NEXT NORDIC GREEN TRANSPORT WAVE - LARGE VEHICLES

Available by-product hydrogen in the Nordic countries

Deliverable 2.1
September 2020

Nordic Innovation

Table of contents

Next wave - about the project

Electrification of the transport sector already began and the Nordic countries, specifically Norway and Iceland, have taken major steps resulting in battery electric vehicles (BEVs) already accounting for a substantial percentage of the total sales. The world is looking towards the Nordics as they are providing global examples for success. However, little is happening regarding larger vehicles as battery solution still are not able to provide heavy-duty users (e.g., buses, trucks and lorries) the mobility they need.

Fuel cell electric vehicles using hydrogen as a fuel can solve this. The project focuses on providing infrastructure for a large-scale deployment of trucks, buses and lorries. The goal is to further stimulate the global technological lead, which the Nordic countries have by stimulating the very first hydrogen infrastructure roll-out for larger vehicles while at the same time map how the infrastructure build-up needs to be done, so that the transition to hydrogen vehicles can happen smoothly. Such roll-out will also benefit the use of hydrogen for trains and the maritime sector. Furthermore, in addition of sourcing the hydrogen as a by-product from the industry, in the Nordic region we have the unique opportunity to produce the hydrogen in a green manner exploiting renewable electricity production.

Already, Nordic industries have taken international lead in the field of hydrogen and fuel cells and a unique cooperation exists between "hydrogen companies" via the Scandinavian Hydrogen Highway Partnership (SHHP) cooperation. Jointly they have marketed the Nordic platform for hydrogen and, at the same time, paved the way for vehicle manufacturers to deploy such vehicles in the Nordic countries. When it comes to hydrogen, the Nordics have globally leading companies both within the infrastructure and the fuel cell business. The project therefore sets forward four key activities in a unique project where technical innovation and deployment strategies are intertwined.

The project will deliver an analysis on large-scale transport of hydrogen with mobile pipeline, a description of the innovation and business potential for a roll-out of FC-buses in the Nordic region, as well as a coordinated action plan for stimulating the FC truck demand and a prospect for utilising hydrogen in heavy-duty equipment. Finally, the project will contribute to national and Nordic hydrogen strategy processes even providing input to a possible Nordic Hydrogen Strategy.

Partners in Next Wave:

KUNNSKAPSBYEN LILLESTRØM

VTT

Brintbranchen Hydrogen Denmark

ÍSLENSK NÝORKA ehf ICELANDIC NEW ENERGY Ltd.

VÄTGAS SVERIGE

NORSK HYDROGENFORUM hydrogen.no

Authors:
Name of author, contributors company/ organization
VTT, Finland: Jari Ihonen
Hydrogen Sweden: Anna Grzelec, Erik Wiberg, Björn Aronsson
Icelandic New Energy: Jón Björn Skúlason
Hydrogen Denmark: Tejs Laustsen Jensen
Norwegian Hydrogen Forum: Knut Linnerud
Kunnskapsbyen Lillestrøm Norway: Jon Eriksen

Disclaimer:
This publication is part of the Nordic Smart Mobility and Connectivity initiative **Next Wave** (Next Nordic Green Transport Wave - Large Vehicles) co-financed by **Nordic Innovation**. The project partners are responsible for its content.

Photo: Kelly Lacy, Pexels

Summary

An overview for the availability of by-product hydrogen in Finland, Sweden and Norway was prepared. Significant amounts of by-product hydrogen are produced in Finland, Sweden and Norway by chlor-alkali or sodium chlorate industry.

However, it seems that utilisation of this hydrogen is currently very high in Sweden and Norway. Only in Finland there are sites (Äetsä, Joutseno) where significant amounts of hydrogen are vented or utilised only in heat production.

Either Iceland or Denmark has any by-product hydrogen production.

Background

In Finland, Sweden, and Norway, there are large amounts of hydrogen available as by-product from industrial processes. This hydrogen is only partially utilised and therefore a part of it could be used for hydrogen heavy duty vehicles.

Since some of the current use of hydrogen has mostly relatively low value (< 1 €/kg) the use in traffic would provide an opportunity for increased revenue for the industry producing by-product hydrogen. For instance, a large part of by-product hydrogen from sodium chlorate production in Finland is vented and most of the rest is used for heat production. This hydrogen does not fulfil FCEV requirements (ISO 14687). However, it should be possible to develop cost efficient purification methods.

The total amount of by-product hydrogen from global chlorate and chlor-alkali industries in 2016 was ~2 million tonnes (Mt) per year, which corresponds to 67 TWh/year (240 PJ/year) of energy based on net calorific value. This is about 2% of total hydrogen production globally.

Either Iceland or Denmark has any by-product hydrogen production.

Photo: Alexas_Fotos, Pixabay

Finland

The amount of by-product hydrogen production and utilisation of it has been studied in some previous studies (Hurskainen 2019; Ihonen 2013; Kauranen Pertti, Solin Jussi, Törrönen Kari, Koivula Jouko n.d.; Perrin, Steinberger-Wilckens, and Trümper 2007). The description here is an update for those studies, containing also some additional and new information.

Sodium chlorate production (Äetsä, Oulu, Joutseno)

Sodium chlorate is mostly used for making bleaching chemicals in pulp and paper industry. Global sodium chlorate market was 3.8 Mt/year in 2016 which corresponds to 200 kt/year of by-product hydrogen.

Sodium chlorate ($NaClO_3$) is produced via electrolysis of sodium chloride according to following equation:

$NaCl + 3\,H_2O \dashrightarrow NaClO_3 + 3\,H_2$

Theoretically, for each tonne of sodium chlorate, 56 kg of hydrogen is thus formed as by-product. According to Hedenstedt commercial sodium chlorate cells are operating at current efficiencies ranging from 92 to 95 % (Hedenstedt 2017). Since the cathodic and the anodic current efficiencies can be different the real figure can be ± 1-3 kg different from theoretical figure (56 kg).

By-product hydrogen production from the sodium chlorate production is globally one order of magnitude smaller than hydrogen production from chlor-alkali production. However, in some countries such as Finland, it is a dominant source of electrolytic by-product hydrogen due to extensive use of pulp industry, which uses most of the sodium chlorate.

In Finland sodium chlorate is produced by Kemira in Äetsä and Joutseno factories and by Nouryon Finland Oy in Oulu.

According to environmental permits and other documents (E.-S. Aluehallintovirasto 2017; L. sisä-S. Aluehallintovirasto 2013; Pohjois-Suomen Aluehallintovirasto 2017) the maximum amounts of hydrogen production are 7560 t/year for Äetsä, 9520 t/year for Joutseno and about 3080 t/year for Oulu assuming 56 kg of hydrogen is produced for each ton of sodium chlorate. In total this amounts to 20,160 tonnes/year.

The actual hydrogen production figures for all factories are not public or available only for some years. Using limited data and typical utilisation factors for these chemical plants, hydrogen production can be estimated to be about 90% of theoretical maximum. Therefore, it can be estimated that 18,000 tonnes of hydrogen are produced annually in these factories.

Use of hydrogen from sodium chlorate factories in Finland

In Äetsä hydrogen is used as fuel for heat, steam and compressed air production and as raw material in fine chemical production. A small part is sold to Woikoski merchant H_2 (quality 2.5).

In Oulu all hydrogen is sold to Stora Enso and used in Stora Enso's lime kiln in nearby pulp factory. Due to closure of chlor-alkali plant (mercury process based) in 2017 the amount of HCl production has decreased significantly and only a small fraction of hydrogen (200 t/year) is used for HCl production.

According to environmental permit, 80% of hydrogen is utilised in Äetsä (L. sisä-S. Aluehallintovirasto 2013). The use in Oulu seems to be 100% for the Stora Enso's lime kiln. In Joutseno, there is currently significant excess of hydrogen production but no exact figures for the utilisation are given. From different sources an estimate between 50% and 80% can be assumed. In Joutseno, hydrogen is mostly used for heat and power production and for HCl production.

