# Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

Final Report

**Amber Grid, EPSO-G**
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# Version log

| Version | Date shared | Comments from authors |
|---|---|---|
| 1_0 | 06th April 2022 | Working Draft shared for content review |
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**Contact details of the authors:**

Jayesh Parmar: Jayesh.Parmar@baringa.com
Ervinas Škikūnas ervinas@civitta.com
Shane Heffernan: Shane.Heffernan@baringa.com

Please address all inquiries about this report to Shane Heffernan and Ervinas Škikūnas

Source: EC 2020a; EC 2020b; EPRS 2021; IRENA 2020a

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# Common abbreviations used in this study

| Abbreviation | Description |
|---|---|
| CCGT | Combined cycle gas turbine |
| e-fuel | Fuels derived from electricity, usually from combining green hydrogen and carbon dioxide |
| ENNOH | European network of network operators for hydrogen |
| ETS | Emissions trading scheme |
| EU | European Union |
| EV | Electric vehicle |
| GHG | Greenhouse gas emissions |
| HDV | Heavy duty vehicle (heavy goods vehicles and passenger buses) |
| HGV | Heavy goods vehicle |
| JTF | EU Just Transition Fund |
| KW / MW / GW | Kilowatts / megawatts / gigawatts |
| LH2 | Liquefied hydrogen |
| LNG | Liquefied natural gas |
| LT | Lithuania |
| MoU | Memorandum of understanding |
| MWh / GWh / TWh | Megawatt hours / gigawatt hours / terawatt hours |
| NECP | National energy and climate plan |
| NG | Natural gas |
| PV | Photovoltaic (solar) |
| P2G | Power to gas |
| G2P | Gas to power |
| RES | Renewable energy sources |
| RFNBO | Renewable fuel of non-biological origin |
| Syn fuel | Synthetically derived fuels |
| TSO | Transmission network operator |
| ZLEV | Zero or low emissions vehicles |

# Table of contents

# Introduction to the study

## The study combines a review of international hydrogen policy and Lithuania's specific context to develop long term scenarios for Lithuania that are used to propose a national strategy

**Contents of the full report**

| | |
|---|---|
| 1. Policy review | In section 1, EU policy relating to hydrogen, as well as the strategies and policies of 10 countries with published hydrogen strategies have been reviewed to assess levels of ambition, target use cases, funding, market making mechanisms, regulation, and initiatives to promote value chain participation. This Section deliberately stays agnostic to Lithuania but provides the context for appraisal of Lithuania and Sections 2 and 3 |
| 2. SWOT analysis | In Section 2, Lithuania's strengths, weaknesses, opportunities and challenges have been analysed in the context of hydrogen development. This section attempts to provide a clear context for which use cases can be targeted, what technologies can be used, what opportunities exist through development hydrogen to further broader national objectives, and what challenges exist in keeping pace with hydrogen economy development in Europe |
| 3. Scenario modelling | In Section 3, long term scenarios for hydrogen are assessed with the intent to support a long term vision for hydrogen in Lithuania and shorter term targets for nurturing the hydrogen economy. These scenarios give a high level estimation of hydrogen demand as well as the level and cost of infrastructure needed to deliver that demand and use the benchmarks set in both Sections 1 and 2 to underpin that view |
| 4. Strategy and implementation | In Section 4, we present a long-term 2050 vision and plan for developing the 'Base case' view of the hydrogen economy in Lithuania developed in Section 3. A roadmap and action plan complete with ownership responsibilities is provided for achieving the 2030 horizon of that vision |

# Executive summary

## Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

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# Putting hydrogen in context

## Ambitious EU targets are driving a range of strategies, but with common themes

### Scale up of industrial hydrogen demand and transport use cases within next 10 years

| | | Incumbent fossil fuel | Likely EU scale-up period |
|---|---|---|---|
| Feedstock | Fertilizer | Grey $H_2$ | 2025 - 35 |
| | Oil refining | Grey $H_2$ | 2025 - 35 |
| Transport | Buses* | Diesel / LPG | 2020 - 30 |
| | Passenger cars (SUVs) | Diesel | 2030 - 40 |
| | Trucks* | Diesel | 2020 - 30 |
| | Rail | Diesel | 2025 - 35 |
| | Shipping* | Fuel oil | 2030 - 40 |
| | Aviation | Kerosene | 2030 - 40 |
| Power | Flexible power | Nat. gas | 2030 - 35 |
| Heat | Building Heat | Nat. gas | 2035 - 50 |
| | Process heat | Nat. gas | 2035 - 50 |

Note: Assumes USD/EUR FX rate of 1.13, *Buses, trucks and shipping have an uncertainty of 5%, 20% and 40% respectively; assumes 2019 global levels for gas and oil prices

Source: Hydrogen Council 2021 Hydrogen Insights, Project analysis

### How other countries are responding in their strategies

**Supply, transport and storage**

- Increasing energy security through hydrogen is important to many
- Electrolysis is prioritised, but methane reformation with CCS is accepted as low carbon in many cases
- Some countries identify as net importers, others are net exporters

**Ambition, targets and demand use cases**

- 2030 used as a target horizon
- Emphasis on treating proven demand first, but targeting multiple use cases:
- Using public transport to build early confidence
- Testing, but not committing to, hydrogen blending in gas network

**Mechanisms, incentives, and initiatives**

- Hydrogen valleys are already emerging
- Some countries investing early in aviation and marine despite being post-2030 use cases
- Nurturing technologies through pilots but maintaining technology competition in market mechanisms
- Sourcing some hydrogen outside of EU is likely
- Supporting domestic champions and building capabilities
- Addressing total cost of ownership of vehicles, not just fuel cost

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# Putting Lithuania in context

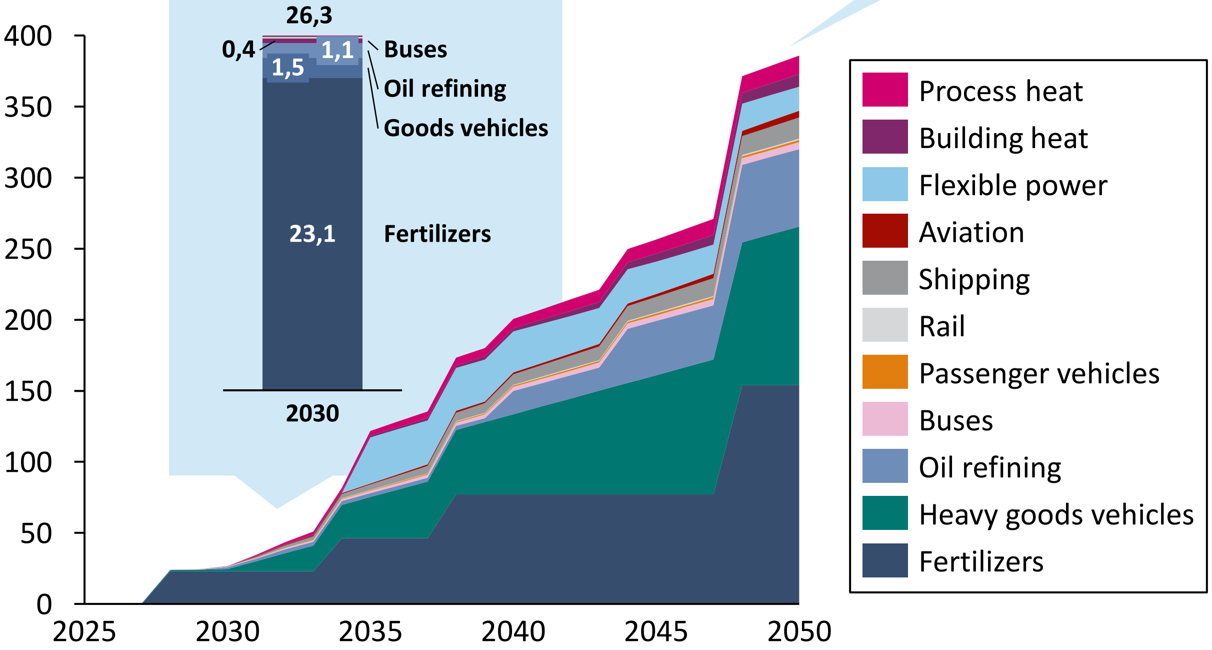
## Plenty of domestic demand capable of enabling renewable power, but with storage challenges

| | |
|---|---|
| **Proven domestic demand in ammonia for fertilizers which is large in context of Lithuania’s overall size; HGVs also present sizeable demand in next decade** | ▲ Lithuania has a relatively large footprint in fertilizer manufacturing and heavy goods vehicles fuel demand for a country of its size. These can be the anchor use cases to provide scale in the next 10 - 15 years, driven by ambitious EU targets for low-carbon ammonia production (50% of all ammonia production by 2030) and the commercial readiness of hydrogen in HGVs, which will be cost competitive with diesel for HGVs later this decade. As a smaller country within the EU membership, Lithuania is arguably less suited to investing in less mature use cases in aviation and marine fuel, while it’s ability to leverage biomass for heating needs means there is less pressure to develop hydrogen in for heating vs other countries more reliant on gas heating |
| **Electrolysers (power to gas) drives energy security agenda and enables ambitious renewables targets** | ▲ Lithuania plans to develop more renewable power to reduce reliance on natural gas and oil, with this need accentuated by the impact of Russia’s invasion of Ukraine. There is also an ambitious target for net zero power system by 2035. Consequently, there is a need for hydrogen to displace gas in the fertilizer, refining and power sectors, while also an opportunity for the production of hydrogen to lower the subsidies required for wind and solar energy. As a result there is incentive for Lithuania to prioritise hydrogen from domestic renewable power over other forms of production |
| **More renewable power supply will need to be unlocked to serve hydrogen production in the long term** | ▲ Supply of renewable electricity is more than adequate for 2030 demand in all our scenarios but limited onshore and offshore wind resource and could impede the ability of domestic renewable power production to meet hydrogen production requirements by 2050. This can be mitigated by cooperation with other countries on either renewable power sourcing for electrolysers, LNG sourcing for blue hydrogen production, or importing hydrogen itself |
| **Demand and feedstock supply clustered in different regions, which can each become hydrogen ‘valleys’** | ▲ Supply of electricity is likely to rely on wind, where resource is located in the north west of the country, while demand from fertilizer production means that hydrogen demand will initially be concentrated in Jonava near Kaunas. There is also a potential cluster of demand centred around oil refinery activity in the north, which could also serve heavy-duty-vehicle transport demand in Siauliai, Panevėžys and Klaipeda. This is broadly similar to other countries where industrial demand is centred on a small number of cluster locations |
| **Well connected networks can be leveraged; storage options more limited but ammonia demand could be an enabler** | ▲ Lithuania lacks the scale of proven geological storage potential of Germany, Denmark and Poland but may have a unique opportunity to use ammonia as a storage carrier given its outsized role in expected Lithuanian hydrogen demand. Like most EU countries it has a mature gas transmission network that will be required for natural gas in the 2020s and 2030s but can be repurposed to hydrogen over time. Hydrogen for heating will require costly distribution network retrofit but only post-2030 and likely on a small proportion of the countries heating demand that cannot be easily electrified or switched to biomass |
| **Active R&D but requiring better links with industry needed to capture value chain** | ▲ Lithuania has established R&D programs in hydrogen production technologies but has little track record of technology commercialisation and is not a currently a manufacturer of any components of the value chain. As a result, developing the ability to participate in manufacturing will require sustained investment in R&D and human capital over time focused in one or two key areas that fit with domestic infrastructure required. It is starting behind countries such as Germany, Finland, Denmark and Sweden, who have already made big steps to capture part of the value chain through existing domestic manufacturing champions |

# Projection for low carbon hydrogen demand

## We estimate 26 kt by 2030 and over 380 kt per year of demand by 2050 in our base case scenario

**Base case** estimate of annual low-carbon hydrogen demand in Lithuania (2025- 50)
kt hydrogen



c.18% of 2019 national final energy demand[1]

What we mean by ‘low-carbon’ hydrogen: this report refers to hydrogen *demand* as low-carbon hydrogen i.e. demand that is driven by decarbonisation (therefore excluding grey hydrogen demand), but is agnostic to technology production. The report recommends green (electrolyser) hydrogen production over other technologies when considering *supply* but does not differentiate between technologies when considering demand

### Key assumptions

- Centralized nature of fertilizer production offers opportunity to scale early, but with full scale occurring once regulation mandates full switch
- Buses are the earliest use case and could adopt up to 1 kt per year by 2026, but this is small in proportion to fertilizer demand
- HGVs take time to roll out but eventually provide a very large demand base owing to large share of international HGV transit
- Lithuania achieved net zero by 2050 but is not as quick to achieve same level of scale in some use cases by 2030 as the more ambitious member states
- Net Zero 2035 in the power sector requires some hydrogen-to-power peakers
- No significant positive export balance is assumed given production cost will be reasonably well aligned with neighbours

Note: 1) 5,2 Mtoe final energy demand for 2019
Source: Project analysis; Enerdata

# Long term vision for hydrogen in Lithuania

## Growth will enable energy independence and can anchor around proven ammonia demand and will form part of a Baltic hydrogen backbone by the 2040s

| | |
|---|---|
| Increasing energy independence | ▲ Low carbon hydrogen will be used to reduce Lithuania's dependence on oil and natural gas imports as part the National Energy Independence Strategy. Over time it will reduce reliance on natural gas used as feedtsock in fertilizer and refinery sectors, on natural gas as fuel for the power sector, and on liquid hydrocarbons in the transport sector. It may also help to provide heat for industrial process heating and building heat, though this is less certain and over a longer time horizon |
| Prioritising hydrogen from domestic renewables | ▲ In order to support the goal of energy independence, Lithuania will prioritise domestic production of hydrogen using renewable electricity over hydrogen imported or produced from fossil fuels. This recognises that renewable electricity can reduce Lithuania's exposure to commodity price volatility and geopolitical risk while still allowing other forms of hydrogen to be developed if cost competitive. This will in turn reduce subsidies required for renewables and in particular help to avoid curtailment of wind generation once wind becomes a large proportion of overall power generation |
| Anchored around low-carbon ammonia and heavy duty vehicles as sources of demand | ▲ As hydrogen demand takes off, green ammonia used in an established fertilizer industry will be the 'anchor' use case that enables scale up of the industry in the 2020s. It can also provide a cost competitive long-duration storage for green hydrogen, in doing so reducing the risk of requiring access to geological storage resource of other EU member states. Lithuania accommodates an outsized share of long-distance HGV transit for which hydrogen presents a realistic long-term solution to decarbonisation. As road transport becomes targeted by EU ETS regulation, a network of hydrogen refueling stations based on hydrogen or hydrogen-derived fuels is envisioned. This will be enabled by some locally based HGVs and buses switching to hydrogen |
| Deployment in aviation and marine fuel, but over longer term | ▲ In the longer term aviation and marine fuel demand will increasingly require hydrogen or ammonia and e-kerosene derived from hydrogen. Synthetic natural gas derived from hydrogen for use in heating is not envisaged. While in the nearer term these will come under less regulatory pressure from the EU, in the 2030s and 2040s they will scale up considerably. |
| Baltic hydrogen highway for transport and import/export by 2040 | ▲ Hydrogen supply will be enabled by a gradual transformation of energy nework infrastructure. In the 2020s the existing electricity and natural gas network will be able to support pilots and early scale up of hydrogen while in the 2030s dedicated hydrogen pipelines will emerge to help locate production close to renewable electricity supply. This may operate in parallel to natural gas pipelines at first but could eventually replace it as the role of natrual gas will reduce in the 2040s as Lithuania's approaches Net Zero. This domestic network will be joined by the EU hydrogen backbone connecting the Baltic states by 2040, which will act to stabilise hydrogen pricing and promote cross-border trade of hydrogen in the Baltics |
| Capturing the value chain to create more jobs | ▲ The hydrogen economy is guaranteed to create sustainable construction and asset maintenance but the journey will also aim to capture upstream manufacturing components of the value chain. These will be built off of existing R&D capability in several hydrogen-enabling technologies but also through international collaboration on pilot projects, with a sustained focus on building capability through partnership with countries already emerging as leaders in component manufacturing, as well as targeted funding for training that creates home grown human capital |

# 2030 goals

## 300 MW of production capacity by 2030 to serve 26 kt of demand

### ‘Concrete’ targets proposed

**Capacity and demand**

- Target 300 - 350 MW[1] of electrolyser production capacity (or equivalent through other technologies) by 2030 and 30 kt of low-carbon hydrogen production, representing approx. 1% of target 2030 EU capacity and 0.3% of production respectively
- 15% of domestic ammonia production enabled by low-carbon hydrogen
- Hydrogen buses in place wherever they are the preferred zero emisisons solution in 5 major cities
- Optional pilots: 1 pilot hydrogen train along a freight route
- 1% of HGV fuel demand served by hydrogen by 2030

**Transport and storage**

- Approximately 2% of demand in seasonal storage by 2030, with preferred seasonal storage method to be determined
- 50 – 100 HGVs powered by hydrogen by mid-2020s and at least 5 refuelling stations in place to accommodate roll out of hydrogen across TEN-T network
- Pilot tests on blending into the gas transmisision network

**Regional and socioeconomic development**

- Establish first valley centred around fertilizer production with aim to serve 2030 targets, including involvement from R&D and academic institutes in Kaunas and Vilnius
- Establish 1 – 2 other valleys strategically placed, most likely around Klaipeda, to optimise location of future supply and demand
- 1.2k sustainable jobs in construciton and asset maintenance created by 2030

### ‘Softer’ targets proposed

**International collaboration**

- Establish MoUs with neighbouring EU member states on areas of collaboration to increase regional security of supply and coordinate on transmissions / storage / import / and export infrastructure

**Human capital investment**

- Dedicated degree courses targeting both ‘hard-hat’ and ‘white-collar’ roles required in gas systems and renewable technologies
- Incentives in place for bringing interanational talent with appropriate qualifications into Lithuania

**Capturing value chain**

- Demonstrating value chain capture in at least one component of the value chain, particularly in supply and storage infrastructure where investment is heaviest

Note: 1) Assumes an electrolyser load factor of approx. 35%

# A 14-point action for 2030

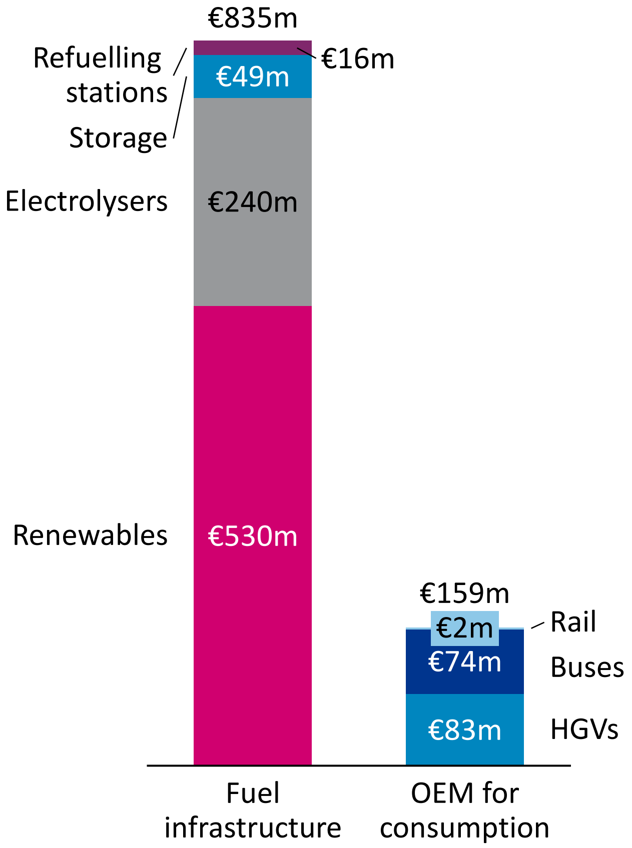
## We have identified 14 actions required to deliver the 2030 goals and log term ambition of our proposed strategy

| Action | | | Assumed responsible | Timeframe for completion | Time to complete |
|---|---|---|---|---|---|
| Mid 2020s targets | 1 | Take ownership of strategy and lead governance | Ministry of Energy | 2022 | < 1 year |
| | 2 | Develop a pilot use cases in HGVs that supports the minimum EU target for refueling network on TEN-T | Ministry of Energy | 2025-26 | 3 – 4 years |
| | 3 | Rollout of hydrogen buses across 5 largest cities | Ministry of Transport & Comms. | 2025-26 | 3 – 4 years |
| | 4 | Enable projects through establishment of clear health and safety regulation and environmental planning | Ministry of Environment | 2023-24 | 0.5 – 2 years |
| | 5 | Develop a pilot use case in rail | Ministry of Transport & Comms. | 2025-26 | 3 – 4 years |
| 2030 targets | 6 | Deliver scaled up project delivery in fertilizers and establish first hydrogen valley around fertilizer production | Ministry of Energy | 2028-30 | 3 – 4 years |
| | 7 | Begin testing hydrogen blending in the gas network | Ministry of Energy | 2028-30 | 3 – 4 years |
| | 8 | Prepare for market-based scale up | Ministry of Energy | 2028-30 | 3 – 4 years |
| | 9 | Invest in seasonal storage for hydrogen | Ministry of Energy | 2028-30 | 3 – 5 years |
| | 10 | Build capability and human capital in hydrogen | Ministry of Economy and Innovations | 2028-30 | 5 – 10 years |
| | 11 | Assess pilots for aviation and shipping deliverable by 2030 (but not earlier than late 2020s) | Ministry of Energy | 2030 | 3 – 4 years |
| Beyond 2030 | 12 | Establish a business model for low carbon flexibility in power system to deliver net zero power by 2035 | Ministry of Energy | 2030 | 1 – 3 years |
| | 13 | Long term planning for role of hydrogen in fuel mix | Ministry of Energy | 2030 | 0.5 – 2 years |
| | 14 | Long term planning for hydrogen transmission and storage | LitGrid / AmberGrid | 2030 | 0.5 – 2 years |

# Near term investment required

## Nearly €1bn will be required up to 2030 through a combination of public and private sector investment

2022-30 cumulative investment of **€994m** in the **Base Case**



**All will require a combination of public and private sector investment**

- Financial support for development can be administered at state level with different projects or cities competing for earlier prioritisation of funding, which is allocated in a sequenced manner. This sequenced approach has been adopted for allocating funding for industrial clusters in the UK and allows the first sequence of projects to teach and refine subsequent projects
- **Pilot projects** will require a significant portion of their capital cost funded through public support with those competing for funding allowed to present different business models and technologies
- **Scale-up** mechanisms and incentives such as mandates and CfDs then look to push more direct competition by establishing a business model (e.g., carbon CfDs or diesel fuel taxes) which project developers can compete within to provide hydrogen

**Individual items to consider funding (either via EU or domestic funding):**

- Pilot cases for HGVs and refueling stations
- Roll out of hydrogen buses in 5 largest cities
- Funding focused on R&D collaboration with industry
- CfD mechanisms for de-risking competitive investment in heavy industries such as fertilizer and refining
- Incentive mechanisms for vehicle switching in HGVs
- Establishment of hydrogen valleys and required network infrastructure and permitting to facilitate their growth

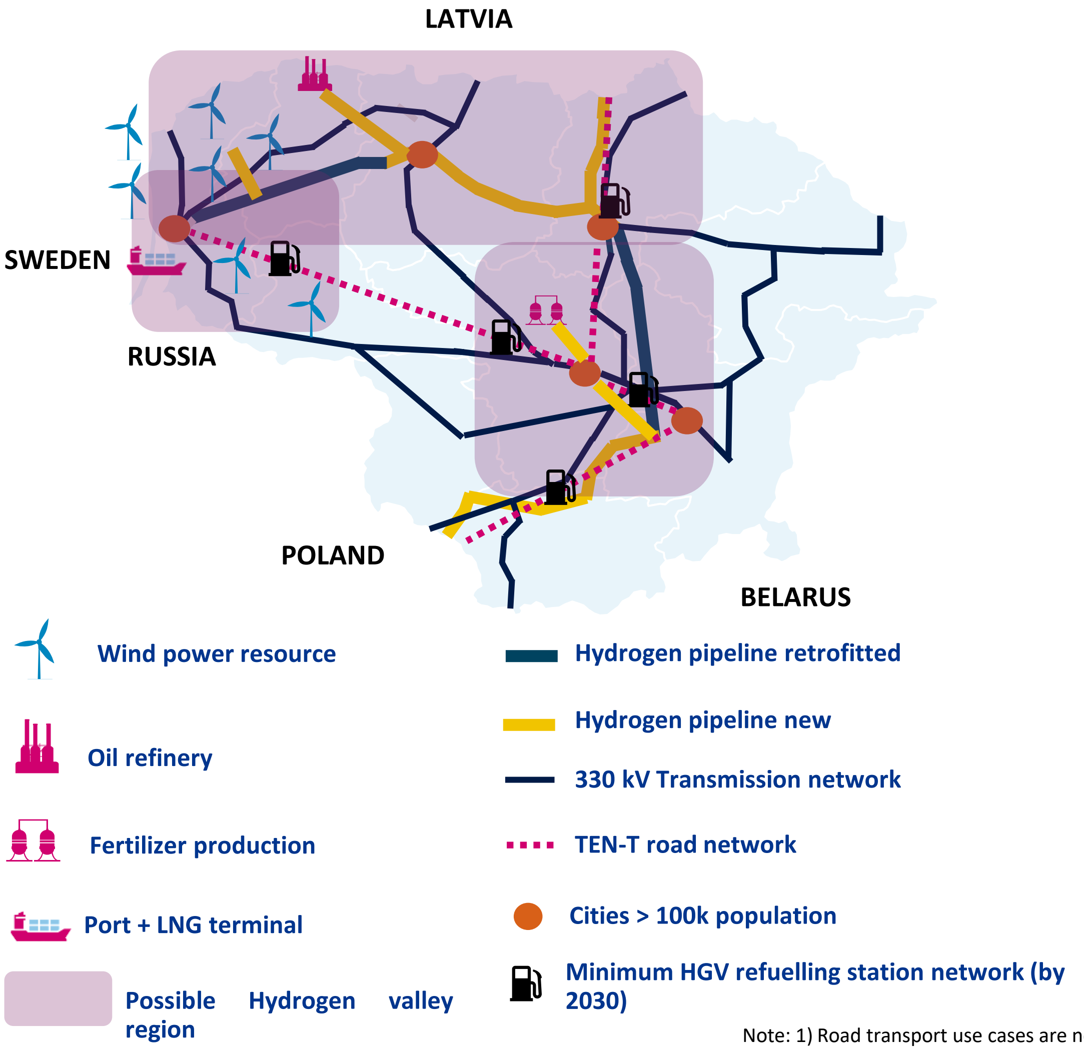
**These could be funded through several revenue raising mechanisms:**

- Fossil fuel taxes (supplier pays)
- Carbon taxes / carbon price premium on top of ETS (fossil fuel consumer pays)
- Electricity and gas end-user environmental levy (household / business pays)
- General taxation (individual pays)

# Hydrogen network infrastructure vision

## Hydrogen production biased towards north-east, with high potential demand in the Central Lithuania region connected via pipeline

**Stylised map of key hydrogen infrastructure for 2030 and 2040**



- **Demand prior to 2030 will be concentrated around the Kaunas area** and (subject to further validation beyond the scope of this study) can be served by locating production close to demand without significant upgrades to the electricity network. Consequently, a hydrogen valley centred on colocation of electrolyser production and demand could be create in the Kaunas-Vilnius region
- In parallel, **location of production closer to renewable energy supply may be preferred as hydrogen pipelines become more economic than electrical transmission** as a means of high-volume transport. This can be located along the existing gas pipeline network, except for a new pipeline route connecting the eastern part of the line with Kaunas via the fertilizer plant at Jonava. This new route may save cost by avoiding a much longer pipeline build via Vilnius, where no concentrated large-scale demand is envisioned[1]
- **A valley can also be created around the Klaipeda region** capable of eventually linking hydrogen supply in this region with hydrogen demand at any point along the pipeline. This valley may include the port of Klaipeda if import and export infrastructure are to be built in the longer term
- This valley could **optionally extend out to the Northern part of the country** where further demand will come from the refinery and the cities of Panevėžys and Šiauliai for transport use cases
- The **minimum initial refueling network for HGVs required to meet EU criteria of one station every 150 km requires 5 stations** situated along roads connecting the major cities and onward to Poland and Latvia. Additional refueling will be required for buses

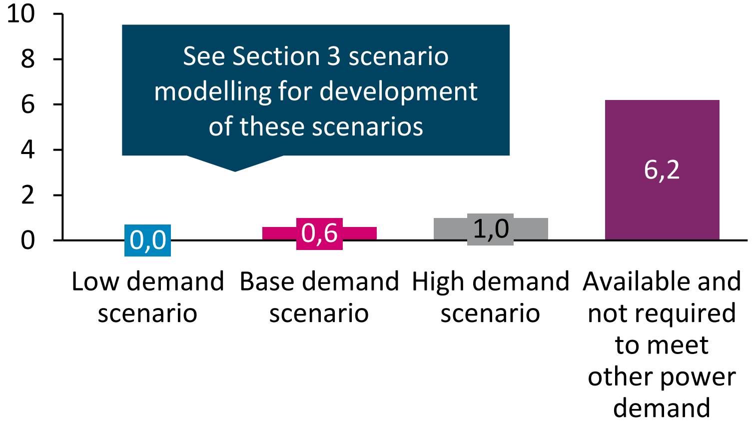
Note: 1) Road transport use cases are not considered large scale and can be served via a distribution network of refuelling trucks

Sources: Litgrid, LVEA, Ambergid

# Is there enough renewable power to serve demand?

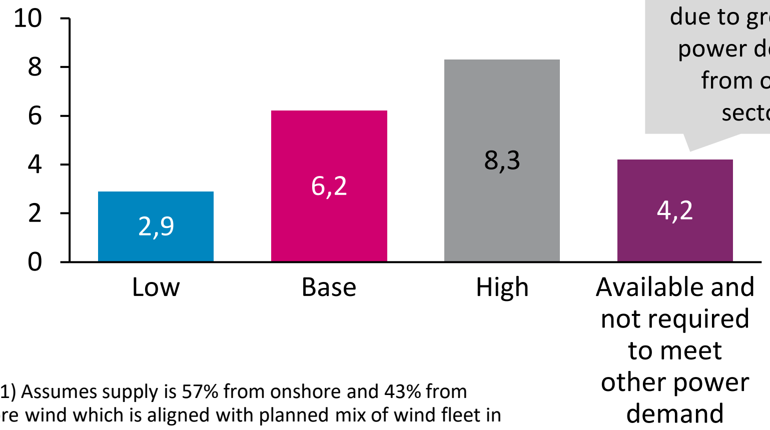
## Renewable power development plans should be sufficient to cover hydrogen demand until 2030, but thereafter more renewable power is needed, and network upgrades required

**2030** GW wind power[1] required for hydrogen demand in Lithuania scenarios vs renewable power available



See Section 3 scenario modelling for development of these scenarios

**2050** GW wind power[1] required for hydrogen demand in Lithuania scenarios vs renewable power available



Lower than 2030 due to growth in power demand from other sectors

**Basis of estimation of power available vs power required for hydrogen production**

- Current plans for 7 GW of renewables (3.6 GW onshore wind, 1.4 GW offshore wind, 2 GW solar)
- Current and future demand for electricity outside of hydrogen and future plans for flexible power
- Resulting power available for electrolyser operation is conditional on these targets being met and on the price of electricity to the electrolyser being at most €35 – 40 / MWh (See Section 3) to ensure competitiveness of hydrogen

**Conclusions:**

- Our 2030 demand scenarios can be catered for under the existing plan for renewables deployment
- At some point between 2030 and 2050 more renewables will be required via either
    - collaboration with neighbouring states to co-develop or import more renewables
    - developing renewables and hydrogen outside the electricity network (e.g., by colocation) may be required
    - Significant investment in the electricity network to accommodate more renewables
- Meanwhile, exports of hydrogen in the near term may be limited to 'balancing' volumes of green ammonia rather than a true export industry, more like Portugal's strategy than the Australia/Chile strategies
- In the longer term, the analysis suggests expansion of renewable development plans or import of hydrogen or renewable power may be required to serve ambition set by the Base case

Note: 1) Assumes supply is 57% from onshore and 43% from offshore wind which is aligned with planned mix of wind fleet in 2030

# 1. Policy review

Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

# Overview of Section 1

## The EU policy review assesses targets and direction of travel for hydrogen, while individual countries provide insight on mechanisms and variation of focus and ambition

### EU and international policy review

- The EU Hydrogen Strategy, the new EU Gas Package, and the Fit for 55/Red III proposals are reviewed
- The review sets out what long term vision has been set by the 2020 strategy and the proposed Gas package as well as what 2030 targets have been set by both these and the Fit for 55 proposals
- The views of industry representative bodies (IEA, IPCEI, FCH JU, Hydrogen Europe, IRENA) have been considered in developing our assumptions for hydrogen demand and infrastructure requirements in Section 3 and accompanying annexes but for brevity are not summarised here

### Country policy review

- The hydrogen strategies of 10 different countries (8 of which are EU members) are reviewed. The review assesses:

**Supply, transport and storage**

- What is the broader context of drivers that influence hydrogen strategy e.g., current industrial activity, fossil fuel mix and network infrastructure?

**Ambition, targets and demand use cases**

- What hard targets have been set and how ambitious are they in the context of energy consumption and decarbonisation trajectory?
- What is the high-level sequencing of the strategy and when are the major milestones?

**Mechanisms, incentives, and initiatives**

- What subsidies and mechanisms are in place to begin delivering against targets? How direct vs market-based are these? Do they target supply or demand?
- How and by whom are incentives regulated?
- Which are the major early projects?
- What partnerships have been put in place by policy makers and what is the role of each partner?

# EU hydrogen strategy

## The EU hydrogen strategy published in 2020 sets the aspiration of EU to lead the Hydrogen opportunity

- **EU Hydrogen Strategy published in July 2020**
  - Hydrogen essential to the 2050 climate neutrality commitment of the EU
  - EU registers a massive increase of planned global investments in electrolysers by 2030, most of them in the Europe
  - European Clean Hydrogen Alliance to help build up robust pipeline of investments
  - EU Hydrogen Strategy establishes that cumulative investments in renewable Hydrogen in Europe could be as high as EUR 180 to 470 billion by 2050
  - Priority for the EU is developing renewable hydrogen, but recognizes that in short and medium term other low-carbon hydrogen forms are required

- **EU Roadmap until 2050 in key numbers**
  - Phase 1– 2020 to 2024: at least 6 GW of renewable hydrogen electrolysers in the EU & up to 1 million tons of renewable Hydrogen in the EU
  - Phase 2 – 2025 to 2030: integrated energy system, at least 40 GW of renewable electrolysers by 2030 & up to 10 million tons of renewable hydrogen in the EU
  - Phase 3 – 2030 to 2050 : renewable hydrogen technologies to reach maturity and to be deployed at large scale – reach all `hard-to-decarbonise sectors`

Source: EC 2020a; EC 2020b; EPRS 2021; IRENA 2020a

# Hydrogen and gas markets decarbonisation package

## Published in December 2021, the package builds on natural gas market infrastructure re-use preference and governance and allowing blue hydrogen

- The package has been proposed as part of the EU Green Deal and is complimentary to revised Red II directives and ETS regulation
- For existing natural gas TSOs (such as Amber Grid), there are some changes that relate to the introduction of hydrogen and the desire to move away from unabated fossil fuels in favour of low and zero carbon gases enabling plans to become a hydrogen system operator i.e., convert part of its system to hydrogen
- **Key messages hydrogen relevant to Lithuanian strategy context:**
  - **Hydrogen market design could build on gas market type of governance experience**
    - various articles Directive and regulation, e.g. article 54 Regulation enabling network codes design for hydrogen; provisions on ENNOH
    - Implicit choice for 'piped Hydrogen' emerging and the EU Hydrogen backbone (no exclusion of ships, rail, trucks, off-grid as transport)
  - **Natural gas is discouraged after 2049 in favour of hydrogen and/or biomethane:**
    - Article 27: Directive – no long-term contracts after 2049
    - Article 51: Ten Year Network Development Plan to include decommissioning and integrated planning including hydrogen
    - Implies TSOs agile thinking on integrated view on biomethane, Hydrogen, power and abated natural gas
    - No favour given to what mix of biomethane versus hydrogen will emerge
  - **Regional integration is encouraged:** article 6 Directive, with implicit encouragement for collaboration between Baltic states, Poland, and Finland (as with natural gas markets)
  - **Blue hydrogen is allowed:** article 8 Directive – 'low carbon hydrogen' that reduces GHG by at least 70%)
  - **Maximum blend of hydrogen set through Europe:** 5% maximum blend across-border from October 2025
  - **Transmission and distribution to collaborate on Hydrogen integration including retail:** article 35 Directive
  - **Gas TSO can assign new tasks** (e.g. Hydrogen transmission) to a new TSO subject to unbundling and certification (article 35 Directive)
  - **Must connect biomethane and Hydrogen producers to the grid under reasonable conditions:** article 37 Directive (negotiated third party access connection);
    - Article 16 Regulation - 75% discounts on production and storage fees for renewable gases (including hydrogen)
    - 100% (zero fees) at borders/interconnection points. This implies subsidies from natural gas to new gases development
- Further to this package, the REPowerEU outline plan for increasing energy security and combating high energy prices, most notably including a measure to refill gas storage to 90% by October 1st each year

# EU carbon regulation impact on hydrogen

## All use cases currently or will soon come under some form of EU carbon price regulation

### Covered by current ETS

- The current emissions trading system (ETS) covers heavy industrial activities as well as power generation and sets a carbon price based on a 2.2% overall annual reduction in emission until 2030, with more ambitious reduction envisaged by the Fit for 55 package
- Flights within the EU are covered by the ETS

### Will be covered by separate buildings and Transport ETS

- The Fit for 55 package proposes a new ETS for road transport and buildings which will run separately from the current ETS and proposes to start in 2025, with a cap on emissions set from 2026.
- This new upstream system will regulate fuel suppliers. The cap in this new ETS will be reduced annually to yield emissions reductions of 43% in 2030 compared to 2005

### Will be impacted by carbon border adjustment

- The Carbon Border Adjustment Mechanism (CBAM) is a proposed carbon tariff on carbon intensive products, such as cement and some electricity, imported by the European Union. This is currently being legislated as part of the European Green Deal and may take effect in 2026 with reporting starting in 2023

**Hydrogen use cases covered**

Covered by current ETS:

- **Fertilizer production**
- **Oil refining**
- **Industrial process heat**
- **Flexible power**
- **Aviation (EU)**
- **Marine (proposed)**

Will be covered by separate buildings and Transport ETS:

- **Buses**
- **Heavy goods vehicles**
- **Rail**
- **Heavier passenger vehicles**
- **Building heat**

Will be impacted by carbon border adjustment:

- **Fertilizer production**

Steel is excluded from use cases as there is currently no steel production in Lithuania

# Major EU funds available

## There are multiple sources of EU funding in existence, some of the largest pots which Lithuania is entitled to are shown below

### EU sources of funding and development finance

| Total size of fund (€ bn) | | | |
|---|---|---|---|
| 724 | **Recovery & resilience facility** | Commercial | Provides large-scale financial support for mitigating the economic and social impact of the covid-19 pandemic.Lithuania receive €2.22bn in grants, €0.84bn of which is for climate objectives |
| 470 | **European Investment Bank** | Commercial, pre-commercial, R&D | Finances strategic investments in renewable energy and energy efficiency. €470bn investment expected in green hydrogen by 2050, €0.5bn in environment & innovation in Lithuania in 2020 |
| 372 | **InvestEU** | Commercial | Offers guarantees in order to mobilize public and private finance for strategic investments - €372bn between 2021-2027. Hydrogen is one of the key strategic sectors to be supported |
| 96 | **Horizon Europe** | R&D and pre-commercial | Supports research and innovation, and funding for industry, climate, energy and mobility related clusters. 2021-2027 budget is €95.5bn |
| 30 | **Connecting Europe Facility** | Commercial | Supports financing of infrastructure projects in the energy, transport and digital sectors with a large focus on cross-border collaboration. €5.83bn specifically for energy |
| 18 | **Just Transition Mechanism** | Commercial | Supports territories most affected by the transition towards climate neutrality |
| 15 | **Modernization Fund** | Commercial | Funded through ETS receipts and targets investments in energy decarbonisation in 10 lower-income EU countries including Lithuania |
| 10 | **Innovation Fund** | Commercial, pre-commercial | Supports both small and larger scale decarbonisation projects demonstrating innovation |
| 7 | **EU Structural Funds** | Commercial, pre-commercial | EU funds aimed at helping Lithuania's economic development – combines CF, ERDF and ESF. €7bn allocated for Lithuania up until 2027, transport & energy networks and low-carbon economy have specific allocated quantities of investment |

