



INTERNATIONAL ASPECTS OF A POWER-TO-X ROADMAP

Executive Summary

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The Weltenergieerat - Deutschland e. V., based in Berlin, represents the German energy system in the network of the World Energy Council. Among its member are over 60 companies and associations. The council looks at the entire energy spectrum with a fact-based eye in order to promote a better understanding of energy issues and solutions from a global perspective.

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EXECUTIVE SUMMARY

The global energy system needs to fundamentally transform towards carbon-neutral energy sources over the next decades to meet the long term goals set in the Paris Agreement – to keep the increase in global average temperature to well below 2 °C above pre-industrial levels. National governments around the world have committed to highly ambitious goals to reduce greenhouse gases (GHG, including CO₂) in the years to come. The Federal German Government has set the goal to reduce GHG emissions by 80% to 95% by 2050 compared to 1990s levels. Reaching this goal entails a massive change in the supply and utilisation of energy as we know it today.

The increasing use of renewable energies will be a key element for the global energy transformation – alongside improving energy efficiencies. There are numerous ways to deploy renewable energy: directly in end-user applications (biomass, solar panels, geothermal etc. in heating), as electricity (e.g. in electric cars, heat pumps etc.) or as synthetic fuels produced from renewable energies.

In this study, we focus on the latter – synthetic fuels generated from renewable electricity (Power-to-X or PtX), i.e. renewable or “green” fuels.¹ These include green products such as hydrogen², ammonia, methane, methanol, diesel, gasoline, and kerosene. The renewable fuels can be deployed across all sectors – such as transport, heating, industry, power generation – and replace conventional fuels from hydrocarbons as the primary energy source and feedstock.

The aim of this study is to develop a dedicated roadmap for establishing a global PtX industry over the course of the next decades. We explain the need for international PtX production and trade on a global scale, explore potential PtX producing and exporting countries around the world and identify major pillars and milestones of a roadmap towards a global PtX market.

The final recommendations of the three pillars of the PtX roadmap are:

- Enhance and support the scaling up of PtX technologies and plant sizes to achieve significant cost savings, paving the way for international trade;
- Create a level playing field for PtX and conventional fuels rewarding the carbon-neutral character of these green synthetic fuels, thereby ensuring reliable demand structures and spurring the growth of the global PtX market; and
- Facilitate an adequate framework for investments via binding and non-binding policy measures, including cooperations and standards for trade.

Finally, complex interdependencies between these core pillars and accompanying recommendations require a coordinated approach to develop a global PtX market.

The main results of the study are summarised as follows.

¹ Unless explicitly stated otherwise, references to PtX or synthetic fuels in the remainder of this study refer exclusively to renewable, i.e. green, products.

² Hydrogen is produced via water electrolysis and is therefore not synthesised. In the context of this study, however, we count hydrogen as part of the categorisation of synthetic fuels (for simplicity).

PtX is a necessary element of the global energy transition

PtX will be an integral part of the transformation towards a low carbon energy system. In many countries it will accompany the other key elements carrying this change – the direct use of renewable energy and the direct use of renewable electricity. Green PtX complements these solutions due to a number of reasons.

- **Lack of alternatives:** In some sectors, fuels with high energy density are required for logistical reasons. This applies in large parts to the aviation and shipping industries, for example, but equally to specific high-temperature industrial or chemical processes. PtX fuels provide, in addition to biofuels, the technically feasible solutions to achieve the necessary CO₂-reductions required in these applications.
- **Storability improves security of supply:** The future renewable energy system in Europe will require large scale energy storages, e.g. for shifting renewable power generation from summer to the winter season for heating purposes. PtX products are well placed for this seasonal storage of electricity and the flexibility of PtX products will therefore improve the security of supply.
- **Immediate demand potential:** Most synthetic fuels, including synthetic methane, diesel, gasoline, kerosene and others, can immediately be used in existing appliances and infrastructure. CO₂-reductions can take place within a short timeframe without waiting for lengthy replacements of end-user applications to other technologies. This is especially relevant for the heating sector (using existing heating facilities) and in the transport sector (prolonged use of combustion engines).
- **Strengthened acceptance:** The public acceptance of new infrastructure developments impacting the environment and landscape is limited. Creating the option to use existing energy infrastructure via PtX, such as gas pipelines, can help to overcome public concerns.
- **Cost considerations:** Renewable fuels allow in many cases to save costs due to the option to use existing infrastructures such as gas pipelines, filling stations and storage facilities. Also, the usage of existing and affordable end-user application such as low-cost condensing boilers reduce the need of significant infrastructure investments.