Hydrogen quality

The use of by-product hydrogen from sodium chlorate production as FC vehicle fuel has been studied by Braxenholm (Braxenholm 2016) and an overview of a typical sodium chlorate hydrogen purification system is shown in in *Figure 1*. First 2 steps are minimum purification in order for the hydrogen to be vented. The additional (optional) purification is then added according to the final use of the hydrogen.

As a side reaction both Cl_2 and O_2 are formed reducing the energy efficiency of the process (Hedenstedt 2017). As a consequence, gas mixture contains H_2, Cl_2 (0.5%) and O_2 (3%). This hydrogen must be purified before it can be vented. This is illustrated in *Figure 1*.

After the basic purification (first 2 steps), H_2 still contains about 3% oxygen and small amount of Cl_2 and/or HCl and possibly other chlorine compounds, totalling under 2 ppm. In addition, typically there will be CO_2 in the order of a few tens of ppm and N_2 in the order of a few hundred ppm in the hydrogen, both levels exceed ISO standard (14687; specifies the quality characteristics of hydrogen fuel) levels.

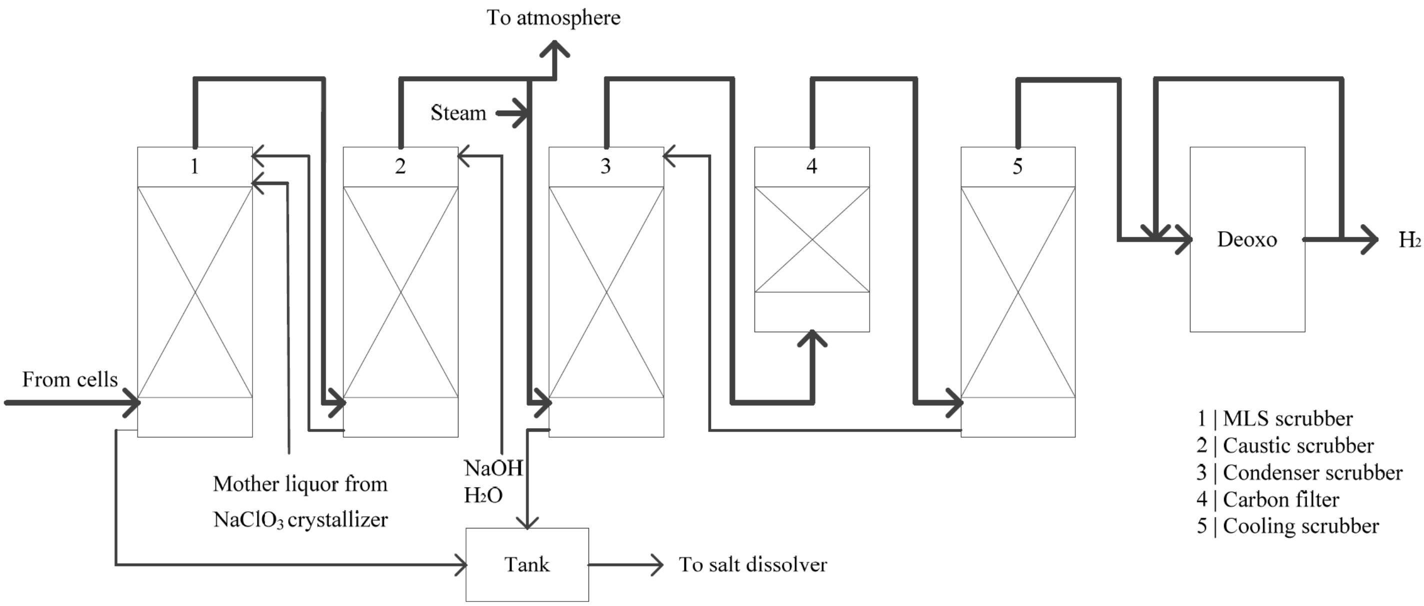


Figure 1. Overview of a typical sodium chlorate hydrogen purification system (Braxenholm 2016).

In Äetsä factory, additional purification is used. The levels of CO, CO_2 and CH_4 has been measured in the HyCoRA project (Viitakangas 2017). For instance, CO_2 level was often over 30 ppm.

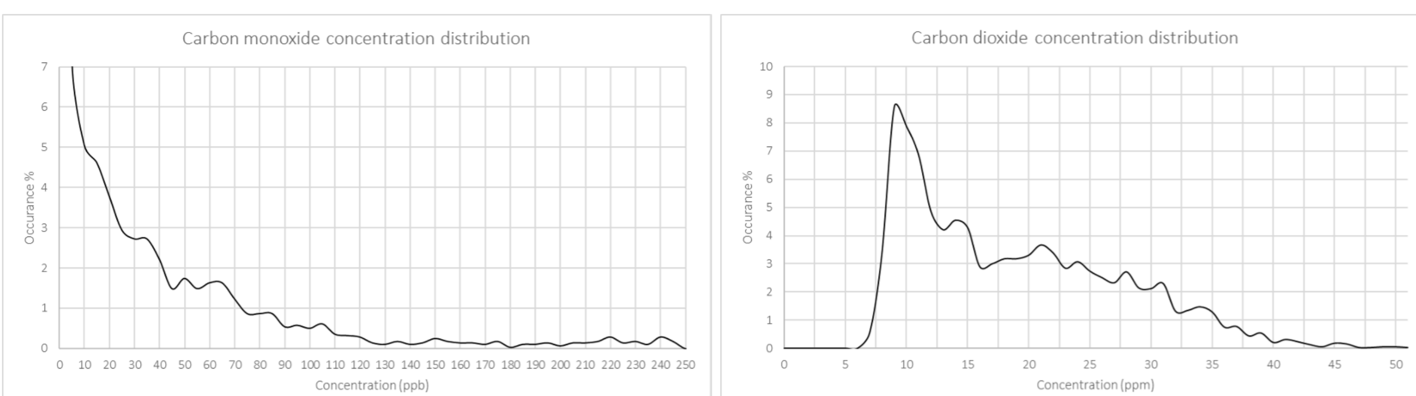


Figure 2. Carbon monoxide and carbon dioxide concentration distribution during stable factory operation.

In the HyCoRA measurements, nitrogen level was not measured. Therefore, it is not known how much the hydrogen index must be improved. Most probably, every now and then nitrogen level exceeds 300 ppm, which will be the new limit in ISO 14687 standard. It would be important to measure average nitrogen level.

Chlor-alkali production (Joutseno)

In chlor-alkali plants, caustic soda (sodium hydroxide, NaOH) and chlorine (Cl_2) are produced via electrolysis of aqueous solution of sodium chlorine (NaCl) according to following equation:

$$2\ NaCl + 2\ H_2O \rightarrow 2\ NaOH + Cl_2 + H_2$$

Theoretically, for each tonne of caustic soda produced, 25 kg of hydrogen is produced as a by-product. This is also case in practice due to high caustic current efficiency. Hydrogen is often used to produce hydrochloric acid (HCl) on-site, like in Joutseno. It is also used as fuel to provide the needed energy for the process. However, significant amount of hydrogen is also vented in chlor-alkali plants.

The annual production of caustic soda was ~72 Mt in 2016. This corresponds to ~1,800 kt of hydrogen and it has been estimated that around 15% of this is currently vented.

In Joutseno factory, 1600 tonnes of by-product hydrogen are produced annually from chlor-alkali process (Kärkkäinen 2015; Myller 2015) (before expansion). Most part of it is used for the production of HCl, while some of it is sold and some of it is vented (Kärkkäinen 2015).

In 2014-2015, Myller studied different options for Kemira to increase chlor-alkali production and in 2018 Kemira announced that there will be an investment for the increased production[1].

