Power-to-X: the pathway to a carbon-free world

Deploying renewables across all sectors of the global energy economy is seen as crucial in meeting zero carbon emissions targets. Power-to-X is the key to unlocking the potential of this so-called sector coupling.

Junior Isles

There is a general consensus that far more has to be done, and far more quickly, if the world is to avoid irreversible climate change. In an effort to limit global warming to well below 2°C above pre-industrial levels, the Paris Agreement, negotiated at the 2015 United Nations Climate Change Conference, requires effectively zero emissions by 2050.

The global climate effort has resulted in huge investment in renewables in the electricity sector, increasing the share of renewables to up to 22 per cent globally. But it has had little impact on global carbon emissions. Some 60 per cent of global carbon emissions come from outside power generation, i.e. in transportation, buildings, industry and heating, and there has been very little progress in decarbonising these sectors.

To reach the target of zero CO_2 emissions by mid-century, there has to be an integrated approach to decarbonising all sectors of the economy.

Using renewable electrical energy from the power sector – especially energy from wind and solar that cannot be immediately consumed – to decarbonise energy across all sectors unlocks enormous environmental and business benefits. This so-called ‘sector coupling’ is one fundamental element of the energy transition and involves increased direct electrification of other sectors as well as provision of renewable energy to other sectors in a suitable (e.g. chemical) form.

It is a growth area that Siemens believes has tremendous potential and is therefore investing in technologies known as Power-to-X (P2X) that enable sector coupling.

Commenting on the idea, Dr. Volkmar Pflug, Vice President Energy Consulting, Siemens AG, said: “Of all the buzzwords over the last 10 years, sector coupling is a very big one because it really can change the world.

“The idea of sector coupling is nothing more than bringing renewable energy from the power sector into the other sectors to thereby decarbonise the entire energy system, making electricity the backbone of energy supply in the future. As an example, an increase of power generation by 25 per cent would reduce primary fossil energy consumption by a half, due to the increased efficiency associated with electrification of other sectors.”

Although there has been growing interest around this line of thinking for the past two or three years, it has really come to the fore in recent months. “This,” says Dr Pflug, “is because there are now, practically, not just theoretically, enough technologies available at reasonable cost that can help decarbonise the world.”

As one of many activities to decarbonise global energy production and use, Siemens is active in the “Power-to-X for Applications” Working Group at the Mechanical Engineering Industry Association (VDMA), which has 3200 member companies and is Europe’s largest mechanical engineering organisation. Siemens says its involvement with VDMA is part of its commitment to social and environmental responsibility.

Siemens is driving three pathways for P2X. The first is what it calls e-hydrogen – using renewables to generate electricity, which is then fed to an electrolyser to produce hydrogen. Hydrogen is a versatile energy carrier, which can be stored and used in the transport, industrial or chemical sectors or as a fuel in gas turbines.

Currently, over 50 Mt of hydrogen is produced worldwide every year from fossil sources via the steam methane reforming (SMR) process. About half of it is used for the synthesis of ammonia, which is the basis for ammonia phosphate or urea and other chemicals, mainly methanol. Hydrogen is also used in refineries for hydrocarbon cracking and other processes.

Unlike the SMR method, the generation of e-hydrogen via electrolysis of water with electrical energy from renewable sources is completely free of CO_2 emissions. “This pathway is pretty straightforward,” said Dr Pflug. “We are already seeing the first projects because it can be done on a small scale, e.g. for private passenger cars or hydrogen buses and trucks.”

He added: “Right now we are developing a project in Chile. This is the world’s best renewables location and we can produce green hydrogen from electrolysis at the same cost as from steam reforming of natural gas.”

