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HYDROGEN ENERGY STORAGE FOR GEORGIA

HYDROGEN AS A COMPLEMENT TO NATURAL GAS AND POTENCIAL SITE CONSIDERATIONS

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ACRONYMS

ADB	Asian Development Bank
ADEME	French Environment and Energy Management Agency
ALAS	Air Liquide Advanced Separations
APG	Austrian Power Grid
ARENA	Australian Renewable Energy Agency
CAPEX	Capital Expenditure
CO2	Carbon Dioxide
EBRD	European Bank for Reconstruction and Development
ENTSO-G	European Network of Transmission System Operators for Gas
EU	European Union
FH2R	Fukushima Hydrogen Energy Research Field
GEDF	Georgian Energy Development Fund
GoG	Government of Georgia
GOGC	Georgian Oil and Gas Corporation
GW	Gigawatt
GWh	Gigawatt Hour
HPP	Hydro Power Plant
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt Hour
MW	Megawatt
MWh	Megawatt Hour
NEDO	New Energy and Industrial Technology Development Organization
NEL	Norway-based hydrogen company, delivering optimal solutions to produce, store and distribute hydrogen from renewable energy
NG	Natural Gas
NREL	National Renewable Energy Laboratory
OPEX	Operating Expense
PEM	Proton Exchange Membrane
PtG	Power-to-Gas
SCP	South Caucasus Pipeline
SOE	Solid Oxide Electrolysis
STB	Stack Test Bed
TANAP	Trans Anatolian Pipeline
TAP	Trans Adriatic Pipeline
TSO	Transmission System Operator
TWh	Terawatt Hour
USAID	United States Agency for International Development
USD	United State Dollar
UWSCG	United Water Supply Company of Georgia Ltd.

CONTENTS

1. EXECUTIVE SUMMARY

This report provides a high-level evaluation of hydrogen energy storage technology and how it could be implemented in Georgia.

Section 1 provides background context;
Section 2 provides technical information on hydrogen storage technology;
Section 3 provides a high-level view of hydrogen implementation in Georgia;
Section 4 dives into further details for a Georgia implementation site.

In Georgia, abundant hydro resources and developed hydropower systems present many opportunities for various combinations of solar, wind, and hydro energy with energy storage technologies. The primary existing storage technologies in Georgia is hydromechanical storage, where water storage basins created by dams store autumn rainwater for winter energy generation. Other energy storage has not been adopted by the Georgian energy sector yet, presenting significant opportunities to maximize renewable energy sources. This report will overview one cutting edge renewable energy storage option which is being looked at seriously by the global energy market, and with huge potential for Georgia: hydrogen energy storage.

Hydrogen energy storage is a form of chemical energy storage where electrical power (generated by renewable energy sources) is converted into hydrogen molecules through electrolytic splitting of water. The term “green hydrogen” comes into play if the energy used in the electrolytic splitting comes from “green” or renewable energy sources. These hydrogen atoms are the stored energy and can be used later as gaseous fuel in a combustion engine or a fuel cell.

Hydrogen gas can also blend with natural gas for other energy storage and export applications. The use of such a blend for both power generation and domestic needs provides not only mitigation of carbon emissions but also contributes to energy independence of Georgia, creating a domestic source of gaseous fuel, normally imported from other countries.

There are four core benefits to blending hydrogen with natural gas:

1. **Maximize usage of spilled hydropower –** Georgia’s immense hydropower resources have seasonal fluctuations, which create an excess of generation in the summer and deficit in the winter. According to the Georgian Energy Development Fund (GEDF), Georgia spills 956,000 MWh of energy annually (11% of energy generation) and hydropower resources ramp down 25% for 2 months in the summer. This lost power could be economically harvested and stored long-term by converting excess power to hydrogen and storing it;
2. **Reduce Georgian dependency on natural gas -** hydrogen could substitute a portion (initially ~5%, increasing over time) of Georgia’s imported natural gas, which reached 2.58 billion m^3 of imports in 2019. This improves Georgia’s energy security;
3. **Mitigate carbon dioxide emissions** – Green hydrogen comes from renewable sources, reducing carbon dioxide CO2 emissions. If Georgia were to substitute 5% of their total imported natural gas (125,000,000 Nm^3) with hydrogen, it would eliminate 245,000 tons of CO2 emissions;
4. **Export** – The hydrogen/natural gas blend can be exported to other countries for their own energy demands. This can drive a profit for the Georgian economy, which is currently underutilizing their energy storage economic potential. As European Union (EU) countries aim for the European Green Deal’s[1] zero net emissions by 2050, Europe’s hydrogen backbone[2] pipeline continues to grow, and Georgia is well positioned to sell low-cost green hydrogen to all of Europe.

This ecologically sustainable and economically viable energy supply is a high priority in European Union policy. Sector coupling via Power-to-Gas (PtG) is fundamental to the transformation of the European energy system and a significant economic parameter. For Georgia, implementation of PtG

[1] European Commission. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en#actions
[2] European Hydrogen Backbone. Enagás, Energinet, Fluxys Belgium, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Snam, Swedegas, Teréga, July 2020. https://www.actu-environnement.com/media/pdf/news-35879-etude-dorsale-hydrogene-europe.pdf

projects will provide a strong, green, power stimulus and contribute to long-term economic and technological development.

Once hydrogen is produced from renewable energy, there are two main realistic possibilities to implement green hydrogen in Georgia:

1. Inject hydrogen into South Caucuses Pipeline for export, and into the local gas distribution pipeline for domestic use in Georgia; and
2. Inject hydrogen into the Samgori South Dome Underground Gas Storage outside of Tbilisi (under construction, planned for commission in 2024).

In the Georgian context, the domestic use of a hydrogen-natural gas blend would integrate into Georgia's natural gas network, enabling large scale implementation (energy storage and export) across the country.

Already, as this report is finalizing in September 2020, the Georgian government signed a deal with the European Bank for Reconstruction and Development[3] to explore potential for green hydrogen to blend and transport to end-user through existing gas pipelines, part of the €217 million euro deal with the Georgian Oil and Gas Corporation (GOGC). "Georgia is making a very timely move in terms of utilizing its hydro potential and future-proofing its gas infrastructure to accept low carbon fuels. We are pleased to support them with these first steps," said Aida Sitdikova, Director and Head of Energy Eurasia, in the European Bank for Reconstruction and Development (EBRD's) Sustainable Infrastructure Group.

[3] EBRD article available at https://www.ebrd.com/news/2020/georgia-joins-the-race-to-produce-green-hydrogen.html

2. BACKGROUND

The objective of USAID's Energy Program is to support Georgia's efforts to facilitate increased investment in power generation capacity to increase national energy security, facilitate economic growth, and enhance national sovereignty. The project will have a significant impact on the energy market reform efforts of the Government of Georgia (GoG) to comply with the country's obligations under the Energy Community Treaty. The project investment objectives will be achieved through the provision of technical assistance to a variety of stakeholders in the energy sector.

The goal of this program is to enhance Georgia's energy security through improved legal and regulatory framework and increased investments in the energy sector. The ultimate expected outcome of this program is an energy legal and regulatory framework that complies with European Union requirements and encourages competitive energy trade and private sector investments.

This report on hydrogen technology review and potential project sites for Georgian hydrogen energy storage aligns to USAID's Energy Program's Task 5: Strategic Advisory Assistance to the GoG to Increase Energy Security, and Sub-Task 3. Supporting Energy Investment Projects. Specifically, the GEDF is exploring the topic of hydrogen's production perspectives in Georgia, energy usage applications, basic economics, and potential in absorbing excessive variable renewable energy production. Due to lack of experience in this area, GEDF asked USAID Energy Program to provide consultative assistance. The assistance includes this report, covering international leading practices, descriptions of available technologies, and possible project(s) in Georgia.

This is the second of two reports covering the characteristics, benefits, and feasibility of hydrogen storage in Georgia. The first report, titled ""***The Role and Place of Hydrogen Energy in the Sustainable Development of Energy and Economy of Georgia***", written by Dr. Simon Bakhturidze, covers renewable electricity supply characteristics and possibilities of blending hydrogen in natural gas system in Georgia.

This report analyzes specific site considerations and will survey, enumerate, and review technologies appropriate for producing hydrogen from electrolysis, blending hydrogen into a natural gas transmission system, and reviewing a potential Georgian hydrogen energy site.

This report was composed with key insights from Dr. Gabriel Jinjikhashvily, Energy Systems Expert, retired Senior Expert to Israel Electric Corporation.

