RENEWABLE POWER TO GAS/LIQUID – A PROMISING STORAGE TECHNOLOGY

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ABSTRACT

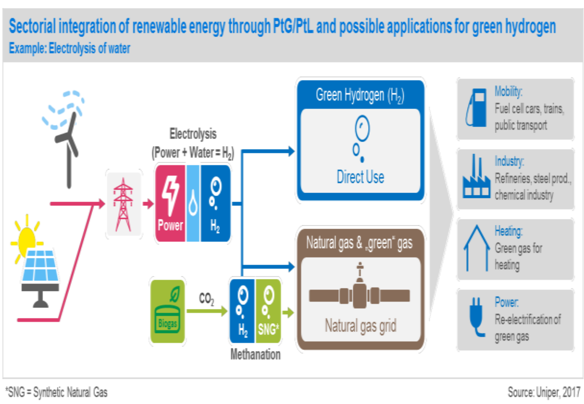
The recent developments at COP21 in Paris highlighted the importance of Energy Storage Systems for Renewable Energy in India. India has proposed reducing carbon emissions to a tune of 33% to 35% by the year 2030 as compared to 2005, and specifically mentioning energy storage in its INDC. Increasing the power generation from renewable energy sources (RES) and decarbonizing India's energy system are the main targets of today's energy policy in India. India has seen an unprecedented growth when it comes to Renewable energy capacity addition. India is currently having world's largest renewable energy expansion program with a target of 175GW till 2022. Solar installation capacity has recorded 370% increase in last three years from 2.6GW to more than 12.2GW. Year 2016-17 also saw highest ever wind capacity installation of 5.5GW. The growth is also fuelled by reducing power tariffs. Plug and play solar setups resulted in 75% reduction in solar tariffs. Solar power saw lowest ever tariff of Rs. 2.44 unit while Wind power achieved record low of Rs. 2.64 per unit. Such tariffs were unbelievable few years ago. The increasing share of renewables in the grid are creating new challenges subject to the inherent variability and unpredictability. With such high renewables in the energy mix and constant focus on quality of power, the relevance of storage systems is increasing remarkably.

Energy storage has long been recognized as a potential "game changer" allowing the power system to reflexively adjust to the limitations dictated by the laws of physics by adding a new dimension to energy delivery that is not currently available. Though, presently it remains a huge missing link in the entire energy story. This paper focuses on one of the less explored Chemical Storage Technology of the energy storage systems i.e. Power to Gas and Power to Liquid technology. Both Power-to-Gas (PtG) and Power-to-Liquid (PtL) allow using electricity generated from RES to produce Green Hydrogen and other energy carriers. This will help to reduce greenhouse gas (GHG) emissions by substituting energy from fossil sources. Since PtG and PtL are able to be produced flexibly, they can provide additional flexibility to the electricity grid and thereby support the integration of intermittent renewable generation as well as the deployment of additional RES installed capacity. Furthermore, PtG and PtL are key technologies for sectoral integration (sector coupling), i.e. improving the link between different energy and economic sectors, thereby increasing the overall efficiency at energy system level while contributing positively to energy security. This paper also outlines the developing energy and climate policy framework for India and how it is a driver of demand for energy storage with the integration of RES and the transition to a low-carbon energy system.

I. INTRODUCTION

For many years, energy storage was not considered a priority for the energy system, in part because the technologies were not yet economically viable and in part because the benefits of storage were valued less in a centralized fossil fuel-based energy system. However, this situation is rapidly changing due to the cost-performance improvements in energy storage technology and the public policy commitment to de-carbonization, leading to a significant increase in RES as a share of electricity generation.

Energy storage is essential to balance supply and demand. Peaks and troughs in demand can often be anticipated and satisfied by increasing, or decreasing generation at fairly short notice. In a low-carbon system, intermittent renewable energy (RES) makes it more difficult to vary output, and rises in demand do not necessarily correspond to rises in RES generation. Higher levels of energy storage are required for grid flexibility and grid stability and to cope with the increasing use of intermittent wind and solar electricity. Smart cities, a key energy policy goal, require smart grids and smart storage. As earlier mentioned, PtG and PtL are key technologies for sectoral integration (sector coupling), i.e. improving the link between different energy and economic sectors, thereby increasing the overall efficiency at energy system level while contributing positively to energy security.



