equinor

Memo

16 December 2019

To	Gassnova, attention Aslak Viumdal
Copy	Norwegian Ministry of Petroleum and Energy, attention Bjørn Haugstad
From	Steinar Eikaas, Vice President, Equinor New Energy Solutions
Subject	Equinor's Low Carbon Solutions strategy in the context of Northern Lights

1 Background and Purpose of Paper

The Northern Lights project delivered the "Plan for long-term use of the Northern Lights infrastructure" (RE-PM673-00078) to Gassnova 3.12.19. In the dialogue leading up to that delivery, the Ministry of Petroleum and Energy (MPE) signalled an interest in receiving the partner companies' perspectives on two additional themes:

- In which way is Northern Lights strategically valuable for the partners?
- What are the partners' perspectives on hydrogen, and how does Northern Lights enable that development?

Since these questions are more for the partners than the project to answer, the Northern Lights project agreed with Gassnova that these two questions would not be addressed in the plan. Instead, the project has communicated to each of the three partner companies that they are invited to optionally submit individual memos addressing these two questions. The memos can be sent directly to Gassnova, and they can be made confidential in relation to the other partners if so wished. This memo provides Equinor's response to the two questions.

The purpose of this paper is to demonstrate the rationale for 1) implementing Equinor's Low Carbon Solutions (LCS) strategy; as well as for 2) realising the Northern Lights CCS project in the context of the LCS strategy. While LCS here refers specifically to hydrogen and CCS, it is important to recognize that Equinor also has many other low carbon initiatives, such as growth in renewables and reduction of emissions in own operations.
The paper aims to explain how the Northern Lights project is of strategic relevance for Equinor and how it can contribute to developing a CCS and low carbon hydrogen market in Europe. The paper also outlines plans for realising Equinor's LCS strategy and provides an overview of Equinor's LCS project portfolio. Given that the perspectives on opportunities and maturation of relevant CCS markets have been described in detail in the previous reports "Plan for long-term use of the Northern Lights infrastructure" and "Northern Lights contribution to benefit realisation", the main focus is here on the hydrogen and decarbonized gas part of Equinor's strategic agenda.

2 Political context

In the past decade, the EU's energy policy has become increasingly more focused on sustainability and climate change mitigation. The EU has long been a global leader for climate action, a leadership position that was in 2015 reaffirmed with the Paris Agreement. The EU now wants to take a step further with regard to its long-term climate commitments. The newly-elected President of the European Commission Ursula von der Leyen has pledged to work towards a climate-neutrality by 2050 target for the EU. She aims to set the framework conditions for a European Green Deal – a set of legislative acts to enable the achievement of a climate-neutral Europe by mid-century, which should be published in March 2020. The European institutions are currently negotiating whether a climate-neutrality target could become the EU's commitment to the Paris Agreement during the COP26 next year. The political pressure for GHG emissions reduction in line with the EU's commitments is therefore a key driving force for decarbonisation of energy supply and the energy intensive industries, which account for the bulk of EU's emissions.

In particular, the EU's climate considerations affect Equinor's key markets for gas, including the UK, Germany, Belgium, the Netherlands, France among others. A number of individual states across Europe have already committed to significant emission reduction targets. In 2018, the Dutch government presented a Climate Act that calls for a 49% reduction in greenhouse gas emissions by 2030, compared to 1990 levels, and a 95% reduction by 2050. In 2019, the UK became one of the first major economies in the world to sign into law a target that will require bringing all greenhouse gas (GHG) emissions to net-zero by 2050. In the same vein, France has also pledged to carbon-neutrality by 2050. Germany is under growing pressure to set ambitious GHG emission reduction pledges. Given the size of its economy, significant presence of heavy-industry as well as the exposure to trade, the German government is taking smaller and more cautious steps when it comes to climate commitments. Nevertheless, Germany has perhaps the most ambitious renewable energy policy in Europe, which needs to be backed up with solutions for dispatchable clean energy to manage the intermittency – an issue that the German government is gradually coming to terms with. Energy and climate have become a very politicised topic in Europe, while the societal pressure for delivering on the set mid-term goals and promised long-term pledges is only increasing. It is likely that future consumer choices for energy, products, services and lifestyle in general will be considerably impacted by climate considerations, thereby strengthening the rationale for change on the supply side.