Imports of green synthetic fuels and the development of a global PtX market support the energy transition

The energy transition in Germany will require substantial imports of green fuels from abroad for various reasons.

- **Cost advantages through import:** PtX produced in those regions of the world that demonstrate favourable site conditions for renewable energies (PV, wind) is significantly cheaper than PtX produced in Europe (e.g. Germany) – even considering transportation costs.
- **Availability of sites for RES-E:** The availability of sites for generating electricity from renewable energy sources (RES-E) is limited in many European countries, e.g. in Germany – especially regarding wind, but also biomass. This

may be reinforced by environmental constraints in some countries, such as landscape protection and maritime protection. The expectation is therefore that a substantial share of the renewable energy consumed in Europe/Germany must be imported.

- **Transportability of PtX is comparatively strong:** For importing larger capacities of renewable energy, chemical energy carriers (including PtX) are the first choice: large scale international infrastructure exists and the transportation costs for long distances are relatively low.
- **Global PtX trade supports economic growth and welfare:** Imports and exports of energy are common, strengthening international trade relationships, cooperations and political ties. International trade facilitates political stability and welfare. Exporting countries can benefit from investments and growth, importing countries can benefit from lower energy costs. Furthermore, countries that export technologies and equipment (plants and installations), such as Germany, benefit from ramping up the market.

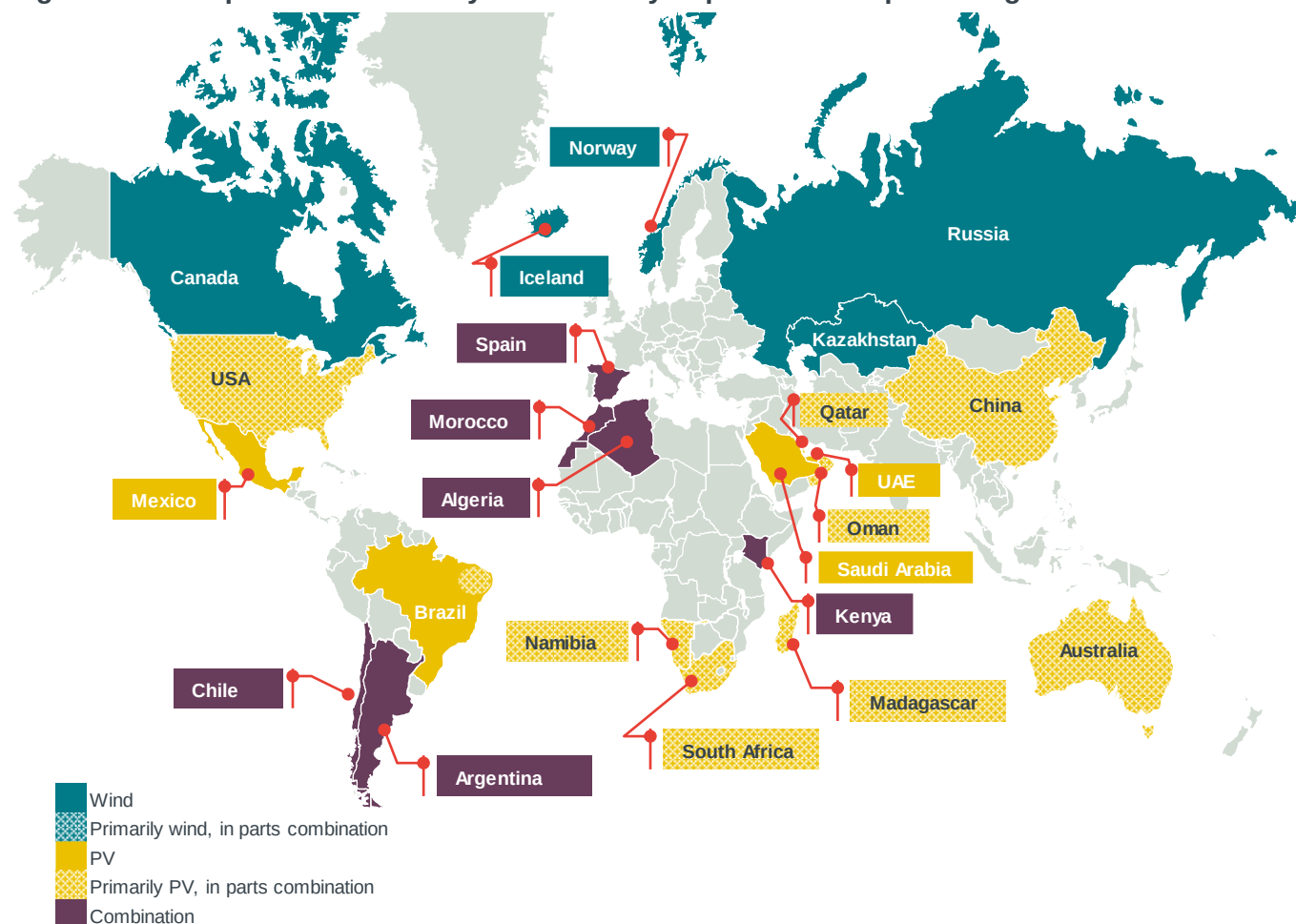
A global market for PtX can be huge in size in the long term – driving substantial investments in PtX plants and infrastructure