3. HYDROGEN ENERGY STORAGE TECHNOLOGY REVIEW

3.1 INTRODUCTION TO HYDROGEN ENERGY STORAGE

POWER TO GAS CONCEPT

An increase in power generation is needed for the sustainable development of Georgia. As the country is scarce in fossil fuel reserves, the demand for power generation would require an increase in renewable energy for sustainability. Hydropower is well-developed and wind power is started, and both will be developed more. Solar power is only in the very initial stages in Georgia. But all three of these large-scale renewable energy sources are limited by their variability of power output due to weather and seasonal fluctuation. This common drawback is actively being addressed with energy storage technologies across the globe. Five common types of energy storage technologies include:

- Batteries – use electrochemical storage solutions;
- Thermal – capture heat and cold to create energy on demand or offset energy needs;
- Mechanical Storage – harness kinetic or gravitational energy to store electricity;
- Hydrogen – excess electricity generation is converted into gaseous hydrogen fuel via electrolysis and stored *(the focus of this report);*
- Pumped Hydropower – create large-scale reservoirs of energy with water.

In Georgia, abundant hydro resources and developed hydropower systems present many opportunities for various combinations of solar, wind, and hydro energy with energy storage technologies. The primary existing storage technologies in Georgia are hydroelectric plants where water storage basins created by dams store autumn rainwater for winter energy generation. Other energy storage has not been adopted by the Georgian energy sector yet, presenting significant opportunities to maximize renewable energy sources. This report will overview one cutting edge renewable energy storage option shaking the global energy market, with huge potential for Georgia: hydrogen energy storage.

Hydrogen energy storage is a form of chemical energy storage where electrical power (generated by renewable energy sources) is converted into hydrogen molecules through electrolytic splitting of water. These hydrogen atoms can later be used as gaseous fuel in a combustion engine or a fuel cell. Hydrogen gas can also blend with natural gas for other energy storage and export applications. The use of such a blend for both power generation and domestic needs provides not only mitigation of carbon emissions but also contributes to energy independence of Georgia, creating a domestic source of gas fuel, normally imported from other countries.

This ecologically sustainable and economically viable energy supply is a high priority in EU policy. Sector coupling via PtG is fundamental to the transformation of the European energy system and a significant economic parameter. For Georgia, implementation of PtG projects will provide a strong stimulus for green power generation and contribute to economic and technological development.

PtG is already rapidly developing in Europe, with 128 demonstration projects in operation or planning in 2018. According to S&P Global[4], as of November 2019, EU gas grid operators are planning up to 17 renewable power-to-gas projects by 2025 as part of efforts to cut CO2 and keep their grids in use as the EU moves away from natural gas.

BLENDING HYDROGEN WITH NATURAL GAS

Fundamentals - Hydrogen produced using renewable energy plays an important role as an energy carrier in a sustainable, reliable, and cost-effective energy future. This is especially true for Georgia because its abundant resources of green energy fluctuate dramatically during the year can be accumulated and stored seasonally (long-term) in the form of hydrogen (or alternative hydrocarbons from hydrogen). These gases address major issues facing the development of renewable energy sources, including long-term storage of fluctuating renewable electricity sources, alternative energy

[4] Siobhan Hall, S&P Global, Nov 2019. Available at: https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/111819-eu-gas-tsos-plan-17-power-to-gas-projects-by-2025-to-help-cut-co2

transport via the existing gas infrastructure, reduction of greenhouse gas emissions, and increase in local production and use.

Hydrogen is stored during high generation (in Georgia, summer months with high hydropower output) or low demand periods. Later, when generation is lower (or Georgia is depending more on natural gas imports to generate power), this hydrogen is accessible for generating power. Both fuel cell technology and gas turbines technology can utilize hydrogen as a fuel.

Option 1: Pure Hydrogen Storage - But storage of hydrogen is not simple; it can be stored physically as either a gas or a liquid. Storage of hydrogen as a gas typically requires high-pressure tanks (350–700 bar tank pressure). Storage of hydrogen as a liquid requires cryogenic temperatures because its boiling point at a pressure of one atmosphere is −252.8°C. Storage of hydrogen in chemical compounds offers a much wider range of possibilities, but no single material investigated to date exhibits all the necessary properties. The storage solution requires breakthroughs in materials performance that can only come from innovative and basic research that looks beyond the materials considered, to date. In Georgia, hydrogen storage makes the most sense in the gaseous form, both from a cost perspective and for the ability to blend with Georgia's current in-place natural gas transmission infrastructure.

Option 2: Blending Hydrogen with Natural Gas - Another option is the use of hydrogen blended with natural gas. Blending green hydrogen with natural gas is a key area of interest for decarbonization and increasing flexibility in energy systems, as it has the potential both to absorb renewable electricity at times of excess renewable generation and to provide backup energy at times of high demand. Furthermore, overall pollutant emissions from the gas grid can be reduced.

Joint use of the natural gas infrastructure for hydrogen and natural gas might be a favorable strategy, providing a realistic and simple solution for green electricity absorption. In Georgian conditions, blending green hydrogen in the existing natural gas pipeline network might increase the output of renewable energy systems. This depends on the concentration of hydrogen. If implemented with relatively low hydrogen concentrations, about 5%–6% by volume, this strategy of storing and delivering renewable energy to consumers appears to be viable without significantly increasing risks associated with utilization of the gas blend in end-use devices (such as household appliances), overall public safety, or the durability and integrity of the existing natural gas pipeline network. However, the appropriate blend concentration may vary significantly between pipeline network systems and natural gas compositions and must therefore be assessed on a case-by-case basis. Given the large scale of Georgia and Europe's existing natural gas infrastructure, even very low % blends (less than 3%–5% Hydrogen) could absorb large quantities of wind or solar power in the most cost-effective way. Germany and other European countries have been studying feasibility of using a blend of natural gas and hydrogen in their networks. French natural gas network operators consider that French network could initially use a blend of natural gas with 6% hydrogen. They recommended that the government set a target of 10% by 2030 and 20% beyond that.

ELECTROLYSIS OVERVIEW

Hydrogen can be produced in numerous ways, but in the context of energy storage, the most common production process is through the electrolysis of water. In this process, electrolysis breaks down water into hydrogen and oxygen atoms by using electricity. If the electricity used comes from renewable energy sources like wind, hydro, or solar, this form of electrolysis is referred to as "green hydrogen".

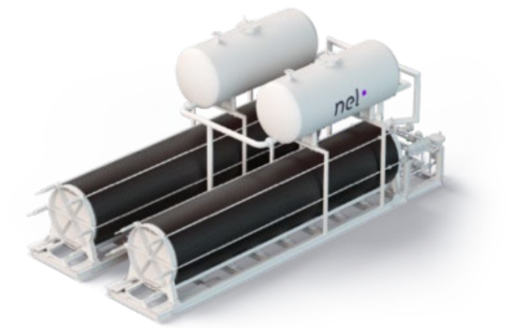
Splitting water into hydrogen and oxygen by electricity was discovered more than 200 years ago. The advent of low-cost electricity from solar and wind raises the possibility of creating hydrogen from low carbon resources. Today, commercially available hydrogen is primarily derived from processing natural gas and has a significant carbon footprint. Realizing the carbon benefit of substituting hydrogen for natural gas necessitates a low-carbon source of "green" hydrogen. At its simplest, electrolysis is accomplished by conducting an electric current through water. As the current flows, water splits into hydrogen around one electrode, and oxygen around the other electrode. The process results in three important products: hydrogen, oxygen, and heat. Making use of all three products is essential to realizing the greatest value from electrolysis applications. Modern electrolysis has come a long way and continues to improve in both efficiency and cost. There are three categories of electrolyzers today, each with its own characteristics and potentials: Alkaline, Proton Exchange Membrane (PEM), and Solid Oxide Electrolysis (SOE). Since SOE is not considered commercially mature as of August 2020, it is not considered in this report.

3.2 COMMERCIAL MATURITY

ALKALINE ELECTROLYZERS

These electrolyzers are the least expensive and most time-compared to other commercial electrolysis technologies. They have been in commercial use since the 1950's. Although it is currently the cheapest of all electrolysis processes to purchase, it has relatively high maintenance costs. As the electrolyte is liquid, the alkaline electrolyzer requires more peripheral equipment, such as pumps for the electrolyte, solution washing and preparation.

Most of the large-scale applications of electrolysis today are of the alkaline electrolyzer type. A 135 MW alkaline electrolyzer in Norway was in service from 1953 to 1991. Its purpose was to use excess hydro power to produce hydrogen that was used in the production of ammonia-based fertilizer.



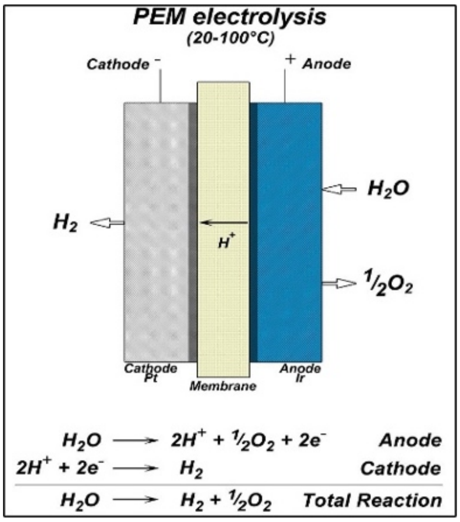
NEL (Norway-based hydrogen company) Atmospheric Alkaline Electrolyzer, 150-3,880 Nm³/h

While technology maturity, commercial scale, cost, and efficiency are important advantages of the technology, alkaline electrolysis has certain limitations compared with the newer PEM technology, including:

- longer startup times (>10 minutes)
- sensitivity to rapid changes in input power levels, -
- lower power densities that lead to relatively larger space requirements, -
- produced gas is at relatively low (1-15 bar) pressure.

