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Hydrogen-based steelmaking increases momentum

In support of the steel industry's continuing quest to decarbonize production, major worldwide technology partner Tenova is drawing on decades of experience of using hydrogen. Tenova executive vice-president Paolo Argenta and Tenova HYL president and CEO Stefano Maggiolino discussed the many opportunities, as well as some of the challenges, with Richard Barrett

As the global steel industry continues its efforts to lower its carbon emissions, the efficient use of hydrogen as an energy vector and as a reducing agent for production of DRI is receiving ever-greater attention.

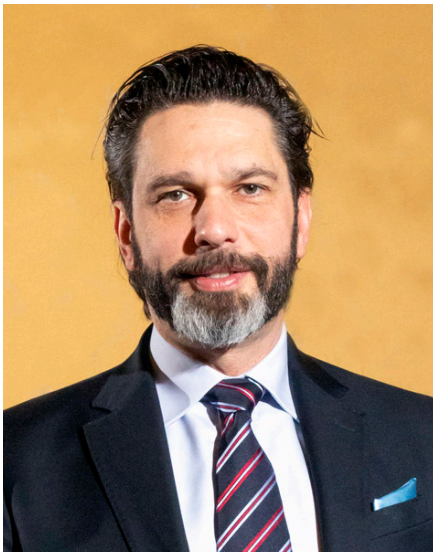
Technology companies with many years of experience in the use of hydrogen as a process gas are keen to point out that they already know much about its application in existing industrial plants and they have become active partners in designing, planning and building the latest systems to deploy the gas. With headquarters in Italy and operations worldwide, Tenova is a key contributor to this trend, and its DRI competence center, Tenova HYL, has particular expertise in the use of hydrogen as a reductant.

In recent months, Tenova has increased its momentum in supplying technology for hydrogen-based steelmaking, announcing in late November 2020, for example, that it has signed a contract with the HBIS Group in China for the implementation of the Paradigm Project, a hydrogen energy development and utilization plant. The project includes a 600,000 tpy Energiron® DRI plant, based on the technology jointly developed by Tenova and Danieli.

Tenova executive vice-president Paolo Argenta outlined some of the company's key steps leading up to that most recent development.

"We started looking at hydrogen application for steelmaking a while ago," he said, highlighting Tenova's contribution to the HYBRIT fossil-free steelmaking project in Sweden as one example. "The first real achievement for us was when we landed the order to supply some equipment for their hydrogen-based DRI plant in Lulea. Obviously, HYL has been active in terms of R&D in the past, looking into high hydrogen usage, but, first, let me call it not an industrial but a big pilot plant application," he added.

"Looking at DRI, we also signed a contract to supply Salzgitter with a demo plant for them as well. That is part of the SALCOS Project," said Argenta.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"We see the Chinese market as a huge potential market for us in the future," said Tenova executive vice-president Paolo Argenta

Stefano Maggiolino, Tenova HYL president & CEO, said that Salzgitter do not consider their plant to be a pilot plant because, "They know that the technology is ready. They prefer to think of this small plant as like a training centre, because there is a mind-set change in moving from blast furnaces to DRI, so it is more a training unit than a pilot plant."

"If we look outside direct reduction, we have been presenting a project for the [EU] Innovation Fund, together with our sister company Tenaris Dalmine, and that is about using hydrogen for the EAF," said Argenta. "Tenaris Dalmine, Edison and Snam have joined a project in Italy to increase the use of hydrogen in an electrical steel shop. Tenaris Dalmine is working on a first phase in which the idea is to produce green hydrogen and oxygen with an electrolyser, and use both of them in the EAF," he explained.

When more hydrogen becomes available, it can be used for reheating and heat treatment furnaces. "That is another area where Tenova has been active. We have tested hydrogen burners," he noted. Tenova's TSX SmartBurners for reheating furnaces have been successfully tested using natural gas/hydrogen mix up to 100% hydrogen.

"To make hydrogen burners that have an extremely low level of NOx released into the atmosphere is very important and that is what we have been achieving," said Argenta. "We have built a test plant and special burners where we have put all the instrumentation together and we prove that we can keep a very low NOx level on a burner that is running on up to 100% hydrogen," he explained. "That was a very good achievement for our R&D. We are aware that there are many companies worldwide that are looking at going towards burners using a high percentage of hydrogen in the fuel with the aim of reducing the carbon footprint, so we believe there are going to be opportunities there."

DRI technology advantages

Maggiolino highlighted key reasons why Tenova, and specifically the Energiron DRI technology, is gaining momentum in the market.