Early government support for effective emission mitigation tools and creation of low carbon markets for energy and products has been an important issue in many European countries. For instance, the UK government has recognized the use of large-scale hydrogen production with CCS for various sectors (power, industry, maritime, heating). It has recently announced GBP250 MN in funding to decarbonize the steel industry, GBP 100MN to mature low-carbon hydrogen as part of a wider set of policy milestones, and GBP 315MN to help high energy user industries cut their emissions. The Committee on Climate Change, the advisory body to UK government, concluded that hydrogen and CCS is key to meeting the UK's net-zero target. In May 2019, Germany's Chancellor Angela Merkel has famously said that CCS will be necessary to realise the long-term carbon-neutrality commitments. In addition, the German government has recently stated that green and blue hydrogen with CCS is needed to meet German emissions targets. The Netherlands and Sweden are taking concrete steps to support early-stage CCS projects. Similarly, the EU is under pressure to create an enabling framework for significant emissions reduction before 2050, which implies that promising technologies must be developed in the upcoming decade to be scaled up and applied commercially leading up to 2050. At the same time, the European industries are under increasing pressure from the EU ETS, which introduces ever-more stringent carbon price and a reduction of free allowances that were originally created to mitigate carbon leakage. The next five years of the new European Commission's mandate will revolve around the existing climate momentum to design policies that will prove decisive for Europe's energy sector as well as Europe's competitiveness.

Globally, countries such as Japan and South Korea have expressed interest in developing a domestic hydrogen economy. Japan is actively pursuing an import strategy sourcing low-carbon hydrogen from several sources. South Korea has announced that it intends to invest the equivalent of USD 4 billion to construct 25 hydrogen production plants and 700km of pipelines by 2030. The Quest Project, in Canada, has been in operations for 4 years, producing low-carbon hydrogen from natural gas to help decarbonize Shell's oil sands operations, and has sequestered 4MT of CO2 to date. These are just a few examples of the global initiatives related to hydrogen and CCS and unlike conventional renewable energy sources such as onshore solar/wind, Equinor is one of the few companies with the competence to deliver these solutions and is strategically positioned for the European market. This presents a window of opportunity for the oil & gas industry to demonstrate that LCS have a role to play in future energy systems. However, there is a sense of urgency as the policies that will take Europe to net-zero are currently being developed and it is up to the oil & gas industry to demonstrate the viability of decarbonised gas within the next 5-6 years if natural gas is to play a role in future energy systems.

3 Strategic Rationale for Low Carbon Solutions

Equinor has put extensive focus on reducing carbon emissions from the existing operations and developing new business opportunities with the lowest possible carbon footprint. In the context of a tightening legislative framework for fossil-derived energy in particular in Europe – our key gas market – Equinor is considering new options, which would significantly diminish the CO2 footprint of the energy supplied while retaining a profitable market position.

Equinor's Low-Carbon Solutions (LCS) strategy focuses on the transport and storage of captured CO2 (CCS) and hydrogen derived from natural gas with CCS. It encompasses several, mostly EU-based, CCS and hydrogen projects, which are described in section 5.2. It is important to highlight that the implementation of the LCS strategy is conditional on the policy success of the EU and Norway's long-term climate commitments and projections as well as on an enabling policy framework. Policy advocacy, market development for low carbon products and viable business models as well as confidence building have therefore become the areas of priority for Equinor's LCS realisation. Equinor has adopted a comprehensive approach to developing LCS. Listed below are five strategic beliefs that form a major part of the strategic rationale for developing LCS:

Net-Zero Challenge: A net-zero target implies that all parts of the energy mix need decarbonized alternatives. This includes low-carbon electricity, hydrogen, biofuels, and CCS targeting hard-to-decarbonize sectors.

Shaping the Future of Energy: In a net-zero scenario there will be limited room for unabated fossil-fuel energy. Developing a market for LCS is therefore essential to the continued profitability of Equinor's core oil & gas business. By providing LCS, including negative emissions (e.g. via bioenergy with CCS (BECCS)), Equinor secures the market for its oil and gas volumes, its license to operate, its continued access to capital, and its ability to continue to attract and retain talent. This is also about entering new market segments and developing business opportunities for Equinor. Self-preservation is ensured by shaping the future of energy.

Government Action: LCS will not be able to compete with conventional unabated methods without active policies in the transition period towards sustainable CO2 pricing or direct regulation. By adopting net-zero policies governments will provide incentives for low-carbon energy or restrict the use of unabated energy. The burden of proof is on the oil & gas industry to show that LCS are scalable, cost-effective options that can meet net-zero climate targets and that they can do so safely.

Carbon Capture and Storage for Industry: CCS is needed for decarbonizing fossil fuels but will also be one of the principle tools to reduce industrial emissions (e.g. concrete and steel production). Developing clean solutions for the energy-intensive industry is a crucial business development choice in order to establish CCS as a cost-effective and preferred mitigation measure for reducing emissions in various sectors. By providing CCS services to industry, the oil and gas sector can build trust in CCS and thereby enable its application for the decarbonization of natural gas. Hydrogen solutions based on CCS can create the anchor for decarbonization in industrial clusters.