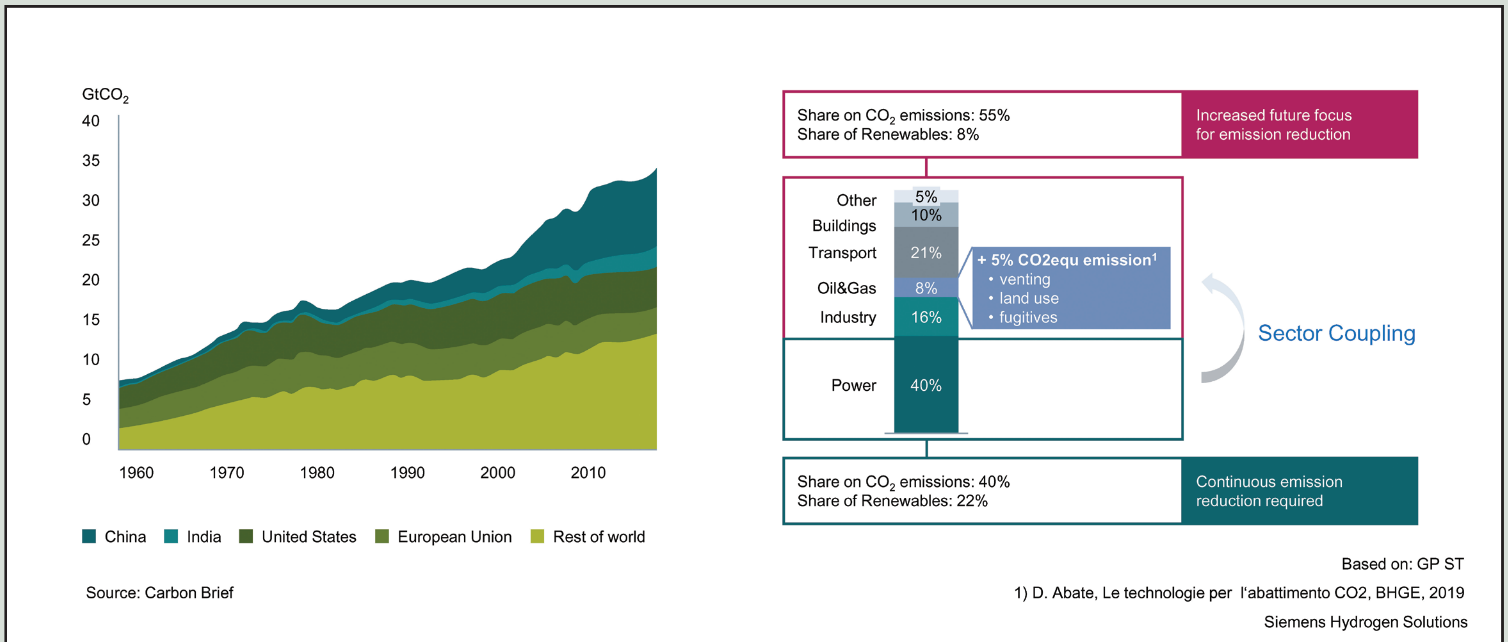
The second pathway, which Dr Pflug believes will be “a significant part of the future”, is using hydrogen to produce synthetic fuels. Although the direct electrification of cars through batteries is an important lever in the utilisation of green electricity, he says it cannot be applied to all types of transport.

“If you look at the energy consumed in mobility, 50 per cent goes to heavy trucks and long haul marine and aviation. These three areas cannot use battery-based energy storage. This is where hydrogen and synthetic hydrocarbon fuels kick-in.”

Using synthesis with carbon dioxide (from biogenic sources, unavoidable industrial emissions or from the air), hydrogen can be converted into synthetic, sustainable ‘e-fuels’ such as e-methanol or e-jet fuel or other carbon-based chemicals.

These “green fuels” can replace fossil fuels, lowering the carbon emissions from their expended energy by as much as 90 per cent. They can also replace biofuels, such as ethanol, which now consumes considerable farmland to grow its main feedstock, corn. This can resolve the food-versus-fuel debates on the use of increasingly valuable farmland and return acreage to food production or non-crop uses, such as nature reserves, recreation areas, residential developments and reforestation.

E-fuels can immediately be mixed with fossil fuels to reduce the overall carbon footprint. P2X thus allows a



CO_2 emissions reduction has so far focused on power, but all sectors in the economy must contribute

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smooth transition from the fossil world to one that is largely carbon-neutral.

Dr Pflug noted that synthesising to methanol is hugely important. "We strongly believe that methanol is the substance of choice; it could be a substitute in the replacement of bio-ethanol, for example. The big advantage is that, basically, you can create any kind of hydrocarbon fuel using methanol as the basic substance.