Indicative estimations illustrate that a mature global market for green synthetic fuels can easily demand between 10,000 to 20,000 TWh/a in the long term (2050 and beyond). This corresponds to around 50% of today's global demand for crude oil. The required capacity for water electrolyzers (producing hydrogen) alone can reach between 3,000 to 6,000 GW.

A future global PtX market will be sizeable as even a partial materialisation of this indicative global PtX market potential requires significant investments in PtX technologies and plants over the next decades. These investments will need an adequate framework and early action, paving the way towards a global PtX industry.

There is a large number of potential PtX producing countries, however, whether and when they enter the market depends on individual motivations

A global PtX market could be supplied by many potential PtX producing countries. The spread of these countries across the world illustrates the diversity of potential suppliers and shows that the demanded volumes can be provided. Countries and regions with favourable conditions for renewable energies and high technical potential for producing power from renewable energy sources are strong candidates for PtX production and exports (see Figure 1).

Figure 1 Snapshot of the variety and diversity of potential PtX producing countries

Source: Frontier Economics.

Note: Illustrative presentation of the strongest RES potentials only; not an extensive list of all countries.

Each country will have an individual story and diverse incentives as to why it would choose to play a part in a global PtX market and at which stage it might be ready and willing to enter. Indicatively, we identify certain categories of “PtX types” according to the countries’ current stage of engagement with PtX, their possible motivations to produce synthetic fuels and their potential role in a global market.

We identify “frontrunners” (e.g. Norway), “hidden champions” (e.g. Chile), “hyped potentials” (e.g. Morocco), “converters” (e.g. Saudi Arabia), “giants” (e.g. Australia) and “uncertain candidates” (e.g. China) (Figure 2). The countries are analysed in more depth for illustrative purposes and were selected as representatives for a group of other countries with similar characteristics and PtX potentials. Similarly, the allocation of these candidate countries to a specific type is not necessarily fixed and confined, and elements of other types might also apply. Equally, some countries may be categorised in a number of types as they are not mutually exclusive and may complement each other.

Figure 2 Types of possible PtX producers/exporters and selected example country

Type	PtX motivation and readiness	Selected example
 Frontrunners	- PtX already on countries (energy) political radar - Export potential and PtX readiness evident - Uncomplicated international trade partner ➤ Especially favourable in early stages of market penetration	Norway
 Hidden Champions	- Fundamentally unexplored RES potential - Largely mature, but often underestimated, (energy) political framework with sufficiently strong institutions ➤ PtX could readily become a serious topic if facilitated appropriately	Chile
 Giants	- Abundant resource availability: massive land areas paired with often extensive RES power - PtX readiness not necessarily precondition, may require facilitation ➤ Provide order of PtX magnitudes demanded in mature market	Australia
 Hyped Potentials	- At centre of PtX debate in Europe with strong PtX potential - Energy partnerships with Europe foster political support ➤ Potential to lead technology development; may depend strongly on solid political facilitation	Morocco
 Converters	- Global long term conversion from fossil to green energy sources - PtX to diversify portfolio as alternative long-term growth strategy ➤ Strong motivation for PtX export technology development; may requires political facilitation and partnership with the EU/DE	Saudi Arabia
 Uncertain Candidates	- Partially unexplored RES potentials, possibly paired with ambitious national climate change policies - PtX export in competition with growing national energy demand ➤ PtX export motivation and potential unclear – may drive PtX technology development, however export uncertain	China

Source: Frontier Economics.

Note: The PtX types and the allocation of a possible candidate country within each category serve as starting point to identify possible PtX development strategies; not a concise list and readily alterable.

