Belgium as a hydrogen importhub

Roadmap towards 2030 and beyond

COLOFON

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Content

Management summary

With this roadmap the Hydrogen Import Coalition wants to draw up the implications, actions and boundary conditions required to reach the target hydrogen import and off-take in Belgium.

This roadmap refers to the Belgian targets in the updated hydrogen 2030 vision of October 2022, and even more to the EU targets for 2030 and 2035 on hydrogen off-take, prescribed in the provisional agreement on the revision of the Renewable Energy Directive (RED) of March 30th of 2023 (reference: tinyurl.com/Viewstrategyhydrogen). This revision explicits a share of renewable hydrogen in industrial use of 42% in 2030 and 60% in 2035 and in transport of up to 5,5%[1] in 2030.

The coalition strongly believes that renewable hydrogen progressively will earn its position in the energy landscape of the future and will be indispensable in our energy system. Import of hydrogen based renewable molecules will enable long term energy storage, system efficiency and affordable & secured energy supply. It also represents an opportunity for energy export towards our neighbouring countries. **But at the same time the coalition calls to realism with regard to the 2030 targets. The targets are very ambitious, drastic and within reach, but immediate action is required, as pictured and flagged in the roadmap below.**

1. Joint target of 5,5% with biofuels, with a minimum of 1% of hydrogen based fuels.

Backbone (BE) — Interconnection (DE)

2023 2024 2025 2026 2027 2028 2029 2030

MARKET DESIGN

1ST BE SHIP IMPORT

BE SHIP IMPORT & TRANSIT

BE	10 - 15 TWh/Y
DE, NL	25 - 35 TWh/Y
Terminals	35 - 50 TWh/Y
Cracking	15 - 25 TWh/Y
Backbone	30 TWh/Y

Volumes based on REDIII projections

PRIORITY ACTIONS

POLICY
- **Regulation**
- **Certification**
- **International market platform**
- **Support mechanisms**

INFRA
- **Backbone**
- **Terminals and cracking facilities**
- **Trains & barges**
- **Seagoing vessels**

INNOVATION
- **NH_3 conversion to hydrogen**

COMPLEMENTARY ACTIONS

GLOBAL TRADE
- **Collaboration with export countries**
- **Cross border technology trade and investments**

INNOVATION
- **Direct air capture and carbon loop**
- **LOHC and liquid hydrogen**
- **GW scale electrolysis**

The Belgian hydrogen vision and the provisional RED targets are resulting in a 2030 projection of 10 to 15 TWh/year renewable hydrogen off-take in Belgium, being in same order of magnitude as the current fossil hydrogen off-take. As the potential of local production in Belgium is limited and Belgian energy intensity is high, import of hydrogen will play a key role representing more than 90% of the total supply. Adjacent regions like North-Rein-Westphalia in Germany and Geleen/Chemelot in the Netherlands are in a comparable situation. As for natural gas today, **Belgium will be a key partner in import and transit for these regions to enable implementation of RED and national targets.** Import and transit volumes to these regions in 2030 can run up to 35 TWh/year. The Belgian seaports, especially the port of Antwerp-Bruges, and the Belgian natural gas infrastructure, both with its central position, existing terminals, actual large off-take and strong industrial relations with both adjacent regions, are the unique selling points in regard to this transit.

The projected import and transit volumes require important investments in infrastructure, mainly in terminals, cracking facilities and backbones, but also in transport equipment such as sea going vessels, trains and barges.

The EU ambitions are undeniably and gradually stimulating already as of today the local EU demand and initiating a large number of hydrogen production initiatives globally as listed by the IEA in its Hydrogen report 2022. Also in Belgium several key initiatives are already taken, e.g. in the development of terminals and ammonia cracking facilities in the Port of Antwerp-Bruges and of an open-access backbone within and in between Belgian industrial clusters. Furthermore, Belgian based companies are developing worldwide large scale hydrogen and derivatives production with Belgian technology.

However without additional decisive action this will not be sufficient. **Priority actions have to be flagged in the field of regulation, policy and infrastructure, resulting in a decision on an effective market design in 2023 and first ship import via the Belgian seaports in 2027.**

To start with, REDIII needs to come into effect and to be converted into national legislation as soon as possible in a way that it supports our specific industrial ecosystem..

Priority policy 'red flag' actions for an effective market design in 2023

- To make hydrogen competitive with fossil fuels in the start-up phase until market ramp up, new effective support mechanisms must be put into operation and scaled up. Through double sides auctions a first price signal can arise, and an efficient and temporary spending of public money can be realised.
- To develop a liquid market and the off-take of hydrogen, adequate and pragmatic **certification** of renewable and low-carbon hydrogen must be ensured. Currently, the lack of a clear and well-organized framework for hydrogen certification hinders the development of the hydrogen market in Belgium and with neighbouring countries.
- To establish trade in hydrogen, a **hydrogen exchange** must be set up that ensures proper market functioning and transparent, efficient pricing.

Priority actions 'red flag' for first ship import via Belgian seaports ready in 2027

- Kickstart and ensure sufficient supply of renewable molecules into the European mainland import **NH_3 terminals and NH_3 cracking** facilities will be key. The need for additional import methanol terminals will follow on NH_3 terminals, but due to increasing interest sooner than anticipated now.
- Transport of hydrogen via **backbones** will be necessary to link supply and demand. The Belgian system requirements and expectations in the field of **planning, balancing and H_2 purity** must be mapped by the Belgian government within an EU context. The compatibility of system design to enable interconnection between Belgium and adjacent countries for H_2 must be ensured.
- A positive climate for investments in inland transport means for derivatives, e.g. **backbones, trains and barges**, has to be established to link supply and demand.
- To kickstart and ensure sufficient supply of renewable molecules into the European mainland, the existing NH_3 supply chain of **sea going vessels** can be repurposed and expanded.

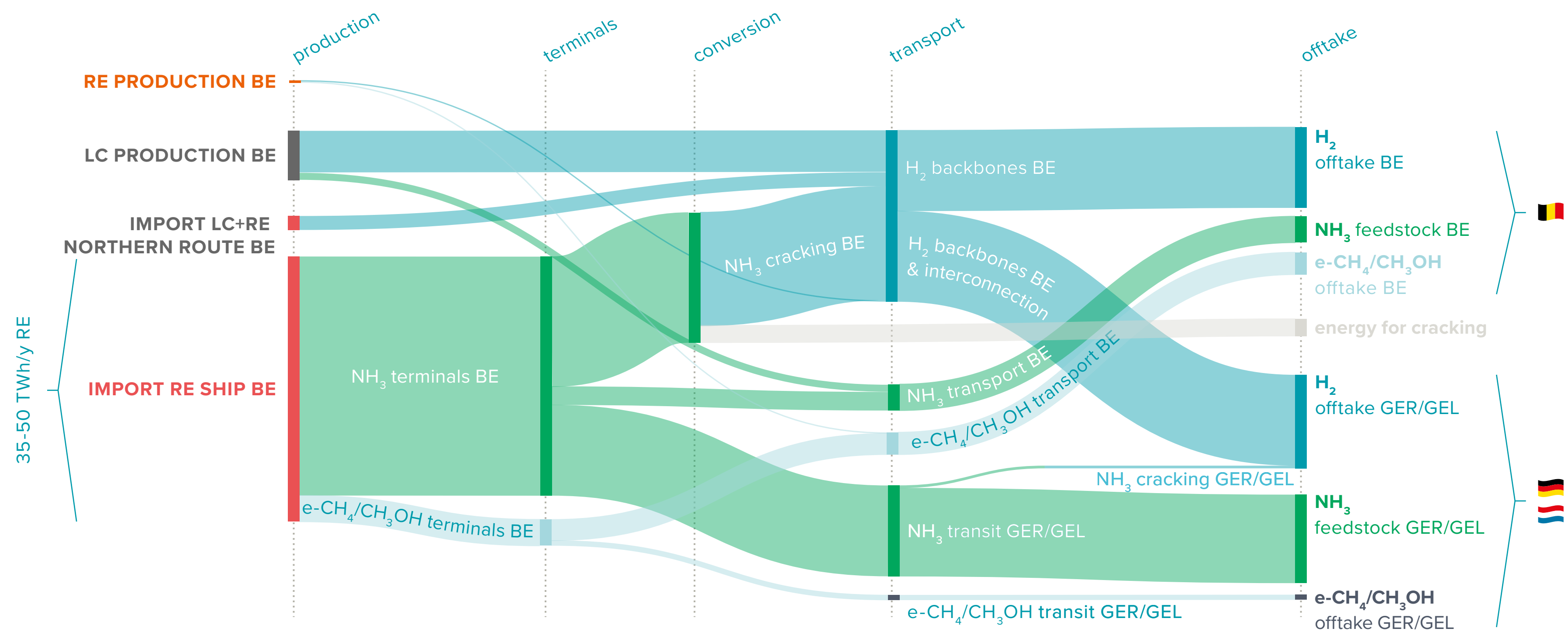
Complementary to these priority 'red flag' actions effective collaboration with export countries has to be established to effectively develop supply channels of hydrogen molecules towards Belgium. This can be achieved by levering existing and settling new **bi-lateral agreements** on e.g. certification **alignment**. Parallelly, in order to make the most of the opportunities of the global hydrogen economy, the export of technology, concepts and test infrastructure must be stimulated and supported, as well as attracting investments.
Finally innovation has to be fostered to build a cost effective and reliable supply chain on the longer term.

- For import the priority 'red flag' field of **innovation** and development on the short term to support is the technology for cracking of ammonia.

Research and innovation on hydrogen related technology in general should be supported in a structured way, with focus on the key elements of the Belgian hydrogen strategy, i.e. the export of key technologies (e.g. electrolysers) and new concepts for storage and conversion of hydrogen carriers.

The ability to adapt to progressive new market trends and insights towards 2027 and beyond, including switching and conversion between hydrogen and ammonia molecules, will be key to success. Our Belgian seaports are unique platforms in this perspective. Also in this view low carbon or blue hydrogen and other chemicals like synthetic methane will be a complement to mainly renewable hydrogen in a transition to boost the early market. In the longer term, towards 2040 and 2050, the share of renewable hydrogen will increase and eventually renewable will become the sole source of hydrogen. The Sankey-diagram below gives an impression of the relative magnitudes in 2030 of the flows of renewable (RE) and low carbon (with carbon capture - LC) hydrogen and derivatives within Belgium from production and import to local offtake and transit.

The pictured magnitudes are first indications and will be subject to continuous evaluation and adjustment following concrete commercial initiatives.



Please find alternative 'what if' scenarios on page 24

RE: renewable hydrogen
LC: Low carbon hydrogen (e.g. from SMR/ATR from methane)
GER/GEL: Germany/ Geleen

Mission of the roadmap

On March 30th of 2023, a provisional but ambitious agreement was reached within the EU, for binding targets towards 2030 for the share of renewable hydrogen and its derivatives in industry and transport.

Once the legislative process of RED III is completed, the new legislation will be formally adopted and enter into force. The implementation is key for a region like Belgium, that has all the assets, but also clearly the ambition to occupy a leading position within Europe in the roll-out of a hydrogen[2] economy as stated in the October 2022 update of the federal vision and strategy on hydrogen[3]. Belgium positions itself as a hub for the import and transit of renewable molecules in Western Europe based on its central position in this region with its seaports and industrial ecosystem. The seaports will continue to support the adjacent countries with access to energy: today with LNG and natural gas, tomorrow with H_2 molecules and H_2 derivatives. This positioning is in line with the European, federal and regional hydrogen strategies, e.g. the Flemish vision[4] of November 2020. With this central role in the hydrogen economy policy aims to foster further innovation in and export of hydrogen technology, wherein regions like Flanders are already leading today.

Prior to this vision the Hydrogen Import Coalition brought together its industrial expertise already in 2019 in order to analyse the import of renewable energy by means of hydrogen carriers. The analysis covers all steps of the value chain from renewable energy production, electrolysis and synthesis into a hydrogen carrier molecule, to shipping, terminalling and end use in Belgium. The coalitions study published in January 2021 provided necessary insights into the technological and economical aspects of the hydrogen import value chain.

In order to fully acknowledge this continued focus on hydrogen, the Hydrogen Import Coalition wants to provide a basis for its further roll-out by means of a roadmap on hydrogen import with a 2030 time horizon. The roadmap is a proposition how to secure a key EU-position in 2030 and beyond in the supply of sustainable hydrogen and its derivatives by setting specific targets, milestones and actions. The roadmap wants to set out stepstones and build trust within the community of future hydrogen consumers that there will be significant import of sustainable hydrogen and derivatives to feed growing demand towards 2030 and onwards and supporting security of supply. The roadmap is supportive to the entire sustainable hydrogen supply system but focusses mainly on the import via Belgian seaports of hydrogen derivatives and the hinterland transport of these derivatives in Belgium and to Germany or The Netherlands.