# How ambitious are Fit for 55 hydrogen targets?

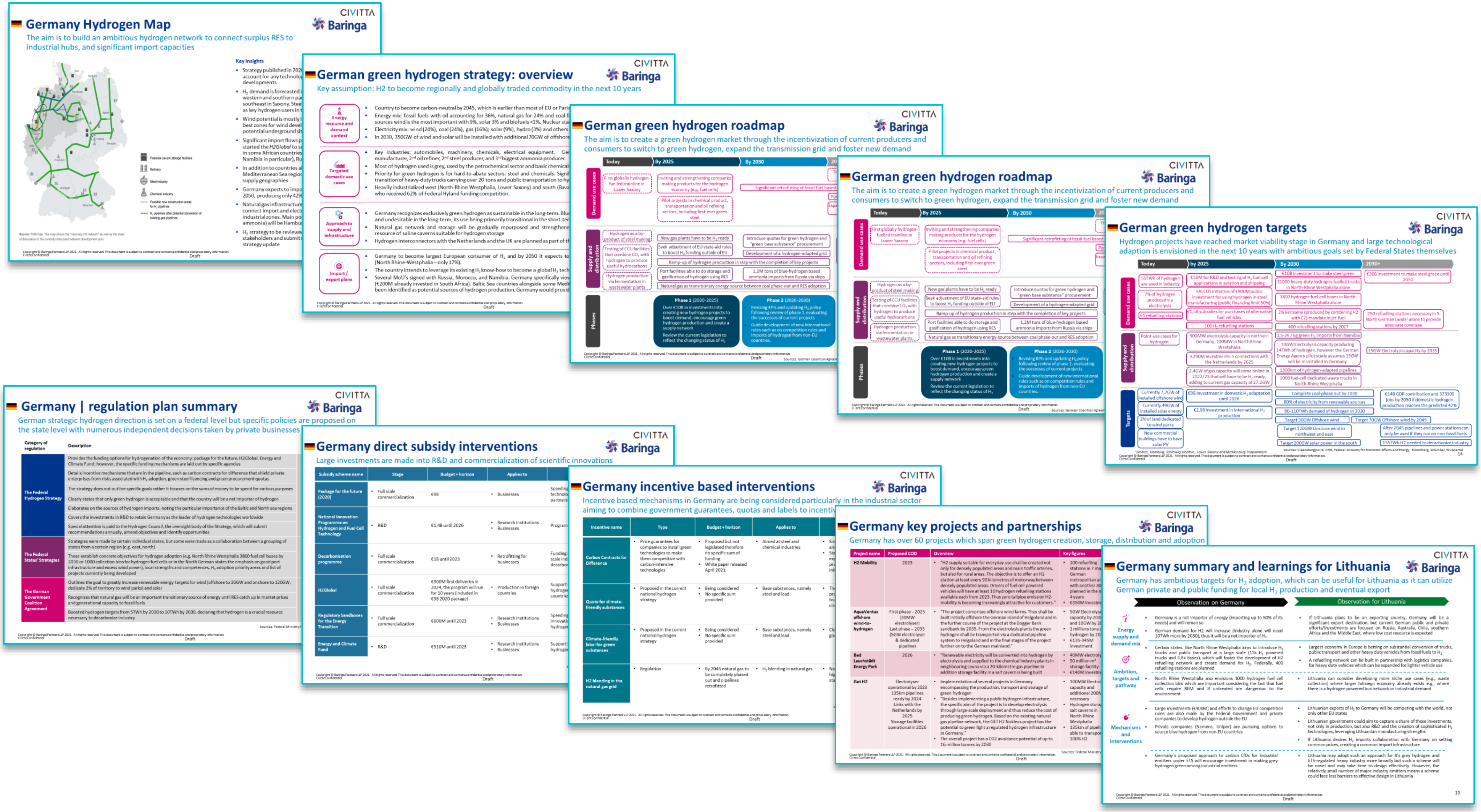
## 2030 horizon targets are especially ambitious for green ammonia and the transport sector

| Use cases for hydrogen in Lithuania | EU target that is primary driver of hydrogen adoption | Impact on hydrogen demand by 2030 |
|---|---|---|
| **Fertilizer** | 50% RFNBO target in traditional hydrogen sectors | Effectively **mandates 50% of hydrogen feedstock** to be renewable |
| **Oil refining** | 2.6% share of renewable fuels of non biological origin (RFNBO) in final energy demand in all forms of transport by 2030, with green hydrogen used as feedstock eligible, with RFNBOs counted where they are produced and not consumed | Aside from aviation, where a 2030 target has been set, no distinction has yet been made on which classes of vehicle the RFNBO target is intended to impact<br>**However it is likely that the RFNBO target will fall across HDVs (HGVs and buses) given** passenger vehicles and rail are more likely to pursue electrification and marine decarbonisation will be slower paced<br>**Renewable hydrogen used as feedstock in oil refining** will also be eligible under this target |
| **Rail, buses,** | | |
| **Buses** | | |
| **Heavier passenger vehicles** | | |
| **Heavy goods vehicles** | 'Super-credit' incentive within zero-or-Low-Emissions Vehicles (ZLEVs) for up to 2% of all new (~0,2% of fleet) HGVs as part of HDV $CO_2$ emissions standards on vehicle manufacturers | |
| **Marine** | 6% greenhouse gas (GHG) emissions intensity reduction vs 2005 for onboard fuels by 2030 | Limited impact as targets can be achieved through efficiency and adoption of liquefied natural gas (LNG) fuelling |
| **Aviation** | 0,7% synthetic aviation fuels by 2030 | Will drive e-fuel production in countries with cheap renewables |
| **Flexible power** | 61% GHG reduction by 2030 vs 2005 under ETS | Will drive higher carbon prices and increase renewable roll-out but will not promote mas switching away from unabated gas in favour of hydrogen this decade |
| **Industrial heat** | | |
| **Building heat** | An annual increase of renewable energy sources (RES) share in the heating & cooling (H&C) sector by 1.1% | Could drive some limited grid blending but more likely to drive adoption of biomethane, biomass, and electric heat pumps |

Source: EU Directive 2018/2001 (July 2021); International Council on Clean Transportation Fit for 55 Policy Review

# Individual country reviews

## We have included individual country reviews in the Annex materials and provide summary conclusions in this section


Germany Hydrogen Map
The aim is to build an ambitious hydrogen network to connect surplus RES to industrial hubs, and significant import capacities

German green hydrogen strategy: overview
Key assumption: H2 to become regionally and globally traded commodity in the next 10 years

German green hydrogen roadmap
The aim is to create a green hydrogen market through the incentivization of current producers and consumers to switch to green hydrogen, expand the transmission grid and foster new demand

German green hydrogen roadmap
The aim is to create a green hydrogen market through the incentivization of current producers and consumers to switch to green hydrogen, expand the transmission grid and foster new demand

German green hydrogen targets
Hydrogen projects have reached market viability stage in Germany and large technological adaption is envisioned in the next 10 years with ambitious goals set by Federal States themselves

Germany | regulation plan summary
German strategic hydrogen direction is set on a federal level but specific policies are proposed on the state level with numerous independent decisions taken by private businesses

Germany direct subsidy interventions
Large investments are made into R&D and commercialization of scientific innovations

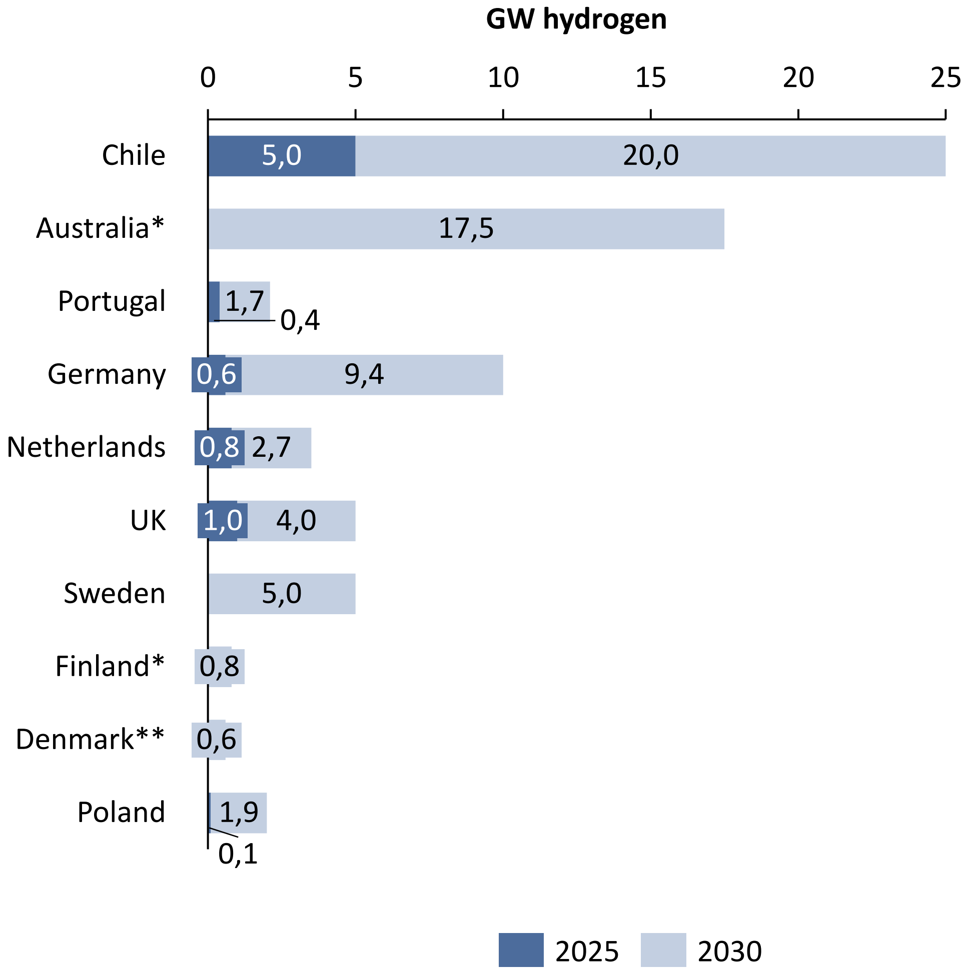
Germany incentive based interventions
Incentive based mechanisms in Germany are being considered particularly in the industrial sector aiming to combine government guarantees, quotas and labels to incentivise

Germany key projects and partnerships
Germany has over 60 projects which span green hydrogen creation, storage, distribution and adoption

Germany summary and learnings for Lithuania
Germany has ambitious targets for $H_2$ adoption, which can be useful for Lithuania as it can utilize German private and public funding for local $H_2$ production and eventual export

# Levels of production ambition among peers

Most countries do not focus on a quantitative ambition for 2025 but set ambitious targets for 2030



| | MW Hydrogen / TWh energy demand |
|---|---|
| Chile | 138 |
| Australia* | 33 |
| Portugal | 22 |
| Germany | 9 |
| Netherlands | 14 |
| UK | 8 |
| Sweden | 43 |
| Finland* | 9 |
| Denmark** | 10 |
| Poland | 6 |

**Self identified exporters** – *Countries with very cheap and very abundant renewable power*

**Self-identified importers** – *Countries with very high industrial demand and more limited renewable power resource*

**May be export or import** – *Countries with both industrial demand and good renewable resource and strong ambition*

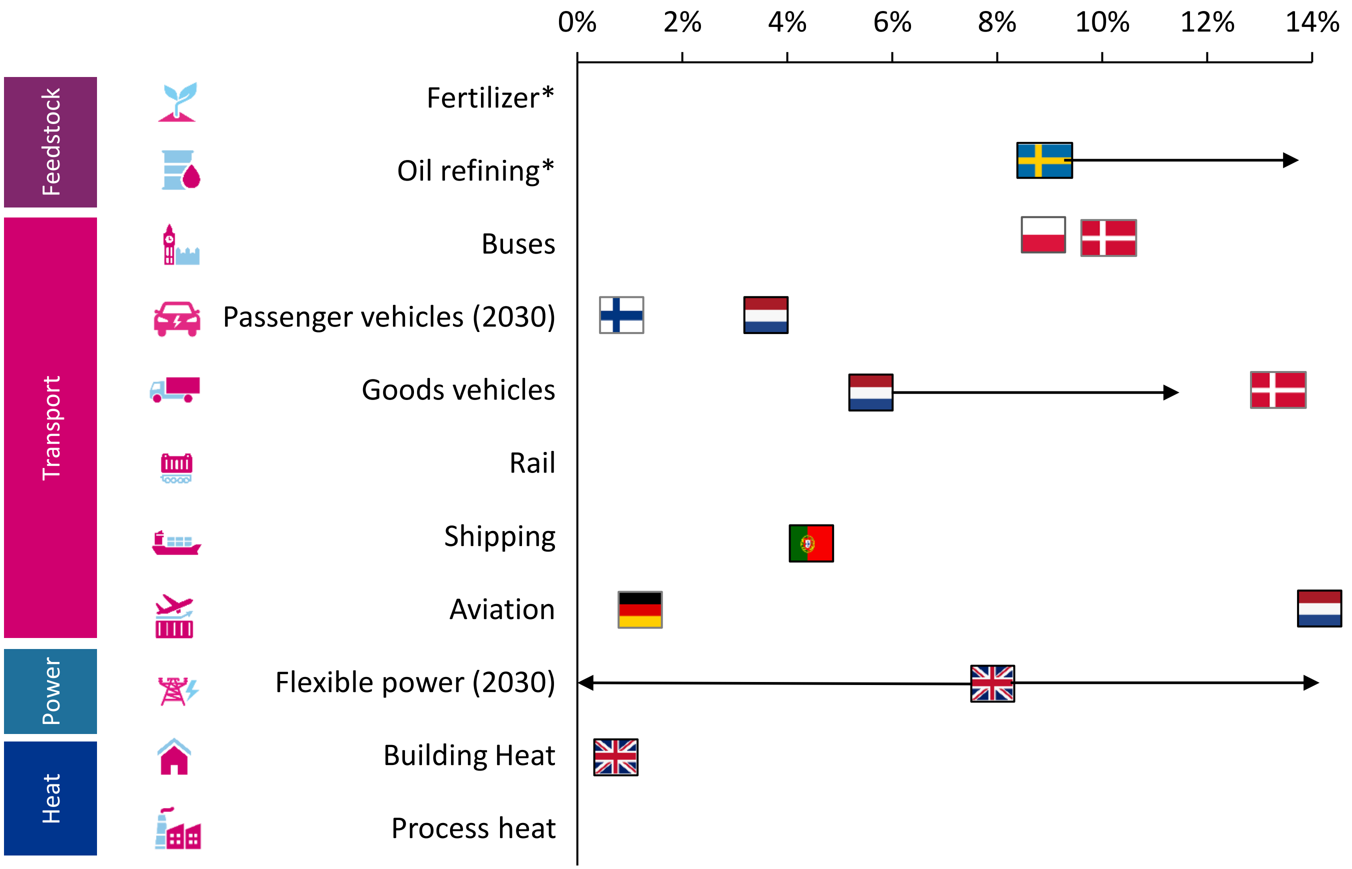
**Lower ambition** – *Strong industrial demand but markedly lower pace of ambition vs other countries with strong industrial demand*

Note: *Value is not a stated national ambition, but projections made by the EU and Deloitte for FI and AU respectively **High ambition

Source: National Hydrogen Strategies, IEA

# Peer targets for individual use cases

## Most strategies shy away from setting use case specific targets though some have set targets that are material and move beyond pilots. Notably no targets for fertilizer or refining



**% of demand from hydrogen in 2030**

Broader 2030 demand-based targets

*2-5% in industry, 1-5% in transport, **10 – 15% gas grid blend***

*4 – 9% for Industry and 0 – 1.5 % for transport*

*Other targets focus on mix of renewable fuels, not specifically hydrogen*

*No demand targets set*

*No demand targets set*

Note: *Numbers are equivalent energy demand for level of feedstock hydrogen required; 2030 demand used for power and vehicles to reflect significant change in underlying demand highlighted in planning documents over next 10 years

Source: Analysis of National Hydrogen Strategies

# Conclusions of individual country reviews (1 of 2)

## Several themes have emerged from the review in both supply strategy and approach to demand use cases

**Supply, transport and storage**

- **Increasing energy security through hydrogen is important to many:** Hydrogen is seen as an opportunity for countries such as Chile and Portugal with high production potential, as well as countries such as Netherlands with high reliance on foreign natural gas
- **Electrolysis is prioritised, but methane reformation is accepted as low carbon**: Countries generally deem blue hydrogen as acceptable but less preferable to green, although countries with strong reliance on gas or proven access to sequestration sites are betting more on blue. Notably Portugal and Germany have distanced themselves from subsidising or supporting blue hydrogen (but without outright banning it)
- **Some countries identify as net importers, others are net exporters**: Access to cheap resources of both renewables and carbon storage is a major driver of export ambitions, while existing grey hydrogen demand has led some countries to accept the need for an import trade balance. Chile, Portugal, and Australia expect to serve as net suppliers to other countries due to a strong solar and wind resource
- **2030 used as a target horizon**: All countries are reserved on what hydrogen demand will be beyond 2030. Targets up until 2030 can be based on real economics and policy direction but the pace of decarbonisation, trends in technology costs and regulation mean that targets are generally not being set for 2035 or 2040 horizon

**Ambition, targets and demand use cases**

- **Targeting multiple use cases**: countries that have set strategies aimed at delivering Net Zero by 2050 or earlier have adopted approaches that aim to deliver against multiple use cases this decade. None of these countries are focusing solely on industrial demand while ignoring transport, or vice versa
- **Emphasis on treating proven demand first**: Germany is adopting an approach of addressing industrial demand in steel, fertilizer, and refining first, while Sweden is focusing on green steel. Such demand is somewhat less economic to switch than HGVs but may prove to be less cost-sensitive and carries no risk of picking the wrong commodity, as hydrogen is already the required commodity
- **Using public transport to build early confidence**: Publically controlled demand is often used as a way of kick-starting through smaller projects. Projects involving small city bus fleets provide early scalable cases but are smaller in scale versus what is required to decarbonise whole refineries or fertilizer plants. They can provide stable long-term demand, while costs can to some extent be recuperated through passenger fares. Such projects also build public acceptance of hydrogen as a fuel, more so than less visible use cases such as refineries and ammonia production
- **Testing, but not committing to, hydrogen for heat**: Although all countries are experimenting with hydrogen blended into existing gas networks, no one is assuming that hydrogen is the favoured solution to replace natural gas for building heat in countries with winter peaks of building energy demand (i.e. Northern Europe). It is accepted that hydrogen might be a viable solution in some cases but that other solutions such as biogas and electric heat pumps could play a bigger role

# Conclusions of individual country reviews (2 of 2)

## Commonalities and differences in approaches to delivering the strategy also emerge from the review

**Mechanisms, incentives, and initiatives**

- **Hydrogen valleys are emerging**: Most countries aim to promote investment in production through dedicated spatial planning e.g., regional clusters or special economic zones (sometimes referred to as 'valleys'). However the rationale behind such zones can differ – in Chile the purpose is solely to facilitate foreign investment through easier planning while in Poland there is an aim to keep supply close to demand and reduce network infrastructure

- **Some countries investing early in aviation** and **marine** which are highly likely to use some form of hydrogen derived fuel but only in the longer term. Denmark is focusing on marine aviation while Germany and Netherlands are leading on port infrastructure. These efforts included targeted R&D as well as investments in proven technologies. These will be some of the last use cases to scale up decarbonisation but countries are eager to gain experience given the low probability of alternative solutions

- **Nurturing hydrogen through pilots but maintaining technology competition in market mechanisms**: Rhetorically there is an approach to incentives of not picking technology winners, but in reality many incentives and subsidies have dedicated money set aside for hydrogen in the expectation that it is needed to begin achieving economies of scale. Some notable exceptions are incentives that focus on carbon pricing or taxation, such as Germany's proposed carbon CfD or UK's cap-and-trade transport fuel obligation. More open competition tends to come from demand-led approaches where emissions are targeted rather than specific fuel solutions. One exception is the potential to blend hydrogen into the gas grid, where demand is through the network operator rather than end user, provided a safe blending limit can be established. Portugal is an example of countries taking this approach to nurture growth of supply development.

- **Sourcing outside of EU is likely**: Countries are quickly establishing memoranda of understanding (MoUs) and establish working groups where synergies in strategy appear possible. Some of these are focused on import / export potential e.g., between Chile and European states, while others are more focused on developing projects of common interest through development of transport infrastructure between neighbours

- **Supporting domestic champions and building capabilities.** Domestic OEM partnerships are emerging as countries look to ensure their manufacturing brands emerge stronger from the energy transition. In Sweden, Daimler Volvo are involved in hydrogen projects, while in Finland Neste is leading projects relating to it's Porvoo refinery. Other countries with major vehicle manufacturers such as Germany and Italy will also leverage hydrogen as a means to channel money from the EU into these champions

- **Addressing total cost of ownership of vehicles** is a common feature of transport use cases, where major changes in drivetrain technology are required to facilitate fuel switching. Several countries have introduced tax rebates on fuel cell vehicles though none of the benchmarked countries have gone as far as Switzerland in fully aligning incentives to observed cost of switching

# 2. SWOT analysis

## Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

# Overview of Section 2

## This section established the Lithuanian context across five elements of an energy economy

**Demand**

- How much demand for hydrogen is already proven i.e. Exists today but not in the form of low-carbon production methods?
- How much potential is there for demand driven by decarbonisation?
- What benefit is there to power system flexibility in deploying electrolysers for hydrogen production?

**Resources**

- To what extent does Lithuania have the resources to produce renewable hydrogen?

**Physical infrastructure**

- To what extent does Lithuania have the infrastructure to transport and store hydrogen as well as other resources relating the othe hydrogen value chain?

**Human capital**

- How capable is Lithuania in delivering hydrogen infarstructure and participating in the value chain beyond project construction and operation?

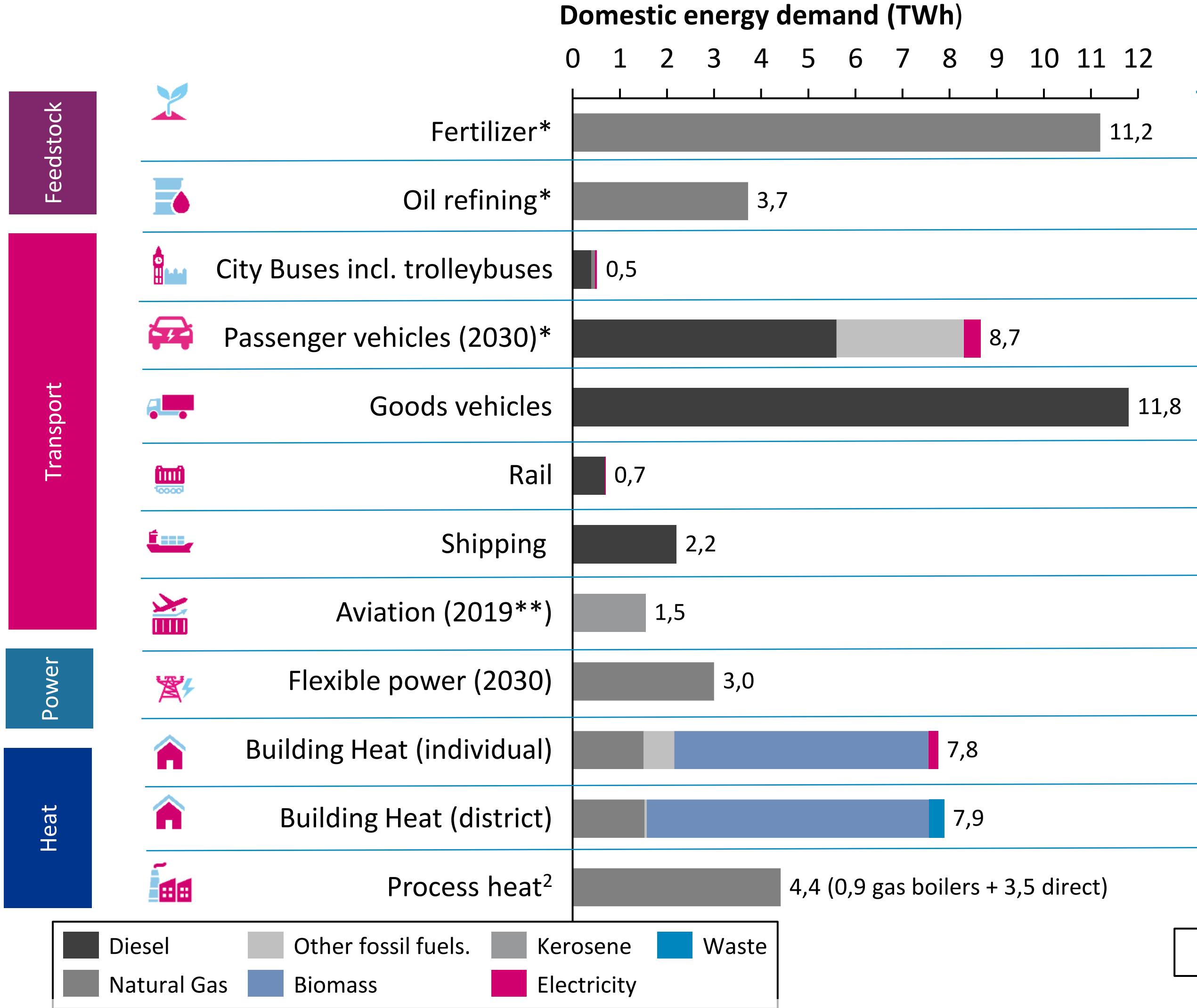
**Regulation**

- What regulation does Lithuania need to implement to enable hydrogen use in it's economy?

Source: EC 2020a; EC 2020b; EPRS 2021; IRENA 2020a

# Potential demand for hydrogen in Lithuania

## Fertilizer, oil refining, HGVs, and building heat are the use cases with the largest potential demand



| | | Domestic energy demand (TWh) | Transition solutions | Long-term sustainable fuels |
|---|---|---|---|---|
| Feedstock | Fertilizer* | 11,2 | | **$H_2$** |
| | Oil refining* | 3,7 | | **$H_2$** |
| Transport | City Buses incl. trolleybuses | 0,5 | Biodiesel | **$H_2$ FCEV**<br>BEV |
| | Passenger vehicles (2030)* | 8,7 | Biodiesel | $H_2$ FCEV<br>**BEV** |
| | Goods vehicles | 11,8 | | **H2 FCEV**<br>BEV<br>Biogas |
| | Rail | 0,7 | | $H_2$ FCEV<br>**Electricity** |
| | Shipping | 2,2 | E-methanol | **Ammonia** |
| | Aviation (2019**) | 1,5 | Biofuel | **E-kerosene** |
| Power | Flexible power (2030) | 3,0 | Gas + CCS | H2P<br>Biogas |
| Heat | Building Heat (individual) | 7,8 | | $H_2$<br>Biogas<br>**Biomass**<br>**Electricity** |
| | Building Heat (district) | 7,9 | | $H_2$<br>Biogas<br>**Biomass**<br>**Electricity** |
| | Process heat² | 4,4 (0,9 gas boilers + 3,5 direct) | | $H_2$<br>Electricity<br>Biogas |

$H_2$ or $H_2$ - derived

**Typically favoured solution**

Note: *Numbers are equivalent energy demand for level of feedstock hydrogen required; 2030 demand used for power and vehicles to reflect significant change in underlying demand highlighted in planning documents over next 10 years. EV number projection differences- lower (118 000) and higher (230 000). ** For year 2020 (travel restrictions during pandemic)- 738 GWh; 2) Excludes biomass

Source: Lithuania Department of Statistics, Cities Transport Reports (2020), LAND report (2019), Lithuanian District Heating Association, DNV study „Scenario Building for the Evolution of Lithuanian Power Sector for 2020 – 2050“ national trend.

# Analysis of demand for hydrogen in Lithuania

## Higher than average demand from fertilizers and heavy good vehicles exists in Lithuania

### Lithuania has proven demand for hydrogen as feedstock chemical in the fertilizer and refining sector

- Lithuania produced approximately 1m t of **ammonia from hydrogen for use in fertilizer** in 2019, and possesses c. 6% of production capacity within the European Union, making it an outsized contributor to GDP
- Additionally, a minority of domestic ammonia demand is imported from Russia to a Russian-owned fertilizer producer. The longevity of this demand is less certain given the recent invasion of Ukraine by Russia
- All ammonia production requires hydrogen which is currently produced in proximity by reformation of natural gas taken from the Lithuanian gas transmission network. This process represents one of the largest sources of demand for natural gas in Lithuania
- There is c.200 kt hydrogen demand for ammonia production assuming the largest fertilizer producer's two ammonia plants are working at full capacity
- There is also c.180 kt of ammonia imported into Lithuania, equivalent to c.10 kt of hydrogen, for fertilizer producers who do not produce their own ammonia and currently import or buy from major fertilizer producer
- Approximately 54 kt of hydrogen is used within the refinery process (e.g., for desulphurization of fuels) in Lithuania's **refinery sector. E**xact volumes produced from methane reformation (as opposed to recycling of hydrogen as a byproduct within the refinery process) is not known and demand can vary significantly from year to year depending on utilization of refinery capacity
- No steel is produced in Lithuania and consequently steel has been excluded from assessment of demand

### Demand driven by decarbonisation can leverage a higher-than-average contribution of heavy goods vehicles in the transport sector[1]

- Hydrogen is suitable as a zero emissions fuel or feedstock for liquid fuels for transport wherever large payloads preclude electrification, notably in heavy duty vehicles (buses and heavy goods vehicles).
- Lithuania has a higher-than-average share of **heavy-duty vehicle (HDV)** energy demand in overall road transport (41% in 2020) compared to the EU average (32%), largely arising from international road freight through the Baltic regions along the TEN-T road network. 90% of this international freight is loaded and unloaded within the EU and will therefore involve vehicles registered in the EU and refuelling in the EU (and by extension subject to EU rules and regulations). Today HDV demand is almost entirely fossil fuel based, with current Ministry of Transport plans to introduce biogas and electric drivetrains this decade introduced in the most recent NECP
- **Aviation** and **marine** fuel represent the other key transport sectors where hydrogen can play an extensive role. These play a more minor role in energy demand in Lithuania, with shipping representing 8.9% of Lithuanian energy demand in 2017 (vs 14% EU average) and aviation representing 5% (vs 14% EU average)
- Within **building heat** demand, hydrogen can, alongside other solutions, replace natural gas. Lithuania is considerably less exposed to natural gas consumption vs EU, with only 11% of building energy coming from natural gas (vs 34% EU average) thanks to extensive use of biomass for district heating and within individual boilers
- For higher temperature **industrial process heat**, Lithuania is more balanced, with 27% of industrial process heat coming from natural gas (32% EU average)

Demand within each use case is discussed in more detail in Annex 2

Note: 1) All comparisons to EU averages taken from Fuel Cell Hydrogen Observatory and pertain to most recent available year at time of study (2017 – 2020)

Source: World Data Atlas, EU Fuel Cells and Joint Hydrogen Undertaking (Opportunities for Hydrogen Technologies Considering National Energy and Climate Plans); Fuel Cell Hydrogen Observatory; Eurostat

# Does Lithuania keep pace with EU?

## Fit for 55 proposal is especially ambitious for green ammonia and hydrogen in transport

| Use cases for hydrogen in Lithuania | EU target that is primary driver of hydrogen adoption | How much will this 'force' renewable hydrogen demand in Lithuania by 2030? |
|---|---|---|
| **Fertilizer** | 50% RFNBO target in traditional hydrogen sectors (Effectively mandates 50% of hydrogen feedstock to be renewable) | Stakeholder feedback from fertilizer industry suggests **15% is realistic** without major refurbishment of plant and is achievable with EU funds (e.g., JTF) available. This may change if carbon price begins to reflect RFNBO target of 50% |
| **Oil refining** | 2.6% share of renewable fuels of non biological origin (RFNBO) in final energy demand in all forms of transport by 2030, with green hydrogen used as feedstock eligible, with RFNBOs counted where they are produced and not consumed | **Impact on oil refineries not clear at present** - Oil refineries can blend RFNBOs with fossil fuels and be counted in RFBO targets but will not receive funding support for doing so. It is not clear from current proposals how 1 kg of hydrogen used as refinery feedstock will be accounted versus 1 kg used for final energy consumption |
| **Rail, buses,** | | |
| **Buses** | | |
| **Heavier passenger vehicles** | | **Target will drive HGV adoption but is very ambitious for Lithuania** - 38% of Lithuanian transport demand is in goods heavy duty vehicles. It would take c.6% penetration of fleet to meet RFNBO targets through HDVs. Given cost parity will only occur in late 2020s, such rapid fleet penetration would imply nearly all new vehicles sold are hydrogen powered in the late 2020s. Benchmarks set by higher-GDP countries such as Netherlands and Denmark for HGV roll out imply that this level of ambition will be very expensive for countries to achieve given the risk of stranded vehicle assets or the need to accelerate purchasing before vehicles are cost competitive. |
| **Heavy goods vehicles** | 'Super-credit' incentive within zero-or-Low-Emissions Vehicles (ZLEVs) for up to 2% of all new (~0,2% of fleet) HGVs as part of HDV $CO_2$ emissions standards on vehicle manufacturers | |
| **Marine** | 6% greenhouse gas (GHG) emissions intensity reduction vs 2005 for<br>onboard fuels by 2030 | Not guaranteed to drive hydrogen demand anywhere by 2030 |
| **Aviation** | 0,7% synthetic aviation fuels by 2030 | Very low hydrogen demand by 2030 as aviation is very small % of transport energy demand in Lithuania |
| **Flexible power** | 61% GHG reduction by 2030 vs 2005 under ETS | Not guaranteed to drive hydrogen demand anywhere by 2030; Lithuania's own 2035 target will be the bigger factor |
| **Industrial heat** | | |
| **Building heat** | An annual increase of renewable energy sources (RES) share in the heating & cooling (H&C) sector by 1.1% | Not guaranteed to drive hydrogen demand anywhere by 2030 |

# Benefit of electrolysers in the power system

## Hydrogen production will improve economics of renewable power and help provide flexibility and system balancing

**Electrolyser production of hydrogen (power-to-gas / P2G) can play an important role in the development and integration of renewable power. This role is now more important as ambition has since increased to target Net Zero power by 2035**

- Periods of excess wind generation can cause power prices to go zero or negative, as well cause power curtailment due network constraints. Power to hydrogen can limit these periods because it is flexible, electrolysers which can comfortably operate between 30 – 100% load and can therefore follow renewable load
- Prior studies conducted before Lithuania increased its ambition to have a net zero power sector by 2035 estimated over €100m savings in renewables subsidies through using hydrogen production to support renewable capture prices above €30 / MWh, by modelling the impact of using power to hydrogen for price periods below €20 / MWh, as shown in the table below

**Potential impact of electrolysers in preventing wind curtailment in 2050**

| | No Power to Hydrogen | Power to Hydrogen |
|---|---|---|
| Wind Curtailment | 1.4% | 0% |
| Fraction of wind below 0.1 €/ MWh[2] | 27% | 0% |
| Average capture price of wind (€/ MWh)[2] | 21.9 | 31.5 |
| Total need for subsidies (M €)[3] | 177 | 66 |

**Hydrogen production will also bring flexibility to the power system However, contracting between electrolysers and renewables will need to appropriately value power system services and the cost of hydrogen storage**

- It is estimated that electrolysers operate at 17% load factor. This may be too low for generating timely project returns and for providing use cases with the most economical supply, since storage costs will increase as electrolyser operation becomes more intermittent
- When providing incentives / contracts / subsidies for electrolyser production, **Lithuania should factor in all energy system benefits**: the benefit of **reducing renewables subsidies**, the benefit of **providing physical flexibility** to the power system and the benefit of **reducing hydrogen / ammonia storage capacity** requirements
- Energy policy and regulation can do this by:
    - Allowing **electrolysers to access balancing and (for PEM electrolysers)** grid ancillary services markets such as **fast frequency response**, reducing the level of system inertia needed through synchronous compensators
    - Allowing **flexibility in how electrolysers contract with renewables assets** e.g., through power purchase agreements that are dynamic with respect to power price signals but allow flexibility for electrolysers to draw power when hydrogen demand is high

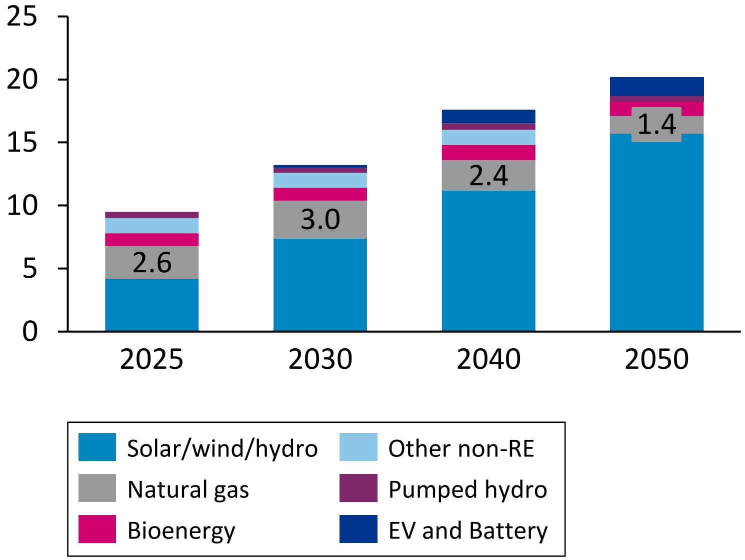
Note: 1) Polymer electrolyte membrane 2) We assume c.35% in our scenario modelling 3) Includes both on and offshore wind 4) subsidies include generation, hydrogen to power, and batteries. Values presented from this study are intended to show ability of power to hydrogen to reduce system costs but are not intended to provide hard targets for electrolyser deployment

Source: All numbers are from Litgrid DNV RAIDA 2050 study (High Flex 2050 Scenario) - assumes 1.2 GW electrolyser production capacity in 2050

# Benefit of hydrogen-to-power in the power system

## Hydrogen-to-power can displace natural gas to meet Lithuania's 2035 net zero target

**Projected generation mix under previous system stability scenario planning** (TWh power)



**Flexible renewable power sources are required to replace natural gas in order to reach net zero**

- Under previous net zero power targets, Litgrid-DNV estimated natural gas use in the power system will decrease by 54% to 1.6 TWh in 2050. However the Ministry of Energy has since stated 2035 Net Zero target for the power sector which will require much faster reduction in fossil-fuel-to-power consumption
- Any continued gas use is now not compatible with the new target of net zero power beyond 2035. Additionally, switching to low carbon energy sources in the power sector has implications for heating due the use of gas in CHP plants

**Hydrogen, bioenergy, batteries and interconnection are likely replacements of remaining gas demand**

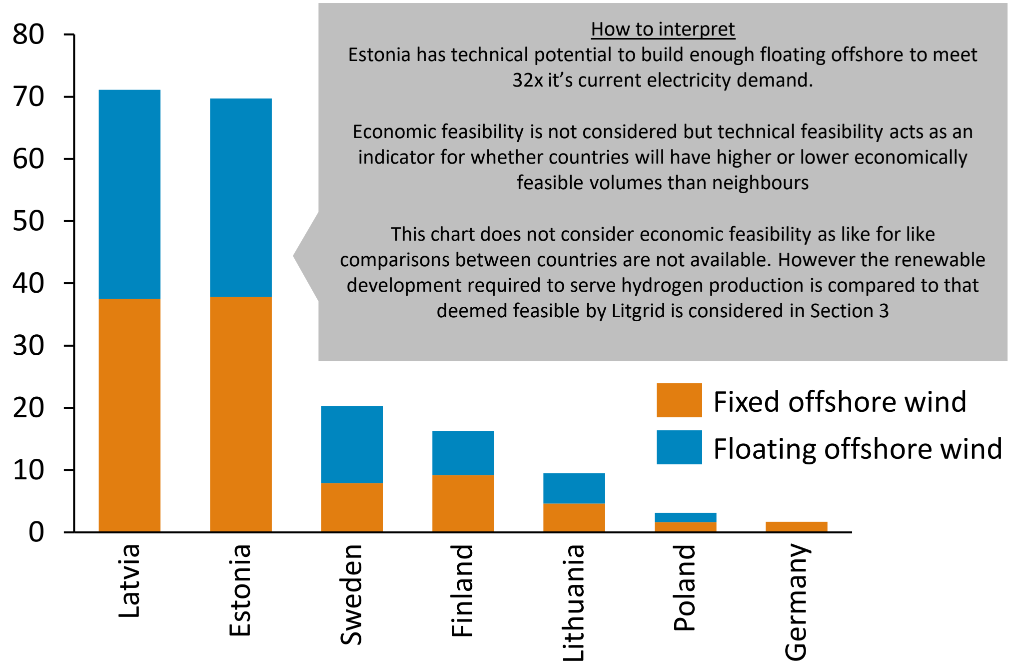
- Battery and EVs are a flexible renewable power source able to provide peaking, which Litgrid-DNV estimates will grow to 1.5 TWh by 2050
- Interconnector capacity can provide grid flexibility, however it is not gauranteed to be zero carbon, and gas power using carbon capture and storage is likely to be costly due to the need to export captured $CO_2$
- The most probable flexible power for dealing with prolonged variation in demand (e.g., seasonal) are therefore likely to be hydrogen and biogas
- Biogas is currently considered to be less expensive than hydrogen but as the cost of low-carbon hydrogen falls this may change. In addition, biogas production costs can vary widely and depend on whether production occurs through waste, manure, or other feedstock

Source: Litgrid, EIA, Eurostat, Ministry of Energy

# Availability and cost of renewable power

## Lithuania should have competitive renewable power costs but has less offshore wind potential than neighbours, opening up collaboration opportunities with other Baltic states

**Ratio of offshore wind technical potential vs domestic electricity demand in Lithuania and neighbouring member states** (TWh potential / TWh demand)



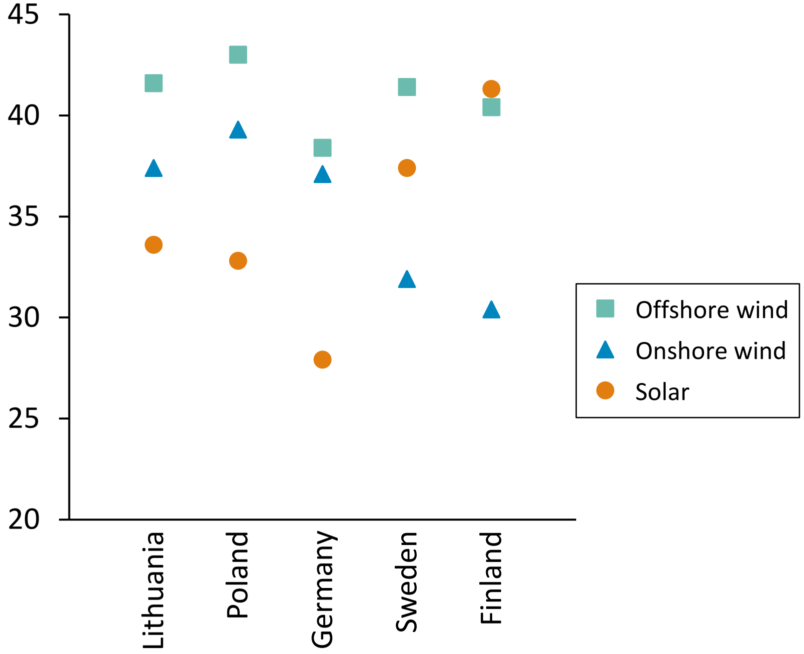
How to interpret

Estonia has technical potential to build enough floating offshore to meet 32x it's current electricity demand.