Market Build for low carbon hydrogen: Today 2400 TWh of hydrogen is produced globally, however, nearly all volumes are used for the chemical sector and refineries. The use of low carbon hydrogen for the energy sector is a new market with different business models, commercial arrangements and policies. Furthermore, the use of hydrogen in power, heat and industrial processes needs to be developed via a step-wise approach. Therefore, the first LCS projects will have to be market build projects, creating a precedent for an enabling policy and legislative framework.

Assuming that decarbonisation targets and policies become ever-more stringent in the context of the EU and other developed markets, policy makers will be under increasing pressure to design enabling legislative and market policies for low carbon energy and products. In the EU, low carbon hydrogen and CCS technologies can benefit from the existing large-scale infrastructure by converting the existing natural gas facilities into a hydrogen system. It is important to note that unabated natural gas and upstream gas assets is at risk of becoming stranded assets under this scenario. While this might seem like an implausible scenario given the EU's dependence on fossil fuels today, one should take note that policies can be a considerable factor for changing market conditions. In November 2019, the European Investment Bank voted to revise its lending policy by which it would phase out financial support for unabated fossil fuel-based projects, including natural gas, starting from 2021. This example illustrates the EU's determination to lead the transition towards a low carbon economy.

Building an LCS strategy now demonstrates a commitment from the supplier side to decarbonise the gas value chain towards 2050. This would in turn have a positive effect on the demand side as it would underscore the viability of gas-based low carbon solutions as being consistent with a carbon-neutral scenario for 2050. This improves the marketability of natural gas today before LCS have been implemented.

4 Roadmap to commercial deployment of Low Carbon Solutions

4.1 Rationale for blue hydrogen

In a future where large amounts of renewable energy are being produced, and where fossil fuel-based energy is increasingly less available, renewables-based hydrogen is a desirable low carbon energy carrier. However, renewables are not yet available at large enough volumes for renewables-based hydrogen to fill a role in the large-scale deployment for decarbonising the energy sector. Instead, natural gas-based – 'blue' – hydrogen is a viable option to advance the clean energy transition, build up the scale, market and infrastructure for hydrogen from renewable energy in the long-term.

To illustrate the scale of the clean hydrogen needs, one can take a theoretical example of decarbonising 8000 TWh of fossil fuel-based energy, which corresponds to Europe's annual oil & gas consumption. In order to decarbonise half of this amount – 4000 TWh – through electrification would require 1000 GW of installed renewable energy capacity. This corresponds to 250 Dogger Bank wind farms, which will be the world's biggest offshore wind farm – yet to be built. To decarbonise the other 4000 TWh through electrolyser-based hydrogen, one would first need 150 new nuclear plants of the size of Hinkley Point, which is an enormous scale, in particular taking into account the unfavourable political and market conditions for new nuclear builds in Europe. As a next step, converting the electricity produced to low carbon hydrogen would necessitate around 50 000 of the largest PEM electrolyser units (10 MW) existing today. On the other hand, if the same energy is to be decarbonised via CCS and blue hydrogen, it would take 500 ATR reformers of 1 GW each to correspond to the same capacity. Putting this in the context, the global production of comparable equipment for ammonia, methanol as well as the LNG industry corresponds to roughly a 100 GW of capacity added on an annual basis. It is an illustration of the existing supplier basis with the capacity to deliver large-scale energy sector decarbonisation solutions.

4.2 Project prioritisation

Figure 1 below illustrates the key market factors which are assessed for project prioritisation in the LCS strategy.

Key Drivers	**Description**
Key market for Equinor	Short-term priority is key export markets. In the long-term countries with an Equinor presence through renewables, upstream activities, and trading.
Political environment and willingness to pay for LCS	The Government has a favorable position to decarbonized fossil energy using CCS. There exists a willingness to pay for LCS via various funding programs.
Large market potential for LCS due to commitment to Paris agreement (i.e. quality as a Market Build platform)	Energy demand and use of gas as an energy vector or chemical feedstock. Commitment to Paris agreement to mitigate climate change through reducing CO_2 emissions (i.e. phasing out coal). Undergoing structural changes creating opportunities for LCS (i.e. phasing out of nuclear/coal). Local project market potential (e.g. prospect for expansion due to presence of nearby industry).
Partnerships	Strength of partners for LCS projects. Partners across LCS value chain (H_2 production, CO_2/H_2 transport, CO_2/H_2 storage, CO_2/H_2 end users/producers, equipment suppliers). Resources and strategic value (i.e. partners who would want to lift the next big projects and who can have a positive influence on policy).
Building competence & confidence	Building internal competence in delivering industrial-scale H_2/CCS projects. Partners building internal competence in delivering industrial-scale H_2/CCS projects. Customers building internal competence in using industrial-scale H_2/CCS.