Storage to chemicals and materials, is a route having an enormous potential, but it is underestimated and insufficiently researched. Excess electricity can easily be transformed into bulk chemicals that can easily be transported by ships or pipelines over long distances; at arrival, these chemicals can be used directly or be transformed into electricity, heat or other useful products. In Europe, Scientists and researchers have presented to the Commission more than 20 ideas; all make scientifically, technically and economically sense, but no pilot plant has been built up to date. These routes include power to hydrogen, Power to gas, Power to chemicals, Power to materials, etc.

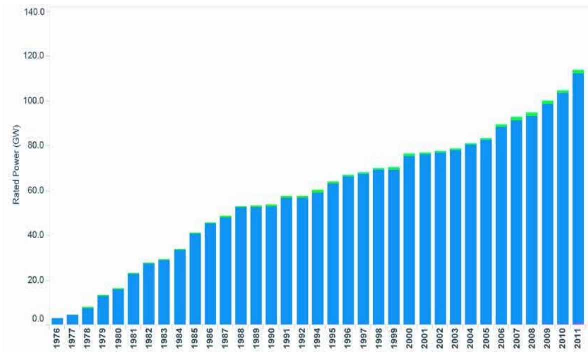
The hydrogen to chemicals route: The gasification of biomass and other low rank feedstock or low rank coal can provide the necessary gaseous fuels (syngas – IGCC process) to produce electricity and heat to back up the intermittent Renewable generation. The use of carbonic gaseous fuels also paves the way for the chemical storage of renewable energy sources. There is the option for a syngas based production of storage fuels, which are usable to equalize fluctuating power demand by incorporating renewable hydrogen. At the same time it could supply the chemical industry by new raw materials in a syngas based chemistry process (replacement of petroleum by biomass, coal, low rank feedstocks without CO2 emissions). This is a promising way to decarbonise power production and to store electricity indirectly. The market time line is estimated at 15 to 40 years by different experts.

Power to gas: Today the cheapest way to produce hydrogen is the chemical reaction of natural gas. The gas industry plans to use the reverse reaction to produce natural gas from hydrogen. This well-known reaction is mature and used in oil and gas industries since decades. The adaptation from CO as carbon carrier towards CO2 and the dynamic use in a RES power system still is rather at pilot and demonstration scales. The weakest link in the chain is the production of hydrogen from variable wind electricity. Thus power to gas and hydrogen will penetrate the market, once cheap and electrolysers allowing variable operation have been developed. The market time line is estimated at 10 to 40 years by different experts.

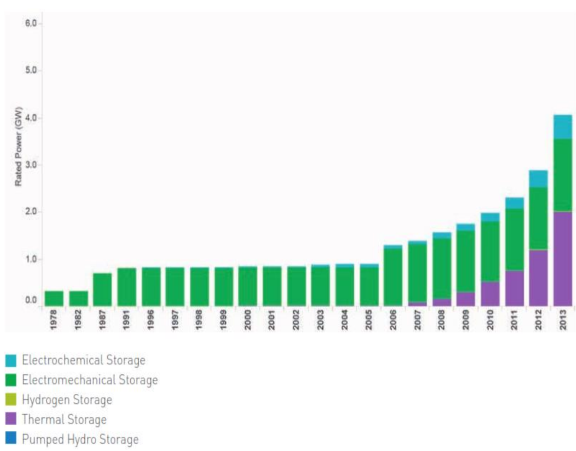
In an energy system based on renewable energy, there is a need for improved links between different energy carriers (e.g. electricity, gaseous fuels, liquid fuels, and heat) to absorb surplus electricity generation and decarbonise sectors that are still heavily reliant on fossil fuels. Energy storage provides an effective means to establish links between different energy carriers. This is the so-called Power-to-X (P2X) scheme that couples the electricity sector to the gas and oil sectors, providing both effective long-term large-scale energy storage by existing infrastructure and a solution to decarbonise road, sea, and air transport.