Economic feasibility is not considered but technical feasibility acts as an indicator for whether countries will have higher or lower economically feasible volumes than neighbours

This chart does not consider economic feasibility as like for like comparisons between countries are not available. However the renewable development required to serve hydrogen production is compared to that deemed feasible by Litgrid is considered in Section 3

**2030 projected levelized cost of renewable technology for Lithuania vs neighbours** (€ / MWh)



- Lithuania has relatively finite offshore wind resource in territorial waters versus neighbours due to more limited coastline
- As a result an expanding hydrogen economy presents an opportunity for further coordinaton with neighbouring states to pool resources to leverage renewable power availability across the region

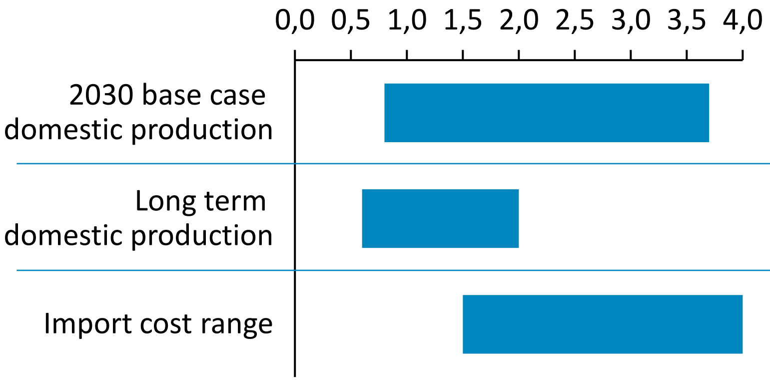
- Lithuania is neither advantaged or particularly disdvantaged in the cost of renewable electricity with respect to neighbouring countries and is therefore could experience similar costs of hydrogen production

Source: ESMAP 'Offshore wind technical potential'; Baringa projected LCOEs; Eurostat

# Import and export

## Lithuania does not appear to need a net import balance and does not appear competitive enough for a net export balance

**€ / kg domestic production versus import costs in 2030**



**Key assumptions**

- €35 - 45 / MWh renewable power, €665 / kW electrolyser
- €18 - 27 / MWh renewable power, €221 / kW electrolyser
- Based on 2035 import costs into Europe from Oman, Australia, Chile, and Morocco

**Import costs do not appear likely to out-compete domestic supply**

- While production costs will be much lower in countries with lower cost renewable resource, the high cost of transport over long distances and supply-side storage will add up to make imported hydrogen on par with that produced domestically, assuming renewable power can be developed at similar cost levels to neighbouring countries
- Other European countries are actively investigating imports where domestic development is likely to be spatially constrained (e.g., Germany, Netherlands). Nevertheless, Lithuania should monitor import opportunities closely to ensure there is not a clear rational for importing. In particular, the price of green ammonia imported vs domestic green ammonia production warrants close monitoring as transport and storage costs may be less

**Domestic production does not appear likely to be competitive enough to make Lithuania a net exporter**

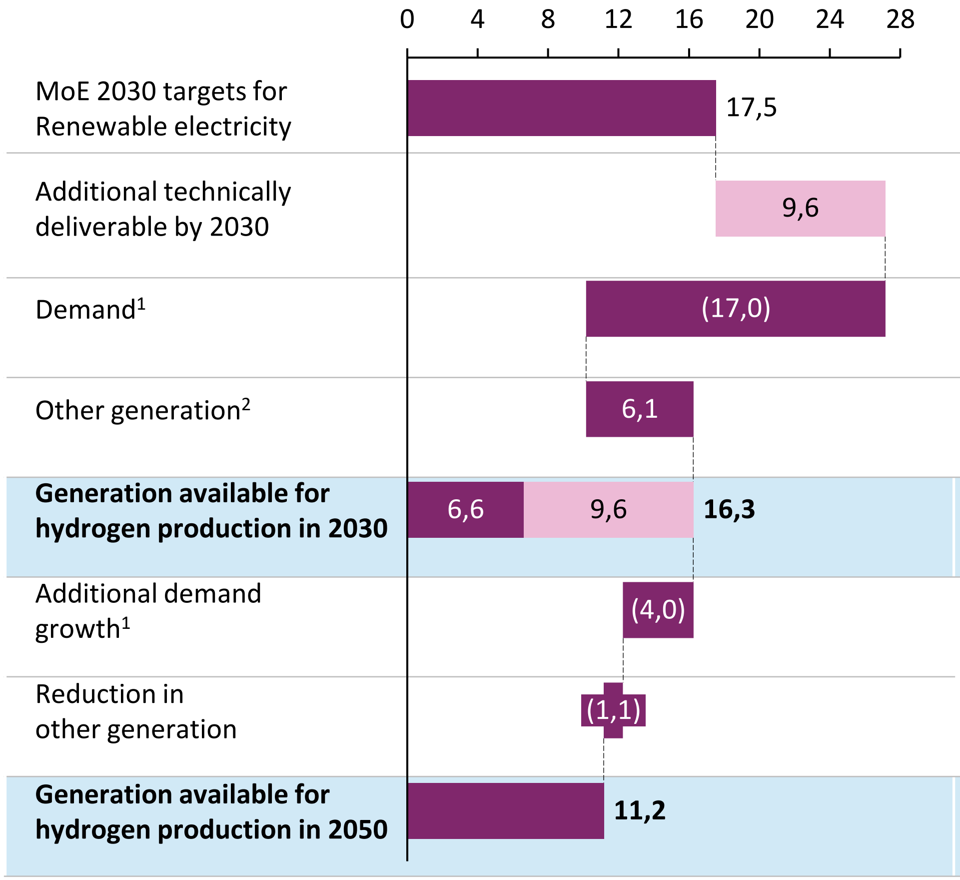
- While Lithuania is expected to have similar costs of production to neighbouring countries, it does not have a clear advantage that suggests it will be a net exporter

Note: Hydrogen Import Coalition; McKinsey
Note: *Assumes USD/EUR FX rate of 1.13

# Supply of renewable power available for hydrogen

## 16,3 TWh of renewable generation for hydrogen could be available by 2030 and 11,2 TWh by 2050 as electricity demand from other sectors increases

**Annual renewable generation available for hydrogen in 2030 and 2050** (TWh)



- 7 GW of renewable electricity targeted by Ministry of Energy for 2030: 3,6 GW onshore wind, 1.4 GW offshore wind, 2 GW solar
- An additional 3 GW (1 GW onshore, 2 GW offshore) could be added after implementing additional network upgrades outside the scope of the synchronization project program
- According LitGrid prognosis for the upcoming new 10 years network development plan (to be published in July 2022).
- Battery, hydro, gas and biomass generation estimated by Litgrid's RAIDA 2050 scenario planning report
- Equivalent to 6,2 GW of wind capacity[2]
- Both demand growth and reduction in other generation are according to by Litgrid's RAIDA 2050 scenario planning report. There may be a larger reduction in other generation given increased ambition of Ministry of Energy to achieve Net Zero power
- Equivalent to 4,2 GW of wind capacity[2]

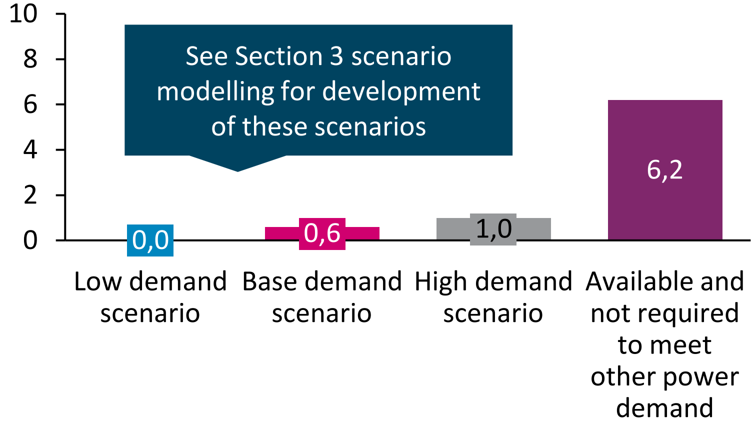
Note: 1) Excludes P2G demand and based on draft Litgrid TYNPD 2) excludes pumped and battery storage 2) Assumes supply is 57% from onshore and 43% from offshore which is aligned with planned mix of wind fleet in 2030

Sources: Litgrid, LitGrid RAIDA 2050 Scenario Planning Study 2020

# Is there enough renewable power to serve demand?

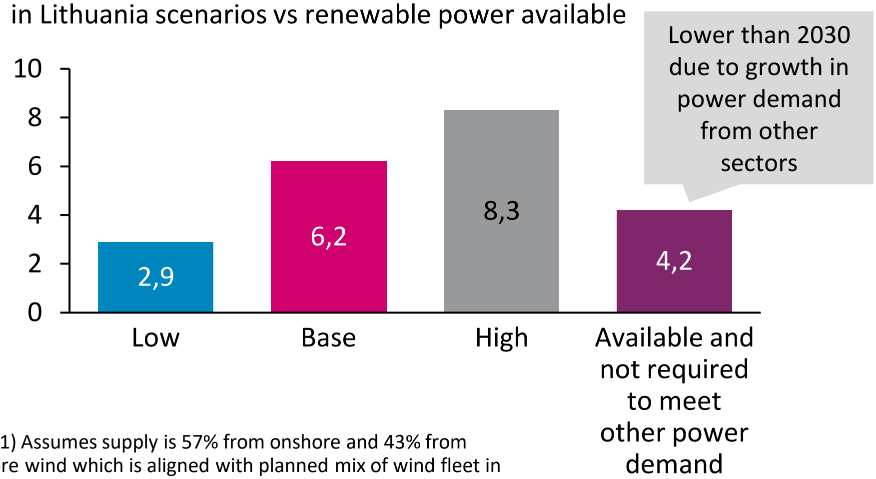
## Renewable power development plans should be sufficient to cover hydrogen demand until 2030, but thereafter more renewable power is needed and network upgrades required

**2030** GW wind power[1] required for hydrogen demand in Lithuania scenarios vs renewable power available



See Section 3 scenario modelling for development of these scenarios

**2050** GW wind power1 required for hydrogen demand in Lithuania scenarios vs renewable power available



Lower than 2030 due to growth in power demand from other sectors

**Basis of estimation of power available vs power required for hydrogen production**

- Current plans for 7 GW of renewables (3.6 GW onshore wind, 1.4 GW offshore wind, 2 GW solar)
- Current and future demand for electricity outside of hydrogen and future plans for flexible power
- Resulting power available for electrolyser operation is conditional on these targets being met and on the price of electricity to the electrolyser being at most €35 – 40 / MWh to ensure competitiveness of hydrogen

**Conclusions:**

- Our 2030 demand scenarios can be catered for under the existing plan for renewables deployment
- At some point between 2030 and 2050 more renewables will be required via either
    - collaboration with neighbouring states to co-develop or import more renewables
    - developing renewables + hydrogen outside the electricity network (e.g., by colocation) may be required
    - Significant investment in the electricity network to accommodate more renewables
- Meanwhile, exports of hydrogen *in the near term* may be limited to ‘balancing’ volumes of green ammonia rather than a true export industry, similar to Portugal strategy and not Australia/Chile strategy
- In the *longer term*, the analysis suggests expansion of renewable development plans or import of hydrogen or renewable power may be required to serve ambition set by the Base case

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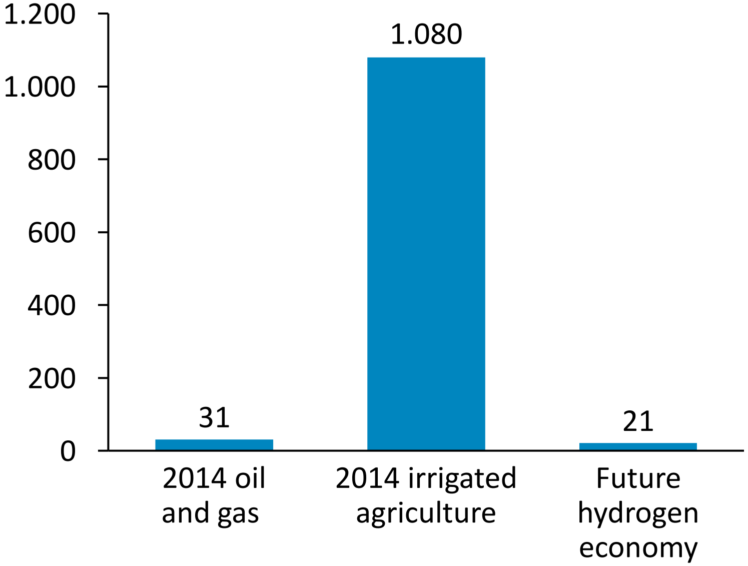
Note: 1) Assumes supply is 57% from onshore and 43% from offshore wind which is aligned with planned mix of wind fleet in 2030

# Availability of water

## Availability of water is not generally an issue for the hydrogen sector and there is no specific long-term threat to freshwater supply from hydrogen in Lithuania

**Hydrogen will not dramatically impact competition for water resource**

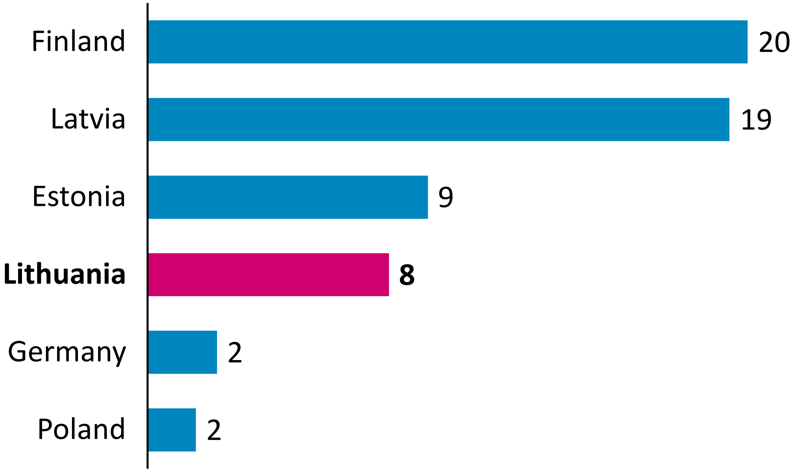
**Global freshwater consumption: future hydrogen consumption vs historical fossil fuel and agriculture** (bn $m^3$)



- At a global scale hydrogen is expected to impact freshwater supplies less than fossil fuels do currently
- However, strain will occur  on water supply in certain regions or localities where supply is already low

**Lithuania is not especially scarce of freshwater resource among it's neighbours**

**M cubic metres renewable freshwater resource  / 1000 inhabitants**

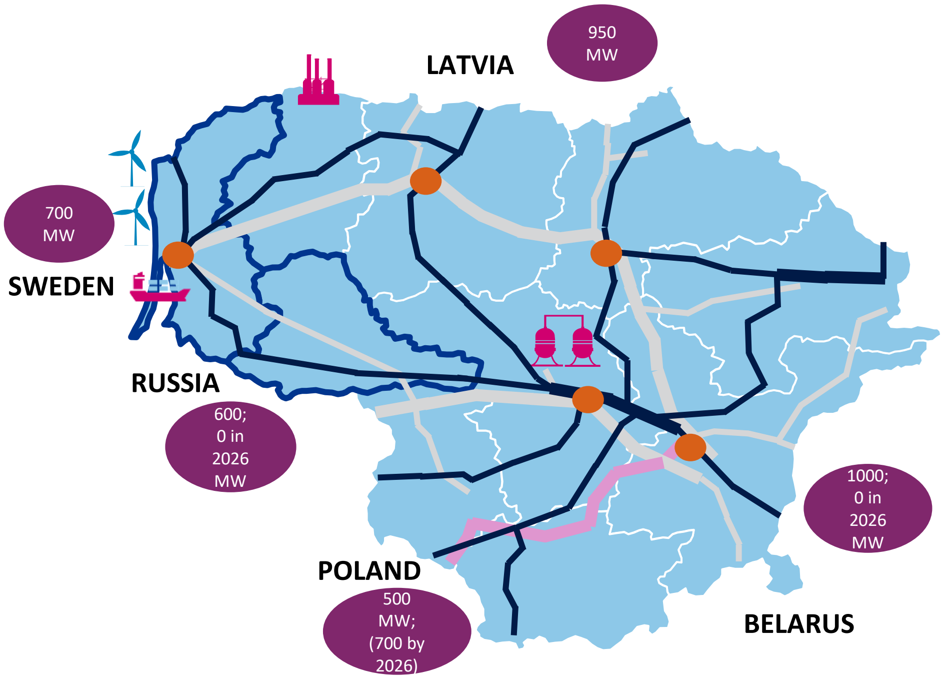


- Lithuania has reasonably good freshwater supply by EU standards and better than neighbouring Poland and Germany where hydrogen demand is expected to be more intense than EU average
- However, consideration should be given to the impact on local water supply when planning hydrogen valleys, water network investment and approving electrolyser projects

Source: European Commission (link); ACS Energy Lett. 2021, 6, 3167−3169

# Lithuania’s current energy network infrastructure

## Renewable resource biased towards north-west, with high potential demand in the Central Lithuania region



- Projected offshore wind power plants
- Oil refinery
- Major fertilizer producer
- Wind power generation regions
- Port + LNG terminal
- Natural gas pipelines
- Lithuania-Poland gas connection, completion 2022
- Electricity grid
- Power interconnection capacity
- ● Population centres

- Lithuania has a well-connected transmission grid connecting all major population centres, with planned connection to Poland to be completed in 2022
- The electricity grid is also well connected; Litgrid have indicated that no major reinforcements are likely to be required in order to accommodate plans for a hydrogen electrolyser capable of serving 15% of fertilizer production in the Central Lithuania region
- Any similar scale of developments for serving the refinery in the north would require significant upgrades, though a detailed cost assessment has not yet been conducted
- By 2026 the Lithuanian electricity grid will disconnect from the Russia grid system and join the Continental Europe network, with interconnections with Sweden and Poland planned to replace connections with Belarus and Kaliningrad. This process may be accelerated given recent invasion of Ukraine

Sources: Litgrid, LVEA, Ambergid

# Infrastructure opportunities and challenges

## The existing power and gas networks can support rollout, while ammonia could be used as a vector for long term storage

### Key strengths and challenges for Lithuania’s eventual hydrogen infrastructure

| | | |
|---|---|---|
| **Opportunity** ✓ | Ability to leverage gas network in long term | ▲ AmberGrid has indicated that sections of the existing gas transmission network can be retrofitted while still maintaining a single line for natural gas. Where new lines are needed, the existing gas network line provides the permitted real estate for most of that line, ensuring that only a small minority of the line, specifically the last legs connecting the line to points of fertilizer and refinery demand requires greenfield development |
| **Opportunity** ✓ | Ability to leverage electricity network in short term | ▲ Litgrid has indicated that the electricity network can handle the initial 2030 target of hydrogen production and consumption set by fertilizer producers. This will help the hydrogen economy achieve scale while allowing time for preparation of a gas transmission network that in the longer term will be more economical for higher volumes |
| **Challenge** | Availability of geological storage | ▲ The Lithuanian Geological Society has acknowledged that research on pure hydrogen storage in Lithuania has been limited, since most projects to date have had hydrogen as a part of a gas mixture. Criteria for pure hydrogen storage is being developed on an EU level[1] , but specific cases have not been tested in practice. Nevertheless, possible locations in Lithuania for geological storage of hydrogen are depleted oil fields, aquifers, and large salt deposits (e.g. near Usėnai) |
| **Challenge** | Hydrogen import/export infrastructure development | ▲ There may be a challenge in the available space in the port of Klaipėda for hydrogen import/export, Feedback from stakeholders has indicated that although no detailed assessment has been completed, territories available for expansion are near residential areas and may end up being prioritized for offshore wind infrastructure. Furthermore, the current LNG terminal infrastructure can not be repurposed for hydrogen due to the more stringent cooling and storage requirements of hydrogen |
| **Opportunity** ✓ | Ability to leverage ammonia storage | ▲ Our demand scenarios for Lithuania indicate that ammonia will play a major role in Lithuania’s hydrogen economy, through the fertilizer industry initially and in the longer term potentially through shipping fuel demand. As a result, there is an opportunity to leverage ammonia storage as a long-term storage vector for hydrogen demand but without the costly step of conversion to ammonia and reconversion to hydrogen which typically makes this form of storage less attractive than geological or pressurized storage. This can be considered alongside geological storage options for larger-scale storage |

Note: 1) Hydrogen storage standardisation and components optimization for mass production | Programme | H2020 | CORDIS | European Commission (europa.eu)

# Capability required to deliver infrastructure

## None of the capabilities required to deliver infrastructure represent disadvantages for Lithuania provided action is taken soon and includes collaboration with industry and other member states

| Category of regulation | Description | Current status of capability in Lithuania | Is this a significant advantage or disadvantage to Lithuania? |
|---|---|---|---|
| **Production / supply** | Renewable power | Expanding fast, will more than double by 2030 | No, most smaller EU countries are starting from a similar place |
| | Electrolysers | Pilots in planning, including financing | |
| | Development of SEZs | Present in Klaipeda FEZ | |
| **Transmission, distribution, and storage** | Pipeline transmission | Amber Grid proven deliverer of large gas infrastructure | No, All EU countries are starting from a similar place, collaboration can be sought with industrial gas majors who bring working knowledge of pure hydrogen pipes |
| | Pipeline distribution | Capability within distribution network operators | |
| | Truck distribution | Not present | No but capability building should be in scope as part of bus / HGV pilots and in collaboration with existing fuel station owners |
| | Refuelling stations | Not present | |
| | Tank storage | May be present in refinery sector but not confirmed | No, this is a mature technology |
| | Cryogenic storage | Present through Klaipeda LNG | No, LNG experience across Europe will be re-oriented towards hydrogen |
| | Geological storage | Not present | No, not common anywhere in Europe and if geological storage is pursued, human capability can be developed through Geological Survey in collaboration with private parties |
| | Ammonia storage | Not present outside of fertilizer industry | No, this is a mature technology |
| **Use case / point of use** | Fuel cells | Not present | No, can be owned by vehicle OEMs |
| | FCEVs | Not present | |
| | Hydrogen turbines | Not present | No, can be owned by today's turbine manufacturers |
| | Hydrogen boilers | Broader gas boiler capability through home heating | No, can be imported through international collaboration |
| | Ship refueling | Not present | Possibly in future, will need to be developed by today's bunker operators refuelling depots |
| | Aviation refueling | Not present | Possibly in future, will need to be developed by today's refuelling depots |

# Research, innovation and capturing value chain

## Stakeholder feedback identifies several initiatives that could increase the amount of the value chain captured in the Lithuanian economy by improving R&D impact and investing in education

### Opportunities to create value through R&D

**There are programs of work across multiple institutions focused on technologies in early research development which will not be commercialized this decade but may play a role in the future**

- The **Smart Energy** innovation ecosystem based in Vilnius has initiated a working group which aims to research novel technologies relating to hydrogen, including hydrogen separation membranes, improving electrolysis through using nanoparticles, and lowering the cost of fuel cell element production
- **Vilnius University** and **Kaunas University Technology** and the **Lithuanian Energy Institute** research novel designs and materials associated with solid oxide hydrogen fuel cells (SOFCs)
- The **Center For Physical Sciences And Technology** group works with hydrogen production from boring oil reserves, which could compete with electrolyser production in the long term
- **Vytautas Magnus University** researches the role of renewable energy prosumers in implementing energy justice theory and energy security on regional/national level

**Alongside this there are several initiatives underway which can help Lithuania scale up hydrogen and potentially capture part of the value chain for buses and railroads**

- **Klaipeda University** has a centre of excellence for LNG which will hold capability in cryogenic storage and shipping that can be applied to a future hydrogen economy. The university has also obtained funding from the EU to research hydrogen producing technologies in collaboration with institutes in Eindhoven, Groningen, and Trieste
- **Lithuania railroads** have expressed interest in buying a train with hydrogen as a fuel source as a pilot trial
- **Vilnius Gediminas Technical University (VGTU)** is working in collaboration with Scania and SG Dujos on blending Hydrogen and natural gas for buses

### How can Lithuania build on this to create more jobs in hydrogen?

**Improving links between research and industry**

- Feedback suggests Lithuania could improve industry and business inclusion regarding research and that while there is healthy representation of proven technologies and early-stage R&D, there is less participation in near-commercial R&D where industry participation plays more of a role
- Stronger links between industry participants and researchers who focus on fuel cells, materials, portable applications, and electrolysis should be made. Network operators, refineries and fertilizer producers could be the best partners for the research and development sector to introduce hydrogen to their system

**Proactively attracting value chain participants**

- Pilot projects can act as a launch-pad for attracting parts of the value chain (e.g., components manufacturers) to Lithuania. Achieving this will require the relevant arms of the government to plug into pilots to identify opportunities to court manufacturers
- A recent example cited where Lithuania could ‘do better’ is the hydrogen production startup which received funding from the Ignitis innovation fund and is looking for a second location for their factory in Europe which Lithuania has so far been unable to secure

**Focusing on hydrogen in funding for research, in a way that improves the strategy**

- Hydrogen fueled trucks, linking hydrogen to offshore wind, and developing long-term storage capabilities through both ammonia and geological formations are all areas where research capability can be used to assist strategic challenges

**Investing in home-grown human capital**

- Stakeholders identified a lack of degree courses for energy specialists, not just within hydrogen but more broadly in the energy sector – an example cited is that currently there is no university course related to natural gasses for energy purposes even though it is widespread in Lithuania

# Why member state market mechanisms are required

## EU carbon pricing pushes decarbonisation in the long run but member state interventions are required to push the 2030 agenda

- **Carbon pricing** has the advantage of being technology-neutral – allowing the market to steer towards least cost solutions – and acting across all sectors. While EU carbon prices will play the largest role in the long term, they may be insufficient to unlock investment in several key sectors in the next 5-10 years. They should therefore be complemented, at least initially, by other measures which drive early hydrogen demand:
- **Mandates** which require a rising percentage of fuels to come from zero-carbon sources, including potentially hydrogen and hydrogen derivatives. Amongst the strongest policy signals available, mandates could be particularly powerful instruments in long-distance shipping, aviation, and current hydrogen uses
  - Grid carbon intensity standards, another form of mandate, can also be used to accelerate the development of zero-carbon energy technologies, especially zero-carbon dispatchable generation to meet seasonal balancing challenges such as hydrogen burnt in compatible CCGTs
- The **removal of fossil fuel subsidies** - both at production and at consumption level – distorts of competition between high-carbon and low-carbon energy sources and should not be considered in isolation to carbon pricing
- **Voluntary premiums** on greener products make sense for industries such as steel where the product is a small part of the added value of end products such as vehicles but are less effective on commodities such as ammonia and refined oil products where the end-product has less value added from other inputs
- **Contracts for difference** (CfDs) make sense wherever exposure to commodity prices is a major barrier to investment. This includes power prices, carbon prices, oil prices and gas prices and the intervention amounts to government taking the long-term market price risk on behalf of industry. This has become the established mechanism for funding renewable power generation
- **Public procurement** is effective at sending signals of support to the industry and allowing some early scale via buses and rail but is not a long-term mechanism due to public sector's relatively small market share of overall energy demand in Europe

# Suitability of mechanisms to use cases

## CfDs may provide the most help to industry and power demand, while mandates, surcharges, and public sector procurement can help scale up more decentralized transport demand

| Priority for 2030 | Mechanism | Carbon pricing | Voluntary Green Premium | Mandates | Public procurement | CfDs |
|---|---|---|---|---|---|---|
| | Motive | Decrease fossil competitiveness | Create demand for green products | | | Cover cost differential |
| | Cost bearer | All end- users | Green product end-user | | Government budget | |
| → | **fertilizer** | ⬜ Covered by EU ETS | ⬜ Only for premium organic farming | ▨ Lifecycle emissions standards for fertilizers | ⬜ Government is not a big buyer | 🟩 On ammonia spot price or carbon price |
| → | **Refining** | | ⬜ Not applicable as end product not decarbonised | ▨ Implement EU RFNBO mandate | | ⬜ Not applicable as end product not decarbonised |
| → | **Road transport** | ▨ Fuel tax on fossil fuels | ▨ Ticket / service surcharge for buses | 🟩 Implement new EU standards | ▨ Use bus procurement to achieve some scale | ⬜ Impractical for individual fleets with small volumes |
| → | **Power** | ⬜ Covered by EU ETS | ▨ Green tariffs will have limited impact on hydrogen | 🟩 Sunset / ban on technologies competing in flex markets | ▨ Gov. focus on renewable PPAs | 🟩 Dispatchable power agreements or capacity auctions |
| | **Aviation** | ⬜ EU traffic covered by EU ETS | ▨ Ticket surcharge | 🟩 Fuel blending mandates to support early projects | ⬜ Government is not a big buyer | ▨ CfDs versus kerosene price |
| | **Shipping** | ⬜ Covered by EU ETS | ▨ Green shipping offer from shippers | 🟩 Mandate share of green shipping in port traffic | | 🟩 CfDs for sustainable fuel vs fuel oil price |
| | **Rail** | ⬜ Impractical for individual fleets with small volumes | 🟩 Ticket surcharge for decarbonised travel | ⬜ Small market makes mandates less easy | ⬜ Gov. not a big buyer | ▨ Impractical for individual fleets with small volumes |
| | **Heat (building and industrial** | ⬜ Impractical for individual buildings, industrial covered by ETS | ▨ Only applicable if end users have genuine choice | 🟩 Rising efficiency standards | ▨ Use buildings (e.g., universities) to test boilers | 🟩 CfDs for hydrogen and biomethane versus gas |

Source: Adapted from ECT – Making the Hydrogen Economy Possible (2021)

🟩 More suitable ▨ Helpful ⬜ Less suitable

# Health and safety regulation required

## Most health and safety regulation requirements may need action at national level

| Category of regulation | Description | Standard setter | Status in Lithuania |
|---|---|---|---|
| **Production / supply** | Certification and traceability of low-carbon hydrogen | EU + member state | Monitoring required |
| | Carbon capture and storage / blue hydrogen production | EU + member state | Monitoring / action required |
| | Electrolyser production facilities | ISO 22734:2019 | Action not required |
| **Transmission, distribution, and storage** | Gaseous and liquid hydrogen transport on public roads | Member state | Action may be required |
| | Hydrogen injection in transmission and distribution networks | Member state | Action may be required |
| | Handling and storage of dangerous cargo in port areas | Member state | Action may be required |
| | Hydrogen containers tanks, and cryogenic storage units | ISO under development | Action not required |
| | Inclusion in storage of dangerous substances regulations | Member state | Action may be required |
| **Use case / point of use** | Gaseous hydrogen use in industrial machinery and vehicles | Member state | Action may be required |
| | Technical, construction and safety requirements for FCEVs | ISO 13985:2006 | Action may be required |
| | Emergencies and accidents concerning FCEVs | Member state | Action may be required |
| | Hydrogen vehicles repair and maintenance workshops | Member state | Action may be required |
| | Gaseous and liquid hydrogen vehicle parking garages | ISO 13984:1999 | Action not required |
| | Gaseous hydrogen use in domestic appliances | Member state | Action may be required |
| | General workplace safety where hydrogen is present | Member state | Action may be required |
| | Shipping fuel standards | 2030, ISO/AWI 11326 | Action not required |
| | Aviation fuel standards | Member state | Action may be required |
| | Combustion of hydrogen in boilers and furnaces | Member state | Action may be required |

# Lithuania: strengths and weaknesses

## Strengths include proven addressable demand and know-how, while the availability of renewable electricity and carbon sequestration could be a challenge

**Lithuania's strengths to lean into**

- There is **proven addressable demand** via fertilizer and refinery through which Lithuania can quickly achieve economies of scale
- There are a **smaller number of variables and stakeholders** vs larger economies such as Poland and this may allow for more manageable central planning with less stakeholders to align
- There is **know-how in grey hydrogen** production should Lithuania ever opt to pursue blue hydrogen

**Lithuania's weaknesses to manage**

- The **total stock of feasible renewable electricity** could limit hydrogen in longer term unless collaboration with neighbouring countries is sought to develop more renewables
- There is **less access to carbon sequestration** in the North Sea vs Poland, Germany, Netherlands, Belgium (who will compete with Lithuania's fertilizer industry) and as a result Lithuania may have to pay more to have carbon taken away
- There may be an **absence of large storage potential for hydrogen** that would probably be required if hydrogen was used for seasonal heating and for flexible power

**Not strong or weak, but important to consider...**

- Lithuania's **track record of attracting foreign direct investment** is on par with Poland (as a % of GDP) but less than Latvia or Estonia
- The **cost of renewables** for feeding green hydrogen production is on par with neighbours but not globally/regionally competitively advantaged for export
- Lithuania's **ability to deploy renewables** is comparable to neighbours, Poland and Estonia have equally managed to roll out onshore wind and are beginning to roll out offshore wind, while Latvia has had legacy hydro
- Lithuania has **existing research programs** in hydrogen technologies but, as with most countries, it **does not have a strong track record of commercialisation** of technologies researched and will require closer collaboartion with industry and international partners to achieve this
- Much of the human capital required to deliver hydrogen infrastructure exists within the power and gas sector or sits with international OEMs. As such there is neither a major defecit or opportunity associated with human capital required for construction and asset maintenance

Source: World Bank (Foreign direct investment as % GDP)

# Lithuania: opportunities

## Collaboration

**Low-regret opportunities to pursue**

- Hydrogen presents an opportunity to improve the economics of renewables in Lithuania by ensuring a flexible source of demand that can be optimised to serve intermittant renewable loads
- Lithuania can **leverage the strength of its neighbours through collaboration:**
  - To ensure hydrogen supply can stay green, Lithuania can take a lead in **unlocking more offshore and onshore wind reserves through collaboration with Baltic states,** building on the joint declaration of Baltic states to accelerate offshore wind in the region**.** Although Lithuania's own offshore wind reserves are limited, there is vast potential (93GW) for offshore wind in the Baltic sea which neighbours may be willing to collaborate in developing, as Latvia and Estonia are currently doing through planned joint offshore wind auctions
  - To **ensure storage** Lithuania can collaborate with Poland and Germany to assess transit routes to salt cavern storage sites in those countries
  - To **build capability** Lithuania can collaborate with a wide range of other states. A natural hydrogen corridor between Lithuania and Poland should emerge given high level of proven demand within both countries and in spite of Poland's modest targets for infrastructure so far
  - To **ensure supply** Lithuania can look beyond Northern Europe to future exporters such as Spain, Portugal, Middle East, Iceland and Chile
- Hydrogen is a means to leverage Just Transition Fund and Lithuania can take the lead among Baltic states in delivering programs that **deliver EU hydrogen backbone** and EU's desire for hydrogen valleys, which are currently concentrated in the West
- **Buses and trains can be used to build acceptance of hydrogen** as a fuel and if rolled out in cities can deliver a reasonable economy of scale, promote building of refueling infrastructire and potentially benefit from larger use cases nearby (e.g., Vilnius and Kaunas buses integrating with fertilizer demand)

**More ambitious opportunities**

- Lithuania could **take a lead on the HGV sector**. There is a high level of international transit and roads connecting Klaipeda, Kaunas, Vilnius, Riga, and Warsaw represent part of the EU's Trans-European-Transport Network (TEN-T), where hydrogen refuelling stations are expected to be available every 150 - 200km by 2030. Lithuania could focus on develping some domestic demand for hydrogen trucks to provide demand for refueling stations while allowing those stations to serve international freight on the TEN-T network
- Lithuania can use hydrogen to **build technology capability and industry champions**. Linking R&D with industry and by collaborating with countries already holding strong capability in parts of the value chain can enable capability to develop over time. As an example: turbines produced by Wartsila in Finland, or HGV trucks produced in Germany or Netherlands could be leveraged. Similar apporaches have led to excellence in manufacturing in Japan and South Korea in the last 50 years
- Lithuania can **further strengthen the importance of Klaipeda port and region** within the Baltic region as it can be an import and export hub for the Baltic states. Competitors will be Porvoo, Gdansk, Kaliningrad, but of these only Porvoo looks like moving early on building infrastructure for the hydrogen economy
- There is an opportunity to **re-use old oil and gas infrastructure**, primarily natural gas pipes which can be retrofitted to dedicated hydrogen pipes but also liquid fuel bunkers which can be used to store synthetic fuels derived from hydrogen

