HYDROGENICS

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Hydrogen-based energy conversion solutions

An interview with **Filip SMEETS**, General Manager On-site Generation at Hydrogenics

*By Romain Debarre & Benoit Decourt from the **Schlumberger - SBC Energy Institute***

1 MW RH_2-WKA power-to-gas plant in Mecklenburg-Vorpommern, Germany

2 MW E.ON power-to-gas facility in Falkenhagen, Germany

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1 - MAKING THE CASE

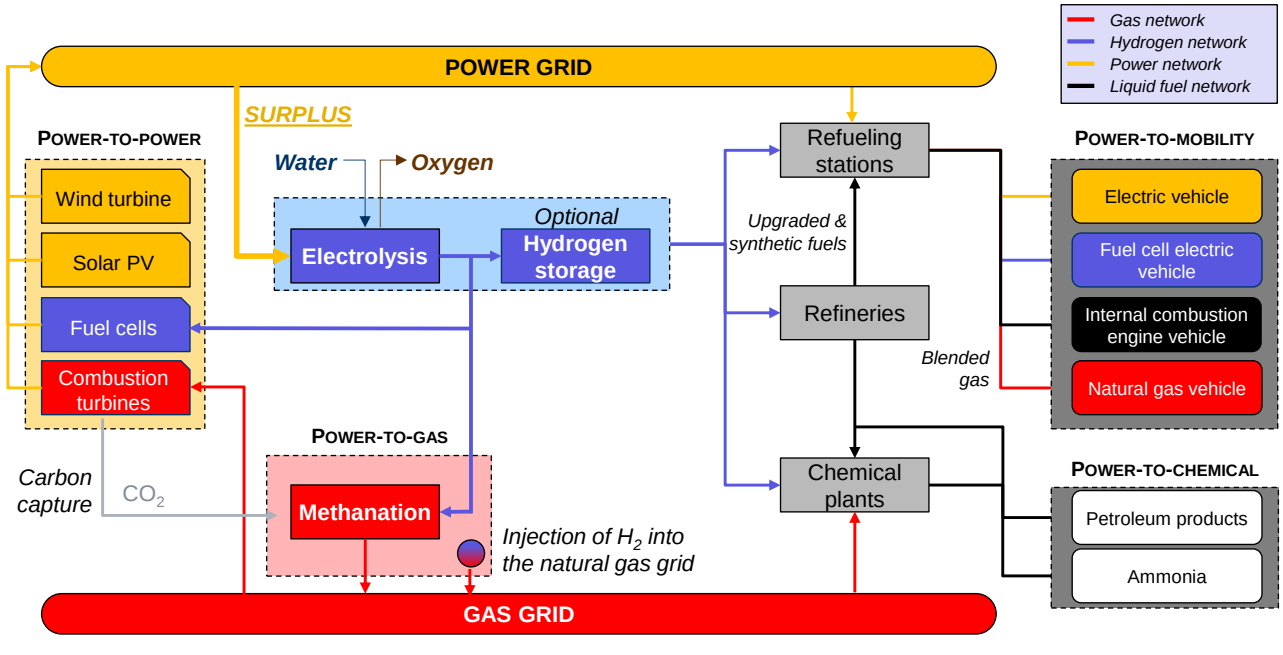
***SBC Energy Institute**: There has been a resurgence of interest in hydrogen-based energy solutions in recent years, because of the growing need for flexible systems that enable intermittent sources of energy to be integrated into the power grid. But hydrogen solutions are in competition both with alternative storage technologies, such as pumped hydro storage, and with other methods of achieving flexibility, such as demand-side-response management and better market inter-connections. What are, in a nutshell, the main advantages of hydrogen-based solutions over alternative flexibility options?*

Filip Smeets: Let me start by saying that all options, demand-side management, supply-side management, enhanced grid capacity and energy storage will be necessary and thus will find a market in a future with higher renewables. It is not a matter of 'or', but a matter of 'and'.
The captivating aspect of hydrogen-based solutions is that they have the unique potential to play on all options. It is, if you like, a very versatile and robust mid-fielder with unparalleled ball distribution capability. Hydrogen technology interconnects the four main energy verticals or silo's: electricity, heat, mobility and industry.

