Cleaner Trucks, Ships Within Reach With This Fuel, Start-Up Says

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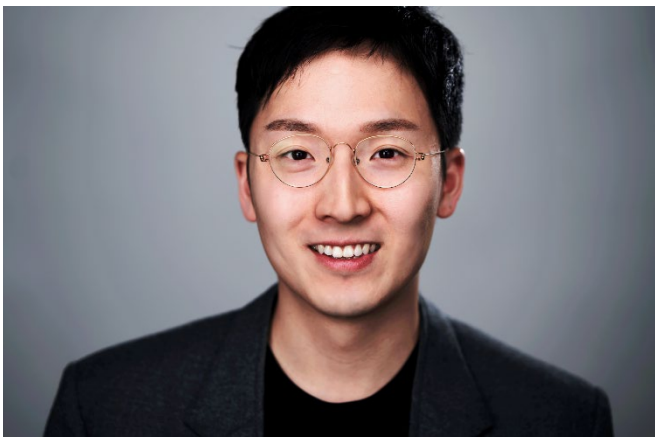
Decarbonizing heavy industry – particularly heavy transportation such as trucking and maritime shipping – is notoriously difficulty. Alternative fuels are costly and in short supply. Batteries are heavy, bulky and limited in the amount of energy they carry. Ships running on liquefied natural gas are known to release methane in a process known as methane slip. Hydrogen from renewable sources is expensive and difficult to transport.

New York City-based Amogy Inc., which was founded by four Massachusetts Institute of Technology alumni, has another solution. Led by Seonghoon Woo, a former research staff member at IBM and a former staff scientist at the Korea Institute of Science and Technology, Amogy has developed technology to tap into the potential of ammonia, a colorless gas that's also the main ingredient in artificial fertilizers. Ammonia is also energy dense, meaning it's able to store a huge amount of energy in a small space.

Amogy has developed technology to split ammonia into its component parts of hydrogen and nitrogen. The hydrogen is then fed into a fuel cell to produce electricity to power an electric motor, making it optimal for mobility. Key to Amogy's ammonia-to-power system is a chemical catalyst that allows the 'ammonia cracking' to occur at lower temperatures than is typical today.



Seonghoon Woo, chief executive officer of Amogy Inc. Photo courtesy of Amogy.

"The industry that we are focusing on like maritime shipping — that's the industry where batteries can never be a solution simply because of the fundamental energy density challenge," Woo told BloombergNEF in an interview. "Even compared with liquid hydrogen, ammonia has 40% higher energy density on a volume basis and ammonia can be liquid at room temperature which makes it much more affordable and effective."

Amogy has demonstrated its ammonia-fueled power system in a drone, a tractor and a truck. The company will later this year test the technology in a tugboat in hopes of showing that it can work in a marine environment. Commercial production comes next.

Although less than three years old, Amogy has caught the attention of investors. Earlier this month, the start-up announced the conclusion of its $150 million Series B, bringing total fundraising to $220 million in the past 2 1/2 years. The company's backers

include SK Innovation, Amazon's Climate Pledge Fund, Aramco Ventures, AP Ventures, and DCVC.

In May, LSB Industries Inc. and Amogy announced a memorandum of understanding to promote the adoption of low-carbon ammonia as a marine fuel, initially for use on inland waterways in the US. Highlighting the US start-up's Norway connection, Amogy in November signed a collaboration agreement with Yara Clean Ammonia, a subsidiary of Oslo-based Yara International ASA.

Woo spoke to BNEF at the end of May from Norway where Amogy has established its first international office. The following transcript has been edited for length and clarity.

Q: How does your ammonia-to-power technology work? And a follow-up, what is a cracking module in the context of your technology?

A: The most popular way of generating power using fuel is combusting the fuel. There are companies, especially traditional engine makers, trying to develop combustion of ammonia but ammonia is not really a good combustion fuel because it generates a lot of NOX (nitrogen oxides). The bigger problem is that it's not really combustible. You can't really combust ammonia alone so you have to mix it with other combustible fuels like diesel.

Instead of combusting ammonia, our approach is to crack the ammonia and combine the cracker with a conventional typical hydrogen fuel cell. Hydrogen fuel cells have been available for about 20 years so they're very mature. But the fuel cell vehicles in transportation have not been well adopted to the market yet, not because of the fuel cell but mainly because of the difficulties dealing with the hydrogen fuel itself. Our technology is essentially enabling the use of the fuel cell but using a different, much more effective fuel – ammonia — by integrating ammonia-to-hydrogen cracking together with the hydrogen fuel cell.