"The first one is that our process scheme, which is a zero reformer scheme, is naturally fit for the use of hydrogen. The process scheme used with hydrogen, which has a process gas heater and no reformer, is exactly what we have been using in the past 30 years. We have a proven industrial solution for plants up to 2.5 Mtpy, which already operate with this process scheme. So we already have control of the technical solution at industrial level," he explained.

"The second point is that, in some of our plants, because of the process conditions, where we use a steam reformer, we already have process gas entering into the reactor with a composition of more than 70% hydrogen. So when we say that there is no big change, it's a fact. We already operate with plants where the process gas contains 70% hydrogen," he stressed.

"The third point is that, in the 1990s, we already did tests at our pilot plant with campaigns up to above 90% hydrogen. So we already have a lot of data, from which we are already confident in the design of the reactor and the product itself – how to produce low-carbon DRI. The use of higher pressure allows better hydrogen distribution in the reactor and enhances safety for the well-proven use of gas sealing valves," he added.

"There is one additional point," Maggiolino elaborated. "Every steelmaker is seeing hydrogen as a point of arrival in an energy transformation process, where basically you have to start from natural gas. Our process scheme allows you to move from 100% natural gas to 100% hydrogen, basically with no change." He said that steelmakers using DRI technologies with natural gas and a reformer need to remove their reformer and insert a process gas heater if they want to switch from using 100% natural gas to 100% hydrogen.

Capturing carbon too

While the shift to the use of 100% hydrogen for direct reduction is an attainable goal when required, a transition whereby the mixture of gases used to reduce iron in a DRI plant, including natural gas with hydrogen, is re-balanced towards larger percentages of hydrogen is the practical approach being taken by many steelmakers to reduce their carbon emissions.

As of now, technologies already exist to reduce the level of carbon emissions generated by conventional reducing gas mixtures. "In the end, the final goal is to cut CO_2 emission. In our solution with natural gas, we already have a CO_2 absorption unit, which allows us to capture approximately 250 kg of CO_2 for each tonne of DRI, out of 400 kg of CO_2 totally produced in the DRI process (a blast furnace typically produces approximately 1,600 kg CO_2 per ton of liquid steel)" said Maggiolino, stressing that the Energiron process already generically captures CO_2, as proven in plants installed in Mexico, Abu Dhabi, Indonesia and elsewhere.

In certain areas, the plants are supplying the CO_2 to nearby industries, such as the food industry, oil & gas industry or for dry ice production. "Basically two-thirds of the CO_2 that is produced in the process we already capture, and some of the plants using our technology sell it to industries that make use of it," said Argenta.

Maggiolino pointed out that represents a significant revenue stream. For example, for a steelmaker producing 5 million tonnes of DRI per year, "We save 250 kg per tonne of captive CO_2. If you sell it at $25 per tonne that adds up to millions [31.25m] of dollars per year."

The HBIS DRI plant will use make-up gas with about a 70% hydrogen concentration. Owing to the high amount of hydrogen the plant will use, it is designed to produce a total of 250 kg of CO_2 per ton of DRI. Additionally, part of this carbon dioxide will be selectively recovered and it will be reutilized in downstream processes, with a final net emission of about 125 kg of CO_2 per ton. The plant is due to begin production by the end of 2021.

Chinese policy

The absence of affordable natural gas supplies in China has discouraged the installation of DRI plants there up to now, but Argenta sees a shift in thinking by the world's largest steelmaking nation as it too moves towards more sustainable steelmaking from production dominated by the integrated, blast-furnace-based route.

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"What we have seen is a political willingness on the Chinese side to move towards cleaner steelmaking. They are finding ways to get gas available. We are also seeing other plants that are looking at ways for synthetic gas to be used for DRI, using whatever they have available," he said. "If you look today at the CO_2 footprint of Chinese production, it is typically 2 tonnes of CO_2 per tonne of steel. So basically it is the typical emission level of a blast furnace."

That is not to say that the Chinese steel industry has not already invested heavily in the advantages of using EAFs. "I have to say that is our biggest EAF market in the world," said Argenta. "We see that they tend to use a great deal of hot metal, of liquid pig iron in EAFs, so they somehow see the advantages of having hot metal available with the lower environmental impact of the EAF."

The Chinese government's resolve to move towards eventually achieving net zero carbon emissions is seeing steps being taken towards that target now. "I've heard that they intend to invest a lot in hydrogen production, so we see the Chinese market as a huge potential market for us in the future," added Argenta. "Sustainability has become very important, so almost every country is looking for ways to improve the carbon footprint of energy-intensive ▶

industries, but there are definitely some lighthouse projects coming up."