Fast startup and ability to ramp quickly are positive attributes for units responding to potentially variable power from renewable resources. Most hydrogen applications require compressed gas, necessitating a compression stage that reduces efficiency and can involve additional maintenance costs.

PROTON EXCHANGE MEMBRANE (PEM) ELECTROLYZERS



Another electrolysis technology that is gaining in importance is PEM electrolysis, based on special polymer materials that can pass protons. The membrane separates the produced oxygen and hydrogen, allowing higher pressures to develop without dangerous blending of hydrogen and oxygen within the cell. Importantly, this technology is virtually identical to PEM fuel cells that produce electricity from hydrogen and oxygen—the basic process is virtually reversible. Fuel cells are the power source for most hydrogen fueled vehicles, and the association with fuel cells makes PEM a target of research and development efforts.

ELECTROLYZER CONCLUSIONS

For Georgia, a decision to focus on PEM electrolyzers could accompany the first planned project or pilot project. The efficiency of electrolysis is determined by the amount of electricity used to produce an amount of hydrogen. Depending on the method used, the efficiency of water electrolyzer is currently in the region of 60 to 80 % (based on the calorific value).

Alkaline electrolysis was originally the most highly developed and cheapest technology and therefore most commonly used. Nowadays, however, PEM electrolyzers are a serious alternative to alkaline electrolyzers and they are used in several PtG pilot plants. PEM electrolyzers can reach higher efficiencies and can deal with fast load changes, which can be very beneficial in PtG projects, using renewable energy sources, which are essentially variable. In an expert elicitation study[5] a majority of experts expected PEM electrolysis to become the most important electrolysis technique by 2030 due to its superior characteristics for intermittent operation. Before this would lead to a commercial advantage over alkaline electrolysis, however, more experience is required, and alkaline electrolysis is expected to remain the most important technology in the coming years.

One more advantage of PEM electrolyzers is higher pressure of discharged hydrogen, the feature important for PtG projects. While electrolyzers are already in operations, research continues to further improve them. Research priorities with regard to electrolyzers currently include increasing the efficiency of the electrolyzer system as a whole, along with its operating life, power density and stack size, reducing costs (especially material costs), introducing pressurized systems to avoid the need for subsequent compression of the H2 produced, and just as importantly developing flexible systems adapted to intermittent and fluctuating power supply.

Table 1: Comparison Between PEM and Alkaline Electrolyzers

Characteristics	Alkaline	PEM	Unit
Current Density	0.2-0.7	1.0-2.2	A/cm2
Operating Temperature	60-80	50-84	Degree C
Electricity Consumption (Median)*	50-73 (53)	47-73 (52)	kWh/kg-H2
Min. Load	20-40%	3-10%	%
Start-up Time from Cold to Minimal Load	20-60+	5-15	minutes
System Efficiency (LHV) (Median)	45%-67% (63%)	45%-71% (63%)	%
System Lifetime (Median)	'20-30 (26)	10-30 (22)	Years
System Price**	760 - 1100' (930)	1200-1940 (1570)	USD

** electrolysis only*
***Including power supply, system control and gas drying. Excluding grid connection, external compression, external purification and H2 storage*

Sources of data: Bertuccioli et al., 2014, NREL 2017

3.4 OPERATIONAL PROJECTS / SUPPLIERS

There are many options in the current energy market for implementing hydrogen storage in Georgia. Some corporations that specialize in electrolyzers and hydrogen storage projects include NEL, Hydrogenics, and Thyssenkrupp. The following section will outline potential technology providers.

NEL

NEL is a global, dedicated hydrogen company, delivering optimal solutions to produce, store and distribute hydrogen from renewable energy. NEL owns both alkaline and PEM technologies.

NEL has mastered hydrogen energy storage for decades through the two largest electrolyzer plants worldwide set up by Norsk Hydro. These 135 MW plants each had a production capacity of 30 000 Nm^3 of hydrogen per hour, corresponding to an annual production of more than 20 million kilos.

Proven NEL A•485 alkaline electrolyzer converting up to 2.2 MW of energy at high efficiency has contributed to these two success stories. M Series electrolyzers can produce up to 4,000 Nm^3/h of hydrogen gas. The M Series provides fast response times and production flexibility making it suitable for hydrogen generation utilizing renewable power sources, with minimal maintenance and siting

[5] Manufacturing Competitiveness Analysis for PEM and Alkaline Water Electrolysis Systems. Mark Ruth (Presenter), Ahmad Mayyas, and Maggie Mann National Renewable Energy Laboratory Fuel Cell Seminar and Energy Expo 11/08/2017

requirements. Featuring a scalable modular design that can be containerized, these systems offer solutions that are well-suited for a variety of industrial, fueling and renewable energy applications.

HYDROGENICS

Hydrogenics is a manufacturer of hydrogen generation and hydrogen fuel cell modules. The company has over 60 years of experience designing, manufacturing, building and installing industrial and commercial hydrogen systems around the globe. The company received an award by Air Liquide Canada (“Air Liquide”) to design, build and install a 20 MW electrolyzer system for a hydrogen production facility located in Canada. The facility is expected to be in commercial operation by the end of 2020, with an output of just under 3,000 tons of hydrogen annually. The 20 MW plant will use Hydrogenics’ advanced large-scale PEM electrolysis technology, offering the smallest footprint and highest power density in the industry. With best-in-class efficiency and cost-effectiveness, Hydrogenics has established itself as the market leader for multi-megawatt PEM electrolyzers to global customers, including Air Liquide. Both companies continue to see growing interest and opportunities for the deployment of large-scale electrolysis across the globe.

SIEMENS

The compact design, based on proven PEM technology, enables easy scale up for multi-MW plants, without sacrificing efficiency, response or durability. It also delivers substantially reduced plant size and costs, while improving deployment flexibility for grid balancing, energy storage and fueling applications. With over 20 MW of energy storage plants commissioned and under construction, Siemens developed an innovative PEM electrolysis system that uses wind and solar energy to produce hydrogen – SILYZER series.

A 5 MW PEM SILYZER 200 electrolyzer is operating in Hamburg, Germany. The Siemens SILYZER 200 has a modular design which makes it adaptable to specific needs, providing maximum flexibility, which important for use of renewable energy sources. The basic system consists of at least one 1.25 MW skid. Multiple basic systems can be combined into a PEM electrolysis network that delivers up to 20 MW and beyond. Depending on needs, a variety of technical options round out the complete package, including a re-cooling system, water treatment system, power grid connection, and much more. SILYZER 200, the was the first PEM electrolysis system to exceed the megawatt range. It has been commissioned in 2015 and was directly connected to 8 MW wind farm and its highly dynamic operation allows it to be operated in the overload mode. Green hydrogen is fed into the local gas network.

PEM electrolyzers in the SILYZER generation have proven experience from decades of development and optimization, which has culminated in SILYZER 300. Large-scale industrial application SILYZER 300 is the latest and most powerful product line in the double-digit megawatt class in the PEM electrolysis portfolio from Siemens.

SILYZER 300’s modular design makes the unique use of scaling effects to minimize investment costs for large-scale industrial electrolysis plants. The optimized design results in very low hydrogen production costs thanks to high plant efficiency and availability.

Flexible and dynamic smart system solutions enable customer specific, optimized configuration thanks to a high degree of design flexibility. The challenge of integrating renewable energy can be met by means of SILYZER 300’s highly dynamic mode of operation.

Technical specifications:

- Hydrogen production: 100 – 2,000 kg per hour;
- Plant efficiency: ~ 75%;
- Start-up time: < 1 minute. Dynamics: 0 – 100% in 10% / s;
- Minimum load: ≥ 5%;
- Water consumption (DI): 10 l per kg hydrogen;
- Hydrogen quality: ultra-high purity.

THYSSENKRUPP

Thyssenkrupp is a German multinational conglomerate[6] with focus on industrial engineering and steel production. The company is based in Duisburg and Essen and divided into 670 subsidiaries worldwide. It is one of the world's largest steel producers; it was ranked tenth-largest steel producer worldwide by revenue in 2015. As a globally renowned EPC specialist for electrochemical plants, Thyssenkrupp has planned, built and commissioned hundreds of electrolysis plants and installations all over the world.