# Lithuania: challenges

## Energy dependence, stranded assets, competitiveness of industries, and cost of not meeting targets are the primary threats

**Lithuania's specific challenges in delivering a hydrogen economy**

- There is a risk of **reducing capacity for delivering energy independence** again if Lithuania has to become an importer of hydrogen, gas-for-hydrogen or if power-for-hydrogen. This can be mitigated by unlocking as much onshore and offshore renewable resource as possible and also by considering whether hydrogen is the best option for some use cases where domestically produced biomass or biogas could provide energy security at similar cost
- The **transition away from natural gas risks stranded assets**. Specifically the economic lifetime of both the gas pipeline network and the LNG terminal at Klaipeda must be considered
- There is a risk that fertilizer and refinery plants **become less competitive** over time, which will impact the wider hydrogen economy as they will account for the majority of hydrogen demand. Successful implementation and calibration of the EU carbon border adjustment mechanism will mitigate some of this risk
- There is a risk of **failing to meet targets if appropriate health and safety legislation is not implemented** alongside market mechanisms. This legislaton will need to consider the value chain from production through transport and storage to individual use cases, as well as the value chain from manufacturing to use

# Putting Lithuania in context

## Plenty of domestic demand capable of enabling renewable power, but with storage challenges

| | |
|---|---|
| **Proven domestic demand in ammonia for fertilizers which is large in context of Lithuania’s overall size; HGVs also present sizeable demand in next decade** | ▲ Lithuania has a relatively large footprint in fertilizer manufacturing and heavy goods vehicles fuel demand for a country of its size. These can be the anchor use cases to provide scale in the next 10 - 15 years, driven by ambitious EU targets for green ammonia production (50% of all ammonia production by 2030) and the commercial readiness of hydrogen in HGVs, which will be cost competitive with diesel for HGVs later this decade. As a smaller country within the EU membership, Lithuania is arguably less suited to investing in less mature use cases in aviation and marine fuel, while it’s ability to leverage biomass for heating needs means there is less pressure to develop hydrogen in for heating vs other countries more reliant on gas heating |
| **Electrolysers (power to gas) drives energy security agenda and enables ambitious renewables targets** | ▲ Lithuania plans to develop more renewable power to reduce reliance on natural gas and oil, with this need accentuated by the impact of Russia’s invasion of Ukraine. There is also an ambitious target for net zero power system by 2035. Consequently, there is a need for hydrogen to displace gas in the fertilizer, refining and power sectors, while also an opportunity for the production of hydrogen to lower the subsidies required for wind and solar energy. As a result there is incentive for Lithuania to prioritise hydrogen from domestic renewable power over other forms of production |
| **More renewable power supply will need to be unlocked to serve hydrogen production in the long term** | ▲ Supply of renewable electricity is more than adequate for 2030 demand in all our scenarios but limited onshore and offshore wind resource and could impede the ability of domestic renewable power production to meet hydrogen production requirements by 2050. This can be mitigated by cooperation with other countries on either renewable power sourcing for electrolysers, LNG sourcing for blue hydrogen production, or importing hydrogen itself. |
| **Demand and feedstock supply clustered in different regions, which can each become hydrogen ‘valleys’** | ▲ Supply of electricity is likely to rely on wind, where resource is located in the north west of the country, while demand from fertilizer production means that hydrogen demand will initially be concentrated in Jonava near Kaunas. There is also a potential cluster of demand centred around oil refinery activity in the north, which could also serve heavy-duty-vehicle transport demand in Siauliai, Panevėžys and Klaipeda. This is broadly similar to other countries where industrial demand is centred on a small number of cluster locations |
| **Well connected networks can be leveraged; storage options more limited but ammonia demand could be an enabler** | ▲ Lithuania lacks the scale of proven geological storage potential of Germany, Denmark and Poland but may have a unique opportunity to use ammonia as a storage carrier given its outsized role in expected Lithuanian hydrogen demand. Like most EU countries it has a mature gas transmission network that will be required for natural gas in the 2020s and 2030s but can be repurposed to hydrogen over time. Hydrogen for heating will require costly distribution network retrofit but only post-2030 and likely on a small proprotion of the countries heating demand that cannot be easily electrified or switched to biomass |
| **Active R&D but requiring better links with industry needed to capture value chain** | ▲ Lithuania has established R&D programs in hydrogen production technologies but has little track record of technology commercialisation and is not a currently a manufacturer of any components of the value chain. As a result, developing the ability to participate in manufacturing will require sustained investment in R&D and human capital over time focused in one or two key areas that fit with domestic infrastructure required. It is starting from behind countries such as Germany, Finland, Denmark and Sweden, who have already made big steps to capture part of the value chain through existing domestic manufacturing champions |

Baringa
Brighter together

# 3. Scenarios for the hydrogen economy in Lithuania

Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

# What are the use cases?

## We have identified 11 use cases for hydrogen in Lithuania, which we have developed scenarios for based on stakeholder feedback and our own research

### Use cases for hydrogen in Lithuania

- **Fertilizer production,** where hydrogen is a feedstock for ammonia
- **Oil refining,** where hydrogen is a feedstock
- **Buses**, where batteries are less feasible or less economical
- **Heavier passenger vehicles,** such as SUVs
- **Heavy goods vehicles**, particularly over longer distances
- **Rail**, as an alternative to electrification on less busy routes
- **Marine**, as a precursor to ammonia or e-methanol
- **Aviation**, as a precursor to e-kerosene
- **Flexible power**, to deal with seasonal peaks served by gas turbines
- **Building heat**, in cases where biomass may not be an option
- **Industrial process heat**, where electrification may be less attractive

**Steel** is the only notable hydrogen use case we exclude

### How we are developing demand scenarios

**Stated ambition by Lithuanian stakeholders**
*Where stakeholder interviews have indicated that certain targets are feasible or certain plans have been drafted for use of low carbon hydrogen*

**Cost of decarbonising the use case**
*Using knowledge of economics of switching away from fossil fuels as a guide for timeframe of decarbonisation i.e. now, next 10 years or beyond 2030*

**Competing low-carbon technologies**
*Using knowledge of economics and feasibility of competing alternatives to hydrogen such as electrification and biofuels as a guide for realistic range of market share of hydrogen in decarbonising use cases, particularly in the longer term*

**Scalability**
*Acknowledging where demand is highly centralised or disaggregated, and recognising that the time and cost of developing infrastructure for the latter is greater*

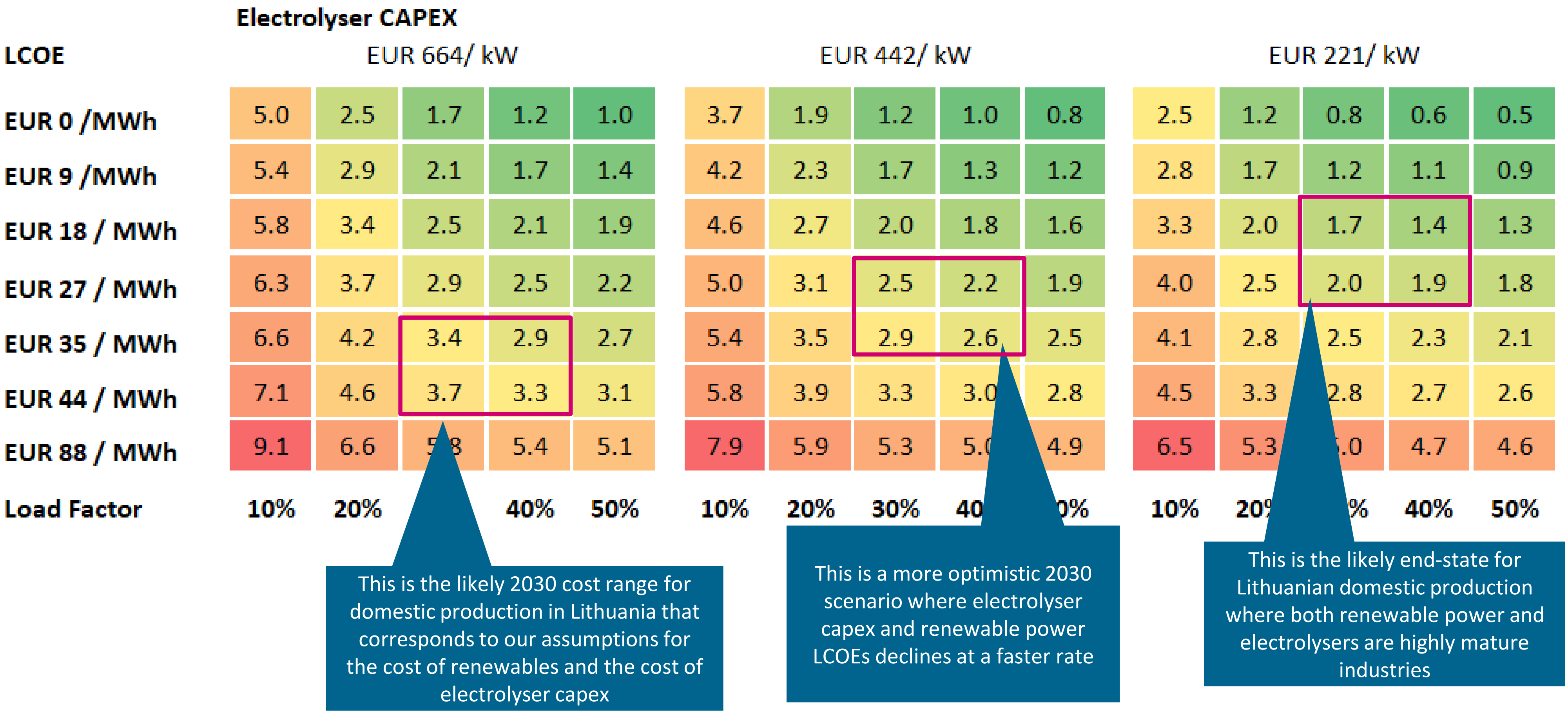
**Benchmarks set by other countries**
*Using data from 10 county benchmarks and targets set in EU regulation to guide or validate the range of hydrogen demand among use cases, particularly in the next 10 years*

*We will have 3 scenarios: a **low**, **base**, and **high** scenario*

# How much will hydrogen cost?

## Assuming cost of electricity of €35 – 45 / MWh and electrolyser costs decline as expected, this price is likely to be €3.0 – 4.0 / kg by 2030

Levelised cost of hydrogen production for different capex, load factors and input electricity prices



| | **Electrolyser CAPEX** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LCOE** | EUR 664/ kW | | | | | EUR 442/ kW | | | | | EUR 221/ kW | | | | |
| **EUR 0 /MWh** | 5.0 | 2.5 | 1.7 | 1.2 | 1.0 | 3.7 | 1.9 | 1.2 | 1.0 | 0.8 | 2.5 | 1.2 | 0.8 | 0.6 | 0.5 |
| **EUR 9 /MWh** | 5.4 | 2.9 | 2.1 | 1.7 | 1.4 | 4.2 | 2.3 | 1.7 | 1.3 | 1.2 | 2.8 | 1.7 | 1.2 | 1.1 | 0.9 |
| **EUR 18 / MWh** | 5.8 | 3.4 | 2.5 | 2.1 | 1.9 | 4.6 | 2.7 | 2.0 | 1.8 | 1.6 | 3.3 | 2.0 | 1.7 | 1.4 | 1.3 |
| **EUR 27 / MWh** | 6.3 | 3.7 | 2.9 | 2.5 | 2.2 | 5.0 | 3.1 | 2.5 | 2.2 | 1.9 | 4.0 | 2.5 | 2.0 | 1.9 | 1.8 |
| **EUR 35 / MWh** | 6.6 | 4.2 | 3.4 | 2.9 | 2.7 | 5.4 | 3.5 | 2.9 | 2.6 | 2.5 | 4.1 | 2.8 | 2.5 | 2.3 | 2.1 |
| **EUR 44 / MWh** | 7.1 | 4.6 | 3.7 | 3.3 | 3.1 | 5.8 | 3.9 | 3.3 | 3.0 | 2.8 | 4.5 | 3.3 | 2.8 | 2.7 | 2.6 |
| **EUR 88 / MWh** | 9.1 | 6.6 | 5.8 | 5.4 | 5.1 | 7.9 | 5.9 | 5.3 | 5.0 | 4.9 | 6.5 | 5.3 | 5.0 | 4.7 | 4.6 |
| **Load Factor** | **10%** | **20%** | | **40%** | **50%** | **10%** | **20%** | **30%** | **40** | **0%** | **10%** | **20** | **%** | **40%** | **50%** |

This is the likely 2030 cost range for domestic production in Lithuania that corresponds to our assumptions for the cost of renewables and the cost of electrolyser capex

This is a more optimistic 2030 scenario where electrolyser capex and renewable power LCOEs declines at a faster rate

This is the likely end-state for Lithuanian domestic production where both renewable power and electrolysers are highly mature industries

Note: *Assumes USD/EUR FX rate of 1.13
Source: McKinsey

# How scalable is hydrogen?

## Use cases with more centralised demand will scale more quickly than those which require highly distributed network infrastructure and disaggregated (i.e. consumer led) decision making

**Scalability rating**

**Use cases for hydrogen in Lithuania**

**1. Highly centralised**

- Use cases which centre on a small handful of points of activity and can therefore switch to green hydrogen through a small number of projects with point to point transport infrastructure between production and demand
- Fertilizers and refining are examples where demand is centred around 1 – 2 sites
- All other things being equal, these use cases will scale more quickly than more decentralized use cases and will undergo large step changes in demand associated with completion of large projects

**Fertilizer production**
**Oil refining**
**Marine**
**Flexible power**

**2. Small networks**

- Use cases which require a distribution network that can to some extent be centrally planned because of the relatively small number of network points
- Examples are captive refueling depots of buses, HGVs, trains, and aviation where vehicle refueling is well coordinated through a small number of points
- Similarly, a small number of industrial stakeholders can be relatively well coordinated

**Buses**
**Heavy goods vehicles**
**Rail**
**Aviation**
**Industrial process heat**

**3. Highly decentralized**

- Use cases which require hundreds or thousands of network points to scale up and will therefore scale more slowly as a result of the high number of stakeholders involved and additional investment required in distribution versus more centralized use cases
- All other factors being equal, these use cases will scale more slowly than more centralized use cases but will grow exponentially
- Examples of these are passenger vehicles, where > 100 refueling stations and 1000s of vehicle owners will be involved. Equally home heating will require 1000s of home owners switching boilers

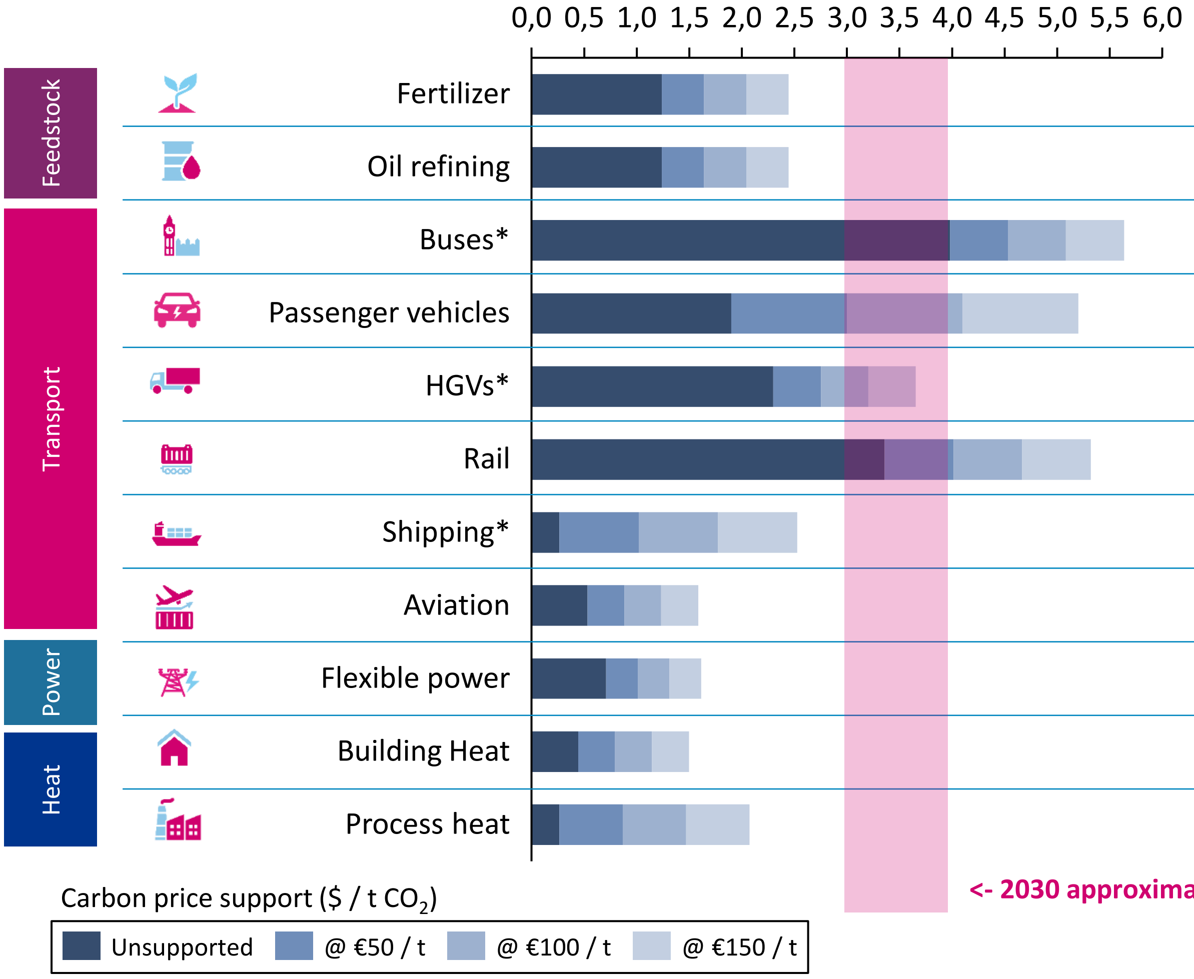
**Heavier passenger vehicles**
**Building heat**

Source: EU Commission, Baringa power market model projections, press articles

# How fast will use cases arrive?

Based on cost and scalability, industrial use cases and heavy duty vehicles will be the first use cases to scale. Hydrogen to power may also come quickly to meet net zero 2035 targets

**Estimated breakeven switching point vs incumbent fossil fuel @ different carbon prices** (€ / kg hydrogen)



| | Incumbent fossil fuel | Scalability rating | Likely EU scale-up period |
|---|---|---|---|
| Fertilizer | Grey $H_2$ | 1 | 2025 - 35 |
| Oil refining | Grey $H_2$ | 1 | 2025 - 35 |
| Buses* | Diesel / LPG | 2 | 2020 - 30 |
| Passenger vehicles | Diesel | 3 | 2030 - 40 |
| HGVs* | Diesel | 2 | 2020 - 30 |
| Rail | Diesel | 2 | 2025 - 35 |
| Shipping* | Fuel oil | 1 | 2030 - 40 |
| Aviation | Kerosene | 1 | 2030 - 40 |
| Flexible power | Nat. gas | 1 | 2030 - 35 |
| Building Heat | Nat. gas | 3 | 2035 - 50 |
| Process heat | Nat. gas | 2 | 2035 - 50 |

Covered by ETS but sensitive to cost increases

Close to competitive but lacking carbon price to push

Longer asset life = slower trajectory

Most expensive to switch

Expensive but targets are ambitious

Most expensive to switch

**<- 2030 approximate Lithuania cost at electrolyser gate ~€3,0 – 4,0 / kg**

Note: Assumes USD/EUR FX rate of 1.13, *Buses, trucks and shipping have an uncertainty of 5%, 20% and 40% respectively; assumes 2019 global levels for gas and oil prices
Source: Hydrogen Council 2021 Hydrogen Insights, Project analysis

# Scenarios for Lithuania

## The Base Case is ambitious but realistic and assumes current Fit for 55 proposals will be tempered and fall proportionally on higher-GDP countries

| Low case | Base Case | High Case |
|---|---|---|
| *The Low Case represents a scenario which is both tempered in ambition and more pessimistic about the role of hydrogen in a decarbonised economy. It assumes very little delivery of hydrogen infrastructure this decade beyond what is already in planning. Beyond 2030 it assumes that the cost of enabling technologies will be at the more pessimistic end of forecasts and consequently hydrogen's role in transport and other use cases vs other low carbon alternatives will be more limited and the overall pace of decarbonisation will be slower* | *The Base Case represents a scenario which is both ambitious but achievable for Lithuania. It acknowledges that scale hydrogen this decade is achievable by focusing on use cases such as fertilizers where there is proven demand and EU funding available, and heavy-duty vehicles where there will be economic parity with diesel before 2030. However, the base case does not assume that proposed EU Fit-for-55 2030 targets are met entirely through domestic supply and demand of hydrogen, acknowledging that the affordability and logistical challenge associated with these targets will be extremely challenging considering Lithuania's size and GDP. However, in the longer term it does adhere to the EU vision of full decarbonisation by 2050, enabled by a highly interconnected hydrogen backbone that includes the Baltic region* | *The High Case represents a scenario which is both highly ambitious in scale of hydrogen the near term and more optimistic in the share of hydrogen in a decarbonised energy system in the long term. It assumes Lithuania keeps pace current with Fit-for-55 proposals for 2030 and that those targets are approved as proposed. Much of the investment seen in the 2030 – 2050 period in the Base Case occurs 5 – 10 years earlier in the High Case. Where there is larger uncertainty in hydrogen's role versus other technologies (e.g., in heating) the High Case is more optimistic on hydrogen and consequently results in greater investment, despite also assuming more optimistic decline in the cost of enabling technologies* |

# Demand use cases – Base projections

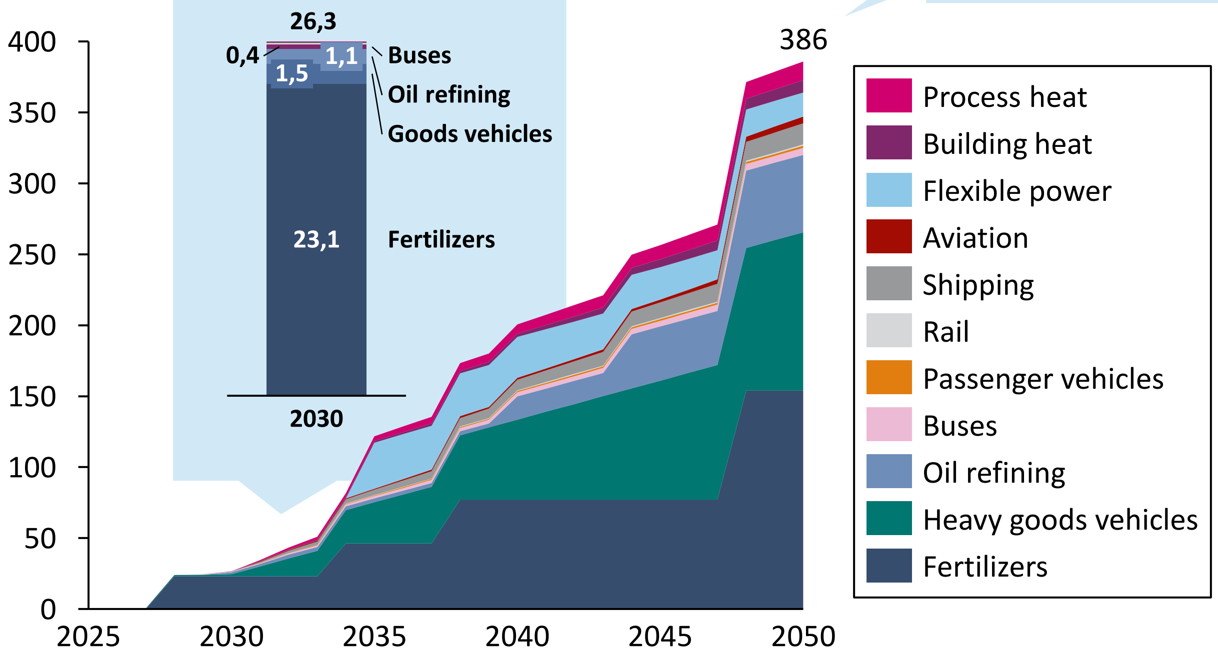
## Fertilizer, oil refining, HGVs, and building heat are the use cases with the largest potential demand

| | Use case | Conversion to low-carbon $H_2$ (2030) | Conversion to low-carbon $H_2$ (2050) |
|---|---|---|---|
| **Feedstock** | Fertilizer | 15% of total ammonia production | 100% of ammonia production. |
| | Oil refining | Pilot project (2.6% conversion) to meet RED III RFNBO objectives | 100% conversion to green $H_2$ with today's level of underlying demand |
| **Transport** | Buses | 25% of public transport buses in top 5 cities | 50% of all buses (not only public transport) |
| | Passenger vehicles | 0% | 2% (battery-electric dominant technology) |
| | HGVs | 1% (more tempered ambition than NL and DK) | 75% (hydrogen-electric dominant for long distances) |
| | Rail | Pilot project (<1% conversion) | 50% of remaining unelectrified demand |
| | Shipping | Demonstration project | 60% ($H_2$-derived , 80% ammonia - aligned with IRENA) |
| | Aviation | 0,7% (Proposed EU fuel mix regulation) | 28% (Proposed EU fuel mix regulation) |
| **Power** | Flexible power | 0% | 40% conversion of natural gas demand to $H_2$ to power from 2035. |
| **Heat** | Building Heat | 0,2% of natural gas heating demand (assumed blended) | 20% of natural gas home heating demand (assumed dedicated hydrogen heating). |
| | Process heat | 1% (pilot only, with continued adoption of biomass for low-grade heat) | 10% (adoption of hydrogen in industries which require high grade process heat) |

# Projection for low carbon hydrogen demand

## We estimate 26 kt by 2030 and over 380 kt per year of demand by 2050 in our base case scenario

**Base case** estimate of annual low-carbon hydrogen demand in Lithuania (2025- 50)
kt hydrogen



c.18% of 2019 national final energy demand[1]

What we mean by ‘low-carbon’ hydrogen: this report refers to hydrogen *demand* as low-carbon hydrogen i.e. demand that is driven by decarbonisation (therefore excluding grey hydrogen demand), but is agnostic to technology production. The report recommends green (electrolyser) hydrogen production over other technologies when considering *supply* but does not differentiate between technologies when considering demand

**Key assumptions**

- Centralized nature of fertilizer production offers opportunity to scale early, but with full scale occurring once regulation mandates full switch
- Buses are the earliest use case and could adopt up to 1 kt per year by 2026, but this is small in proportion to fertilizer demand
- HGVs take time to roll out but eventually provide a very large demand base owing to large share of international HGV transit
- Lithuania achieved net zero by 2050 but is not a quick to achieve same level of scale in some use cases by 2030 as the more ambitious member states
- Net Zero 2035 in the power sector requires some hydrogen-to-power peakers
- No significant positive export balance is assumed given production cost will be reasonably well aligned with neighbours

Note: 1) 5,2 Mtoe final energy demand for 2019
Source: Project analysis; Enerdata

# Approach to supply infrastructure modelling

## We have considered the cost of infrastructure required to deliver supply, transport, and consumption of the hydrogen demand in each of our scenarios

**Production**

- Benchmarking production technologies
- Electrolyser capex and efficiency
- LCOE of renewable power
- Renewable generation capex and load factor

**Transmission**

- Technology readiness level and levelized cost
- Transmission system route
- New pipeline and pipeline retrofit capex
- Powerline capex

**Storage**

- Long- and short-term storage demand
- Technology readiness level and levelized cost
- Pressurized container, ammonia and salt cavern capex
- Import/ export fuel levelized cost

**Distribution and consumption**

- Truck and refueling station capex, capacity and utilization rate
- New pipeline and pipeline retrofit capex
- Hydrogen boiler capex
- Hydrogen turbine capex

**Investment and impact**

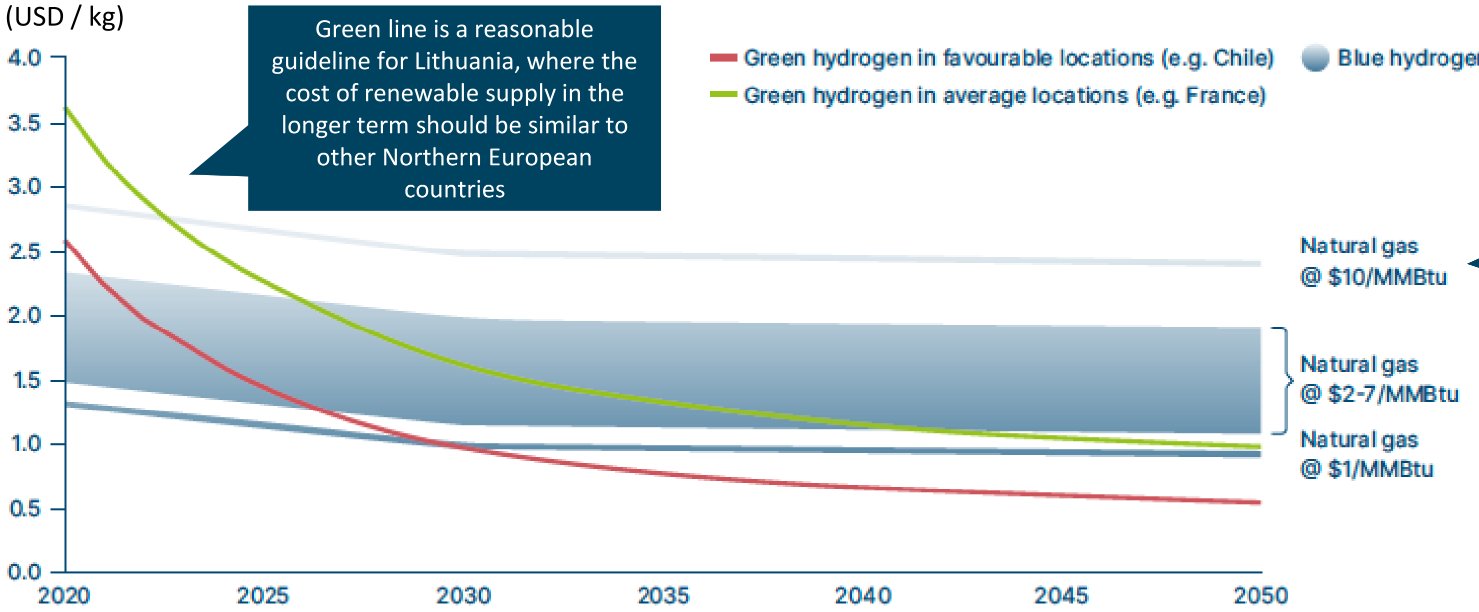
- Jobs/ unit capex
- Emissions abated

Assumptions for each are stated in Annex 3

# Choice of production technology

## Electrolyser production is expected to be the dominant technology over the longer term and could be competitive with blue hydrogen by 2030

**Projected cost of green and blue hydrogen over time for different gas prices and different production locations**



Green line is a reasonable guideline for Lithuania, where the cost of renewable supply in the longer term should be similar to other Northern European countries

Versus $33 / MMBtu TTF spot price today, $11 / MMBtu forward price 2025

- Prior to the tightness in European gas markets, blue hydrogen was expected to remain lower cost than green hydrogen to 2030, assuming gas would cost $2 – 7/ MMBtu. However today's gas prices mean **green hydrogen could be competitive with blue hydrogen this decade**[1]
- green hydrogen is expected to become lower in cost as PEM electrolyser technology improves and solid oxide electrolysis becomes commercially feasible. Blue hydrogen via reformation is not expected to undergo similar cost reductions due to the largely mature state of the technology
- As a result, green hydrogen is expected to form the bulk of long-term capacity, with blue hydrogen expected to deliver more rapid scale up of the hydrogen economy in the nearer term
- Apart from the price of gas, the cost of CCS is the largest uncertainty associated with blue hydrogen. Production is expected to be centred on locations with strong demand for CCS from other sources (power plants, refineries, steel furnaces) and sequestration sites are located nearby and thus the price of $CO_2$ transport and storage are more favorable

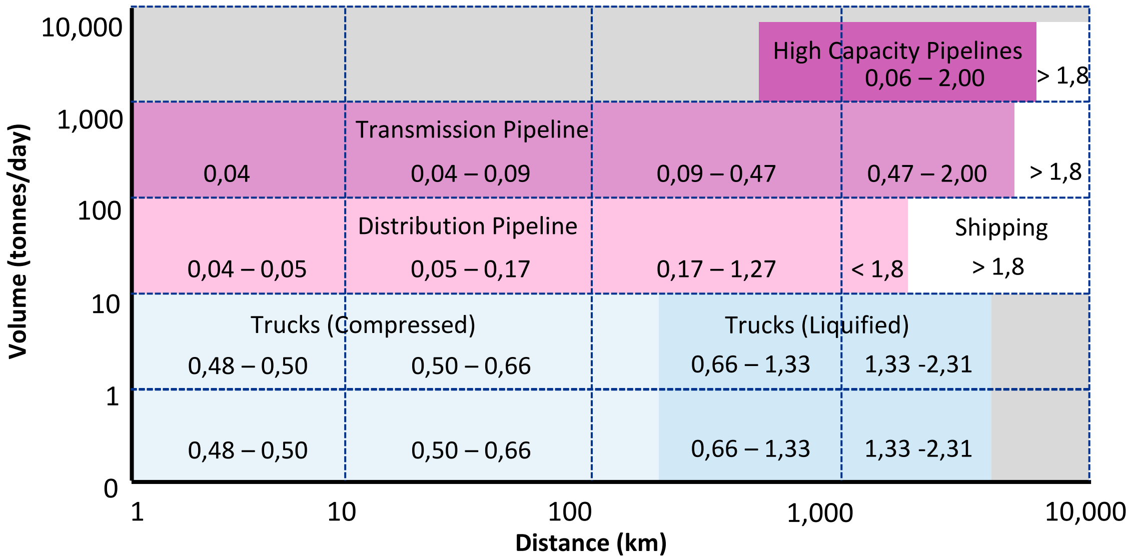
Note: Although 'green' and 'blue' methods are considered here; other methods are assessed and discounted in Annex 3

Source: CME Group; ETC – Making the Hydrogen Economy Possible (2021)

# Choice of transport technology

## Trucks are cheapest hydrogen carriers for low volumes, while pipes are cheapest for high volumes

**Lowest cost hydrogen transport method as a function of volume and distance (€ /kg)**



**Key takeaways on optimal transport vectors:**

- Ammonia shipping requires distances greater than 3000km to be economical. This is because shipping has low transport costs, but high conversion and storage costs
- Pipelines require large flowrates to justify high capital costs. Distribution and transmission pipelines become economical above 10 tonnes/day and 100 tonnes/day respectively
- Compressed hydrogen trucks are cheaper than liquified for distances less than c. 300 km. Liquified trucks have higher up-front conversion costs, but can travel more hydrogen per truck

| Technology | Technology Readiness Level | |
|---|---|---|
| Blending in natural gas grid | R&D | The amount of hydrogen that can be tolerated in natural gas pipelines depends on the pipe and downstream units – it is not standardised, and thus technical progress is delayed. Technical challenges such as hydrogen embrittlement and the cyclical loads for changes in pressure persist. |
| Liquid Hydrogen Tanker | Pilot | Liquid $H_2$ (LH2) is similar to LNG but operates at 90 $^{0}$C lower temperature, which requires a special thermal insulation system for LH2 transportation. The first demonstration project began in 2021, using the green innovation fund |
| Ammonia Tanker | Mature | Ammonia is already traded inter-country using ships. Properties of ammonia are similar as LPG thus LPG ships have compatibility for ammonia transport |
| Pipeline | Mature | Gaseous transport of hydrogen in pipelines is already used in the European Union and the United States |
| Trucks | Mature | Trucking is a mature technology for transporting ammonia, and in the absence of pipelines, is the most common mode of high volume transport for liquid hydrogen |

Source: Global Hydrogen Review (IEA), ETC, Clean Energy Technology Guide (IEA)

# Transmission system modelling assumptions

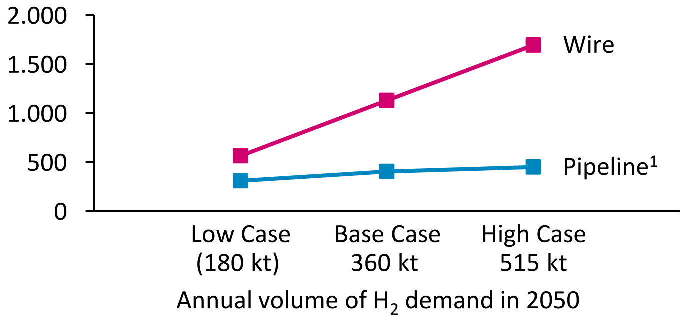
## We assume pipeline transmission infrastructure is used to transport hydrogen beyond 2035 in order to serve domestic demand

### Rational for use of pipelines over wires

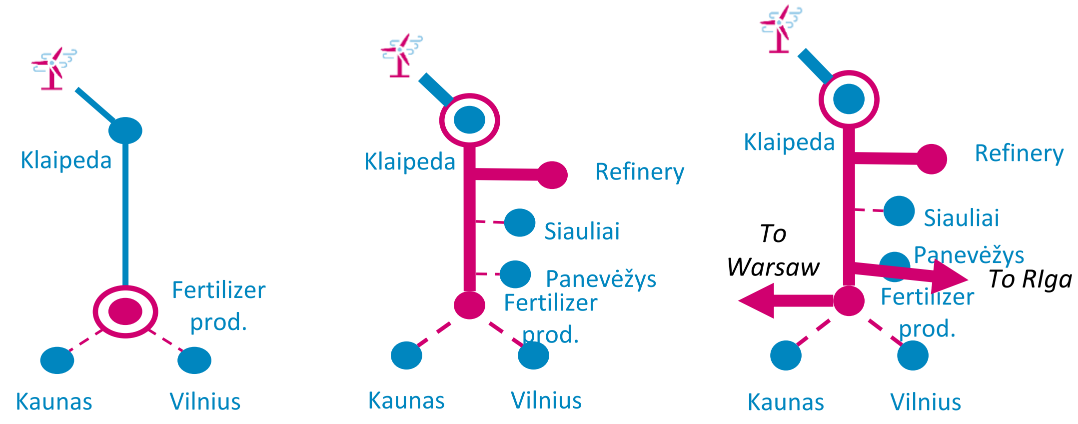
**Pipeline transmission infrastructure is assumed to be a more economical alternative for transporting Lithuania's 2050 hydrogen demand in all scenarios**

- This conclusion depends on the volume of hydrogen transported, and has greatest uncertainty in the low demand scenario; for example, underground sections of powerline may be required in populated areas, which would increase powerline costs
- Approximately one third of the transmission backbone is expected to be retrofitted gas pipe, with the remaining new dedicated hydrogen pipe. If less pipeline can be retrofitted than is currently expected, pipeline costs would increase significantly
- Economic comparison is based on capex and does not include the cost of compression. A comparison that includes opex is not expected to alter our conclusions, as it is less than 10% of total levelized costs for the pipe diameters modelled. In all scenarios, the capex of powerlines are almost 100% greater than the pipeline capex

**Comparison of pipe vs wire capex required to serve 2050 hydrogen demand** (€m)



### Timeline of transmission pipeline build



**Stage 1 (pre 2030)** **Stage 2 (2030s)** **Stage 3 (by 2040)**

- Litgrid estimate that fertilizer sector's 2030 plans, which make up most of Base case demand require no major grid reinforcement
- Once the next phase of fertilizer demand becomes realised (in mid-2030s in Base case), a dedicated hydorgen pipeline is built to avoid further networtk upgrades and accomodate future demand growth
- By 2040 the networks links to a Baltic hydrogen backbone linking Estonia, Finland, Latvia, Lithuania, and Poland