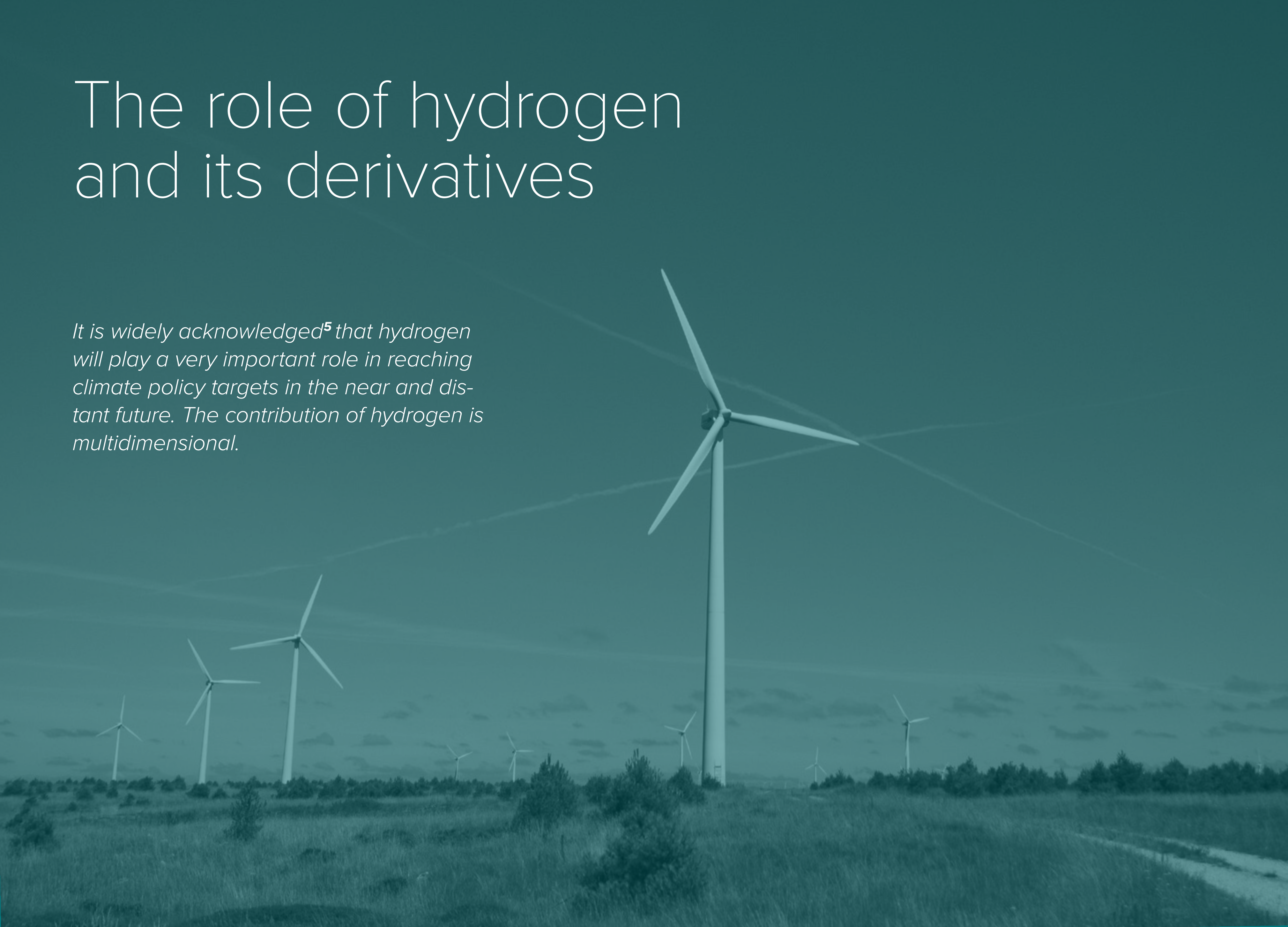
By enabling the upscaling of hydrogen technology and applications, this roadmap will support the agenda for technological leadership of its regions and worldwide export of its products in the global hydrogen economy.

> "The roadmap wants to set out stepstones and build trust within the community of future hydrogen consumers"

2. Hydrogen includes both hydrogen molecules and hydrogen derivatives such as ammonia, methane, LCOH and methanol.
3. https://economie.fgov.be/sites/default/files/Files/Energy/waterstof-visie-en-strategie.pdf
4. https://beslissingenvlaamseregering.vlaanderen.be/document-view/5FAD539C$_{20}$B6670008000274

The role of hydrogen and its derivatives

It is widely acknowledged[5] *that hydrogen will play a very important role in reaching climate policy targets in the near and distant future. The contribution of hydrogen is multidimensional.*



Indispensable storage in the energy system

In the pursuit of a carbon-neutral and robust energy system by 2050 in Europe, as envisaged in the Green Deal and RepowerEU, hydrogen, in the form of both H_2 molecules and derivatives, will play a key role. When all the possibilities for energy efficiency and electrification have been exploited, the energy supply will also require molecules to make the puzzle. Despite the declining costs, battery storage remains expensive and other solutions are needed for longer term storage. Moreover, batteries require significant amounts of scarce raw materials in their production. Molecules can be a much more efficient storage medium for storing large volumes of energy for a longer period of time (seasonal regulation capabilities), thereby helping to maintain system stability.

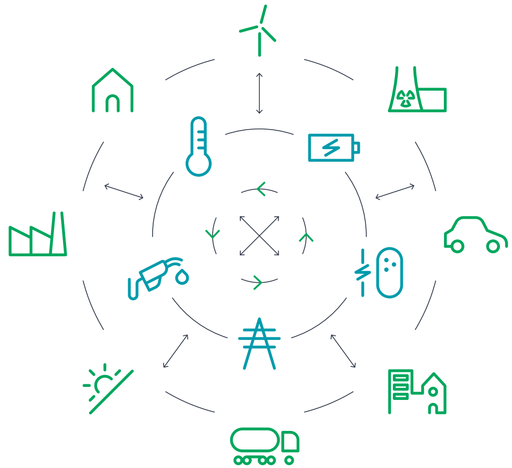
Widely and concretely applicable

Hydrogen is like direct electrification a sustainable solution to substitute fossil energy. Moreover not all energy consumers can use electricity as an energy source as easily, or they require heat at high temperatures which electricity cannot provide as efficiently. Besides, many industrial processes require molecules for intermediate and end products. The current molecules used in these processes need to be net carbon zero. Renewable hydrogen and hydrogen-based platform-molecules provide a feasible decarbonisation path for the latter. The importance of derivatives is clearly put forward in EU legislative proposals, e.g. allowing the use of fossil CO_2 as a carbon source for synthetic methanol and methane[6] until 2040.

Affordable and secure energy

The role of hydrogen (derivatives) is not just a supporting role. It will play a leading role in the coming decades, side by side and complementary to other options such as full electrification. After all, the most important advantages of hydrogen and derivatives are its flexibility, transportability and the global scale of production, trade, transport and use. It makes economic sense to produce a part of the necessary affordable renewable energy in regions like the Middle East, North-Africa, Australia or the Americas where the combination of sun, wind and space is abundant and renewable energy production is much cheaper, shown as red shaded areas in the picture on page 12. These regions with abundant resources from sun and wind are of critical importance to European energy security because Europe is expected to keep its historical negative energy balance in the future. The question is how to get this energy to users located in Western Europe. Hydrogen (derivates) acting as a transport vector provide the solution, since molecules can be transported efficiently by ship, even across very long distances up to 10.000 kilometres.

> "Molecules can be a much more efficient storage medium for storing large volumes of energy for a longer period of time (seasonal regulation capabilities), thereby helping to maintain system stability."



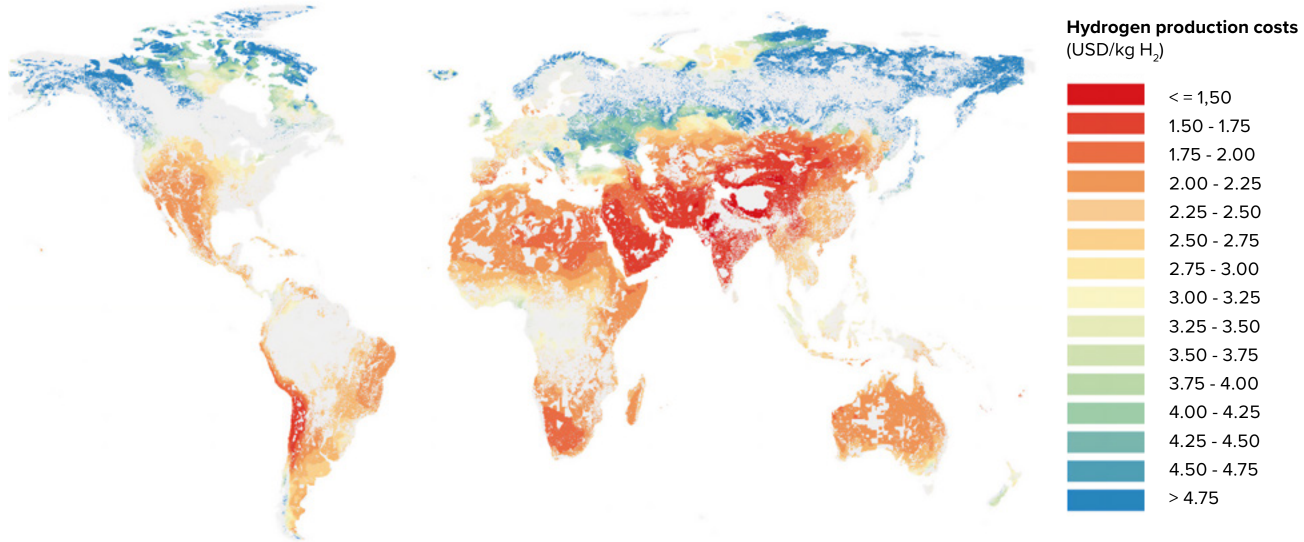
Source: EU Commission

5. IEA Hydrogen report 2022
6. Proposal **Commission delegated regulation (eu)** …/… supplementing directive (eu) 2018/2001 allowing the use fossil CO_2 as a carbon source) until 2040, provided that the source is subject to an effective carbon accounting system.

Export opportunities

The hydrogen economy undeniably offers unique opportunities in technology development. Hydrogen (derivatives) have unique properties and applications, but also significant challenges. In other words, hydrogen is not a silver bullet. Fortunately companies and research institutions based in Belgium have a leading position in hydrogen technologies in which they can distinguish themselves and which we must maintain and strengthen, with cooperation in a number of spearhead sectors. By enabling the upscaling of hydrogen technology and applications in Belgium, hydrogen import will support the agenda for technological leadership of its regions and worldwide export of its products in the global hydrogen economy.

"By enabling the upscaling of hydrogen technology and applications in Belgium, hydrogen import will support the agenda for technological leadership of its regions and worldwide export of its products in the global hydrogen economy."



source: IEA Hydrogen report 2022

Short term promising applications for hydrogen (derivatives)

The number of applications for hydrogen (derived) is virtually unlimited. Each enumeration therefore has the disadvantage of being incomplete. In this section, the enumeration is limited to the most obvious short-term applications, which were put forward by energy experts during interviews.

INDUSTRY

Organic chemistry, a sector that is well represented in Belgium and that produces the high value chemicals we use every day, is entirely dependent on the supply of hydrogen and carbon molecules as its raw material. It is evident that these products must become low carbon and renewable in the end. In part, these hydrocarbons might originate from sustainable biomass, to the extent that these are available in sufficient quantities. Circular processes (recycling) will deliver part of the molecules required for high value chemicals just like hydrogen carriers, the same that facilitate the transport and storage of energy. In fertilizer industry ammonia is produced today using hydrogen from fossil fuels. To produce sustainable fertilizers, the hydrogen will be low carbon or renewable. In the steel industry, hydrogen will be used as a reducing agent to replace coal in order to drastically reduce CO_2 emissions. Synthetic methanol and methane will substitute the fossil based variants in feedstock and energy supply.

Hydrogen will also provide high temperature heat, unattainable for heat pumps, in all industrial sectors. In a first phase this will partly be done in a fuel mix with natural gas.