Ammonia cracking is not a new technology. It's been done for a while. However, all the existing cracking technologies are more optimized for stationary applications. They haven't been able to think about it for mobility because you need very high temperatures in conventional cracking technologies – 800C or even higher – so you need massive infrastructure. The core technology we developed is that even if we are using conventional catalyst-based ammonia cracking, our catalyst operates at much lower temperature – something like half the conventional temperature. That reduces the infrastructure. At the same time, we developed our own way of integrating the cracker with the fuel cell with a strong focus on reducing the footprint as much as possible. Our cracker with the same capability has a footprint a hundred times less than a conventional cracker. By developing a mobile, compact cracker you can now use ammonia cracking for mobility.

Q: So ultimately these are fuel cells that power electric motors?

A: That's right. It's essentially an electric vehicle.

Q: What can you tell me about the catalyst?

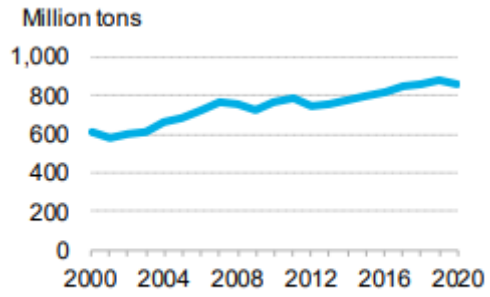
A: We use a ruthenium-based catalyst. It's one of the platinum group metals. We use a minimal amount of ruthenium so we don't have much concern about the availability of the material itself.

Q: What is the advantage of an ammonia fuel system over a more conventional technology like lithium ion batteries or even fuel cells alone?

A: In our system, ammonia is what's really enabling the transportation and storage of hydrogen. We bring the ammonia-to-hydrogen process all the way into the power train so that the customer can deal with the ammonia alone and they don't have to deal with the hydrogen logistics at all.

Ammonia, unlike hydrogen, can be stored as a liquid at room temperature. We're also using the same ammonia as in fertilizer. The United States has a massive corn belt where they heavily use ammonia as fertilizer so they have an ammonia pipeline, storage terminals and barges. People have used the experience of transporting ammonia for fertilizer to help develop the system of storage and transportation, which we are actually tapping into for our system.

CO2 Emissions From Shipping



Source: BloombergNEF

Q: What about the energy density of ammonia? How does it compare with batteries for example?

A: The industry that we are focusing on like maritime shipping, that's the industry where batteries can never be a solution simply because of the fundamental energy density challenge. Even with a battery as big as a container ship, you can't make transpacific or transatlantic journeys because the energy density is very limited. You have to use highly energy dense liquid fuel. That's why people wanted to use fuels like liquid hydrogen or ammonia. But even compared with liquid hydrogen, ammonia has 40% higher energy density on a volume basis and ammonia can be liquid at room temperature which makes it much more affordable and effective.

Q: What about safety concerns?

A: Ammonia is a toxic substance so there are safety concerns, which is why I don't see ammonia being used as an active consumer fuel in consumer applications. However, in commercial industry like commercial shipping, people have been transporting ammonia at massive scale, so there are well-established safety protocols and systems in place. Our technology is designed for commercial transportation like commercial shipping and commercial large-scale power generation so we and our customers don't have significant concerns on safety. At the same time, we're working together with industry certifiers and regulators like DNV, Lloyd's Register and the US Coast Guard to ensure the safety of the technology during commercial operations.

Q: Can you talk about the efficiency of the entire system.

A: Our system efficiency, meaning ammonia to power, is about 40%. The efficiency loss is heavily coming from the hydrogen fuel cell where hydrogen to power is the industry standard 50%. The rest of the components – the cracking and the rest of the process – is roughly 80-85% of the efficiency.

Q: Is there anything you can do to increase that efficiency?

A: The biggest increase would come from hydrogen fuel cell efficiency improvements. We chose to use low-temperature PEMFC (proton-exchange membrane fuel cell) because it is most available and most matured and therefore we can go to market as soon as next year. However, there are

newer fuel cell technologies being developed such as the solid oxide fuel cell, or PAFC (phosphoric acid fuel cell). These fuel cells have efficiency of about 70% to 80%. Our cracker is designed to be agnostic in terms of the type of fuel cell. As new fuel cells become available, the efficiency is going to dramatically increase.