"You could also use existing infrastructure [for methanol], e.g. transport logistics and refuelling stations, which you could not do if you go the (molecular) hydrogen pathway. And you avoid step increases in technology that are initial cost and performance hurdles to their widespread implementation in established markets"

Notably, Dr Pflug says that the need for CO_2 in producing e-fuels could trigger a renaissance of carbon capture, i.e. carbon capture and utilisation. CO_2 could be captured from existing, unavoidable point sources, e.g. from cement production, biomass power plants or fossil fuelled power plants. In future, recovering CO_2 from the atmosphere (direct air capture, DAC) could also become an option, especially for regions that are rich in renewable energy but far away from industrial sites.

The third pathway that Siemens is pursuing, is power-to-ammonia. Here, e-ammonia (NH_3) is synthesized from e-hydrogen and nitrogen derived from an air separation using the Haber-Bosch process. E-ammonia can be used as feedstock for fertilizers (urea, ammonia phosphates) and other chemicals. With about 175 kg hydrogen per tonne of ammonia, it is an excellent carrier of hydrogen to transport it over long distances. Ammonia cracking processes are under development for recovering the hydrogen.

"The problem here," says Dr Pflug, however, "is that there are no green drivers for ammonia, and no one wants to make food more expensive. So, reducing the cost of green ammonia production is an imperative."

Siemens is currently developing technology solutions in line with the three pathways that it foresees for hydrogen.

One clear component is the electrolyser. There are three types of electrolysis: alkaline, which has the longest experience; solid oxide (SO), which is currently used at smaller-scale; and proton-exchange membrane (PEM) electrolysis. With PEM technology the electrolyser can be switched on and off without preheating, leading to high flexibility, ramp rates and overall system efficiencies even with partial loads.

With an extended operating range, PEM technology can ramp up instantly in its operating capacity. It can then operate at from 5-100 per cent of capacity at very high ramp rates.

This, says, Siemens makes it perfectly suited for the load profiles of renewable power sources like wind and solar which are volatile by nature.

Siemens has what it calls its H_2 package, which comprises all units to produce e-hydrogen. "We have one of the most advanced PEM electrolyser portfolios," noted Dr Pflug.

In 2015, Siemens deployed the Silyzer 200, a large-scale, commercial version of PEM electrolysis at one of the world's largest power-to-gas plants in Germany. Today, the company has taken that technology into its third generation, with the deployment of the Silyzer 300 at the H2FUTURE project, in partnership with Verbund Solutions GmbH, voestalpine Stahl GmbH, K1 MET GmbH, and the Austrian Power Grid AG.

The Silyzer 300 consists of up to 24 PEM electrolytic modules per array that together draw 17.5 MW of power to produce up to 340 kg/h of virtually pure hydrogen with no CO_2 emissions. The system operates at over 75 per cent efficiency,

The Siemens Silyzer development roadmap targets fourth-generation hydrogen plants that, by 2023, can draw more than 100 MW of power for hydrogen production at ever greater efficiencies. By 2030 and beyond, Siemens envisions building 1000 MW, fifth-generation plants.

The second area of technology development for Siemens is what Dr Pflug calls "Power-to-X solutions", where the current focus is power-to-methanol and power-to-ammonia. Here Siemens can provide all equipment related to these applications, including the electrolyser, compression and storage equipment, instrumentation and controls, electrical equipment (transformer, switchgear, rectifier etc.); water treatment and de-ionisation equipment, hydrogen cleaning systems, etc.

The third big area is in developments that allow hydrogen to be fired in gas turbines. Green hydrogen produced by electrolysis can be converted into electricity again (re-electrification) and used as an admixture with natural gas or in pure form to fuel gas turbines.

"Over time, oil and gas will be displaced by green fuels or green gases. Hydrogen would be a very good option here," said Dr Pflug.

Several gas turbine manufacturers are already making progress in this area.

In 2019, as part of its commitment toward environmental sustainability, Siemens signed a European industry agreement that promises that its new gas turbines will be capable of operating on 20 per cent hydrogen (mixed with natural gas) by 2020 and 100 per cent hydrogen from 2030 onwards.

Parts of these commitments have already been fulfilled, as much of the Siemens gas turbine portfolio can use fuel mixtures with hydrogen levels of up to 30 per in large gas turbines, 60 per cent in medium sized machines and even up to 100 per cent in aeroderivative models with a wet low emissions system.

"It's an area where we are continually working," said Dr Pflug. He stressed: "Gas turbines can operate on natural gas from fossil sources or green gas such as hydrogen. This makes gas turbine plants a sustainable investment and avoids the risk of ending up as stranded investments when decarbonisation is enforced by regulators. All scenarios for a deeply decarbonised world in the year 2050, consider gas turbines as the most economic option to provide security of supply."