SHIPPING AND AVIATION

In ships and airplanes that require a high degree of autonomy and power, the

energy density of a liquid hydrogen based fuel cannot be matched by stored electrical energy.

In deep sea shipping, combustion engines powered by hydrogen derivatives are a viable option besides biofuels. In the sector, the shipping companies' choices are divided between ammonia, methanol and synthetic LNG. Similar choices are being made in short sea shipping, where in some cases liquid or pressurized hydrogen is also being considered when it comes to alternative fuels. Inland shipping, especially over longer distances, is looking at combustion engines on hydrogen, methanol or synthetic LNG. Hydrogen based e-fuels (SAFs) are gradually being introduced today in aviation.

HEAVY DUTY ROAD TRANSPORT AND MACHINES

Promising applications for hydrogen (derivatives) are in heavy truck transport and heavy duty machines in logistics, construction, agriculture, ports and airports. The possible types of drive range from fuel cells on hydrogen to combustion engines on hydrogen or methanol.

Hydrogen can be a solution for public busses, touring cars and light vehicles.

Promising trends in global renewable hydrogen production

Renewable hydrogen production is done by water electrolysis, using renewable electricity to split water into hydrogen and oxygen. In 2021, water electrolysis accounted for only around 0.1% of global hydrogen production. But the installed capacity of electrolysers globally is expanding quickly and reached 510 megawatts (MW) by end-2021. The rapid scale-up in electrolyser capacity is expected to continue and accelerate in coming years. Globally, there are about 460 electrolyser projects currently under development or construction.

According to the pipeline of hydrogen production projects that the IEA tracks, the number of announced projects that will produce so called 'low emission[7]' hydrogen is rising at an impressive pace. If all the announced projects for hydrogen from water electrolysis or fossil fuels with CCUS currently under development are realised, the annual production of sustainable hydrogen could reach more than 792 TWh/year by 2030.

112
Gigascale production
Renewable H2 Projects
> 1 GW, low carbon
H2 projects > 200 Kt / y

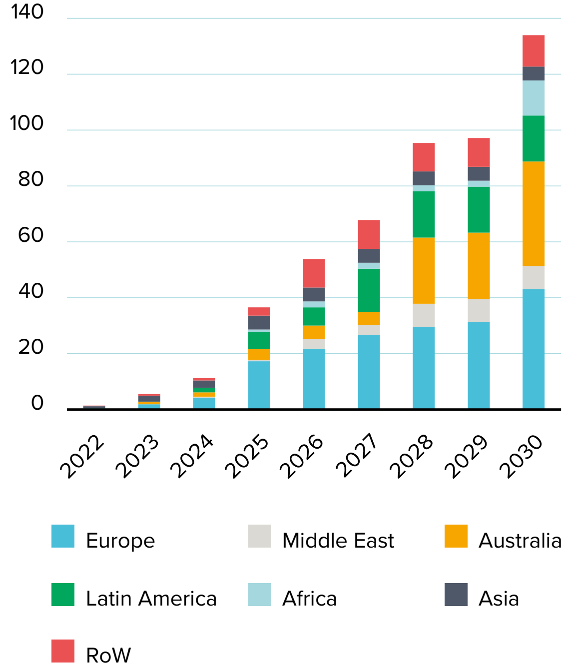
7. In the IEA definition low-emission hydrogen includes hydrogen produced via electrolysis where the electricity is generated from a low-emission source (renewables or nuclear), biomass or fossil fuels with CCUS
8. Hydrogen Insights 2023, Hydrogen Council, McKinsey Company, May 2023

In the coming years, various projects for renewable hydrogen production will be developed in Belgium with electrolyser capacities ranging from 1 to 100 MW. At least as interesting is that Belgian based companies are currently developing large-scale **hydrogen** projects worldwide with planned electrolyser capacity of up to 500 MW in a project. Projected project capacities worldwide go even beyond gigascale as in estimated more than 112 renewable hydrogen projects worldwide[8].

Hydrogen derivatives are getting increasing attention due their potential for global trade and transport and the potential to substitute fossil feedstock chemicals. There is a growing capacity and future project pipeline for hydrogen-derived fuels and feedstocks from electrolytic hydrogen as shown in the figure below by start year and region

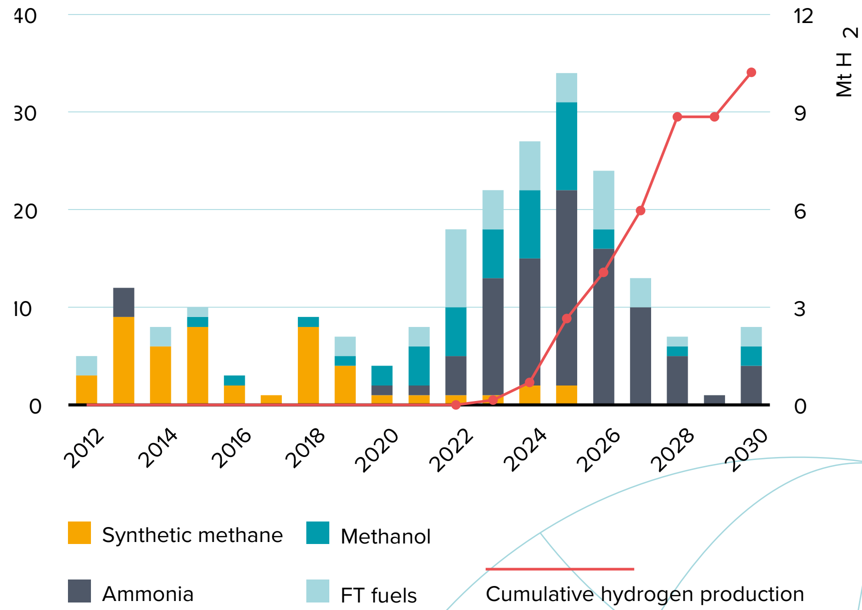
"Hydrogen derivatives are getting increasing attention due their potential for global trade and transport and the potential to substitute fossil feedstock chemicals."

Total capacity by region (GW)



Source: IEA

Hydrogen-derived fuels number of projects by fuel



Starting points

Sustainable hydrogen

Since renewable and low -carbon hydrogen (derivatives) need to make, aside direct use of renewable electricity, a contribution to a carbon-neutral society, this document focuses exclusively on renewable and low carbon (together "sustainable") hydrogen and its derivatives. This is also in line with the European hydrogen strategy, where both electrolysis produced renewable[9] and low -carbon[10] hydrogen are seen as elements that contribute to making industry and transport sustainable. Low carbon or blue hydrogen will be a complement to mainly renewable hydrogen in a transition to boost the early market. At the same time, the demand for new applications must be stimulated. To be able to act quickly and to reduce global warming, low carbon hydrogen is an inevitable step. In the longer term, towards 2040 and 2050, the share of renewable hydrogen will increase and eventually renewable will become the sole source of hydrogen.

Upscaling of demand

The demand for sustainable hydrogen (derivatives) is growing strongly, mainly in industry and in the transport sector driven by future RED legislation[11], RepowerEU ambitions and local carbon zero roadmaps. RepowerEU entails a number of ambitious, albeit not binding, objectives towards 2030 summarized to the right. The table also provides the deduced renewable H_2 consumption in Belgium.

Renewable hydrogen production RepowerEU (EU)*	**Renewable hydrogen import** RepowerEU (EU)	**Renewable hydrogen offtake** RepowerEU (EU)	**Renewable hydrogen offtake** RepowerEU (BE)**
330 TWh/y	330 TWh/y	660 TWh/y	23 TWh/y
10 Mton	10Mton	20 Mton	0,7 Mton

* Expressed as LHV as in the EU communication

** Taking Into account the population share of Belgium within the EU and the relatively high energy intensity of Belgium compared to the EU average (+36%)

RED-proposals for 2030	**Industry**	**Transport**
% renewable H_2	42% of hydrogen use	1-5,5% of total fuel use[12]
Belgian offtake of renewable hydrogen 2030	10 – 15 TWh/year	

The RED III is a concrete translation of the prevailing EU objectives into legislation. The RED has recently been revised to join the new Green Deal objectives of the EU. The new RED targets of March 30th of 2023 provisional agreement are summarized in the table above. This table also provides a 2030 projection of the Belgian offtake with a range based on the October 2022 update of the federal hydrogen vision (10 TWh/year renewable H_2), complemented with a additional margin for new industrial hydrogen off-takers actually in development phase e.g. in steel manufacturing or chemical industry. This range is in line with the RED provisional agreement.

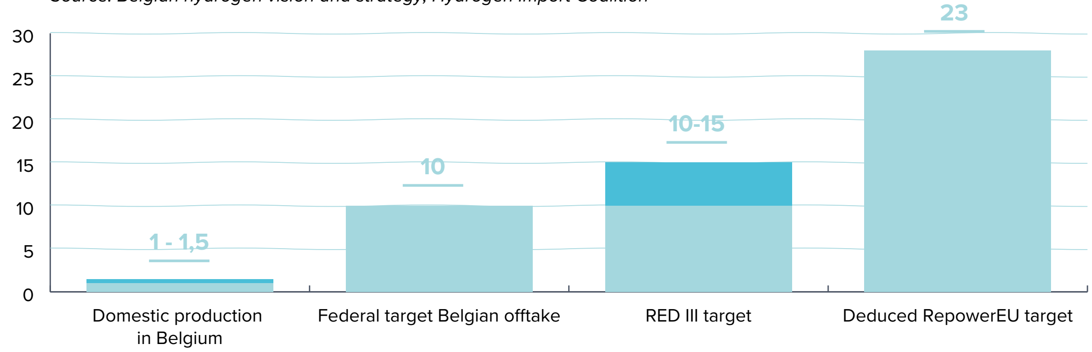
It is relevant to note that the provisional agreement requires correction today since imported renewable ammonia doesn't count for the 42% industrial target. This will not constraint import as such but will potentially favor import of fossil ammonia over renewable and low carbon.

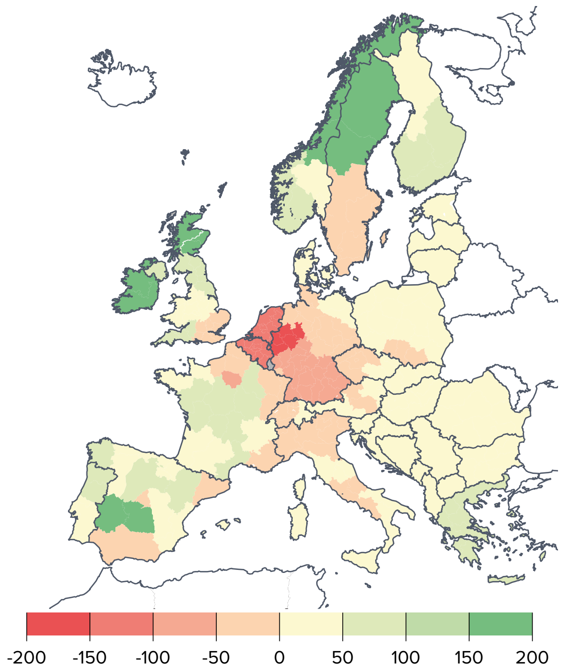
The provisional agreement on RED III foresees a further increase in the share of renewable hydrogen after 2030, in-casu 60% by 2035 for industrial use of hydrogen.

9. If the electricity in the electrolysis comes from renewable sources and the CO_2 footprint of the total process - being from electricity generation to delivered hydrogen - is below a certain limit value, then we speak of renewable or green hydrogen.
10. If the fossil CO_2 is collected and stored (Carbon Capture and Storage - CCS), we speak of low carbon or blue hydrogen. Low carbon hydrogen is also the hydrogen that is released as a residual product for another production process
11. Renewable Energy Directive E.U.
12. Joint target of 5,5% with biofuels, with a minimum of 1% of hydrogen based fuels

In parallel, the Fuel EU Maritime Law is being revised with the aim of replacing the use of fossil heavy fuel oil in the maritime sector with renewable and low carbon fuels like ammonia and methanol (proposal reaching from 1,2 to 2% by 2030). Based on the current bunkervolumes in Belgium this would mean 1,5 TWh of demand by 2030. In addition, maritime shipping will become part of the ETS in the future. The draft regulation ReFuelEU for aviation proposes obligations with an increasing share of SAF (Sustainable Aviation Fuel, mainly hydrogen derivatives), starting with 1,2% in 2030. International aviation is already subject to the ETS today.

