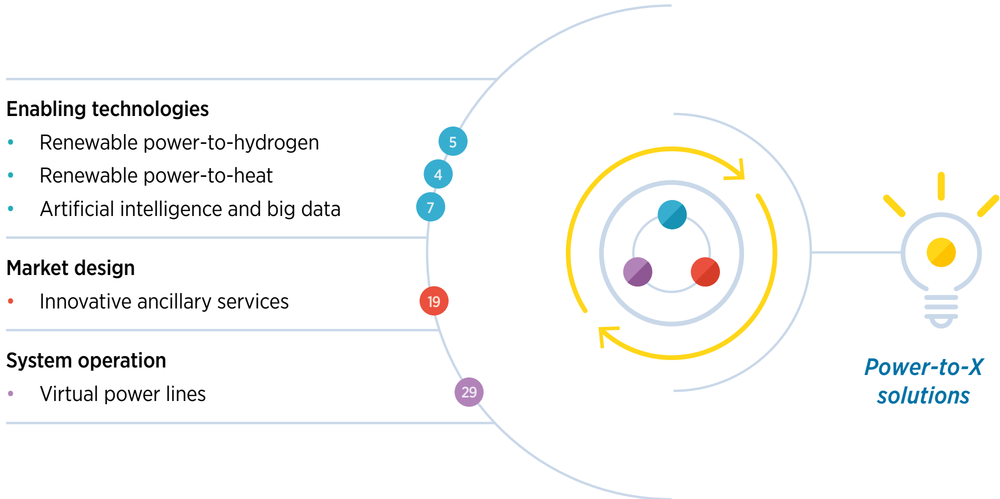
SOLUTION XI

Power-to-X solutions

Figure: Synergies between innovations for power-to-X solutions



Apart from using batteries as **enabling technologies**, electricity can be stored by being converted into hydrogen or heat. The value of storage is also given by its potential to decouple generation from demand, thus facilitating the integration of high shares of VRE and avoiding curtailment of the generation surplus. While intraday variations can be better managed with batteries, the electrification of other sectors shifts the demand from these sectors to the power sector. If well managed, this can add significant flexibility to the system.

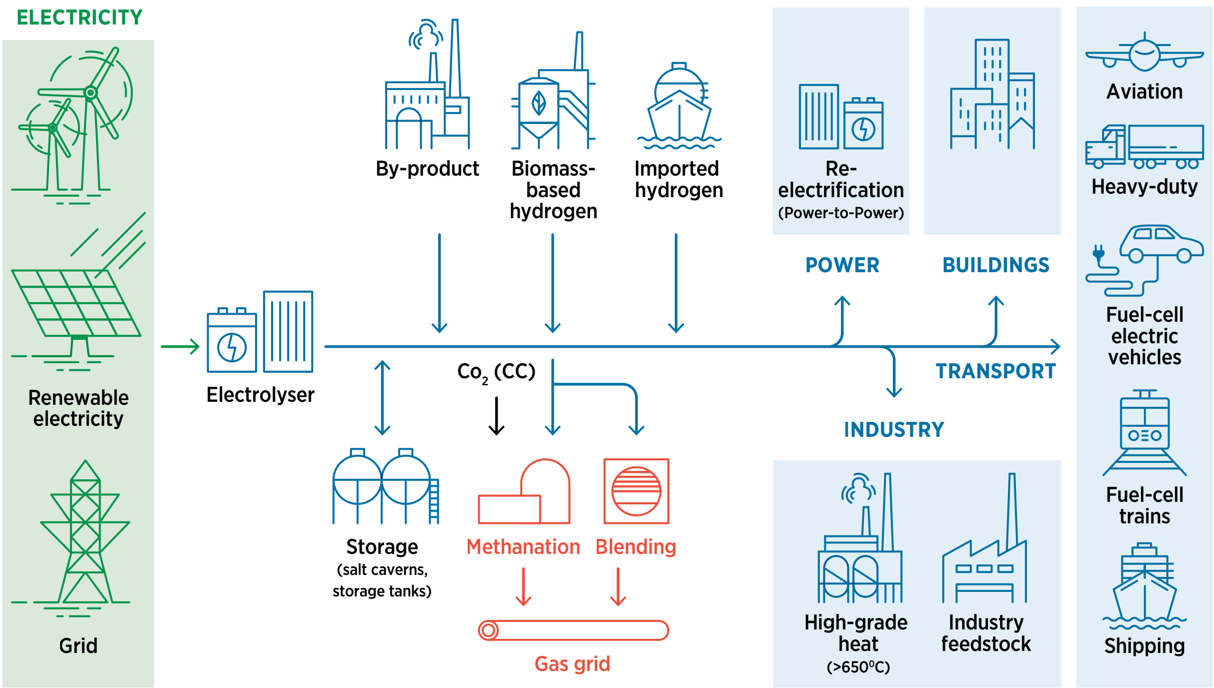
The process of converting the power generated from solar and wind sources to different types of energy carriers for use across multiple sectors, or to be reconverted back into power, has the potential to greatly increase the flexibility of the power grid. It builds an optional place to put the temporary surplus of power from VRE and reduces carbon by displacing fossil fuel energy sources in other sectors.