At the center of Thyssenkrupp's electrolysis technologies[7] are patented large electrochemical cells for high efficiency in industrial scale hydrogen production. The principal design is well-proven in hundreds of electrochemical plants worldwide, making Thyssenkrupp the world's No. 1 supplier for electrolytic production equipment

Current discussions on water electrolysis include mainly two different methods – alkaline water electrolysis and PEM water electrolysis. While alkaline is a robust, low- Capital Expenditure (CAPEX) method, PEM has higher flexibility and low Operating Expense (OPEX). Thyssenkrupp developed their own technology that combines the best of both.

Hydrogen production needs to be as efficient and flexible as possible. Thyssenkrupp delivers both in a modular, cost-effective solution for multi-megawatt hydrogen installations. Thyssenkrupp has optimized technology and materials through decades of R&D in electrochemistry. Combined with a well-established supply chain and production facilities, they offer a cost-effective system which delivers high hydrogen quality.

OTHER LARGE OPERATIONAL PROJECTS

On January 1, 2017, a European flagship project H2FUTURE has started on. The project is for the generation of green hydrogen using electricity from renewable energy sources. It has a duration of 4.5 years. H2FUTURE is under the coordination of the utility VERBUND, the steel manufacturer Voestalpine and Siemens, a PEM electrolyzer manufacturer, a large-scale 6 MW PEM electrolysis system will be installed and operated at the Linz steel plant in Austria. The Austrian Transmission System Operator (TSO) Austrian Power Grid (APG) supports the prequalification of the electrolyzer system for the provision of ancillary services. The Netherland's research center TNO and K1-MET (Austria) will study the replicability of the experimental results on larger scales in EU28 for the steel industry.

Additionally, a Japanese consortium has launched the Fukushima Hydrogen Energy Research Field (FH2R), a renewable energy-powered 10-MW class hydrogen production unit, the largest class in the world. FH2R has been under construction since 2018 and is based in Fukushima Prefecture. The consortium consists of the New Energy and Industrial Technology Development Organization (NEDO), Toshiba Energy Systems & Solutions Corporation (Toshiba ESS), Tohoku Electric Power Co., Inc. and Iwatani Corporation.

FH2R uses renewable energy, which is subject to large fluctuations. FH2R will adjust to supply and demand in the power grid in order to maximize utilization of this energy while establishing low-cost, green hydrogen production technology. FH2R uses 20 MW of solar power generation facilities on a 180,000m2 site along with power from the grid to conduct electrolysis of water in a renewable energy-powered 10 MW-class alkaline water electrolysis hydrogen production unit. It has the capacity to produce, store, and supply up to 1,200 Nm^3 of hydrogen per hour (rated power operation).

SUPPLIER CONCLUSIONS

Siemens and Hydrogenic are the strongest hydrogen electrolyzer suppliers based on bankability and technology discussed prior.

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[6] Thyssenkrupp energy division: https://www.thyssenkrupp.com/en/products/energy-generation-and-distribution

[7] Thyssenkrupp Hydrogen technology overview: https://www.thyssenkrupp-uhde-chlorine-engineers.com/en/products/water-electrolysis-hydrogen-production

Table 2: Commercial Large-Scale Hydrogen Electrolyzer Suppliers

Commercial Large-Scale Hydrogen Electrolyzer Suppliers	Assets (B USD)	Revenues (B USD)	Market Cap (B USD)	Employees
NEL nelhydrogen.com/	.3	.06	3.4	300
HYDROGENIC hydrogenics.com/	19.7	23.6	31.2	170,000
SIEMENS new.siemens.com/	118.2	92.0	135.7	76,000
THYSSENKRUPP thyssenkrupp.com	35.7	49.5	4.9	162,000
ITM itm-power.com	.122	.006	1.3	200

3.5 PLANNED HYDROGEN PROJECTS

According to European Network of Transmission System Operators for Gas (ENTSO-g), EU gas grid operators plan up to 17 renewable power-to-gas projects by 2025 as part of efforts to cut CO_2 and keep their grids in use as the EU moves away from natural gas. The EU's formal gas transmission system operators' body ENTSO-g has included such projects in its latest draft EU 10-year network development plan, to be finalized next year. The EU's drive to cut carbon emissions has boosted renewable power output in recent years, bringing it into competition with natural gas as a fuel source.

The EU has a goal to cut its greenhouse gas emissions by at least 80% from 1990 levels by 2050 and is considering increasing this to being net-zero carbon by then. The EU's five biggest power markets -- France, Germany, Italy, Spain and the UK -- produced 315.4 TWh of renewable power for the year to end-October (2019), the latest S&P Global Platts renewables tracker showed.

Germany is considering 7.5 GW of electrical input power-to-gas plants by 2030, according to information provided to ENTSO-g. The Element Eins project, for example, involves gas TSOs Gasunie, Tennet and Thyssengas building a 100 MW electrical input power-to-gas plant in Lower Saxony, Germany. This will be one of the largest such plants in the country, according to the project description. The plant is planned online in phases starting in 2022, using North Sea wind power to produce hydrogen that can be transported to the Ruhr region, used for transport or stored underground.

Spanish gas TSO Enagas has the only "advanced" project in the list, for its Hub Baleares in the Balearic Islands, which include Mallorca. This project is planned online in 2023 and involves Enagas developing a 10 MW photovoltaic power-to-gas plant to produce green hydrogen for use by the transport sector and in the natural gas grid. The project in the draft list where the final investment decision is already taken is Jupiter 1000, which is described as the first industrial-scale power-to-gas demonstration plant in France. The EUR30 million Jupiter 1000 power-to-gas project at the port of Marseille is the first industrial scale demonstrator of its type in France that points the way to a future green hydrogen economy. Financed jointly by the EU, the French Environment and Energy Management Agency (ADEME), and the Provence-Alpes-Côte d'Azur region, Jupiter 1000 transforms surplus renewable electricity into hydrogen via electrolysis of water. The project is coordinated by GRTgaz, which owns and operates 32,000 km of underground pipelines in France.

Jupiter 1000 has a power rating of 1 MWe for electrolysis and a methanation process with carbon capture. Green hydrogen will be produced from 100% renewable energy using two electrolyzers involving different technologies. The resultant hydrogen will then be fed into the gas network. The idea is to implement the power-to-gas concept throughout France – with potential for over 15 TWh of gas produced annually by 2050."

Belgium, the Netherlands, and Germany all have serious projects in which ports are playing a major role. The target to reduce CO2 emissions in Belgium by 80% by 2050, compared to 2005 levels, inspired the ports of Antwerp and Zeebrugge – along with industrial partners Engie, Exmar, Fluxys, and WaterstofNet, plus dredging major DEME – to form the country's first body to conduct a joint study to coordinate the delivery of concrete projects that shape the production, transport, and storage of hydrogen and take steps towards a Belgian hydrogen economy. The initial 12-month phase will see the partners make a joint analysis of the entire hydrogen import and transport chain. The aim is to map the financial, technical and regulatory aspects in the logistics chain and produce a roadmap indicating the best way to transport hydrogen for various applications in the energy and chemical sector. In March this year, DEME also announced its HYPORT Duqm green hydrogen project in Oman. "The facility will significantly contribute to the decarbonization of Oman's chemical industry, as well as providing green hydrogen and/or derivatives –

such as green methanol or ammonia – to international customers in Europe," the company states, adding: "The envisaged first phase electrolyzer capacity is estimated between 250 and 500 MW, and future upscaling of the installation is foreseen."

In Germany, Port of Hamburg held a major hydrogen workshop on 29 January 2020, with senator Michael Westhagemann bringing together 24 Hamburg-based companies. "In terms of building electrolysis plants, we had to identify the level of demand. The workshop determined that 100 MW is not enough even in the medium term – demand in the port alone is much higher," Westhagemann noted. "We must establish the hydrogen economy here in Germany now and with high priority."

Finally, in the Netherlands, the Port of Rotterdam has pioneered research into green hydrogen and the power-to-gas concept, and with partners is planning to build 'the largest green hydrogen plant in Europe' with a decision expected in 2022.BP Nederland government affairs head Corné Boot explained, "The plant we have in mind must produce 45,000 tons of green hydrogen annually. The challenge is that we need a lot of green electricity – 250 MW." The plant is to produce "green" hydrogen from two electrolyzers with a total power rating of 1 MWe using renewable energy, according to the project description. The project is also to demonstrate a methanation process with carbon capture. Project partners GRTgaz and Terega plan to use data from the demonstrator's performance to decide how to design a future full-sized installation.

Eastern European TSOs are also planning demonstration power-to-gas projects as part of efforts to "green" their gas grids. A Latvian project envisages using excess power from up to 800 TWh/year produced by planned 567 MW of wind farms to produce hydrogen and possibly synthetic methane with carbon capture. These green gases would be injected into the existing natural gas grid, and potentially stored in existing or new storage facilities. Slovakia's "Gas to Future" project is focused on using electrolyzers to create hydrogen that will then be stored in existing natural gas underground storage facilities. Project partners GRTgaz and Terega plan to use data from the demonstrator's performance to decide how to design a future full-sized installation. These green gases would be injected into the existing natural gas grid, and potentially stored in existing or new storage facilities.