Figure 1 Key market factors for project prioritisation

4.3 Implementation roadmap

The overall objective of the early-phase LCS strategy is to enable policy for a wider roll-out, develop the market, and create confidence in the value-chain for meeting net-zero by 2050. Equinor is currently developing several large-scale industrial projects for different energy segments such as power, heat, industrial processes and maritime transport in the key gas markets. The first large-scale projects for low-carbon hydrogen and CCS must be deployed by mid next-decade in order to advance the case of decarbonised gas in Europe. Once a European market for low carbon energy and products starts to mature, Equinor will work further to develop a fully-fledged LCS value chain, with focus on a European CCS network and a low carbon hydrogen market.

The LCS implementation roadmap focuses on activities which need to occur alongside conventional project development to successfully develop markets for LCS. In particular, it implies market development for low carbon energy and products and formation of business development activities. Such activities require a high degree of cooperation with other industrial players, governments as well as strong communication with the civil society. Market development activities include policy development which ensures that enabling regulatory frameworks and funding are in place as well as outreach and communication.

4.4 LCS project portfolio and partnerships

Equinor is leading the development of low carbon hydrogen and CCS in Europe, with a portfolio of ambitious large-scale projects, see Figure 2 below. Building partnerships within each of these projects allows Equinor to focus on delivering on areas of the LCS value chain which are of strategic interest as shown in Figure 3 below. As an LCS provider Equinor would be interested in the transport and storage of CO2 and the production and storage of low-carbon hydrogen. Equinor will need partners to assume lead roles in the rest of the value chains. Figure 3 summarizes the current partnership structure for each LCS project in the portfolio. Furthermore, cooperation with governments is a key requirement for maturing LCS projects as they will be key in setting a forward-looking legislative framework and assist with project funding opportunities.