> *"Hydrogen technology interconnects the four main energy silo's: electricity, heat, mobility and industry. This interconnectivity creates enormous efficiency, both in terms of investment and operating cost"*

This interconnectivity creates enormous efficiency, both in terms of investment and operating cost of our new energy infrastructure. Additionally it contributes to de-carbonizing all verticals. For instance your hydrogen electric vehicle will be driving on wind energy, and your industrial furnaces will be fueled by solar power, and the fertilizers we use to grow our crops will be fully renewable. 'Hy-perconnection' is the term I would like to use here.
Apart from that hydrogen-based solutions are extremely scalable in terms of capacity and operational mode. They will find application in residential markets as well as in grid scale investments.

SIMPLIFIED VALUE CHAIN OF HYDROGEN-BASED ENERGY CONVERSION SOLUTIONS



Note: Simplified value chain. End uses are non-exhaustive. For more information on the technologies mentioned in this diagram, please refer to next chapter or to the Hydrogen FactBook.
Source: SBC Energy Institute analysis.

2 - WATER ELECTROLYSIS

***SBC Energy Institute**: Achieving efficient, flexible and cost-effective water electrolysis is essential, since electrolysis is a pre-requisite for converting electricity produced from intermittent renewables into chemical fuels. What are, in your view, the challenges electrolysis technologies must overcome to make hydrogen solutions competitive and how would you characterize the interplay between technologies – alkaline, proton exchange membrane (PEM) and novel concepts such as high temperature solid oxide?*

Filip Smeets: Most importantly we need to get paid for the zero-emission value we contribute. Fossil-based operation has hardly any penalty for the medium to long-term costs they leave behind for society to bare. A policy solution is needed here.

If we leave this most important value component aside for a moment, we can state with confidence that the water electrolysis technology is ready for energy applications. The technology does what it needs to do and with proven durability. But an investor will not invest in an energy project if the cash flow projections are negative and/or volatile and he has limited trust in policy robustness. Business cases are driven by revenue streams, operational cost and capital investment. So let's look at those factors one by one.

Hydrogen solutions offer five different value components: the strategic, climate, infrastructure, flexibility (capacity), and calorific value. Of these, only the calorific value can be monetized straightforwardly. So there you have your second challenge. Regarding operational cost, that is singularly defined by the cost of electricity. Conversion efficiency can be better, and will get better, but we are not so far away from what is the thermo-neutral potential taking into account balance-of-plant requirements to produce safely, automated, and reliably. So access to low cost or high value renewable electrons, virtually, is what is needed to overcome this third challenge. Lastly the capital investment is only going to impact significantly your business case if your utilization rate is low, say below 30-40%. Given the small volume our industry is shipping today, and comparing that to the vast potential of the energy market we can anticipate a steeply downward slide on the cost-learning curve, if the volume starts to compound. So, in a nutshell, the water electrolysis industry will take-off when the policies are in place to support a fast-track market deployment, aka solar, aka wind, etc… We all know fossil is heavily government subsidized, so we are not looking for additional funding, but a shift of funds.

Regarding the different technologies you mentioned I can say the following. Alkaline is mature and has still some stretch in it. PEM is in full development, with certain potential advantages over Alkaline, those will be confirmed over the next years. Solid oxides is embryonic for a very long time already with little convincing progress on key flaws.

> *"There is no doubt that with increased intermittent renewables [...] the timely mismatch between supply and demand will widen and create opportunities for shifting this energy to other sectors than electricity"*

Hydrogenics is developing a 1 MW single cell-stack PEM module. The novel cell-stack will be the core component of Power-to-Gas pilot plant for E.ON Hanse, Hamburg, deliverable in the fall of 2014.

***SBC Energy Institute**: Do you think temporary excesses of power from renewables will occur frequently enough to reduce the cost of producing hydrogen from electrolysis to a point where it can compete with other methods of manufacturing hydrogen?*