Power-to-hydrogen

Power-to-hydrogen is the process of using electrolysis to split water into hydrogen and oxygen using electricity. Hydrogen is a versatile, clean and safe energy carrier that can be used as a fuel for power or as a feedstock in industry. It can be stored and transported as a liquid or a gas and can be combusted or used in fuel cells to generate heat and electricity. Therefore, hydrogen might play a key role in the seasonal storage of renewable electricity, while also having the potential to decarbonise other sectors when used for other applications, such as mobility applications, industrial uses or injection into the gas grid (see figure below).

Power-to-gas is the process of converting renewable energy to gaseous energy carriers such as hydrogen or methane. Power-to-gas also uses electrolysis to generate hydrogen from renewable power, which is then reacted with carbon dioxide in the presence of bio-catalysts to produce methane. Synthetic methane can be used as a direct replacement for fossil natural gas, for example in marine transport or power generation. It also is a low-cost way to arrange seasonal energy storage or to transport energy in large quantities by using existing infrastructure.

Figure: Integration of VRE into end-uses by means of hydrogen



Source: IRENA, 2018d.

A similar concept is power-to-liquid fuels, in which hydrogen generated from electrolysis is reacted with carbon dioxide to produce liquid fuels such as synthetic crude, gasoline, diesel and jet fuel. These electrofuels (liquid fuels produced from renewable power) can replace fossil fuels without the need to change end-use technologies (IRENA, 2018d). Also, hydrogen can be used as feedstock to produce bulk chemicals, such as methanol or ammonia, that are used in the industry sector (a concept known as power-to-chemicals).

Using hydrogen for energy storage provides unique opportunities. Hydrogen can be produced during times of excess renewable electricity and it can be converted back to electricity to provide power when the renewable source is unavailable, helping stabilise the utility grid. Additionally, the electrolyser can be cycled up and down rapidly to be used as a flexible load providing low-cost balancing services to the power system. *(Key innovation: Renewable power-to-hydrogen)*

- Innovation in **system operation** could consist in using power-to-hydrogen as a solution to defer network investments. Some of the best wind resources are located offshore or in rural areas. Wind energy can be converted into hydrogen, which can be liquefied and transported to regions with energy deficits or demand centres. This facilitates wind power development without requiring large investments in a new transmission capacity. *(Key innovation: Virtual power lines)*

High investments and policy support are needed to adopt this solution. The Power-to-X alliance in Germany is investing up to EUR 1.1 billion to facilitate the production of green hydrogen and synthetic methane.

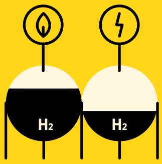
Power-to-heat

- Another **enabling technology**, renewable power-to-heat, involves using the electricity produced from renewable energy sources to generate heat through heat pumps or large electric boilers. Heat pumps use electricity to transfer heat from surrounding heat sources (air/water/ground) to buildings. Heat pumps can be used for demand-side management applications, such as load shifting and peak shaving. Renewable power-to-heat solutions can be implemented as either centralised or decentralised solutions. In the case of centralised heating systems, heat pumps or large-scale electric boilers generate heat, which is then transmitted to several buildings through a network of pipes. These systems are also known as district heating systems. Decentralised systems consist of heat pumps or electric boilers for heating individual buildings or residences. *(Key innovation: Renewable power-to-heat)*

Power-to-heat systems can use the excess electricity supplied from these sources to address heating needs and avoid the curtailment of renewable energy generation. For instance, the Inner Mongolia Autonomous Region in China had about 22.3 GW of installed wind power at the end of 2014, but also had very high curtailment levels due to transmission constraints, among other reasons (9% wind curtailment in 2014; 15% wind curtailment in 2015 (Zhang, 2016)). To avoid curtailment, the Chinese National Energy Administration is installing electric boilers with a capacity of 50 MW, which can be used to generate heat using excess renewable energy for the district heating system that conventionally has depended on inefficient coal boilers. The project is targeted for completion in 2020 and aims to generate about 2.8% of yearly planned district heat generation (IRENA, 2017).