Erik Zindel, Director Energy Consulting at Siemens added: "Fifty or 60 per cent of the time, there is sufficient sun, wind or hydro available. The rest of the time, you can use the stored hydrogen by combusting it in conventional combined cycle plants. Gas turbines are the technology of choice for providing dispatchable power when there is not enough solar or wind power in the grid. It is an area of great interest to plant owners, many

With sector coupling, the increased electrification reduces primary energy consumption significantly

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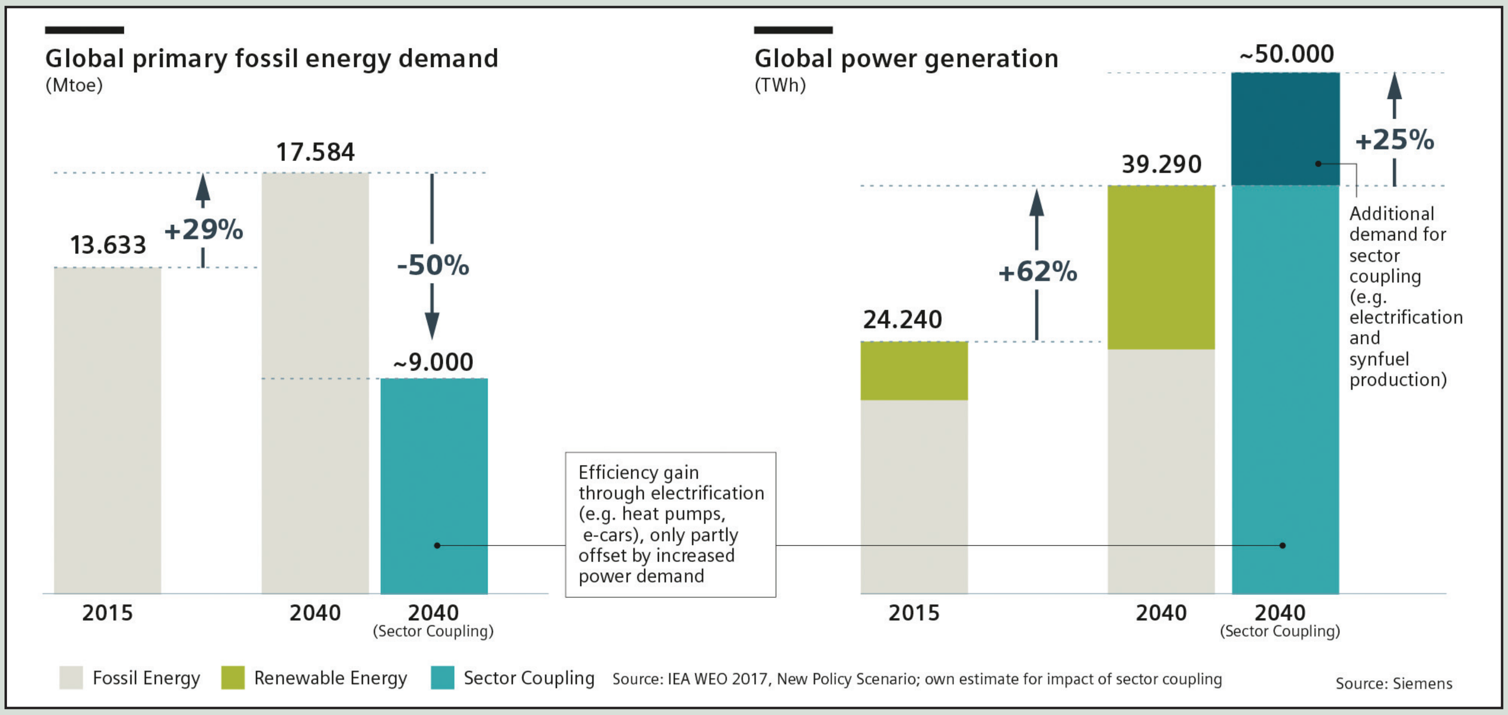

