Electrolysis

Ammonia plants & Electrolysis projects in Europe - Road to decarbonisation?

Ammonia production and synthesis is quite well known in the industrial world and is carried out via the Haber-Bosch process. The chemical formula for ammonia is NH_3, and this means in order to produce ammonia there is a need for a stream which can supply nitrogen (N_2) and a stream which can supply hydrogen (H_2). The stream which supplies nitrogen is usually air which is stripped off of oxygen (in an ASU- Air Separation Unit) before being fed to the ammonia synthesis reactor and the stream which supplies hydrogen is usually natural gas (CH4) which undergoes a series of reactions to get converted to hydrogen before being fed to the same synthesis reactor. Depending on the plant design, the ASU may or may not be needed and this is especially true if natural gas is used as a feedstock [1]. Now this **conversion of natural gas to hydrogen leads to formation of carbon dioxide CO_2 (as a by-product) and this is the main cause of emissions** in the whole process. The **second main cause of CO_2 emissions is the combustion of natural gas for steam generation**. There are other smaller emissions coming out of the ammonia plant but not as significant in magnitude as the two mentioned before. As on date, there is no better method to synthesise ammonia other than the **Haber-Bosch process** and since natural gas is used as a feed stream for the hydrogen supply, the emissions from ammonia synthesis are quite significant. The emissions from ammonia production via the conventional route is roughly 1.9 tonnes of CO_2 per ton of ammonia produced [1]. This is the number that one wants to bring down and scientists, researchers and engineers are all working hard to find viable solutions to make this, in an ideal case, to 0 tonnes.

In order to reduce the emissions from the ammonia synthesis process, the hydrogen supply or hydrogen generation must be without emissions and this is exactly what the electrolysis process (with Electrolysers at its core) coupled with renewable electricity aims to do. An electrolysis plant under ideal conditions can produce hydrogen with zero CO_2 emissions and when this is used in the ammonia synthesis process then the CO_2 emissions from this process is also zero. Although theoretically feasible, this approach has many practical challenges.

Most of the ammonia plants have a pipeline that delivers natural gas which is then reformed to generate hydrogen. The flow from this pipeline can be turned on and off depending on the need for natural gas which in turn depends on the need for the ammonia production planned for a certain day, week or month. Now, the same cannot be said for pipelines that deliver hydrogen because there are almost no 100% hydrogen ready pipelines which deliver hydrogen from source to end use. Since Europe has an extensive pipe network for natural gas, many have assumed that the infrastructure for gas transport exists and one can simple replace or switch natural gas with hydrogen and achieve the broader goal of decarbonisation.

Anhydrous ammonia plant, ca. 1954 (Image Source: https://www.wired.com/2016/05/chemical-reaction-revolutionized-farming-100-years-ago-now-needs-go/)

However, it is not as simple as one might think. In the paper from Paul Martin et al [2], it is clearly discussed and outlined as to why pipelines meant for natural gas will not work for hydrogen, warranting completely new designs tailored specifically for hydrogen and at the cost of increased use of energy in pumping hydrogen through the entire gas network. Hence, it is important for electrolysis plants to be located as close as possible to the ammonia manufacturing plants else there will be hydrogen losses along the supply path and the amount of hydrogen needed at the ammonia plant will not be met. Also, ammonia production is usually not done with batch feedstocks, meaning feedstock supply needs to be continuous and this is currently not the case with ‘Green Hydrogen’. Hence, having a hydrogen storage infrastructure on site at the ammonia plant is also not a viable option. Additionally, it is stated in the report from Hydrogen Europe [3] that the ammonia industry will be one of the biggest consumers of green hydrogen which in turn translates to increased electrolyser system manufacturing and installation. However, with the **critical piece of hydrogen pipe network being absent**, it is quite possible that even though GW (giga watt) scale electrolyser plants are commissioned, if they are far away from ammonia plants then getting sufficient quantities of hydrogen in a continuous manner will be a huge challenge and one may not achieve decarbonisation of ammonia production. There is an urgent need for meticulous planning/ upgrading/retrofitting at different ammonia plants if one wants to bring down emissions from ammonia production.

The questions that will be answered in this report are:

I. Where are the ammonia plants (manufacturing sites) located in Europe?

II. How much is the hydrogen demand at the ammonia plants?

III. What & where are the current operational and working electrolysis plants in Europe?

IV. Can electrolysis technology cater to the demand of the ammonia plants?

These questions will stimulate critical thinking into what needs to be done to decarbonise the ammonia production industry in Europe.

Location of NH_3 plants

The production capacity of ammonia in Europe is currently close to 20 million tonnes and the production plants are scattered across Europe. It was quite a challenge to find the exact location of these ammonia plants but after extensive search and some consultation with people from industry, the locations could be narrowed down. The reader is advised to refer to the projection map made on www.venkacon.com (click here) to get information on where these plants are actually located. The same information is also given in Table 1.

According to an old report published by the EU in the year 2014 [4] (the contractor being Centre for European Policy Studies), there were 42 operational plants in the EU (which included UK at that time) however as on date (2024), the number of operational plants is reduced to 28 in the EU (including UK which is now not part of the EU).

Countries	**No. of ammonia plants as per EU report [4]**	**No. of ammonia plants actually operational**	**Remarks**
Germany	5	3	The number of plants is reduced
Poland	5	4	The number of plants is reduced
Netherlands	2	2	
Romania	6	1	The number of plants is reduced
France	4	4	
Lithuania	1	1	
Bulgaria	3	2	The number of plants is reduced
UK	3	2	The number of plants is reduced
Belgium	2	2	
Spain	3	2	The number of plants is reduced
Italy	1	1	
Austria	1	0	Could not find any data on the ammonia plant in Austria
Slovakia	1	1	
Hungary	2	1	The number of plants is reduced

Countries	No. of ammonia plants as per EU report [4]	No. of ammonia plants actually operational	Remarks
Czech Republic	1	1	
Estonia	1	0	Could not find any data on the ammonia plant in Estonia
Greece	1	0	Could not find any data on the ammonia plant in Greece
Norway	0	1	This plant was not included in the EU report
TOTAL	42	28	

Table 1 - Number of Ammonia manufacturing plants in Europe

Note: *The 'Clean Ammonia Report' [5] states there are 32 operational ammonia plants in the EU. However, no information could be found about the plants in Austria, Greece & Croatia. This would make the total number close to 32.*

Now with the 28 plants listed in Table 1, the production capacity is 20 million tonnes per year and in the latest clean ammonia report from hydrogen Europe, the production capacity is listed as 19.4 million tonnes [5]. Hence, it is reasonable to assume that the data obtained from the search for the ammonia plants in Europe and their stated production capacity closely matches with that of what is stated by Hydrogen Europe.