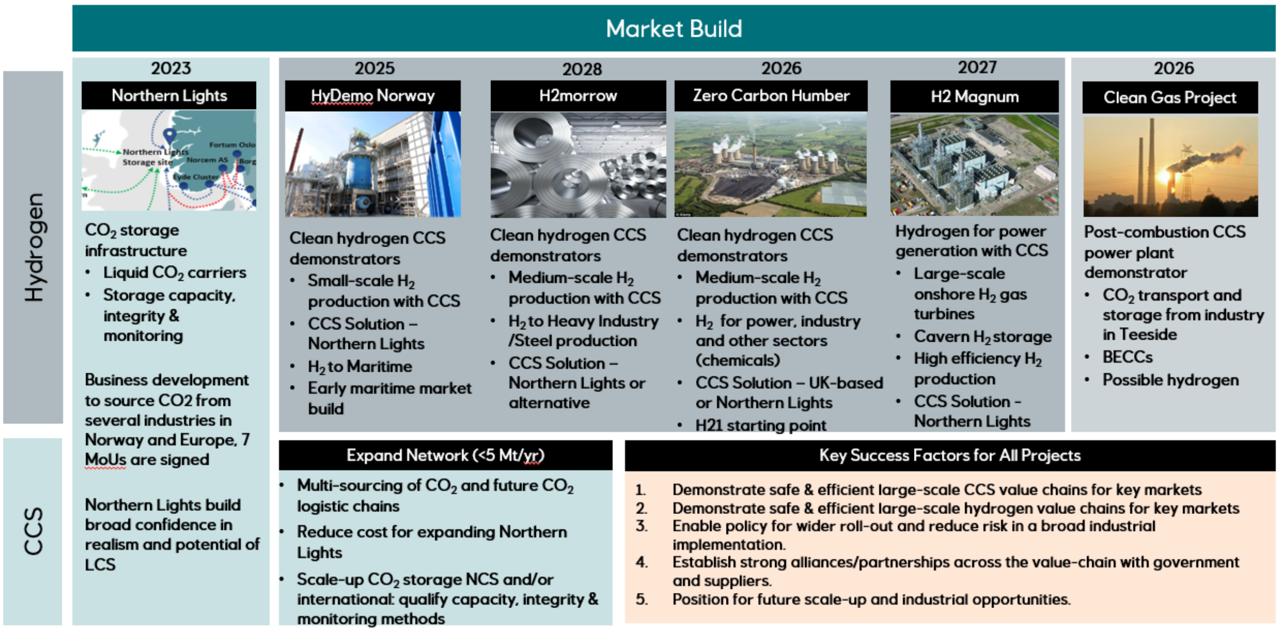

Figure 2 LCS project portfolio

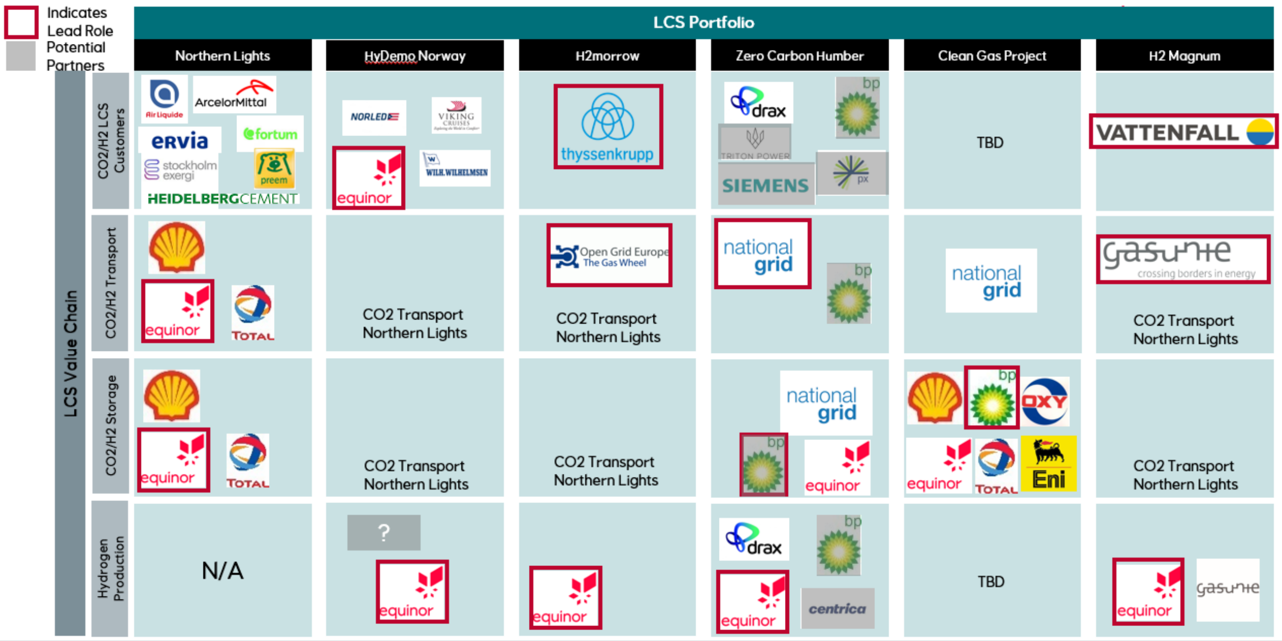

Figure 3 LCS partnerships

Equinor aims to execute the first CCS projects before 2025, and the first industrial hydrogen projects by 2025/26 to initiate the realisation of the LCS strategy and kick-start market development for low carbon energy. Northern Lights comes as a crucial piece of the strategy as it can become an enabler for the rest of Equinor's LCS projects. In the mid- to long-term, maturing Equinor's LCS portfolio is crucial to establish a platform for future expansion of LCS in new geographies or market segments.

4.5 Key risks

A long-term societal climate neutrality target creates the risk of stranded assets and losing the license to operate for the oil & gas industry. On the other hand, there is also a risk of the policy and market failure to deliver on a carbon-neutral economy, for instance if the energy consumers cannot afford to pay a higher price for the energy. It is also possible that governments are unable to deliver the enabling legislative and funding conditions, thus putting excessive costs on energy providers to build the low carbon markets. This could further endanger the viability of a climate-neutrality target by mid-century. Furthermore, there is a risk associated with the uncertainty related to the cost of LCS. In case the LCS projects turn out to be far more expensive than previously estimated, Equinor and its counter-parts risk to be blamed for misleading the public.

5 LCS projects in more detail and Northern Lights as a strategic project

5.1 Projects in more detail

Figure 2 above shows Equinor's low carbon solutions project portfolio. Below is a brief description of the main LCS projects in Equinor's portfolio.

The *Zero Carbon Humber* campaign was launched in 2019 with the aim to build the world's first zero carbon industrial cluster and decarbonise the North of England, in partnership with Drax Group, Equinor and the National Grid Ventures, CATCH and the Humber Local Enterprise Partnership. The companies will work together to explore the opportunity to scale-up the innovative bioenergy CCS pilot project at the Drax power station in order to create the world's first carbon-negative power station in the 2020s. They will also aim to explore the strategic opportunities in developing a cutting-edge hydrogen economy in the region.

H21 North of England is a concept study on the viability of repurposing the gas network used for heating in the UK from natural gas to 100% hydrogen. The study aims to demonstrate the feasibility of large-scale low carbon hydrogen deployment as a solution to decarbonize heating. As a first step, the feasibility study was carried out by partners Equinor, Northern Gas Networks and Cadent and published in 2018. The study scope envisages an 85 TWh hydrogen production facility along with 8 TWh of inter-seasonal storage in salt caverns. The captured CO_2 would be transported offshore for permanent storage in deep reservoirs at a rate of up to 20 million tons per year. In the H21 concept, the hydrogen would enter a specially designed transmission pipeline linked to the existing natural gas distribution system, repurposed to transport hydrogen. Realisation of such a project would generate economic benefits of scale and would be big enough to make a tangible impact on significantly reducing GHG emissions.