In 2015, installed large-scale energy storage capacity world-wide was estimated at 150 GW with approximately 96% of this capacity consisting of pumped hydro storage (PHS). More than 70% of new installations completed in 2014 are still PHS. The development of worldwide installed energy storage capacity in recent years is shown in figure 1. It shows that thermal energy storage, large-scale batteries, flywheels, and compressed air energy storage (CAES) are the main components of the non-PHS energy storage capacity.

Global Energy Storage Project Installations



Global /energy Storage Project Installations – excluding PHS

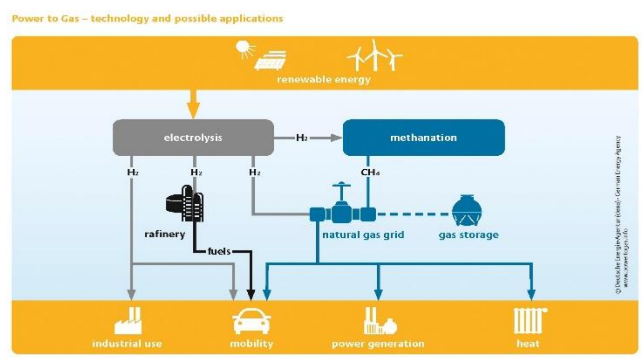


II. TECHNOLOGY

Chemical energy storage is based on the transformation of electrical energy into the energy of chemical bonds. It allows an exchange of energy between different vectors of the energy system, establishing cross-sectorial links of the power sector with the gas, fuel and chemical sectors. The heading Power-to-X (P2X) groups a range of generic technologies that convert low-carbon electricity into hydrogen, with the possibility to combine it with CO_2 to synthesise energy-rich gases (Power-to-Gas) and liquids (Power-to-Liquid) which can be used as fuels or to combine with nitrogen to produce chemicals, such as ammonia.

PtG and PtL are innovative applications of the proven water electrolysis technology to produce hydrogen or synthetic natural gas (SNG) with a subsequent methanation step or synthetic fuel (SF) like methanol with electricity from RES. There are several use cases for Green Hydrogen short- to mid-term, especially in the transport sector and the chemical industry. In the long-term, hydrogen can act as a seasonal storage for renewable energy. From an economic point of view, this is feasible if RES are the dominant source of energy and if the carbon pricing mechanisms deliver appropriate investments signals.

Power to Gas Schematic



With regard to the current ambitious GHG emission reduction targets and future mandate on the minimum shares of low carbon and renewable fuels in the transport sector, Green Hydrogen contributes in several ways:

- Green Hydrogen can be used directly in the production process of fuels, thereby replacing conventional fossil hydrogen from steam reformation of natural gas which has high GHG emissions;
- Green Hydrogen and Low Carbon Synthetic Fuels such as methanol can be used in mobility;
- SNG and SF from Green Hydrogen can drive existing internal combustion engine (ICE) vehicles, including natural gas vehicles (NGVs).

Electrolysers are fast-reacting devices, once a voltage is applied above the equilibrium voltage. Existing experience with electrolysers demonstrates that they have the ability to react within a second or lower upon changes in electricity supply or demand, both up and down. Electrolysers are therefore well suited for provision of many types of ancillary services for the future electrical grid with a high penetration of renewables including primary operational reserves. Cold-start duration depends on electrolyser technologies and varies from tens of minutes to hours for electrolysers operating at temperatures highly above ambient.

a) Hydrogen

Electrolyzer technology uses electricity to split water (H_2O) into Hydrogen (H) and Oxygen (O). Alkaline electrolyser technology is well known and has been utilised for about a century. Higher power density and efficiency is obtained with proton exchange membrane (PEM) cells. Recent developments include high temperature ceramic electrolysers based on solid oxide technology, which can make use of CO_2 and produce syngas or synfuels. In addition, plasma-chemical conversion or plasmolysis. To split CO_2 or water through vibrational excitation of the molecules in thermal non-equilibrium has been shown to be possible. Another development is photo-electrolysers that can direct H_2 production from sunlight.

Hydrogen plays a central role in chemical energy storage. However, its low volumetric energy density requires compression of usually between 200 and 700 bar or liquefaction. Hydrogen has an extended versatility of use: it can be reconverted to electrical energy for stationary applications (power and heat generation, internal combustion engines and turbines, direct steam generation, catalytic combustion, and fuel cells) or mobile applications (transport) giving only water vapour as a reaction product, transmitted in dedicated pipelines to connect production sites with consumer sites, admixed into the existing natural gas grid to a certain limit, converted to others fuels (methane, methanol) or used in the chemical industry.