Domestic renewable H2 production compared to targets in 2030 in TWh/year
Source: Belgian hydrogen vision and strategy, Hydrogen Import Coalition





Saldo of total generation potential minus total demand inclusive H_2 in TWh (source: Wuppertal institute)

Need for import

Aside from the economics, Western Europe will continue to need more energy than it can produce locally. In specific terms, the highly industrialised region of Belgium-Netherlands-North-Rhine Westphalia consumes much more energy than what can be provided locally or even regionally, as shown in the map. Europe, in general, is also expected to keep its negative energy balance in the future.

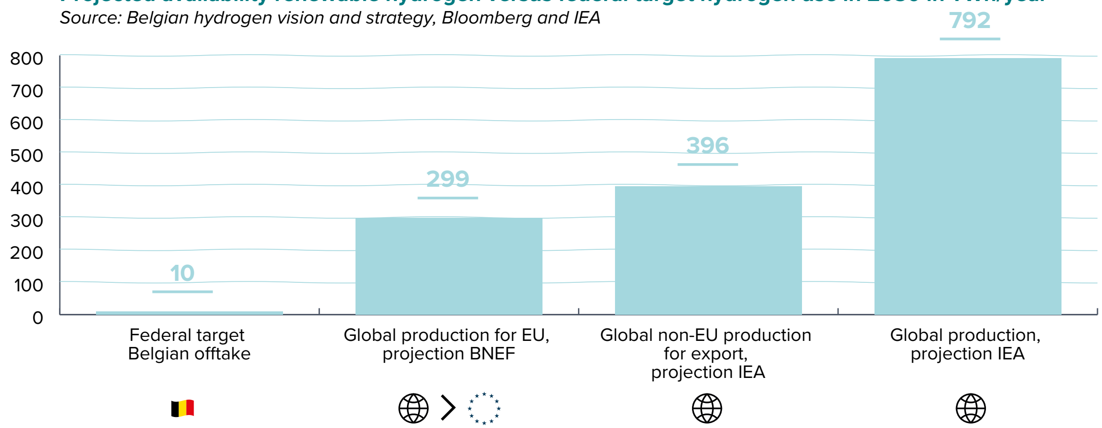
The domestic renewable hydrogen production in Belgium in 2030 will amount 1 to 1,5 TWh/year[13] of sustainable hydrogen. This is far below the projected demand, both that of the federal strategy, those of the maximum proposed RED III targets and the RepowerEU target. The import need for Belgian offtake of green hydrogen, excluding transit volumes, is estimated at 10 to 15 TWh/year in 2030, not taking in account the more voluntaristic target of RepowerEU which, converted to Belgium, amounts to 23 TWh/year (LHV as used in RepowerEU communication).

Furthermore it is noticed that the hourly requirement (additionality principle) in the RED-legislation tends to favour import compared to local production. Hydrogen production in the region of Belgium-Netherlands-North-Rhine Westphalia, where wind and solar input are relatively more variable, will far more be constraint by this requirement.

Increasing global supply by 2030

According to IEA the renewable hydrogen production outside Europe and available for export could amount 396 TWh/year by 2030. Parallelly Bloomberg estimated that by 2030 the global production for EU destination could reach up to 253 TWh/year. This is a multiple of the projected use of 10 TWh/year of renewable hydrogen in Belgium in 2030 in the Belgian hydrogen vision and strategy. Although these projections don't prove sufficient supply to cover specifically Belgian demand, they at least give a clear indication that globally capacity is being build up to supply the EU and Belgium with an significant volume of hydrogen.

Projected availability renewable hydrogen versus federal target hydrogen use in 2030 in TWh/year
Source: Belgian hydrogen vision and strategy, Bloomberg and IEA



Import hub for North-Western Europe

Belgium is centrally located in a region with significant import needs, has important ports connected to the North Sea and invests in import and transport infrastructure for hydrogen molecules and derivatives. At the same time Belgium hosts important industrial clusters that can kickstart the hydrogen scale up. Therefore Belgium can be an important import- and transit hub in this region, just like today with transit of natural gas from Norway, the United Kingdom or LNG tankers to its neighbouring countries. The federal hydrogen strategy estimates that this transit can lead to a doubling of the expected import volumes from all over the globe compared to the volumes to be consumed domestically. The import of renewable molecules is estimated in this strategy on 20 TWh/year towards 2030, of which 10 TWh/year will be available for transit to adjacent countries.

The coalition believes that the transit will transcend this estimation taking in account the unique positioning of the Belgian seaports:

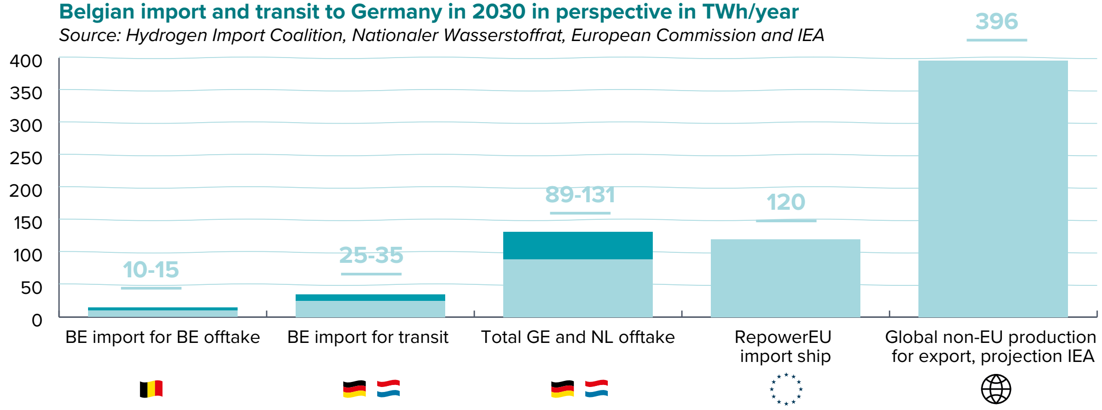
Antwerp is the largest integrated chemical cluster in Europe bringing along

- Outstanding pipeline connectivity, tank storage and product handling
- Import and production of chemical commodities for the Global and North-West European market
- Leading chemical companies that are present in the cluster and continue to invest in Antwerp
- Current large offtake of hydrogen, methane, methanol and ammonia
- Large bunkermarkt and multi fuel port strategy to facilitate bunkering of ammonia and methanol by 2025
- 2nd largest container hub in Europe with many pilots in development for hydrogen fuelled port equipment, barges and trucks
- Concrete plans of tank storage providers to expand ammonia import capacity and ammonia cracking
- Methanol storage capacity is present and easily expanded by reconversion of existing tanks

13. Own calculation based on inventory of announced projects in Belgium

Belgian import and transit to Germany in 2030 in perspective in TWh/year

Source: Hydrogen Import Coalition, Nationaler Wasserstoffrat, European Commission and IEA



Zeebrugge is a key gas import hub North-West Europe

- Supplying 15% of EU gas market by LNG and offshore pipelines with large supply to e.g. the German market
- With expansion plans ongoing for additional gas throughput capacity and future energy carriers with important developments for future renewable hydrogen import by pipeline

North Sea port is an important manufacturing hub with

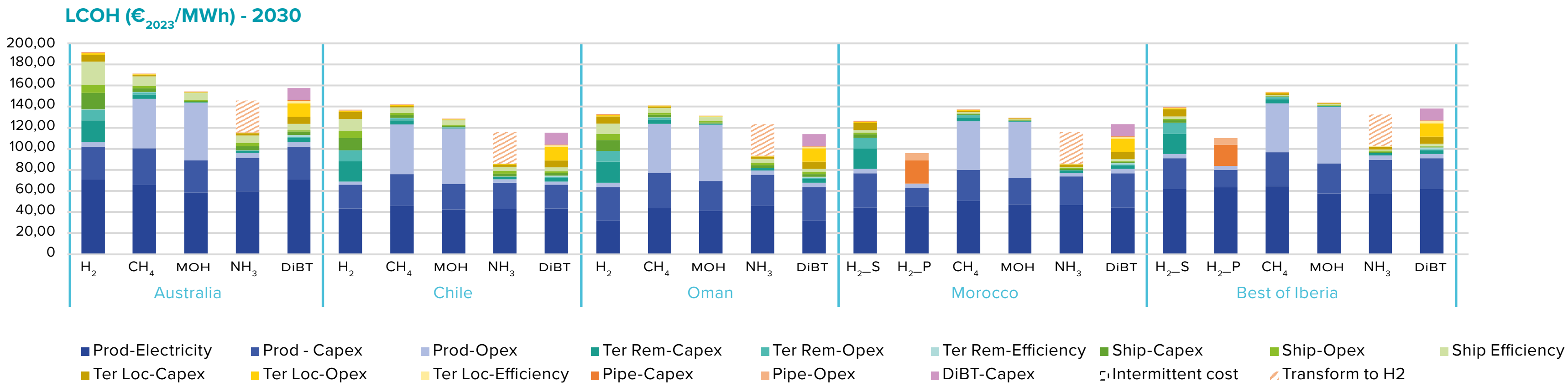
- Outstanding pipeline connectivity, tank storage and product handling
- Hosting a leading steel manufacturing plant

Important transit will take place to the German market. Taking in account recent German total offtake and import demand estimates by the German Nationaler Wasserstoffrat and assuming a share of 30 to 50% via the Belgian hub - complementary to the German and Dutch import hubs - the Belgian import and transit to Germany can reach up to 25-30 TWh/year in 2030, which is higher than the assumption in the Belgian strategy. This ambition is not only justified by the unique position of our ports, also by the strategic partnership with the German industry:

- Major German chemical and logistic players host their production and import/export facilities in Antwerp, linked with German industrial sites
- Supply of natural gas through Zeebrugge
- Key port for steel, machinery and car(parts) import and export to/from Germany
- Rail and barge connections (20Mton/y) for a multitude of products and commodities as well as pipeline connections
- The planned hydrogen backbone interconnection with Germany by 2028 and Fluxys share in OGE.

Next to transit to Germany, due to its proximity and interlinkage to the port of Antwerp, it is well conceivable that the petrochemical cluster of Geleen/Chemelot in the Netherlands would also be significantly supplied by in particular the Antwerp port. The demand in hydrogen and derivatives to Geleen/Chemelot could reach up to 5 TWh/year in 2030.

Finally by 2030 a limited exchange of hydrogen with Northern France can occur via local interconnections, e.g. between Mons and Valenciennes.



Competitive cost

Hydrogen can be transported as pure hydrogen by pipeline or ship depending on the distance or, after synthesis with carbon or nitrogen, as methanol, methane, ammonia or liquid organic hydrogen carriers (LOHCs). Transport by ship of these hydrogen carriers becomes more efficient in case of longer transport distances, up to a level that it, in case of some regions of origin like Chile or Oman, becomes competitive with transport of hydrogen by pipeline from nearby regions like Spain or Marocco. This was a conclusion from the financial analysis in the study Hydrogen Import Coalition of 2021[14]. The analysis was summarised by means of a unsubsidized "Levelized Cost of Hydrogen" (LCOH), expressed in euros per MWh, similar to the existing concept of Levelized Cost of Energy (LCOE).

The analysis was updated in March 2023 with focus on 2030 taking into account the evolution in cost of capital, electricity cost, currencies, cost of CO_2-capture by direct air capture, electrolyser cost (sourced in EU),... between 2019 and 2023. The updated levelized cost of hydrogen (LCOH) in the same pool of countries as in 2019 are shown above.

The evolution has an average impact of +33% on the LCOH in real terms while electricity and gas prices nearly doubled in Europe. Pipelines and ammonia remain best in class. The LCOH of methanol and methane increased more than average due to a higher estimated cost for CO_2-capture by means of direct air capture.

The real cost of derivates will likely be lower taking in account:

- The increase of competition due to the emergence of new producing countries (e.g. Namibia, US, Brazil, Canada,...)
- Especially for methanol and methane
  - Technology break throughs in direct air capture leading to cost decrease[15]
  - Changes in regulation (e.g allowing the use fossil CO_2 as a carbon source)[16]

14. This study contains an extensive explanation of the financial model and economic assumptions and reading guide (https://www.waterstofnet.eu/_asset/_public/H2Importcoalitie/Waterstofimportcoalitie.pdf)
15. Based on IEA Direct Air Capture 2022
16. proposal COMMISSION DELEGATED REGULATION (EU) .../... supplementing Directive (EU) 2018/2001 allowing the use fossil CO_2 as a carbon source) until 2040, provided that the source is subject to an effective carbon accounting system.