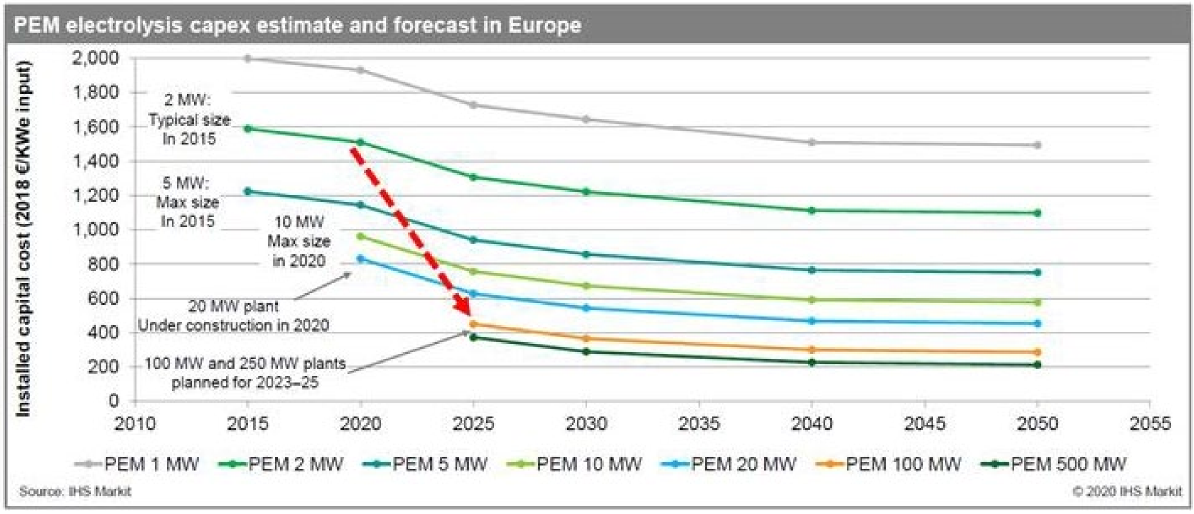
Finally, in British Columbia, ITM Power, Chiyoda Corporation, Mitsui & Co. Ltd and G&S Budd Consulting Ltd conducted a techno-economic analysis of hydrogen production. Hydrogen generation using ITM Power's state of the art PEM electrolyzer technology is paired with a means for the storage and transportation of hydrogen in the form of a liquid organic hydrogen carrier (LOHC) developed by Chiyoda Corporation called SPERA Hydrogen. The objectives behind the study where to examine the technical and economic feasibility of building centralized renewable hydrogen production plants in British Columbia for three plant sizes. These included 10 MW, 100 MW and 300 MW plants.

3.6 COST OF INSTALLATION

When determining the installation costs of electrolyzers, it is important to specify what is included in the cost and whether this is only the electrolyzer stack or the complete electrolyzer system – including not only the electrolyzer stack but also water and gas treatment, power conversion, structure housing, piping and measurement equipment (the balance of plant, or BoP). Investment costs are usually expressed in terms of costs per electrical input (€/kW_{el} or USD/kW_{el}).

Electrolyzer Costs: Smolinka, based on a 2018 study by Fraunhofer ISE and IPA estimates that the production of a membrane-electrode unit – the heart of a PEM electrolysis cell – accounts for 60% to 70% of the total cost, while pure material costs – including the expensive precious metals – account for only 30% to 40%. Furthermore, he adds that the power electronics used in large electrolyzers are currently not yet a mass product, but rather a customer-specific one-off item. Accordingly, prices are likely to fall dramatically once sales volumes increase.

Figure 1: PEM Electrolysis CAPEX Estimate and Forecast in Europe



Source: HIS Markit

In July 2020, Air Products & Chemicals announced plans for a 4 GW green hydrogen plant in Saudi Arabia, where Thyssenkrupp will supply the electrolyzers. Last month the company revealed its electrolyzer manufacturing capacity had reached 1 gigawatt, with the option to ramp up further. Norwegian firm Nel and the U.K.'s ITM Power are also developing electrolyzer gigafactories.[8]

Up to now, most electrolyzers have been manufactured in work processes involving little automation or even entirely by hand, says Smolinka. "Highly automated production, especially for cell components, as already exists for PEM fuel cells, would not be a problem technically." However, he adds, that the current low level of market demand is preventing manufacturers from making the necessary investments. Automated production is based on experience curves and economies of scale due to the following factors:

- fixed cost digression (increased utilization of different sectors in the company, such as administration, R&D, production, logistics, and distribution);
- reduction of production time (increased manpower efficiency due to learning effects);
- increased specialization (standardization, focus on core competence and product family);
- variation in resources (e.g., alternative and less expensive (raw-)materials, optimized employment of staff according to qualifications);
- improved production technologies;
- optimization of product design to simplify the production process.

The produced volume of PtG plants, and therefore the gained experience and economies of scale depend on the development of the future global demand for PtG products, which is subject to climate and policy measures (e.g., carbon taxes, the scope of government R&D, subsidies, and market introduction programs) and economic factors (e.g., economic growth).

The investment costs for a PEM electrolyzer in (Walker et al., 2016) are derived from data provided by industrial partners. They are assumed to be about 1,500 $/kW (~ 1,130 €/kW) for a 5 MW electrolyzer and about 1,250 $/kW (~940 €/kW) for a 30 MW electrolyzer.

According to information of the (Energieinstitut an der JKU Linz, 2018) from different projects, which are based on requests in the year 2017, the investment costs for alkaline electrolyzers are in the range of about 600 – 2,500 €/kW at a power of about 0.5 – 2.5 MW. For PEM electrolyzers the costs are about 1,600 – 2,000 €/kW for a rated power of 0.5 – 2 MW.

The share of investment costs of the electrolyzer stack in the total electrolyzer system costs is not often discussed. Apart from the earlier mentioned estimate of (Steinmüller et al., 2014) where the stack costs approximately 50% of the total, other estimates are given by (Hofstetter et al., 2014) and

[8] Source: GreenTech Media, July 2020, available at https://www.greentechmedia.com/articles/read/us-firm-unveils-worlds-largest-green-hydrogen-project

(Noack et al., 2014) where the stack is estimated to cost about 30% and 32% of the total investment costs, respectively.

In order to evaluate the economic feasibility of PtG plants, the efficiency of the electrolyzer (system), as well as the lifetime of the electrolyzer (stack) and operating costs, are also required.

Within STORE&GO, two demonstration sites use an alkaline electrolyzer. The plant in Italy reports investment costs of roughly 1,400 €/kW (200 kW), which is thus in the same range as literature sources suggest. For the German demonstration plant investment costs of the electrolyzer are currently unknown. The PEM electrolyzer system in the Swiss demonstration site (350 kW, bought in 2014) was estimated to cost around 951,395 CHF (~€808,686), which equals to 2718 CHF/kW (~2311 €/kW). This price includes the electrolyzer stack, rectifier, grid connection, control system, drying system, piping, measurement equipment and water treatment and the investment costs are indeed almost twice as high as those of an alkaline electrolyzer.

Market players are of course working to bring down investment costs. An example of this is the joint venture between ITM Power and Linde, which plans to open a semi-automated factory in Sheffield, U.K., this year to produce 1 GW of electrolysis capacity per year, primarily for multi-megawatt projects, such as the one in Cologne. Other well-known companies have also announced major projects and are expanding production. NEL, for instance, is currently gearing up for a 20 MW project in Denmark, and Hydrogenics is preparing to launch a similar-sized project in Canada. Alongside project size, stack performance is also improving.

Low cost high-capacity electrolysis system is a key technology that can support greater deployment of zero-carbon hydrogen for a variety of applications and represents a technology that can potentially facilitate integration of greater renewable electricity sources.

Strategic Analysis Inc. National Renewable Energy Laboratory (NREL) data[9] estimated the uninstalled PEM electrolysis system cost to be around $940/kW (in 2012 dollars). Their estimate for future forecourt that can produce up to 1,500 kg-H2 per day is $450/kW. In this report, authors also note the potential cost reduction of huge central PEM plant that can produce up to 50,000 kg-H2 per day.

Hydrogenics estimated that capital cost of the future central PEM plant could reach as low as $400/kW. Thomas (2018), as part of the cost analysis done for Hydrogenics, estimated the price of a MW-scale PEM electrolysis system to be around $1,000/kW by 2030, and $550/kW by 2050. This price, however, can be reduced to $700/kW and $385/kW for multi-MW system in 2030 and 2050, respectively.