Moreover, it is one of the very few options to store energy over days and weeks, e.g. in solution-mined salt caverns, which has been tested in the US for decades and is considered as a safe and cost-effective solution for large-scale storage of H_2.

b) Other chemical energy carriers

The second method is to combine the hydrogen with carbon dioxide and convert the two gases to methane using a methanation reaction such as the Sabatier reaction, or biological methanation resulting in an extra energy conversion loss of 8%. The methane /SNG may then be fed into the natural gas grid or further converted in to LPG by synthesizing SNG with partial reverse hydrogenation at high pressure and low temperature. LPG in turn can be converted into alkylate which is a premium gasoline blending stock because it has exceptional antiknock properties and gives clean burning. The third method uses the output gas of a wood gas generator or a biogas plant, after the biogas upgrader is mixed with the produced hydrogen from the electrolyzer, to upgrade the quality of the biogas.

In order to increase volumetric energy density and make use of existing infrastructure, other energy carriers and chemicals using hydrogen, carbon dioxide or nitrogen can be used either as fuels or basis material for chemical industry. These are mainly methane (CH_4), methanol (CH_3OH), and ammonia (NH_3). Further synthesis would allow production of transportation fuels such as dimethyl ether (DME) and kerosene. These fuels are of non-fossil origin as they are produced from feedstock, air, and water. Conversion into synthetic hydrocarbons not only allows long-term large-scale energy storage, it also enables a carbon neutral fuel cycle, essential for decarbonizing the transport sector.

III. ADVANTAGES OF PTX

- Integration of renewable electricity into various sectors of the energy system, which supports the objectives of the "RE mission" and the long-term vision of the Government of India;
- CO_2 emission reduction by substituting fossil based hydrogen from steam methane reforming of natural gas
- Provision of flexibility to the electricity grid by integration of variable generation of RES and the provision of balancing energy

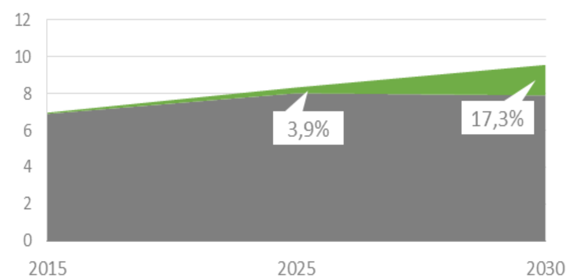
- Ability to be used in multiple setups, such as industry (refineries, steel production, fertilizer production), mobility, and heating;
- Ability, in the long run, to be used to store energy in the form of gas or liquids to absorb surplus electricity or to be used to generate electricity for backup purposes or at times of peak pricing;
- Ability, in the short run, to be used in industrial processes (chemical industry, refineries) and mobility;
- It is the only energy storage option available to store large amounts of energy seasonally and provide it on-demand to different sectors and applications.

PtG and PtL installations use electricity from RES. Flexible and fast-reacting electrolysers can quickly increase their production in times of surplus electricity. This mitigates curtailment of wind farms and helps avoid grid congestion and stabilise the electric grid. At the same time, in a future with more RES integration and less surplus electricity, these installations will contribute to the "additionality principle" whereby they incentivize in a market oriented manner the deployment of more RES installed capacity, supporting the long-term vision of the country.

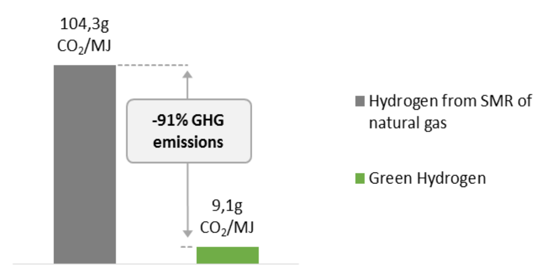
Green Hydrogen produced with electricity has significantly lower land use compared to biomass based fuels. Furthermore, there is no indirect land use change (ILUC) caused by Green Hydrogen. The carbon footprint of Green Hydrogen is low. With a transparent and Green Hydrogen used in the production process of fuels (diesel and petrol) does not change the chemical composition of the final product and is a short to medium-term option without changing existing infrastructure or vehicle engines. It represents a "soft" turnaround towards renewable fuels, and high public acceptance can be expected.