Commercial viability

While the environmental benefits of using hydrogen for steelmaking are clear, the additional costs of exploiting it remain a challenge.

"Nowadays, the economics does not stand on its feet," observed Argenta. "Producing hydrogen is still too expensive. In most countries, making DRI plus an EAF costs more than making steel via the blast furnace. I see that in the future there is still the need for governments, international trade associations, to support the change. Europe does a lot now, for example," he added.

In the US, about 70% of steel production is already via EAFs. "The US needs to do work on the metallics side. In order to produce the steel grade that they need, they will have pig iron, DRI, HBI. You cannot do that only with scrap. Also the scrap availability might not be there to support production," noted Argenta.

"So the whole sustainability effort needs to be supported, because the economics are not there. You might see different solutions. One is taxation on carbon sources, or reduced taxation on substitutes for carbon. Another important factor is which premium the industry will be willing to pay for 'low-carbon' products – the carbon footprint of a tonne of steel is going to become a characteristic, just like the chemical and physical characteristics," he added.

In summary, he believes that the viability of moving towards DRI with gas, and with hydrogen, is also a matter of how the policies around the market will develop. He added that he believes Europe is taking the right approach by supporting the start of these technologies. "If you look at the Innovation Fund, it is not only partially covering the investment, but is also covering the delta of the opex of the plant," he noted.

"So they expect and recognize that the production will be more expensive and they support the plant to bear the extra cost. It is also true that renewable energy will be cheaper in the future. So there are many forces at play. Today, we recognize that it is not economically viable, but all the ingredients are there to make sure they will be economically viable in the future," he added.

Typically, how much more expensive is it at present to produce a tonne of steel by using a high-percentage of hydrogen in the DRI module used to make the iron used than to make that same tonne of iron produced by a blast furnace?

Argenta said that studies for the HYBRIT project concluded that it was about 30% extra using 100% hydrogen. "I have to say that nowadays if you go the Middle East, probably the EAF plus DRI (NG-based) is the best solution. If you go to Europe or the US, 20-30% extra is probably a reasonable figure. If you go to China, where there is no gas and they have to invent something, then it is probably more than that."

"Gas versus coal is probably going to be a question of availability. Keep in mind that the cost of electricity is actually a proxy for the cost of hydrogen because the production of green hydrogen depends on electrolysers," he added.

Maggiolino said that using natural gas to produce hydrogen with a reformer, as well as using coal or natural gas to generate electricity to produce hydrogen does not make any sense. "We have evaluated a cost of 20 cents/kWh as a break-even figure for a reasonable production of steel through green hydrogen compared to using NG, and this is achievable in certain regions, and what we also see is the trend that the cost of green energy is going down very quickly."

Flexible feedstock

Maggiolino said that Tenova's focus is steelmaking and ironmaking, "So looking upstream from there we are not interested in entering the market directly for hydrogen production or generation. Of course, we look at what is happening in the market, there will be opportunities, but so far we think we need to focus on our portion of the value chain. We are looking at many electrolysers technologies, and the same is true for our clients. For the time being we want to keep the flexibility to work with different electrolyser technologies depending on the end user preference."

Beyond hydrogen supply, the price and chemical properties of the raw materials used to produce DRI, and the steel made from it, are other factors affecting both costs and the choice of technologies. Just a few years ago, there were shortages in the world market for direct reduction pellet, so bearing in mind that the cost and availability of raw materials to feed steelmaking plants fluctuates, how much flexibility is there in Tenova's processes to accommodate that variation in feedstock?

"The DRI module is really not concerned about the pellet quality," said Maggiolino. "In our DRI module we basically remove oxygen from iron oxide. We can do it whatever the gangue is, whatever the iron percentage is. The only constraint on the DR grade pellet is a constraint given by the EAF – typically [determined] by the refractory consumption and the metallic yield. The main characteristic of DR grade pellet is the basicity and quantity of the gangue in the pellet," he explained.

"We saw this as an opportunity," he added. "The opportunity is that, given the fact that the DRI process doesn't care what you're feeding, but the melter does, at Tenova we have not only the EAF technology, but we also have melter technology. So we have two projects in North America that are already in the engineering stage, in which we feed into a non-oxidizing electric furnace in the sense that the energy comes from electricity through a different type of electrodes, so that in melting furnaces you do not care any more about the basicity of the gangue. Because while the process in a standard EAF is very much related to the slag-liquid equilibrium, in a melting furnace we just split gangue from steel," he elaborated.