3.7 COST OF OPERATION

Electricity costs are the largest contributor to the operating cost of electrolytic hydrogen production, regardless of system size. Other operational costs depend strongly on lifetime and accepted efficiency drop. An electrolyzer is unlikely to break down but reduces in efficiency until the point that investing in a new electrolyzer stack becomes beneficial[10]. Reports[11] that alkaline electrolyzers need revision every 7 – 12 years for some components but that other components last for 20 years and do not need replacement. The lifetime is reported to be 90,000 hours and no further improvements are expected. For PEM electrolyzers the lifetime is reported to be only 20,000 hours but it is stated that the lifetime improved significantly over the last decade and further improvements up to 60,000 hours are expected for the next 10 – 20 years. Bertuccioli writes that leading alkaline and PEM manufacturers claim stack efficiencies of 90,000 and 60,000 operating hours respectively, meaning that the expected PEM lifetime improvements of Smolinka were already reached 3 instead of 10 – 20 years later. In 2017, Siemens reported a lifetime of at least 80,000 hours for their SILYZER 200 PEM electrolyzer, indicating an even further improvement. (Nel,

Cost of operation of a 2.5 MW NEL PEM electrolyzer has been evaluated by the manufacturer as 0.5% of the CAPEX per year

(i. e 0.5%x3100= 15,500 USD/yr.)

[9] STI.GOVTechnicalReport: Final Report: Hydrogen Production Pathways Cost Analysis (2013 – 2016)
[10] Bertuccioli et al., 2014
[11] Smolinka et al., 2011

2018) states that cell stack replacement for their alkaline electrolyzers is typically needed after 8 – 10 years.

Several literature sources estimate the yearly operational costs of electrolyzers. Carr[12] used an estimate of 4% of investment costs for the yearly operational costs based on several literature sources without indicating a specific type of electrolyzer. Greiner[13] also uses operational costs of 4% of investment costs in their calculations, assuming an alkaline electrolyzer is used. Hofstetter [14] accounts for operational costs of 2% of investment costs based on several literature sources and assuming the use of an alkaline electrolyzer. Ulleberg[15]also assume that the yearly operational costs are 2% of investment costs for an alkaline electrolyzer. Bertuccioli estimates the operational costs based on figures provided by manufacturers and found that these are in the range of 2 – 5% of investment costs per year, without a distinction between alkaline and PEM electrolyzers. The authors state that operational costs differ by plant size and become lower for larger plants. For a smaller plant of about 1 MW they estimate operational costs of 5% of CAPEX per year while this would reduce to 2% for a 10 MW plant.

3.8 FLEXIBILITY TO RAMP UP OR DOWN

The electrolyzer systems used to produce hydrogen can be cycled up and down rapidly as a flexible load, providing grid services such as frequency regulation. The performance of alkaline and PEM electrolyzer technologies differs from this point of view. In general, alkaline electrolyzers offer less flexibility as compared to PEM electrolyzers, as shown in Table below.

Table 3: Electrolyzer Flexibility Characteristics

	Alkaline Electrolyzer	PEM Electrolyzer
Load range	15-100 % nominal load	0-160 % nominal load
Start up	1-10 minutes	1 second - 5 minutes
Ramp up	0.2-20 % per second	100 % per second
Ramp down	0.2-20 % per second	100 % per second
Shutdown	1-10 minutes	Seconds

Based on experimental findings, electrolyzer systems with balance of plant are observed to have a high level of controllability and hence can add flexibility to the grid from the demand side. Researchers at the NREL have developed the Stack Test Bed (STB) research facility, where each component of the electrolyzer balance of a plant can be controlled. The custom control system for the STB allows the demonstration of the full capability of electrolyzers and components that constitute the balance of the plant. The STB includes a de-ionized water system, heat exchangers, power rectifiers, pumps, phase separators, desiccant beds, and process connections for both hydrogen and oxygen.

Researchers conclude that controllable loads, such as electrolyzers, provide flexibility in the electric grids and hence help to meet the challenges associated with renewable energy sources, given their variability and uncertainty.

[12] Carr et al., 2014
[13] Greiner et al., 2007
[14] Hofstetter et al., 2014
[15] Ulleberg et al., 2010

4. IMPLEMENTATION IN GEORGIA

The most realistic option for Georgia to enter the EU Hydrogen economy is to produce green hydrogen from Georgia's excess hydropower generation (spilled hydro reached 956,000 MWh in 2019). This green hydrogen should be injected into the Samgori South Dome Underground Gas Storage outside of Tbilisi (under construction, planned for commission in 2024).

Injection into a gas storage and its further supply to the national grid is the best potential way to implement green hydrogen in Georgia. Hydrogen pressure from both alkaline and PEM electrolyzers is 30 bars; pressure in the gas storage is 25 bars, and the 5-bar difference is not a major hurdle to overcome for injection.

There are two possible locations for a hydrogen processing plant: 1) in the vicinity of a potential planned PV plant and delivery of the produced hydrogen to the gas storage through a pipeline or, 2) nearby the Samgori South Dome Underground Gas Storage. Electrolyzers next to Samgori South Dome Underground Storage can offtake excess summer power (from HPP generation) via the national grid.

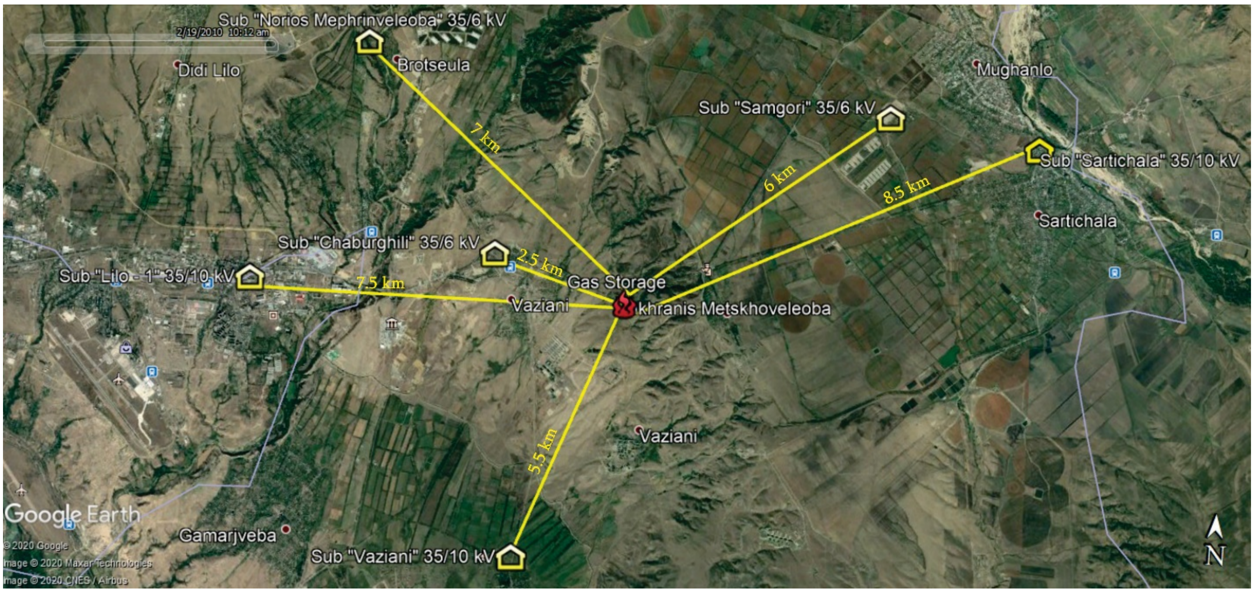
There are pros and cons to each location. The first location allows to feed the electrolyzers with DC directly from the PV station, with no need for inverters and so to reduce the cost of both PV station (if it is dedicated only for hydrogen production) and the electrolyzer. In this case produced hydrogen shall be supplied to the gas storage through a 25km long pipeline.

However, there are many concerns with pipeline transmission of hydrogen over long distances, including: potential for hydrogen embrittlement in the steel pipe and in the welds if used for pipeline construction and the need to prevent hydrogen permeation and leakage from the pipeline. As to the alternative PE pipes, polyethylene with raised crack resistance (PE100-RC) was selected as a potential piping material for hydrogen and special study which considered safety and material aspects, as well as maintenance issues, has been done by the manufacturer. Although the study showed that such pipes can be used, but as there is little experience with the combination of the PE piping material and hydrogen gas-some doubts remain about reliability.

5. OTHER IMPLEMENTATION CONSIDERATIONS

5.1 GRID INTERCONNECTION

A 35 kV EnergoPro substation is at 2.6 km distance from the planed gas storage (Mukhranis Metskhoveleoba). An additional 110 kV substation is planned on-site at the gas storage, thus no problems with grid connection are expected.