The exact location of the ammonia plants and the company that operates it is given in Table 2.

City	Country	Ammonia production (k tonnes/year)	Operating company
Sluiskil	Netherlands	1900	Yara International ASA
Geleen		1450	OCI Nitrogen
Ludwigshafen	Germany	880	BASF
Brunsbüttel		800	Yara International ASA
Wittenberg		1300	SKW
Billingham	United Kingdom	590	CF Industries
Hull		300	Yara International ASA
Porsgrunn	Norway	500	Yara International ASA

Tertre	Belgium	400	Yara International ASA
Antwerp		650	BASF
Ferrara	Italy	600	Yara International ASA
Le Havre	France	400	Yara International ASA
Grandpuits-Bailly-Carrois		390	GPN Agriculture
Le Grand-Quevilly		390	GPN Agriculture
Ottmarsheim		240	Produits et Engrais Chimiques du Rhin
Jonava	Lithuania	1117	Achema
Târgu Mureș	Romania	1600	Azomures
Šal'a	Slovakia	584	Duslo
Police	Poland	500	Grupa Azoty
Pulawy		1200	Grupa Azoty
Tarnów		200	Grupa Azoty
Włocławek		520	Anwil SA
Pétfürdő	Hungary	497	Nitrogenmuvek
Litvínov	Czech Republic	332.15	ORLEN Unipetrol Group
Palos de la Frontera	Spain	415	Fertiberia
Puertollano		200	Fertiberia
Dimitrovgrad	Bulgaria	410	Neochim
Vratsa		500	Chimco

Table 2: List of Ammonia manufacturing plants in Europe - City, capacity & Operator

Note: *It is certainly possible that a few more ammonia plants have been shut down or the production capacity drastically reduced however for this report the data mentioned in the table above will be used. The reader may carry out further research on the individual plants if interested. For data sources please refer to the end of this report.*

Hydrogen demand at ammonia plants

The ammonia production reaction is as follows:

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2\ NH_{3(g)}$$

Conditions needed: 150-200 bar, 450-500 ^{o}C and iron as catalyst

This translates to 1 mole of ammonia needing 1.5 moles of hydrogen or if converted to mass 1 kg of ammonia needing 176.5 g of hydrogen or 1 tonne of ammonia needing 176.5 kg of hydrogen. Since most of the ammonia plants report production in tonnes, it is easy to have a broad picture when using tonnes rather than grams.

1 tonne of ammonia needs 176.5 kg of hydrogen

The annual hydrogen demand at the plants are also listed in the projection map available on www.venkacon.com (click here)

Green hydrogen demand is between 35.3 to 335.35 k tonnes per year at ammonia plants in Europe

The ammonia plant with the smallest capacity is located at Puertollano, Spain and Tarnów, Poland, having an annual production capacity of 200 k tonnes per year, translating to a need of 35.3 k tonnes of hydrogen per year. The ammonia plant with the largest capacity is located in Sluiskil, The Netherlands, having an annual production capacity of 1900 tonnes per year and in turn translating to a need for 335.35 k tonnes of hydrogen per year. The scale of hydrogen needed just for ammonia production is humungous and if this demand is not met then ammonia production will get reduced which in turn will reduce the output of other useful products downstream such as urea, ammonium nitrate etc.

Location of hydrogen electrolysis plants

As per the 'Clean Hydrogen Monitor 2023' report [3], there are currently 166 Electrolyser plants operational in Europe, amounting to a total 228 MW_{el} capacity. Out of this 118 MW_{el} is catered by 13 installations, 86 MW_{el} is catered by 46 installations and the remaining 24 MW_{el} is catered by 107 installations. Figure 1 below shows the respective information.

