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Power to Gas Research Roadmap

Offering a Solution to the Energy Storage Problem?

by **Robert Judd and Dave Pinchbeck**

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The increasing levels of renewable generation bring challenges for our existing energy systems. Their variability means that they rarely provide just the amount of energy needed at any moment. Indeed at peak levels of production, wind power output is already being curtailed due to the limited capacity of the electricity grid, and the difficulty of storing electricity . Investment levels of hundreds of billions of euros in our electricity transport and storage infrastructure have been proposed to meet this challenge. However there is another, potentially lower cost solution. The enormous existing capacity of our gas networks can be used to store this excess energy, my turning the excess renewable electricity to synthetic natural gas or hydrogen. This article discusses this concept and suggests a route through the technical challenges that we face to make it happen.

1. INTRODUCTION

"The European Grid is far from ready for new variable energy sources like wind and solar"

The European Voice, 27th September 2012

The motivation for developing Power to Gas (P2G) technology is driven by the variability of the new renewable energy sources that are the primary route to decarbonising Europe's energy system. The wind doesn't always blow and the sun doesn't always shine when wanted. Conversely, not all of today's electricity grids have enough capacity to carry all of the renewable energy produced during strong wind and bright sunshine. There is therefore need for huge, long-term energy storage as the proportion of renewables in our energy mix increases.

This is particularly so in Germany, but also increasingly in the U.K. and elsewhere. The result is that quite often wind and solar installations have to be switched off as the grid is overloaded whilst, at the same time, significant amounts of compensation (M€) are paid to wind generators, which is an unnecessary waste of energy and money. Investments cost for grid upgrades and interconnections have been estimated at up to €200Bn. Germany's transmission operators have estimated that €20Bn will be needed to implement the grid upgrade required to phase in the renewable energy to replace nuclear.

The P2G approach uses the renewably generated (green) electricity for electrolysis to split water into hydrogen and oxygen. In some cases this could also be followed by methanation, combining carbon dioxide and hydrogen into methane, thereby re-using carbon dioxide and creating synthetic and renewable natural gas. The huge capacity of the existing natural gas grid can then be used to store and transport the renewably produced gas, positioning it at the heart of the transforming European energy system.

The GERG Power to Gas Research Roadmap, to be published this year, sets out to identify the bottlenecks, and solutions for the Power to Gas concept. It will highlight the R&D that will be necessary to achieve a robust solution based on the existing, adapted natural gas grid.

2. WHY? - THE RATIONALE

With the fast pace in developments, in particular in the field of wind energy, the problem of electricity storage has gained a new dimension. At times of peak production of renewable-generated power, existing electricity transmission lines are found inadequate in terms of capacity. The number of pumped storage power stations is limited in many countries. For example, according to Reuters [1], wind farm operators were paid £12.8 million to in 2011 to compensate them for switching off their turbines when the grid was overloaded during stormy days. According to data compiled by the Renewable Energy Foundation (REF) 14 wind farm owners were compensated for switching off a total of 4.65 GWh of electricity capacity on one single day. Clearly with current and projected levels of electricity stor-