In the *H2 Magnum* project, Equinor, Vattenfall and Gasunie are evaluating conversion of a natural gas-based power plant into a hydrogen-powered plant. The Magnum gas power plant has currently three combined cycle gas turbines (CCGT) with a capacity of 440 MW each. One CCGT emits approximately 1.3 MTPA of CO_2. In the first phase the project plans to convert one CCGT to hydrogen, to build a hydrogen plant and use the infrastructure for CO_2 transport and storage that Northern Lights will establish. This would allow to provide a clean flexible electricity as a back-up for solar and wind and help launch a large-scale hydrogen economy.

The *H2morrow* project in Germany is a partnership between Thyssenkrupp Steel Europe (TkSE), Open Grid Europe (OGE) and Equinor. The project aims to replace coal with hydrogen for heat generation and as reduction agent in steel production. The role of Equinor is to review different locations for hydrogen production and CO_2 management. OGE will consider alternative hydrogen transportation routes and TkSE will focus on the conversion from coal to hydrogen at the plant. The technology is partly proven but needs some further de-risking. The potential worldwide potential of applying this technology within steel-making would replace coal and open a natural gas market (as feedstock for hydrogen) of 400 bcm annually (almost an equivalent to the European gas market) and reduce CO_2 emissions with 2 500 million tons annually.

The objective of *HyDemo Norway* is to demonstrate a clean hydrogen value chain at a realizable scale, which would reduce risk and act as enabler of larger H2 development projects. The project would qualify and mature relevant carbon capture and hydrogen production technologies. Key objectives are very high CO2 capture rates and high efficiencies across the value chain. It is planned to have connection to existing CO2 storage initiatives e.g. Northern Lights, with CO2 removal of about 100 - 200.000 tpy (similar to TCM volume). The produced hydrogen is envisaged to have multiple uses; internal Equinor applications, technology testing and maritime markets.

Equinor is also involved in kick-starting the market for maritime hydrogen in Norway. BKK, Equinor and Air Liquide are leading a new initiative that aims to build a complete liquid hydrogen supply chain in Norway for maritime applications. The project has recently been awarded a grant of 33.5 MNOK from the governmental PILOT-E scheme, whose objective is to promote rapid development and deployment of new, environment-friendly energy technology products and services. The participants of the project aim to make liquid hydrogen available for commercial shipping within the first quarter of 2024. The project encompasses the entire value chain from production, storage and transportation to end user in the maritime sector. The other project members are the following: NCE Maritime Cleantech, NORCE, Norled, NorSea Group, Viking Cruises and Wilhelmsen

The *Clean Gas Project* is a Carbon Capture, Utilization and Storage (CCUS) project, based in Teesside in the North East of England. In partnership with local industry and with committed, world class partners, it aims to decarbonise a cluster of carbon-intensive businesses by as early as 2030. Each year, the project plans to capture carbon dioxide emissions equivalent to the annual energy use of up to 1 million homes in the UK. The Clean Gas Project is an integrated CCUS project backed by OGCI Climate Investments and direct project support from six of the largest oil and gas companies globally: BP, ENI, Equinor, Occidental Petroleum, Shell and Total.

5.2 Northern Lights as a strategic LCS project

The projects described above focus on developing low carbon hydrogen solutions for power, heat, industry and maritime transport. Each of these projects are dependent on a carbon capture and storage solution for the residual CO_2 from reforming natural gas. Northern Lights is the by far most mature project in Equinor's portfolio that deals with transport and storage of the CO_2. As a result it provides a crucial link to the rest of Equinor's LCS portfolio.

Key European policy-makers acknowledge and appreciate that Northern Lights together with some few other CCS projects such as Porthos, the Clean Gas project and Acorn, constitute a new generation of CCS projects - "CCS 2.0". This new generation is very different from the first generation which EU and some European industry unsuccessfully tried to establish about ten years ago. The new generation includes several industries and emission sources, many countries, has a network and eco-system approach, and envisions a Europe-wide infrastructure for large scale CO2 removal. Being different from the first generation, which was largely coal-based, is important as that generation is considered a failure which no stakeholders want to repeat. And, as argued above, by providing

CCS services to industry, the oil and gas sector can build trust in CCS and thereby enable its application for the decarbonization of natural gas.

The realization of Northern Lights is hence absolutely crucial for building the broad confidence in the new networked infrastructure which enables low carbon industry in Europe. Hydrogen and decarbonisation of gas will crucial elements of that infrastructure. If Northern Lights would not be realized, that would provide a huge decrease in the belief in CCS, clean industry, hydrogen and decarbonisation of gas. And as a consequence would industry and policy-makers search for, and incentivize, other low carbon solutions.