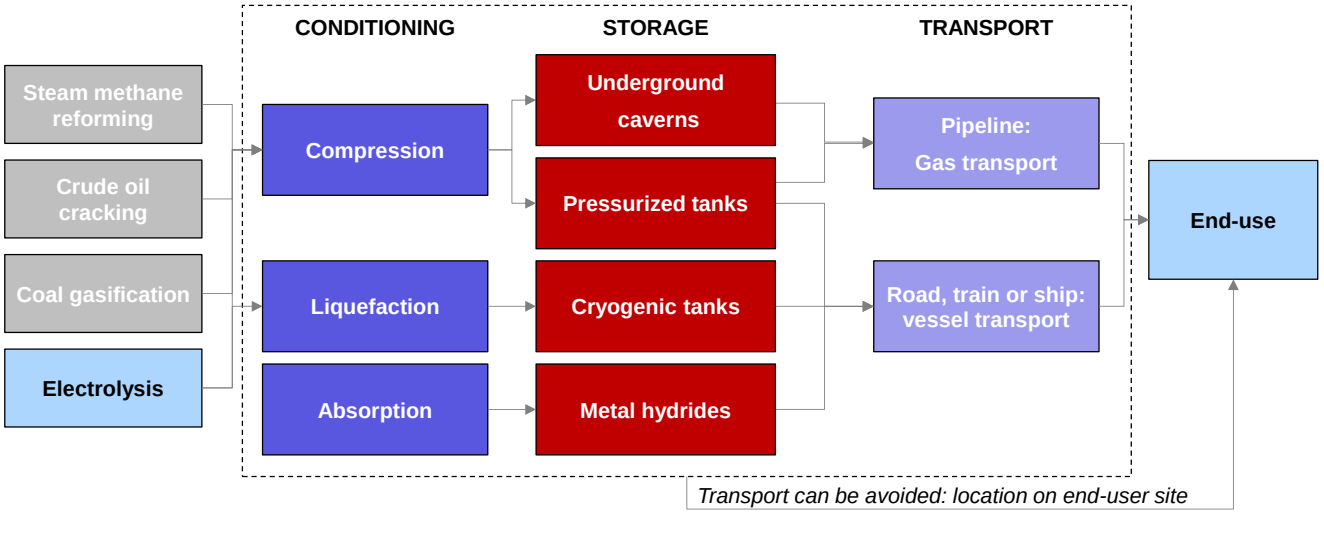
Filip Smeets: If excess of renewables is equal to low-cost electricity, or low marginal cost, we will not want to waste it, of course. There is no doubt that with increased intermittent renewable, namely solar and wind, the timely mismatch between supply and demand will widen and create opportunities for shifting this energy to other sectors than electricity. The size of this excess will be determined by the share of intermittent renewables versus the share of conventional, less flexible, electricity sources. Several studies predict an absolute need for grid-scale seasonal energy storage, meaning longer then 8-12 hours to weeks, as of 2030-2035 in Europe. But before we hit that moment of no-return, vast amounts of energy would already have been wasted. Already today there are wind parks in Europe that waste 30% of their potential. This is not realistic. Energy is the most valuable economic factor and, at marginal cost, solar and wind are unbeatable. So, opportunities exist today to convert profitably that green energy in green chemicals. With some policy support the beast would be forever out of the cage."

3 - HYDROGEN STORAGE & TRANSPORT

***SBC Energy Institute**: Hydrogen storage and transport form the most mature segment of the hydrogen value chain, as a result of the chemicals and petrochemicals industries' extensive experience of hydrogen utilization. However, because of hydrogen's low volumetric energy density at ambient conditions, conditioning is a pre-requisite for storage and transport, resulting in additional costs and energy losses. What are you views on compressed-hydrogen storage, liquefaction, storage in large underground facilities and solid hydrogen storage?*

Filip Smeets: Underground storage has potential in the very long-term for seasonal storage capability. It is a solution for a specific problem and deserves to be further investigated. But I'm afraid the world will be on a decentralized energy mode by the time this solution predicts to have a market place. Liquefied hydrogen has an enormous energy penalty which you cannot solve with technology and will remain a solution for niche applications. Idem ditto for solid hydrogen storage.

HYDROGEN CONDITIONING OPTIONS BEFORE STORAGE AND TRANSPORT OPTIONS



Source: SBC Energy Institute analysis.

***SBC Energy Institute**: Do you think decentralized hydrogen usage and power-to-gas concepts could actually minimize the need for hydrogen storage and transport?*

Filip Smeets: Obviously decentralized production reduces the need for storage and transportation. Since intermittent renewables will also be installed in a distributed fashion the intermeshing is obvious and efficient. Distributed supply intermittency means that you need distributed flexibility on the electricity grid too. If not, you will waste it or need excessive investment in grid enhancements and demand-side solutions. Ultimately you would want each household to be self-sufficient as well as each industrial estate.