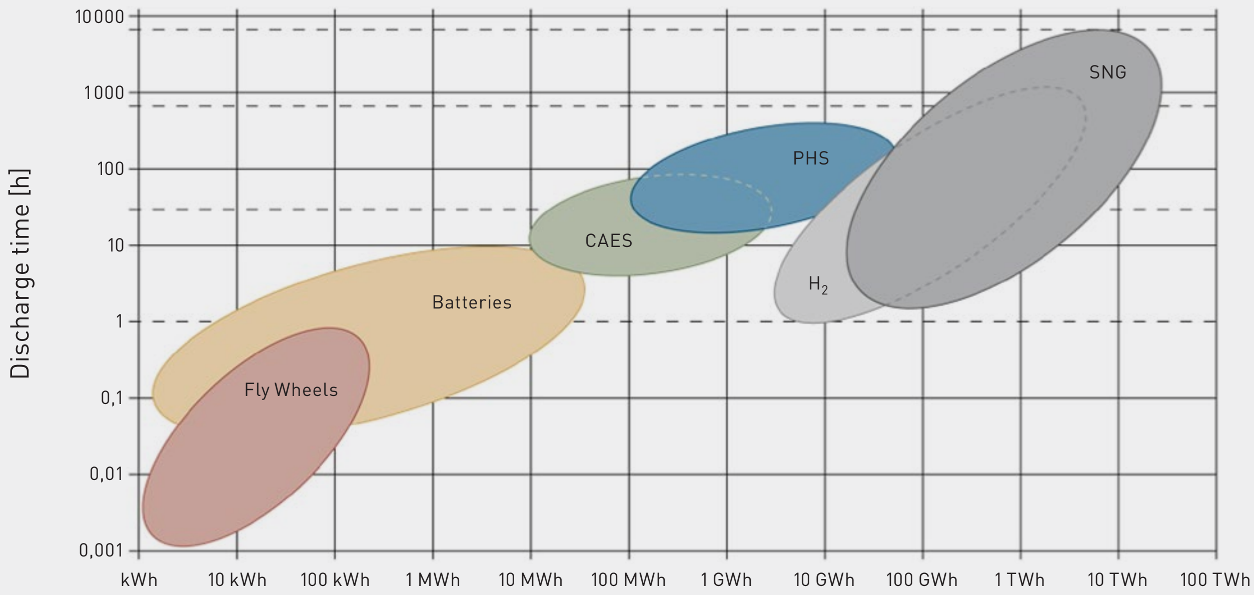

Figure 1. Discharge times and storage capacities. CAES: Compressed Air Energy Storage, PHS: Pumped Hydro Storage, H_2, SNG: Hydrogen, Synthetic Natural Gas.
Source: Research Center Jülich

age, the advantages that increased renewable energy production can give us are not being fully realised. The huge storage and energy delivery potential offered by the gas infrastructure can readily fill this gap. Appropriate technology therefore needs to be implemented to enable both the integration of renewable energies and the increased interlinking of power and gas infrastructures. The widespread plans for an expansion of renewable energy sources will inevitably mean an increased interdependence between natural gas and electricity networks in an integrated energy system of the future.

3. WHY? - THE BENEFITS

If hydrogen from surplus renewable electricity can be injected into the natural gas network, the enormous transportation and storage capacity of the existing infrastructure including underground storage facilities can be used directly. This can make an important contribution to the transportation and storage of surplus or non-transportable renewable electricity. Indeed, it is particularly attractive if it helps to avoid the construction of new electricity transmission lines.

Considering, for example, the injection of 10% of hydrogen, into the natural gas network, the two cases below, both in Germany, are very instructive:

- almost 1,000 TWh [2] of energy are transported annually in the form of natural gas; this is almost twice as much as the electricity consumed. If 10% hydrogen were added to the natural gas, this would correspond to an energy quantity of around 30 TWh. For comparison: the total capacity of the pumped storage power plants in Germany is 0.04 TWh per cycle (40,000 MWh);
- a medium-sized natural gas transportation pipeline has a capacity of, typically, 1 million m^3/h. Injection of 10% hydrogen, equivalent to 100,000 m^3/h, would require an electrical input of more than 400 MW for the electrolysis reaction, which corresponds to the maximum output of several large wind farms taken together.

The examples make it clear that injection of a hydrogen volume into the natural gas network, even as little as 10%, would significantly contribute to solving the problem of transporting and storing surplus electricity generated from renewable resources.

4. WHAT ARE THE PROBLEMS? THE BOTTLENECKS

Earlier analyses have concluded that, with provisos, the existing European natural gas pipeline network presents an attractive and technically feasible means of transportation of hydrogen as a mixture with natural gas.

Several projects have already examined the question of admissible hydrogen concentrations in natural gas networks, notably the EC-funded project, NATURALHY [3] which was initiated by GERG and its members. In addition, experience with pipelines and vessels for the transportation of pure hydrogen has been gathered over decades. Indeed, several GERG members have company-specific experience and considerable know-how related to natural gas/ hydrogen mixtures.

The issue has also been examined to some extent by gas turbine and gas boiler manufacturers who have 'developed' limits on the cautious side. It's clear that there are some very important questions which need to be clarified.

Of the perceived problems related to hydrogen transportation, the potential for degradation of pipeline steels from hydrogen-induced embrittlement has caused most concern. This was, therefore, addressed in detail by the NATURALHY project and is not considered as problematic.

The volume of hydrogen that may at present be added to natural gas is limited. Studies [4] have shown that, with certain restrictions, admixture of approx. 10 - 15% is not critical in most cases, except for three important applications:

- modern gas turbines with premixed burners, where a great number of manufacturers currently specify a limit value below 5%, with constraints on variability;
- The existing appliance population which will be operating outside the range of gas qualities for which they were designed.
- steel tanks in NGVs and CNG fuelling stations, where the current limit value is 2%;
- underground storage, of several types, where substantial gaps in knowledge need to be addressed.