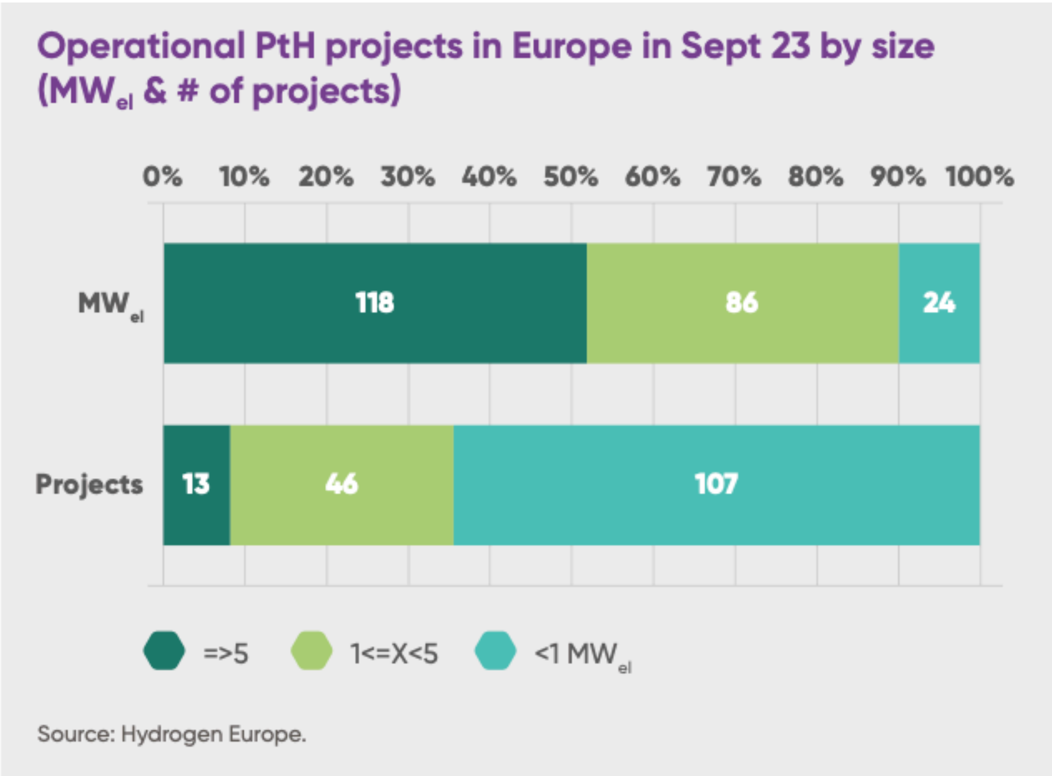

Figure1: Data on hydrogen electrolysis plants in Europe [3]

The 13 installations, in Figure 1, are categorised as large projects with >= 5MW_{el} installed electrolysis capacity for each project, the 46 installations are medium sized projects, between 1 & 5 MW_{el} of installed capacity for each project and the remaining 107 installations are small scale projects with < 1 MW_{el} installed capacity for each project. However, this report [3] provides no information on the quantity of hydrogen that can be produced from this installed base. Without the quantity of hydrogen mentioned, it makes little sense of what to expect and what the projects can deliver in terms of k tonnes of hydrogen per year.

It is also mentioned in [3] that Germany has an installed base of 72 MW_{el}, Spain an installed base of 33 MW_{el} and Sweden an installed base of 30 MW_{el}. This adds up to 135 MW_{el} just with these three countries, the remaining 93 MW_{el} is spread out across the EU. This particular report doesn't specify where these 166 electrolyser plants are located. Hence, further research was warranted to identify the exact locations of these projects.

The International Energy Agency (IEA) provides additional data on electrolysis plants and projects, in the form of an interactive map and an Excel sheet which can be downloaded, and this information can be obtained from [6]. Here, one can filter down the hydrogen production by:

- Technology *viz.* Electrolysis, Fossil fuels with CCUS & Other
- Status *viz.* Concept, Demonstration projects, Feasibility study, FID/Under construction & Operational

In order to be realistic so that only 'Green Hydrogen' production is taken into account, the following filters were applied:

- Only demonstration and operational projects, commissioned between 2000 and 2023 and yet to be commissioned until 2030 were taken into account.

AND

- Technology of choice was 'Electrolysis' because only this guarantees that the hydrogen produced is 'green hydrogen' or at least very low carbon hydrogen.

One can also narrow down the data available from the IEA database country wise, in order to obtain information on the electrolysis plants currently installed in a particular country.

Note: *There is a certain mismatch between the information obtained from the interactive map and the excel sheet. For e.g. if one chooses Netherlands as the country, the interactive map shows only 8 electrolysis projects whereas the excel sheet shows 12 electrolysis projects. Hence, caution must be exercised when obtaining data. For this report, the data from the excel sheet was taken because the number of projects were more in the excel sheet and hence the risk of under estimating the electrolysis capacity is minimised*.

In order to get a quick glimpse and summary on what each country is able to achieve with electrolysis technology as on date (Oct 2024), the reader is referred to the projection map available on www.venkacon.com (click here)

For the countries which have existing and operational ammonia plants, it will be the easiest if there are also electrolysis plants (preferably in the vicinity) which can produce green hydrogen in sufficient amounts. The detailed information on the existing and currently running electrolysis plants/ projects has been extracted (from the IEA database), condensed and summarised below for the sake of convenience.

1. The Netherlands

- The Netherlands has 12 electrolysis plants out of which 7 are operational plants and 5 are demonstration plants/projects. The areas of applications for these electrolysis plants are quite diverse. The details are given in Table 3.

Project Name	Status	Area of application	kt H2/ year
Rozenburg Power2Gas Phase 2	DEMO	Grid injection	~0
DNV Kema/DNV GL	Operational	Grid injection & CHP	~0
Haystack (EnergyStock)	Operational	Other industry & mobility	~0.1
Multiphly	Operational	Refining	~0.5
Cyrus Smith	DEMO	Unknown	~0
Alliances Oosterwolde - solar park of GroenLeven	Operational	Other industry & mobility	~0.2
Hysolar Green on Road - Nieuwegein	Operational	Mobility	~0.3
Hydrogenpilot Oosterwolde	Operational	Power	~0.2
AMpHytrite demonstrator, Port of Rotterdam, Phase 1	DEMO	Unknown	~1.5
WAviatER	DEMO	Mobility	~0
GROHW	Operational	Other industry	~0.1
H2Agro	DEMO	Grid injection	~0

Table 3: List of working electrolysis projects in Netherlands [6]

- The Netherlands has two ammonia plants which have a combined production capacity of 3350 k tonnes/ year and this translates to a need of 591.275 k tonnes/ year of hydrogen. This is the amount of hydrogen needed just to decarbonise ammonia production in The Netherlands.

- As seen from the table above none of these projects come even close to meeting even 1% of the hydrogen demand needed for this industry alone.

- The amount of electricity needed (refer end of report for calculation basis) for generating 591.275 k tonnes of hydrogen per year is 29.6 TWh and and this must be generated within Netherlands or imported.

2. Germany

- Germany has 66 electrolysis projects in total, out of which 13 demonstration projects and 53 are operational plants. The areas of application are very diverse with a large share going into industry which is actually good but the decarbonisation effect that it will have is quite meagre.