However, since there has been no announcements about new construction it can be assumed that the expansion of production capacity is only 20% (Cl_2: 54 kt/year -> 67 kt/year), which can be done by adding more chlor-alkali cells in existing factory building (Myller 2015). This would increase the hydrogen production capacity by 325 tonnes / year.

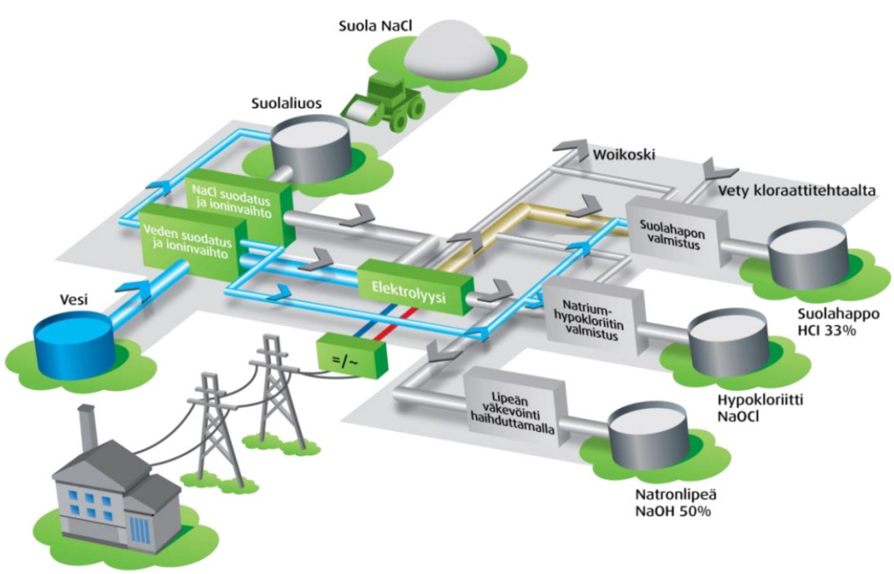
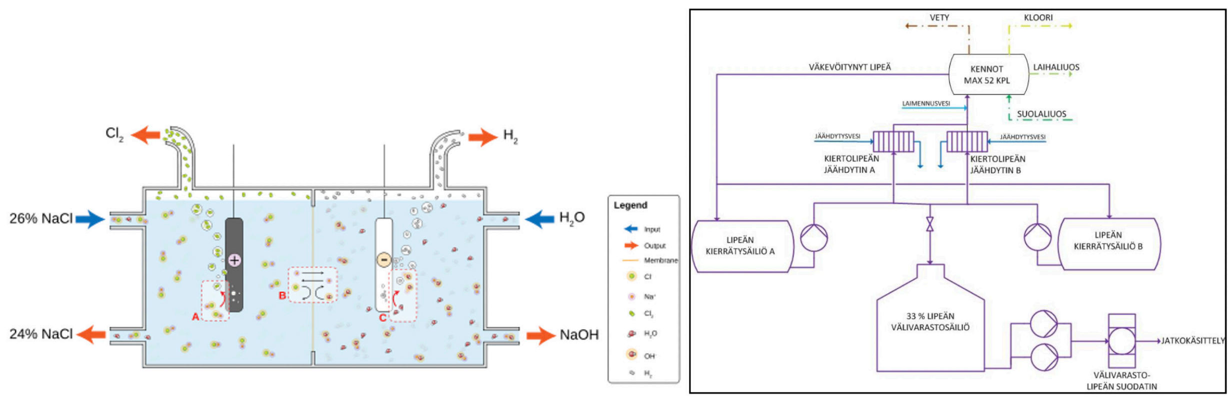


Figure 3. Chart of chlor-alkali factory in Joutseno (Myller 2015).

[1] https://www.kemira.com/company/media/newsroom/releases/kemira-expands-production-capacity-at-its-chlor-alkali-site-in-joutseno-finland/

Hydrogen quality

The quality of by-product hydrogen from chlor-alkali process is almost fulfilling ISO standard (14687). However, when field measurements have been performed there have been violations of N_2, CO_2 and also total hydrocarbon limits (Aarhaug and Kjos 2017). A common contaminant for chlor-alkali and sodium chlorate process would be oxygen (Bacquart et al. 2018) but this should be removed in deoxo system.



(a) *(b)*

Figure 4. a) Basic membrane cell used in the electrolysis of brine[2]. b) Handling of NaOH recirculation (Myller 2015).

Chlorine dioxide production (Kuusankoski)

At Kuusankoski fully integrated plant 1,380 t/a hydrogen is produced yearly (28.1 kg per ton of ClO_2) (K.-S. Ympäristökeskus 2006).

Since this is a fully integrated plant, where all sodium chlorate is used for chlorine dioxide (ClO_2) production, hydrogen is often considered as a by-product of chlorine dioxide production.

This is misleading, as when chlorine dioxide is produced from sodium chlorate, there is no hydrogen production. This applies to all about 10 different chlorine dioxide production alternatives.

In Oulu (Nouryon Finland Oy factory) a part of sodium chlorate is used for chlorine dioxide production (on-site) in so-called integrated process. Production rate for ClO_2 has been 7000-7500 tonnes/year in normal years, which means that one quarter of sodium chlorate is used for integrated ClO_2 production (P.-P. Ympäristökeskus 2015). The use sodium chlorate for integrated ClO_2 production is expected to end in 2020, as Stora Enso changes production in their factory[3].

[2] From: https://en.wikipedia.org/wiki/Chloralkali_process

[3] https://www.storaenso.com/en/newsroom/regulatory-and-investor-releases/2019/5/stora-enso-will-convert-the-oulu-paper-mill-into-a-packaging-board-mill

Summary for Finland

In *Table 1*, a summary for by-product hydrogen production in Finland is given. This is updated from LOHCNESS report (Hurskainen 2019) using more detailed estimates for some of the hydrogen production and using maximum values according to environmental permits. All in all, the maximum hydrogen production would be about 25,000 tonnes. Based on the available data the actual production is expected to be between 18,000 tonnes and 22,000 tonnes. The utilisation of hydrogen is high (> 80%), but it is mostly used for low value purposes. Therefore, there is significant potential for using this hydrogen as transportation fuel after purification.

The locations of by-product hydrogen production sites are shown in green arrows in *Figure 5*.

Table 1. A summary for by-product hydrogen production in Finland. Values are from environmental permits or calculated using information in environmental permits

Company	Plant/site	Annual hydrogen production in recent years		Annual maximum hydrogen production		Hydrogen production process	Use of hydrogen
		t/a	GWh/a (LHV)	t/a	GWh/a (LHV)		
Kemira Chemicals	Äetsä $NaClO_3$ plant	7,000 (2013)	233	7,560	252	By-product (chlorate electrolysis)	Fuel for heat, steam and compressed air production and as raw material in fine chemical production
Kemira Chemicals	Kuusankoski fully integrated ClO_2 plant using $NaClO_3$	591-986 (before 2006)	19.7-32.8	1,380	45.6	By-product (chlorate electrolysis)	Production of hydrochloric acid (HCl)
Kemira Chemicals	Joutseno, $NaOCl_3$ +NaOH plants	-	-	~ 13,000	~ 433	By-product (chlorate +chlor-alkali)	Fuel in boiler, HCl production in NaOH plant & Woikoski merchant H_2.
Nouryon Finland (previously Akzo Nobel)	Oulu, partially integrated ClO_2 plant using $NaClO_3$	1,525-2,767 (2007-2012)[1]	50.8-83.1	3,080	103	By-product (chlorate electrolysis)	Fuel in Stora Enso's lime kiln and HCl production