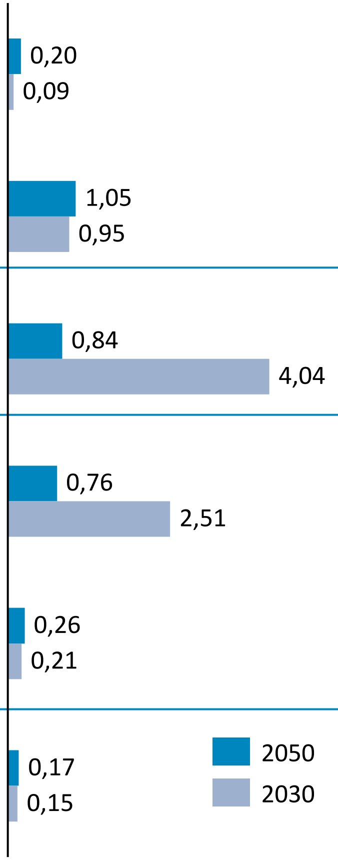
| | | | |
|---|---|---|---|
| ▬ | Electricity transmission | ● | Population centre |
| ▬ | Hydrogen pipeline transmission | ● | Major $H_2$ demand centre |
| ---- | Local distribution | ○ | Major $H_2$ production |

Note: Pipeline based on 17 inch, 25 inch, and 28 inch diameters
Source: EU Hydrogen Backbone, IEA

# Storage technology options

## Pressurized containers are the most economical for short term small volume storage, while geological storage may be most economical for long duration where larger volume is required

| Technology | Scale | Readiness Level | | Estimated € / kg cost in 2030 and 2050 | Suitability for Lithuania |
|---|---|---|---|---|---|
| **Salt Cavern** | Large scale, Long duration | **Mature** | • Lowest cost option for large volumes and long durations but limited by speed of gas withdrawal (c. 1 month for salt caverns)<br>• Used in the UK and USA to support chemical plants and refineries – the largest holding up to 100 GWh of $H_2$ | 0,20<br>0,09 | Should be explored through Geological Society |
| **Depleted Fossil Fields** | | **Pilot** | • Demonstrated for natural gas storage but not $H_2$. Challenges include chemical/biological reactions, consumption of hydrogen by microorganisms, development of biofilms, and pore clogging.<br>• More expensive than salt caverns but can have larger volumes | 1,05<br>0,95 | |
| **Liquefaction** | Flexible scale, medium to long duration | **Pilot** | • Mature for small scale storage but not for large scale<br>• Low temperatures (−253°C versus −33.6°C for ammonia) make cost challenging large volumes and long durations | 0,84<br>4,04 | Likely to be more expensive than alternatives |
| **Ammonia with reconversion** | | **Pilot** | • Reconversion to $H_2$ is at an early stage of development and is the most expensive step, contributing over € 2 / kg of the overall levelized cost | 0,76<br>2,51 | May be main form of long term storage assuming reconversion to hydrogen not required |
| **Ammonia, no reconversion** | | **Mature** | • Extensive existing infrastructure and expertise in ammonia storage | 0,26<br>0,21 | |
| **Pressurised Container** | Small-scale, short duration | **Mature** | • Mature but small scale - standard pressurized containers hold a maximum of c. 1.1 tons of hydrogen.<br>• Overground tanks are the cheapest from of small- scale, short-term storage, and have rapid loading and withdrawal speeds | 0,17<br>0,15 | Likely to be main form of short term storage |

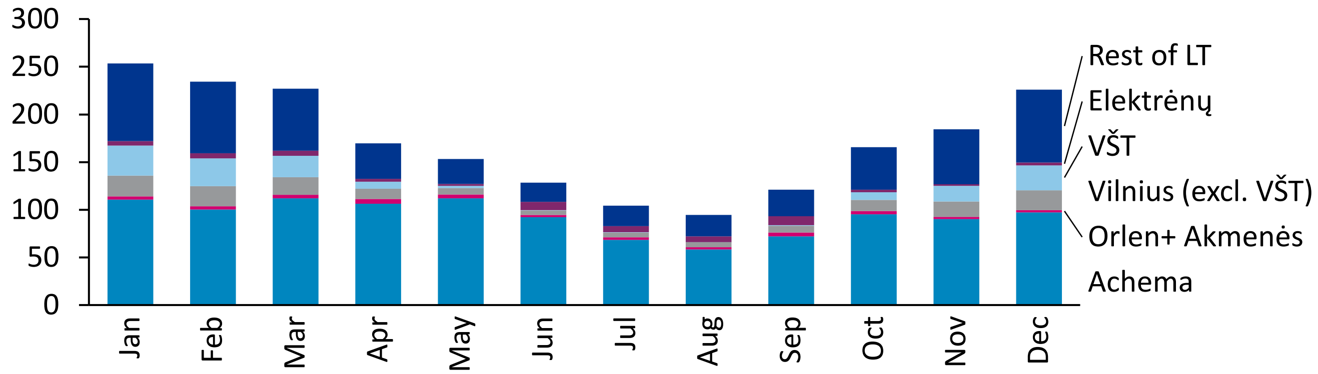


Source: Global Hydrogen Review (IEA), ETC, Clean Energy Technology Guide (IEA), Path to Hydrogen Competitiveness (Hydrogen Council)

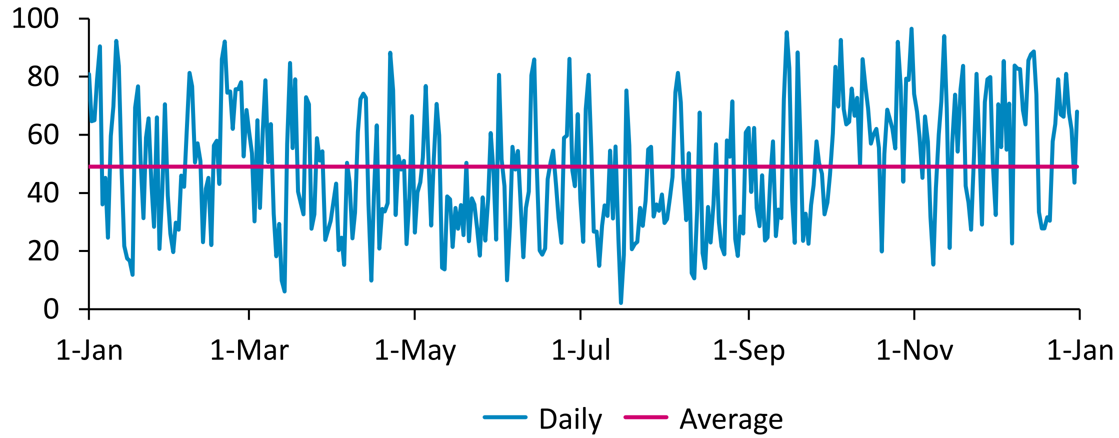
# Required storage

## We have assumed both long term and short term storage requirements

**Average monthly natural gas demand in Lithuania by user (2018-2021*)**
MCM



**Lithuanian offshore wind (theoretical) load factor profile over 2017**
% load factor



- In total, while the global natural gas system currently operates with storage capacity equal to about **12% of annual demand**
- Bloomberg estimates that storage capacity equal to 15 to 20% of annual hydrogen use will need to be available, equivalent to c.50-60 days of demand. IEA estimates 20 days (5.5% annual demand)
- In all scenarios **we assume 25 days of long-term storage are available through a combination for 2040 (increase from 7 days in 2030), reducing to 20 days by 2050 once market is more interconnected with the rest of Europe**
- Using 2017 wind profile as an example, it would take 6 days of storage to provide firm hydrogen supply from offshore wind generation, and 8 days from onshore wind
- We assume **1 day of short-term storage is built** and therefore for early projects where long-term storage is inaccessible, there is some trade off between storage costs and flexibility to run electrolysers on less-than-100% green electricity when storage is depleted
- We have not considered using hydrogen as a contribution to state liquid fuel reserve in scenarios though this may create additional storage requirements post-2030 as liquid fossil fuels are phased out

Source: AmberGrid (gas volumes), Baringa (wind profiles)

# Storage for import and export

## Ammonia is likely to be the dominant carrier for hydrogen imported or exported given it’s cost competitiveness and as a result of Lithuania’s level of ammonia production

**We assume it is possible to provide storage requirement and therefore flexibility via ammonia**

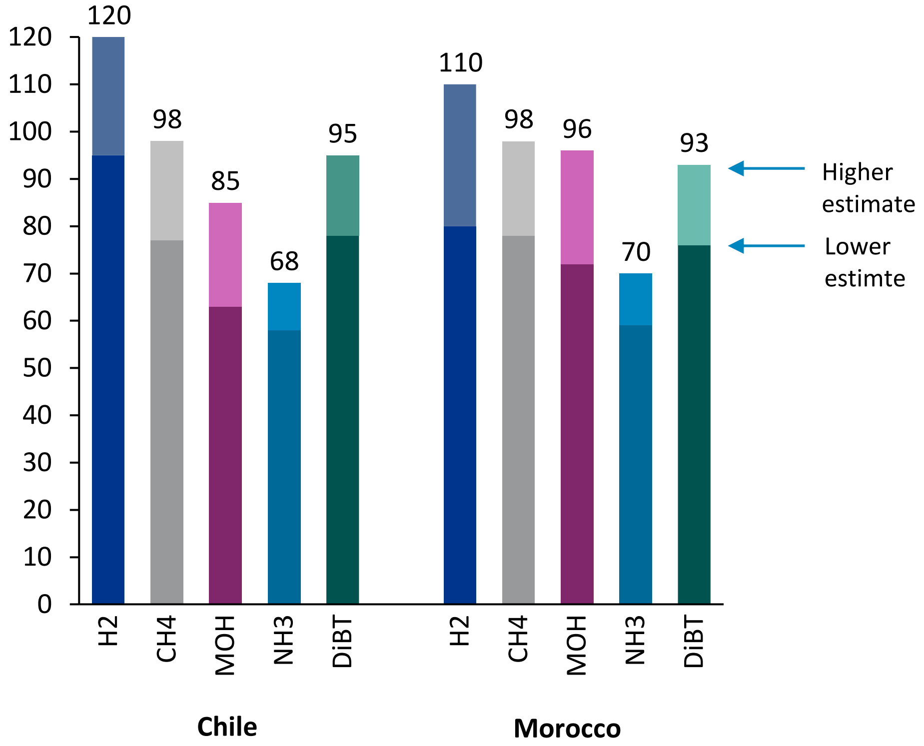
- In our scenarios we do not assume any reconversion of ammonia into hydrogen given the ready demand for ammonia in the fertilizer plant and the high share of overall hyrogen demand that this use case has.
- Rather we assume that in times of excess demand over supply for hydrogen fuel in other use cases, the fertilizer demand can draw off of ammonia in storage while hydrogen production serves other use cases

**In each scenario we add additional ammonia storage capacity in line with hydrogen demand for that scenario and do not differentiate between port capacity and capacity in other locations**

**Ammonia is also assumed to be the dominant carrier for import and export**

- As the global hydrogen economy expands hydrogen will be shipped via liquefied hydrogen, ammonia or liquid organic hydrogen carriers (LOHCs) such as dibenzyl toluene
- While each of these are cost competitive, we assume ammonia is the dominant energy carrier for hydrogen shipped to or from Lithuania
- In recent years, ammonia has been imported via Russia, almost entirely to the smaller fertilizer producers. However in the long term the lowest cost green ammonia may come from ship imports from areas where green hydrogen production is cheapest, while exports could be to any number of countries with import infrastructure at times when Lithuania’s ammonia production exceeds demand

**Upper and lower LCOH estimates for Chile and Morocco in 2035 (€/MWh))**



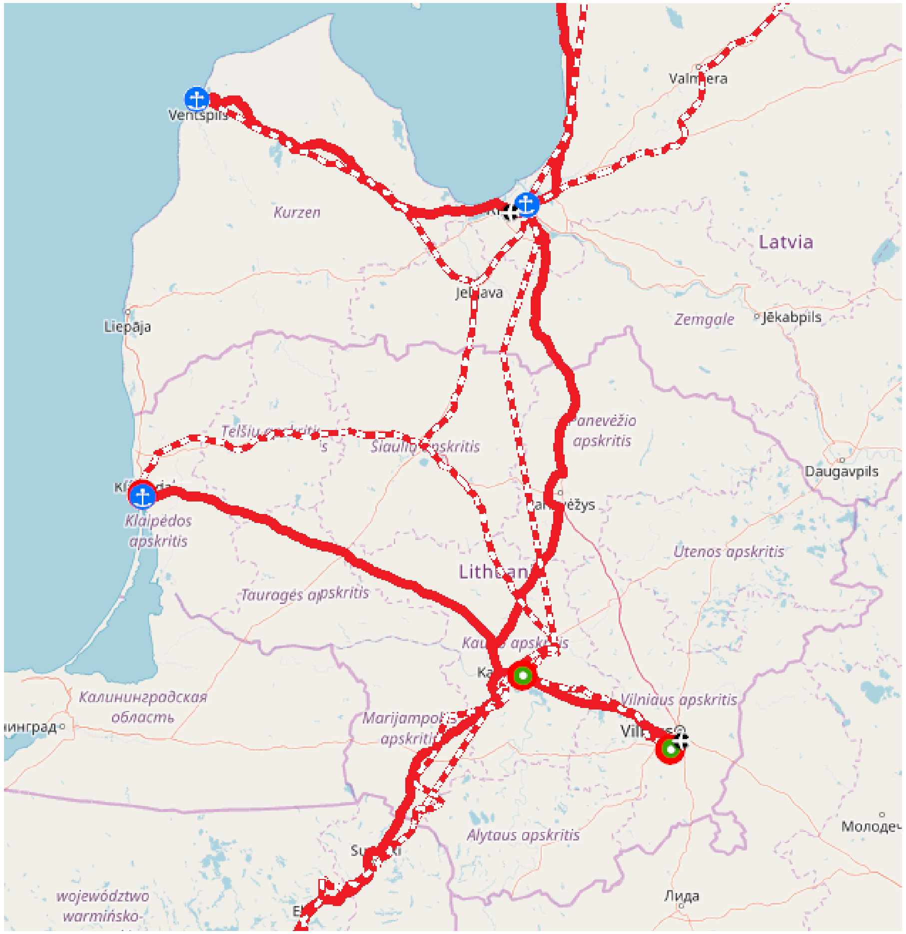
Note: Values for ammonia do not include reconversion

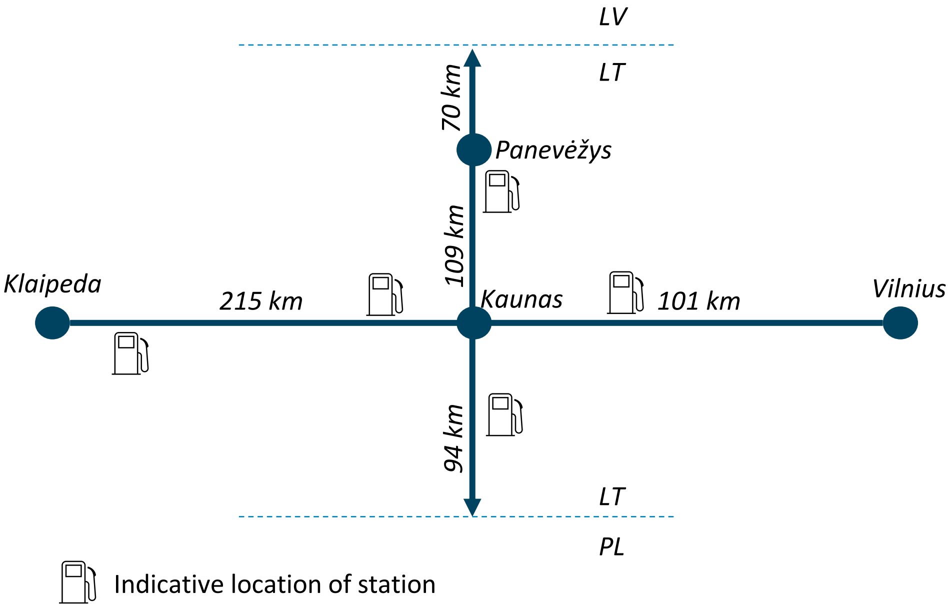
Source: IEA techno-economic assumptions for hydrogen; Hydrogen Import Coalition ‘Shipping the Sun and Wind to Belgium’

# Short term refueling infrastructure for 2030

## Lithuania needs a minimum of 5 hydrogen refueling stations by 2030 to meet EU network targets

**EU TEN-T road and rail network in Lithuania (road in solid red line)**





Indicative location of station

**Lithuania needs 5 hydrogen refuelling stations by 2030**

- Refuelling stations every 150 km on the TEN-T network by 2030, as desired by the EU as part of the EU's Fit-for-55 package.
- This equates approximately to 5 refuelling stations in Lithuania, assuming 2 need to be within 75 km of the Polish and Latvian borders.
- Two stations are required between Kaunas and Klaipeda to ensure a roundtrip from Latvia to Klaipeda encounters one station every 150 km

Source: European Commission, Google Maps

# Key assumptions in infrastructure cost modelling

## The estimations of cost assume production is domestic and through electrolysers

### Key assumptions to flag on infrastructure modelling

**Production**

- **All production is assumed to be through electrolysis**, though we have discussed other production methods in Annex 3
- Production is assumed to be driven **from a combination of onshore and offshore wind** with electrolyser load factor corresponding to renewable generation load factor

**Transport**

- We assume **hydrogen pipelines are less expensive than electricity network reinforcement for large**, but have relied heavily on general assumptions to deduce this, and not detailed cost estimated specific to Lithuania
- We assume hydrogen **transport via dedicated pipeline occurs in the 2030s**, once fertilizer demand moves beyond it’s 2030 target, thereby precipitating a need for either pipeline or network reinforcement

**Storage**

- We assume **that seasonal storage occurs using ammonia** given the large role ammonia plays in our demand scenarios and the absence of proven geological storage. Importantly, we assume **none of this ammonia needs to be reconverted to hydrogen**, but instead ammonia storage allows ammonia demand within the fertilizer industry to be flexible, essentially leveraging Lithuania’s strength as having a ready base of ammonia demand and ammonia handling capability. This is a simplifying assumption in the absence of any detailed assessment of repurposing of existing oil and gas infrastructure

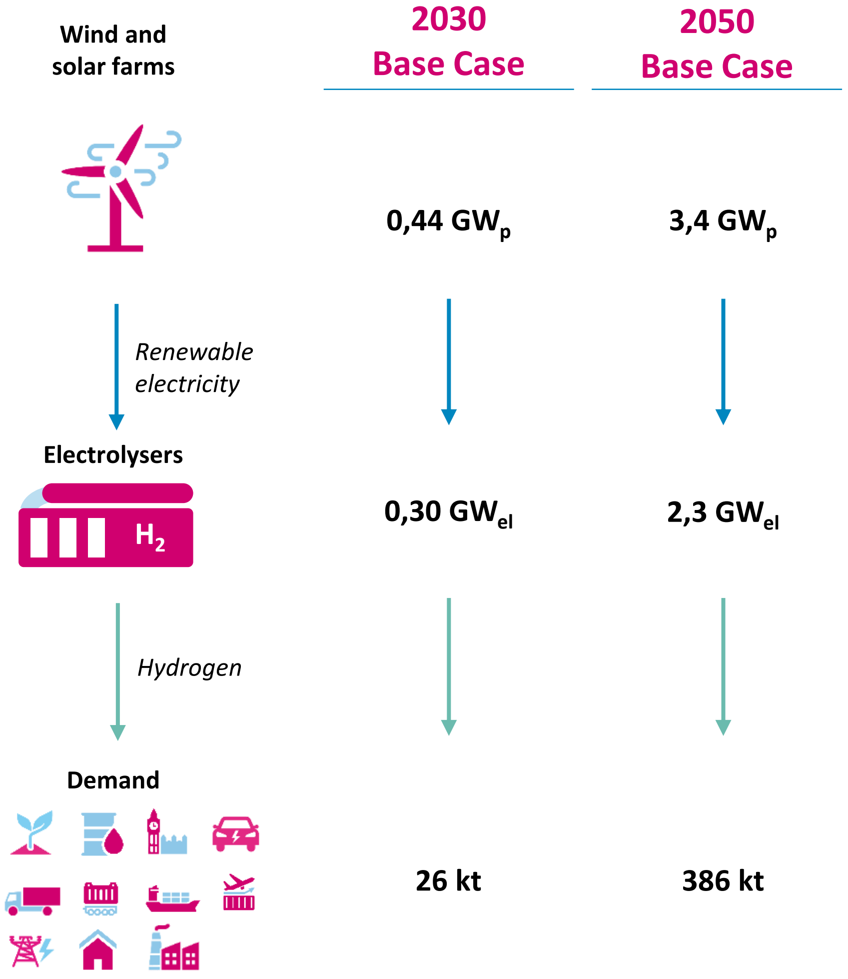
**Distribution and consumption**

- We have checked our demand scenario for passenger vehicles and HGVs based on the number of refueling stations implied by our original estimates. On this basis we cap the number of refueling stations at the current number of refueling stations in Lithuania (c.600) and limit demand in response to this
- For hydrogen powered vehicles, we have included the additional premium cost of vehicle switching in out cost estimations but not the full cost of the new vehicle

**Investment and impact**

- We have included estimates of capex and job creation. Job creation is assumed to be **largely based on sustained asset construction and maintenance**. Other elements of the value chain such as manufacturing are not out of scope for Lithuania but are more difficult to assess at a high level using existing capex -> jobs economic multipliers

# Translating demand into supply capacity



| | 2030 Base Case | 2050 Base Case |
|---|---|---|
| **Wind and solar farms** | $0{,}44\ \mathrm{GW}_p$ | $3{,}4\ \mathrm{GW}_p$ |
| *Renewable electricity* ↓ | ↓ | ↓ |
| **Electrolysers** | $0{,}30\ \mathrm{GW}_{el}$ | $2{,}3\ \mathrm{GW}_{el}$ |
| *Hydrogen* ↓ | ↓ | ↓ |
| **Demand** | 26 kt | 386 kt |

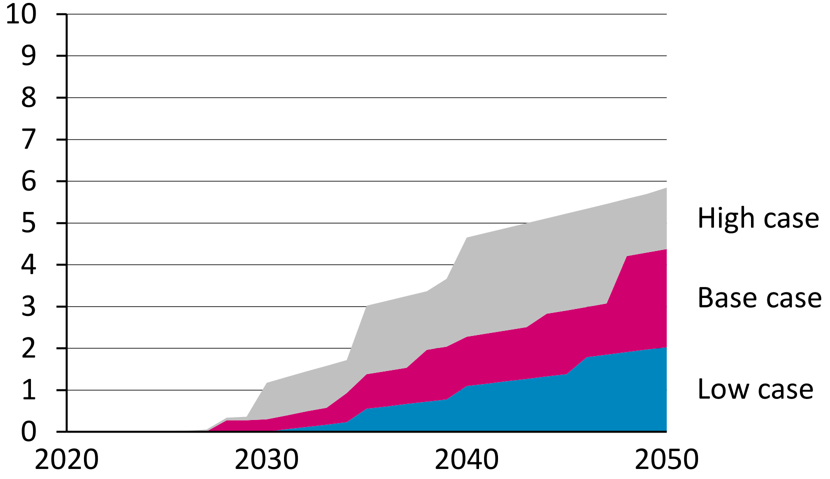
**Translating demand to electrolyser capacity and renewable capacity**

- Scenarios assume that production is from electrolysers and these run at approximately 35% capacity. This capacity factor assumes that the electrolyser load follows renewable load and that the renewable load is primarily onshore wind but includes a significant amount of offshore wind
- This is a slightly simplifying assumption that reflects annual average capacity factors. Electrolysers may follow a renewable load from a single farm for most of its operational output but may also have some reserve capacity for responding to market or system incentives e.g., when there is a risk of curtailment or a need for frequency response
- We have translated electrolyser capacity to renewable capacity by assuming electrolysers are c.63% efficient in converting electrical energy to hydrogen chemical energy today and achieve 75% efficiency by 2050

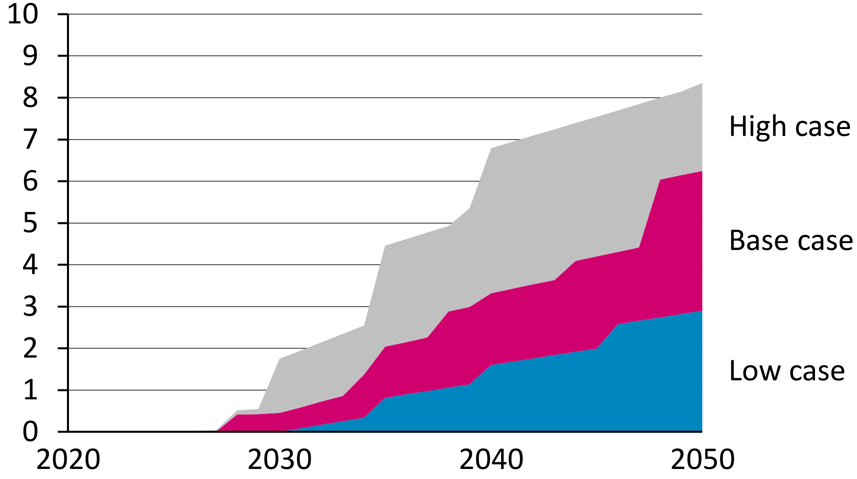
# Supply capacity of hydrogen and renewables

## Up to 1,2 GW of electrolysers required by 2030 (300 MW in the Base case), with up to 5,8 GW required by 2050 (4,3 GW in the Base case)

**Green electrolyser capacity in each scenario** (GW)



**Renewable capacity required in each scenario** (GW)



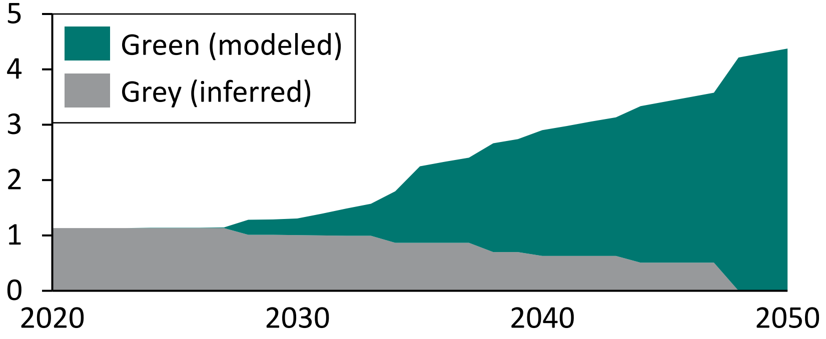
- By 2030, approximately **300 MW of electrolyser capacity is required in the Base case**, while just under 1200 MW is required in the High case, requiring
  - Assuming this is primarily enabled by offshore and onshore wind, and that electrolyser load largely follows renewable load, we estimate that **450 – 1750 MW of renewable power generation capacity** will be required to support this
- Between **2,0 and 5,8 GW of production capacity will be required by 2050** depending on whether demand follows the Low, Base, or High case more closely
  - Assuming this is primarily enabled by offshore and onshore wind, and that electrolyser load largely follows renewable load, we estimate that **2,9 - 8,3 GW of renewable power generation capacity will be required to support this**

# Energy carriers

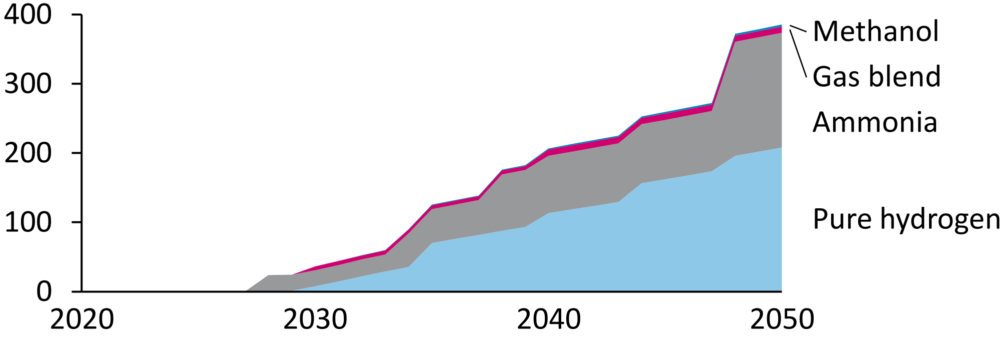
## Production of grey hydrogen will continue to pay a role as users of grey hydrogen replace with low carbon hydrogen in stages rather than all at once

**Total H2 supply capacity – Base case**

(GW hydrogen production capacity)



**Base Case** low-carbon hydrogen demand (kt)



**Role of different colors of hydrogen**

- Green hydrogen underpins all the growth and investment in capacity in our scenarios
- Grey hydrogen production will continue in Lithuania up to the 2040s as current fertilizer and refinery producers move from grey to low carbon hydrogen production through step changes which correspond to decisions to upgrade or replace plant
- Blue hydrogen is not assumed in our scenarios as it appears less economic both now and in the long term. However, it could provide an interim solution for refineries to meet some low-carbon hydrogen demand, particularly if the demand growth trajectory is closer to the high case and cheap natural gas is available

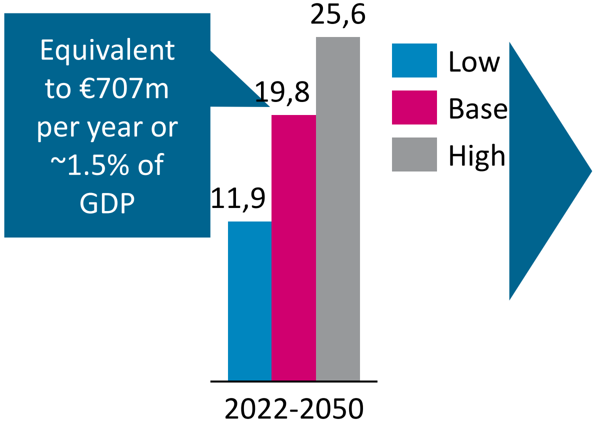
**Role of different end fuels**

- Fuel use is predominantly either hydrogen or ammonia, with a small amount of hydrogen-methane blending in earlier years to accommodate pilot studies, as well as some methanol used for powering ships
- Methanol for use in shipping and e-kerosene in aviation in material quantities from the 2030s[1]
- Hydrogen to synthetic methane using captured carbon does not appear in material quantities as it is deemed likely to be uneconomical given the Lithuania's ability to generate heating through biomethane and biomass[2]

Note: 1) the cost of capture and transport of CO2 required as feedstock is assumed to collocated close to demand and therefore be minimal in cost 2) Of the countries with hydrogen strategies, only Japan is seriously considering syngas from hydrogen and is doing so on the basis that heating largely relies on a gas distribution network which is not suitable for hydrogen, and which would require especially expensive and disruptive retrofitting given the prevailing geology and population density

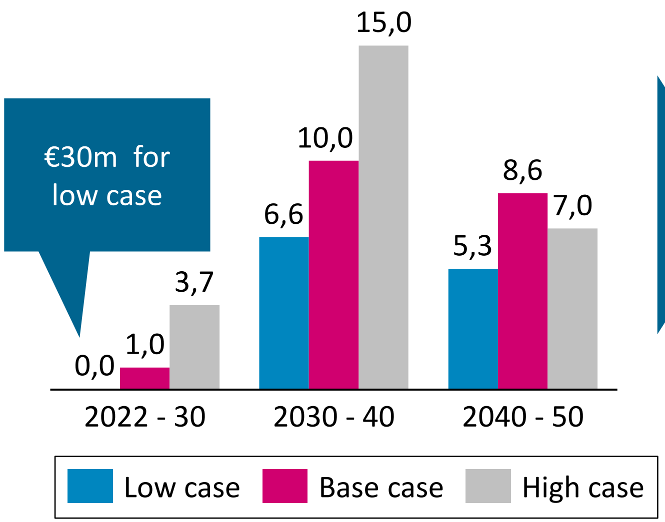
# Total investment required

## Investment required will increase significantly post 2030 once scale up is achieved (but will be achieved through carbon regulation by then)



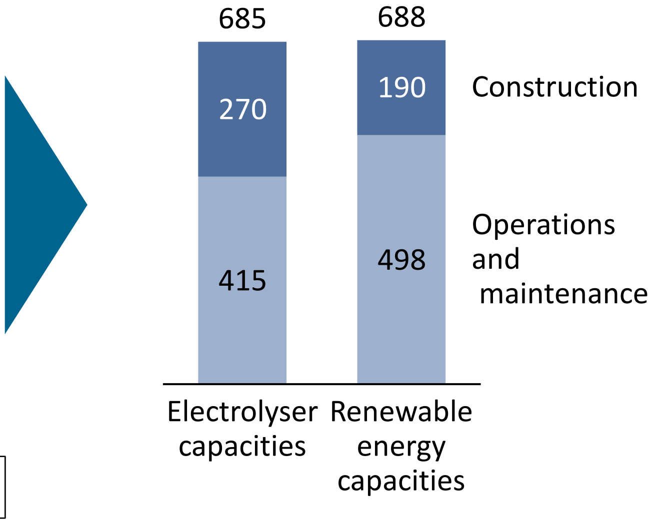
**Total capex investment – all scenarios**
€bn (real, 2022, undiscounted)

Equivalent to €707m per year or ~1.5% of GDP



**Capex required over time - all scenarios**
€bn (real, 2022, undiscounted)

€30m for low case



**Jobs created in the Base case scenario**
€bn (real, 2022, undiscounted)

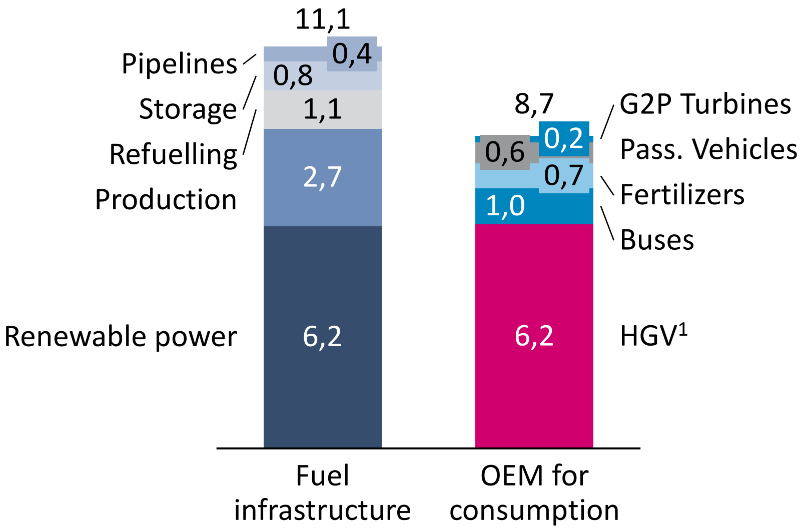
- In the High case investment concentrated in 2030-2040 period reflecting increased demand in those years versus the Base case. Base case investments are more spread out across the 2030-50 horizon
- Investment per unit of hydrogen decreases going from the Low case to the High case, reflecting lower capex costs being associated with higher demand
- In development of electrolysers and power generation, we estimate nearly 460 sustainable construction jobs and over 900 jobs in asset operation and maintenance based on socioeconomic studies of electrolyser projects in other countries and on the wind power industry[1]

Sourc:; 1) Global Wind Energy Council used for wind power assumptions. In estimating sustainable construction jobs we have assumed 2 years construction time for offshore wind and 1 year for electrolysers

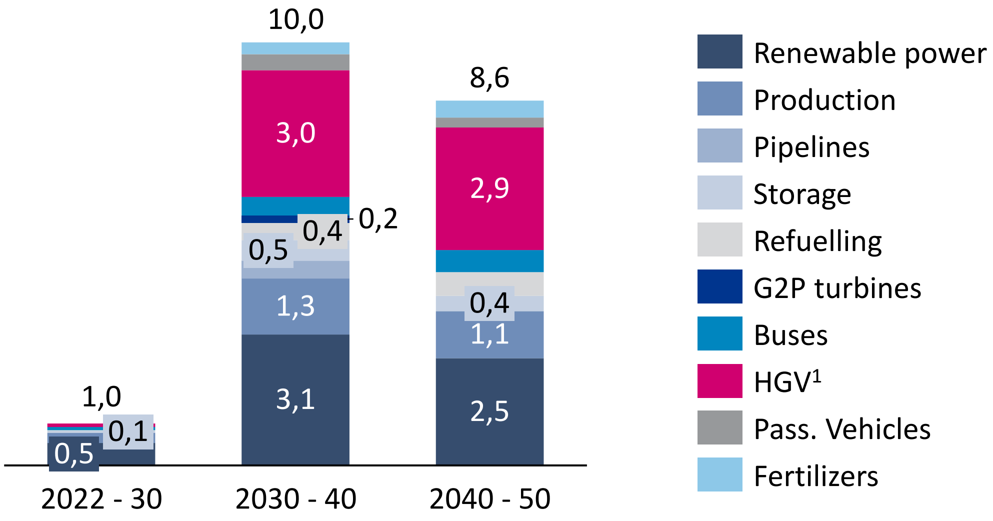
# Investment breakdown

## Investment is distributed across new renewables, electrolysers and storage infrastructure (excluding buses and plant retrofitting to accommodate H2)

**Total cumulative capex investment in the Base Case**
€bn (real, 2022, undiscounted)



**CAPEX across the value chain in the Base Case**
€bn (real, 2022, undiscounted)



- Over the longer time horizon to 2050, renewables, electrolyser and storage each represent a sizeable portion of investment, as total days storage requirements increase as the industry grows to include more use cases and electrolysers come to more exclusively rely on renewable power
- Investment requirements for storage are highly sensitive to the amount of above-ground short term storage required and may be rationalised down further as more storage is shifted from pressurized containers to ammonia storage
- To check our numbers, we have calculated that capex investment will cumulatively cost €3,8 / kg of hydrogen produced between now and 2050 in the Base case. This excludes non-fuel-related operation and maintenance costs associated with each value chain component shown, though these will generally make up a much smaller portion of costs in each case

Note: 1) HGV costs are estimated as the premium paid over diesel-fuelled vehicles and not the total cost of vehicle

# Emissions impact in the Base Case

## Hydrogen will enable 5,8 Mt of $CO_2$ by 2050

**Carbon intensity of fossil fuel displaced in each use case**

| | Use cases for hydrogen demand in Lithuania | Incumbent Fossil Fuel | Carbon Intensity (kg CO2/ kWh) |
|---|---|---|---|
| Feedstock | **Fertilizer production** | Grey $H_2$ | 0.24 |
| | **Oil refining** | Grey $H_2$ | 0.24 |
| Transport | **Buses** | Diesel / LPG | 0.23 |
| | **Heavier passenger vehicles** | Diesel | 0.23 |
| | **Heavy goods vehicles** | Diesel | 0.23 |
| | **Rail** | Diesel | 0.23 |
| | **Marine** | Fuel oil | 0.27 |
| | **Aviation** | Kerosene | 0.24 |
| Power | **Flexible power** | Nat. gas | 0.18 |
| Heat | **Building heat** | Nat. gas | 0.18 |
| | **Industrial process heat** | Nat. gas | 0.18 |

**Impact of the Base Case on emissions**

- In total 1,3 bcm (13 TWh) of natural gas and 1,3 mt of liquid fossil fuel consumption are displaced with hydrogen.
- This will result in 5,8 Mt of $CO_2$ abatement in 2050 and 385 kt of hydrogen demand in 2050, equivalent to 18% of 2019 energy demand (5,2 Mtoe).
- At CO2 price of €100/t average over 2022-50, approximately €7,2 bn is saved cumulatively due to avoided carbon cost net of investment in hydrogen

Source: BEIS, 2020 UK Greenhouse Gas Emissions Data Tables; IEA, Future of Hydrogen

# 4. Strategy, roadmap and implementation

## Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

# Pillars of hydrogen strategy

## We have structured the strategy module into 5 components which step from vision to action plan

| Long term vision | 2030 goals | Incentives + support | Infrastructure planning | Roadmap and action plan |
|---|---|---|---|---|
| • Set in context of decarbonisation targets<br>• Set in context of security of supply<br>• Establish a national infrastructure vision<br>• Define role of different production technologies | • Supply side targets for volume and capacity<br>• Demand side targets for individual use cases<br>• Commitments to support technologies | • Meaningful carbon pricing<br>• Sector specific mechanisms to create demand<br>• Investment support for clusters / valleys<br>• Innovation support for research and development | • Early support for production sites<br>• Power market design to accommodate hydrogen electrolysis role in providing flexibility<br>• Transmission and storage planning | • Safety and regulation<br>• Accountability<br>• Advisory boards |

Source: Adapted from ECT – Making the Hydrogen Economy Possible (2021)

# Recap of Lithuanian context

## Plenty of domestic demand capable of enabling renewable power, but with challenges storage

**Proven domestic demand in ammonia for fertilizers which is large in context of Lithuania's overall size; HGVs also present sizeable demand in next decade**

- Lithuania has a relatively large footprint in fertilizer manufacturing and heavy goods vehicles fuel demand for a country of its size. These can be the anchor use cases to provide scale in the next 10 - 15 years, driven by ambitious EU targets for green ammonia production (50% of all ammonia production by 2030) and the commercial readiness of hydrogen in HGVs, which will be cost competitive with diesel for HGVs later this decade. As a smaller country within the EU membership, Lithuania is arguably less suited to investing in less mature use cases in aviation and marine fuel, while it's ability to leverage biomass for heating needs means there is less pressure to develop hydrogen in for heating vs other countries more reliant on gas heating

**Electrolysers (power to gas) drives energy security agenda and enables ambitious renewables targets**

- Lithuania plans develop more renewable power to reduce reliance on natural gas and oil, with this need accentuated by the impact of Russia's invasion of Ukraine. There is also an abitious target for net zero power system by 2035. Consequently, there is a need for hydrogen to displace gas in the fertilizer, refining and power sectors, while also an opportunity for the production of hydrogen to lower the cost of wind and solar energy. As a result there is incentive for Lithuania to prioritise hydrogen from domestic renewable power over other forms of production

**Availability of domestic renewable power supply could be an issue in the long term**

- Supply of renewable electricity is more than adequate for 2030 demand in all our scenarios but limited onshore and offshore wind resourceand could impede the ability of domestic renewable power production to meet hydrogen production requirements by 2050. This can be mitigated by cooperation with other countries on either renewable power sourcing for electrolysers, LNG sourcing for blue hydrogen production, or importing hydrogen itself.