Project Name	Status	Area of application	kt H2/ year
Apex Energy, Rostock-Laage	Operational	Mobility & Domestic heating	~0.3
Leuchtturmprojekt Power-to-Gas Baden-Württemberg	Operational	Mobility	~0.2
eFarm (5 production sites in North Frisia)	Operational	Mobility	~0.2
Wyhlen hydroelectric power plant	Operational	Power	~0.2
GrInHy2.0	Operational	Iron & Steel	~0.2
PFI - Pirmasens-Winzeln	Operational	Natural gas grid injection	~0.4
MEFCO2	Operational	Methanol	~0.1
Windgas Haurup, 2nd phase	Operational	Power	~0.1
Stromlückenfüller 2nd phase	Operational	Grid injection	~0
Kopernikus	DEMO	Synfuels	~0
Falkenhagen STORE&GO	Operational	Natural gas grid injection	~0.1
Localhy	Operational	Mobility	Not specified
Wind to Gas Südermarsch	Operational	Mobility & Grid injection	~0.4
Carbon2Chem	Operational	Ammonia, Methanol & Other industry	~0.3
H2ORIZON	Operational	Mobility, Power & CHP	~0.1
Windgas Haurup, 1st phase	Operational	Grid injection	~0
Methanation at Eichhof	Operational	Natural gas grid injection	~0
Rostock, Exytron Demonstrationsanlage	Operational	Natural gas grid injection	~0
MicroPyros, Altenstant	Operational	Natural gas grid injection	~0
Alzey, Exytron Null-E	Operational	Power & CHP	~0
Energy in the Container, Fraunhofer IISB, Erlangen, Leistungszentren Elektroniksysteme (LZE)	DEMO	Power	Not specified
Hassfurt	Operational	Power, Grid injection & CHP	~0.2

HPEM2GAS (R&D)	Operational	Grid injection	~0
Hamburg - Schnackenburgallee	Operational	Mobility	~0
WindGas Hamburg-Reitbrook	Operational	Mobility	~0.2
RH2 Grapzow, Mecklenburg Vorpommern	Operational	Power	~0.2
RWE PtG plant Ibbenbüren	Operational	Power, Grid injection & CHP	~0
Stromlückenfüller 1st phase	Operational	Power	~0
H2BER (Berlin airport)	Operational	Mobility	~0.1
Hanau, Wolfgang Industrial Park	Operational	Power & Grid injection	~0
MicroPyros, Staubing	Operational	Natural gas grid injection	Not specified
ETOGAS, Solar Fuel Beta-plant AUDI, Werlte (Audi e-gas)	Operational	Natural gas grid injection	~1.1
WindGas Falkenhagen	Operational	Grid injection	~0.3
P2G plant Erdgas Schwaben	Operational	Grid injection	~0.1
CO2RRECT-Niederaussem	Operational	Natural gas grid injection	~0
MicrobEnergy GmbH, Schwandorf	Operational	Natural gas grid injection	~0
H2Move, Fraunhofer ISE	Operational	Mobility	~0
Refhyne	Operational	Refining	~1.5
H&R Ölwerke Hamburg-Neuhof	Operational	Refining	~0.7
H2Herten	Operational	Mobility, Power & CHP	~0
H2 research center BTU Cottbus	Operational	Power	~0
Cotbus	Operational	Mobility	~0
Eucolino Schwandorf	Operational	Grid injection	~0
Hamburg Hafen City, CEP	Operational	Mobility	~0.1
Hybrid Power Plant Enertrag, Prenzlau	Operational	Mobility, Power, Grid injection & Domestic heating	~0.1
EnBW H2 station, Stuttgart	Operational	Mobility	~0.1
Regenerativer Energipark Ostfalia/ hybrid renewable energy park (HREP)	Operational	Power	~0
Energiepark Mainz	Operational	Other industry, Mobility & Grid injection	~0.9
Hypos - Sunfire	DEMO	Other industry	~0
Wunsiedel Energy Park (Phase 1)	Operational	Other industry & Mobility	~1.3

MethFuel	DEMO	Natural gas grid injection	~0.1
Power to flex (several pilot projects)	DEMO	Mobility, Power & CHP	Not specified
HYPOS (several projects)	Operational	Other industry, Mobility, Power & Grid injection	~0.2
Wuppertal refuelling station	Operational	Mobility	~0.4
SALCOS - WindH2 Windwasserstoff Salzgitter	Operational	Iron & Steel	~0.4
HyWindBalance, Oldenburg	DEMO	Unknown	Not specified
Kopernikus 2.0	DEMO	Synfuels	~0.1
E-CO2MET Raffinerie Mitteldeutschland	DEMO	Refining & Methanol	~0.2
Etzel, Salt caverns	DEMO	Mobility, Power & Grid injection	Not specified
Green Hydrogen Esslingen (P2G2P)	Operational	Mobility & Grid injection	~0.1
HRS Bremervörde - trains	Operational	Mobility	~0.6
Hydrogen Lab Leuna (phase 1)	Operational	Methanol	~0.2
Fairfuel Atmosfair	Operational	Synfuels	~0.2
Steinbeis Innovation Center Braunschweig	DEMO	Mobility	~0.2
Flughafen Rostock-Laage PtX	DEMO	Synfuels	Not specified
GET H2 TransHyDE hydrogen project - Lingen	DEMO	Unknown	~0.1

Table 4: List of working electrolysis projects in Germany [6]

- Germany has three ammonia plants which have a combined production capacity of 2980 k tonnes/ year and this translates to a need of 525.97 k tonnes/ year of hydrogen. This is the amount of hydrogen needed just to decarbonise ammonia production in Germany.
- With all the current electrolysis projects running in Germany, there is capacity of producing ~13 k tonnes of hydrogen per year which is roughly 2.5% of the demand for this industry. However not all hydrogen is going into decarbonising ammonia production as can be seen from Table 4 and this why the decarbonisation effect will be meagre.
- The amount of electricity needed (refer end of report for calculation basis) for generating 525.97 k tonnes of hydrogen per year is 26.3 TWh and and this must be generated within Germany or imported.