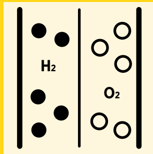
The Swedish utility company Vattenfall will be investing around EUR 100 million over two years to build three power-to-heat units with a combined heating capacity of 120 megawatts-thermal. These units will use excess wind energy to heat water, which in turn will transmit heat to residences and commercial buildings. These units are expected to be operational by 2019, at which point a unit in a coal-fired plant with a total capacity of 330 MWh will be shut down, reducing the use of fossil fuels in heating applications (Vattenfall, 2017).

Thermal storage can store energy for days or even months to help address seasonal variability in supply and demand. This is of particular benefit for energy systems in regions that have a significant difference in heating and/or cooling demands between seasons. Surplus heat produced with renewables in the summer can be stored in thermal storage, which then can be used to meet winter heating demand, thereby reducing the need for non-renewable sources of heat during peak times. Thermal storage also can be used to store natural cold in winter, to then supply space cooling during the summer (IRENA, forthcoming b). Key technologies for seasonal storage are aquifers or other forms of underground thermal energy storage.



HYDROGEN STORAGE

Could provide heat and electricity for homes from otherwise curtailed VRE



ELECTROLYSER

For utility-scale grid stabilisation services

Impact of power-to-hydrogen:

- **Storing solar and wind excess electricity in California using hydrogen would provide heat for up to 370 000 homes or provide enough electricity for up to 187 000 homes.**

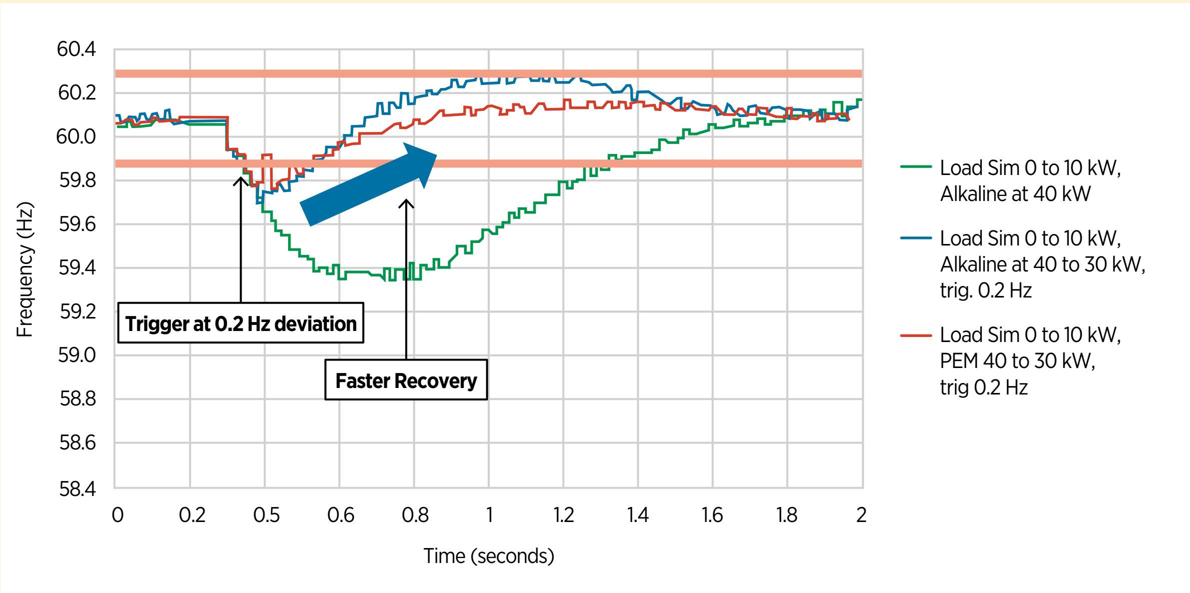
A study by Lawrence Berkeley National Laboratory claims that between 2017 and 2025, between 3 300 GWh and 7 800 GWh of solar and wind energy will be curtailed in California. Hydrogen gas made from excess electricity could be used to power fuel cell cars and trucks, or it could be blended with natural gas and used in anything that is gas fired. If all of the excess solar and wind energy that the study predicts will be curtailed in California were converted to methane and stored as renewable natural gas, it would provide enough energy to heat up to 370 000 homes or provide enough electricity for up to 187 000 homes (Sempra, 2017).