4 - HYDROGEN RE-ELECTRIFICATION

***SBC Energy Institute**: Re-electrifying hydrogen, whether through fuel cells, combustion engines or steam turbines, results in relatively poor round-trip efficiency. Although efficiency is not necessarily the key factor in decision-making, this may impede the development of hydrogen re-electrification solutions outside applications that value the unique reliability of fuel cells or the long storage duration enabled by hydrogen storage (e.g. back-up for telecoms towers). What is your opinion of the role power-to-power applications will play and of the future of fuel cells and hydrogen turbines?*

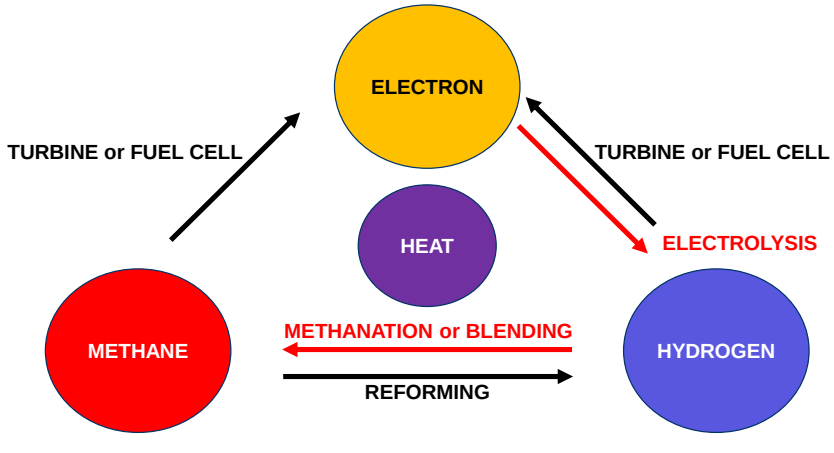
Filip Smeets: Re-electrification of hydrogen for grid-supply, when no wind or solar are sufficiently available, is a system solution to warrant supply all year long. The low efficiency round-trip efficiency is irrelevant one's you have decided that you will implement a sustainable energy system. The last hours of your electricity price duration curve will be expensive with any system choice. At residential level power-to-power application will be rather driven by the less rational motivation of being self-sufficient.

5 - POWER-TO-GAS

***SBC Energy Institute**: Power-to-gas, whether it involves blending hydrogen with natural gas or methanation, is garnering a lot of attention. Its advantages include the ability to use the gas grid to store renewable electricity, pooling gas and power infrastructure flexibility, and the greening of end uses of gas, such as heat generation. However, competing with low-cost natural gas seems challenging in the current economic environment. What is your view of the roles that hydrogen blending with gas and methanation could play in the energy transition?*

Filip Smeets: Clearly if we implement an energy policy to meet Kyoto norms by 2050, we will have very high share of intermittent renewable in our energy mix, and seasonal energy storage capability becomes mandatory. Hitherto

PATHWAYS BETWEEN ENERGY CARRIERS
Power-to-gas pathway in red



Source: SBC Energy Institute analysis.

Power-to-Gas is the only application that can provide that while using an existing storage and energy transportation system.

***SBC Energy Institute**: Blending hydrogen with natural gas seems to be an elegant solution, but blending ratios may be limited by concerns over pipeline safety, gas-grid operating capacity and, most significantly, the performance of end-use appliances. What are your opinions of where hydrogen is most likely to be injected and of the range of blending ratios that are likely to be permitted?*

Filip Smeets: Indeed there are a number of constraints to this concept at different levels of the delivery system and appliances. Nevertheless these technical constraints can be eliminated in a gradual fashion in case a crystal-clear long-term policy is agreed and implemented. You need time though and that is also what we have until 2050 to gradually upgrade the delivery system and specifications for appliances. In the early years you would want to site Power-to-Gas facilities close to industrial sites downstream with yearlong flow in the gas pipeline to warrant good blending. Initially up to 2% should not be an issue. Potentially even to 5%.