3. Belgium

- Belgium has currently three electrolysis plants out of which two are operational plants and one is a demo project/plant. But here the two operational plants are for mobility and reusing an electrolysis plant meant for mobility for large scale ammonia production is not feasible at all.

Project Name	Status	Area of application	kt H2/ year
Don Quichote	Operational	Mobility	~0.1
HRS CMB Port of Antwerp	Operational	Mobility	~0.1
Hydrogen Offshore Production Europe (HOPE)	DEMO	Unknown	~1.5

Table 5: List of working electrolysis projects in Belgium [6]

- Belgium has two ammonia plants which have a combined production capacity of 1050 k tonnes/ year and this translates to a need of 185.325 k tonnes/ year of hydrogen. This is the amount of hydrogen needed just to decarbonise ammonia production in Belgium.
- The HOPE electrolysis project, the largest project aiming to produce 4 tonnes of clean hydrogen per day, translating to roughly 1.5 k tonnes of hydrogen per year. The total low carbon hydrogen possible is not even close to 1% of the hydrogen demand needed for ammonia production.
- The amount of electricity needed (refer end of report for calculation basis) for generating 185.325 k tonnes of hydrogen per year is ~9.26 TWh and and this must be generated within Belgium or imported.

4. United Kingdom (UK)

- United Kingdom has in total fifteen electrolysis projects out of which three are demonstration projects and twelve are operational projects.

Project Name	Status	Area of application	kt H2/ year
Hydrogen plant - Orkney Islands- BIG HIT 2nd phase	Operational	Mobility, Power, Grid injection & Domestic heating	~0.1
HyDeploy	Operational	Grid injection	~0.1
Aberdeen Conference Centre	Operational	CHP & Domestic heating	~0.2
Hydrogen plant - Orkney Islands- BIG HIT 1st phase	Operational	Mobility, Power & Grid injection	~0.1

Hydrogen mini grid system Yorkshire (Rotherham)	Operational	Mobility, Power & Grid injection	~0
Baglan Energy Park Wales	Operational	Mobility & Power	~0
HARI project, West Beacon Farm	Operational	Power & CHP	~0
Fife, Levenmouth Community Energy Project	Operational	Mobility & Power	~0.1
PURE Project, Unst	Operational	Mobility, Power & CHP	~0
Tyseley Energy Park refuelling hub, Birmingham	Operational	Mobility	~0.4
EMEC tidal-battery-hydrogen demo	DEMO	Not specified	~0.1
HRS Swindon	Operational	Mobility	Not specified
Heysham demonstrator 1	DEMO	Not specified	~0.2
Energy hub at MIRA Technology Park	Operational	Mobility	~0.2
Plant Zero.1	DEMO	Synthetic fuels	Not specified

Table 6: List of working electrolysis projects in the UK [6]

- The UK has two ammonia plants at Hull & Billingham respectively which have a combined production capacity of 890 k tonnes/ year and this translates to a need of 157.08 k tonnes/ year of hydrogen. This is the amount of hydrogen needed just to decarbonise ammonia production in the UK.
- There is not a single electrolysis project which is aimed at decarbonising hard to abate industry and devoting expensive green hydrogen to applications (such as mobility and heating) which have other alternatives is a waste of the green hydrogen produced.
- The amount of electricity needed (refer end of report for calculation basis) for generating 157.08 k tonnes of hydrogen per year is ~7.85 TWh and and this must be generated within the UK or imported from elsewhere.

5. Norway

- Norway has nine projects out of which two are demonstration projects and seven are operational plants.

Project Name	Status	Area of application	kt H2/ year
ASKO Midt-Norge	Operational	Mobility	~0.1
Laboratory System at IFE Kjeller Phase 2	Operational	Power	~0
Oslo, CHIC	Operational	Mobility	~0.1
Grimstad Renewable Energy Park	Operational	Power	~0
HAEOLUS	Operational	Other industry, Mobility & Power	~0.4
Deep Purple	DEMO	Other industry, Mobility & Power	Not specified
Energy- Norwegian Catapult Centre	Operational	Unknown	~0.2
Heroya Industrial park	Operational	Unknown	~0.9
PYROCO2	DEMO	Other industry	~0.4

Table 7: List of working electrolysis projects in the UK [6]

- Norway has one ammonia plant in Porsgrunn which has a production capacity of 500 k tonnes/ year and this translates to a need of 88.25 k tonnes/ year of hydrogen. This is the amount of hydrogen needed just to decarbonise ammonia production in Norway.
- The currently running projects has only three projects catered towards industry and the remaining are for applications which have other alternatives.
- The amount of electricity needed (refer end of report for calculation basis) for generating 88.25 k tonnes of hydrogen per year is ~4.41 TWh and and this must be generated within Norway or imported from elsewhere.

6. Italy

- Italy has six electrolysis projects out of which two are demonstration projects and four are operational plants

Project Name	Status	Area of application	kt H2/ year
Troia, STORE&GO	Operational	Natural gas grid injection	~0
REFLEX	Operational	Power	~0
Hydrogen valley South Tyrol - Bolzano, CHIC	Operational	Mobility	~0.3
H2 from the sun, Brunate	DEMO	Power	~0
INGRID	Operational	Other industry, Mobility, Power & Grid injection	~0.2
Fiume Santo, demo plant	DEMO	Unknown	~0.1

Table 8: List of working electrolysis projects in Italy [6]

- Italy has one ammonia plant in Ferrara which has a production capacity of 600 k tonnes/ year and this translates to a need of 105.9 k tonnes/ year of hydrogen. This is the amount of hydrogen needed just to decarbonise ammonia production in Italy.
- There is just one project 'INGRID' which is also catered towards industry besides also serving for other applications. The total amount of low carbon hydrogen that can be produced from these projects is close to 0 k tonnes of H_2 per year.
- The amount of electricity needed (refer end of report for calculation basis) for generating 105.9 k tonnes of hydrogen per year is ~5.3 TWh and and this must be generated within Italy or imported from elsewhere.