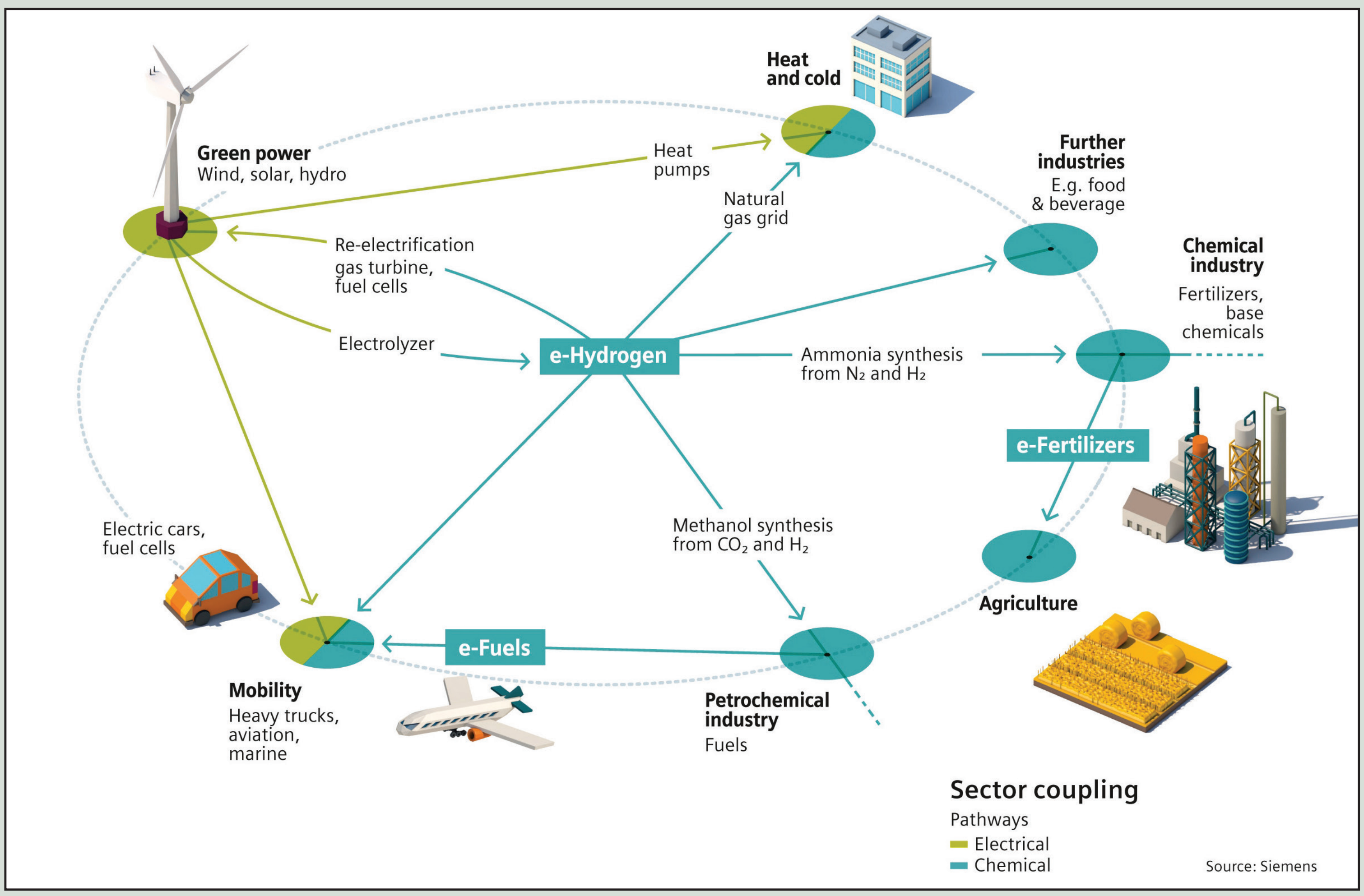

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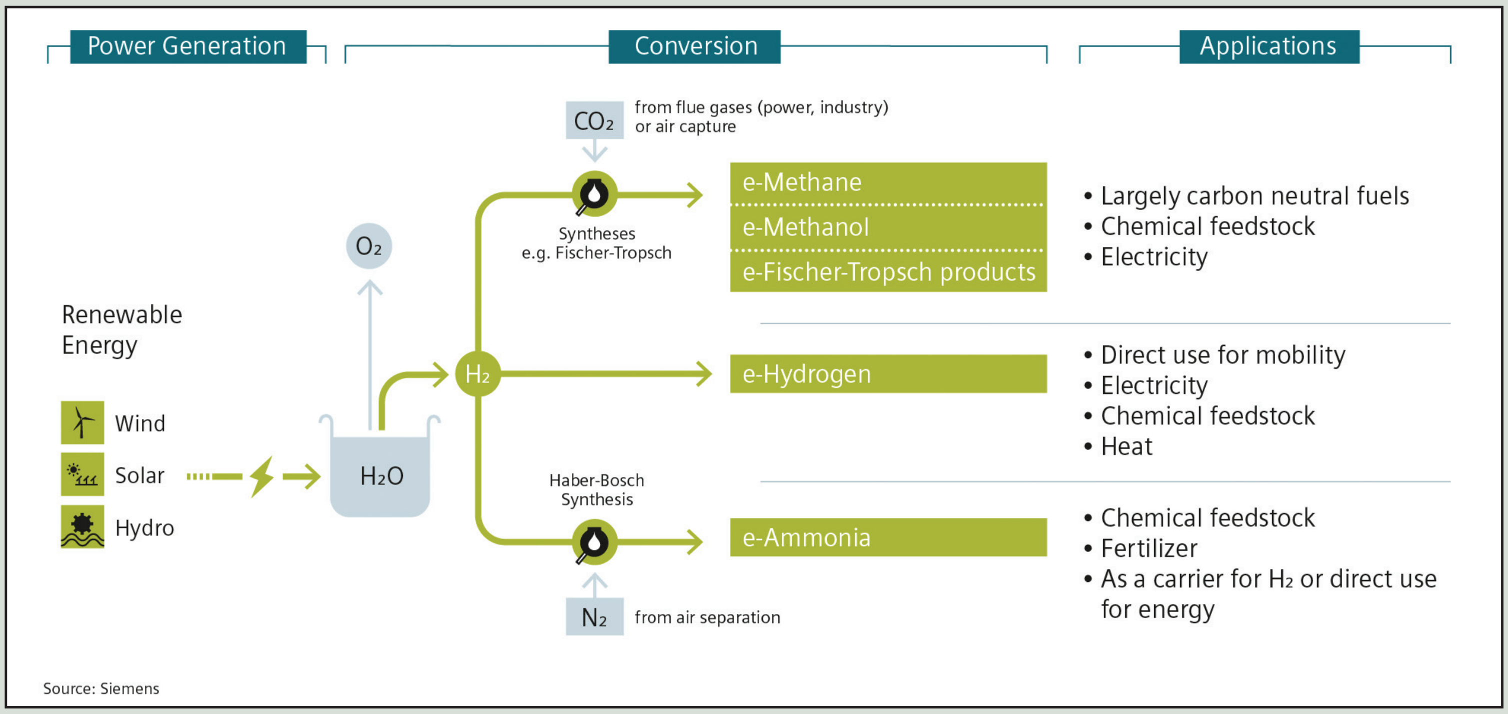

Three pathways of power-to-x: electricity-based molecular hydrogen, ethanol and hydrocarbons, as well as ammonia

of which are already investigating whether their machines can be upgraded in the future to burn hydrogen."

"This would enable the transition to 100 per cent renewables. But we expect this to happen at a later stage, as we believe that at the moment the value of green hydrogen is higher in other sectors than in the pure power generation industry."

Hydrogen is expected to first penetrate the areas, outside of the power sector that are proving difficult to decarbonise such as parts of the chemical sector, the steel and cement industries and mobility.

For P2X to really materialise, however, both technology, which will enable cost reductions, and policy will have to develop simultaneously.

While Siemens says that e-hydrogen can already present a positive business case in some instances, costs will need to be driven down by lowering capex and the levelised cost of electricity of the renewable energy that is used to feed the electrolyser. It also said much depends on the amount of hours that the electricity produced is available. The capacity factor is as important as the LCOE because it defines the capital efficiency of the electrolysis plant.

"These are the main three parameters that define the cost of the hydrogen produced," said Dr. Pflug. "In terms of technology, we are at the beginning of driving down costs by automating the manufacturing side of electrolysers for example. And if you look at carbon capture, you could say we are still at the beginning there too, considering that CO_2 capture never really took off. If you can make this very cheap, it will eventually be a disruptive technology.

"This is another area where we are doing some technology development," he added.