6 - HYDROGEN MOBILTY

***SBC Energy Institute**: Hydrogen has been proclaimed the future of mobility since the 1970s, but has regularly fallen in and out of public favor and continues to face various economic and technological barriers. However, several major H2 mobility initiatives have been launched to help overcome the chicken-and-egg dilemma. And in 2013, various car manufacturers announced major programs and alliances to develop hydrogen's role in mobility. How do you envisage the role of hydrogen produced from electrolysis in mobility?*

Filip Smeets: I think that the techno-economic challenges are still existing and more progress needs to be made before entering better waters. The reason why private and public entities keep believing in it is because the promise of performance, both from a sustainability and efficiency perspective, are so appealing. That being said great progress has been realized over the past decades on the hydrogen-electric vehicle side. And manufacturers are getting more innovative to close the final gap towards a viable commercial platform. Less progress has been made on the refueling side. The compression step remains

THE ROLE OF HYDROGEN IN MOBILITY

FOSSIL FUELS	SYNTHETIC FUELS	PURE HYDROGEN FUEL[1]
		
Diesel and gasoline ▪ Increase hydrogen / carbon [H/C] ratio of heavy oil fractions; ▪ Desulfurization (more stringent regulation). **Natural gas vehicles [NGV]** ▪ Reduce local pollution and increase performance with hydrogen blending (hydrogen compressed natural gas fuel).	**Biofuels** ▪ Enrich biofuel plant with hydrogen to maximize biomass yield and thereby land use; **H-C-O synfuels** ▪ Fix hydrogen with CO_2 to synthesize methane, methanol, dimethyl ether, gasoline…; **Ammonia fuels** ▪ Fix hydrogen with nitrogen and use ammonia as a fuel.	**Pure hydrogen carrier** ▪ Use hydrogen to produce electricity in fuel cell electric vehicles [FCEV]; ▪ Use hydrogen fuel cell in battery electric vehicles [BEV] as a range extender.

Note: Hydrogen internal Combustion engine [H2ICE] that uses a traditional ICE, modified to burn hydrogen instead of conventional gasoline, has lost momentum compared with FCEV and is not mentioned in this slide.
Source: SBC Energy Institute analysis.

expensive, both in capital expenditures as well as in operation expenditures, and the fast fill multiple cycles requirement also increases considerably capital costs of the hydrogen refueling stations. The interesting aspect of hydrogen for mobility is the potential to convert in a highly distributed fashion excess renewable wind and solar into a renewable fuel, providing grid flexibility in the same time.

> *"The interesting aspect of hydrogen for mobility is the potential to convert in a highly distributed fashion excess of wind and solar into a renewable fuel providing grid flexibility at the same time"*

***SBC Energy Institute**: The role of hydrogen in mobility extends well beyond its use as pure hydrogen. Indeed, hydrogen can be used together with carbon to produce synthetic gaseous or liquid fuels, and also to upgrade fossil fuels. What is you view of the importance of these indirect routes in commercializing hydrogen use?*

Filip Smeets: The use of renewable hydrogen to produce renewable fuel for transportation is a very attractive pathway to develop a higher value mobility outlet and increase short-term market potential for electrolysis. You would be able to tap into existing car technology. Nevertheless this requires regulation to reward this alternative to bio-fuels pathway to decarbonize the mobility sector.

6 - BUSINESS CASES

***SBC Energy Institute:** The main challenge for hydrogen conversion seems to be economic rather than technical. Cost reduction is essential, but hydrogen solutions must also find ways to monetize their advantages. What are the main business cases you see arising in the future?*

Filip Smeets: Probably we will find out that the most interested business cases are the ones we do not see yet due to our lack of deep, granular view on the very local opportunities. Nevertheless short to medium term electrolytic hydrogen for industrial applications holds the most promise. Price levels are interesting, markets are existing and vast, and de-carbonization is important and straightforward. Very often there happens to be also a good site proximity between offshore wind and industrial portal hubs. Furthermore, if, and when Europe fixes the broken European Emissions Trading System, I can see opportunities arising in carbon capture and recycling. A lot of industries have a huge CO_2 balance that remains a strategic issue for them and drive delocalization decisions.