Advanced biofuels and traditional biofuels will complement each other in the period up to 2020. The total share of low-carbon and renewable fuels required in the future can only be met by a combination of traditional biofuels and advanced biofuels. As such, existing investments or industries will not be harmed. Electrolysis of water is a mature technology which has been used for several decades. New materials and technologies offer efficiency improvements as well as cost-degression potentials. Today, however, Green Hydrogen is in competition with conventional, fossil based hydrogen. Supporting the integration of Green Hydrogen into existing hydrogen markets would provide a stable environment for companies to invest in electrolysis technologies, thereby creating a solid basis for the further development of applications, such as energy storage.

About 17% of all hydrogen could originate from Renewables and/or low-carbon sources by 2030, Representing a market of about 1.7 million tons of Green Hydrogen per year.



Green Hydrogen has a 91% lower carbon footprint compared to hydrogen from steam methane reforming (SMR) of natural gas.



IV. LARGE SCALE IMPLEMENTATION

A massive increase in renewable energy generation, the electrification of the heating and cooling sector, and soon expanding electric vehicle networks are accelerating the need for efficient, reliable, and economical energy storage solutions.

An increased demand for energy storage will also be driven by the following factors: There will be a significant increase in variable renewable energy in India and all around the world. Energy storage will provide an effective solution to bridge fluctuations at different time-scales in supply and demand. In recent years, we already observe a considerable increase in renewable energy curtailment globally. Energy storage could strongly reduce this level of curtailment, thereby reducing carbon dioxide emissions, decreasing import dependency on fossil fuels, and improving the return on renewable energy generation investments.

The Power Ministry's proposal to provide a compensation mechanism for existing renewable energy projects against grid curtailments will be a major positive. The move will protect the cash flows from grid curtailments. When the proposal is adopted, it would ensure a favorable operational environment for renewable energy projects — both solar and wind energy developers. The compensation to renewable projects will incentivize grid operators and distribution utilities to reduce curtailments, will benefit renewable energy developers in scheduling and forecasting and enable integration of increasing renewable energy capacity. This in turn provides impetus for storage systems.

There is a need to further increase energy efficiency and to reduce CO_2. Energy storage will, for example, contribute to a higher efficiency for energy-intensive industrial processes and more flexibility for conventional power plants.

In order for PtG and PtL to be available for large scale applications (i.e. industries, mobility) by 2030, progress needs to be made in several areas, including the necessity to insure safety: PtG and PtL installations need to be scaled up, efficiencies have to be further increased, and production costs, for e.g. electrolysers, need to be reduced. Sector specific market and regulatory frameworks need to be further developed and barriers need to be overcome where they exist in order to tap the full potential of these technologies.

This progress can be achieved with the following steps:

- Creating a level playing field for Green Hydrogen and other follow-up products in a similar way to biofuels, blending not only directly in mobility but also when used in the production process of fuels. In this way, PtG and PtL could be used already today to reduce emissions in the production process of fuels or their blending components, like methyl tertiary butyl ether (MTBE) or methanol, or during production of synthetic gasoline from Green Hydrogen.

- PtG and PtL have very small carbon footprints and require little land compared to conventional (first generation) biofuels. Advanced biofuels entail exactly these characteristics. Green Hydrogen and follow-up products from PtG and PtL could therefore be recognized as advanced biofuels.

- First large-scale applications will trigger cost reductions and allow for a spill-over effect to other applications such as mobility and other industries.

- Framework conditions need to be created which allow innovative technologies to enter the market. These include allowing customers who are willing to use high shares of renewable electricity to do so already today and to avoid mandatory grid mix models.

V. POLICY RECOMMENDATIONS

Some key regulatory barriers are still blocking such developments. To overcome these hurdles, following measures are recommended:

- Developing a certification system for production pathways of Green Hydrogen and Green Synthetic Fuels. Such a system could be designed on the basis of the Project CertifHy recommendations implemented in EU.