Way forward

General

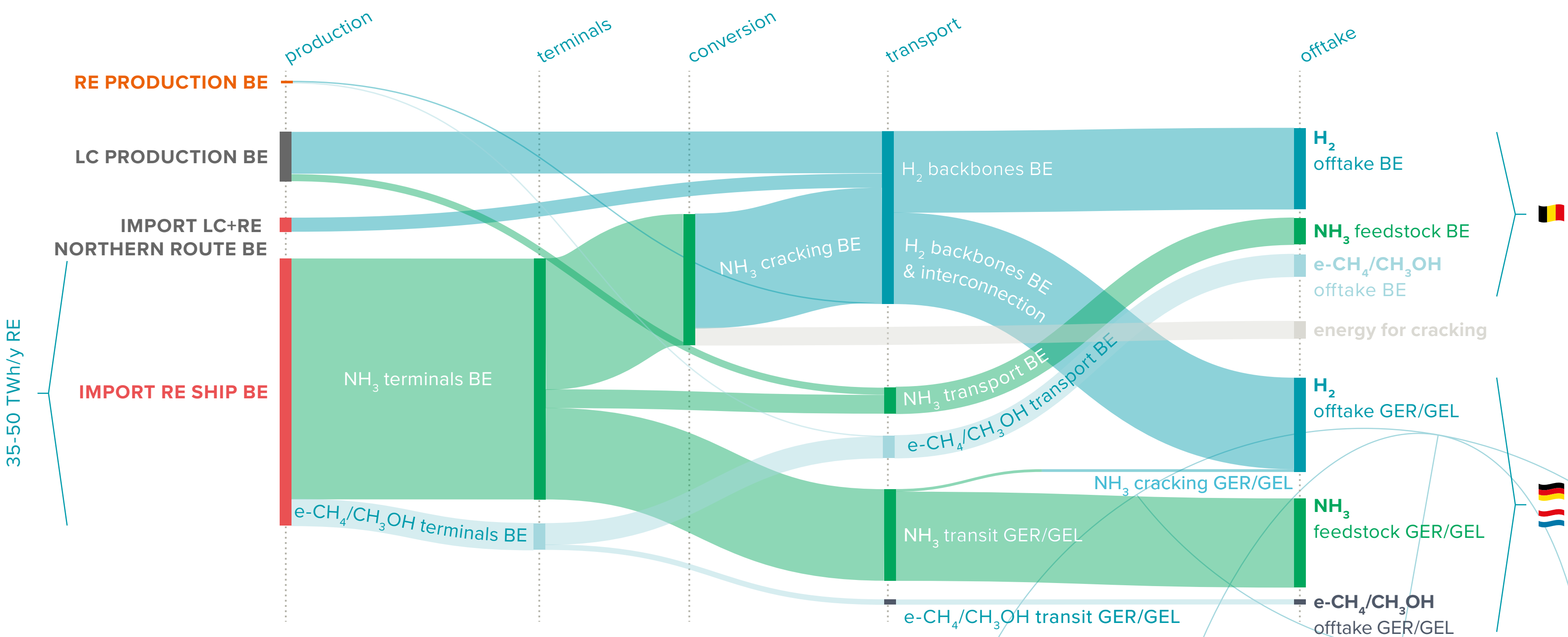
The roll-out of supply, infrastructure and offtake will have to take place between today and 2030. The roll-out consists of 5 phases:

- 2023: planning and development
- 2026: local infrastructure and production
- 2027: first import
- 2028: interconnection with Germany
- 2030: upscaling of hydrogen economy

This roll-out requires the involvement, coordination and cooperation of numerous stakeholders from the complete supply chain, including policy. The roll-out is in full swing driven by stakeholders with ongoing key initiatives as the next paragraphs will show, but a lot of work still needs to be done and a lot of new milestones are ahead of us, including the timely implementation of measures like the introduction of market models, support mechanisms, certification schemes, etcetera.

Considerations on import volumes and infrastructure sizing

In order to secure supply for projected off-take in 2030 in Belgium and transit, adequate import volumes and infrastructure needs to be developed. The Sankey-diagram below gives an impression of the relative magnitudes in 2030 of the flows of renewable (RE) and low carbon (with carbon capture - LC) hydrogen and



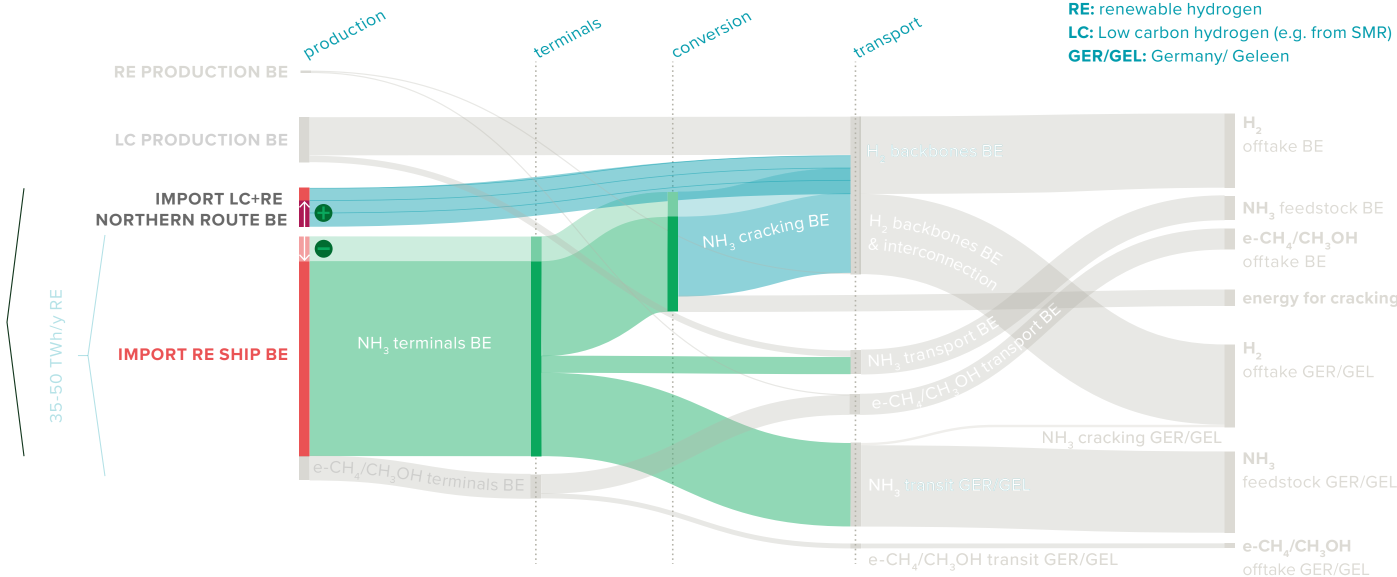
Please find alternative 'what if' scenarios on page 24

RE: renewable hydrogen
LC: Low carbon hydrogen (e.g. from SMR/ATR from methane)
GER/GEL: Germany/ Geleen

What if...

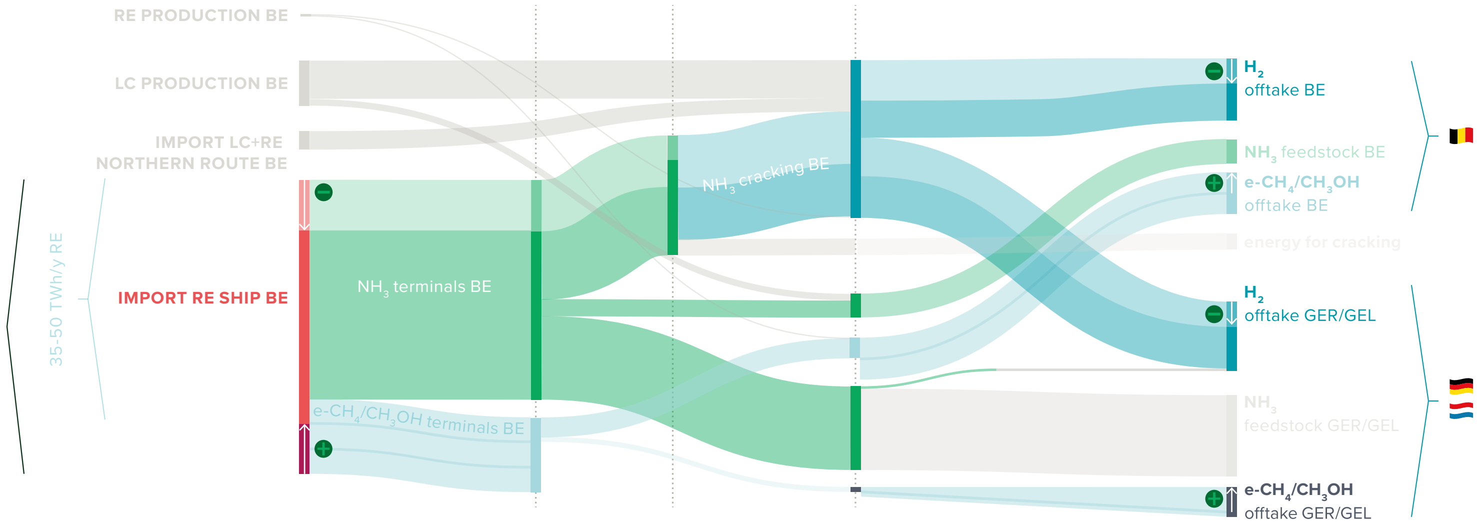
...by 2030 or soon after (eg 2035): The Northern Route supplies more renewable hydrogen?

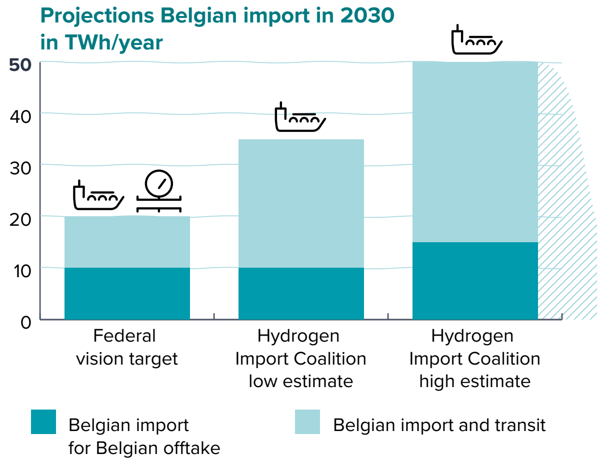
RE: renewable hydrogen
LC: Low carbon hydrogen (e.g. from SMR)
GER/GEL: Germany/ Geleen

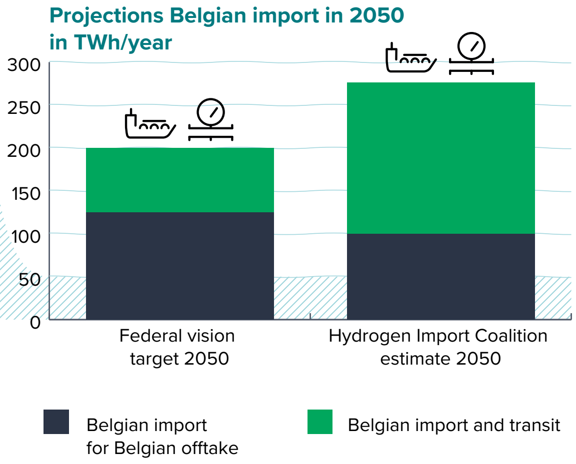


...there is a faster ramp-up in e-CH$_4$/CH$_3$OH demand, e.g. as alternative fuel in NW Europe?

All gray elements remain unchanged







Source: Belgian hydrogen vision and strategy, Hydrogen import coalition

derivatives within Belgium from production and import to local off-take and transit. The pictured magnitudes are first indications and will be subject to continuous evaluation and adjustment. The ability to adapt capacities of the different flows, including conversion between hydrogen and ammonia molecules, to progressive new market trends and insights will be key to success.

In the next paragraphs some considerations on the pictured ranges of magnitudes for import volumes and infrastructure for 2030 are given.

1. TOTAL IMPORT

To secure the supply for RED III imposed off-take in Belgium and partly Germany and Geleen/Chemelot, the Hydrogen Import Coalition estimates that an import capacity of 35 to 50 TWh/year towards 2030 is required to complement import via pipeline interconnections in Zandvliet and Zelzate. This capacity will grow to 275 TWh towards 2050. By 2030 the hydrogen will be imported mainly by ship in the form of derivatives and onwards by both ship and pipeline.