***SBC Energy Institute**: What is your view of business cases with multiple revenue streams?*

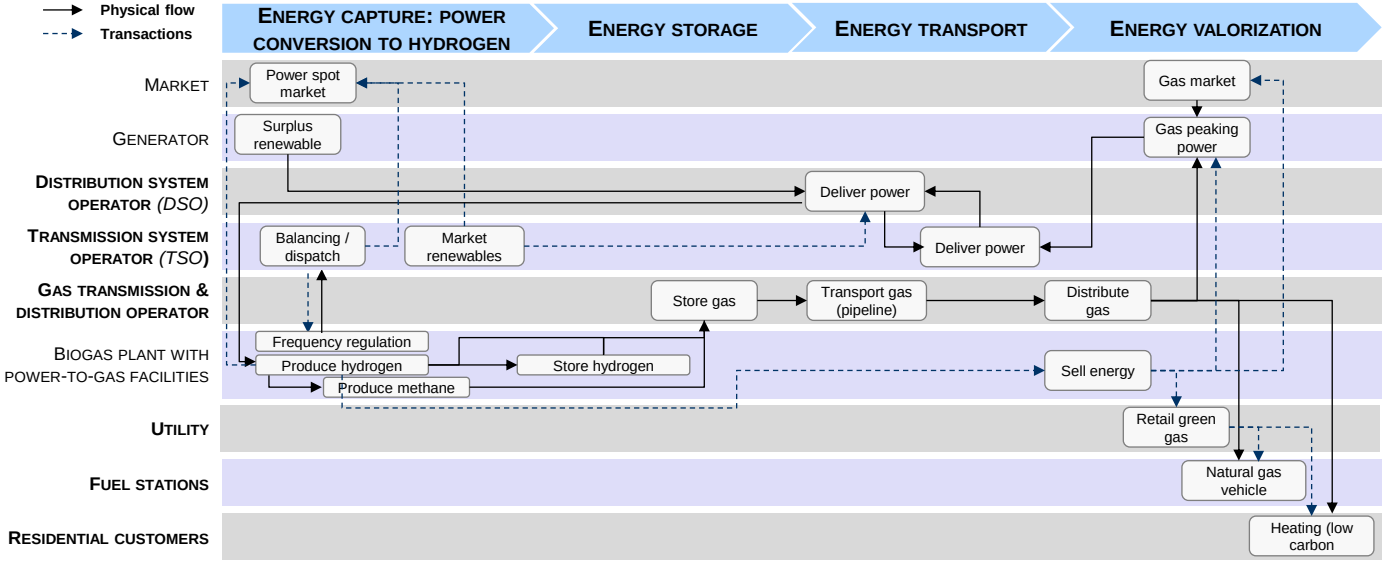
Filip Smeets: As mentioned earlier power-to-gas offers different value buckets: strategic, climate, infrastructure, flexibility (capacity) and calorific value. The flexibility and calorific value are the easiest to capture. But who is going to pay in a direct fashion for reduced dependency on fossil rich regimes, the reduced health cost of treatment against illnesses from aerial fine particles, the mitigation of effects from global warming, the mitigation of development of new energy infrastructure sized for peak demand instead of average demand. These value buckets can only be monetized by socializing the associated deployment cost, similarly to what happened in the past with the electricity grid, natural gas network, district heating, *etc…*

***SBC Energy Institute**: What do you expect from policy makers?*

Filip Smeets: Firstly policy makers need to have a robust, steady handed, long-term energy policy that addresses the fatal consequences of global warming. This is the key driver for increased deployment of intermittent renewables and the need for valorizing thus abundant excess in other energy silo's next to electricity, such as heat, industry and

mobility. Secondly a regulatory framework and support mechanism to encourage fast deployment of power-to-gas solutions. For instance define renewable energy storage in our regulation and allow broad access to this unique interconnector to the different actors in the energy market: transporters, distributors, suppliers, users and traders. Lastly, a good dialogue with the private sector on how this can be accomplished.

SIMPLIFIED STAKEHOLDER INTERACTIONS IN POWER-TO-GAS PATHWAYS IN GERMANY



Note: Feed-in-tariff compensation depends on all systems. In Germany, renewable electricity benefiting from priority dispatch is usually feed into the distribution network. It is then transmitted to TSO for sale on the spot market, where utilities purchase the electricity to send to end-consumers.
Source: SBC Energy Institute analysis, based on Hydrogenics (2012); Brandstätt et al. (2011).