7. France

- France currently has twenty four electrolysis projects out of which nine are demonstration projects and fifteen are operational projects

Project Name	Status	Area of application	kt H2/ year
Houdain bus station HRS (TADAO/ Bulle 6 SMTAG)	Operational	Mobility	~0.1
Febus Pau bus station HRS	Operational	Mobility	~0.1
GNVert H2	Operational	Mobility	~0
Energy observer	Operational	Mobility & Power	~0

AltHytude	DEMO	Unknown	~0
FaHyence	Operational	Mobility	~0
Minatec's semiconductor labs in Grenoble	Operational	Other industry	~0
Vallee Hydrogene Grand Ouest (VHyGO)-H2 Ouest (Phase 1)	Operational	Mobility	~0.1
Vallee Hydrogene Grand Ouest (VHyGO) - EffiH2	Operational	Mobility	~0.2
Vendee hydrogene	DEMO	Mobility	~0.6
MYRTE	DEMO	Power	~0
Hyport - Toulouse Blanca Airport	Operational	Mobility	~0.3
AuxHYGen (Phase 1)	Operational	Mobility	~0.2
ElectroHgena	DEMO	Natural gas grid injection & Natural gas mobility	Not specified
Minerve, Nantes	DEMO	Natural gas grid injection & Natural gas mobility	Not specified
SPHYNX, R&D	DEMO	Mobility	Not specified
Hyflexpower	DEMO	Power	~0.2
METHYCENTRE	DEMO	Mobility	~0
Vallee Hydrogene Grand Ouest (VHyGO) - Saint Nazaire	Operational	Mobility	~0.3
Sirea-Castres site	Operational	Mobility	~0.1
Sealhyfe	Operational	Unknown	~0.1
Hypster	DEMO	Unknown	~0.1
H2PiyR Pamiers	Operational	Mobility	Unknown
Porte de St Cloud HRS station	Operational	Mobility	~0.4

Table 9: List of working electrolysis projects in France [6]

- France has four ammonia plants which have a combined production capacity of 1420 k tonnes/ year and this translates to a need of 250.63 k tonnes/ year of hydrogen, solely needed for ammonia production.
- The bulk of the electrolysis projects are catered towards mobility, and just one is catered towards industry and that too for hydrogen needed in semiconductor production. With all these projects running , France is able to generate 3k tonnes/ year of low emission hydrogen, which is again ~1% of the hydrogen needed for the ammonia industry.

- The amount of electricity needed (refer end of report for calculation basis) for generating 250.63 k tonnes of hydrogen per year is ~12.5 TWh and and this must be generated within France or imported from elsewhere.

8. Lithuania

- This country has currently one demo electrolysis project.

Project Name	Status	Area of application	kt H2/ year
Hydrogen injection into the gas network	DEMO	Grid injection	~0.2

Table 10: List of working electrolysis projects in Lithuania [6]

- Lithuania has one ammonia plant which has a production capacity of 1117 k tonnes/ year and this translates to a need of 197.15 k tonnes/ year of hydrogen, solely needed for ammonia production.
- Besides the one demonstration project, there are no electrolysis projects which can generate green or low carbon hydrogen for the ammonia industry.
- Lithuania must generate ~9.85 TWh of electricity (refer end of report for calculation basis) to produce enough hydrogen just to cater to the needs of the ammonia industry.

9. Romania

- With no electrolysis plants- demo or operational, the ammonia production in Romania is set to continue the traditional way.
- Romania has an ammonia production capacity of 1600 k tonnes/year, translating to a need of 282.4 k tonnes of hydrogen per year which in turn translates to a need of 14.12 TWh of electricity (refer end of report for calculation basis).

10. Poland

- This country has two operational projects for electrolysis

Project Name	Status	Area of application	kt H2/ year
Tauron CO2-SNG	Operational	Natural gas grid injection	~0
Trzebinia Refinery	Operational	Refining & Mobility	~0

Table 11. List of currently working electrolysis projects in Poland [6]

- Poland is one of the major producers of ammonia in Europe, having 4 manufacturing plants, which have a combined production volume of 2420 k tonnes/year. This translates to a hydrogen demand of 427.13 k tonnes/ year.
- With just two electrolysis projects currently running which has almost 0 k tonnes/ year of green or low carbon ammonia production, the task to decarbonise this industry in Poland looks bleak.
- In order to generate the amount of hydrogen mentioned above, one needs 21.35 TWh of excess electricity (refer end of report for calculation basis) which needs to be produced within Poland or imported.

11. Slovakia

- There are no electrolysis plants - operational or demo in Slovakia currently.
- However, Slovakia has an ammonia manufacturing plant with a capacity of 584 k tonnes/ year, which translates to a need for 103.07 k tonnes of hydrogen per year which in turn translates to a need for ~5.15 TWh of electricity needed (refer end of report for calculation basis) to generate this volume of hydrogen.

12. Hungary

- There is currently one operational electrolysis plant in Hungary.

Project Name	Status	Area of application	kt H2/ year
Aquamarine	Operational	Power	~0.3

Table 12: List of currently working electrolysis projects in Hungary [6]

- Hungary has one ammonia manufacturing plant with a capacity of 497 k tonnes / year and this translates to a need for 87.72 k tonnes / year of hydrogen.
- Once again the scope of supplying green or low carbon hydrogen is almost zero from the electrolysis projects that are currently running.
- The amount of electricity needed (refer end of report for calculation basis) for hydrogen production is 4.38 TWh and this needs to come either from within Hungary or imported from elsewhere.

13. Czech Republic

- Just like the countries where there are no electrolysis projects, Czech Republic also has currently zero scope to generate any green or low carbon hydrogen within its borders.
- It has one ammonia manufacturing plant with a production capacity of 332.15 k tonnes/year, translating to a need of 58.62 k tonnes/ year of hydrogen which in turn will demand a supply of ~2.93 TWh of electricity (refer end of report for calculation basis).