- Developing comprehensive and fair life cycle assessment (LCA) methodologies for assessing GHG emission savings from renewable and low carbon fuels in the overall system to evaluate an adequate remuneration scheme for those savings.

- Promoting sectoral integration by reducing the barriers between the different energy and economic systems (mobility, industries, heating, etc.). This includes especially those fees and taxes applied when energy is transferred from one sector to another.

- Developing a coherent remuneration system for flexibility services.
- Creating a level playing field for Green Hydrogen and green fuels/blending components when used in refineries or during the fuel production process by classifying them as advanced biofuels under the revised Renewable Energy Directive (RED).
- Reducing the economic gap by promoting, especially through various global funds available, the development of pilot projects.
- Ensure the procurement of all energy and ancillary services is market-based, subject to a Cost-Benefit Analysis (CBA).

Remove regulatory barriers to demonstration projects is very much needed. In addition to support for technical innovation and demonstration, there is a very important role for demonstration of the practicability and commercial viability of storage projects in a number of applications. Demonstration projects allow for gathering valuable knowledge about the market applications and commercial arrangements for energy storage systems. These projects will in many cases be founded on multiple revenue streams, multiple clients, and multiple contracts. There is complexity in the interface between these, which involves regulatory and commercial risk. The regulatory framework must allow for:
a) funding of such demonstration projects through appropriate revenue collection;
b) the careful and limited waiving of particular regulatory safeguards (such as a network operator not being able to own storage);
c) the prudent waiving of technical and commercial requirements for network connection, especially in jurisdictions where the use of energy storage is not commonplace
d) appropriate participation by such facilities in relevant energy or service markets. Such demonstration projects are a very effective route to pull technologies into commercialization; it is not sufficient just to fund a new technology to see if it works.

In the short term, R&D projects should continue to be supported via direct incentives to allow the up-scaling of technology, cost reductions, and a better integration of the various technologies. This requires general support for the entire chain including electrolysers, plasmolysers, compression and storage technologies, catalytic conversion technologies, and re-conversion technologies.

At National level, we advise the creation of a 10-year R&D programme similar to the Kopernikus Power-to-X programme of the German Federal Ministry of Education and Research (BMBF). As part of this programme, a national research platform is being established to focus on the development of key P2X technologies over the next ten years, with the support of a wide range of research institutions, industry players, and civil society organisations. The aim is to bring P2X solutions from the research or prototype stage to the deployment stage. One unique aspect of the programme is that it combines a long-term project structure with a flexible steering mechanism to adapt to the rapidly changing environment. The project is jointly funded by the BMBF and industry partners.

In the medium term (2020), direct incentives should be progressively replaced by market based incentives to recompense the renewable (or low-carbon) characteristics of the end product in the overall decarbonisation on the EU energy system comprising the power, gas, mobility and industrial sectors. Also on the regulatory side, a number of barriers preventing the competitiveness and deployment of chemical energy storage (e.g. high cost burdens from grid fees or other levies) must be removed.

VI. RESEARCH PRIORITIES

Given the potential of chemical storage and P2X, an ambitious long term RD&D strategy is required at European level, following the example of the German Federal Ministry of Education and Research's Kopernikus P2X programme, and the US Department of Energy's Advanced Research Projects Agency - Energy (ARPA-E) REFUEL programme.

Research priorities include:

- Up-scaling of the technology (multi-MW) via pilot and demonstration projects aiming at generating economies of scale, developing improved manufacturing methods (supply chain optimisation, standardisation and automation), developing electrolyser technology to address the challenges of integrating variable RES, and better incorporating electrolyser technology with downstream processes with the overall objective of decreasing the total cost and improving efficiency.

- Materials and electrochemical process research and development to decrease the total cost of the technology: use of low cost material, new designs and manufacturing methods, high current densities, large area cells, gas separation membranes, improved durability of the equipment, decreased use of noble metals, reduction of the service and maintenance needs, and increased energy density in hydrogen storage.

- Materials and electrochemical process research and development to improve the overall performance of the technology: increase system efficiency, optimise temperature with respect to catalyst activity and material thermal resistance requirements improve catalysts, high pressure electrolysis, improved interfacing between the various technologies and improved design of single equipment and the overall system.