BOX POWER-TO-GAS: HYDROGENICS NEW DEMONSTRATION PROJECT

Feb 18, 2014

Excess Wind Power Turned into Gas in Denmark Using Hydrogenics Technology

Mississauga, Ontario – February 18, 2014 – Hydrogenics Corporation today announced that it will be a participating partner of the Power-to-Gas Biological Catalysis ("BioCat") Project in Denmark. The "BioCat" installation will use hydrogen made from excess wind power to convert biogas from sewage sludge into cleaner methane gas. This new Danish energy project will illustrate how future energy systems can be better integrated.

The "BioCat" project has received 27.6 million DKK (€3.7 million) in funding from the Danish research pool ForskEL. The consortium is led by Electrochaea, a developer of methanation technologies for Power-to-Gas applications, and the Danish transmission system operator for power and gas, Energinet. Other partners in the BioCat consortium include Hydrogenics, Audi, NEAS Energy, HMN Gashandal, Spildevandscenter Avedore, and Insero Business Services.

For this project, Hydrogenics will install a 1 MW water electrolysis plant in Spildevandscenter Avedøre, one of the largest wastewater treatment facilities in Denmark. The site will use surplus electricity from the grid to produce hydrogen using Hydrogenics' electrolyzer, and the hydrogen will then be combined with carbon dioxide from raw biogas and fed into a separate bioreactor – in which microorganisms will perform a catalytic reaction to produce pipeline-grade renewable methane. The facility will be operated in different modes to demonstrate its ability to produce methane under dynamic operations, including while providing ancillary services to the electricity grid. The product gas will be injected into a nearby gas distribution system, and the by-products – oxygen and heat – will be recycled onsite in the wastewater treatment process. The biomethanation technology was developed by Electrochaea.

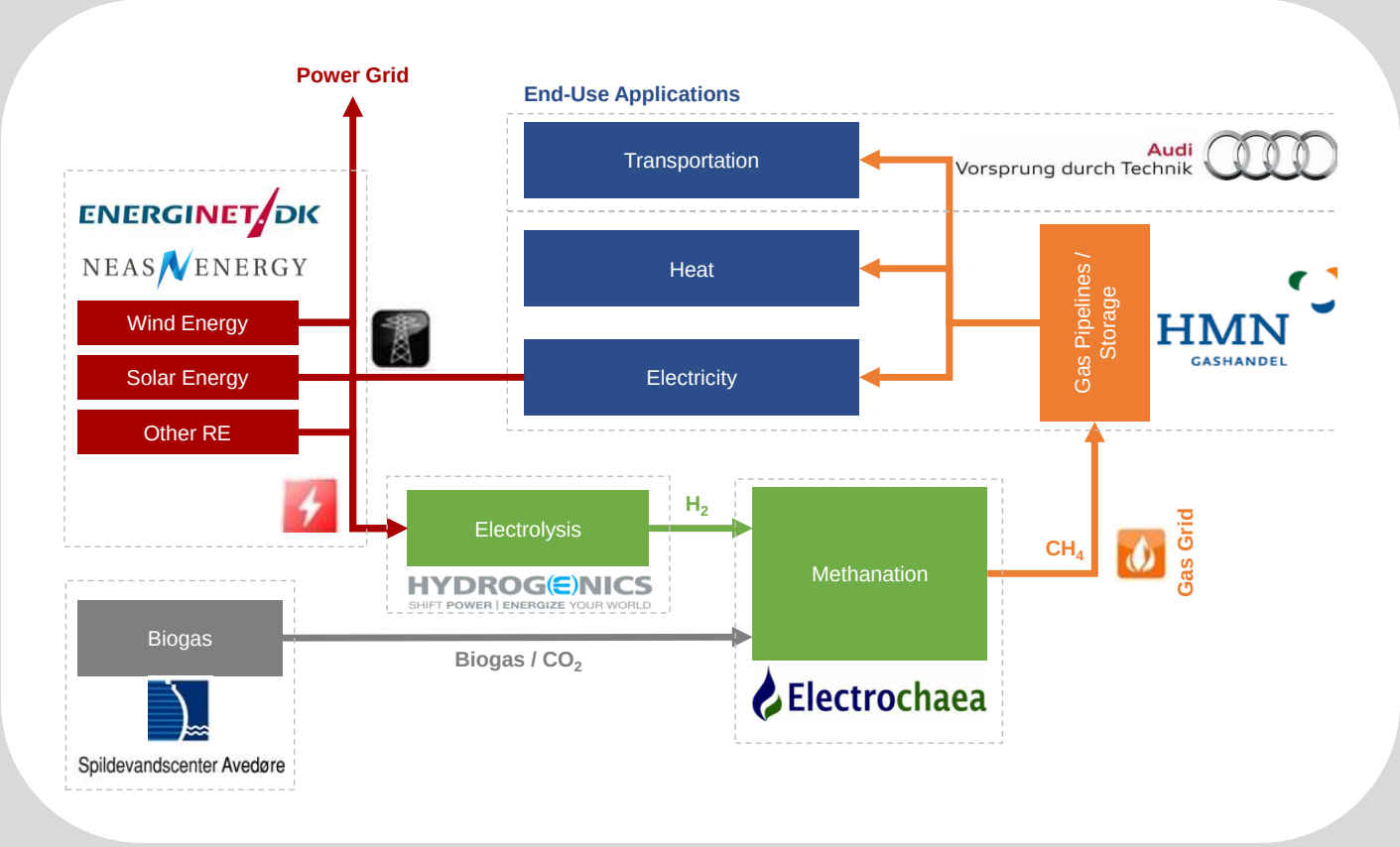
The 1 MW electrolyzer from Hydrogenics will contribute to electricity balancing through the services of NEAS Energy, thus ensuring optimal use of available wind power and demonstrating the full potential of electrolysis for grid management and regulation. The upgraded methane will be supplied to the local gas distribution system and traded by HMN Gashandel, a Danish energy service and gas distribution company managing gas grids, biogas upgrading plants, and grid injection facilities.