14. Bulgaria

- There are no electrolysis plants that are currently running in Bulgaria and that means the scope to supply green or low carbon hydrogen is non existent.
- Bulgaria has two ammonia manufacturing plants with a combined production capacity of 910 k tonnes/ year and this requires 160.61 k tonnes/year of hydrogen. In order to produce this amount of hydrogen, Bulgaria needs to generate close to 8 TWh of excess electricity (refer end of report for calculation basis).

15. Spain

- This country has sixteen electrolysis plants and projects, out of which six are demonstration plants/projects and ten are operational plants.

Project Name	Status	Area of application	kt H2/ year
Iberdrola-Puertollano I	Operational	Ammonia	~3
Green Hysland Mallorca- Phase 1	Operational	Mobility & Grid injection	~0.4
CoSin: Synthetic Natural Gas from Sewage, Barcelona	Operational	Natural gas grid injection	~0
El Tubo- ACTA EL 500	DEMO	Power	~0
ITHER	DEMO	Mobility	~0
RES2H2 Gran Canaria	DEMO	Mobility	~0
CUTE and HyFLEET: CUTE, Barcelona	DEMO	Mobility	~0.1
REMOTE: Spain, Canary Islands	Operational	Power	~0
Seafuel project	Operational	Power	~0
HRS TMB Zona Franca de Barcelona	Operational	Mobility	~0.4
HRS CNH2 Puertollano	Operational	Mobility	~0
Abanto Technology Park	Operational	Refining & Mobility	~0.4
H2-Login	Operational	Mobility	~0
Ocean H2	DEMO	Unknown	Not Specified
Pamesa-eCombustible	Operational	Other industry	~1.4
Navarra hydrogen project	DEMO	Unknown	~0.1

Table 13: List of currently working electrolysis projects in Spain [6]

- There are two ammonia manufacturing plants in Spain with a combined production capacity of 615 k tonnes / year and this translates to a need for 108.55 k tonnes of hydrogen per year.
- From all the projects mentioned in Table 13, Spain has a capacity of generating close to 5.8 k tonnes/year of green or low carbon hydrogen and this comes close to ~5.3% of the total hydrogen demand needed for the ammonia industry. This is currently far from the demand needed for decarbonising the ammonia industry. There is one project 'Iberdrola - Puertollano I' which is dedicated towards the ammonia industry and this is promising to see.
- The amount of electrical energy needed (refer end of report for calculation basis) for generating 108.55 k tonnes of hydrogen per year is close to 5.42 TWh and this must be generated in Spain or imported from elsewhere.

Can electrolysis technology cater to the demand?

With the electrolysis technology currently available at hand, the largest hydrogen capacity that **a single electrolysis plant** is able to produce varies between 1.5 and 3 k tonnes / year and this comes nowhere close to meeting even 1% of the annual hydrogen demand needed at the ammonia plants in most countries. In countries like Germany and Spain, the hydrogen produced from electrolysis can meet up to 3% of the demand from ammonia plants but not all electrolysis plants are devoted to catering to the ammonia industry and that brings down the number even further.

Electrolysis technology alone will very unlikely meet the hydrogen demands of the ammonia industry if multiple projects of larger capacities are not executed.

What will further solidify the analysis for the use case of using electrolysis technology for ammonia production is to make a distance map between the electrolyser plant and the ammonia production plant. This will provide sufficient data on the kilometres of 'hydrogen compatible' pipelines that need to be laid. The longer the distance of the electrolysis plant from the ammonia plant, the longer the pipeline needed and larger will be hydrogen losses along the way.

Conclusions & outlook

The goal is quite straightforward- decarbonisation of the ammonia production process and the industry alike. The quantity of hydrogen needed in the EU (plus UK, Norway and other European countries) just for the ammonia industry is **~3.33 million tonnes/ year**. This is currently supplied by using natural gas as the feedstock. Using natural gas as the feedstock comes with CO_2 emissions as detailed in the beginning of the report. The goal is to not have any CO_2 emissions from the ammonia production process and that is why emphasis is being laid on electrolysis technology to supply green or low carbon hydrogen. By removing natural gas as the feedstock, the CO_2 emissions will be cut however this CO_2 is an input feed stream for downstream urea production and in many of the ammonia plants, urea production also takes place on the same site. In a CO_2 free world, supplying CO_2 for urea production will be the next challenge that the industry will face.

Europe has a strong base when it comes to ammonia production, with location of ammonia plants scattered all over Europe. However, there is not a single electrolysis project, except for 'Iberdola Puertallano I' in Spain, which is exclusively dedicated towards ammonia production. Most of the electrolysis projects/plants in Europe are dedicated towards mobility and this makes little sense when there is an entire industry demanding 100s of ktonnes of hydrogen per year. The ammonia industry has no other alternative to hydrogen for ammonia production, purely due to chemistry reasons whereas mobility does have several alternatives and in such a scenario devoting and using expensive hydrogen for mobility is a waste of a resource.

The fifteen countries where ammonia production plants are located **doesn't have any electrolyser plant which can cater to even 1% of the demand of the hydrogen needed for ammonia production in that country** and to do so they must first build the renewable energy infrastructure in TWhs (Terra Watt hours). This a humungous task that lies ahead. Even if we assume that the entire 228 MW_{el} number for electrolysis (current status of installed electrolyser capacity) is used for hydrogen production for the ammonia industry, it will yield only 4.56 tonnes of hydrogen per year and this number is nowhere close to the required 3.3 million tonnes needed every year. Also, with the critical piece of hydrogen pipeline infrastructure missing, the situation looks bleak.

What needs to be done?

Countries with ammonia production plants must focus entirely on decarbonising this industry first by dedicating bulk of the electrolysis projects solely for catering to the ammonia industry.