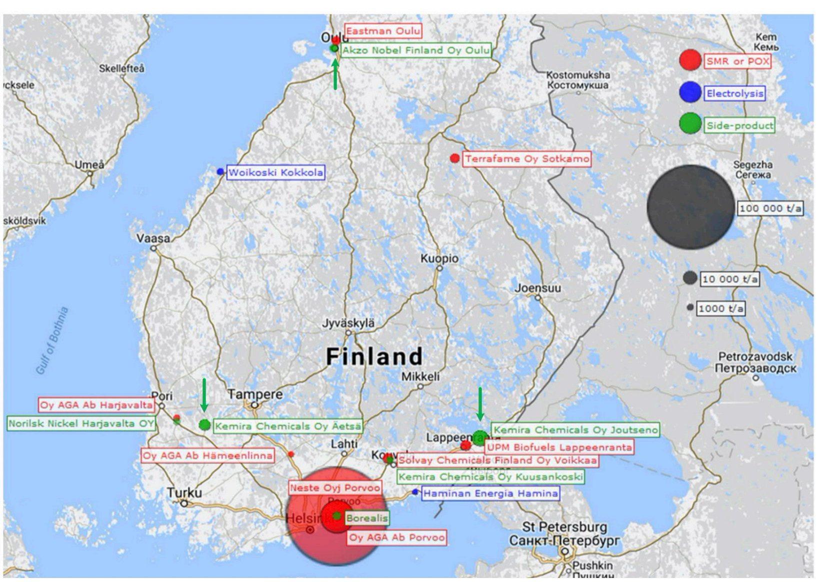


Figure 5. Hydrogen production in Finland from (Hurskainen 2019) including by-product production sites (Äetsä, Joutseno, Oulu).

[4] Includes only sodium chlorate production, as chlor-alkali plant was closed in 2017.

References for Finland

Aarhaug, Thor Anders, and Ole Kjos. 2017. "HyCoRA – D3.3 Results from the 2nd HRS Measurement Campaign." : 0–23.

Aluehallintovirasto, Etelä-Suomen. 2017. Päätös Dnro ESAVI/11436/2016.

Aluehallintovirasto, Länsi- ja sisä-Suomen. 2013. Päätös Dnro LSSAVI/138/04.08/2012.

Bacquart, Thomas et al. 2018. "Probability of Occurrence of ISO 14687-2 Contaminants in Hydrogen: Principles and Examples from Steam Methane Reforming and Electrolysis (Water and Chlor-Alkali) Production Processes Model." International Journal of Hydrogen Energy 43(26): 11872–83.

Braxenholm, Daniel. 2016. "By-Product Hydrogen to Fuel Cell Vehicles." Chalmers University of Technology, Sweden.

Hedenstedt, Kristoffer. 2017. 5 Energy Efficiency in the Sodium Chlorate Process: From Electrocatalysis to Pilot Plant Investigations. https://gupea.ub.gu.se/bitstream/2077/52081/2/gupea_2077_52081_2.pdf.

Hurskainen, Markus. 2019. "Liquid Organic Hydrogen Carriers (LOHC) - Concept Evaluation and Techno-Economics. Research Report VTT-R-00057-19." https://cris.vtt.fi/ws/portalfiles/portal/27082284/VTT_R_00057_19.pdf.

Ihonen, J. 2013. Value Chain Analysis of Hydrogen in Finland. http://hdl.handle.net/11250/276892 (August 28, 2017).

Kärkkäinen, Henri. 2015. "Vedyn Käytön Tarkastelu Kemira Chemicals Oy:N Joutsenon Tehtailla."

Kauranen Pertti, Solin Jussi, Törrönen Kari, Koivula Jouko, Laurikko Juhani. VTT Tutkimusraportti VTT-R-02257-13 Vetytiekartta – Vetyenergian Mahdollisuudet Suomelle.

Myller, Petri. 2015. "Kartoitus Kloori-Alkalitehtaan Tuotantokapasiteetin Kasvattamisesta."

Perrin, Jérôme, Robert Steinberger-Wilckens, and Sören Christian Trümper. 2007. "European Hydrogen Infrastructure Atlas and Industrial Excess Hydrogen Analysis. PART III : Industrial Distribution Infrastructure." Roads2HyCom: 1–38. https://www.ika.rwth-aachen.de/r2h/images/c/c8/Roads2HyCom_R2H2007PU_-_(Part_III)_-_Industrial_H2_Distribution.pdf.

Pohjois-Suomen aluehallintovirasto. 2017. Lupapäätös Dnro PSAVI/1453/2017.

Viitakangas, Jaana. 2017. "HyCoRA Hydrogen Contaminant Risk Assessment." : 2014.

Ympäristökeskus, Kaakkois-Suomen. 2006. 1 Ympäristölupapäätös Dnro KAS-2002-Y-265-111.

Ympäristökeskus, Pohjois-Pohjanmaan. 2015. Lupapäätös Dnro PS-AVI/127/04.08/2013.

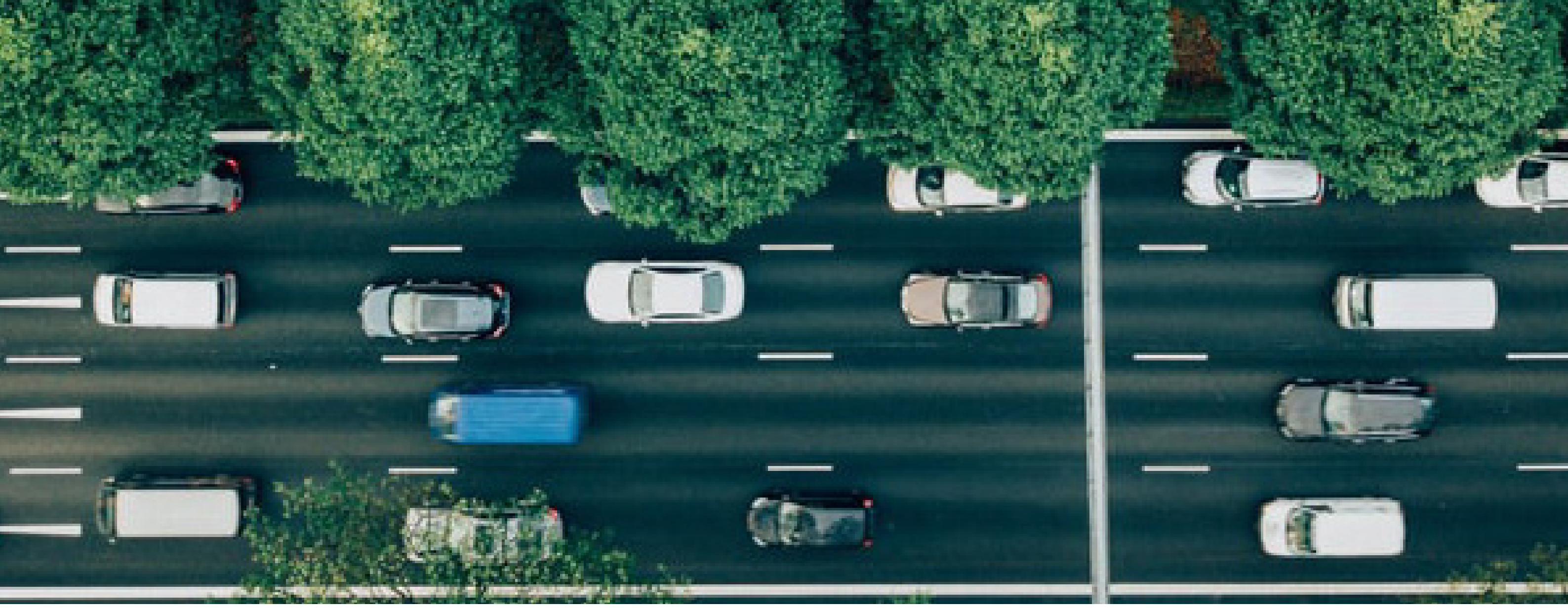


Photo: Chuttersnap, Unsplash

Norway

The two most interesting locations for by-product hydrogen for mobility means in Norway are: 1) the refinery at Mongstad north of Bergen, owned and operated by Equinor, and 2) the refinery at Slagentangen in Tønsberg, owned by ExxonMobil and operated by Esso Norge (DNV GL, 2019).

