Power-to-gas: Climbing the technology readiness ladder

Qualification of integrated power-to-gas systems in real-life environments is the next step

by Lukas Grond and Johan Holstein

Power-to-gas as a technology to provide flexibility to the energy system or to generate low carbon or carbon free gas is currently heavily debated in relation to the energy transition and is considered to be a new and innovative technology. New technology in general introduces uncertainties that imply risks for developers, manufacturers, vendors, operators and end-users. This article discusses the state of power-to-gas in terms of technology readiness and provides insight in recent developments and proposed near-future activities. The current technology readiness level of power-to-gas equipment varies between the technology readiness level (TRL) 5 and 8, depending on the specific processes considered. In order to abate investors’ and policy-makers’ risks and uncertainties in adopting power-to-gas as an energy transition enabler, qualification and verification of integrated power-to-gas systems in operational, real life environments is required to improve on the technology readiness ladder and is crucial for facilitating possible further market penetration.

1. INTRODUCTION

The EU is facing unprecedented energy challenges until 2050. As part of the ‘20-20-20’ goals, 20 % of EU’s energy consumption should be generated by renewable energy sources (RES) in 2020, a 20 % greenhouse gas emissions reduction (relative to 1990 levels) should be realized and EU’s energy efficiency should be improved by 20 % [1]. Such a boost for the implementation of renewables will encourage technological innovation, development and increased employment in Europe. Adoption of enabling technologies by industrial companies is inevitable for realizing EU’s renewable energy targets. A common industry-accepted methodology for qualifying the development state of technology is by classification of the technology readiness level (TRL) of technological systems or system components. This methodology is suitable for comparing similar or competitive technologies and for indicating progress in the technology development [2]. Furthermore it helps to structure and prioritize development and improvement activities. The following technology readiness levels have been defined by US DoD [3]:

TRL1. Basic principles observed and reported
TRL2. Technology concept and/or application formulated
TRL3. Analytical and experimental critical function and/or characteristic proof of concept
TRL4. Component and/or breadboard validation in a laboratory environment
TRL5. Component and/or breadboard validation in a relevant environment
TRL6. System/subsystem model or prototype demonstration in a relevant environment
TRL7. System prototype demonstration in an operational environment
TRL8. Actual system completed and qualified through test and demonstration
TRL9. Actual system proven through successful mission operations

This article discusses the state of power-to-gas in terms of technology readiness and provides insight in recent developments and proposed near-future activities.

2. POWER-TO-GAS IN SHORT

Power-to-gas is the functional description of the conversion of electrical power into a gaseous energy carrier like e.g. hydrogen and/or methane. With the technology currently available, the production chain of power-to-gas consists of electrolysis and optionally methanation can be included. Electrolysis relates to the conversion of electricity into hydrogen by splitting the water molecule [Equation 1]. Methanation is the process of generating methane (and water) from a synthesis process of hydrogen and carbon dioxide [Equation 2].

\[
2\text{H}_2\text{O} (l) \rightarrow 2\text{H}_2(g) + \text{O}_2(g) \quad [1]
\]

\[
\text{CO}_2(g) + 4\text{H}_2(g) \rightarrow \text{CH}_4(g) + 2\text{H}_2\text{O} (l) \quad [2]
\]

The main purposes for the development and implementation of power-to-gas are (i) to deliver flexibility to the energy system by offering a controllable power load to facilitate the implementation of intermittent renewable energy sources into the existing energy system and (ii) to enhance decarbonisation of the gas sector, mobility sector or chemical industry by establishing the conversion of renewable power to natural gas substitute, hydrogen fuel/foodstock or carbon recycling via methanation. However, solely based on the rationale of energetic efficiency, electricity should always be directly used as electricity whenever possible, namely every conversion step imposes energy losses.

3. POWER-TO-GAS READINESS

Until recently electrolysis (mostly alkaline electrolysis) has generally been applied for continuous industrial processes like the production of fine chemicals or for vehicle fuel and can be characterized by TRL 9. Both these applications however did not require the electrolysis process to be very flexible for its application in terms of ramping up or down. With the increasing penetration of intermittent power resources the need for more controllable load in the power system increases (see Figure 1). This has been a direct motivation for electrolyser manufacturers to adapt their technologies to this market demand. So even though the electrolyser process is already known for decades and widely applied, the demand for flexible operation drives the innovation of the technology towards a system that is able to quickly and adequately respond to power production fluctuations. This means that this new application for the electrolyser technology forces it to be considered in TRL level 5 to 7 again.
Table 1. Advantages and disadvantages of the predominantly considered electrolysis technologies [5][6]

<table>
<thead>
<tr>
<th>Technology</th>
<th>Advantage</th>
<th>Disadvantage</th>
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<tbody>
<tr>
<td><strong>Alkaline Electrolysis</strong></td>
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<tr>
<td>Commercial technology (high technology readiness level)</td>
<td>Limited cost reduction and efficiency improvement potential</td>
<td>High maintenance intensity</td>
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<td>Low investment electrolyser</td>
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<tr>
<td>Large stack size</td>
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<td>Modest reactivity, ramp rates and flexibility (minimal load 20 %)</td>
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<tr>
<td>Extremely low hydrogen impurity (0.001 %)</td>
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<td>Stacks &lt; 250 kW require unusual AC/DC converters</td>
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<tr>
<td>(heat recycling)</td>
<td></td>
<td>Corrosive electrolyte deteriorates when not operating nominally</td>
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<tr>
<td><strong>Proton Exchange Membrane Electrolysis (PEM)</strong></td>
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<tr>
<td>Reliable technology (no kinetics) and simple, compact design</td>
<td>High investment costs (noble metals, membrane)</td>
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<td>Very fast response time</td>
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<td>Limited lifetime of membranes</td>
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<td>Cost reduction potential (modular design)</td>
<td>Requires high water purity</td>
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<tr>
<td>Solid Oxide Electrolysis Cell (SOEC)</td>
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<tr>
<td><strong>Advantage</strong></td>
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<tr>
<td>Highest electrolysis efficiency</td>
<td>Very low technology readiness level (proof of concept)</td>
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<tr>
<td>Low capital costs</td>
<td>Poor lifetime because of high temperature and affected material stability</td>
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<tr>
<td>Possibilities for integration with chemical methanation (heat recycling)</td>
<td>Limited flexibility, constant load required</td>
<td></td>
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</table>