5.2 WATER AVAILABILITY

Although Georgia is abundant in water resources there are serious problems with water supply in certain regions, specifically in the Gardabani district, in the vicinity of the planned project site. The region is mountainous, with limited underground and surface water resources, summer is hot and water demand is high. The problem solving of the water supply of this region (external Kakheti) has been started in the 80s of the past century, but due to the financial and source-related difficulties it has not yet been completed. Now, the Gardabani Water Supply Project is being implemented by the United Water Supply Company of Georgia Ltd (UWSCG). Reservoirs of potable water will be filled with water extracted from the bore well (for which the remaining infrastructure is to be arranged) as well as from underground horizontal drainages through collecting pipes. During spring and autumn seasons (when there is plenty of water) only horizontal drainages and collecting pipes will be used and electricity consumption will be saved. In summer, a bore well will also be used for filling reservoirs.

For the first stage of the proposed project, the electrolyzers would produce 1.25 x 10^8 Nm^3 i.e. 11,250 tons of hydrogen per year. This requires about 11,000-12,000 m^3 of water per year. This is extracted from the above rehabilitated water grid, and a booster pump might be needed. Further expansion and increase of water intake is feasible given the current supply.

5.3 SOURCE OF RENEWABLE ENERGY / LAND AVAILABILITY

Electrolyzers next to Samgori South Dome Underground Storage can offtake excess summer power (from Hydro Power Plant (HPP) generation) via the national grid. Georgia spills 956,000 MWh of energy annually (11% of energy generation) and hydropower resources ramp down 25% for 2 months in the summer. This is the most convenient and economic method to improve Georgia's energy economy.

The primary drivers of cost for green hydrogen are 1. Cost of renewable energy, and 2. Utilization of electrolyzers. Since the renewable energy supply is essentially free from spilled hydro, Georgia should look to maximize the utilization of their planned electrolyzers by maximizing time under power. This leads to another option: an additional renewable energy source, such as a solar PV facility, dedicated to feeding electrolyzers directly with DC. This avoids losses from transmission's DC to AC conversion at the generation site and vice-versa at the electrolysis one. Assuming electricity consumption for hydrogen production is about 5.4 kWh/Nm^3, electricity needed to generate the above hydrogen quantity, needed to substitute 5% of the imported natural gas. i.e. $1.25x10^8$ Nm^3 (or with correction with account to Wobbe) $1.27x10^8$ Nm^3 is about 680,000 kWh electricity per year. For such a PV power station, with an efficiency factor of solar energy to electricity at about 17%, this translates to total solar energy about 4 billion kWh. Assuming the solar irradiation in Eastern Georgia is 1400 kWh per square meter, this would require 287 hectares of land (4 billion kWh/1400 kWh/m2 = 287 hectares). This rough estimate requires further analysis, but is a feasible option to increase hydrogen production and lower overall cost.

5.4 GAS PIPELINE INTERCONNECTIONS

Both sites, near the solar or near the National Gas Storage, are considered possible electrolyzers plant locations and are connected to the national natural gas network. Injection of the green hydrogen into gas storage potentially can provide its even distribution over the country within blend with the natural gas. Certainly, it will start with small ratio, increasing in parallel with hydrogen production.

Injection of the green hydrogen into the gas storage provides a win-win situation for the renewable energy generators and gas consumers. The green energy generating facilities get in this way a (more or less) stable purchaser of the electricity at any time and in any quantities. Consumers get fuel that is not only carbon neutral but also has better combustion characteristics, providing perfect combustion, with lower CO and NOx emissions, which is true for both industrial and residential consumers. Sure, each consumer's case should be considered separately, one-by-one.

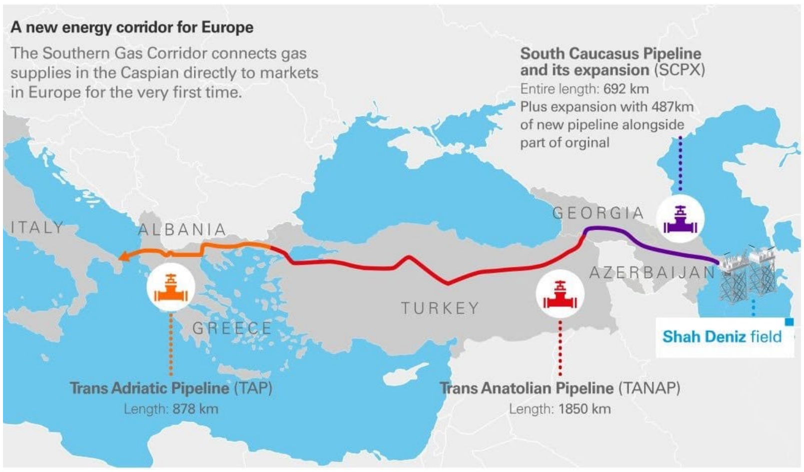
5.5 POTENTIAL USES FOR BLENDED GAS

Blended gas can be used for export, domestic energy generation, or energy storage.

Storage – Storage is a simple and safe option.

Export - Exporting hydrogen is cheapest as a blend, starting with a low hydrogen concentration and slowing increasing it. The end user can use the blend for powering systems or separate the hydrogen out for other applications. Possibilities of hydrogen export can be a game changer, providing participation of important partners. The technology and profit margins to export green hydrogen makes production feasible and even very profitable. The cheapest way to export hydrogen is in a blend, where exporting can start with a low hydrogen content and slowly increase the concentration.

An example of Australia's blended gas export is strongly inspiring. Australian Renewable Energy Agency (ARENA) is planning large scale (about 1.7 billion USD) export of green hydrogen to Japan, China, South Korea and Singapore. The membrane technology developed by CSIRO paves the way for bulk hydrogen to be transported as ammonia using existing infrastructure and then reconverted into hydrogen at the point of use.



TAP to TANAP to SCPX pipelines ***Source: Turkish Coalition***

Georgia has an opportunity to do something similar to Australia. Georgia has massive pipelines supplying natural gas from Azerbaijan to Europe, including the South Caucasus Pipeline (SCP), the Trans Anatolian Pipeline (TANAP), and the Trans Adriatic Pipeline (TAP). Green hydrogen can be supplied blended with natural gas and recovered from the blend using membranes, for example, Air Liquide Advanced Separations' (ALaS) hollow fiber membranes. The ALaS membranes operate based on selective permeation. Each membrane is composed of millions of polymeric hollow fibers similar in size to the diameter of a human hair. The "fast gases," or gases with a higher permeation rate, first hydrogen permeate through the membrane into the hollow interior and are channeled into the permeate stream. Simultaneously, the “slower gases” flow around the fibers and into the residue stream. As a result, the fibers can selectively separate a hydrogen from methane and other slower gases.

5.6 REGULATORY FRAMEWORK CONSIDERATIONS

Hydrogen can reduce Georgia’s CO_2 emissions. Consider the impact of using 5% blend instead of pure NG. Georgia annually imports about 2.5 billion Nm^3 natural gas. 5% of this amount is 125,000,000 Nm^3 hydrogen or ~11.5 thousand tones. Substitution of 125,000,000 Nm^3 natural gas with hydrogen will permit to avoid emission of 245,000 tons of CO_2. The target electricity sources are green energy sources, hydro, wind and mainly solar.

For the further development of the introduction of hydrogen, a regulatory framework is needed regarding production, transportation and use, as well as a blueprint for the hydrogen industry in Georgia. All types of renewable energy sources (hydro, solar, wind, biomass) should be considered in terms of hydrogen production, as well as all areas of its beneficial use, including existing export markets.

Potential sources of financing shall be accounted for, including green grants, carbon credits, and private investments. New hydrogen technologies are developing quickly and can change all considerations of low economic profitability, for example, recent developments of plasma gasification of plastic waste or photo-electro-chemical water splitting or concentrated solar power.

One more action which is needed is the establishment of a partnership with Hydrogen Council. The Hydrogen Council is a global initiative of leading energy, transport and industry companies with a united vision and long-term ambition for hydrogen to foster the energy transition.

As its goal is to accelerate investments in the development and commercialization of the hydrogen sector through appropriate policies and support schemes, its cooperation with Georgia with its potentially abundant sources of green energy and, besides, the state's existence on the fossil fuel replacement map by renewable hydrogen, can provide various advantages, at least access to hot information on the latest developments and technologies.

6. CONCLUSIONS

Hydrogen energy storage technology is gaining unprecedented momentum and support from governments and industries all over the world. This is largely because hydrogen is a viable and efficient tool for supporting carbon-free power by addressing the weaknesses and variability of renewable energy.

Hydrogen energy storage is beneficial for Georgia because it:

- Improves energy independence by increasing energy supply via natural gas blend
- Mitigates carbon emissions
- Improves hydrogen/natural gas blend export options to neighboring countries and European markets using existing natural gas pipelines
- Increase energy efficiency in generation (yield more energy from existing renewable energy) from Georgia's large-scale green power generation
- Encourage future development of Georgian "green" energy generation
- Stabilizes electricity price by increasing flexible energy storage options

The primary recommendation is to inject hydrogen into the Samgori South Dome Underground Gas Storage outside of Tbilisi (under construction, planned for commission in 2024). This hydrogen is best utilized to supplement natural gas supply.