- Research, demonstration and industrial optimisation of:
    - Catalytic formation processes for chemical fuels (gas or liquids) by conversion of hydrogen, nitrogen and CO_2 to: ammonia, methane, methanol, dimethyl-ether, oxy-methylene ether (OME), synthetic kerosene, formic acid, and other chemicals;
    - The integration of these processes with upstream (renewables, electrolysers CO_2 streams) and downstream processes (industrial processes, distribution networks);
    - The applications using these chemical fuels: fuel cells, combustion engines, gas turbines.

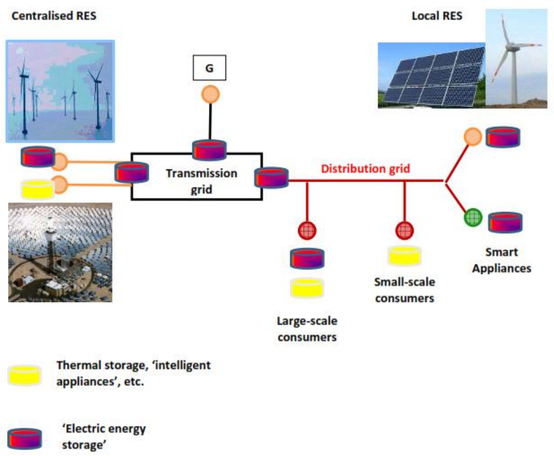
- Knowledge build up for health and safety, environmental compatibility (emissions, emission control),reduction of risk of pipeline leakage and corrosion due to hydrogen admixture, existing legal boundary conditions and their further development concerning: production of chemical energy carriers, storage, transport, handling and use, economy, sustainability of overall solutions.

VII. APPLICATIONS

Chemical energy storage has a wide variety of applications, including:
• CO_2 emissions reduction
• Energy security (indigenous electricity conversion into methane, liquid hydrocarbon fuel)
• Energy resilience (integration of electricity, gas, fuel, and chemical sectors)
• Use of existing infrastructure for storage, transport, and use
• Reduction of RES curtailment
• Island and remote location energy sufficiency energy arbitrage
• Seasonal energy storage (TWh scale)
• Electrification in the chemical industry by providing hydrogen carriers (H_2) or NH_3
C1 building blocks (methane, methanol)
• Indirect electrification of aviation, marine sector and transport by cars and trucks by synthetic fuels based on electricity
• Grid services (voltage, frequency stability):

Energy storage can be integrated at different levels of the electricity system: Generation level: Arbitrage, balancing and reserve power, etc. Transmission level: frequency control, investment deferral. Distribution level: voltage control, capacity support, etc. Customer level: peak shaving, time of use cost management, etc. These different locations in the power system will involve different stakeholders and will have an impact on the type of services to be provided. Each location will provide a specific share of deregulated and regulated income streams. Different energy storage systems will have to be considered (centralised and decentralised) and specific business models will have to be identified. A localisation map will help to define the possible needs for regulatory change and incentives. It is important to ensure that electricity from RES keeps its RES label, even if it has been stored before the final consumption. Possible feed in tariffs should not be affected by intermediate storage. Only the share of renewables at the point of pumping should qualify as renewable electricity. In a future low-carbon energy system, storage will be needed at all points of the electricity system.

Integrating Energy Storage



VIII. CHALLENGES

The main challenge for energy storage development is in economic front. The economic and business case varies from case to case, depending, among other things, on where the storage is needed: generation, transmission, distribution or customer level. The benefits for users/operators is also closely linked to the question of storage location. The investment costs (Rs/kW) need to be reduced to expand application areas for chemical energy storage.

Mainly with an up-scaling of the technology, more product standardization, mass production and supply chain optimization are challenges. On the technical side, higher efficiency, higher pressure, higher power density, and higher durability are the key challenges for all hydrogen technologies.

Additionally challenges for storage are:

i) technological
- increasing capacities and efficiencies of existing technologies,
- developing new technologies for local (domestic), decentralised or large centralised application,
- and market deployment;

ii) market and regulatory issues
- creating appropriate market signals to incentivise the building of storage capacity and provision of storage services,
- building up a National level market and common balancing markets, as exist in Nordic countries and between Germany and Austria,

iii) strategic
- developing a systemic or holistic approach to storage, bridging technical, regulatory, market and political aspects.