Furthermore, bio-refinery in Sarpsborg has by-product hydrogen production. In 2019, the amount was just above 2,700 tonnes per year. However, based on the information received from the refinery there is no excess hydrogen available as all of it is used for hydrochloric acid production.

Until recently, also by-product hydrogen from INOVYN's VCM-factory at Rafnes just outside Herøya in Porsgrunn was fed through a tunnel underneath the Frierfjord, *Figure 6*, supplying the oldest refuelling station in Norway with FC-grade hydrogen (Porsgrunn hydrogen refuelling station was opened in 2007 and was operated by Hyop AS – a predecessor of today's Hynion AS). Nowadays, INOVYN Rafnes defines their hydrogen more a product than a by-product and a new agreement between INOVYN and Hynion has not been signed. The INOVYN (an INEOS-company) operation in Norway is related to the INOVYN/INEOS operation Sweden – as described below. The hydrogen production at INOVYN Rafnes is approx. 25 tonnes/day (Hynion, 2020).

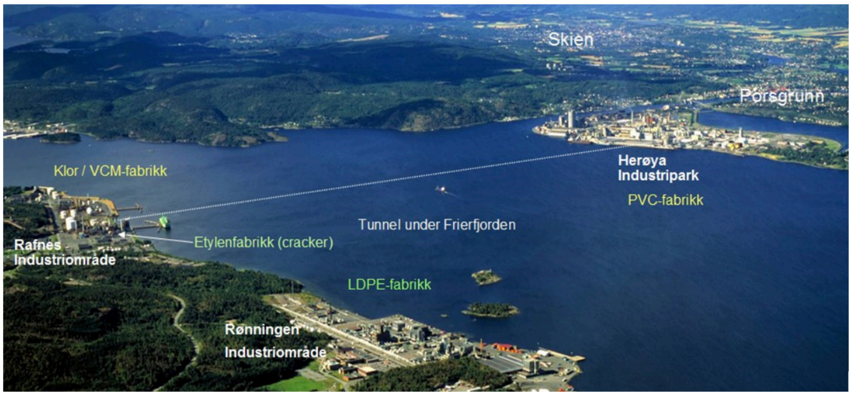


Figure 6. By-product hydrogen from INOVYN's VCM-factory at Rafnes being fed through a tunnel underneath the Frierfjord supplying the Porsgrunn refuelling station with FC-grade hydrogen (Blue Move, 2018).

Mongstad

The Mongstad refinery has a capacity of nearly 12 Mt of crude oil per year, with most of the production going for export, especially to the European continent. The refinery produces gasoline, diesel, aviation fuel and other light petroleum products, as well as petrol coke used for anodes in the aluminium industry (DNV GL, 2019).

Mongstad does not have a hydrocracker. As a result, Mongstad does not have its own hydrogen plant. Instead, the need for hydrogen (for instance for the desulphurisation processes) is covered by the by-production of hydrogen in upgrading crude oil to gasoline. According to (DNV GL, 2019), this amounts to between 30,000 and 35,000 tonnes of hydrogen per year. About half of this is used in further treatment of petroleum products, and the remainder is used for firing as part of the fuel gas stream.

About half of the surplus hydrogen at Mongstad has a hydrogen concentration that allows cost-efficient extraction of the hydrogen for use in refinery processes or for other purposes outside the refinery. Therefore, should there be a market for it, as of today there is a commercial potential to produce approx. 20-25 tonnes of hydrogen per day for use outside the refinery. However, it should be noted that the need for hydrogen to refine additional volume of oil from the Johan Sverdrup field (from 2019) will help to reduce the amount of "excess hydrogen" and that in the long run it may be necessary to buy extra hydrogen or have a separate hydrogen plant at Mongstad.

A possible decision to produce hydrogen for use outside the Mongstad plants, or possibly design a hydrogen plant for such production, requires a secure market for this, and a robust business case with at least 10-15 years of perspective.

Slangentangen

The ExxonMobil refinery at Slagentangen in Tønsberg has a capacity of around 6 million tonnes of crude oil, and produces propane and butane, gasoline, kerosene, diesel and heating oil. The refinery also has a biodiesel blend plant and ethanol blend in gasoline. About 60% of the refinery's production of petroleum products are exported (DNV GL, 2019).

As at Mongstad, neither this refinery has a hydrocracker and the hydrogen produced comes from the refinery process itself. According to (DNV GL, 2019), this amounts to around 9,000 tonnes of H_2/year, of which around 30-45% is used for firing. In the short term, there are no current plans that will change this balance. It is therefore potentially possible to extract hydrogen from this combustion gas for use outside the factory. However, this will require extra supply of natural gas (or other fuel) and will only be appropriate from a climate perspective if produced CO_2 is trapped and deposited in a suitable CO_2 storage facility (the current CO_2-emissions from the refinery amounts to approx. 360,000 tonnes per year). No such plans exist today. Nor is there any other industry near the refinery that are current users of large quantities of hydrogen.

In the longer term, it may be appropriate to produce more biofuels at Slagentangen, for instance from wood. This will require large amounts of hydrogen, and more than what is available from the refinery process itself. This means that a separate hydrogen production plant is required for a significant production of wood-based biofuel to be realised. As a result, ExxonMobil wants to look at opportunities to establish a hydrogen plant in or near the refinery, not necessarily owned by ExxonMobil, which can supply hydrogen for increased consumption at Slagentangen, and possibly also for sale to other consumers (DNV GL, 2019).

Summary for Norway

In Norway, around 225,000 tonnes of hydrogen per year is produced from industrial processes. Yara's ammonia production at Herøya and Equinor's methanol production at Tjeldbergodden account for most (182,000 tonnes) of this. Both of these plants have their own gas reformer and produce all the hydrogen they need themselves. The rest of the hydrogen production in Norway is mainly a by-product of gasoline production at the oil refineries at Mongstad and Slagentangen (DNV GL, 2019). In addition, by-product hydrogen is produced by Borregaard. However, this is used for hydrochloric acid production.

Overall, this means that there are no significant amounts of unutilized or low value by-product hydrogen available in Norway for road traffic.

Additional information:

Back in 2007, the EU-project Roads2HyCom listed various industrial hydrogen production sites around Europe in Annex 4 of their, "Deliverable 2.1 and 2.1a - European Hydrogen Infrastructure Atlas and Industrial Excess Hydrogen Analysis"-report (Roads2HyCom, 2007). A follow-up study of the Norwegian companies listed (*Table 2*) were made in the Next Wave-project. The outcome of the follow-up study is listed in *Table 3*. In summary, for the companies still operative, it seems that the overall situation caused by the Corona pandemic has made it difficult to prioritize response to our requests, on the side of the company's core businesses.