Table 4: Project Implementation Considerations

Implementation Considerations	
Grid interconnection	A 35 kV EnergoPro substation is at 2.6 km distance from the gas storage, but another one, a 110kV substation is planned at the gas storage, thus no problems with grid connection are expected.
Water availability	Georgia could produce 11250 tons of hydrogen per year, requiring11,000 – 12,000m^3 of water per year. recently rehabilitated water grid is connected
Land for large scale solar	If a solar PV plant generating 700 million kWh were indicated, it would require 300 hectares of land needed, the land between "Mukhranis Metskhveleoba" and Vaziani is available government land
Gas pipeline interconnections	Planned Underground Gas Storage will be connected to the National Gas Transmission Network
Destination of blended gas for export, domestic use, or storage	• Inject blend into Samgori South Dome Underground Gas Storage • Distribute blend domestically • Reduce dependency on Georgia's imports of natural gas (2.58 billion m^3 in 2019)
Other implementation consideration	• Needs regulatory framework • Should consider all types of renewable energy sources (hydro, solar, wind, biomass) • Export markets to EU are growing (long term usage)

Table 5: Technology Provider Considerations for the Project

Technology Provider Considerations	
Commercial maturity	Two commercially mature technologies of hydrogen production by electrolysis are suitable for Georgia (alkaline electrolysis and PEM)
Bankability of technology provider	Both large scale firms and smaller specialty firms market electrolyzers, which may be considered bankable under a project financing scenario
Planned projects	There are many comparable planned projects. EU plans 17 renewable PtG projects by 2025. The EU's gas transmission system has included such projects in its latest draft EU 10-year network development plan, to be finalized next year.
Cost of installation	Cost of installation is projected to be $700/kW in the optimistic scenario
Cost of operation	About $0.30 USD/Nm^3 at electricity price $0.05 USD/kWh
Flexibility to ramp up or down	Alkaline electrolyzers Start-up 1-10 min, rump-up and down 0.2-20% per sec, shutdown 1-10 min. PEM electrolyzers startup 1 sec-5 min ramp-up and down-100% per second, shutdown-seconds.

While existing hydrogen production technologies are sufficiently mature, they are still improving. Most recently, the European Commission has sent the European Green Deal on its way and a preliminary version of its anticipated hydrogen strategy has been leaked. The plan is ambitious as the EU seeks to assert tech leadership in green hydrogen through coordinated efforts across the value chain.

In Georgia, we must act as soon as possible, with the aim to identify ourselves on the green power-to-hydrogen production and implementation map and begin to explore the opportunity for international cooperation in this field.

ANNEX A: ARTICLE ON HYDROGEN STORAGE IN ASIA

It's clean, powerful and available: Are you ready for hydrogen energy?

Asian Development Bank's Yongping Zhai discusses how renewable energy, such as hydropower, could be key to helping developing countries unlock the potential of hydrogen.

The Nam Theun 2 Hydroelectric Plant in Lao PDR. Image: Asian Development Bank, CC BY-SA 2.0 via IFPRI Flickr

By Yongping Zhai

May 14, 2019

As the world responds to the challenges of climate change, energy systems are evolving, and evolving fast. The past 10 years have seen the rise (and dramatic cost reduction) of renewable energy such as wind and solar, to the extent that they are no longer considered alternative energy. They have become mainstream energy sources. Now, what will be the "next big thing" as the world shifts to a low carbon future? So far, indications point towards hydrogen energy.

ENERGY

In post-COVID Asia, countries should develop their own renewable energy capabilities.

Read now

The combustion of hydrogen with oxygen produces water as its only byproduct, a better result than fossil fuels, such as coal or natural gas, which produce carbon dioxide (CO_2) and other pollutants such as sulfur dioxide and nitrogen oxide. Hydrogen can be used directly as fuel in power generation and other heat applications, and can be blended with natural gas in pipeline networks.

In particular, hydrogen used with fuel cells (a device that converts chemical potential energy into electrical energy) is most promising for heavy duty transport applications (like trucks, rail, and ships) and industrial applications which require both electricity and heat.

The Hydrogen Council, a global initiative of leading energy, transport and industry companies, envisages that by 2050 hydrogen may power more than 400 million passenger cars worldwide and up to 20 million trucks and five million buses. It expects hydrogen technologies to provide 18 per cent of the world's total energy needs by that time, with the annual sales generated from the hydrogen fuel cell market reaching $2.5 trillion and creating 30 million jobs globally. The broader "hydrogen economy" could be much larger.

However, before this can happen, energy industries have to answer one crucial question: Where will all this hydrogen be coming from?

Currently more than 95 per cent of the world's hydrogen is produced from fossil fuels such as natural gas via the steam methane reforming process. Unfortunately, this is a carbon intensive process, with emissions of seven kilograms (kg) of CO2 on average when producing one kg of hydrogen.

The steam methane reforming process can be coupled with carbon capture and storage technology to cut CO2 emissions but the cost of producing hydrogen carbon capture and storage is about 45 per cent higher. And the cost of CO2 avoidance is also high, at about €70 per ton. This is not financially viable and would require technological breakthroughs in carbon capture and storage to become a sustainable solution.

As an alternative, hydrogen can also be produced by electrolysis, which uses electricity to split water into hydrogen and oxygen, using zero-carbon and low-cost renewable energy. Hydrogen produced from renewable electricity also could facilitate the integration of high levels of variable renewable energy into the energy system by using surplus renewable output for electrolysis, storing hydrogen for long periods of time, then using hydrogen to produce electricity in fuel cells.

This overall cycle is somewhat similar to pumped hydropower storage in terms of the ability for long-term storage and time-shifting of renewable output. The oxygen produced by electrolysis also has market value for industrial and medical applications (it is important to keep in mind that for each kg of hydrogen produced there are eight kilograms of oxygen produced). Developing countries can maximize the development of their renewable energy potential by participating in the global hydrogen economy.

Developing countries would be the big winners from a "hydrogen economy"

The world needs pioneers who are willing to take the lead and bear the cost of "first movers" for hydrogen energy, just like Germany did for solar photovoltaic technology. In Japan, as part of its "3E+S" (energy security, economic efficiency and environmental protection, plus safety) energy policy, the government formulated the world's first 21st century hydrogen strategy in December 2017, with the aim of establishing a "hydrogen economy" by 2050.

The hydrogen economy is premised on the use of hydrogen as a fuel, particularly for electricity production and hydrogen vehicles; and using hydrogen for long-term energy storage and for the long-distance transportation of low-carbon energy. The key to achieving such a hydrogen economy is to bring the cost of hydrogen down from more than $10 per kg to about $2 per kg, which would then be competitive with natural gas.

Developing countries would be the big winners from the move toward a hydrogen economy. First, on the supply side, developing countries could tap their renewable energy resources to produce hydrogen and export it to other countries, as is already done with liquefied natural gas.

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For example, renewable energy (including hydropower, wind, biomass and solar) in the Lao People's Democratic Republic (Lao PDR) may represent a potential of about 50 GW. The country and its neighbors need about 20 GW to meet their electricity demand, so the unused renewable energy potential could be used to produce hydrogen with zero CO2 emissions. So potentially, Lao PDR could become a significant exporter of renewable energy through the hydrogen supply chain.

Second, on the demand side, developing countries could start using hydrogen technologies in specific areas. For example, fuel cell vehicles can be charged fully with hydrogen within five minutes for a driving range of 500 kilometers and more, with zero CO2, sulfur dioxide or nitrogen oxide emissions.

How to avoid 30 million tons of CO2 emissions

In recent years, due to transmission bottlenecks, the People's Republic of China has been curtailing its renewable energy (wind, solar and hydro) power generation by about 100 terawatt hours annually. This curtailed energy output could be used to produce about 1.5 million tons of hydrogen, enough to power about 10 million hydrogen-based fuel cell cars for one year. This avoids about 30 million tons of CO2 emissions. In line with national air quality objectives, ADB has supported fuel cell buses in Zhangjiakou City in Hebei Province, the site of next Winter Olympic Games.

What are the next steps? Development finance institutions such as ADB can do more by supporting its members in five specific ways:

1. Share information on hydrogen energy so policy makers and industry players are aware of the latest trends and technologies
2. Help governments to develop a strategy, roadmap and regulatory framework for hydrogen energy development
3. Enhance the carbon trading platform to cover the extra cost of fossil fuel-based hydrogen production with carbon capture and storage
4. Pilot hydrogen technologies and business models for scaling up
5. Finance hydrogen energy projects, including production, transportation and distribution infrastructure, as well as market applications.

Adopting these initiatives will make developing countries “hydrogen ready”. For the good of the environment and the development of new and dynamic industries, the world is undergoing a low carbon energy transformation. No country should be left behind.

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