Siemens has developed a process for the post-combustion removal of CO_2 from power plant flue gases. Employing an environmentally friendly aqueous solution of an amino acid salt (PostCap™), approximately 90 per cent of the CO_2 from flue gases are captured. Siemens is looking for an opportunity to re-demonstrate its PostCap technology together with customers/partners in the context of P2X.

With regards to policy, Siemens believes a few things have to happen. First and foremost there has to be legislation in support of carbon reduction. "As these technologies are still more expensive than the conventional black fuels, all of this won't happen if there is not a clear regulatory push for decarbonisation," said Zindel. "It's a bit like solar and wind power; 20 years ago they were completely out of the market in terms of cost… now their LCOEs are a third of most modern gas fired stations. You need incipient markets to warrant R&D investment and economies of scale to bring the costs down."

Secondly, the value of e-fuels produced from green hydrogen has to be recognised by governments. "The use of synthetic fuels from green sources has to be accepted," said Dr Pflug. And to some extent, this is already happening. Under the new Renewable Energy Directive (RED II) the EU stipulates that green fuels should represent 14 per cent of the market share of transport fuels by 2030.

Despite the target, Dr Pflug believes, however, that the emphasis that governments have put on EVs has created an uneven playing field for technologies. "There has to be a level playing field between e-cars and [cars running on] synthetic fuels," he stressed.

"The emissions they associate with e-cars are measured from the battery to the wheel, so there are no emissions. But if you look at the lifecycle – taking into consideration battery production and the energy mix used to provide electricity to charge the battery – for the first one or two years, e-cars emit a similar amount of CO_2 as a regular car," Dr Pflug explained. "And if the lifetime of a battery is only around four years before it has to be disposed of, you have a significant carbon footprint for a battery-powered car."

He argues that if carbon emissions are assessed over the entire lifecycle, there would be much greater focus on e-fuels or hydrogen fuelled cars.

Thirdly, Dr Pflug says there needs to be government support for the installation of large scale demonstration projects, as we have seen in Germany. Germany is investigating how hydrogen can be used on a large scale as an energy carrier in the heat market, the transport sector and industry. The project will cost the ministry more than €100 million per year, and results should be seen by 2020.

In July this year, Federal Economics Minister Peter Altmaier said Germany wants to be a global leader in the development of hydrogen technologies. The government also said it will develop a hydrogen strategy by the end of the year.

In terms of frontrunners, geographically, Siemens says much depends on production and consumption.

Zindel said: "If we are talking about methanol, we don't have to produce the methanol in the same country that it will be consumed. We can produce it in areas where there is good wind or solar and export it those where there is a good price premium for it, such as Europe, California or Japan."

Dr Pflug added: "Much depends on the regulatory regime and energy policies. If the green fuel is attractive and fetches a premium, then it makes a business case feasible. Projects are developing in Austria, Denmark, Germany, Switzerland and the UK, and we see a number of things coming up in Latin America, Central America, Canada, China and parts of the US."

Essentially, developed countries with a goal to decarbonise are the main areas for consumption, while production will be in places where conditions are good for renewable energy, such as the Middle East, which is increasingly looking to take advantage of its favourable solar conditions.

According to Siemens, it is seeing varying degrees of interest from potential customers.

Zindel said: "They are not so aware of it in places like Africa and Latin America but in Central Europe and Japan, it's already a topic. Some industries like oil and gas know they are in a business that is not sustainable, politically and in terms of regulation, over the long term. Oil majors like Shell and Total are already thinking about these technologies. Utilities looking to reduce their CO_2 emissions are also asking us about our hydrogen capabilities on gas turbines. We have also had a lot meetings with utilities in the US about hydrogen in recent months."

This interest, adds Zindel, extends across various sectors, noting that car manufacturers and airlines are also enquiring about Siemens' capability in the field of synthetic fuels.

Siemens believes the world is only at the beginning of the switch to a sustainable future. In the power sector there has already been a shift from fossil fuels to renewables but Siemens says it is about more than just the power sector.

Zindel concluded: "It's about energy consumption in all the sectors in the economy worldwide. There has been a huge movement from conventional energy to renewables in the last 10-20 years but looking worldwide at all the sectors, we are just at the beginning of the transition. It's probably one of the largest transformations in energy technology that the world will have seen in the last 100-200 years."

E-hydrogen can already present a positive business case in some instances