Table 2. Norwegian industrial hydrogen production sites as listed by the Roads2HyCom-project (Roads2HyCom, 2007)

Region	Plant site	Owner	Capacity [10^3 m³/day]	Process/ source	Current Use/ Remarks	Availability
Østfold	Sarpsborg	Borregaard Industries	33	CS	Hydrochloric acid	By-Product
Telemark	Rafnes-Stathelle	Norsk Hydro	197	CS		By-Product
Telemark	Rafnes	Noretyl	234	Ethylene		By-Product
Telemark	Rjukan	Norsk Hydro		WE	Gases and chemicals division	Merchant
Sogn og Fjordane	Svelgen	Elkem ASA, Silicon Division	9	CS		By-Product
Sogn og Fjordane	Vadheim	A/S Vadheim Elektrochemiske Fabriker	11	S		By-Product
Nordland	Mo-i-Rana	Eka Chemicals	85	S	Fuel and external sales	By-Product

CS = Chlorine sodium hydroxide electrolysis
S = Sodium chlorate
WE = Water Electrolysis

Table 3. Outcome of the follow-up study on the companies listed in Table 2

Borregaard Industries

- EHS and Sustainability manager:
  We use all the hydrogen we produce ourselves to make hydrochloric acid in hydrochloric acid reactors, where hydrogen and chlorine gas react. (Chlorine gas comes from electrolysis of NaCl with membrane technology). We have no extra capacity hydrogen that can be utilized for other purposes.
- Norwegian Environment Agency:
  Hydrogen production per year from 2013-2018: approx. 1,300 tonnes/year

INEOS

- Together with INOVYN (a company owned by INEOS), INEOS owns and operates the petrochemical industries at Rafnes listed as Norsk Hydro, Rafnes-Stathelle and Noretyl, Rafnes in Table 2.
- Next Move have been in contact with the General Manager of INEOS Rafnes informing us that they did not have resources to follow up on our request due to Corona.
- From the co-operation between INOVYN and Hyop, a hydrogen production rate at INOVYN Norge at Rafnes of approx. 25 tonnes/day has been mentioned.
- From their website:
  - Annual ethylene production at INEOS Rafnes is 600,000 tonnes.
  - VCM (vinyl chloride monomer or chloroethene) and caustic soda are both produced at INOVYN Norge at Rafnes. Annual caustic soda production capacity is 325,000 tonnes. The VCM is used for PVC-production at INOVYN Norge at Herøya, just across the fjord.
  - Annual PVC-production at INOVYN Norge at Herøya is 160,000 tonnes S-PVC and 40,000 tonnes P-PVC.

Nippon Gases Norge

- Owns and operates the hydrogen production capacity at Rjukan listed as Norsk Hydro, Rjukan in Table 2.
- From their website:
  - 1,500 kg hydrogen stored on-site

Elkem

- Next Move have approached Elkem in different ways without any response.
- According to a project list at Ocean Hyway Cluster (OHC, 2020): Hydrogen is a by-product of the Silgrain production process at Elkem Bremanger (located in Svelgen) partly utilised in the hydrochloric acid production produced via electrolysis of brine and further processed via burning of hydrogen and chlorine. Approx. 70% of the hydrogen (300 kg/day) is released into the air together with steam. This gives about 110 tonnes of vented hydrogen per year.

Vadheim Elektrochemiske Fabriker

- Vadheim Elektrochemiske Fabriker owned their own 45 GWh hydropower power plant and was turned into a pure power plant in 2007 after loosing a key contract with Sødra Cell (former Tofte Cellulose) in 2006, (Bergens Tidende, 2015) and (Allkunne, 2010).

Eka Chemicals

- Eka Chemicals situated in Mo industrial park in Rana was shut down in 2009 (Rana Blad, 2009).
- Recently, Statkraft, steel manufacturer CELSA and Mo industrial park signed an agreement with the intent to develop a complete value chain for green hydrogen (Statkraft, 2020). The ambition is to build an electrolysis facility that can produce 2-4 tonnes of green hydrogen per day, enough to replace the fossil fuels currently used in CELSA's production and other applications such as other local industrial applications and as a fuel.

References for Norway

Allkunne (2010) Vadheim Elektrochemiske Fabrikker, https://www.allkunne.no/framside/fylkesleksikon-sogn-og-fjordane/samfunn/industri-naring-og-bedrifter/vadheim-elektrochemiske-fabrikker/1900/76175/

Bergens Tidende (2015) På jakt etter svar om kraftmillioner, https://www.bt.no/nyheter/lokalt/i/W77LG/paa-jakt-etter-svar-om-kraftmillioner

Blue Move (2018) Mulighetsstudie for produksjon, industri, lagring og distribusjon av hydrogen, Rapport KL-2017-01-BM-V2, http://www.scandinavianhydrogen.org/wp-content/uploads/2018/08/Rapport-KL-2017-01-BM-V2.pdf

DNV GL (2019) Produksjon og bruk av hydrogen i Norge (2019-0039, Rev. 1, p83 - 94). https://www.regjeringen.no/contentassets/0762c0682ad04e6abd66a9555e7468df/hydrogen-i-norge---synteserapport.pdf

Hynion (2020) Ulf Hafseld, CEO, e-mail communication 2020-05-26

Norwegian Environment Agency. https://www.norskeutslipp.no/no/Diverse/Virksomhet/?CompanyID=5086

OHC (2020) Project listing, https://www.oceanhywaycluster.no/projectlist/elkem

Rana Blad (2009) Eka Chemicals legger ned, https://www.ranablad.no/naringsliv/eka-chemicals-legger-ned/s/1-93-4235911

Roads2HyCom (2007) Deliverable 2.1 and 2.1a - European Hydrogen Infrastructure Atlas and Industrial Excess Hydrogen Analysis, Doc. No.: R2H2006PU.1, http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=0E578CF5F428097C8BD4DF4A7706DA81?doi=10.1.1.477.3069&rep=rep1&type=pdf

Statkraft (2020) Hydrogen production and green steel in Mo Industrial Park, https://www.statkraft.com/newsroom/news-and-stories/archive/2020/hydrogen-og-stal/

Photo: Markusspiske, Pixabay

Sweden

19% of the hydrogen produced in Sweden comes as a by-product (Karlsson 2001), while most of it is produced through steam reforming of natural gas (54%), electrolysis (20%) and cracking (7%). Hydrogen as by-product can mainly be found in the chemical industries, which in the case of Stenungsund are organized in a cluster. Another area where hydrogen is commonly produced as a by-product is in oil refineries.

Hydrogen clusters

Figure 7. The Swedish methane gas grid (Swedegas 2020).

In Sweden today there is limited methane gas infrastructure, since the use of methane in dwellings, heating and electricity generation is not widespread. The Swedish gas grid stretches from Dragör in Denmark to Stenungsund on the Swedish west coast with some branch pipelines extending to a total of 600 km, *Figure 7*. The main grid is owned by the company Swedgas and distribution networks are connected to it. The pipelines are built of steel with a lining of polyethylene. The pressure in the grid is 80 bar and the diameter between 40 cm and 60 cm, decreasing to the north (Swedgas 2020). Natural gas is being transported from Denmark to different industries and clusters, as well as a powerplant. Bio methane is injected along the way at several points.

Moreover, the Swedish energy authorities (Hovsenius & Haegermark 2005) have calculated that the transport cost of hydrogen is high compared to other gases since the energy contents is lower. By not including the environmental aspects of hydrogen in their calculation they have contributed to dis-incentivizing the hydrogen trade.

There are however locally established pipelines, between companies located in geographical proximity. One such example is Sandviken, where there is a pipeline between Linde and the factories of Sandvik and the refueling station (located next to a Sandvik factory) (Sandviken municipality 2019). Linde produces hydrogen through electrolysis for commercial purposes, i.e., it is not a by-product. Sandvik utilizes the hydrogen for the cutting technologies and steel processing that they deliver to clients.

There is another hydrogen cluster in Stenungsund, around the chemical industries. The chemical industry is also the main producer of hydrogen as a by-product in Sweden (Wallmark et al. 2014). Two chemical companies in Stenungsund are Borealis (producer of ethylene and propylene) and Inovyn (producer of polyvinyl chloride and caustic soda). Borealis provides one client (Perstorp) with hydrogen through a pipeline, and there is also a pipeline between Inovyn and Borealis, where Inovyn supplies hydrogen to Borealis as a back-up in the situations where Borealis cannot provide their client with hydrogen. This is illustrated in *Figure 8* (where Inovyn has their old name: Ineos).