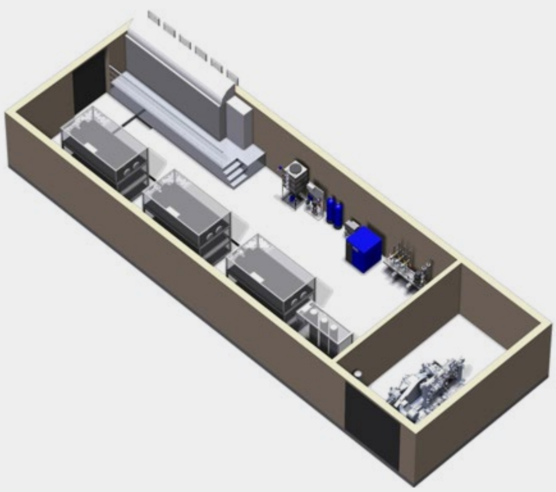

Figure 2. 1 MW Turnkey Electrolyser (Hydrogenics).

4.1 State of the art

As a first step, it will be essential to establish and analyse the level of knowledge existing regarding admissible hydrogen concentrations for all components of the natural gas system: transportation, storage, distribution, utilisation, etc. It will be important to detail all sensitive areas where hydrogen concentrations below 10% would be problematic. In addition, measures will be proposed that will allow hydrogen concentrations to be increased to approximately 10%.

As an essential preliminary step, a GERG project [5] is already under way in which competent gas companies and institutes have been charged with collecting and analysing the entire knowledge available. In addition to publications and research reports, the project will benefit from the experience and know-how of the many partners who comprise many GERG members and key external organisations, such as EUTurbines and Euromot.

On the basis of the information collected and collated, two categories of gas infrastructure components and appliances will be defined:

- components/appliances not sensitive to hydrogen (10 to 20% hydrogen concentration in natural gas admissible);
- components sensitive to hydrogen (concentrations < 10% not admissible or no reliable specification possible).

Clearly the aim of this preliminary GERG project is to help identify "show stoppers" and to develop proposals for key research projects which will allow hydrogen tolerances to be increased.

5. ENABLING TECHNOLOGIES

In addition to the network impacts, it will be important to develop the enabling technologies for P2G which will allow the reinjection of renewable gas into the grid. These fall into the two broad categories of hydrogen production and methanation. When hydrogen production from wind or solar energy is considered, the front runner is electrolysis, and this is where most effort is currently concentrated. However, other innovative hydrogen production technologies should not be discounted, and could include photocatalytic water splitting, plasma waste gasification, and plasma based pyrolysis.

5.1 Electrolysers

Electrolysers are key to P2G, for their ability to convert excess renewable electricity to hydrogen and oxygen by electrolysis of water. However, it's clear that in order to make this approach economically viable on a large scale technical breakthroughs will be necessary.

Electrolysers are fairly straightforward technology but they are expensive. Developments must be targeted towards significant reductions in investment cost and increasing efficiency and durability (lifetime) of catalysts.

There are developments taking place [6] and hydrogen and utility-scale next generation electrolysis can take gas-electricity convergence into new territory [7]. However to provide useful grid service, electrolysers may have to be scaled-up significantly, probably to the 10 MW range (in distribution grids), and even higher for transmission grids. They will need also to be capable of higher pressure operation with greater flexibility and reliability.

Developments in PEM [8] electrolysers may provide a way forward, as this approach can offer short start-up times and flexibility across a wide range of loads.

5.2 Methanation

Although much of the focus so far has been on hydrogen injection, hydrogen could also be used to produce methane, the main constituent of natural gas. Although the process would involve further capital expenditure and energy losses, it has real advantages. Not least of these it that the natural gas network is built to handle methane, and many of the technical issues described earlier, and by extension the costs of mitigation, disappear. The other advantage is that methanation of hydrogen removes and re-uses CO_2 from the ecosystem. It is of considerable interest and worthy of research, and there are promising and novel technology option which with appropriate support could yield real results in the coming years.

Methanation is a process that is used for the generation of SNG which can be fed directly into the gas grid. It can use either a classical chemical process or more recently developed approaches using biological catalysts which, for example, feed carbon dioxide and hydrogen to methane-producing microbacteria (*archaea*) in a biological methanation process called methanogenesis. The necessary reaction is:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

A typical system for CO_2 methanation, with options for storage of both CO_2 and renewable energy uses well established and reliable technologies (electrolysis of water, methanation reactors, fuel cells, etc.). The technology is not yet completely mature and improvements in efficiency need to be made. However, a breakthrough methanation-based application is being built by the Audi Group, where CO_2 from biomethane is being combined with renewable hydrogen to produce SNG or "e-gas". This will be injected in the grid in sufficient quantities to fuel a new range of commercially available Audi TCNG A3 vehicles [9].