**Demand and feedstock supply clustered in different regions, which can each become hydrogen 'valleys'**

- Supply of electricity is likely to rely on wind, where resource is located in the north west of the country, while demand from fertilizer production means that hydrogen demand will initially be concentrated in Jonava near Kaunas. There is also a potential cluster of demand centred around oil refinery activity in the north, which could also serve heavy-duty-vehicle transport demand in Siauliai, Panevėžys and Klaipeda. This is broadly similar to other countries where industrial demand is centred on a small number of cluster locations

**Well connected networks can be leverages; storage options more limited but ammonia demand could be an enabler**

- Lithuania lacks the scale of proven geological storage potential of Germany, Denmark and Poland but may have a unique opportunity to use ammonia as a storage carrier given its outsized role in expected Lithuanian hydrogen demand. Like most EU countries it has a mature gas transmission network that will be required for natural gas in the 2020s and 2030s but can be repurposed to hydrogen over time. Hydrogen for heating will require costly distribution network retrofit but only post-2030 and likely on a small proprotion of the countries heating demand that cannot be easily electrified or switched to biomass

**Active R&D but requiring better links with industry needed to capture value chain**

- Lithuania has established R&D programs in hydrogen production technologies but has little track record of technology commercialisation and is not a currently a manufacturer of any components of the value chain. As a result, developing the ability to participate in manufacturing will require sustained investment in R&D and human capital over time focused in one or two key areas that fit with domestic infrastructure required. It is starting from behind countries such as Germany, Finland, Denmark and Sweden, who have already made big steps to capture part of the value chain through existing domestic manufacturing champions

# Long term vision for hydrogen in Lithuania

## Growth will enable energy independence and can anchor around proven ammonia demand and will form part of a Baltic hydrogen backbone by the 2040s

| | |
|---|---|
| Increasing energy independence | ▲ Low carbon hydrogen will be used to reduce Lithuania's dependence on oil and natural gas imports as part the National Energy Independence Strategy. Over time it will reduce reliance on natural gas used as feedtsock in fertilizer and refinery sectors, as as fuel for the power sector, and on liquid hydrocarbons in the transport sector. It could also assist in helping to provide heat for industrial process heating and building heat. |
| Prioritising hydrogen from domestic renewables | ▲ In order to support the goal of energy independence, Lithuania will prioritise domestic production of hydrogen using renewable electricity over hydrogen imported or produced from fossil fuels. This recognises that renewable electricity can reduce Lithuania's exposure to commodity price volatility and geopolitical risk while still allowing other forms of hydrogen to be developed if cost competitive. This will in turn support renewable power capture prices and helping to avoid curtailment of wind generation as renewables become the dominant source of electricity |
| Anchored around low-carbon ammonia and heavy duty vehicles as sources of demand | ▲ As hydrogen demand takes off, green ammonia used in an established fertilizer industry will be the 'anchor' use case that enables scale up of the industry in the 2020s, as well as providing a cost competitive long-term storage for green hydrogen, in doing so reducing the risk of requiring access to geological storage resource of other EU member states. Lithuania accommodates an outsized share of long-distance HGV transit for which hydrogen presents a realistic long-term solution to decarbonisation. As road transport becomes targeted by EU ETS regulation, a network of hydrogen refueling stations based on hydrogen or hydrogen-derived fuels and enabled by some locally based HGVs buses switching to hydrogen and scale up of hydrogen-powered buses is envisioned |
| Deployment in aviation and marine fuel, but over longer term | ▲ In the longer term aviation and marine fuel demand will increasingly require hydrogen or ammonia and e-kerosene derived from hydrogen. Synthetic natural gas derived from hydrogen for use in heating is not envisaged. While in the nearer term these will come under less regulatory pressure from the EU, in the 2030s and 2040s they will scale up considerably. |
| Baltic hydrogen highway for transport and import/export by 2040 | ▲ Hydrogen supply will be enabled by a gradual transformation of energy nework infrastructure. In the 2020s the existing electricity and natural gas network will be able to support pilots and early scale up of hydrogen while in the 2030s dedicated hydrogen pipelines will emerge to help locate production close to renewable electricity supply. This may operate in parallel to natural gas pipelines at first but could eventually replace it as the role of natrual gas will reduce in the 2040s as Lithuania's approaches Net Zero. This domestic network will be joined by the EU hydrogen backbone connecting the Baltic states by 2040, which will act to stabilise hydrogen pricing and promote cross-border trade of hydrogen in the Baltics |
| Capturing the value chain to create more jobs | ▲ The hydrogen economy is guaranteed to create sustainable construction and asset maintenance but the journey will also aim to capture upstream manufacturing components of the value chain. These will be built off of existing R&D capability in several hydrogen related technologies but also through international collaboration on pilot projects, with a sustained focus on building capability through partnership with countries already emerging as leaders in component manufacturing, as well as targeted funding for training that creates home grown human capital |

# 2030 goals

## 300 MW of production capacity by 2030 to serve 26 kt of demand

### ‘Concrete’ targets proposed

| | |
|---|---|
| Capacity and demand | Target 300 - 350 MW[1] of electrolyser production capacity (or equivalent through other technologies) by 2030 and 30 kt of low-carbon hydrogen production, representing approx. 1% of target 2030 EU capacity and 0.3% of production respectively<br>15% of domestic ammonia production enabled by low-carbon hydrogen<br>Hydrogen buses in place wherever they are the preferred zero emisisons solution in 5 major cities<br>Optional pilots: 1 pilot hydrogen train along a freight route<br>1% of HGV fuel demand served by hydrogen by 2030 |
| Transport and storage | ~2% of demand in seasonal storage by 2030, with preferred seasonal storage method to be determined<br>50 – 100 HGVs powered by hydrogen by mid-2020s and at least 5 refuelling stations in place to accommodate roll out of hydrogen across TEN-T network<br>Pilot tests on blending into the gas transmisision network |
| Regional and socioeconomic development | Establish first valley centred around fertilizer production with aim to serve 2030 targets, including involvement from R&D and academic institutes in Kaunas and Vilnius<br>Establish 1 – 2 other valleys strategically placed, most likely around Klaipeda, to optimise location of future supply and demand<br>1.2k sustainable jobs in construciton and asset maintenance created by 2030 |

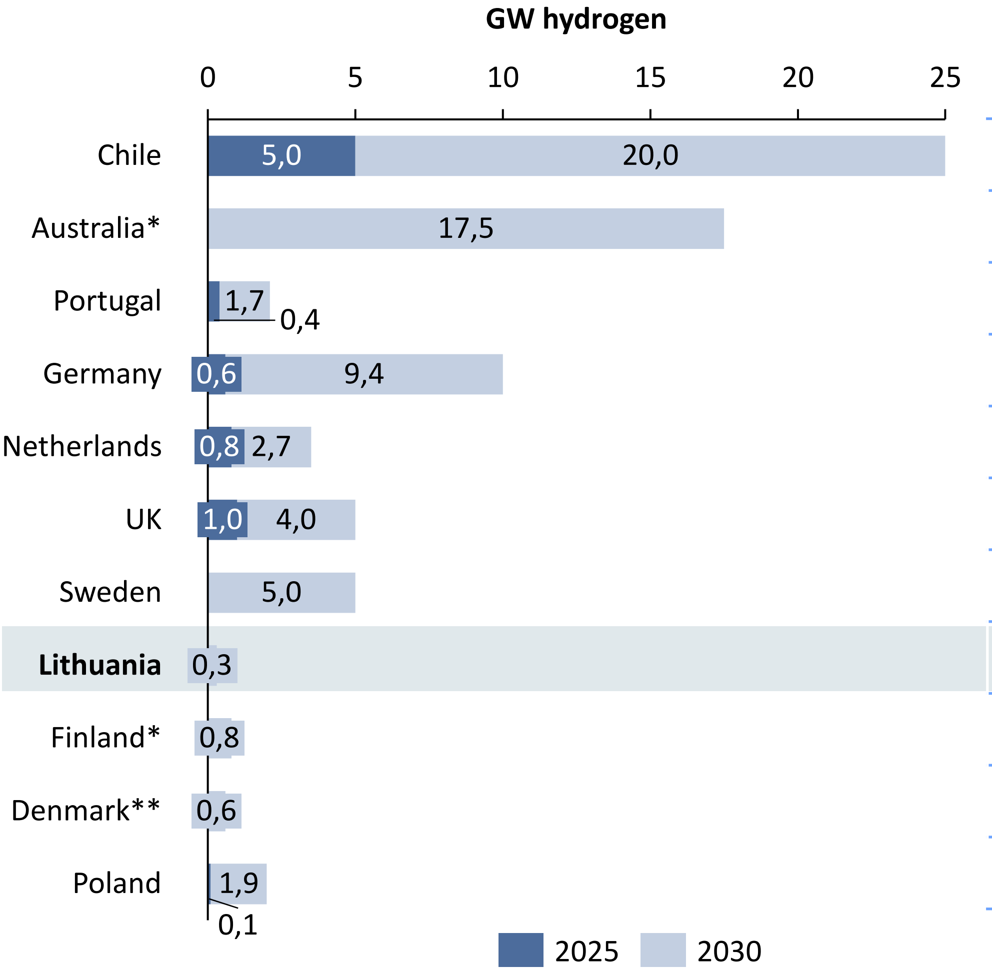
### ‘Softer’ targets proposed

| | |
|---|---|
| International collaboration | Establish MoUs with neighbouring EU member states on areas of collaboration to increase regional security of supply and coordinate on transmissions / storage / import / and export infrastructure |
| Human capital investment | Dedicated degree courses targeting both ‘hard-hat’ and ‘white-collar’ roles required in gas systems and renewable technologies<br>Incentives in place for bringing interanational talent with appropriate qualifications into Lithuania |
| Capturing value chain | Demonstrating value chain capture in at least one component of the value chain, particularly in supply and storage infrastructure where investment is heaviest |

Note: 1) Assumes an electrolyser load factor of approx. 35% which is based on assuming 57% of demand comes from onshore wind and 43% from offshore wind

# How ambitious are production targets versus peers?

## Targets are ambitious but appropriate to a country looking to serve proven demand through domestic production



| | MW Hydrogen / TWh energy demand |
|---|---|
| Chile | 138 |
| Australia* | 33 |
| Portugal | 22 |
| Germany | 9 |
| Netherlands | 14 |
| UK | 8 |
| Sweden | 43 |
| **Lithuania** | 21 |
| Finland* | 9 |
| Denmark** | 10 |
| Poland | 6 |

| | |
|---|---|
| **Self identified exporters** | *Countries with very cheap and very abundant renewable power* |
| **Self-identified importers** | *Countries with very high industrial demand and more limited renewable power resource* |
| **May be export or import** | *Countries with both industrial demand and good renewable resource and strong ambition* |
| **Lower ambition** | *Strong industrial demand but `markedly lower pace` of ambition vs other countries with strong industrial demand* |

Note: *Value is not a stated national ambition, but projections made by the EU and Deloitte for FI and AU respectively **High ambition
Source: National Hydrogen Strategies, IEA

# Suitability of mechanisms to use cases

## CfDs should be investigated by Government as a way to support roll out in industry and power demand; while mandates and surcharges can help scale up more decentralized transport demand

| Use case | Suitable market-based mechanisms for promoting hydrogen in priority use cases | | |
|---|---|---|---|
| **fertilizer** | CfDs on carbon price or ammonia prices to support domestic green ammonia production | Lifecycle emissions standards for fertilizers | |
| **Refining** | CfDs on carbon price to support green hydrogen blending in refineries and/or mandate of EU RFNBO targets in mix of refined fuels | | |
| **HGVs** | Implement fuel mix mandates to drive adoption of zero carbon fuels, combined with incentives for vehicle switching targeted at logistics | Fossil fuel taxes on heavy duty vehicles and/or surcharges | |
| **Buses** | Public procurement of ZLEVs in municipal and/or intercity bus fleets | | Ticket surcharges for passengers |
| **Power** | Dispatchable power agreements or capacity market auctions that specifically target low-carbon flexible technologies needed to reach 2035 net zero target | | |

■ More suitable □ Helpful but less effective

# System and network infrastructure planning

## We have identified several work packages required to better plan infrastructure requirements that could be conducted now

**Hydrogen vs biofuels**

- While the short term priority is to establish scale and capability in the hydrogen economy, the medium and long-term vision can become more clear over time on the role of hydrogen vs other sustainable renewable fuels. In particular the role of biogas in transport and power generation, and the role of biomass in heating will affect how much hydrogen is required
- **Action: Conduct deeper analysis into the long-term economic feasibility of using biofuels versus hydrogen in transport and heating sectors**

**Storage**

- Ammonia has been assumed as the primary long term storage solution in this analysis but it's relative benefit versus other options, as well as how it would work in practice should be examined more closely. Although ammonia storage is technologically proven, it comes with high health and safety risks versus geological storage. Equally, a full scale assessment of Lithuania's geological potential to store hydrogen has not yet been carried out
- **Action: Assess potential for geological storage in Lithuania and neighbouring countries and compare to the cost of storage via ammonia, including assessment of health and safety inmplications for large scale ammonia storage**

**Gas network transition**

- Our modelling suggests dedicated hydrogen gas pipeline transportation may be lower cost than locating electrolysers close to demand centres once demand grows to 50 – 100 kt p.a. This is based on general assumptions for the cost of gas pipeline storage vs electrical transmission infrastructure and a more detailed assessment that is specific to Lithuania and involves close collaboration with AmberGrid and Litgrid is required to determine both costs and at what point in time it makes sense to upgrade to a dedicated gas pipeline. This should account for the role of natural gas pipeline infrastructure and the possibility of fertilizer producers partially or wholely shifting production locations closer to the coastline. It will also reinforce the rationale for choosing the location of hydrogen valleys
- **Action: Assess cost-benefit of locating hydrogen production near renewables generation vs near demand in order to assist long-term network planning for Ambergrid, Litgrid, and the fertilizer and oil refining industry**

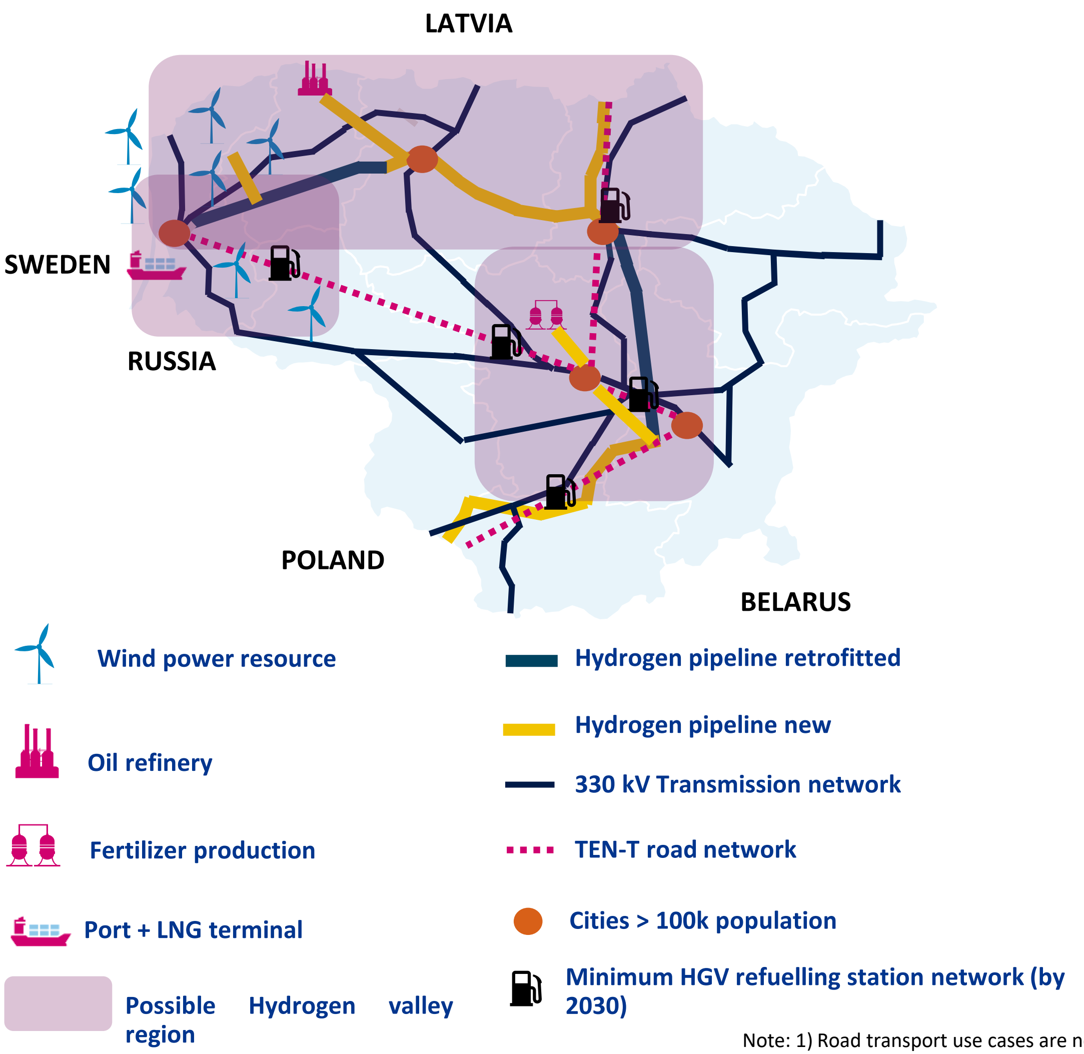
**Benchmarking against CCS**

- While energy independence is central to the strategy, the LNG port terminal in Klaipeda asserts a committment to accessing global gas market. This, in combination with the option to ship carbon to the North Sea should provide a benchmark against which the cost of green hydrogen can be assessed in making large infrastructure decisions and in assessing the value of importing renewable electricity if demand for hydrogen reaches levels where domestic renewable electricity production becomes more expensive
- **Action: Assess potential for blue hydrogen production using imported LNG and shipping of $CO_2$ to other states (e.g., Norway)**

# Hydrogen network infrastructure vision

## Hydrogen production biased towards north-east, with high potential demand in the Central Lithuania region connected via pipeline

**Stylised map of key hydrogen infrastructure for 2030 and 2040**



- **Demand prior to 2030 will be concentrated around the Kaunas area** and (subject to further validation beyond the scope of this study) can be served by locating production close to demand without significant upgrades to the electricity network. Consequently, a hydrogen valley centred on colocation of electrolyser production and demand could be create in the Kaunas-Vilnius region
- In parallel, **location of production closer to renewable energy supply may be preferred as hydrogen pipelines become more economic than electrical transmission** as a means of high-volume transport. This can be located along the existing gas pipeline network, except for a new pipeline route connecting the eastern part of the line with Kaunas via the fertilizer plant at Jonava. This new route may save cost by avoiding a much longer pipeline build via Vilnius, where no concentrated large-scale demand is envisioned[1]
- **A valley can also be created around the Klaipeda region** capable of eventually linking hydrogen supply in this region with hydrogen demand at any point along the pipeline. This valley may include the port of Klaipeda if import and export infrastructure are to be built in the longer term
- This valley could **optionally extend out to the Northern part of the country** where further demand will come from the refinery and the cities of Panevėžys and Šiauliai for transport use cases
- The **minimum initial refueling network for HGVs required to meet EU criteria of one station every 150 km requires 5 stations** situated along roads connecting the major cities and onward to Poland and Latvia. Additional refueling will be required for buses

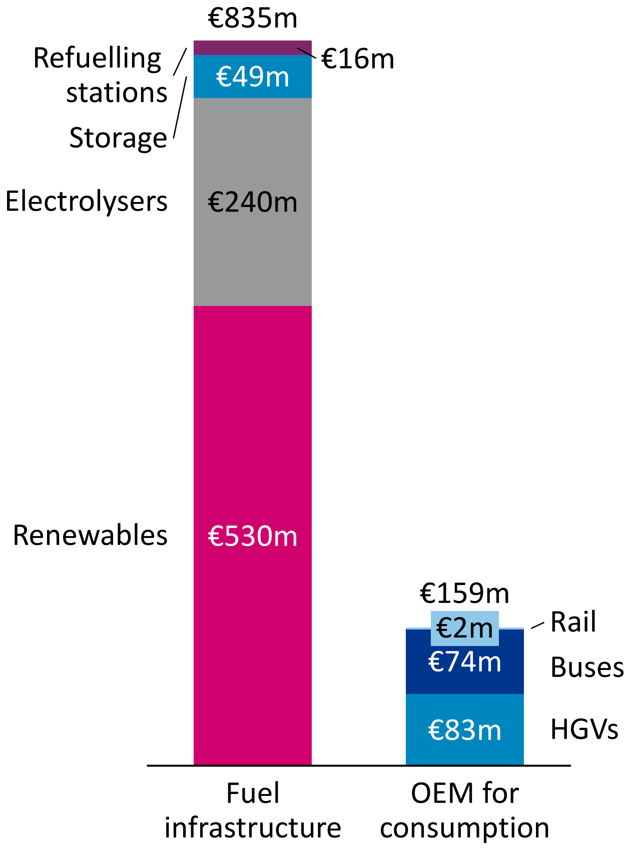
Note: 1) Road transport use cases are not considered large scale and can be served via a distribution network of refuelling trucks

Sources: Litgrid, LVEA, Ambergid

# Near term investment required

## Nearly €1bn will be required up to 2030 through a combination of public and private sector investment

2022-30 cumulative investment of **€994m** in the **Base Case**



**All will require a combination of public and private sector investment**

- Financial support for development can be administered at state level with different projects or cities competing for earlier prioritisation of funding, which is allocated in a sequenced manner. This sequenced approach has been adopted for allocating funding for industrial clusters in the UK and allows the first sequence of projects to teach and refine subsequent projects
- **Pilot projects** will require a significant portion of their capital cost funded through public support with those competing for funding allowed to present different business models and technologies
- **Scale-up** mechanisms and incentives such as mandates and CfDs then look to push more direct competition by establishing a business model (e.g., carbon CfDs or diesel fuel taxes) which project developers can compete within to provide hydrogen

**Individual items to consider funding (either via EU or domestic funding):**

- Pilot cases for HGVs and refueling stations
- Roll out of hydrogen buses in 5 largest cities
- Funding focused on R&D collaboration with industry
- CfD mechanisms for de-risking competitive investment in heavy industries such as fertilizer and refining
- Incentive mechanisms for vehicle switching in HGVs
- Establishment of hydrogen valleys and required network infrastructure and permitting to facilitate their growth

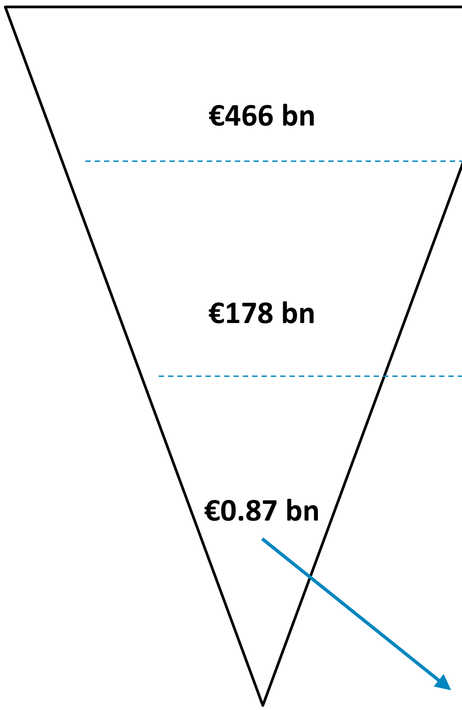
**These could be funded through several revenue raising mechanisms:**

- Fossil fuel taxes (supplier pays)
- Carbon taxes / carbon price premium on top of ETS (fossil fuel consumer pays)
- Electricity and gas end-user environmental levy (household / business pays)
- General taxation (individual pays)

# High level estimation of EU funding accessible by 2030

## While c.€1bn is required to deliver on 2030 base case, approximately €460m could be achieved through direct support, with a further €412m available through EIB loans

EU Funding:



Methodology:

**STEP 1**
- We have noted where explicit funding figures for energy have been disclosed within EU funding mechanisms and allocated pro-rata the fund size over 2022-30 period

**EU funding for Energy**

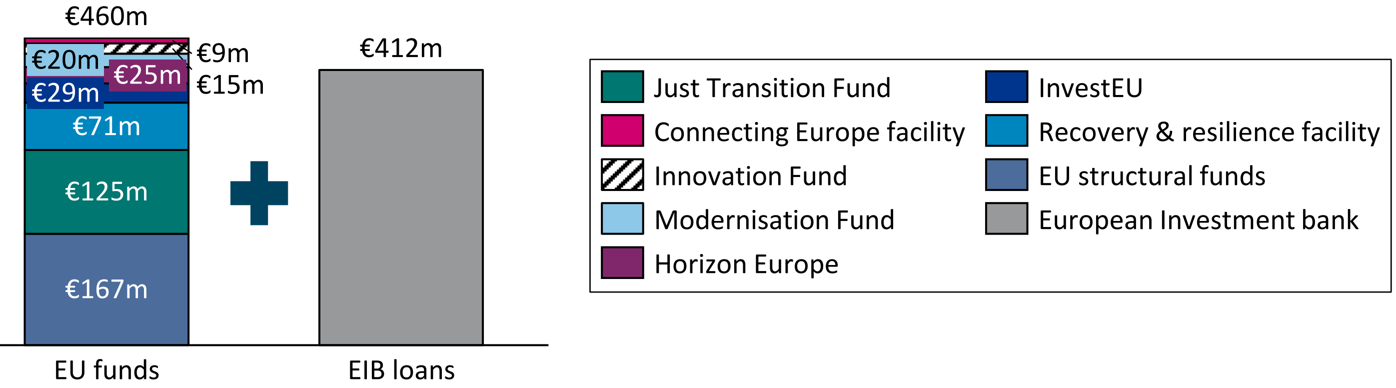
**STEP 2**
- We have noted where funding amounts are explicitly allocated for hydrogen
- Where hydrogen funding has not been explicit, we assume c.5% of funding goes towards hydrogen, using the Horizon Europe fund (where share of hydrogen is disclosed) as a proxy for share of hydrogen

**EU funding for Hydrogen & Hydrogen products**

**STEP 3**
- We have estimated Lithuania's fair share of funding using it's 0.3% share of the Recovery and Resilience fund as a proxy for other funds, except for the Modernization fund where Lithuania's share is 2.6%
- For the Just Transition Fund we have based our assumption on evidence from stakeholder feedback which identifies major fertilizer pilot as a key recipient of JTF money

**EU funding for Hydrogen in LIT**

**Lithuania + Hydrogen's fair share**



# A 14-point action for 2030

## We have identified 14 actions required to deliver the 2030 goals and log term ambition of our proposed strategy

| Action | | | Assumed responsible | Timeframe for completion | Time to complete |
|---|---|---|---|---|---|
| Mid 2020s targets | 1 | Take ownership of strategy and lead governance | Ministry of Energy | 2022 | < 1 year |
| | 2 | Develop a pilot use cases in HGVs that supports the minimum EU target for refueling network on TEN-T | Ministry of Energy | 2025-26 | 3 – 4 years |
| | 3 | Rollout of hydrogen buses across 5 largest cities | Ministry of Transport & Comms. | 2025-26 | 3 – 4 years |
| | 4 | Enable projects through establishment of clear health and safety regulation and environmental planning | Ministry of Environment | 2023-24 | 0.5 – 2 years |
| | 5 | Develop a pilot use case in rail | Ministry of Transport & Comms. | 2025-26 | 3 – 4 years |
| 2030 targets | 6 | Deliver scaled up project delivery in fertilizers and establish first hydrogen valley around fertilizer production | Ministry of Energy | 2028-30 | 3 – 4 years |
| | 7 | Begin testing hydrogen blending in the gas network | Ministry of Energy | 2028-30 | 3 – 4 years |
| | 8 | Prepare for market-based scale up | Ministry of Energy | 2028-30 | 3 – 4 years |
| | 9 | Invest in seasonal storage for hydrogen | Ministry of Energy | 2028-30 | 3 – 5 years |
| | 10 | Build capability and human capital in hydrogen | Ministry of Economy and Innovations | 2028-30 | 5 – 10 years |
| | 11 | Assess pilots for aviation and shipping deliverable by 2030 (but not earlier than late 2020s) | Ministry of Energy | 2030 | 3 – 4 years |
| Beyond 2030 | 12 | Establish a business model for low carbon flexibility in power system to deliver net zero power by 2035 | Ministry of Energy | 2030 | 1 – 3 years |
| | 13 | Long term planning for role of hydrogen in fuel mix | Ministry of Energy | 2030 | 0.5 – 2 years |
| | 14 | Long term planning for hydrogen transmission and storage | LitGrid / AmberGrid | 2030 | 0.5 – 2 years |

# 14 point action plan for 2030 (1 of 3)

## Points 1 – 5 focus on achieving some pilot projects and bus networks over the next 3 – 4 years

**We have developed a high-level action plan for delivery that considers 4 key modes of activity. We have considered these in the context of achieving some early goals for delivery by mid-2020s, 2030 horizon, and post-2030 and grouped according to 4 primary types of activity:**

● **Policy developments** required to establish market confidence and signal a market model that investors can prepare for
● **Anticipatory investments** required to establish capability and provide some of the supporting infrastructure for future investment
● **Long term planning** required to support physical infrastructure and regulatory decisions investment decisions that will be required as the transition to hydrogen continues
● **Regulation** required to support clarity on rules of market participation and promote open markets and competition

### Actions to achieve mid-2020s objectives

**1. Take ownership of strategy and lead governance**

- Establish governance body of public and private sector participants and associated governance framework for monitoring strategy delivery ●
- Finalize and socialise strategy and mobilize groups for delivery through Hydrogen Platform ●
- Agree on share of investment from public sector for development of different use cases ●
- Update long term strategy documents of Ambergrid and Litgrid●

**2. Develop a pilot use cases in HGVs that supports the minimum EU target for refueling network on TEN-T road network**

- Assemble an ecosystem / platform of participants among HGV OEMs, logistics providers, and fuel stations and integrate into Hydrogen Platform ●
- Scope projects, including locations and required public financial support ●
- Prepare bids for EU money eligible for pre-commercial / pilot projects ●

**3. Rollout of hydrogen buses across 5 largest cities**

- If required, expand scope of green procurement in public sector procurement to include transport services in order to promote transport use cases ●
- Provide financial / human capital support to cities to expedite feasibility assessment and action plan for hydrogen bus rollout ●
- Establish working group to assess synergies between bus projects in Vilnius, Kaunas, and Panevėžys with larger fertilizer project targeted for delivery by 2030 ●
- Prepare bids for EU money eligible for commercial-ready projects ●
- Once projects are in flight establish a working group to share knowledge across city projects ●

**4. Enable projects through establishment of clear health and safety regulation and environmental planning**

- Conduct full review of health and safety regulation and legislation required in production and supply, transport and storage and end-use-point ●
- Embed hydrogen electrolyser water consumption into long term water management plans ●
- Establish certification of low-carbon hydrogen, adopting emerging wider standards or establishing a basis for differing from wider standards ●

**5. Develop a pilot use case in rail**

- Identify target route, required private sector partners and required public financial support ●
- Prepare bids for EU money eligible for pre-commercial / pilot projects ●

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# 14 point action plan for 2030 (2 of 3)

## Points 6 – 11 focus on scaling up road transport and fertilizer use cases and investing in storage infrastructure and human capital for 2030

### Actions to achieve 2030 objectives

**6. Deliver scaled-up project for green ammonia in fertilizers and establish first hydrogen valleys around region of fertilizer production**

- Assist major fertilizer players in preparing for Just Transition Fund mechanism ●
- Establish location of first hydrogen valley and facilitate planning certainty and other levers aimed at providing certainty or lowering development costs ●
- Assess potential to integrated fertilizer projects with bus and rail use cases in order to benefit from economy of scale delivered by fertilizer demand ●

**7. Testing hydrogen blending in the gas network**

- Assuming hydrogen will have some role, establish hydrogen blending pilots with the primary aim to identify cost of introducing hydrogen to current gas distribution network ●
- From results develop a long-term heat strategy that is clear on role of biofuels vs heat pumps vs hydrogen ●

**8. Enable market-based scale up of transport, fertilizer and oil refinery use cases**

- Assess potential to integrated fertilizer projects with bus and rail use cases in order to benefit from economy of scale delivered by fertilizer demand ●
- Incorporate EU targets for zero emissions HGVs into National Climate and Energy Plan (NECP) and into law to create mandate for hydrogen HGV pilots ●
- Decide on whether revenue raising mechanisms are feasible e.g., whether fossil fuel taxes could be used to provide subsidies or incentives to vehicle switching ●
- Develop primary mechanism (e.g., carbon CfD) for supporting investment in low carbon solutions for industries regulated under ETS ●
- Develop a mechanism / business model for how electrolysers will contract with renewable power assets such that cost of hydrogen is minimized while providing value to power system ●
- Decide on extent to which blue hydrogen can be facilitated / encouraged for the refinery sector ●

**9. Invest in seasonal storage for hydrogen**

- Assess potential for geological storage and storage via ammonia to determine lowest cost long-duration (i.e. seasonal) storage solution ●
- Integrate delivery of first seasonal storage with timeline for scale up of fertilizer demand in hydrogen valleys ●

**10. Build capability and human capital in hydrogen**

- Develop a coherent strategy for hydrogen-related R&D that integrates current research programs, existing LNG capabilities, targeting value chain participation in manufacturing ●
- Direct bids for EU money aimed at R&D into developing projects near commercialization where industrial partners may be brought in ●
- Assess role of valleys and target participants beyond electrolyser projects, as well as what incentives will be applied to these special economic zones ●
- Invest in R&D and industry collaborations with other member states specifically focused on hydrogen ●
- Establish education pathways aimed at specialization in energy decarbonisation in low carbon gas and liquid fuels ●
- Integrate value chain participation into pilot and scale up projects ●
- Establish incentives within hydrogen valleys for value chain participation ●

**11. Assess pilots for aviation and shipping deliverable by 2030 (but not earlier than late 2020s)**

- Pilot scheme for hydrogen-derived sustainable aviation fuel ●
- Pilot scheme for hydrogen-derived fuels in shipping ●

● **Policy developments**
● **Anticipatory investments**
● **Long term planning**
● **Regulation**

# 14 point action plan for 2030 (3 of 3)

## Points 12 - 14 focus on physical infrastructure planning for beyond 2030 and preparing regulation for a more mature market

### Actions to prepare for after 2030

**12. Establish a business model for low carbon flexibility in power system to deliver net zero power by 2035**

- Establish working group for delivery and validate role of H2P in achieving net zero power by 2035 to provide go-no-go decision on pilot ●
- If go, establish location, business model and required support, ideally co-locating with other target projects in a hydrogen valley ●
- Prepare bids for EU money eligible for pre-commercial / pilot projects ●
- Include support for other forms of low-carbon flexible power in addition to pumped storage in NECP and agree what market mechanisms will be used for decarbonizing flexible power ●

**13. Further system feasibility assessments which inform longer-term decision points**

- Detail feasibility study of Klaipėda port area for the development of hydrogen import/export infrastructure ●
- Analysis of long-term economic feasibility of using biofuels versus hydrogen in transport and heating sectors ●
- Assess long-term role of blue hydrogen production using imported LNG and shipping of CO2 ●
- Engage neighbouring states to collaborate in analysis of potential for further renewable development outside Lithuanian waters to appraise opportunity to export hydrogen via renewables development in the Baltic Sea ●
- Assess long-term role of hydrogen in contributing to state liquid fuel reserves ●
- Develop a framework for hydrogen gas markets in anticipation of a hydrogen gas network with 3rd party access emerging in 2030s ●

**14. Further network feasiblity assessments whih inform long-term decision points**

- Assessment of forms of long-term storage (e.g., geological storage, LOHC) for hydrogen in Lithuania and neighbouring countries, comparing to the cost of storage via ammonia, including assessment of health and safety implications for large scale ammonia storage ●
- Assess potential zones for future hydrogen valleys close to renewable power supply and gas transmission network and accounting for electric network constraints ●
- Cost-benefit analysis of locating hydrogen production near renewables generation vs near demand in order to assist long-term network planning for Ambergrid, Litgrid, and heavy industry ●

● **Policy developments**
● **Anticipatory investments**
● **Long term planning**
● **Regulation**