"With this in mind, we are capable of producing pig iron feeding a special electric furnace with high-carbon DRI. This is a solution for which the first benefit is that we can produce the same quality of pig iron as is produced by the integrated cycle with a blast furnace, using the same BF grade cheap pellet. Using natural gas and electricity means that instead of producing those 2 tonnes of CO_2 per tonne of liquid steel, we produce less than half of it."

From BOF to EAF

Argenta added that when there is a lot of slag in a bath with very low oxygen, a lot of iron oxide enters the slag. "So, one of the key things to matter in a high-carbon bath is yield, because you lose a lot of steel and charge into an EAF when you have a lot of slag. In a melter, when you have 400 points of carbon, so you have 4% carbon in the bath, the amount of iron oxide that goes into the slag is negligible – that is big money for the company running the plant," he explained. "And you can look at that advantage in terms of the flexibility of the charge through," he added.

He highlighted that a big potential market for this DRI+melter technology is to substitute for blast furnaces, "Not brand new plants, but if there is a site with a blast furnace, what about using a DRI plant?"

He explained that if a steelmaker switches wholly to DRI plus EAFs,

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Energiron® plant at Ezz Rolling Mills, Egypt

probably the whole meltshop will need to be replaced, because an EAF does not have the same melting rate as a BOF. "The cycle time is longer and you may have issues trying to maintain the same productivity. Also, for secondary metallurgy, you are not tapping exactly the same steel quality as you would get from a BOF. So the idea is that instead of changing BF, BOF plus the CCM to create a brand new melt-shop, you can buy the DRI and the melter to produce hot metal (liquid pig iron). You can even tap that into the same torpedo cars as are used for a nearby blast furnace."

Keeping the existing melt-shop, the BOF, secondary metallurgy, and continuous casting machine the same is an advantage in terms of investment. He said that Tenova is in the final phase of two projects that will produce pig iron and a few other project plans are at an advanced stage of discussion.

"It is not rocket science and it is not a technology that has never been seen. It is now about applying it on a big scale with DRI that is made with gas as the novelty. It is more about putting things together. Every one of the steps is well known and has been used in the past," he stressed.

"If you look at just the sustainability, this solution, which we believe is very good and we have a lot of interest in and around, has a limit on how much hydrogen you can use. If I need to produce pig iron, obviously I need to supply enough carbon to the pellet or to the smelter in order to have 4% carbon and in order for it to be used in a BOF shop," he added.

"There are ways to reduce that, but definitely if you look at a solution with 100% hydrogen that is not a viable path. At Tenova, we do not believe it is either 100% hydrogen or nothing. We believe in having a flexible solution – different people prefer different solutions," he noted.

Other advantages of DRI plus EAF

Maggiolino stressed the capability of the Energiron DRI technology to produce high-carbon DRI. "High-carbon DRI allows you to produce pig iron," he noted. "Of course, you can produce low-carbon DRI, put it in a smelter furnace, and add carbon, but if you add carbon you're already heading in the other way of where you want to go, which is decarbonization," he added.

"To produce high-carbon DRI, we can use up to 65-70% hydrogen in volume in the feed gas and the rest is natural gas," he said.

"When you use natural gas, you need to put in some energy for the reforming reaction. Either you do it in a reformer or you do it inside the reactor, but in either case you expend energy for the reforming reaction. Hydrogen, by nature, is the best reductant. It is the one with the best kinetics. You just have to heat it up and put it into the reactor to produce DRI," he explained.

"The capability of DRI plus the EAF to be more flexible – not only in terms of [ease of] switching on and off in order to follow the market conditions, but also the capability to use different quantities of scrap versus iron ore – is particularly important because certain steel qualities might require less or more virgin iron units. And there are big fluctuations in steel and iron ore prices," Argenta noted.

His point is that the ratio of raw materials in the charge can be changed according to the relative prevailing prices of scrap and iron ore. "You can always go for an increased amount of scrap when the quality [of the steel to be produced from it] is not particularly demanding," he said.

So switching towards a solution of using DRI plus EAF also gives steelmakers more flexibility for their future in terms of where to source the raw material, "And at the end of the day, we are looking at way more than 50% of the cost of making steel is the cost of raw materials," he added.

"As Tenova, we expect more EAFs to be built in the future, but much more metallics to go around and for there to be even more mining companies to enter the arena," he elaborated, noting that iron ore pellet suppliers, such as Vale and LKAB, are now also planning in their future to sell DRI, HBI and pig iron.