Q: How does your ammonia-fueled system compare to electrification and other decarbonization methods both on capex and opex? And where do you see going in terms of lowering the system cost itself.

A: The most expensive part is actually the hydrogen fuel cell which takes roughly 50% to 60%. At the same time, given the investments happening in the hydrogen fuel cell industry in general – like with batteries over the past 20 years – hydrogen fuel cell costs are expected to drop rapidly for the next 10 years or so. This will make our system very cost-competitive. Even before that happens, our customers are already happy with this kind of system. If you think of maritime shipping or power gen where they use the system for 20 to 25 years, capex is only 10% to 20% and opex is 80% to 90%. When it comes to the opex calculation, we are enabling the use of ammonia, which is a much cheaper fuel compared to hydrogen or other viable renewables. On an energy basis, it's four to five times cheaper than hydrogen at fueling stations. That reduces opex significantly. If you think of the total cost of ownership combining capex and opex, our system even today has a much lower price point compared to other options.

Q: How do you ensure the ammonia you use is clean ammonia?

A: Ammonia production is 99% gray today because they use gray hydrogen (hydrogen created from natural gas or methane) as feedstock. Hydrogen production heavily relies on natural gas reforming. We are collaborating with our partners. For example, our final trial, which is an ammonia-powered tugboat, will be powered by green ammonia provided by a company called Yara, which we're actively collaborating with. At the same time, the biggest difference between the previous ammonia production industry to now is that previously it was maybe the play of the fertilizer companies. Now there are more companies coming from the oil and gas industry. Saudi Aramco have started producing a low-carbon ammonia. SK, which is also our investor along with Saudi Aramco, has started investing heavily in renewable ammonia production as well. Massive investment is already happening and that gives us confidence in green and blue ammonia in the future. The expectation is that as our technology scales in the next 3 to 5 years, there will be enough cost-competitive green and blue ammonia (ammonia made from 100% renewables or from natural gas feedstock with carbon capture) available in the market.

Q: On shipping, getting the ammonia infrastructure in place is critical but difficult. Do you expect that to be built first?

A: This is part of the reason we are going after the shipping industry. Given the international nature of transportation of ammonia as a fertilizer, there are roughly 200 ports available today exporting and importing ammonia. They have the equipment and the infrastructure to handle the ammonia. We can piggyback on the existing infrastructure. However, if you want to use it as a fuel, it's not going to be enough. You need much more widespread infrastructure to be available. I come to Norway quite often and Amogy established its first international office in Norway, because all the innovation and new fuel in maritime shipping starts in Scandinavian countries like Norway.

Singapore as well started its own effort last year making an ammonia bunkering hub for international shipping. We know these different geographical segments are already investing to build the infrastructure and the regulations so we are going after those regional markets in the beginning. As we succeed in these regional markets, we see that the infrastructure will become more available across the globe. That's essentially what happened in other markets like LNG many years ago.

Q: You've done your trial with the drone, the tractor, the truck. You're eyeing the trial with the tugboat. How adaptable is your system to other aspects of electrifying transportation?

A: We essentially are using a state-of-the-art electric power train. We can take the battery out and implement our system so that we can electrify different types of vehicles. However, I'm a big believer in lithium ion batteries for consumer electric vehicles wherever batteries are available and applicable especially given the amount of investment and experience built over the last 20 years. Our technology is really designed for applications where batteries aren't the solution, like shipping or power gen.

Q: Finally, what is the timeline to commercialization? You have the tugboat trial later this year. What comes next?

A: While we're building the tugboat in the United States in Kingston in New York, we're also building a manufacturing facility in Houston, which will be completed by the end of the year or the first quarter of 2024. The plan is to have the tug then we will start producing our product at scale, not at large scale but medium volume starting in 2024 in Houston so we can provide the product to customers. We're already accepting pre-orders from a selective group of customers, to be commercially deployed in the market from 2024. And then we're looking at larger production from 2025 or 2026.

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Contact details

Client enquiries:

- Bloomberg Terminal: press <Help> key twice
- Email: support.bnef@bloomberg.net

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Iain Wilson	Senior Editor	iwilson2@bloomberg.net
Ben Vickers	Chief Editor	bvickers@bloomberg.net

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