Electrolysis plants must be located as close as possible to the ammonia plants and nowhere else. This is for two reasons - one most of the hydrogen produced today (for industry) is transported over very short distances or consumed at the site of production and second hydrogen dedicated pipelines are currently not available. Pumping hydrogen over very large distances will increase the energy usage needed for pumping it and will lead to losses along the pathway thus reducing the decarbonisation potential of the produced green hydrogen. Hence having electrolysis plants hundreds of kilometres away and the transporting this hydrogen makes absolutely no sense from an economic and technical point of view.

Another challenge will be the availability of sufficient renewable energy at the electrolysis site which in turn is fixed by the location of the ammonia plant. The amount of excess electricity needed for producing green hydrogen for the ammonia industry is in TWh for most countries and this amount of excess renewable energy is currently not available in a continuous manner through out the year. If the site (for electrolysis plant) close to the ammonia production plant has scope for sufficient renewable electricity, expandable into TWh, that's a great combination else the electrolysis plant can be hooked up to the grid and slowly the grid can be decarbonised. This will be a better approach than building electrolysis plants at remote locations.

With regard to hydrogen pipelines, what can be done is the following. Based on the locations of the ammonia plants and the electrolysis projects that are currently running, details of which are provided in this report, an initial plan can be laid out for the distance over which hydrogen needs to be transported. This distance must then be compared with the lengths of the hydrogen pipelines that are currently being used and if the lengths match then the electrolysis project can be given the green signal to go ahead else it will remain a challenge to get the green or low carbon hydrogen to the ammonia plant.

References

[1] *Perspective Europe 2030 - Technology options for CO2 emission reduction of hydrogen feedstock in ammonia production*, Florian Ausfelder, Eghe Oze Herrmann, Luisa Fernanda Lopez Gonzalez, DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V, ISBN: 978-3-89746-237-3, Jan 2022

[2] *A review of challenges with using the natural gas system for hydrogen*, Martin P, Ocko IB, Esquivel-Elizondo S et al. Energy Science Engineering 2024;1-15

[3] Clean hydrogen Monitor 2023, published by Hydrogen Europe

[4] Final Report *for a study on composition and drivers of energy prices and costs in energy intensive industries: The case of the chemical industry- Ammonia*, Prof. Christian Egenhofer, Lorna Schrefler et al. Centre for European Policy Studies, 13 Jan 2014

[5] Clean Ammonia - In the future energy system, Bastien Bonnet-Cantalloube, Marie Espitalier-Noel et al. Hydrogen Europe, March 2023

[6] https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map

Data Sources for projection map

For Ammonia plants, production capacity & company operating it:

- For plants at Sluiskil, Porsgrunn, Hull, Tertre, Ferrara, Le Havre, Brunsbüttel - Production capacity report from Yara, https://www.yara.com/siteassets/investors/057-reports-and-presentations/other/2020/production-capacities-by-segment-september-2020-pdf.pdf (Access date: 21 Sept 2024)
- For plants at Geleen, Police, Pulawy, Tarnów, Palos de la Frontera (see below also), Włocławek, Vratsa, Dimitrovgrad, Ottmarsheim, Grandpuits-Bailly-Carrois, Le Grand-Quevilly - From chemical market consultant.
- For plant at Billingham - https://www.cfindustries.com/what-we-do/ammonia-production (Access date: 21 Sept 2024)
- For plants at Antwerp, Ludwigshafen and Wittenberg - https://www.icis.com/explore/resources/news/2023/01/18/10846094/insight-poor-demand-high-costs-stifle-europe-industry-despite-falling-gas-prices/#:~:text=Europe's petrochemicals and fertilizer sectors,production started to ramp up. (Access date: 21 Sept 2024)
- For plant at Joanva -https://www.achema.lt/en/veikla/ (access date: 21 Sept 2024)
- For plant at Puertollano - https://www.fertiberia.com/en/our-group/where-to-find-us/ (Access date: 22 Sept 2024)

- For plant at Palos de la Frontera -
    - https://ammoniaenergy.org/articles/cepsa-renewable-ammonia-in-spain/#:~:text=Cepsa's La Rábida energy park,as other fertiliser manufacturing facilities). (Access date: 22 Sept 2024). The value given here is 400 k tonnes/year
    - From chemical market consultant, the value obtained was 415 k tonnes/ year. This number closely matches with the above source and the higher number was taken for the projection map.
- For plant at Šal'a - https://www.agrofert.cz/en/events-and-news/duslo-has-the-most-modern-ammonia-production-plant-in-europe (Access date: 22 Sept 2024)
    - The value was given in tonnes/day and this number was used to convert it to k tonnes/year assuming 365 days of operation.
- For plant at Pétfürdő - https://www.scopegroup.com/ScopeGroupApi/api/analysis?id=ce027252-521a-479a-a8ae-0b5d36dc345a#:~:text=This reflects Nitrogenmuvek's position as,1,345,000 tonnes), among others. (Access date. 22 Sept 2024)
- For plant at Litvínov - https://www.orlenunipetrol.cz/en/Media/PressReleases/Pages/20230711-TZ_OrlenUnipetrol-cpavkovy-reaktor-EN.aspx (Access date: 22 Sept 2024)
    - The plant capacity on the primary and secondary circuit was given in tonnes/day and this number was used to convert it to k tonnes/year assuming 365 days of operation.
- For plant at Târgu Mureș - https://www.chemanalyst.com/NewsAndDeals/NewsDetails/azomures-in-romania-plans-to-restart-ammonia-production-in-october-20810 (Access date: 22 Sept 2024)

For Electrolysis plants & production capacity:

- https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map

Calculation basis for electrical energy needed for hydrogen production:

50 kWh is approximately needed fro produce 1 kg of H2 via electrolysis. This number can go down based on optimisations etc. but the limit stands at ~42 kWh as on date. For ease of calculations 50 kWh is used.

Disclaimer:

This article has been written by Dr. Vikrant Venkataraman, Director & Founder of VenkaCon Consulting. The analysis and data are based on pure facts that is available on the internet and the views expressed are solely meant for providing a practical and holistic view on the whole electrolysis topic which is receiving great attention as on date.