwise manifested by FCEBs/FCETs?
A. Certarus' current tractor fleet is comprised of CNG and diesel tractors with a plan to expand into FCEV Class 8 Tractors. If there is a customer requirement for the use of FCEVs, we can work with the OEMs to provide this solution.

Q. What is SARTA cost per kg for the hydrogen?
We're about $9 per kg. We did see as low as $5, but only in molecule. As soon as the operations and maintenance are added, that's what pushes the price up.

Q. Could you give us more information about SARTA's fuel economy?
A. One kilogram of hydrogen releases about 99% of the same level of energy that a gallon of diesel does. So, when I [Kirt Conrad] was talking about 7 miles per gallon earlier in the presentation, that's 7 miles per kilogram – which is what we're seeing on that particular ElDorado bus. Furthermore, I think AC is getting closer to 9 miles per gallon on their New Flyer fleet.

Q. If SARTA has seen hydrogen prices double since they started, why would we think prices will go down with more production? Hasn't production been increased already by the new technology and prices have gone the other way?
A. With the Biden administration's $50BN Earth Shot for Hydrogen and trying to get it down to $1/kg is really the game-changer that is happening. Also, up until now, the way that you make hydrogen hasn't really technically changed that much – since NASA started launching the Saturn rockets in the 1950s. But now we're seeing more and more advances with electrolysers and ways that we can make hydrogen that's cheaper. So, the technology moving with Hydrogen Hubs, you're going to see that number go down, because of new research and new ways to make it.

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