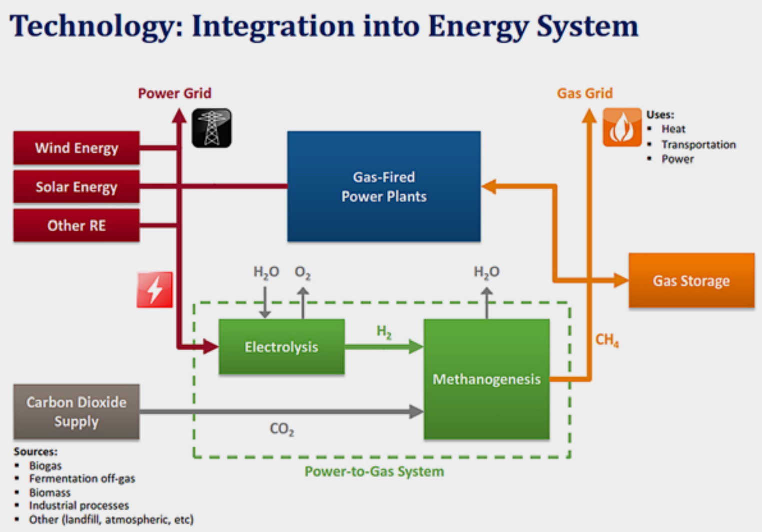

Figure 3. Biological catalyst-based approach.

The biological catalyst [10] approach has shown promise in the laboratory and is certainly of interest. Plans are in progress for a small scale proof of concept demonstration, as shown in **Figure 4**, with plans for a purpose-designed and scaled-up system using a more realistically sized 4MW electrolyser.

6. ECONOMIC CONSIDERATIONS

Solving technical challenges is of little use if the solution cannot be implemented economically. The full business case for Power Gas is yet to be written, as it will depend to a certain extent on the costs of mitigation of the network issues related to hydrogen injection, as well the capital and operating cost of plant which will be used to enable its introduction. However, a number of organisations are already developing power to gas demonstrations at scale of several hundred cubic metres of hydrogen per hour into local gas distribution systems. The outcome of these demonstrations will help to build a business as well as a technical case for Power to Gas. Based on current levels of understanding of network impacts scenarios are currently being produced which will allow a more detailed assessment of costs. Background work by GERG members has indicated that use of power to gas combined with an increased use of cogeneration from gas fired plant can enable the achievement of carbon reduction targets at a cost of €6 to €30 per tonne of CO_2 abatement, as opposed to the €120 per tonne that would be required using reinforcement of the electricity transmission systems.

It is also the case that although methanation has higher upfront and operating costs, requiring more energy input, it also offsets the costs of mitigating any hydrogen impacts on the network, and through carbon re-use would potentially benefit from higher emission credits. It is early days yet, and the work specified in the GERG roadmap will help to deliver the detailed information required both to understand the business case, and to ensure that the pathway to implementation has the largest economic benefits.

A significant barrier that remains in achieving economically viable P2G implementation is regulation. At present, the only value that can be gained from P2G technology is in the production of a gas with re-sale value – hydrogen or SNG. Much of the real value to the energy system comes from elsewhere - in the avoided capital cost of extra infrastructure, in the enabling of maximum utilisation of renewable electricity, and in the increase in renewable content of our gas networks. All these need to be given value through appropriate regulation to give P2G developers the confidence that they can implement a market ready solution.

7. RESEARCH NEEDS

The GERG P2G Research Roadmap will highlight the bottlenecks that exist and attempted to identify the R&D necessary to bring the necessary technologies to the state required to make this approach to energy storage and transportation work for both the energy industry and the consumers in Europe.

Placing P2G in the broader context of our transforming energy system there are a number of overarching R&D needs:

- A Europe wide energy system model which incorporates the natural gas infrastructure as a key element
- SMART Grid concepts should incorporate gas generation, transport, storage and use
- R&D provisions to reduce the cost and improve the efficiency of peak and flexible power provision
- Support for injection of renewable gases– standards and low cost technology (supported by positive regulatory messages)
- Options assessments and demonstrations of power to gas – hydrogen and methanisation, electrolysis.
- Making the natural gas network H_2 ready – P2G and repurposing for the future
- Make appliances, turbines, storage etc H_2 ready
- Develop advanced end use technology and hybrid systems for end use efficiency gains
- EU and International Government support!