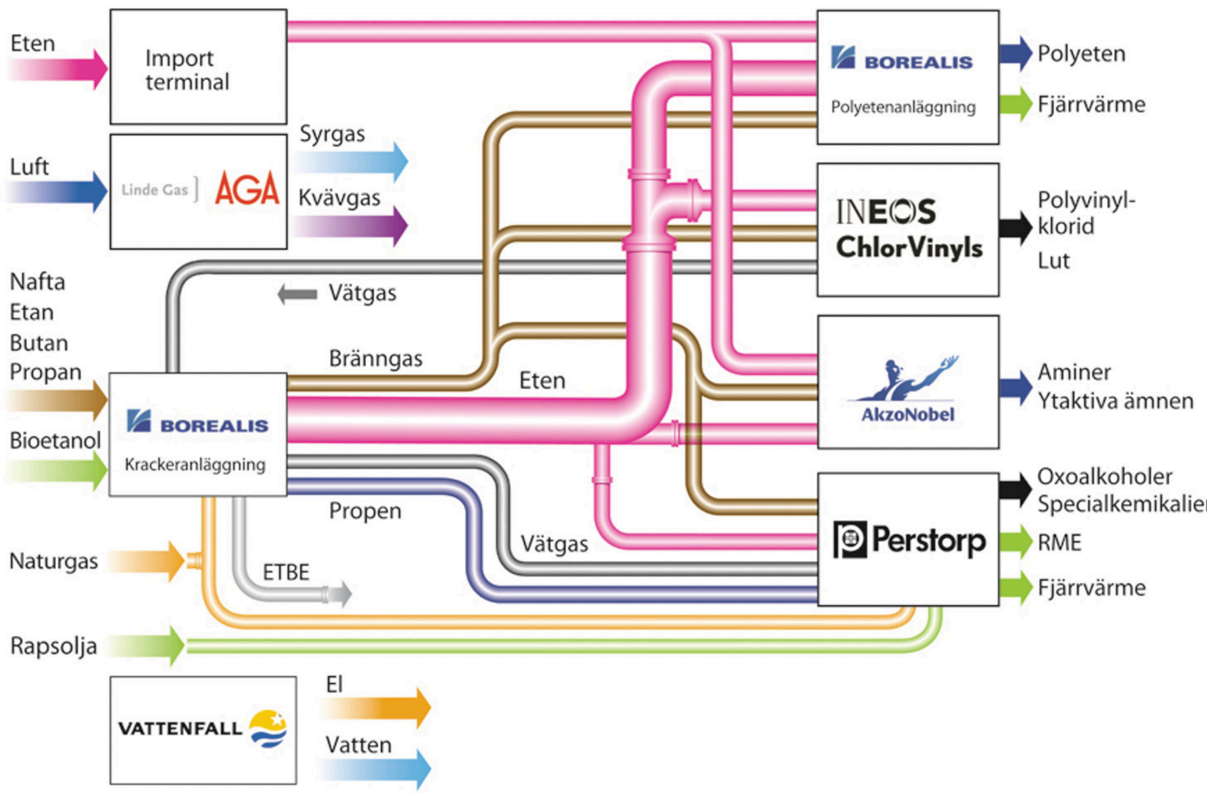


Figure 8. The pipe system of the industrial cluster in Stenungsund, where hydrogen (vätgas) is a small component traded between Inovyn (formerly known as Ineos), Borealis (cracker) and Perstorp (Borealis Environmental report 2014).

Borealis

Borealis manufactures ethylene, polyethylene and propylene through cracking. In this process, hydrogen is also produced, as shown in *Figure 9* (hydrogen = väte in the figure). They yield 3 tonnes of hydrogen per hour, but it is mixed with methane. Pure hydrogen is produced in the volume 0.2 tonnes/hour, and they could produce another 0.5 tonnes/hour (Sundqvist & Petersson 2017). They utilize it in their hydrogenation process when transforming naphtha, ethane, propane and butane into ethylene and propylene, as fuel for the cracking-furnace, as a terminator in the polyethylene production process (108 tonnes/year) and sell the rest, see *Figure 10*.

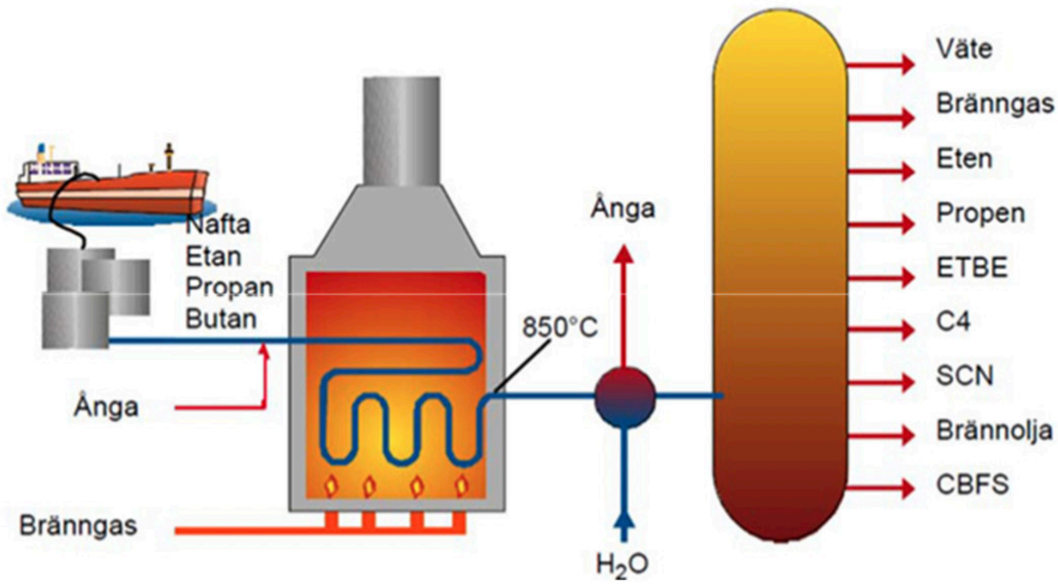


Figure 9. Hydrogen production at Borealis (hydrogen = väte) (Borealis Environmental report 2018).

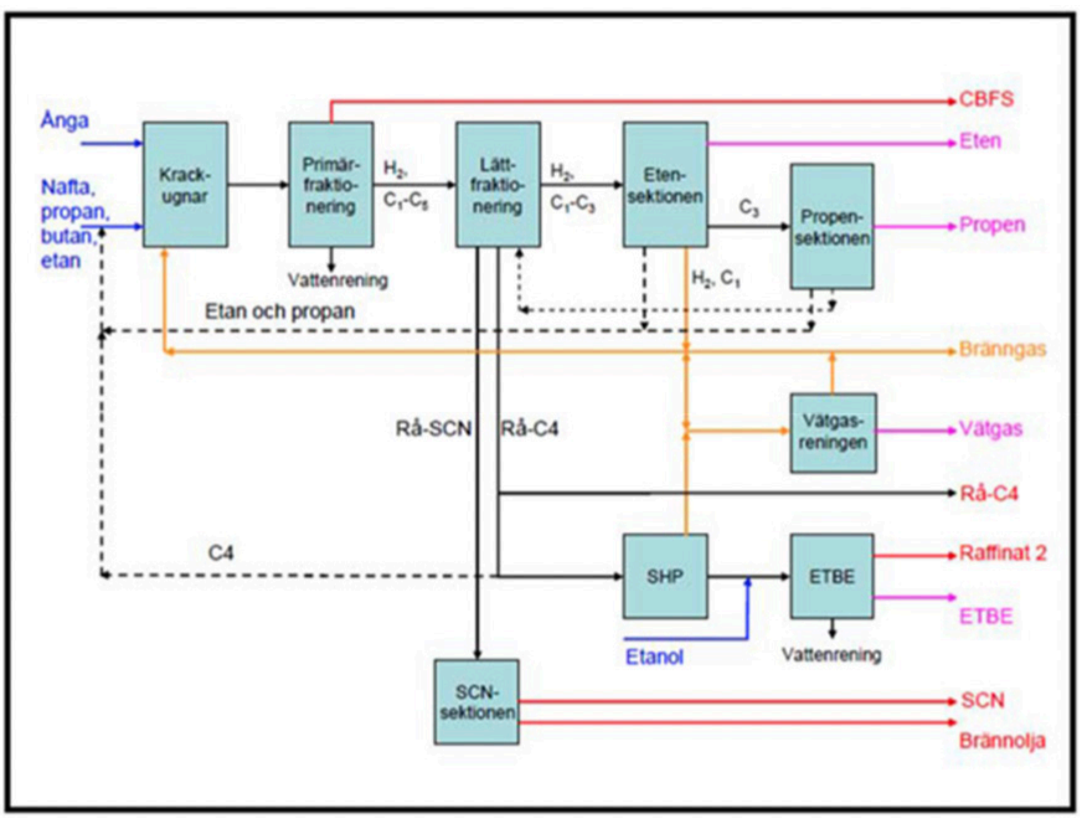


Figure 10. Hydrogen production at Borealis (Borealis Environmental report 2014).