The 2030 projection took as starting point

- for Belgium the renewable hydrogen demand calculated on the targets in the provisional agreement on the revision of the Renewable Energy Directive (RED) of March 30th of 2023 and current hydrogen use in industry and energy use in transport (excl. sea transport & aviation fuels)
- for Germany the recent German total offtake estimates of renewable hydrogen by the German Nationaler Wasserstoffrat[17]
- for Geleen/Chemelot the renewable hydrogen demand calculated on the targets in the provisional agreement on the revision of the Renewable Energy Directive (RED) of March 30th of 2023 and current hydrogen use

This projection exceeds the ambition in the Belgian federal hydrogen vision for 2030. The import target in this vision of 20 TWh/year renewable hydrogen assumes import of hydrogen molecules via pipelines and derivatives by ships. On the longer term the import via pipelines will come from the Northern route[18] (coming from the North Sea area, wind based) and the Southern route (coming from Iberia, sun and wind based). The Northern corridor is assumed to be operational before 2030 in contrary to the Southern corridor that will need more time to be realized. The import by ships will come from production locations worldwide via the Belgian seaports.

The 2050 projection is based on the EU commissions projections of up to 20% hydrogen in the EU's energy mix of 2050 and a equivalent quantity in TWh/year of hydrogen as feedstock in industry. Locally produced low carbon hydrogen (from natural gas) and imported low carbon derivatives like ammonia (also natural gas based) will come on top of this volume.

The higher range of the import capacity estimate of this roadmap is more than double of the federal target, although only counting import per ship, because

- It is based on a increased need for renewable hydrogen in Belgium, Germany and Geleen/Chemelot based on the targets in the provisional RED-agreement and taking in account additional industrial hydrogen offtakers.
- The analysis includes a high share of transit via Belgium to Germany and Geleen/Chemelot based on the unique positioning of the Belgian seaports
- The projection on import capacity of this roadmap holds a contingency in case the Northern Route not contributing enough in 2030 to renewable hydrogen supply.

Signals in the market confirm the increased interest in hydrogen, like the increasing projections in global supply of renewable hydrogen by 2030[19] and the ongoing key initiatives in terminal development in Belgian seaports[20].

2. HYDROGEN OFF-TAKE MIX

Todays off-take ratio between fossil hydrogen molecules and derivatives for industry and transportation (the latter via refineries) is roughly 50/50. Several studies[21] expect that this ratio will be similar in 2030, with a slight advantage for hydrogen molecules (50-75%) as a consequence of Fit for 55 targets like ETS and RED. The off-take ratio might shift to a larger hydrogen molecules share in industry due to major new off-takers. In transport shift can go in both ways depending on fuel choices by sectors and large individual off-takers (e.g. maritime) where hydrogen molecules, ammonia and methanol come in to play. This roadmap takes the 50/50 ratio with a slight advantage for hydrogen molecules as the best assumption for 2030 at this moment of time.

Hydrogen derivatives import however should be able to supply both off-take of hydrogen molecules (after cracking) and derivatives. The main hydrogen carrier imported in 2030 will be ammonia because

- ammonia is the main derivative (ca. 75%) in the current off-take as feedstock in chemical industry
- storage and distribution assets are available today
- the relative low cost of renewable ammonia compared to other derivatives
- the possibility to crack to H_2
- no CO_2 is needed

However there is clearly an increasing interest in methanol as hydrogen carrier, due to legal and operational incentives. An important legal incentive is the proposal of the EU commission (Commission delegated regulation (eu) …/… supplementing directive (eu) 2018/2001) allowing the use fossil CO_2 as a carbon source until 2040, provided that the source is subject to an effective carbon accounting system. The main operational incentive is the relative ease of handling of methanol due to its interesting characteristics[22]:

It is important to notice that the Belgian seaports have the unique flexibility to manage this uncertainty and handle different scenario's of derivatives mixes with their large scale infrastructure

- liquid state at ambient temperature
- high energy volumetric density at ambient temperature (although lower than gasoline)
- use as energy vector and building block in chemistry
- possibility to use it a combustion engine and in fuel cells
- lower risk of flammability
- biodegradability
- the possibility to convert to H_2 in the future

Large energy consumers like ship operators have announced to convert their fossil based assets to bio and synthetic methanol based assets while investing in large synthetic methanol production plants. In chemical industry several companies are ready to start the process of the gradual substitution of fossil methanol by renewable in their feedstock.

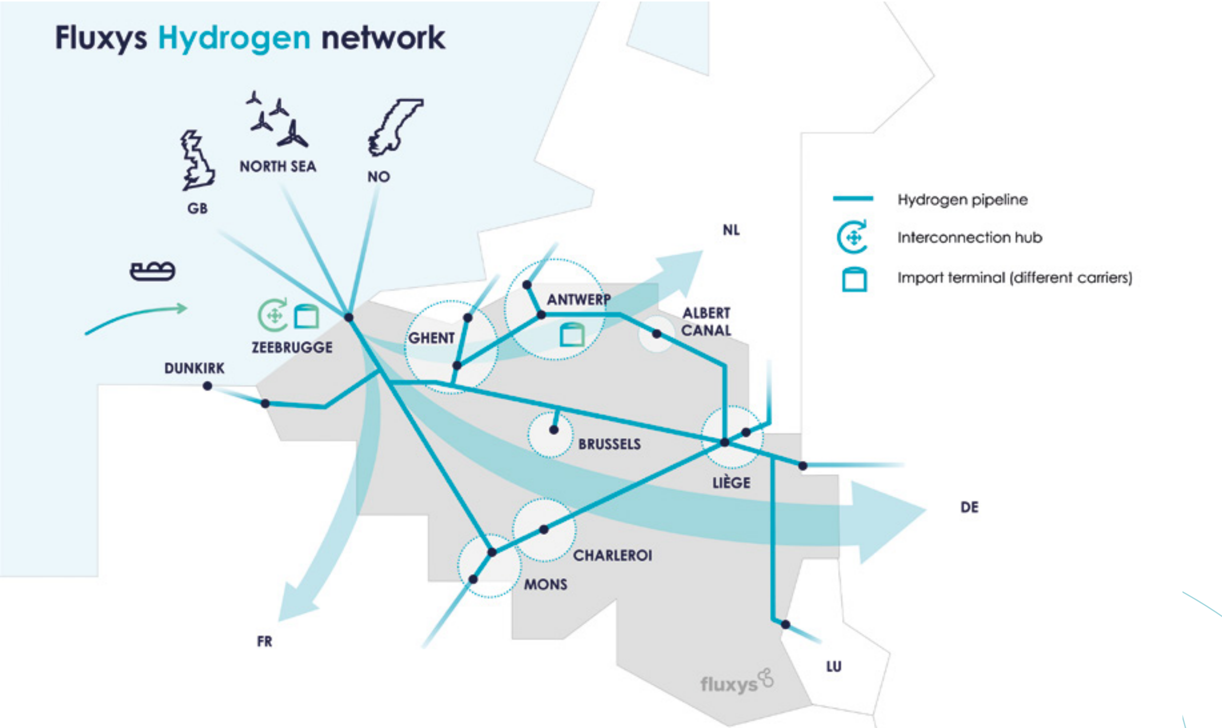
This roadmap is prudent in setting specific targets on the derivative mix. It assumes a continued major importance of ammonia in the derivative mix, but at the same time a significant growth in the share of methanol in the mix towards 2030. It is important to notice that the Belgian seaports have the unique flexibility to manage this uncertainty and handle different scenario's of derivatives mixes with their large scale infrastructure, e.g. existing import capacity for ammonia, methanol and LNG, already available and ability to upscale fast in either one of them.

3. TERMINALS AND TRANSPORT

Storage of derivatives, mainly in the seaports, has to balance supply and off-take. Storage of ammonia and methanol is done in large tanks of up to 100.000 m³ and a capacity of up to 5 TWh/year. With an import for local off-take and transit of 50 TWh/year an equivalent of 10 large tanks is required or a larger number in a combination of larger and smaller tanks.

Transport of hydrogen molecules, methanol and ammonia via backbones, trains and barges will be necessary to link supply and demand.

Fluxys developed a masterplan for the development of a hydrogen backbone with the ambition to transport 30 TWh/year hydrogen by 2030. By 2026 a total of 150 km pipelines for hydrogen molecules will be built within Belgium and by 2028 Germany will be connected.



17. White paper Nationaler Wasserstoffrat February 2023
18. As defined in the European clean hydrogen alliance learn book
19. Based on IEA Hydrogen report 2022
20. See next chapters
21. A Five-Step Plan towards Growing the Role of Hydrogen in Belgium's Economy, BCG, 2022
22. Likewise, its toxicity and corrosiveness are the main disadvantages of methanol

4. CONVERSION TO H_2-MOLECULES

Several studies[23] indicate that at least half or 50% of the renewable hydrogen use in 2030 will be in the form of hydrogen molecules (H_2).

Renewable hydrogen molecules will to a limited extend (<10%) be supplied by local production and imported by pipeline in the case that Northern corridor is fully operational by then. Low carbon hydrogen molecules will be imported as natural gas and produced domestically by SMR or ATR cracking, combined with CO_2-storage.

To secure supply of hydrogen molecules towards 2030 and beyond imported derivatives need to be converted to hydrogen molecules. In first instance we will see renewable ammonia cracking because of the future availability of renewable ammonia. Although large scale ammonia cracking is still at lower TRL, the technology will have to mature and upscale fast. Several cracking projects are in preparation worldwide that should allow this maturation and upscaling, of which four are under development or being researched in the port Antwerp-Bruges.

A cracking capacity in the range of 15 to 25 TWh/year in 2030 is desirable to secure the supply to Belgian off-takers and transit with a minimal 50% share of renewable hydrogen molecules. The ammonia that is not converted will partly be used directly as feedstock in Belgian chemical industry and transited to Germany and Geleen/Chemelot, mainly also as feedstock.

Ongoing key initiatives

1. SUPPLY

Local sourcing

Several projects for sustainable hydrogen production are being developed in Belgium.

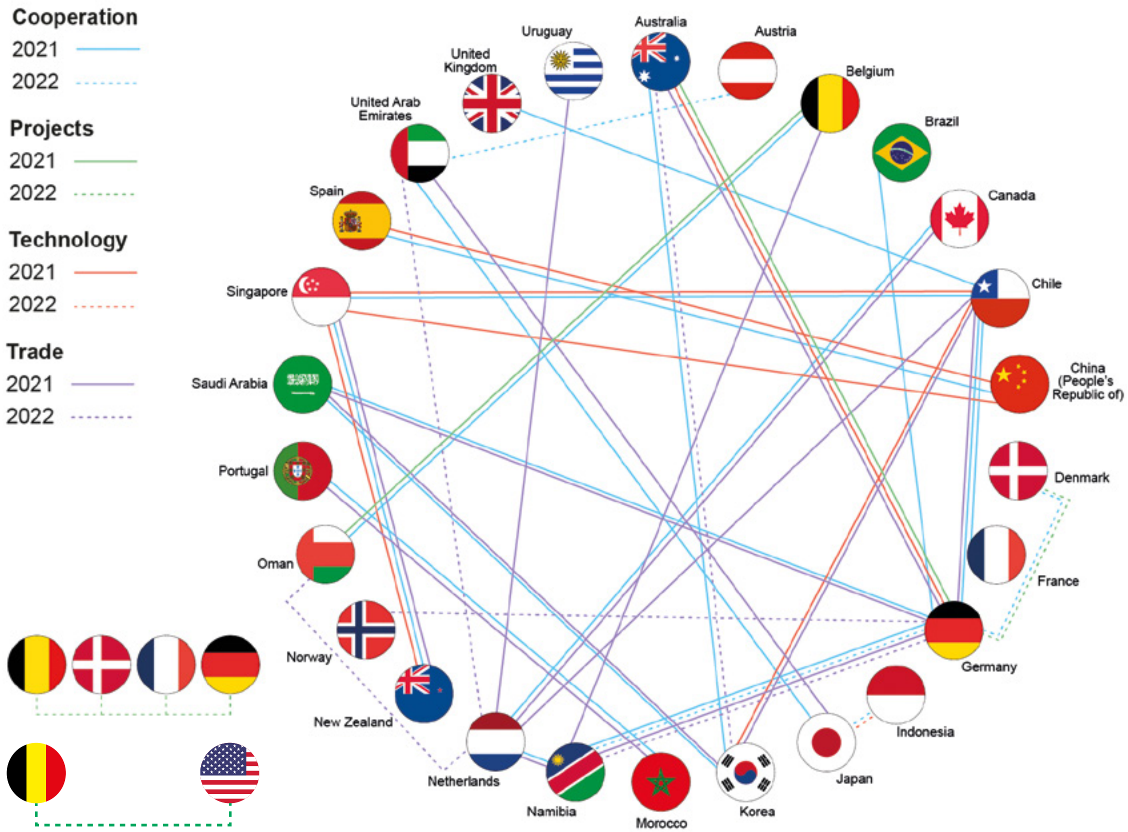
- In the framework of the IPCEI the regional authorities selected renewable hydrogen production projects[24] with a cumulative capacity of more than 300 MW to be realised before mid 2026. This includes projects for the production of derivatives like methanol and methane.
- Outside the IPCEI other large scale renewable projects are in the pipeline with a cumulative capacity of more than 100 MW to be realised before 2026.
- Also large scale low carbon projects are in development within GW scale, where EU support was given to a project in Antwerp.