8. CONCLUSIONS

It's clear that P2G, in both its forms, hydrogen production and methanation, can offer viable storage solutions to expensive and embarrassing problems of over-production of renewably generated electricity.

The proposed P2G solutions clearly fall into the category of "win-win":

- for those electricity companies obliged currently to pay wind farm operators for doing nothing,
- for the public who will benefit from a greener and more secure supply of energy, from reduced levels of CO_2 in the environment and from reduced need for extra electricity infrastructure;
- for gas companies who can and earn revenue from transporting and storing the gas whilst, at the same time, 'greening' their operations and image;
- for policy makers who will be able to use P2G to meet their own demanding targets for CO_2 reduction, security of supply and competitiveness.

P2G is not being developed in isolation from other advances in our energy system. The energy landscape is being transformed as we move to a low carbon future. Electrolysers are not only being developed for P2G. A future incorporating renewable hydrogen and fuel cells depends on their effectiveness. Renewable gas is already being injected into our gas networks from a variety of sources. In the context of a roadmap to the future, P2G could be seen as occupying a pivotal position. It both enables and benefits from the energy transformation to a future based on an increasing renewable content in our energy.

It's clear that whichever P2G approach is adopted, Europe can only benefit from using the enormous storage capacity of the European natural gas system.

A considerable amount of R&D, will be necessary to make this work. However, it's clear that many actors believe that P2G can provide a significant storage solution and have already begun to act. GERG and its members fall into this category and can make a significant contribution.

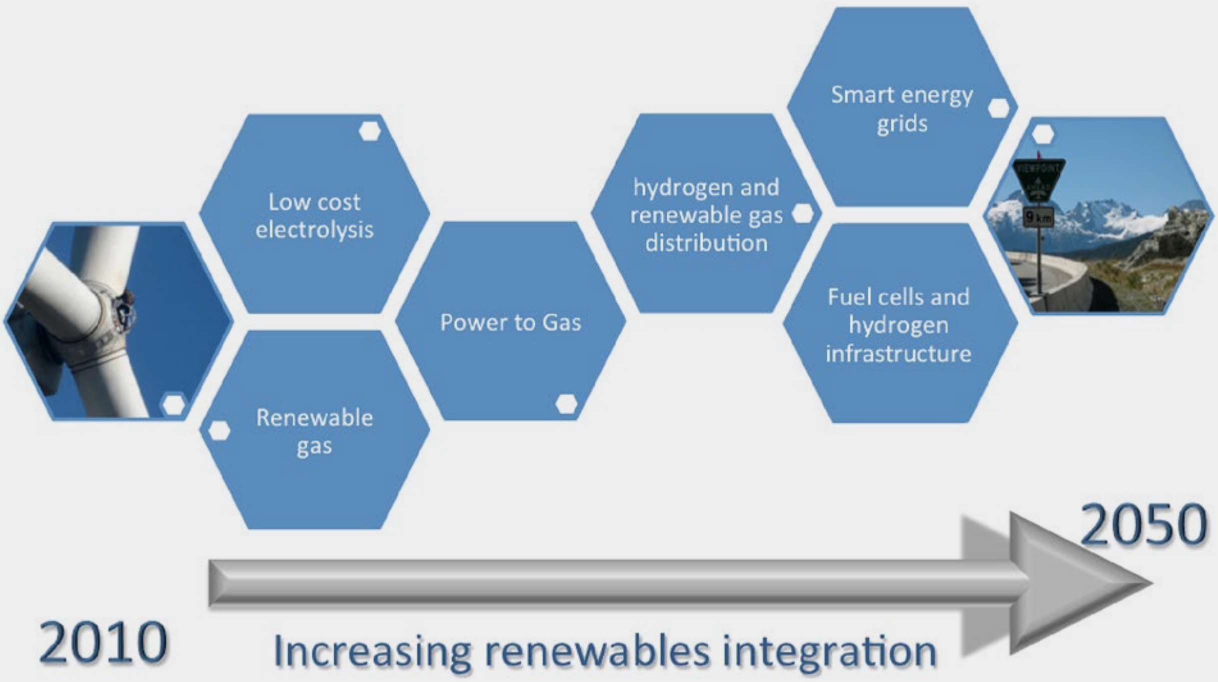

Figure 4. The road to 2050.

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