# Action plan: next 6 - 12 months

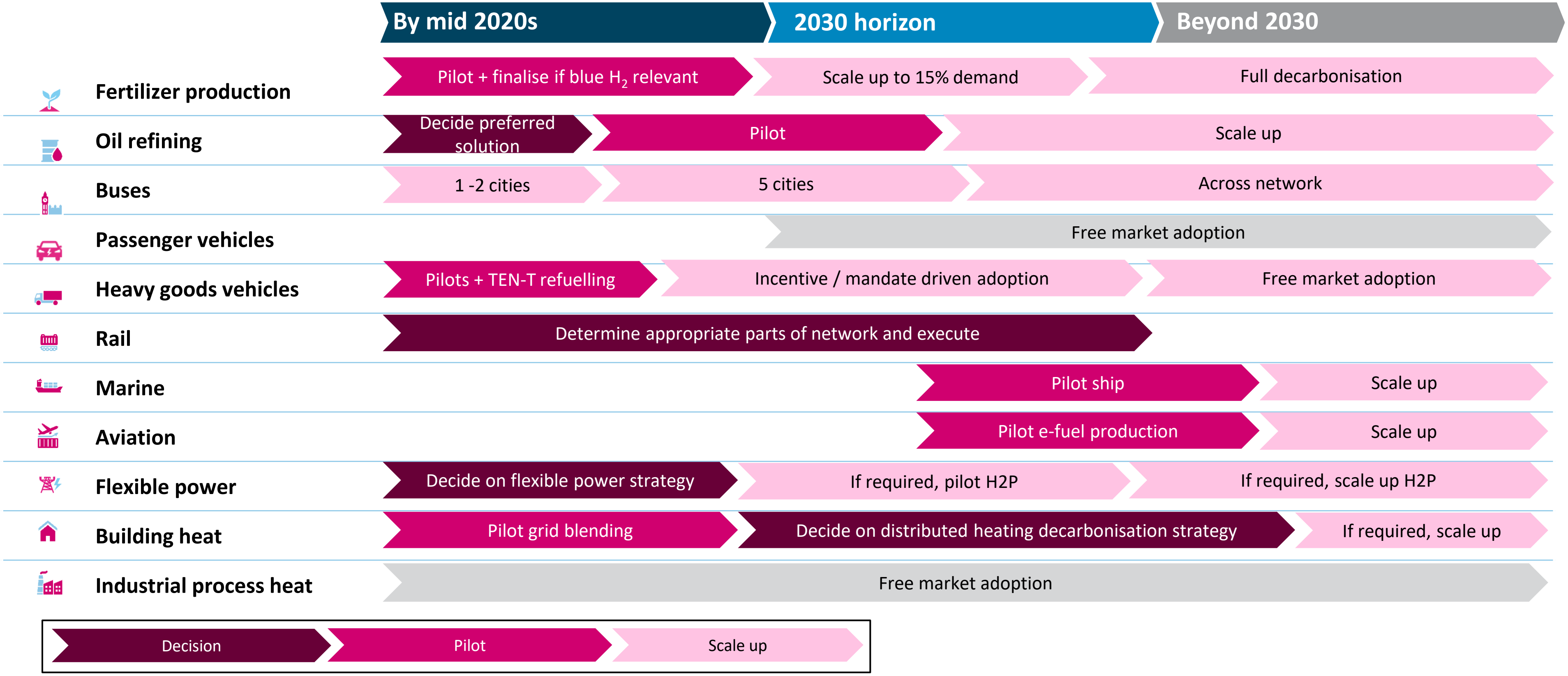
## We have outlined immediate activities to mobilize the strategy

- Agree and legislate for levels of state funding and target levels of EU funding to apply for ●●
- Assemble a taskforce targeting bid preparation for EU money, including responsibility for identifying the key value-add components that could be added to bids e.g., international collaboration, value chain integration, and innovation ●
- Begin seeking MoUs with European partners that are emerging as leaders in value chain participation (e.g., Germany, Scandinavia) with intent to share technology and capability know-how through those agreements ●
- Establish a public-private taskforce to develop the vision and location for the first hydrogen valley ●
- Establish taskforce to develop health and safety regulation across hydrogen value chain ●
- Establish policy group to decide on the market-based mechanisms (CfDs, taxes, etc) used to promote scale up of hydrogen demand in industry and transport in the second half of the decade ●
- Establish a policy group to decide on the market-based mechanism used to allow hydrogen electrolysers to contract with renewable power, in doing so liaising with the relevant European Commission group currently developing the EU definition of green hydrogen. This should be integrated with for low carbon flexible power that helps to meet Lithuania’s 2035 Net Zero target. This could be a sub-committee of the Hydrogen Platform ●
- Develop a coherent strategy for hydrogen-related R&D that integrates current research programs, existing LNG capabilities, and defines specific outcomes for value chain participation, enabled by R&D, by 2030 ●
- Begin to assess potential for geological storage and storage via ammonia to determine lowest cost long-duration (i.e. seasonal) storage solution ●

● **Policy developments**
● **Anticipatory investments**
● **Long term planning**
● **Regulation**

# Key deliverables on use cases

## A high level roadmap for enabling use cases focuses on developing pilots first before scaling up, with some key decision points happening in the near term and the long term



| | By mid 2020s | 2030 horizon | Beyond 2030 |
|---|---|---|---|
| **Fertilizer production** | Pilot + finalise if blue $H_2$ relevant | Scale up to 15% demand | Full decarbonisation |
| **Oil refining** | Decide preferred solution | Pilot | Scale up |
| **Buses** | 1 -2 cities | 5 cities | Across network |
| **Passenger vehicles** | | Free market adoption | |
| **Heavy goods vehicles** | Pilots + TEN-T refuelling | Incentive / mandate driven adoption | Free market adoption |
| **Rail** | Determine appropriate parts of network and execute | | |
| **Marine** | | Pilot ship | Scale up |
| **Aviation** | | Pilot e-fuel production | Scale up |
| **Flexible power** | Decide on flexible power strategy | If required, pilot H2P | If required, scale up H2P |
| **Building heat** | Pilot grid blending | Decide on distributed heating decarbonisation strategy | If required, scale up |
| **Industrial process heat** | Free market adoption | | |

Decision | Pilot | Scale up

- There are decisions required on which technologies should provide low carbon flexible power and which solutions (green or blue) are preferred for the fertilizer and oil refining sector
- Full scale bus programs across cities can be developed as soon as possible
- Grid blending can be piloted but a decision on role of hydrogen in natural gas network is be required in the longer term
- **A 5-yearly strategy review should be in place to review progress to date and appropriate forward ambition in context of EU market and targets**

# Key deliverables on infrastructure

## The high level roadmap for infrastructure focuses on enabling pilots and investing in soft infrastructure in the near term

| | by mid 2020s | 2030 horizon | 2030 - 2050 |
|---|---|---|---|
| **Renewables** | | Strategy update + action plan for enabling further renewables<br>Development of 700 MW of renewables to power electrolysers | Development of equivalent of further 2,9 – 8,3 GW[1] to power electrolysers |
| **Hydrogen production** | < 50 MW production | 300 MW production by 2030 | 2,1 – 5,8 GW of electrolysers |
| **Transport and storage** | Pilot distribution and refueling via HGVs and bus projects: using 5 stations on TEN-T network<br>Validate dominant long-term storage carriers: ammonia vs geological storage | Expanded distribution and refueling via HGVs and buses, expanding coverage of TEN-T network<br>Invest in long term storage infrastructure | First dedicated hydrogen pipeline as demand reaches 100s kt p.a<br>Baltic hydrogen backbone<br>Market-led expansion of refueling infrastructure |
| **Soft infrastructure** | Establish first hydrogen valleys near demand centre (for most of 2030 targets)<br>Educational pathways to build human capital in low carbon gas and liquid fuels | Establish future hydrogen valleys near supply centres (e.g., Klaipeda)<br>Demonstrable value chain participation beyond construction and asset maintenance | |
| **Cumulative Investment[2] :** | €1,0bn | | €19,8bn |

Note: 1) Based on gap between renewable power available and power required for High case where all production is through electrolysers and power is from offshore wind 2) Excludes private investment in vehicles

# Annex 1: Review of other countries

Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

This section has been provided in a separate document for brevity

# Individual countries assessed

## The market appraisal focuses on 10 countries with published hydrogen strategies that covers neighbouring countries, other EU member states , and some non-EU countries

- As part of review we have analysed following countries, which includes two non-European countries:

| | COUNTRY | AMBITION LEVEL | WHY WE HAVE INCLUDED IT IN THE STUDY |
|---|---|---|---|
| 1 | **Chile** | Net Exporter | Exporting potential with a hydrogen strategy draft, growing economy |
| 2 | **Denmark** | Net Exporter | Hydrogen strategy, one of global leaders in renewable energy production. |
| 3 | **Finland** | Net Exporter | Hydrogen strategy draft available, well interconnected with Baltics |
| 4 | **Germany** | Net Importer | Hydrogen strategy, one of global leaders in renewable energy production. |
| 5 | **Poland** | Net Importer | BEMIP country with a hydrogen strategy draft, well interconnected with Lithuania. |
| 6 | **Australia** | Net Exporter | Exporting potential with a hydrogen strategy draft, extensive gas role |
| 7 | **Sweden** | Net Importer | Developed hydrogen strategy, actively develops industrial use cases |
| 8 | **UK** | Net Exporter | A north European country with a hydrogen strategy, gas trading hub, LNG. |
| 9 | **Netherlands** | Net Importer | A medium sized EU country with a developed hydrogen strategy, gas trading hub. |
| 10 | **Portugal** | Net Importer | A medium sized EU country with a developed hydrogen strategy. |

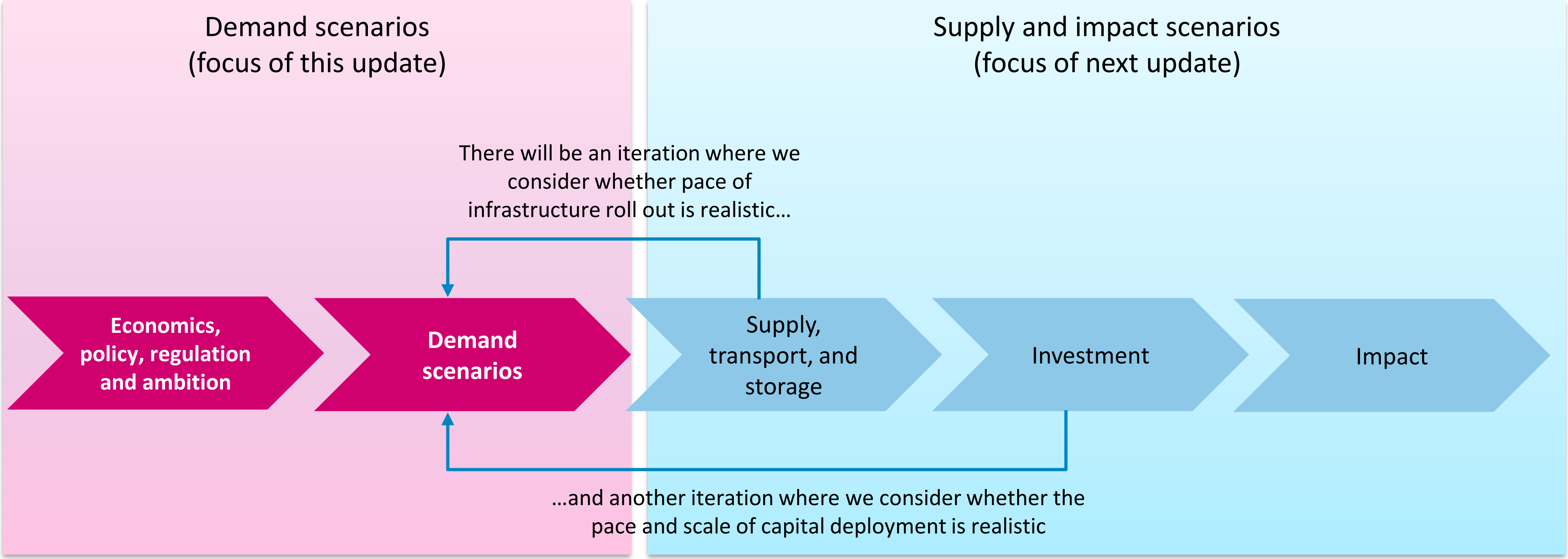
- This analysis is used as an input to identify lead practices that are available to Lithuania, and should be addressed in the hydrogen development roadmap

# Annex 2: Hydrogen demand modelling assumptions

## Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

# Approach to modelling

We consider demand first based on economics, policy and ambition and the infrastructure, but our assessment of infrastructure will help refine the final demand picture



Demand scenarios
(focus of this update)

Supply and impact scenarios
(focus of next update)

There will be an iteration where we consider whether pace of infrastructure roll out is realistic…

**Economics, policy, regulation and ambition**

**Demand scenarios**

Supply, transport, and storage

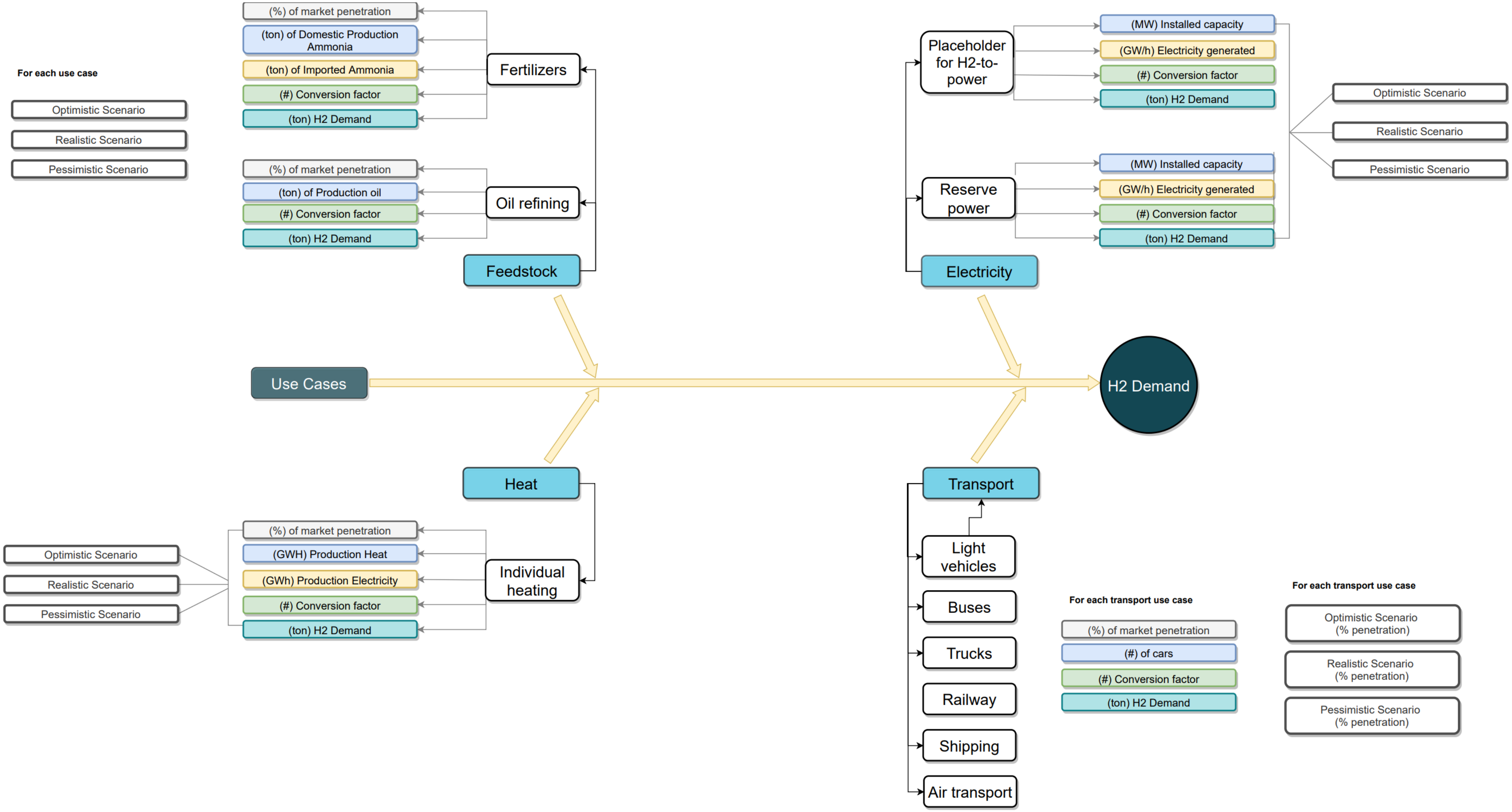
Investment

Impact

…and another iteration where we consider whether the pace and scale of capital deployment is realistic

# Approach to demand modelling

## Demand-side logic: penetration of hydrogen in key use cases to arrive at quantities of hydrogen necessary



**For each use case**

Optimistic Scenario
Realistic Scenario
Pessimistic Scenario

Fertilizers
- (%) of market penetration
- (ton) of Domestic Production Ammonia
- (ton) of Imported Ammonia
- (#) Conversion factor
- (ton) H2 Demand

Oil refining
- (%) of market penetration
- (ton) of Production oil
- (#) Conversion factor
- (ton) H2 Demand

Feedstock

Placeholder for H2-to-power
- (MW) Installed capacity
- (GW/h) Electricity generated
- (#) Conversion factor
- (ton) H2 Demand

Reserve power
- (MW) Installed capacity
- (GW/h) Electricity generated
- (#) Conversion factor
- (ton) H2 Demand

Optimistic Scenario
Realistic Scenario
Pessimistic Scenario

Electricity

Use Cases

H2 Demand

Heat

Individual heating
- (%) of market penetration
- (GWH) Production Heat
- (GWh) Production Electricity
- (#) Conversion factor
- (ton) H2 Demand

Optimistic Scenario
Realistic Scenario
Pessimistic Scenario

Transport
- Light vehicles
- Buses
- Trucks
- Railway
- Shipping
- Air transport

**For each transport use case**

(%) of market penetration
(#) of cars
(#) Conversion factor
(ton) H2 Demand

**For each transport use case**

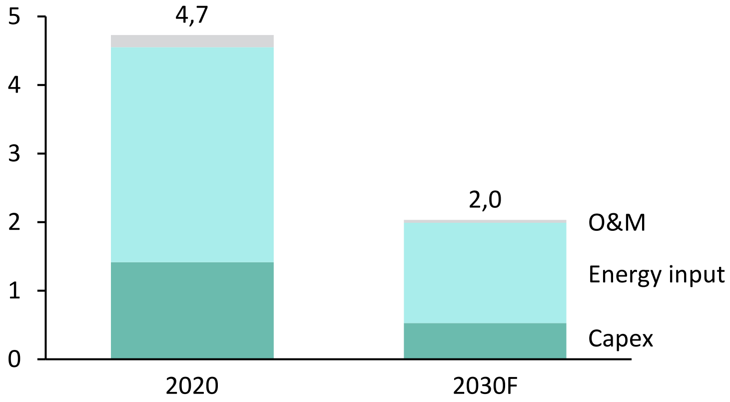
Optimistic Scenario (% penetration)
Realistic Scenario (% penetration)
Pessimistic Scenario (% penetration)

# Assumptions for the cost of hydrogen

## Lithuania is likely to experience a cost of hydrogen similar to the rest of Europe and that this cost will decline significantly this decade

**Green hydrogen production costs should fall and become competitive with grey and blue in the 2030s, although Europe will pay more than the average**

**2020 vs 2030 projected global average green hydrogen production costs*** (€ / kg)

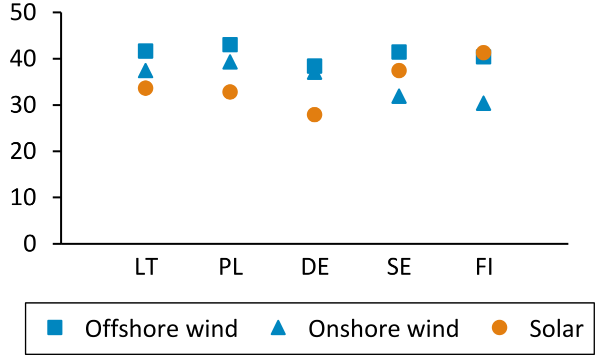


**Drivers of cost reduction in producing hydrogen**

- Learning rates on electrolyser technology are expected to fall as they did when renewables and abtteries were scaled up over the 2010-20 period
- Further falls in cost of renewable energy and focus on procuring from sources with cheaper renewables epected to bring cost of energy input down considerably

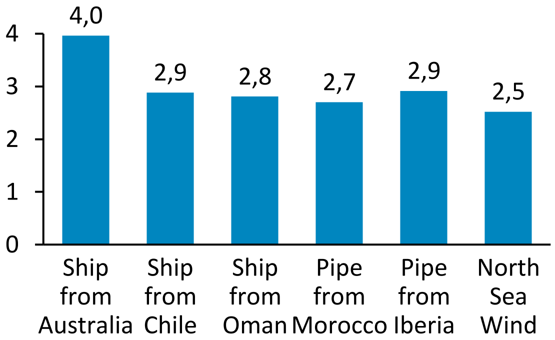
**Lithuania should be able to produce or import hydrogen at prices close to average EU price**

**2030 projected levelized cost of renewable technology for Lithuania vs neighbours** (€ / MWh)



Lithuania comparable to neighbours in cost of renewable electricity…

**2030-35 estimated import costs to Belgium from exporters** (€ / MWh)



…and the threat of imports should keep downward pressure on cost of production in Northern Europe

Note: *Assumes USD/EUR FX rate of 1.13
Source: Hydrogen Council 2021 Hydrogen Insights, Hydrogen Import Coalition, Baringa

# Fertilizer production

## Small defined steps until 2030, then the goal for full conversion to green hydrogen

### Context and rationale for scenario assumptions

- There is c.200 kt hydrogen demand for ammonia production assuming the largest fertilizer producer's two ammonia plants are working at full capacity
- There is also c.180 kt of ammonia imported into Lithuania[2] equivalent to c.10 kt of hydrogen, primarily for minor fertilizer producers , who do not produce their own ammonia and currently import or buy from major fertilizer producer
- Fertilizer stakeholders predict overall hydrogen demand will be stable, but the product mix derived from hydrogen up to 2050 is less certain, for example synthetic fuels could be used if fertilizer demand drops
- 15% of local production conversion to green hydrogen (30% of one of the two methane reformers) is planned as part of the Just Transition Plan measures by 2030. This is equivalent to ~130 MW electrolyser working 24/7 and coupled indirectly with local wind power resources
- Conversion step sizes are roughly 15%; 30%; 50%; 100% of total production. Anything above 15-30% would require major electricity network upgrades as well as major upgrades to ammonia production facilities. If gas use is ceased altogether, additional electric capacities would be needed for production. Appraisal of other markets does not suggest any convergence around targets and timelines for greening ammonia
- Producers have not shared a view of the economics of conversion, but global cost benchmarking suggest a carbon price of over €100 / t and hydrogen price of < €2.5 kg will be required to ensure the switch is cost-neutral, suggesting **full conversion is unlikely to happen before 2030 but could happen before 2040**

### Scenario assumptions

- **Low**:
  - 0% conversion by 2030 if JPT funds are delayed and/or electrolyser production capacities insufficient
  - 50% conversion by 2050: one of the two ammonia facilities
- **Base**
  - 15% conversion by 2030 (as per current plan from major fertilizer producer)
  - 100% conversion by 2050 ("straight line" 2030-2050)
- **High**
  - 50% conversion by 2030 as per EU regulations FitFor55 proposed target for industrial use of hydrogen
  - 100% conversion by 2040 instead of 2050 (accelerated)

Note: 1) 2011-2020 average) 2) 2015-2019 average
Sources: interviews with stakeholders, World Integrated Trade Solution (WITS)

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# Oil refining

## Refinery will be guided by carbon pricing and total hydrogen demand is uncertain

### Context and rationale for scenario assumptions

- Hydrogen consumption in refineries is not well reported and depends on the mix of products refined and the extent to which hydrogen is recycled during refining versus being sourced externally
- The only report of Lithuania’s hydrogen consumption (and by default refinery consumption) is 54 kt per annum. This has been validated with refinery stakeholders.
- We have benchmarked this by assessing hydrogen input versus oil output across several other European countries and found that hydrogen demand per unit of crude oil refined varies widely:
  - the most intensive (Denmark) hydrogen users use c. 40% of what Lithuanian refinery is reported to use…
  - …while the least intensive (Poland) use over twice as much hydrogen per unit of crude oil
- As a result, **the estimate reported for refineries (which could not be verified with stakeholders) has a wide range of error** which we acknowledge in our scenarios
- In addition to this there is uncertainty over the long-term competitiveness of the refinery, as domestic fuel consumption for transport will decrease over time and the refinery is not located close to the coast
- Feedback from stakeholders suggests that although feasibility assessments are underway for decarbonisation, the **pace will follow ETS regulation** and therefore, as with fertilizers, **full-scale decarbonisation is unlikely prior to 2030** if we assume carbon prices will not far exceed €100 / t this decade and green hydrogen production is €2.5 - 3 / kg
- However, if carbon prices increase significantly, **and if there is some mechanism to lock in carbon pricing (e.g., via a carbon CfD), then decarbonisation could occur rapidly** as there is no major refurbishment of the refinery required provided the hydrogen input is the same quality

### Scenario assumptions

- **Low**:
  - 0% conversion by 2030 if carbon prices are low and no government or EU support is provided
  - 0% demand for any hydrogen by 2050 assuming the refinery is no longer active
- **Base**
  - 5% conversion by 2035 with only pilot projects by 2030
  - 100% conversion by 2050 (step changes at 30% and 70% representing major plant investment)
- **High**
  - 30% conversion by 2030 and assuming high carbon prices, mechanisms to de-risk carbon price volatility
  - 100% conversion by 2040 (step changes at 30% and 70% representing major plant investment)

Note: *Assumes USD/EUR FX rate of 1.13
Source: Fuel Cell Hydrogen Observatory

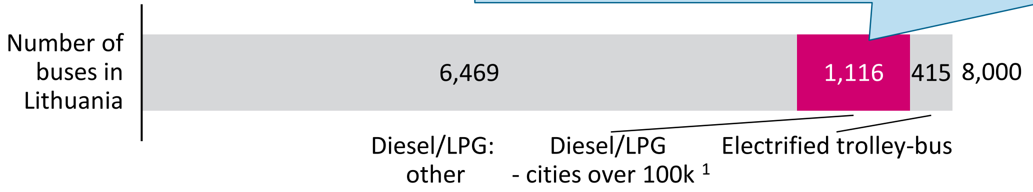
# Buses

## Bus demand will face competition from batteries and biogas but should receive roll out in larger cities

### Context and rationale for scenario assumptions

- According to law, **zero emissions vehicles should make up at least 15% of total vehicles in Lithuania by 2030**, moving to 90% by 2050
- Preliminary transport plan is to focus on Vilnius, Kaunas, Panevėžys, Klaipėda – including newly developed hydrogen filling stations, and with the option to make those accessible for other heavy transport as well
- **Market share of hydrogen vs other solutions**: Stakeholder feedback suggests at least 10% of all "zero emissions" buses purchases could be powered by hydrogen. But it is not a definitive plan as for now
  - Technically hydrogen can be blended with natural gas and biomethane using combustion engines up to 30% without changing vehicle drivetrain
  - Competitiveness versus batteries can depend on location and individual routes, with batteries more suited to flat terrain and milder temperatures
- **Planned activity:** €20 million is earmarked for production of hydrogen (18-24 MW electrolyser) to be potentially used in transport, with additional financing potentially available through the Modernization fund

Focus on this segment between now and 2030, but share of hydrogen vs batteries and methane will probably be 10 – 50%



### Scenario assumptions

- **Low**:
  - 0% conversion by 2030
  - 10% conversion of top 5 cities municipality-owned buses by 2030
- **Base**
  - Roll out is in top 5 cities by 2030, with 25% market share of hydrogen vs other technology options
  - 50% conversion by 2050 ("straight line" 2030-2050)
- **High**
  - 50% conversion of top 5 cities municipality-owned buses by 2030
  - 80% conversion of all bus fleet by 2050

Note: 1) Vilnius, Kaunas, Panevėžys, Siauliai, Klaipeda

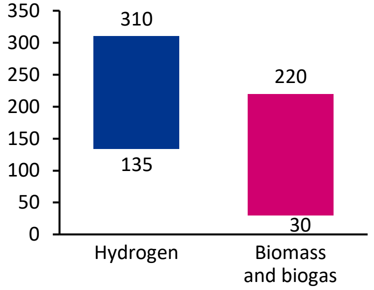
Sources: interviews with stakeholders, Department of Statistics, Regitra, public transport company annual reports

# Hydrogen to power

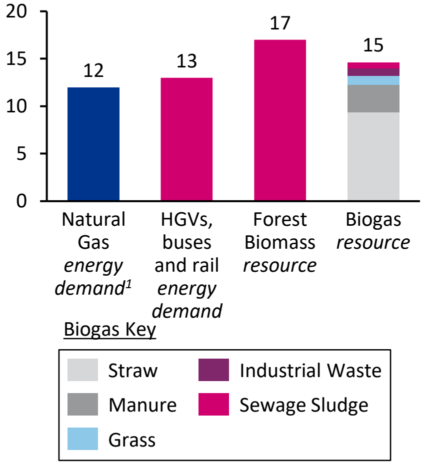
## The extent to which hydrogen is used in the power sector will depend on the availability of low cost bioenergy

### Context and rationale for scenario assumptions

**LCOE of power generation by fuel type** (€ /MWh)



**Biomass resource potential against gas demand (TWh)**



- In the near-term, biomass will likely be more economically competitive than hydrogen, assuming hydrogen is € 2- 4 /kg
- The cost of bioenergy however varies significantly with feedstock type, the cheapest alternatives being agricultural and wood waste
- Lithuania's total biomass resource exceeds current gas demand across power and heat, however this is the maximum resource potential
- Available resource will be reduced after a narrowing to more economically favourable feedstocks, which can also be dependent on supply chain and sustainability constraints. A detailed assessment of available resource has not been assessed here
- The influence of constraints on biomass availability can be significant - biomass manure from cows is only economical for larger farm sizes, and only 3% of cattle are on farms with over 100 cows
- The availability of biomass for new power may be further reduced by a competition for resources, as there is expectation that biofuel will be needed to decarbonise transport use cases

### Scenario assumptions

**Low**:

- 0% hydrogen to power

**Base**

- 0% hydrogen to power by 2030
- By 2035 40% of natural gas demand in the power system equivalent to one 260 MW hydrogen CCGT turbine running at 50% capacity factor) is served by hydrogen, while remaining majority is served by more batteries or biogas

**High**

- All future natural gas demand in the power system is served by hydrogen by 2035 due to bioenergy availability constraints (most likely as a result of prioritizing biomethane for transport and heating)

Source: IRENA 'Cost Power Projections 2020', EIA, LEI 'Biogas Upgrading, a Lithuanian Perspective', Energy Strategy Journal 'Forest Bioenergy feedstock in Lithuania'; LitGrid RAIDA 2050 Scenario Building

# Shipping

## Hydrogen derived fuels for shipping will largely occur post 2030 but will have a higher share than other low carbon solutions

### Context and rationale for scenario assumptions

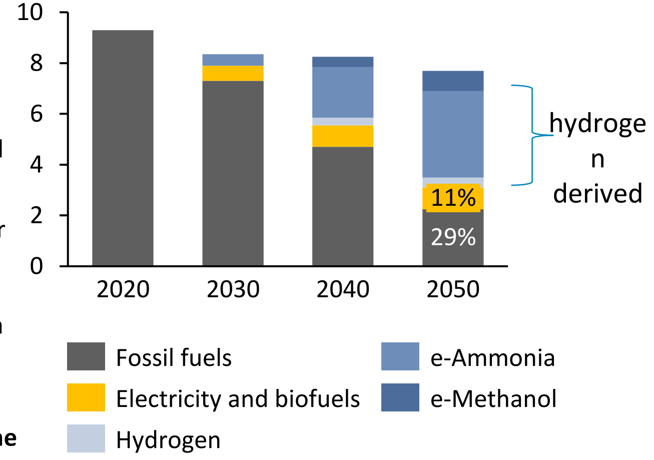
**Pace of decarbonisation in shipping will be slow in the near term**

- Shipping decarbonisation relies on international collaboration, and thus the type and rate of low carbon fuels adopted are expected to follow wider EU trends and policy
- The 2021 EU Directive for maritime calls for stringent limits on the carbon intensity of vessels beyond 2025, with expectation of scale up in 2035-45, and therefore acts as a guideline for the pace of renewable adoption

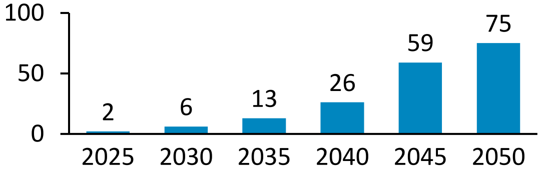
**Hydrogen derived fuels should account for the largest portion of fuel demand in the long term**

- Immediate emission reduction targets are expected to be met through efficiency measures; short term targets aided by the introduction of advanced biofuels; and medium to long term targets achieved through hydrogen-based fuels

**IRENA projected shipping energy demand under 1.5$^o$C Scenario, by energy source (EJ )**



**GHG reduction under EU Directive against 2020 reference (gCO2/MJ)**



### Scenario assumptions

- **Low**:
  - 0% by 2030
  - 40% of shipping form hydrogen derived fuels by 2050, reflecting slower decarbonisation
- **Base**
  - 1 demonstration project
  - 60% of shipping form hydrogen derived fuels by 2050, of which 80% s ammonia (aligned with IRENA)
- **High**
  - 6% in fuel mix by 2030
  - 90% of shipping form hydrogen derived fuels by 2050 (of which 80% s ammonia)

- Hydrogen strategies in western Europe with shipping targets aim for 4 - 6% hydrogen in the fuel mix by 2030. Over 100 pilots for zero emissions ships are in progress or completed, over half of which are connected to European states
- Ammonia is expected to form the backbone of shipping decarbonization; favoured over methanol by 4.5 to 1
- The projected ratio of ammonia to methanol is sensitive to the availability of carbon as a methanol feedstock. It is therefore dependent on the adoption of technologies such as BECCS and CCUS

Note: *Assumes USD/EUR FX rate of 1.13
Source: 2021 EU Directive, IRENA, Global Maritime Forum

# Process heat (1 of 2)

## Hydrogen may be required to deliver high temperature process heat, but will likely not be adopted at scale before 2030

### Context and rationale for scenario assumptions

- The temperature of process heat required varies with industrial application e.g., heavy industry activities such as cement production need heat at temperatures 10 times greater than in the production of paper or pulp
- There are more renewable heating alternatives that are able to generate low grade heat, and thus **greater competition for hydrogen fuel in low grade heat**

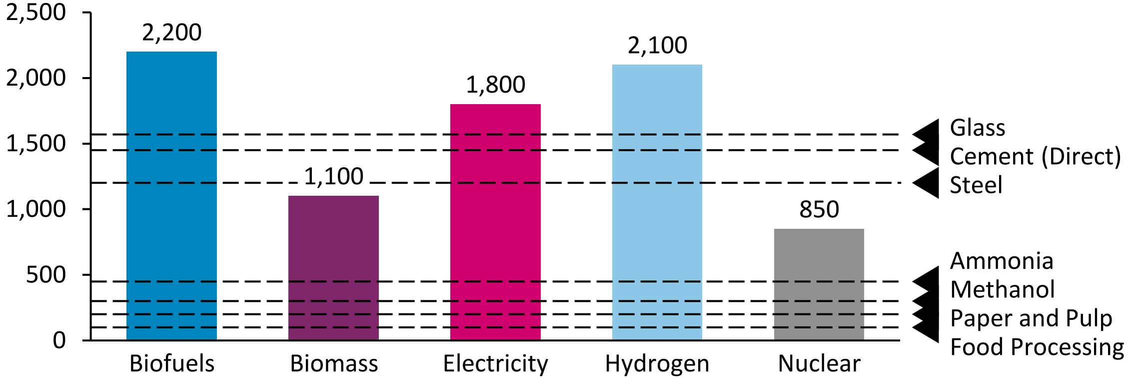
**Low temperature process heat**

- Lithuania has reduced natural gas consumption in favour of biomass and electricity as a low grade heat source
- **Low grade heat accounts for 55% of total process heat demand in Lithuania**, covering industries such as food and beverage, textiles, paper and pulp, and wood processing

**High temperature process heat**

- In the near term **natural gas is likely to continue to serve industries** that require high temperature process heat
- When considering alternatives for high grade heat production, the temperature they can reach and whether they deliver direct (which requires combustion of a fuel) or indirect (which can be delivered by electric resistors) heat must be understood
- Cement production at **Akmenės Cementas** requires high temperature direct heat and is therefore a **potential use case for hydrogen in the long term**, with only CCS providing a viable alternative
- Selection of high grade heat alternatives on an economic basis requires case-by-case consideration, as high level cost **estimates show significant overlap in cost range**
- **Decarbonisation of industrial process heat with hydrogen will not occur at scale prior to 2030 due to the large cost of switching away from natural gas**

**Temperature requirement of selected industries, and temperature generated by low carbon alternatives**



**Cost comparison of low carbon process heat options (€/GJ)**

| Alternative | Heat Cost Minimum (€/GJ) | Heat Cost Maximum (€/GJ) |
|---|---|---|
| Hydrogen SMR (90% CCUS) | 13 | 16 |
| Renewable hydrogen[1] | 16 | 25 |
| Biomass | 13 | 26 |
| Advanced nuclear | 8 | 12 |
| Electric (35 - 75 €/MWh) | 10 | 22 |

Note: 1) €2 – 3 / kg

Source: Centre of Global Energy Policy

# Process heat (2 of 2)

## Scenario assumptions

**Low**: No adoption of hydrogen in process heat, reflecting preference for CCS in provision of high grade heat

**Base**

–0% of Process Heat energy demand by 2030, with biomass continuing to be adopted for low-grade heat

–10% of Process Heat energy demand by 2050, reflecting adoption of hydrogen in industries which require high grade process heat, such as cement

**High**

–45% of Process Heat energy demand by 2050, equivalent to the amount of natural gas used for process heat in cement and chemical in Lithuania today, and assuming no use of CCS or decline in underlying demand for heat in these sectors

# Heavy goods vehicles (1 of 2)

**Context and rationale for scenario assumptions**

| Truck journey category | Candidate technologies | Assumed share of hydrogen | % of road freight t km in Lithuania | % of road freight HGV t km in EU27 | Assumed dominant weight class |
|---|---|---|---|---|---|
| > 500 km | Hydrogen / biofuels | 70 - 100% | 81% | 42% | > 16 t |
| 150 – 500 km | Hydrogen / biofuels / batteries | 25 – 75% | 15% | 37% | (mixed) |
| < 150 km | Batteries | 0% | 4% | 21% | < 16 t |

**Hydrogen's long-term share of HGV demand[1]**

- Long term, a realistic share of hydrogen demand would equate to trucks with the heaviest payload and longest distances, where batteries are unlikely to be economical
- C.80% of road freight in Lithuania is international, either loading or unloading in Lithuania or transiting through. However only c.10% is loaded or unloaded outside the EU, implying **HGV fuel demand in Lithuania will be heavily influenced by the pace of decarbonisation of fleet in the larger EU area.**
- As with distances travelled, Lithuania is has a much higher share of heavier weight class transport, with 85% of road freight classed as 15.6 t or higher (vs c.60% for EU as a whole), indicating use of heavier weight classes correlates with longer travel distances.
- Refuelling station requirements are assessed in the supply-side modelling assumptions annex

**Pace of introduction of zero-emissions vehicles in the EU**

- Regulation (EU) 2019/1242 requires the average CO2 emissions of **new lorries** from heavier HDV categories be reduced by 15% in 2025 and by 30% in 2030, with a penalty of over €4k / t $CO_2$ for non-compliance. In addition to this, requirements for 2,6% RFNBO fuel on road transport by 2030 under EU Fit for 55 will likely fall largely on HGVs as passenger vehicles are more suited to batteries
- Approx. **two thirds of HGV emissions** are regulated but they represent the **heaviest vehicle weight categories** which dominate long haul and where hydrogen is expected to provide the long-term solution
- To promote scale up of zero-emission technologies there is a **zero emissions vehicle (ZEV) benchmark of 2% of new vehicles sold by 2025**, with no benchmark set yet for 2030
- Heavy truck (> 16t) sales in EU totalled 240k in 2021 and c, 265k in 2019 pre-COVID. On this basis the benchmark implies a minimum of **c.5k ZEV trucks sold per year by 2025 across the EU**
- Beyond 2025 **more ambitious member states (NL, DK) are targeting up to 5 – 15% of HGVs being hydrogen by 2030**, though these states will higher vehicle replacement rates than Lithuania, where HGV vehicle age is well above EU average. The EU overall envisages 60k trucks by 2030 (1% of total fleet) with trucks becoming cost competitive by 2027 if hydrogen can be delivered at €6/kg at pump

Note: All figures are based on 2019 statistics for freight transport and are based on t km freight

Source: ACEA (Vehicles in Europe), European Commission (presentation)(press), Eurostat

# Heavy goods vehicles (2 of 2)

Scenario assumptions

**Low**:

–0,2% HGV demand by 2030, reflecting low ambition for ZEVs in EU regulation and reliance on low emissions vehicles to reach targets

–Hydrogen has 60% of HGV share by 2050

**Base**

–Pilot scheme of 50 - 100 trucks by 2025 (1% of expected EU fleet) in order to provide some scale for TEN-T refuelling stations

–1% of all goods vehicles energy demand by 2030 (0,35% of road transport, c.0.3% all transport demand), reflecting large share of international freight in demand but more tempered ambition than NL and DK, acknowledging much freight goes east rather than to EU and vehicle replacement rate is slower

–Hydrogen has 75% share of Lithuania's HGV t km by 2050 (aligned with assumed share of hydrogen across journey distances and long distance freight's higher than average share of total freight in Lithuania

**High**

–5% of HGV energy demand by 2030, assuming broader pace picks up among other EU states, aligns with ambition of Fit for 55 package target of 2,6% RFNBO by 2030

–90% of HGV energy demand is hydrogen by 2050, reflecting higher share of hydrogen in ZEVs

Source: ACEA (Vehicles in Europe), European Commission (presentation)(press), Eurostat

# Rail

## Electrification is a priority, hydrogen potential is in closing the gap to full decarbonization

### Context and rationale for scenario assumptions

**Lithuania:**

- 9%  electrified tracks, 40% by 2024.
- Plans to purchase 40-50 electric locomotives by 2025 and 26 electric trains in place of diesel-powered units.
- Current projections are 75% of freight and around 66% of passengers being carried by electrified railways in 2024.
- Currently pre-feasibility study performed to assess hydrogen-powered train pilot, potentially on the Kaunas-Warsaw route, to be operation until 2030.
- No significant hydrogen demand is expected until all electrification plans are done in full (until 2030, possibly earlier). Following that, hydrogen could potentially be used for remaining sections: maneuvering in ports and cargo stations, parts of passenger network, parts of cargo routes, including access branch to oil refinery.
- Given hydrogen supply in place, hydrogen-powered trains due to relatively lower CAPEX (and relatively higher OPEX) might be used for less utilized railway sections.