Sourcing by import

Import of hydrogen is an essential cornerstone of the Belgian hydrogen developments, as emphasised in the study of the Hydrogen Import Coalition already in 2021.

- The federal government is working towards an substantial increase of potential routes for imports by ship. That is why it has signed Memoranda of Understanding (MoU) with Oman and Namibia. These memoranda are however not unique in the world. There are 22 international co-operation agreements signed over the last three years that deal with clean energy technologies which include hydrogen and its derivatives as shown in the figure.
- In addition to the governmental MoU’s and to facilitate the market ramp-up of the global supply chain, the Port of Antwerp-Bruges set out several partnerships around the world with cooperation agreement with partners in Chile, Oman, Namibia, Brazil, the USA and Canada.

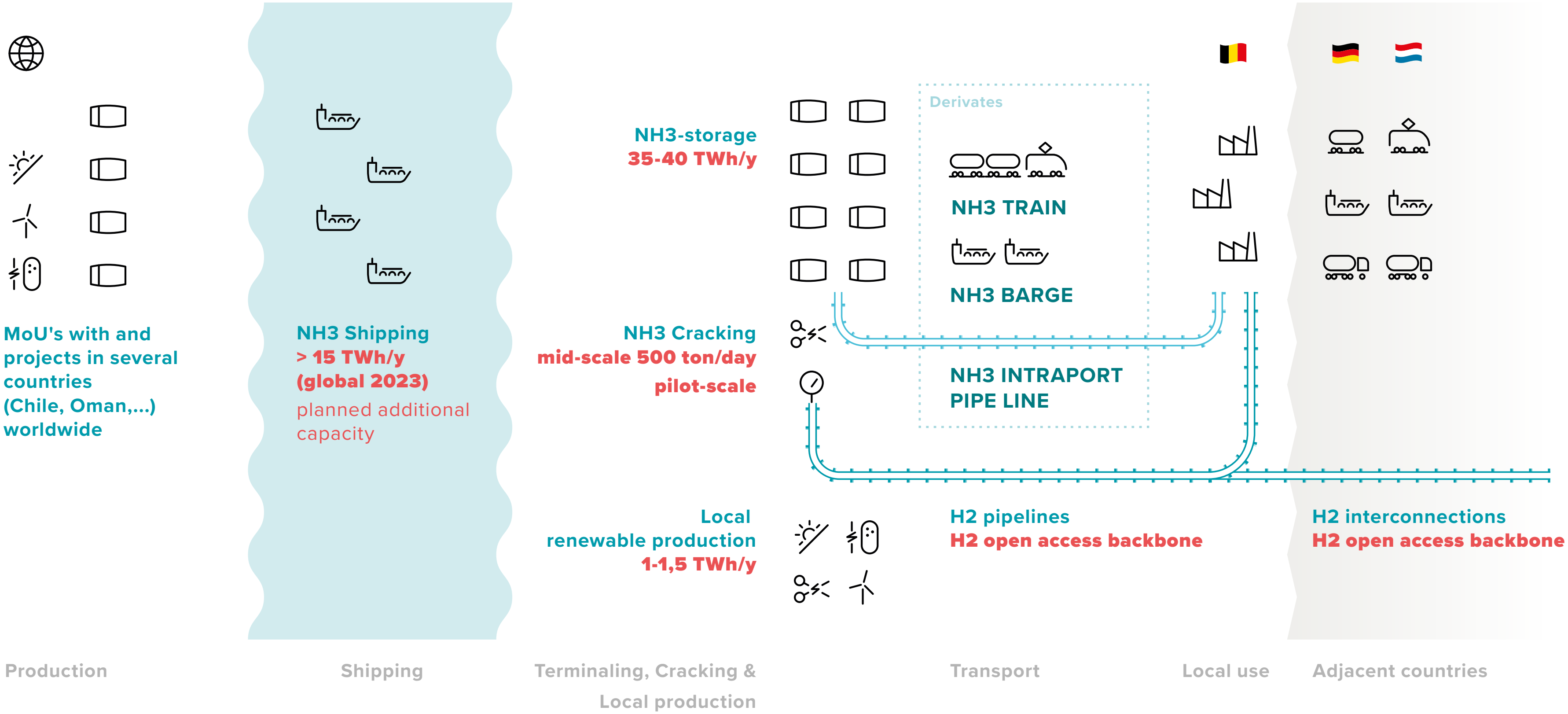
23. A Five-Step Plan towards Growing the Role of Hydrogen in Belgium’s Economy, BCG, 2022
24. https://economie.fgov.be/sites/default/files/Files/Energy/IPCEI-hydrogen-List-BE-Potential-Direct-participants.pdf



Source: IEA

- The Hydrogen Import Coalition of industrial partners with expertise throughout the full value chain of hydrogen import proofed the technical-economical feasibility of hydrogen import with their study in 2021. In this next phase all partners are developing separate projects and continue to collaborate on advocating the right framework in Belgium for import.
- Belgian based companies are currently developing large-scale hydrogen projects abroad with planned electrolyser capacity of up to more than 1GW in a project.
- Interconnections with the Netherlands and Norway are being developed or studied to supply hydrogen via pipeline.

Ongoing key initiatives



The coalition partners are involved as initiator, partner or stakeholder in the majority of the displayed ongoing new initiatives

DEME · ENGIE · EXMAR · fluxys · Port of Antwerp Bruges · WaterstofNet

Shipping
Shipping methane, methanol or ammonia is already carried out on a large scale today. Methane is shipped as LNG (Liquefied Natural Gas) in a large fleet of LNG ships. Ammonia and methanol transport over sea takes place on a much smaller scale at the moment, but the existing shipping technology can easily and quickly be enlarged if the demand turns out to be there. These ships will be powered by their own CO_2-neutral cargo, e.g. by ammonia for which the engines will be developed in time. Renewable ammonia is generally considered to constitute the major part of import by 2030 to align with REDIII.

Belgian shipping companies have an existing fleet with a global capacity of more than 15 TWh/year of ammonia today and additional capacity is planned.

2. INFRASTRUCTURE

Terminals
Large-scale terminals already exist in Belgium for molecules such as methane (LNG) in Zeebrugge and methanol, synthetic kerosene and ammonia in Antwerp. LOHC can easily be stored in existing oil tanks. All of this existing infrastructure could therefore be readily reused for the decarbonised alternatives.

Ammonia terminal capacity of at least 40 TWh/year is being studied or developed already today in the Port of Antwerp-Bruges. Here, amongst others Fluxys together with Advario is developing a NH_3 import terminal comprising two tanks of 100.000 m^3 by 2027. Next to this other initiatives are being developed within the port, of which one of them includes the integration of a processing plant directly with a terminal.

Domestic transport
By 2026 an infrastructure of 150 km of open access pipelines will be constructed for transporting hydrogen within and in between the major Belgian industrial clusters and by 2028 a connection with Germany will be foreseen. Parallel to this open access backbone an existing private network already has today a very large basis in Belgium, including interconnections with neighbouring countries.

Hydrogen carriers such as ammonia will be partly converted to hydrogen gas that can be injected in the hydrogen backbone. A consortium with Fluxys is looking at the feasibility of developing a mid-scale ammonia cracking facility in the Port of Antwerp-Bruges by 2028. In total around 34 TWh of cracking capacity is being researched by several parties in the Port of Antwerp-Bruges. Europe's first ammonia cracker will be operational already in 2024 on pilot scale, operated by Air Liquide.

Ammonia and synthetic methanol will be transported by rail and barges, as these modii are already used for its fossil alternative today.

Meanwhile a network for the transport of captured CO_2 will be build, in and between the Belgian industrial clusters, to destinations for storage, e.g. in the North Sea, or for circular reuse, for example in the production of hydrogen derivates such as methanol, synthetic-methane or even construction materials.

Interconnections
Belgium has the ambition to interconnect its hydrogen transport network to at least Germany, France and the Netherlands, for its international positioning as a hub for the import and transit of renewable energy. The interconnection with Germany will be realized by 2028.

3. OFFTAKE

The Belgian hydrogen market already amounts 15 TWh/year of almost exclusively fossil hydrogen. The demand for sustainable hydrogen and derivatives will scale up in the next years, stimulated by EU targets and legislation like RepowerEU, the Renewable Energy Directive, the Fuel EU Maritime Law and ReFuelEU for aviation. Several initiatives are ongoing to map the potential offtake by 2030, of which the following are the most important:

- The identification of hydrogen off-take clusters and a request for information by Fluxys, mainly in energy intensive sectors[25]
- The roadmaps by WaterstofNet and the Hydrogen Industry Cluster on offtake in all sectors[26]
- Bilateral consultations with Germany[27]
- Stimulus of co-operation throughout the value chain in the existing industrial ecosystems, Waterstof Industrie Cluster and H_2Hub, working together under the umbrella of the Belgian Hydrogen Council[28]

Companies in organic chemistry, fertilizer industry, refining and steel industry are planning large scale projects for a partial substitution by or introduction of sustainable hydrogen. Engines using hydrogen, e.g. dual fuel, are available for coastal shipping and heavy duty applications and ammonia based engines for deep sea shipping will Terminals and cracking facilities available in coming years.

THE HYDROGEN ECOSYSTEM AND EXPORT

Belgium holds a large ecosystem of companies and academia with high expertise in hydrogen technology. With regard to hydrogen production, Belgium has a strong representation of technology players, both in the field of electrolysis (alkaline and PEM) and reformers. There are large construction companies with expertise in pipeline construction or that focus on the construction of large hydrogen plants. There are also numerous technology players or players in the field of hydrogen applications in Belgium, such as compressors, storage tanks, hydrogen filling stations, various heavy duty and offroad vehicles, fuel cells, combustion engines, boilers, CHPs,....

They have all a leading position globally generating significant export which must be maintained and strengthened.

25. https://www.fluxys.com/en/energy-transition/hydrogen-carbon-infrastructure/hydrogen_preparing-to-build-the-network
26. https://www.waterstofnet.eu/nl/kenniscentrum/roadmaps
27. https://www.hydrogeninsight.com/industrial/germany-wants-to-link-its-hydrogen-pipelines-with-belgium-s-by-2028-despite-concerns-about-readiness/2-1-1405470
28. https://belgianhydrogencouncil.be/

Actions and milestones

To secure supply that matches demand in 2030 immediate action in different domains is required. This roadmap gives an overview of the most important actions, without being exhaustive and 100% conclusive to meet the targets. The need for additional actions and adjustments will come up in the coming years.

Backbone (BE) — Interconnection (DE)

2023 2024 2025 2026 2027 2028 2029 2030

MARKET DESIGN (2023)

1ST BE SHIP IMPORT (2027)

BE SHIP IMPORT & TRANSIT (2030)

BE	10 - 15 TWh/Y
DE, NL	25 - 35 TWh/Y
Terminals	35 - 50 TWh/Y
Cracking	15 - 25 TWh/Y
Backbone	30 TWh/Y

Volumes based on REDIII projections

PRIORITY ACTIONS

POLICY

- **Regulation**
- **Certification**
- **International market platform**
- **Support mechanisms**

INFRA

- **Backbone**
- **Terminals and cracking facilities**
- **Trains & barges**
- **Seagoing vessels**

INNOVATION

- **NH_3 conversion to hydrogen**

COMPLEMENTARY ACTIONS

GLOBAL TRADE

- **Collaboration with export countries**
- **Cross border technology trade and investments**

INNOVATION

- **Direct air capture and carbon loop**
- **LOHC and liquid hydrogen**
- **GW scale electrolysis**

Priority actions

1. REGULATION

To start with, the provisional agreement on REDIII needs to come into effect and to be converted into national legislation as soon as possible.
However it is important to note that the provisional agreement requires correction since imported renewable ammonia doesn't count for the 42% industrial target. This will not constraint import as such but will potentially favor import of fossil ammonia over renewable and low carbon.