Successful deployment of the Northern Lights will encourage the realization of consecutive LCS projects and foster market development for low carbon energy and products. Demonstrating the potential for a market build-up will enable other energy-intensive industries to consider the CCS option in a bid to mitigate their own emissions exposed to carbon pricing, thereby further expanding the scale-up of a European CCS network. One should therefore consider the Northern Lights as an enabler of Equinor's LCS portfolio and the very first step of proving the viability of large-scale deployment of CCS in Europe. The viability of transport and storage of CO_2 on the Norwegian Continental Shelf at a cost-competitive price will be a key determinant of the viability of the CCS and low carbon hydrogen value chains.

6 Annex: Market potential

When it comes to comparing different decarbonisation technologies, the policy debate often distinguishes between electrification with an accelerated rate of renewables deployment and decarbonising the fossil fuel-based energy supply. This debate is particularly relevant in a European context, where an increasing share of electricity in the energy system; deployment of renewable energy as well as energy efficiency measures are politically-favoured decarbonisation choices. While still more controversial in the European debate, LCS such as low carbon hydrogen and CCS have two crucial advantages in comparison – the potential to be deployed at scale as well as to provide dispatchable energy on demand. These advantages are becoming central in the decarbonisation debate as policy makers increasingly acknowledge that a system based on intermittent renewable power is neither realistic, nor cost-competitive.

In 2018, wind and solar produced 1,850 TWh of electricity globally. A recent study from the Oxford Institute for Energy Studies concluded that even if the rate of investment in renewable energy trebled overnight, to an unprecedented USD 1 trillion per annum, it would take 55-years for wind and solar to ramp up to 50% of the world's energy mix to its expected level in 2050.

Today, most of the hydrogen produced is used as feedstock for the chemical industry and not as an energy carrier, which is hardly illustrative of its actual market potential. However, comparing the global LNG figures and LNG liquefaction facilities can be a realistic analogy to assess the hydrogen market potential, as they are similar in cost and complexity to hydrogen reforming facilities. In 2018 the world produced 4200 TWh of LNG per annum and reached final investment decisions (FID) on an additional 473 TWh per annum. The hydrogen industry, which shares similar supply chains to the oil & gas industry, will be capable of providing the world with large quantities of low-carbon energy needed to meet the 2050 climate targets. The rest of this section will describe the market potential within the heating, industrial, power, and maritime sectors.

The challenge with decarbonizing the heating sector is the inter-seasonal demand and peak requirements. To illustrate the scale of the challenge, while global solar and wind energy production in 2018 equalled 1,850 TWh, 75% of the 4,500 TWh of the heat consumed by the European households and industry was sourced from fossil fuels. Figure 4 illustrates the energy demand for the UK, showing the large seasonal variation for heat. The key takeaway is that the current natural gas-based system, developed over many decades, is designed to meet these requirements and a complete shift to electricity will require a major infrastructure upgrade and a disruptive replacement of the current gas boiler system to an air-source heat pump system in the existing building stock. The UK is one of the most advanced countries when it comes to designing policies to mitigate climate change. However, attempting to decarbonize UK heat with an all-electric option, as well as adding additional load from transport, would be extremely challenging. This understanding is shared by the Director for the Internal Energy Market of the EU Commission Klaus-Dieter Borchardt, who stated that *'an all-electric world is neither technically feasible nor economically acceptable because it would significantly increase the energy costs for all consumers.'*