**Elsewhere in Europe**:

- German national railway operator plans to achieve climate neutrality until 2040 – already 60% electrified. UK and France to achieve climate neutrality until 2050.
- Germany was the first to use hydrogen fuel cell trains made by ,,Alstom” for public transportation and 41 more expected in 2022. UK also has a contract for 10 such trains in 2022.
- France, Italy, Sweden, Austria had successful trials as well. Poland is also considering hydrogen as replacement for its freight diesel locomotives.

### Scenario assumptions

100% - fossil fuel use in particular year.

- **Low**:
  - 0% until 2030
  - 10% until 2050  (in case further electrification, reduced rail demand, or improvement of competing technologies)
- **Base**
  - 0,5% until 2030 (pilot project implemented)
  - 50% until 2050
- **High**
  - 0,5% until 2030 (pilot project implemented)
  - 100% until 2050

Sources: LitRail  reports and strategy 2030, press releases.,

# Air travel / freight

## No significant use until 2035, then large degree of uncertainty

### Context and rationale for scenario assumptions

- Main carriers are Ryanair, Wizz Air, and Air Baltic (66% of all passengers transported). Wizzair is the only one to comment publicly that conversion to hydrogen-derived fuels could be done not earlier than 2035 after next plane-lease period ends and technology is available and economically feasible.
- Aviation as a sector to reach zero emissions until 2050 by implementing sustainable aviation fuels (biofuels from waste, residues, non-food crops and also e-fuels from renewable electricity and $CO_2$ sourced from direct air capture).
- EU level - a European Commission proposal for a regulation on ensuring a level playing field for sustainable air transport, if adopted, would mandate the following shares of

| | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| Sustainable fuels, % | 2% | 5% | 20% | 32% | 38% | 63% |
| Out of which synthetic aviation fuels, % | - | 0,7% | 5% | 8% | 11% | 28% |

- Finland targets 30% share of biofuels by 2035. Sweden targets 5% aviation fuel to be renewable in 2025; domestic flights to be fossil free by 2030; all flights to be fossil free by 2045 (likely a mix of bio and hydrogen derived fuels).
- Denmark's government has announced a goal to make domestic flights fossil fuel-free by 2030. Copenhagen Airport intends to have 30% of jet fuel by 2030 to be non-fossil fuels (most likely e-kerosene).
- Germany would like to use 0.5% of the 10 million tons used by the German aviation industry each year to be e-kerosene by 2026, with that rising to 2% or 200,000 tons by 2030.

### Scenario assumptions

Conversion to hydrogen derived fuels.

- **Low**:
  - 0% in 2030
  - 15% in 2050 (half of proposal for regulation)
- **Base** (as per EU proposal for regulation):
  - 0,7% in 2030
  - 28% in 2050
- **High:**
  - 2% conversion for 2030 (Germany as inspiration)
  - 56% conversion by 2050 (2x proposal for regulation)

Sources: European Commission, Reuters, Fossil-Free Air Transport 2045 project (Sweden), Hydrogen Central, flight carrier websites

# Building heating

## Conversion to heat pumps most likely, $H_2$ usage unlikely to extend beyond blending

### Context and rationale for scenario assumptions

- Hydrogen boilers are likely to become commercially available in 2025 and blending 20% hydrogen and 80% gas potentially technically possible (with 5% limit set by EU Gas Package for cross-border transmission) without requiring a complete piped network overhaul. In addition to this, several European countries intend to blend hydrogen into their gas network system this decade
- However, there is a consensus forming that heat pumps are a more economic option for delivering building heat in most cases, even where electricity prices are high. Use of synthetic natural gas derived from hydrogen is being considered in Japan where retrofitting the gas distribution network is particularly expensive due to more challenging geology and higher urbanization. It is not currently being considered in Europe
- EU current regulations regarding gas boilers are under preparation but it is likely that from 2025 or later there will be a requirement for hydrogen blending with natural gas which could be set as high as 20%
- According to IEA suggestions, fossil fuel boilers should no longer be sold from year 2025 unless they are compatible with hydrogen. Lithuanian National Energy and Climate Plan outlines an aspiration to 50k domestic boilers to fossil free heat production sources (mostly heat pumps) by year 2030, however these include biomass fuel

### Scenario assumptions

- **Low** (full switch to heat pumps):
  - 0% in 2030
  - 0% in 2050
- **Base:**
  - 0,2% $H_2$ blending in 2030 (0% boilers converted to hydrogen)
  - 20% of natural gas demand supplied to home-boilers converted to hydrogen in 2050
- **High**:
  - 0,2% $H_2$ blending in 2030 (0% boilers converted to hydrogen)
  - 60% of all boilers converted to hydrogen by 2050

Sources: IAE, NECP, European Commission, European Consumer Organization, press releases

# Annex 3: Hydrogen infrastructure modelling assumptions

## Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

# Approach to supply modelling

## We consider demand first, based on economics, policy and ambition, but our assessment of infrastructure will help refine the final demand picture

**Production**

- Electrolyser capex and efficiency
- Blue hydrogen capex and capture rate
- Levelized cost of renewable power
- Renewable generation capex and load factor

**Transport**

- Technology readiness level and levelized cost
- Transmission system route
- New pipeline and pipeline retrofit capex
- Powerline capex

**Storage**

- Long and short term storage demand
- Technology readiness level and levelized cost
- Pressurized container, ammonia, and salt cavern capex
- Import/ export fuel levelized cost

**Distribution and consumption**

- Truck and refueling station capex, capacity and utilization rate
- New pipeline and pipeline retrofit capex
- Hydrogen boiler capex
- Hydrogen turbine capex

**Investment and impact**

- Jobs/ unit capex
- GVA/ unit capex
- Emissions abated

# Viable methods of production

## Electrolyser production and methane reformation with CCS are the current commercially proven pathways to make low carbon hydrogen

| Feedstock | Production process | Relevant for near term / reason for exclusion | Cost competitive? | CCS required? | Technology ready? | Sustainable? |
|---|---|---|---|---|---|---|
| Water splitting | Electrolysis | Relevant for near term deployment (‘green’ hydrogen) | ✓ | - | ✓ | ✓ |
| | Nuclear thermochemical | Lab scale with tech breakthroughs required | ? | - | ✗ | ✓ |
| | Solar-chemical | Lab scale with tech breakthroughs required | ? | - | ✗ | ✓ |
| Natural gas reforming | Steam reforming (SMR) | Relevant for near term deployment as ‘blue’ hydrogen | ✓ | ✓ | ✓ | ✓ |
| | Autothermal (ATR) | | ✓ | ✓ | ✓ | ✓ |
| | Partial oxidation | | ✓ | ✓ | ✓ | ✓ |
| | Chemical looping | Lab scale, no major industry investment | ? | ✓ | ✗ | ✓ |
| | Pyrolysis | Lab scale only to date | ? | - | ✗ | ✓ |
| Other hydro-carbons | Partial oxidation | Interim solution for refineries only | ✓ | ✓ | ✓ | ✗ |
| | Coal gasification | Less efficient and more carbon intensive than SMR | ✗ | ✓ | ✓ | ✓ |
| Biofuels | Biomass pyrolysis | More expensive, mainly relevant for negative emissions during latter stages of reaching net zero | ✗ | ✓ | ✓ | ✗ |
| | Biomass gasification | | ✗ | ✓ | ✓ | ✗ |
| | Biochemical reforming | | ✗ | - | ✓ | ✗ |
| | Biomethane reforming | | ✗ | ✓ | ✓ | ✗ |

Source: ETC – Making the Hydrogen Economy Possible (2021)

# Production assumptions in model

## We have assumed production in Lithuania is exclusively through electrolysis in our modelling

### Technology choice assumptions

- We assume in all scenarios that **green hydrogen from electrolysers represents all hydrogen production** for the following reasons:
  - Blue hydrogen requires CCS and Lithuania does not have proven geological storage sites for CCS that it wishes to exploit. The Ministry of Energy has clarified that storage of $CO_2$ on Lithuanian soil is against current government policy
  - Blue hydrogen is less competitive in the long runs versus green hydrogen
  - Blue hydrogen does not play into Lithuania's ambition to become more energy independent through deployment of renewables
  - The most obvious choice for CCS location facilitating blue hydrogen in Lithuania is near the refinery, where both refinery emissions and cement emissions only have CCS as a decarbonisation pathway. In the case of both the refinery and the nearby cement plant, the timeline for decarbonisation is post-2030, by which time blue hydrogen will no longer be competitive with green

### Cost of green hydrogen assumptions

**Electrolyser Capex assumptions (€ / kW)**

| Scenario | High capex case (corresponds to Low demand case) | Base case | Low capex case (corresponds to High demand case) |
|---|---|---|---|
| 2020 | 1496 | 1050 | 736 |
| 2030 | 1116 | 723 | 487 |
| 2050 | 736 | 511 | 202 |

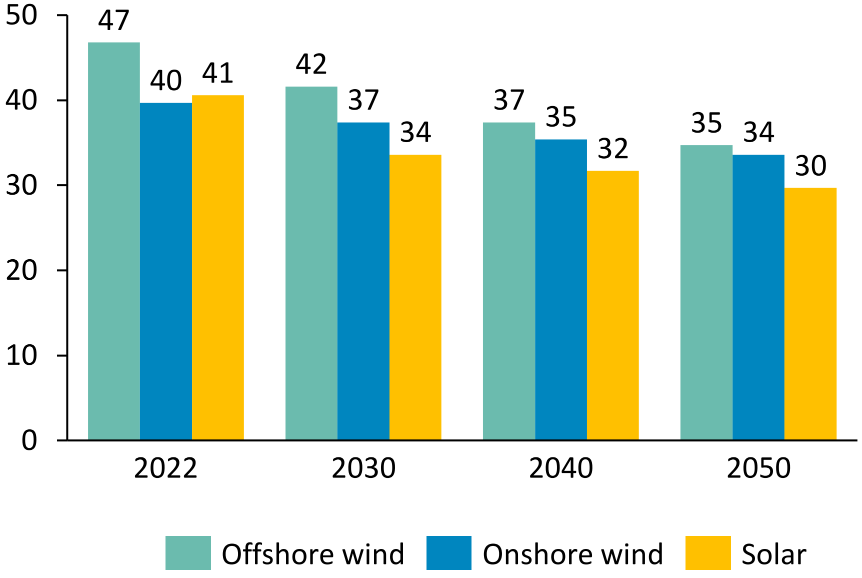
- Electrolyser stacks account for 60 % of total capex due to the use of expensive materials
- Future cost reductions are expected due to the development of less costly materials for electrodes and membranes, and the economies of scale achieved through multi-stacking
- As long-range cost estimates anticipate significant technology innovation, they hold the greatest uncertainty
- We assume electrolyser capex costs are an average of PEM and Alkaline estimates published by BEIS, IEA, Element Enegry and Bloomberg to reflect the current outlook on technology development

Source: The Future of Hydrogen (IEA), BEIS, Element Energy, Bloomberg, Imperial College London, Energy Systems Catapult, Deloitte, National Grid, Wood

# Cost of renewable electricity assumed

## We have assumed LCOEs decline as renewables deployment increases in Lithuania

**Projected LCOE of renewable power in Lithuania (€/MWh)**



**Scope of LCOE costing calculation covers all CAPEX, OPEX, and electrical output of a power plant's lifetime**

- CAPEX includes the cost of plant development, construction and connection. It is annuitized over the economic lifetime of the plant according to a technology and market-specific weighted-average cost of capital (WACC)
- WACC is composed partially of Debt, i.e. capital secured by loans, and partly of Equity, i.e. capital secured from shareholders, and mainly depends on levels of market risk that the generator is exposed to, technology maturity, and a country risk premium
- OPEX includes fixed operations and maintenance costs (FOM), insurance, and transmission and distribution. Balancing and route-to-market costs, which strongly depend on market arrangements, are also included on a per MWh basis.

**Key assumptions include financing risk and market arrangements**

- Assumed cost of capital reflects projects which are assumed to have a long term fixed price contract with a highly credit worthy counterparty e.g., a government-backed long-term contract of 15 years, thereby reducing market price exposure and lowering finance costs
- We assume power from renewables is contracted directly to hydrogen production and (conservatively) do not assume any time-of-use optimisation e.g., only running electrolysers at night
- This is a simplifying assumption and does not reflect:
  - opportunities the effective price of electricity into the electrolyser to be reduced through avoiding periods of high prices, allowing renewable assets to sell tot he arket in these periods
  - Additional electricity networ costs chargeable, which may or may not be xempyted for electrolysers

Source: Baringa Wholesale Market Power Model, 2022

# Additional renewable investment

## Every MW of electrolyser capacity will require 1,4 – 1,6 MW of renewable power capacity, the majority of which will be wind

### Renewable Costs and Load Factors

**Renewable Capex (€ / kWp) and Load Factor**

| Technology | 2020 | 2030 | 2050 | Load Factor |
|---|---|---|---|---|
| Offshore | 1462 | 1343 | 961 | 50% |
| Onshore | 1011 | 904 | 706 | 35% |

**Electrolyser Efficiency (kWel / kWp)**

| Scenario | 2020 | 2030 | 2050 |
|---|---|---|---|
| Low demand | 60% | 64% | 69% |
| Base | 63% | 67% | 73% |
| High demand | 65% | 70% | 77% |

- Renewable capex and location specific load factors have been taken from Baringa's in-house power price market modelling. These are based on our continuous engagement with renewable developers across European markets.
- Electrolyser efficiency impacts total capex of renewables dedicated to hydrogen production. Ranges shown are an average of PEM and Alkaline cells from IEA and BEIS.
- Some uncertainty surrounds electrolyser efficiency due to varied learning rate predictions and share of competing technologies

### Treatment of renewables in model

- We assume renewable power that feeds electrolysers is dedicated to hydrogen production. Each unit of hydrogen capacity therefore represents additional power demand whos cost must be accounted for in cost estimates
- In order to approximate load factors and levels of renewable deployment required, we assume a mix of offshore and onshore wind in the ratio of 43:57, with a minor role for solar power. This is approximate and reflects previous Litgrid scenario projections[1] for renewable deployment
- The required renewables capex per unit of electrolyser capex increases with time due to falling electrolyser costs

**Renewable requirements per unit of electrolyser**

| | 2020 | 2030 | 2050 |
|---|---|---|---|
| MW renewables/ MW electrolyser | 1,6 | 1,5 | 1,4 |
| Renewables capex/ electrolyser capex | 1,1 | 1,5 | 1,6 |

Note: LitGrid RAIDA 2050 Scenario Building

Source: IEA, BEIS, IEA, Baringa Pan-EU Power Model

# Transport via Hydrogen or Electrons

## The decision to use pipelines or power lines for transmission is influenced by factors including cost and system integration

- Conversion of electricity to hydrogen via electrolysis can occur near the site of electricity production, or near the site of energy demand
- Hydrogen produced at the site of electricity production can be transported through transmission pipeline
- If hydrogen is produced at demand sites, energy can be transported by HVDC or HVAC transmission powerlines
- The cost-optimal energy transport option depends on factors such as the quantity of energy to be transported, distance, availability and cost of storage, the desired end-use energy carrier, grid stabilisation, and location

| Factor | Effect on selection of transport medium |
|---|---|
| **Quantity of energy** | ▲ Transmission pipelines are more economical than powerlines for transporting large volumes of energy |
| **Distance** | ▲ Overhead HVDC lines are more economical than pipelines of the same capacity for distances > c. 1000km, as pipelines require compressor stations at regular intervals. The significant increases in variable renewables and electrification will likely see further cost declines of HVDC transmission lines, while pipelines are considered a more mature technology with less cost reduction potential.<br>▲ The upfront transformer costs of overhead HVDC makes it more expensive than HVAC over shorter distances, but due to lower transmission losses it becomes more cost effective beyond c. 600km |
| **Desired end-use energy carrier** | ▲ Transmission as electricity will always be preferred from a cost and energy efficiency perspective to converting to hydrogen, transporting as hydrogen, and converting back to electricity; save for where seasonal storage is required |
| **Availability and cost of storage** | ▲ If low-cost hydrogen storage is available close to the production site, but is not available close to the end use location, hydrogen pipelines are preferred<br>▲ If low-cost hydrogen storage is feasible close to the end use location, the relative economics of HVDC and pipeline will decide the optimal solution |
| **Location** | ▲ Where available, retrofitted natural gas transmission pipelines will offer the lowest transportation costs, at c. 30% of new pipelines<br>▲ Costs vary greatly in line with population density, land costs, and degree of local opposition to development, and increase dramatically for powerlines if undergrounding is required |
| **Grid Stabilisation** | ▲ Conversion to hydrogen at the site of electricity generation creates more opportunity for grid stabilization services<br>▲ Hydrogen pipelines and their pipeline volume & pressure can serve as energy storage medium |

Source: EU Hydrogen Backbone, ETC

# Roadmap of Baltic EU hydrogen backbone

## The EU hydrogen backbone envisages high volume pipeline transmission through the Baltics at some point within the 2040s

**What the EU Hydrogen Backbone says about hydrogen pipeline transmission in the Baltics**

- The EU Hydrogen Backbone establishes the long-term vision for hydrogen gas pipelines across the EU based on:
  - The presence of current natural gas pipeline available for retrofitting
  - Future supply hubs where renewables will be inexpensive
  - Current and future demand hubs where heavy industry is concentrated
- Lithuania/Ambergrid was added to EU hydrogen backbone initiative on the 3rd of Feb and the backbone envisions retrofitting of gas transmission to hydrogen transmission from Porvoo->Tallin->Warsaw through Lithuania
- Based on 2022 Hydrogen Backbone it will likely mean a combination of new and retrofitted gas pipelines connecting Latvia -> Panevėžys -> Jonava-Elektrenai-Jauniunai junction -> Warsaw
- The EU backbone also marks an interconnection between Poland and Lithuania via GIPL (Gas Interconnection Poland - Lithuania) as a 2040 goal

**Other elements informing evolution of high-volume transmission**

- The Eastern Europe corridor from Poland to Lithuania has been identified through an independent study (Agora Energywiende) as one of only four “no regret” pure hydrogen corridors in central Europe. Study based on technology costs and proximity to industrial demand and storage
- Feedback from Ambergrid suggests a preference for the existing natural gas pipeline network to be used for natural gas transmission into the 2040s in line with the economic life of the LNG terminal

Source: Agora Energywiende ‘No regret Hydrogen’ (2021) , EU Hydrogen Backbone

# Transmission system modelling assumptions

## We have conducted a generalised (i.e. not Lithuania-specific) cost comparison of dedicated hydrogen pipeline versus power line over Ambergrid's proposed Lithuanian Hydrogen Backbone

**Powerline and pipeline data is taken from European Hydrogen Backbone analysis, which assumes:**

- Direct transportation from dedicated renewable generation to electrical demand with no off-takes (In reality the transmission system will be a complicated network, with greater costs than a single line)
- Powerlines are oversized to compensate for electrolyser efficiency of 70%
- Land access and development costs are a representative average for EU transmission infrastructure

### Pipeline Assumptions

- Pipeline infrastructure costs increase with pipeline diameter and compressor size
- Three reference pipeline diameters were chosen (48-inch, 36-inch and 20-inch) to guide costing estimates. These reflect the typical range of pipeline diameters found at the transmission level.
- Compressors were sized to operate at 100% of a pipeline's throughput capacity. Systems designed to operate at 75% capacity cost c. 10% less for 48-inch pipes and < 1% less for pipes under 20 inches.
- Compressor stations are assumed every 100 – 200 km, as is used in the European Hydrogen backbone. This introduces an uncertainy of total pipeline costs of 1 - 20 % as pipelines increase in size.
- All pipelines are assumed to operate for 5,000 full load hours (as per EU Hydrogen Backbone), which is a typical average for natural gas transmission pipelines, but to be feasible would require generation side hydrogen storage

**Infrastructure cost for reference pipeline sizes (€/ m)**

| Pipe Diameter (inches) | Hydrogen Throughput (kt/yr.) | New Pipeline capex | Retrofit Pipeline capex | Compressor capex |
|---|---|---|---|---|
| 48 | 4444 | 2750 | 500 | 1476 |
| 36 | 1261 | 2200 | 400 | 316 |
| 20 | 300 | 1510 | 275 | 88 |

Source: EU Hydrogen Backbone

### Powerline Assumptions

- Powerline infrastructure costs are driven by power rating, converter station capex, and the use of underground or overhead lines
- Two common types of overhead transmission line were chosen (380 kV, 2,8 GW HVAC and 800kV, 8 GW HVDC). Note overhead 800kV HVDC lines do not currently exist in Europe due to regulatory hurdles but are common in the USA and China.
- A 38% load factor was assumed to reflect the 43:57 ratio of offshore and onshore wind
- If hydrogen demand exceeded the transport capacity of a powerline, it was assumed a second powerline would be built in parallel

**Powerline infrastructure costs (€/ m )**

| Powerline | Hydrogen throughput (kt/yr.) | Powerline capex | Converter (€/kt) |
|---|---|---|---|
| Overhead HVAC (380kv) | 74 | 532 | - |
| Overhead HVDC (800kv) | 213 | 2040 | 850 |

# Storage modelling assumptions

## We assume in each scenario ammonia is the dominant long term storage option, while short term storage is provided through pressurised containers

- The cost of pressurised containers is driven by maximum rated pressure and cycle rate
- There is uncertainty about the required pressure of containers, as well as the costs associated with each pressure. We have assumed an average of high and low pressure costs reported by BEIS and the Dutch Energy Agency
- Ammonia costs are for storage only. The inclusion of conversion or reconversion facilities would greatly increase required investment
- We assume ammonia is the dominant long term storage option, however we recommend salt cavern and fossil fuel field storage are considered in further detail
- Salt cavern storage capex shown is an average of existing salt caverns in the UK, which are commonly c. 0.05 € m/t, but can be over 1 € m/t. The least economical projects have smaller storage capacities due to lower operating pressure and cave volume

**Pressurised Container Cost Variation**

| Source | Low Pressure capex (€m / t) | High Pressure capex (€m / t) |
|---|---|---|
| BEIS | 0.31 | 0.96 |
| Danish Energy Agency | 0.42 | 0.76 |

**Storage Capex and Levelized Cost**

| Technology | Capex cost (€m / t) | Levelised cost (€ / kg) | Source |
|---|---|---|---|
| **Pressurised Container** | 0.62 | 0.16 | Danish Energy Agency, BEIS, BNEF |
| **Ammonia** | 0.008 | 0.23 | EU hydrogen backbone, Deloitte |
| **Salt cavern** | 0.12 | 0.15 | Danish Energy Agency, BEIS, BNEF |

# Long term refueling infrastructure

## We have followed IEA assumptions on cost and utilisation of refuelling stations

### How refuelling stations scale with vehicle demand

| Input assumption | | Source |
|---|---|---|
| Capex cost (€m / station) | 3.5 | IEA Hydrogen assumptions |
| Utilisation | 50% | |
| Capacity (kg / station / day) | 1,000 | |
| Derived assumption (derived from input assumptions | | |
| Capex investment required (€ / kg annual demand) | 19 | |
| Network size (# stations / kt road transport demand) | 5.5 | |

- Refuelling infrastructure will scale differently for different vehicle types and at different stages of maturity for the use cases:
    - Initially, stations will be smaller and more expensive, with pilot stations being of the order of 100 – 200 kg / day capacity for passenger vehicles, and larger capacities achievable through captive fleets such as buses or taxis
    - As the fleet of fuel cell powered vehicles scales both average capacity and utilisation will increase
- As a second reference point to the IEA, the UK hydrogen mobilty roadmap estimates utilisation of 46% during inital pilot cases, where the station netwok is < 20 stations, while 77% utilisaiton is achieved once the network grows to be > 70 stations

### Assumptions for distribution to refuelling stations

| Input assumption | | Source |
|---|---|---|
| Trailer capex cost (€ / kg truck capacity) | 705 | Danesbergs, 2019 |
| Truck capex cost (€ / 1000 kg capacity) | 244 | IEA Hydrogen assumptions |
| Utilisation (kg truck capacity / kg daily demand) | 0.5 | Baringa assumption |

- Distribution from points of production and transmission is expected to occur via compressed gas containers on road vehicles (Danesbergs, 2019) at a capex cost of €400 – 1500 / kg of capacity, based on literatuire review of several technoeconomic assessments
- We have taken the mean value of €705 capex investment per hydrogen container from this review and assumed 2 refuelling trips per day on average
- We have assumed additional truck capex as the low energy density of hydrogen will mean the existing fleet of diesel refuelling trucks will not suffice to serve hydrogen refuelling demand

Note: 1) Assumes 1.13 ERU/USD FX rate; 2) Assumes 10.1 EUR / NOK FX rate

Source: IEA techno-economic assumptions for hydrogen; Denesbergs (2019 – “Techno-economic Study of Hydrogen as a Heavy-duty Truck Fuel“

# Distribution heating and power assumptions

## We have assumed costs post 2030, once distribution technology and supply chains are no longer in the early stages of development

### Assumptions for distribution to refuelling stations

| Input assumption | | Source |
|---|---|---|
| Cost of replacing natural gas boiler with hydrogen boiler (€ / household) | 1,250 | BEIS, Hydrogen Supply Chain Evidence base |
| Cost of new distribution pipeline (€  M / Km) | 35 | IEA, The Future of Hydrogen |
| Cost of distribution pipeline retrofit (€  M / Km) | 9 | European Hydrogen Backbone |
| Cost of utility scale hydrogen-to-power turbines (€ / kW) | 650 | European Climate Foundation, Element Energy |

- Costs represent values for post 2030, after projects become mature following lessons learned from first of a kind projects
- Lithuania's distribution network contains 60% polyethylene and may incur lower retrofitting costs versus a wholly metal pipeline system as a result
- Distribution pipeline costs are an average of common high- and low-pressure lines, which vary in capex by c.30%
- Cost of replacing natural gas boilers with hydrogen boilers includes boiler cost (60%), installation cost (20%), and retrofit of internal gas pipework (20%)
- Current hydrogen boiler costs can be as high as €2,500, but they are expected to reach parity with natural gas boiler costs beyond 1 million installations
- The capex of hydrogen turbines is not expected to decrease significantly over the next few decades

Note: 1) Assumes 1.13 ERU/USD FX rate; 2) Assumes 10.1 EUR / NOK FX rate

Source: IEA techno-economic assumptions for hydrogen; Denesbergs (2019 – "Techno-economic Study of Hydrogen as a Heavy-duty Truck Fuel"

# Annex 4: Stakeholder engagement and key references

## Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

# List of key reference reports used

| Key reference reports used in developing this report |
|---|
| Lithuania National Energy Independence Strategy – Lithuanian Government (2018) |
| National Energy And Climate Action Plan Of The Republic Of Lithuania For 2021-2030 – Lithuanian Government (2020) |
| Lithuanian Energy System: Now And Then – Lithuanian Energy Agency (2021) |
| Scenario Building for the Evolution of Lithuanian Power Sector for 2020 – 2050 – LitGrid (2020) |
| Geopolitics of the Energy Transition (The Hydrogen Factor) – IRENA (2022) |
| Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy – Energy Transition Commission (2021) |
| Does the Green Hydrogen Economy Have a Water Problem – ACS Energy Letters (2021) |
| A Hydrogen Strategy For A Climate-neutral Europe – European Commission (2021) |
| No Regret Hydrogen: Charting Early Steps For $H_2$ Infrastructure In Europe – Agora Energiewiende (2021) |
| Gas Decarbonisation Pathways 2020–2050 - Gas for Climate (2020) |
| When and How to Regulate Hydrogen Networks? – ACER (2021) |
| Techno-economic Study of Hydrogen as a Heavy-duty Truck Fuel – KTH Dept of Energy Technology (2019) |
| Hydrogen generation in Europe: Overview of Costs and Key Benefits – European Commission (2020) |
| Shipping Sun and Wind to Belgium is Key in Climate Neutral Economy – Hydrogen Import Coalition (2020) |
| The Future of Hydrogen: Seizing Today's Opportunities – IEA (2019) |
| Transporting Pure Hydrogen by Repurposing Existing Gas Infrastructure – ACER (2021) |
| European Hydrogen Backbone – Gas for climate (2020, 2021) |
| Harnessing the EU ETS to Reduce International Shipping Emissions – UMAS (2021) |
| Hydrogen Insights: A Perspective on Hydrogen Investment, Market Development and Cost Competitiveness – Hydrogen Council (2021) |
| Recharge EU: How Many Charge Points will Europe Need in the 2020s - European Federation for Transport and Environment (2020) |
| Fuel Cell Hydrogen Trucks – FCH (2020) |
| Heavy-duty vehicles: Charging and Refuelling Infrastructure Requirements (ACEA) |
| E-Fuels: A Techno-economic Assessment of EU domestic Production and Imports Towards 2050 - Concawe Symposium (2021) |
| Hydrogen Production Costs 2021 – UK Government Dept. of Business, Energy and Industrial Strategy (2021) |
| *Hydrogen Strategies for Australia, Chile, Denmark, Finland, Germany, Netherlands, Poland, Portugal, Sweden, UK* |

Note: *All sources are referenced in individual slides but may be abbreviated to the Author for brevity

# List of stakeholders consulted

## 20 stakeholders have been consulted in the process of this study

| Consulted stakeholders |
|---|
| Ministry of Energy |
| Ambergrid |
| EPSO-G |
| Lithuanian Energy Agency |
| Litgrid |
| Ministry of Economy and Innovations |
| Klaipedos nafta |
| Achema |
| Ministry of transport |
| Klaipeda Free Economic zone |
| Orlen Lietuva |
| Lithuanian Geological Survey |
| Green genius |
| Lithuanian Confederation of Industrialists |
| Lithuanian Energy Institute |
| SG Dujos |
| Akmenes Cementas |
| Contrarian Ventures |
| Lifosa |
| Lithuanian Railways |

Source: BEIS, 2020 UK Greenhouse Gas Emissions Data Tables; IEA, Future of Hydrogen

# Annex 5: EU funds for hydrogen

## Lithuanian Hydrogen Sector Development Roadmap and the Action Plan for its Implementation

# Smaller EU funds with potential application to hydrogen economy roll-out (1 of 2)

## Investment preparation funding

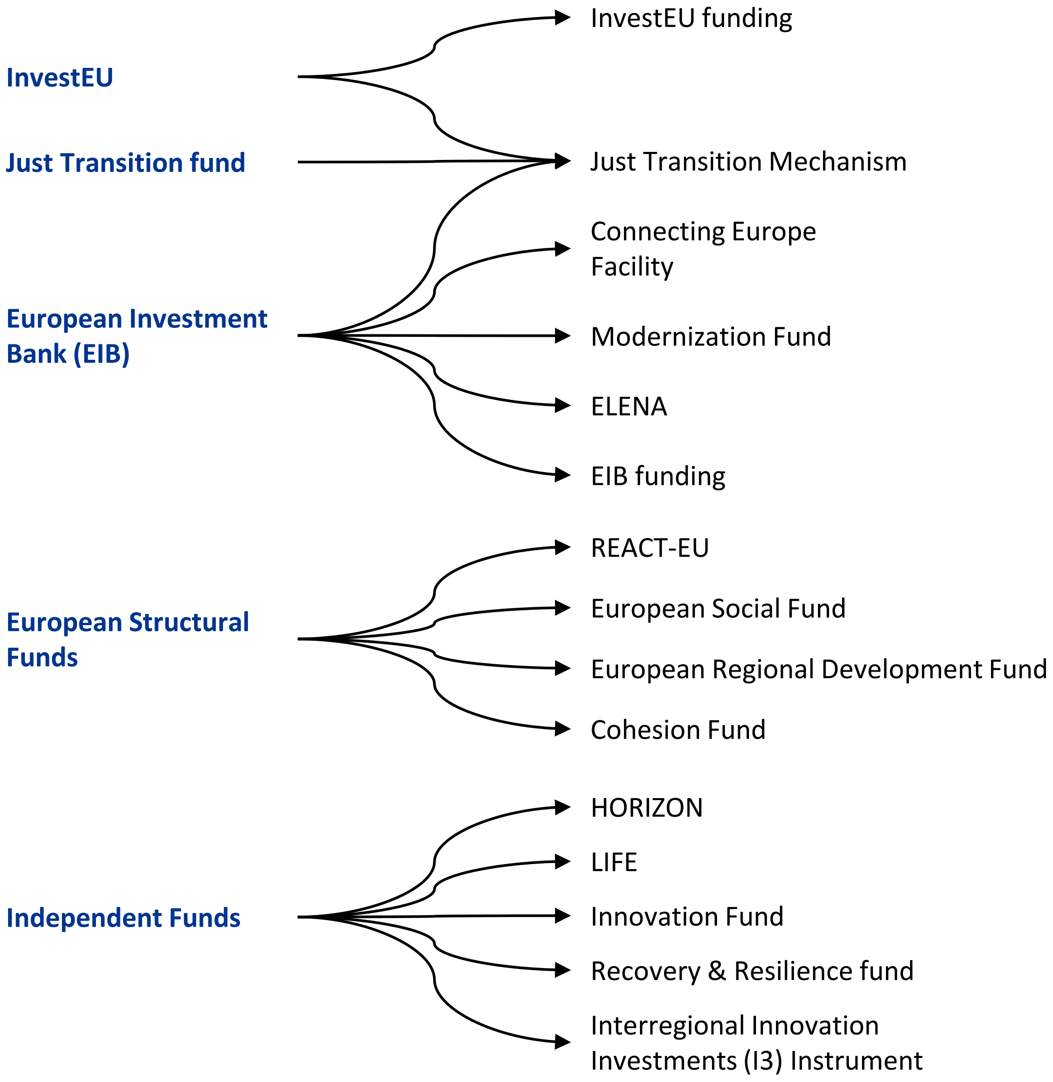
| Source | Pot size | Type | Member state competition | Use cases | Stage | Max % of project covered | Absolute project cap | Other key criteria |
|---|---|---|---|---|---|---|---|---|
| ELENA | Annual budget of €40-50m | Grant | Competitive | Energy efficiency/ sustainable residential/ Urban transport & mobility | Project development costs | 90% of technical assistance/ project development costs | - | Typically above €30m projects |
| LIFE Climate Change Mitigation and Adaptation | €905m | Grant | Competitive | Supports public authorities, NGOs and private sectors to shit towards a low carbon economy. Activities related to energy efficiency and renewable energy | Project management & development support | 60% | Typically max. €1.75m | Focused on catalysing large-scale deployment of policy related solutions- works with authorities to build up and implement skills |
| LIFE Clean Energy Transition | £1bn | Grant | Competitive | Building a national, regional and local policy framework supporting the clean energy transition; accelerating technology roll-out, enhancement of the related professional skills on the market; attracting private finance for sustainable energy; supporting the development of local and regional investment projects; | Pre-commercial | 60% | Typically max. €1.75m | |

# Smaller EU funds with potential application to hydrogen economy roll-out (2 of 2)

## Implementation project funding

| Source | Pot size | Type | Member state competition | Use cases | Stage | Max % of project covered | Absolute project cap | Other key criteria |
|---|---|---|---|---|---|---|---|---|
| EU Innovation fund | €10bn | Grant | Competitive | Innovation in low-carbon technologies and processes in sectors | Demonstration – projects and pilots | >€7.5M | | Fund primarily focuses on new innovations 'close to the market' – mainly demonstration projects and pilots |
| Interregional Innovation Investments (I3) Instrument | €77m annual budget | Loan | Competitive: Feb and October 2022 | Aims to support interregional innovation projects in their commercialization and scale-up phases | TRL 6-9 | 70% | €60,000 | Suitable if you want to work further on the impact of previous EU funded Hydrogen projects from other regions, and if you want to gain knowledge on green technologies |
| Modernization fund | €16m for LIT | Loan | Competition | Supports investment in RES, energy efficiency, energy storage, energy networks and just transition in carbon dependent regions | Commercial | 70% | | Loans backed by EIB |
| REACT-EU | €274m for LIT | Grant | Competition | Contributes to the ecological, digital and resilient recovery of the economy | Commercial | 100% | | Addition to the structural funds |

# Map of EU Funding structure



**InvestEU**

**Just Transition fund**

**European Investment Bank (EIB)**

**European Structural Funds**

**Independent Funds**

InvestEU funding

Just Transition Mechanism

Connecting Europe Facility

Modernization Fund

ELENA

EIB funding

REACT-EU

European Social Fund

European Regional Development Fund

Cohesion Fund

HORIZON

LIFE

Innovation Fund

Recovery & Resilience fund

Interregional Innovation Investments (I3) Instrument

# Types of mechanism for promoting demand

**Short term demand side mechanisms for the 2020s**

| Archetype | Execution | Impact |
|---|---|---|
| **Additional $CO_2$ pricing** | • Taxes + subsidy removal on fossil fuels | • Helps drive consumer choice in transport sectors and can be technology neutral i.e. promoting electric vehicles and biofuels |
| **Mandates** | • Requirements on the percentage of hydrogen in a sector’s fuel mix<br>• A required grid carbon intensity<br>• Outright bans e.g. on new greenfield grey hydrogen production sites | • Mandates are one of the strongest policy signals available, with clean fuel mandates particularly powerful in industries with existing hydrogen demand, or the transport sector<br>• Grid carbon mandates can support zero-carbon dispatchable generation, such as hydrogen turbines<br>• Mandates can help overcome the ’chicken-and-egg‘ barrier to achieving economies of scale |
| **Standards + voluntary commitments** | • Companies which sell products to end consumers purchase products made with zero-carbon hydrogen (e.g., goods transported using synthetic aviation fuels, or ammonia shipping services)<br>• Define CO2 standards for products (e.g., cars), based on consistent and verifiable lifecycle carbon emission assessment methodologies | • Product commitments are more feasible when the value chain is small and the carbon emissions associated with each stage can be traced<br>• Many harder-to-abate sector initiatives, including within both steel and aviation, are currently assessing the opportunities for this approach<br>• Standards would aim to prevent products below the defined threshold from being traded and send a strong, direct signal to producers to meet a particular carbon intensity target<br>• This solution can more easily be applied to products with existing energy efficiency standards that can be expanded to encompass lifecycle carbon footprint, like construction or white goods |
| **Green public procurement policies** | • Governments mandate or preferentially purchase products based on carbon-related criteria | • The biggest opportunity is likely to be in steel and concrete, as public building and infrastructure projects represent a meaningful share of demand for those sectors |
| **Contracts for Difference (CFD)** | • Governments pay a producer of a green product a subsidy to compensate the price difference of the high-carbon alternative, with reverse auctions used to minimise the subsidy required | • A green hydrogen CFD could unlock clean hydrogen use in existing applications, but would likely be insufficient to bridge the “green premium” in many other end uses<br>• CFDs are applicable to the ammonia industry, as there is a limited number of companies and large offtake volumes in a market with defined spot prices |

Brighter together

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