A number of uncertainties strongly affect the value assessment of energy storage: The existence of compensation schemes for storage: this is a key issue when some stakeholders are part of the regulated market (TSO's/DSO's) and the other are part of the deregulated market (e.g. producers and end customers). The potential to develop new and innovative business models: energy storage studies in both Europe and US demonstrate that the provision of a single service (e.g. kWh) was not sufficient to make the storage scheme cost effective; services such as frequency stabilisation and voltage stabilisation have a much higher commercial value. Ownership of the future energy storage systems whatever the location and the grid connection (Transmission or Distribution): should storage be owned by utilities or TSOs.

Another challenge is grid integration. Energy Storage should not be seen as a stand-alone technology. It will certainly compete and /or complement other ways to improve the grid flexibility.

A whole package of integrated measures is needed: Large centralised and small decentralised storage, Flexible generation systems (centralised and decentralised), Back-up capacity, More cables: Transmission and Distribution grid upgrades are a vehicle for flexible sources and allows to share flexibility over a larger geographic area, including interconnections and interoperability of different smart energy networks (heat and electricity, demand side management and demand response A further issue is overall system cost. One single solution will probably not be the most cost-optimal solution. A mix of all solutions is needed, tailored for each region and system architecture.

Another issue which present challenges to storage development are the future of the CO_2 emissions framework, public acceptance of cables, grid access and investment priorities. If they are adequately addressed, the situation for energy storage could be considerably improved.

IX. CONCLUSION

The above set of barriers is illustrative and not exhaustive; there are numerous other entry barriers which could be enumerated here. The rapid development and employment of energy storage technologies, as well as their integration into the grid, could be supported with broader regulatory reform and the elimination of these barriers. When discussing R&I efforts, it is important to underline that a supportive regulatory framework for storage is vitally important to the market roll-out of innovative storage technologies. Even more than just supporting these technologies, a suitable regulatory framework can allow energy storage to live up to its full potential for supporting the integration of RES while ensuring power system efficiency.

The share of electricity from renewable sources in the Indian electricity mix is increasing. As the power generation from wind and solar fluctuates, the match between renewable power supply and demand is becoming more challenging. At the same time, there are additional challenges to transmit the increasing volumes of renewable power from wind or solar farms to end users. The gas infrastructure can accommodate large volumes of electricity converted into gas in case that the supply of renewable power is larger than the grid capacity or than the electricity demand. As a result, power-to-gas enables the share of renewables in the energy mix to increase, making this innovation an important topic in achieving a carbon-neutral gas supply by 2050.

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Bachelor of Engineering in Mechanical Engineering (2007-11),
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Professional Experience:

- National Thermal Power Corporation Limited (2011 – Present)
    - Working as a Deputy Manager in Operation department at 'Kawas Gas Power Project' (KGPP) (656 MW), Gujarat, India
    - Completed training at 'Talcher Super Thermal Power Station' (3000 MW), Odisha, India

Major Workplace Projects:

- Gas and Steam Turbine: Renovation and Modernization (R&M) (2014)

Undergraduate Project:

- CFD Analysis of 3D ONERA M6 Wing (2011)
    - Project objective was to find the Lift and Drag coefficients, and plotting the pressure coefficient along the length of ONERA wing.
    - Created geometry and domain mesh of ONERA wing using ICEM CFD.
    - Performed transonic flow analysis with air taken as a viscid and compressible, using FLUENT 12.1 solver.
    - Achieved results very much in concordance with the wind tunnel experimental results available with AGARD report

Technical Expertise:

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- Control system design using MATLAB R2013a and SIMULINK
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- Programming in C, C++, JAVA

Professional Achievements:

- Certificate of Recognition at Regional NOCET meet, NTPC (2016-17)
- Paper submitted on Distributed Energy Storage at IPS 2017
- Certificate of Recognition at Regional NOCET meet, NTPC (2015-16)
- Certificate of Recognition at the 13th National Level Professional Circle Convention, NTPC (2013-14)
- First position and Certificate of Merit at the 13th Western Region-I Professional Circle Convention, NTPC (2013-14)
- First position and Certificate of Achievement at the 13th Project Level Professional Circle Convention, NTPC (2013-14)