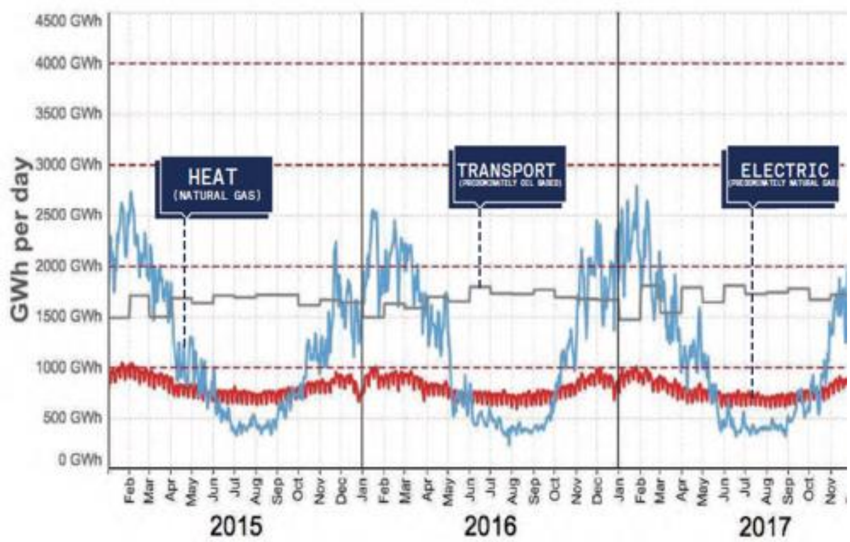

Figure 4 UK energy demand

Furthermore, power sector decarbonisation will likely prove just as challenging. Referring to the UK example once again, a recent report by the Committee on Climate Change stated that 23% of the UK's power in 2050 (158 TWh) will come in the form of gas with CCS (either pre-combustion or post-combustion). This figure is comparable to the UK's current gas power generation fleet which in 2018 delivered 272 TWh. If battery storage delivered this it would require approximately 1.2 million units of the world's largest battery park currently in Australia, taking up 5% of the UK's land area. This serves as a good illustration of the scale of the challenge. As the share of intermittent renewable energy increases the electricity price will become more volatile, dropping during periods of excess production and climbing during periods of low production requiring flexible generation sources to fill the gaps. Figure 5 illustrates this using a 2040 scenario of high wind and solar proportions in North Western Europe's electricity mix developed by Energynet, the Danish national transmission operator for electricity and gas. The figure highlights price ranges where dispatchable plants, such as low-carbon hydrogen CCGTs, are expected to operate. The more intermittency that is introduced to the electricity system, the larger the need for flexible generation, the greater the role low-carbon hydrogen power generation can potentially play. Thus, the demand for flexible low carbon energy will create a considerable market opportunity for large volumes of clean hydrogen.

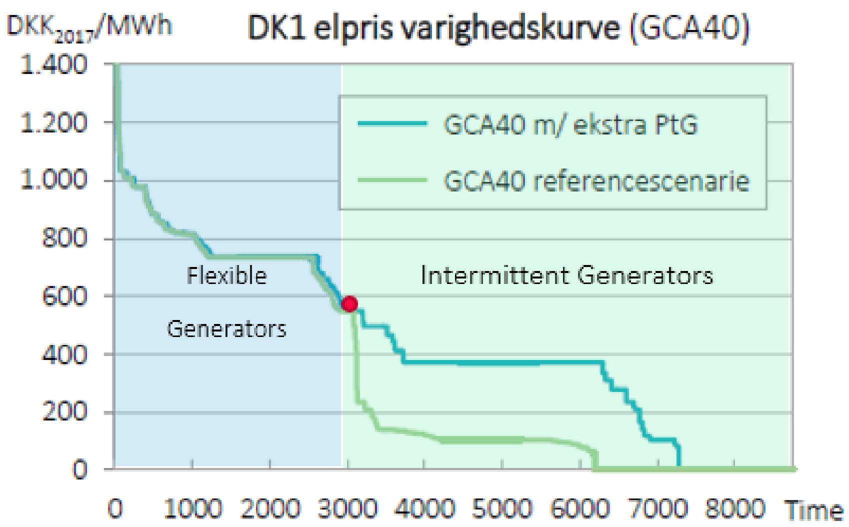

Figure 5 European Electricity Prices in 2040. Note: Using the GCA40 reference scenario power prices in the blue area range from 727 – 1,400 DKK/MWh (97.5 – 188 EUR/MWh) and power prices in the green area range from 0 – 139 DKK (0 – 18.6 EUR/MWh). The red dot indicates that power prices are at least 541 DKK/MWh (72.6 EUR/MWh) for 3050 hours (35%) of the year.

Decarbonising the fossil fuel energy or feedstock supply is the only viable decarbonization option for a number of energy-intensive industries. According to McKinsey, industrial decarbonisation faces multiple technical and economic challenges. On the technical side, 45% of CO_2 emissions come from feedstock and not fuels, while 35% of CO_2 emissions come from burning fossil fuels for high-temperature heating applications which are hard to electrify (as electric processes cannot produce the same level of heat). From an economic point of view, many industries are exposed to international competition through trade (much unlike the heating or electricity sectors) and are as a result unable to pass on the costs of decarbonization to their customers. As a result, standardising the capture of the carbon element and its removal from deeply interconnected and integrated industrial operations to bring lower unit costs can contribute to building a robust and cost-efficient decarbonisation strategy for industrial applications.

The maritime sector has the potential for becoming a large future LCS market. In 2018 the International Maritime Organization (IMO) agreed to set an ambition to reduce the international shipping sector's greenhouse gas (GHG) emissions by at least 50% from the 2008 levels by 2050 (-1.7% annually). However, the UN Conference on Trade and Development (UNCTAD) forecasts seaborne trade to grow by 3.2% on average during 2018-2022. Forecasting this to 2050 would require an annual reduction in carbon intensity of 4.7% from 2008-2050. This is not possible without addressing emissions associated with marine fuels because improvements in energy efficiency will not be sufficient. DNV, a Norwegian classification society, forecasts that the global use of low-carbon fuels in 2050 in the maritime sector can be equivalent to 885 MBOE/year. This is more than the combined equity oil and gas production of Equinor in 2018 which was 770 MBOE/year.