2. POLICY

Support mechanisms, e.g. contracts for difference

Short explanation

To make hydrogen competitive with fossil fuels in the start-up phase until market ramp up and to ensure those volumes also pass through our own Ports, new effective support mechanisms must be put into operation and scaled up.

Necessary actions	Timing
• In accordance with future reality of EU import-hubs and transit between countries the government must first and foremost support initiatives like H_2Global and plead for European funds that bridges the difference between the cost of grey and sustainable hydrogen, for example with Contracts for Difference and double sided auctioning. Where necessary additional room within the member state budget must be made for operational support for hydrogen.	in the shortest possible time as they are absolute prerequisites for project final investment decisions and offtake agreements
• The risk of investing in hydrogen can be further reduced by – granting an increased investment deduction and other tax benefits for investments in H_2. – subsidy schemes such as the Ecology Premium + in Flanders, whereby the list of hydrogen technologies must be permanently adapted to the needs. – Periodic (e.g. annually) thematic calls for investment support throughout the hydrogen chain	
• In the general tax regime, the possibilities for differentiated taxation of energy carriers must be continuously investigated and utilized.	
• Possible quantitative future scenarios (<2030) must be drawn up, monitored and shared annually on the supply and demand of hydrogen and derivatives in different sectors within Belgium, which can serve as the basis not only for policy plans, e.g. budgeting of operational support but also for infrastructure plans.	

29. RFNBO stands for renewable fuels of non-biological origin. They roughly correspond to hydrogen and its derivatives.

30. ISCC is a global sustainability certification system for all feedstocks.

Certification scheme for hydrogen and derivatives

Short explanation

To develop a liquid market and the off-take of hydrogen, adequate and pragmatic certification of sustainable hydrogen must be ensured. Currently, the lack of a clear and well-organized framework for hydrogen certification hinders the development of the hydrogen market in Belgium and with neighbouring countries.

Necessary actions	Timing
• Set up (temporary) voluntary RFNBO[29] certification schemes at Belgian level, awaiting eventual initiatives at EU level. It is crucial that every Belgian hydrogen certification/GO system is compatible with the German certification system, although this also applies to any other neighbouring system (NL, FR, LUX). The certification system should be aligned for both low-carbon and renewable hydrogen, whether locally produced or imported.	in the shortest possible time as they are absolute prerequisites for project final investment decisions and offtake agreements
• Ensure that the GOs are interchangeable between EU-regions by setting the same standards and make the use of certificates independent of quality/purity issues or the type of infrastructure, to avoid further market fragmentation and an increase in transaction costs for certification.	
• Link GO- and RFNBO-systems to avoid double counting	
• Alignment of certification schemes with ISCC[30].	
• Define roles & responsibilities on certification	
• Set up test cases and pilots within off-takers in different sectors	

Priority actions

An international market platform to trade hydrogen and derivatives

Short explanation

To establish trade in hydrogen, a hydrogen exchange must be set up that ensures proper market functioning and transparent, efficient pricing.

Necessary actions	Timing
• A local Belgian exchange, comparable to the 'Zeebrugge Trading Platform' or ZTP for natural gas will be set up starting on pilot scale (HyBex). An important parameter in this choice is compatibility with other markets, in the first place with those of neighbouring countries.	in the shortest possible time as they are absolute prerequisites for project final investment decisions and offtake agreements
• For a properly functioning hydrogen exchange, the following services must be developed in addition to certification – an index that makes it transparent at what price hydrogen can be traded. – a spot market, possibly with a local spot market in a certain area (eg a port) as a first intermediate step. – trading tools to balance the network and store hydrogen.	

3. INFRASTRUCTURE

Terminals and cracking

Short explanation

To kickstart and ensure sufficient supply of renewable molecules into the European mainland import NH_3 terminals and NH_3 cracking facilities will be key. The need for additional import methanol terminals will follow on NH_3 terminals, but due to increasing interest sooner than anticipated now.

Necessary actions	Timing
• Develop additional NH_3 import terminals in Antwerp, including open access terminals.	2027
• Develop a large scale NH_3 import terminal in Zeebrugge	2030
• Develop first small-scale NH_3 cracking pilot	2024
• Develop first mid-scale NH_3 cracking pilot – 500 ton/day	2028
• Develop full-scale NH_3 cracker	2030
• Pilot project – injection of H_2 in backbone from NH_3 cracking or electrolysis facility	2027
• Anticipate on steep ramp up of methanol demand and supply and the development of pilots and terminals	2030

Priority actions

backbones

Short explanation

Transport of hydrogen via backbones will be necessary to link supply and demand. The Belgian system requirements and expectations in the field of planning, balancing and H_2 purity must be mapped by the Belgian government within an EU context. The compatibility of system design to enable interconnection between Belgium and adjacent countries for H_2 must be ensured.

Necessary actions	Timing
• Develop H_2 backbone in main industrial clusters – 5 TWh/y volume, 100-160 km	2026
• Develop H_2 pipeline interconnection between Belgium and Germany	2028
• Align on European H_2 specification requirements	Q2 2024
• Identify regulatory framework and hurdles for hydrogen networks by structural exchange between the national hydrogen councils.	Q1 2024
• Parallelly CO_2 backbones need to be developed to transport and use CO_2 from industry in the production of synthetic methanol or methane locally or cross border.	2026
• Establishment of the regulatory framework for hydrogen pipeline transport (ref: Gas Package)	2024

trains and barges

Short explanation

A positive climate for investments in transport means for derivatives, e.g. backbones, trains and barges, has to be established to link supply and demand.

Necessary actions	Timing
• Develop hub for NH_3 barging in Antwerp	2027
• Develop train routings for NH_3 – increase rail capacity	2027
• Develop NH_3 intra-port backbones for local consumption	2030
• Anticipate on steep ramp up of methanol transport needs	2030

seagoing vessels

Short explanation

To kickstart and ensure sufficient supply of renewable molecules into the European mainland the existing NH_3 supply chain can be used by repurposing and expanding of existing NH_3 assets.

Necessary actions	Timing
• Ensure ammonia tankers can use their cargo as zero-emission fuel	2026
• Increase the size of the ammonia tankers to allow for an increase in transport volumes and transport efficiency	2025
• Increase of the fleet of ammonia tankers to allow for larger volumes to be transported	2027-2030
• Anticipate on steep ramp up of methanol demand and supply and the development of an appropriate fleet of methanol tankers	
• Set up a regulatory and safety framework for bunkering of ammonia, methanol and hydrogen in ports	2025

Complementary actions

1. GLOBAL TRADE

Effective collaborations with targeted export countries

Short explanation

Effective collaboration between states or large infrastructure operators like the Port of Antwerp-Bruges are important frameworks to effectively develop supply channels of hydrogen molecules towards Belgium levering existing and settling new agreements on e.g. certification alignment.

Necessary actions	Timing
• Leverage existing MoUs in the form of effective collaboration and subsequently in lessons learned for future developments.	Actions ongoing, to be continuously improved and leveraged.
• Select countries worldwide to target for additional cooperation and MoUs based on security of supply of all required derivatives, sustainability and cost criteria	
• Provide a MoU canvas that can be customized in the targeted countries, tackling all other aspects than cooperation for secure supply that can serve Belgian economy, e.g. promotion of Belgian technology, projects and partners, collaboration on local added value,....	
• Organize hydrogen commercial missions and master classes to establish close relationships with key exporting partners	

Cross border technology trade and investments

Short explanation

In order to make the most of the opportunities of the global hydrogen economy, the export of technology, concepts and test infrastructure must be stimulated and supported, as well as attracting foreign investments.

Necessary actions	Timing
• The most promising export products or investment opportunities for foreign companies in Belgium must be identified.	Actions ongoing, to be continuously improved and leveraged.
• The most promising destinations for export must be mapped (including where there is already a large presence of Belgian hydrogen companies) with a view to feed the selection of countries worldwide to target for cooperation and MoUs	
• Create and maintain strong Belgian narrative with unique selling points.	
• Networking events, study visits to Belgian projects, companies and research centres must be organized for international clients complementary to the masterclasses for key exporting countries.	

2. IMPORTANT INNOVATIONS RELATED TO IMPORT

Reforming to hydrogen

Ammonia cracking at small scales (1-2 tpd) and high temperature (600-900 °C) is already commercially available and used in metallurgy, but the energy consumption is around 30% of the energy content of the ammonia and rarely includes hydrogen purification. Ammonia cracking at lower temperatures (<450°C), which would decrease energy consumption, and without the use of precious metals as catalysts is at low maturity levels **but should be available at large scale in 2030**. The Strategic Research and Innovation agenda 2012-2027 of the EU Clean Hydrogen Joint Undertaking aims to decrease the overall energy consumption associated with the use of hydrogen carriers, including the round-trip efficiency of ammonia production, shipping and conversion to hydrogen to 36% by 2030. In addition, the technology for separation and purification of hydrogen after ammonia cracking needs to become less costly and more efficient, e.g. comply with the composition requirements set out for fuel cells (ISO 14687). For fuel cell vehicles, the minimum hydrogen purity is 99.97%, and the maximum concentration of ammonia is 0.1 parts per million by volume (ppmv) and of inert gases (nitrogen and argon) is 100 ppmv. Therefore, innovation around ammonia cracking needs to address challenges related to efficiency, costs, purity and scale[31].

Methanol reforming to hydrogen is a relatively well established process. However the future research trend is to develop methanol conversion under the condition of low temperature (around 100°C) and low pressure[32].

Direct air capture and carbon loop

Direct air capture, capturing CO_2 from the air, is the most expensive application of carbon capture. The CO_2 in the atmosphere is much more dilute than in, for example, flue gas from a power station or a cement plant. This contributes to DAC's higher energy needs and costs relative to these applications. But DAC also plays a different role in net zero pathways, including as a CDR solution. Future capture cost estimates for DAC are wide-ranging and uncertain, reflecting the early stage of technology development. With deployment and innovation, capture costs could fall significantly. DAC costs are dependent on the capture technology (solid- or liquid-based technologies), energy costs (price of heat and electricity), specific plant configuration and financial assumptions. The Middle East and the People's Republic of China (hereafter "China") could be among the least-cost locations for DAC deployment, together with Europe, North Africa and the United States. However, the potential for costs to fall to these levels will be strongly dependent on increased public and private support for innovation and deployment[33].

Carbon loop, where CO_2 is used as a carrier molecule for renewable hydrogen, could prove to be a more cost efficient alternative to direct air capture to support the development of renewable methanol or renewable methane. The CO_2 which is produced during the usage of e-methanol or e-methane is captured, liquefied and returned back to the renewable energy terminal. Combined with renewable hydrogen this CO_2 is reused to produced e-methanol or e-methane. In this way CO_2 becomes a circular product supporting the development of a hydrogen economy. Several developments are ongoing for the construction of CO_2 capture installations, CO_2 terminals and liquefied CO_2 shipping with a target to have such solutions ready-to-market in 2026.

LOHC and liquefied hydrogen

LOHC: Hydrogen can also be incorporated in an organic molecule, resulting in a LOHC with similar properties to oil products. LOHCs do not require cooling and can be transported and stored using the existing oil infrastructure. At the destination, the hydrogen is extracted from the LOHC. The hydrogenation and dehydrogenation processes require energy, which corresponds to around 35-40% of the energy content of the transported hydrogen. Although some degradation occurs, the carrier molecule can be reused, but it needs to be shipped back to the export terminal, resulting in additional shipping fuel consumption, which is only slightly higher than for an empty ship[34]. The hydrogenation and dehydrogenation processes need further R&D to reduce to energy use and energy cost.

Liquefied hydrogen: The energy sector has vast experience in producing, transporting and storing LNG; however, the lower boiling point of hydrogen (-253 °C) compared to natural gas (-162 °C) requires different technologies. The low volumetric energy density of LH_2 makes it also inefficient to transport over large distances. The transport of hydrogen in the form of LH_2 may be attractive for users requiring high purity hydrogen. Hydrogen liquefaction and storage are mature technologies that have been used for decades, mostly for space applications and petrochemicals; however, at relatively modest levels compared with the LNG industry. Ships for transporting LH_2, however, are not yet commercially available. R&D projects are working on an efficient upscaling of the different steps of the supply chain[35].

31. Based on IEA Hydrogen report 2022
32. Jiaqi Zhao, 2020
33. Based on IEA Hydrogen report 2022
34. Based on IEA Hydrogen report 2022
35. Based on IEA Hydrogen report 2022