- **Electrolyser technology for utility-scale grid stabilisation services.**

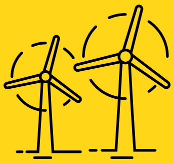
Hydrogenics Corporation completed a trial in 2011 with Ontario's Independent Electricity System Operator aimed at demonstrating the use of electrolyser technology for utility-scale grid stabilisation services. Experimental analysis done by the US National Renewable Energy Laboratory also shows that electrolysers can rapidly change their load point in response to grid needs and at the same time accelerate recovery in case of frequency deviation (Gardiner, 2014).

The figure below shows the result of the experiment conducted. A load simulator was used to generate harmonics on the grid (green line in figure), which reduces the frequency below the lower limit of 59.8 hertz (Hz). A control signal is generated when the frequency reaches a defined point, and that signal is transmitted to the electrolysers to reduce power consumption. The red and blue lines in the figure show the response of the electrolyser (by reducing the power consumption) once the frequency dips by 0.2 Hz. The time taken for such response is less than a second, enabling the electrolyser to provide such services. Commercial tenders from power companies are demanding fast response times including sub-second enhanced frequency response. Revenues from grid balancing payments serve to reduce the cost of hydrogen production via electrolysis (ITM Power, 2015; NREL, 2012).

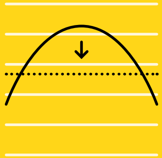
Figure: Use of electrolyser for fast frequency response



Source: NREL, 2017.



5 %
Heat demand supplied by electric boiler from excess wind generation



47 - 61 %
REDUCTION IN PEAK LOAD using EVs and heat pumps

Impact of power-to-heat:

- **Electric boiler with heat storage unit reducing curtailment during the night and providing ancillary services in Germany.**

The town of Lemgo in Germany implemented a 5 MW electric boiler in 2012 to contribute to district heating services. The electric boiler draws excess power from the grid during night time and generates revenue by providing this ancillary service. The electric boiler is accompanied by a heat storage unit that enables it to match supply and demand for heat. As per estimates, the electric boiler can compete with the existing combined heat and power plants during the 500 peak-load hours that occur every year. The boiler generated 27 terajoules or 7.5 GWh of heat, which comprised 5% of total heat supply in Lemgo in 2012 (IRENA, 2017c).

- **A project in Denmark demonstrated that a 47% to 61% reduction in peak load could be achieved using EVs and heat pumps.**

The ability to reduce peak load by adding flexibility to residential heating demand was demonstrated as part of the eFlex project conducted by DONG Energy (now Orsted) in Denmark (DONG Energy, 2012). The project assessed the potential peak load reduction by using heat pumps attached to smart devices that can control its functioning, exposed to price-based demand-response programmes. The system was designed so that the heat pump would reduce its consumption or shut off during peak demand intervals (if the house is sufficiently heated) and turn back on during low demand intervals. The study indicated that optimising the heat pump's performance resulted in reducing the peak load by 47% to 61%, depending on the time of day and prevailing temperature conditions.

IMPLEMENTED SOLUTION

POWER-TO-HYDROGEN DEMONSTRATION PROJECTS

HyStock, the Netherlands

HyStock is a project developed by EnergyStock, a subsidiary of the Dutch gas transmission system operator Gasunie, and is the first power-to-gas facility in the Netherlands. The project consists of a 1 MW proton exchange membrane (PEM) electrolyser together with a 1 MW solar field that will supply part of the electricity required to generate hydrogen from water. The HyStock project is located close to a salt cavern that can be used as a buffer to store the hydrogen being produced by the electrolyser after its compression. This hydrogen then can be inserted into storage cylinders and transported to end-users. The project also is investigating how this electrolyser could provide benefits to the power sector by, for example, providing ancillary services to the grid (EnergyStock, 2018).