5. CERTIFICATION OF HYDROGEN AND METHANE

The products from the power-to-gas process need to be valued properly in order to realize a viable business case for the owner or investor. In most European countries (except Germany), the hydrogen and methane from power-to-gas are not yet fully integrated in national subsidy schemes or stimulation programs. Neither can power-to-gas plants currently be exempted from regular taxes nor grid fees. It can be considered legitimate through to introduce supporting financial or legal measures for power-to-gas because the technology is implemented to relieve pressure on the power grid and to enhance the energy transition.

For the purpose of producing low carbon or CO₂-neutral methane for fuelling Audi’s g-train vehicles, certification of methane is essential for Audi in order to comply with the recent (Euro 5), the future (Euro 6) and national vehicle emission standards.

Similar discussions can be introduced for the use of power-to-gas for energy storage or flexibility purposes. In that case its real value is in storing energy to provide flexibility to the energy system. However, valuing only the caloric value of the hydrogen or methane produced does not address its service benefit properly. As with any development process, it is infallible to have a positive balance between the power-to-gas system costs and its benefits.

6. CURRENT STATUS; DEMONSTRATION OF DIFFERENT SYSTEM CONFIGURATIONS

Most of the investments in power-to-gas have until now been in macro-level research such as techno-economic technology assessments, energy systems analysis studies, feasibility studies and business case assessments, road maps and fact books. Results from these works are essential for companies and institutions to determine the appropriate approach towards further development of the technology. Two striking examples of European initiatives having the main objective to investigate the viability of the concept in this stage of the development by exploiting these aforementioned activities are the North Sea Power to Gas Platform (initiated and chaired by DNV GL) and the Strategieplattform Power-to-Gas (initiated and chaired by DVGW). The North Sea Power to Gas Platform is a joint body, based on an integrated network of stakeholders, which aims to explore the viability of power-to-gas in the countries surrounding the North Sea.
8. ENHANCING THE ENERGY TRANSITION

Developments of new power-to-gas technologies such as solid oxide electrolysis and biological methanation and the further adaptation and optimization of well-known technologies such as alkaline electrolysis, proton exchange membrane electrolysis and chemical methanation offer opportunities for the energy transition, by offering flexibility as well as decarbonisation. The technology readiness of power-to-gas technologies today varies between TRL 5 and 8, depending on the specific processes considered. In order to abate investors’ and policy-makers’ risks and uncertainties in adopting power-to-gas as an energy transition enabler, qualification and verification of integrated power-to-gas systems in operational, real life environments is the first next step that needs to be taken. DNV GL acknowledges that qualification, standardization and verification is crucial for further improvement of power-to-gas on the technology’s TRL and thus for harvesting the technology’s potential to enhance the energy transition and realise EU’s RES ambitions.

REFERENCES


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Figure 5. Methanation reactors (above) and IR photo (below) of the methanation process in the Netherlands, a project of Stedin, Ressort Wieren, Agentschap NL, Gemeente Rotterdam and DNV GL [12].

DNV GL has technologically supported the Dutch distribution grid operator Stedin in realizing the first Dutch power-to-methane plant, by defining engineering guidelines, validating the selected technology and ensuring gas grid injection compliance. This project has the objective to show the value of power-to-gas as a smart gas grid technology that enables wind and solar power accommodation as methane, which is used by households in the city of Rotterdam (Figure 5).

The world’s first power-to-methane full-scale demonstration plant of Audi in Werlte, Germany, is remarkable since it kick-starts the large scale deployment of the industrial produced methane vehicle fuel from wind power as a tool for Audi to comply with new European vehicle emission legislation. Another remarkable pilot project is the proof of concept of a biological methanation technology, which turns out to be a highly efficient process and capable of very rapid response to fluctuating input [10][11].

7. INCREASING NEED FOR TECHNOLOGY QUALIFICATION

Implementation of new technology introduces uncertainties that imply risk for its developers, manufacturers, vendors, operators and end-users. Concepts with well-known and proven technology are often preferred over solutions with elements of non-proven technology, even if the latter provides significant operational improvement or cost-efficiency [2].

With the current status of power-to-gas technologies (TRL 5–8), investors take a risk that their investment might not return within the envisioned period, due to e.g. design errors, technological failure, underestimated maintenance intensity or operational faults. Technology qualification and verification enables the TRL upgrade to TRL 9, needed to facilitate the implementation of power-to-gas and enhancing the creation of new business opportunities and/or improved profitability. Verification of the technology or project gives investors and potential operators reliable information about the technology of interest and helps them mitigating investment and technology related risks. Successful deployment of plants initiated by the pioneers in the energy transition is crucial. There is a need to set technical engineering guidelines and recommended practices for power-to-gas projects in order to enable technology qualification and provide transparency for vendors, investors and operators. Also other stakeholders, like public policy-makers and regulators have an interest in clear indications of the performance achievable by such technologies. This, subsequently, enables verification of projects to well-accepted standards and accelerates realization of projects and technology and market developments.