Inovyn

Inovyn (formerly known as Ineos) produces polyvinyl chloride and caustic soda. For this they need to produce chloride, which generates hydrogen as a by-product, see Figure 11. In the electrolysis process, salt solution is led to the anode and caustic soda to the cathode. Sodium passes from the anode to the cathode which produces sodium hydroxide. At the anode, chlorine gas is produced and at the cathode, hydrogen gas. The hydrogen gas is first cooled, and then compressed. It is then used to fuel their steam production (277,101 GJ energy was produced from hydrogen in 2019) and some of it (87 tonnes in 2019) is delivered to Borealis as a back-up when Borealis cannot deliver to their client. 264,000 kg of hydrogen is also released into the air (Inovyn Environmental report 2019).

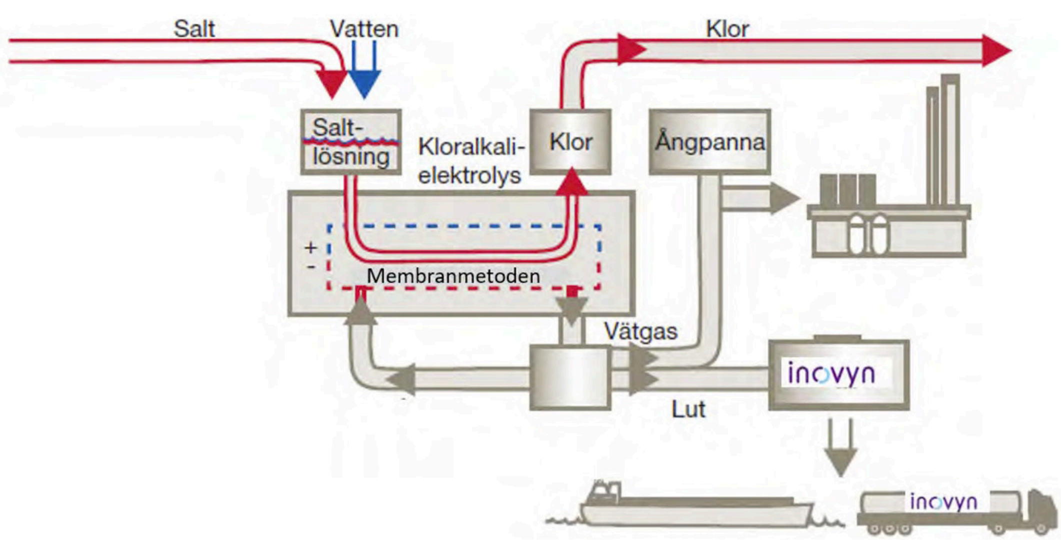


Figure 11. Chloride production process at Inovyn, where hydrogen come out from the chlor-alkali electrolysis, and is delivered to the steam heater (Inovyn Environmental Report 2019).

Inovyn is satisfied with using their surplus hydrogen production in their steam heater, as it lowers their CO_2 emissions compared with other methods to fuel their steam heater. Therefore they are not interested to sell any more of their hydrogen for other purposes (Eliasson, e-mail communication 2020-05-08). One important aspect of hydrogen as a by-product is that it is not known how pure it is, and therefore it is not clear if it can be utilized directly into a fuel cell (Braxenholm 2016), or if it needs to be purified (Sundqvist & Petersson 2017). One study of how the hydrogen of Inovyn performs in a fuel cell showed mixed results (Agartson 2013).

Nouryon

The chemistry company Nouryon produces a variety of chemical substances. In their sodium chlorate process, at their plant outside Sundsvall (Stockviksverken), hydrogen is formed as a by-product, about 30 million Nm^3, corresponding to 89 GWh / year. Of this, 30 percent is used by the sister company Surface Chemistry for the production of detergents, 60 percent is used as energy supplement (for drying and steam production). A small quantity is sold to Linde and 10 percent is vented away due to difficulties in synchronizing use and production. The company also has a sodium chlorate production plant in

Alby, 1 km outside Ånge, where about twice as much hydrogen is produced as in Sundsvall. The hydrogen gas is used here to produce hydrogen peroxide (Biofuel Region - Regionala förutsättningar för infrastruktur för elfordon och förnybara drivmedel –i Västernorrland, Juni 2019).

Summary for Sweden

In Sweden by-product hydrogen is mostly produced in large industrial clusters (e.g., Stenungsund) where it is utilised or it is otherwise utilised efficiently. This means that only a minor amount of by-product is available from industry to road vehicles. Even though this hydrogen is not available for vehicles, stationary fuel cells can be used to increase efficiency in heating and electricity over the year in these industries.

References for Sweden

Agartson, E. (2013), The performance of a pemfc operating on by-product hydrogen from chemical industry, Master thesis in material science and engineering, KTH Material Science and Engineering, Stockholm.

Biofuel Region - Regionala förutsättningar för infrastruktur för elfordon och förnybara drivmedel –i Västernorrland, Juni 2019

Borealis Miljörapport (Environmental report) 2018

Borealis Miljörapport (Environmental report) 2014

Braxenholm, D. (2016). By-Product Hydrogen to Fuel Cell Vehicles. Master thesis, Chalmers University of Technology, Sweden.

Eliasson, I. Environment/Communication specialist Inovyn, e-mail communication 2020-05-08

Hovsenius, G. & Haegermark, H. (2005), Väte i det svenska energi- systemet? En framtidsstudie, Elforsk rapport 05-18

Inovyn Miljörapport (Environmental Report) 2019

Karlsson, A. (2001), Vätgasinblandning i cng - förstudie, Rapport SGC 122 ISSN 1102-7371 ISRN SGC-R-122-SE . Chalmers Tekniska Högskola.

Sandviken municipality 2019-05-03 https://sandviken.se/nyheter/start/sandvi-keniframkantnardetgallervatgas.5.552981e816a53a0961f639c3.html https://sandviken.se/download/18.552981e816a53a0961f643d8/1556801108225/Sandviken.pdf (accessed 2020-05-11)

Sundqvist, A. & Petersson, A (2017) Vätgas som biprodukt -En Affär? Kandidatexamensarbete, Kungliga Tekniska Högskolan, Skolan för Industriell Teknik och Management.

Swedgas (2020), Svenska stamnätet, https://www.swedegas.se/gasnatet/gasnatet

Wallmark, C., Mohseni, F., Schaap, G. et al. (2014), Vätgasinfrastruktur för transporter i Sverige 2014-2020 TEN-T, HIT-1 NIP-SE http://www.vatgas.se/wp-content/uploads/2016/02/Vatgasinfrastruktur_Huvudrapport.pdf

Next Nordic Green Transport Wave - Large Vehicles

Deliverable 2.1

Available by-product hydrogen in the Nordic countries

Version 1.0

2020