HyBalance, Denmark

HyBalance is a Denmark-based project that demonstrates the use of hydrogen in the energy system. Under this project, excess wind power is used to produce hydrogen by electrolysis, which helps to balance the grid. The hydrogen that is produced is then used in the transport and industrial sectors in Hobro, Denmark. The project is expected to help identify potential revenue streams from hydrogen as well as changes in the regulatory environment that are required to improve the financial feasibility of power-to-hydrogen.

H2Future, Austria

H2Future consists of a 6 MW electrolyser, proposed to be installed at the Voestalpine Linz steel production site in Austria, and is expected to study the use of the electrolyser to provide grid balancing services such as primary, secondary and tertiary reserves, while also providing hydrogen to the steel plant. The hydrogen would be produced using electricity generated during off-peak hours to take advantage of time-of-use power prices.

REFHYNE, Germany

- The REFHYNE project consists of a 10 MW electrolyser, established at a large oil refinery in Rhineland, Germany, to provide the hydrogen required for refinery operations. The electrolyser is expected to replace the existing supply from two steam methane reformers. At the same time, it is expected to balance the internal electricity grid of the refinery and to provide primary control reserve services to German transmission system operators. The pilot is expected to be evaluated after two years, and the data collected is expected to explore the conditions under which the electrolyser can become financially viable. This project also includes a study of a 100 MW electrolyser at the Rhineland refinery, for large-scale analysis (FCH JU, 2018).

GRHYD, France

- A consortium led by ENGIE is demonstrating the GRHYD hydrogen energy storage project in France. France aims to meet 23% of its gross end-user energy consumption from renewable sources by 2020, so the GRHYD project aims to convert the surplus energy generated from renewable energy sources to hydrogen. The hydrogen produced is blended with natural gas – called Hythane(1) – and incorporated into the existing natural gas infrastructure. The project aims to demonstrate the technical, economic, environmental and social advantages of mixing hydrogen with natural gas as a sustainable energy solution (ENGIE, 2018).

POWER-TO-HEAT PROJECTS

Heat Smart Orkney project, Scotland

- A wind power-to-heat scheme is being implemented as part of the Heat Smart Orkney project, which secured funding of GBP 1.2 million through the Scottish Government's Local Energy Challenge fund. Households will be provided with energy-efficient heating devices that will draw the excess power generated from the community-owned wind turbine, otherwise meant to be curtailed. The household heating devices will be connected to the Internet and will get switched on when the wind turbine receives a curtailment signal.

Power-to-heat expansion in Denmark

- In 2015 the city of Aarhus, Denmark, expanded the capacity of an existing CHP plant by adding an 80 MW electric boiler and a 2 MW electric heat pump to provide district heating services to the neighbourhood. The plan was to expand the heat pump's capacity to up to 14 MW after assessing the performance of the existing heat pump (IRENA, 2017). The electric boiler and the heat pump are designed to utilise the excess wind generation in western Denmark, typically the greatest in winter and coincident with the increased demand for heat.

SUMMARY TABLE: BENEFITS AND COSTS OF POWER-TO-X SOLUTIONS

POWER-TO-HYDROGEN SOLUTION

Power-to-hydrogen solution	**Low**	**Moderate**	**High**	**Very high**
BENEFIT				
Potential increase in system flexibility				●
Flexibility needs addressed	from minutes to months			
COST and COMPLEXITY				
Investments in technology and infrastructure				●
	access to stacked revenues, access to existing gas infrastructure			
Required changes in the regulation framework			●	
	clear regulation established for the technologies used as network assets as opposed to market assets			
Required changes in the role of actors		●		

POWER-TO-HEAT SOLUTION

Power-to-heat solution	**Low**	**Moderate**	**High**	**Very high**
BENEFIT				
Potential increase in system flexibility			●	
Flexibility needs addressed	from seconds to months (*e.g.*, heat storage in large water caverns, containers or aquifers enables seasonal heat storage)			
COST and COMPLEXITY				
Investments in technology and infrastructure		●		
Required changes in the regulation framework		●		
	access to stacked revenues			
Required changes in the role of actors	●			

This document is extracted from a longer report:

IRENA (2019), ***Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables.*** International Renewable Energy Agency, Abu Dhabi (**ISBN 978-92-9260-111-9**).

The full report and related materials are available on the IRENA website (**www.irena.org**).