Ole Albaek Pedersen, CEO of HMN Gashandel, said, "We are pleased to be part of a project that combines hydrogen from excess wind and excess CO2 from biogas, thus offering more green gas to its consumers. We believe that the way forward will be to exploit the various systems' strengths, including natural gas' large existing flexibility and capacity that has already been paid for. While the electricity grid needs to be made smart, gas is born smart."

"We finally made the link between Denmark's abundant wind energy and the production of environmentally friendly gas for the Danish people. Integrated planning is an essential piece when we have to divert energy systems and phase out coal, oil and natural gas in the long term," says Kim Behnke, Research and Environmental Manager at Energinet.dk.

Filip Smeets, General Manager for Hydrogenics Europe, N.V., added, "We are very proud to be part of such a strong consortium that represents the full value chain of a Power-to-Gas applications. Denmark is a global leader in sustainable energy policy development, and our company is thrilled to find itself in a pivotal technology role. Our team is ready to bring a new generation of our water electrolysis technology into this leading edge biomethanation project."

Coverage of Power-to-Gas value chain by consortium members



To see video of SBC Energy Institute interview with Filip Smeets, visit
http://www.sbc.slb.com/SBCInstitute/Publications/Hydrogen.aspx

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ABOUT HYDROGENICS

Hydrogenics Corporation is a globally recognized developer and provider of hydrogen generation and fuel cell products and services, serving the growing industrial and clean energy markets of today and tomorrow. Based in Mississauga, Ontario, Canada, Hydrogenics has operations in North America and Europe.

For more information: www.hydrogenics.com

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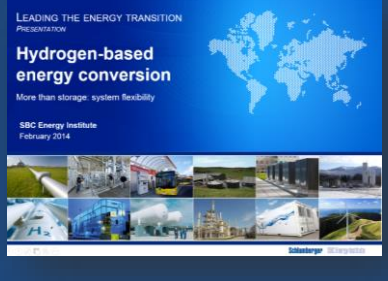
ABOUT THE SBC ENERGY INSTITUTE

The SBC Energy Institute is a non-profit energy research group created in 2011 to generate and promote understanding of the current and future energy technologies that will be needed to provide a safe, secure and reliable mix as world energy supply shifts from carbon intensive to carbon restricted.

The SBC Energy Institute released in February 2014 the Hydrogen-based energy conversion FactBook. The FactBook is a comprehensive, academically-reviewed and copyright free document that presents the role of hydrogen in the energy system and analyzes hydrogen-based solutions developed to overcome the intermittency challenge of renewable energies.



For more information and direct links to publications on hydrogen:
http://www.sbc.slb.com/SBCInstitute/Publications/Hydrogen.aspx