The roadmap towards a global PtX industry is based on three pillars: Scaling up technology, creating markets/demand and facilitating investment/supply

Global markets for the trade of synthetic fuels will only develop if both supply and demand mature at relatively similar rates over time. The following core pillars build the framework to develop and establish an international PtX market and trade:

- **Pillar ‘Technologies’ – technological roadmap for building up a large scale PtX industry.** A global market for PtX will require further technological upscaling and cost reductions. Additionally, the initialisation of a global PtX market can be supported by complementing technologies such as “blue” hydrogen (e.g. based on steam reforming of natural gas) or – temporarily – capturing of CO₂ from biomass and/or industrial processes (required for synthetic fuels with carbon content).

- **Pillar ‘Markets and Demand’ – roadmap for building up markets and reliable demand structures.** Synthetic fuels will have to find their markets to ensure the financing of investments. There will be no substantial PtX industry if consumers do not buy and pay for green PtX. Therefore, the environmental value of PtX must be transferred into monetary terms in countries importing synthetic fuels (e.g. Europe/Germany).
- **Pillar ‘Investments and Supply’ – roadmap for building up a favourable investment frameworks to secure PtX supply.** The PtX industry needs to be build up in both producing and exporting countries and the framework for investments in PtX plants must be appropriate to attract the necessary global investments. For realising investments in potential PtX exporting countries, international cooperations can be key.

The pillars are interlinked and should be developed simultaneously.

Pillar ‘Technologies’: Scaling up technologies for significant cost savings

Technology development needs large scale projects and greater numbers of installations to standardise manufacturing of applications and processes. Cost reductions require considerable learning effects and efficiency improvements of PtX technologies. The key drivers to achieve these technological improvements and cost savings are therefore:

- Scaling up plant unit sizes – various studies show that investment costs fall with increasing plant unit size.
- Scaling up manufacturing processes – to standardise the production of installations in standardised modular units. For this, significant growth in the market size for the installations is required.

In addition, at least in the short and medium term, the development of a global PtX market can benefit from low-cost technologies that can complement PtX, such as

- “blue hydrogen” (hydrogen produced from steam reforming of natural gas with carbon capture and storage (CCS)); and
- and carbon capture from lower-cost sources (such as industrial emissions and biomass instead of direct air capture).

Although there are already a number of active PtX projects around the world, only very few (and no large scale) international projects based on renewable energies currently exist demonstrating the feasibility and technical capability of PtX exports across the value chain. Synthetic fuels are currently produced on a smaller scale and in some cases, the electricity is taken from the public electricity grid. Furthermore, today’s PtX pilot and demonstration projects are built for local niche markets. Therefore, larger scale integrated pilot projects to demonstrate the viability of PtX exports to Europe based on renewable power can be the next step towards developing an international PtX market.

Pillar 'Demand and Markets': Policies reflecting the green value of PtX

To establish a global market for PtX, it is key that investors can secure the financing of their projects and find long term markets for their products. In this context, this implies that green synthetic fuels must be demanded by customers at a price that covers cost and reflects the value of its carbon-neutrality. Without an adequate demand market and without customers willing to buy the product, investments in PtX technologies and facilities cannot be expected to take place in the longer term – neither inside nor outside Europe.

To support the establishment of PtX markets, the following steps could be envisaged by policy makers:

- In the short term, **support for pilot and demonstration projects** is required: PtX projects will require public support to get financed if the regulatory framework does not incentivise the willingness-to-pay for the green value of PtX. The first plants that offer large scale synthetic fuels generation will require much greater funding than subsequent plants.
- **Regulations of energy markets** should be adapted in a way that R&D and investments in PtX technologies and plants are not obstructed: taxes and levies should be structured in a way that synthetic fuels are not in a position of disadvantage. For example, electricity used for PtX production could be (partly) exempted from energy taxes and levies in the shorter term.
- Market growth can be supported through **targeted policy measures for creating markets in specific sectors and segments**, e.g. by crediting PtX against renewable energy and CO₂-reduction targets/obligations. Another option would be to permit PtX offsetting for the emission thresholds: PtX should be an element of renewable energy policy on an equal footing.
- In the long term, a **level playing field for CO₂-reduction technologies including green PtX** needs to be created on a global scale: green PtX should compete with other CO₂-reduction technologies on equal terms in the long term.

Pillar 'Investment and Supply': Framework for investment and international policies

Significant investments in PtX technologies and plants in producing countries will be essential to develop a global PtX industry and a market. These investments require an adequate political framework. To improve the investment conditions for green PtX, energy policy makers (e.g. in Europe/Germany) should aim to further improve the green with (potential) PtX exporting countries. These improvements could include:

- Intensifying **the (non-binding) cooperations** with energy exporting countries and increasing the number of states/regions with an energy partnership. A PtX industry can support both climate change policy in importing countries (e.g. Europe/Germany) and the development of economies and energy systems in the exporting countries.

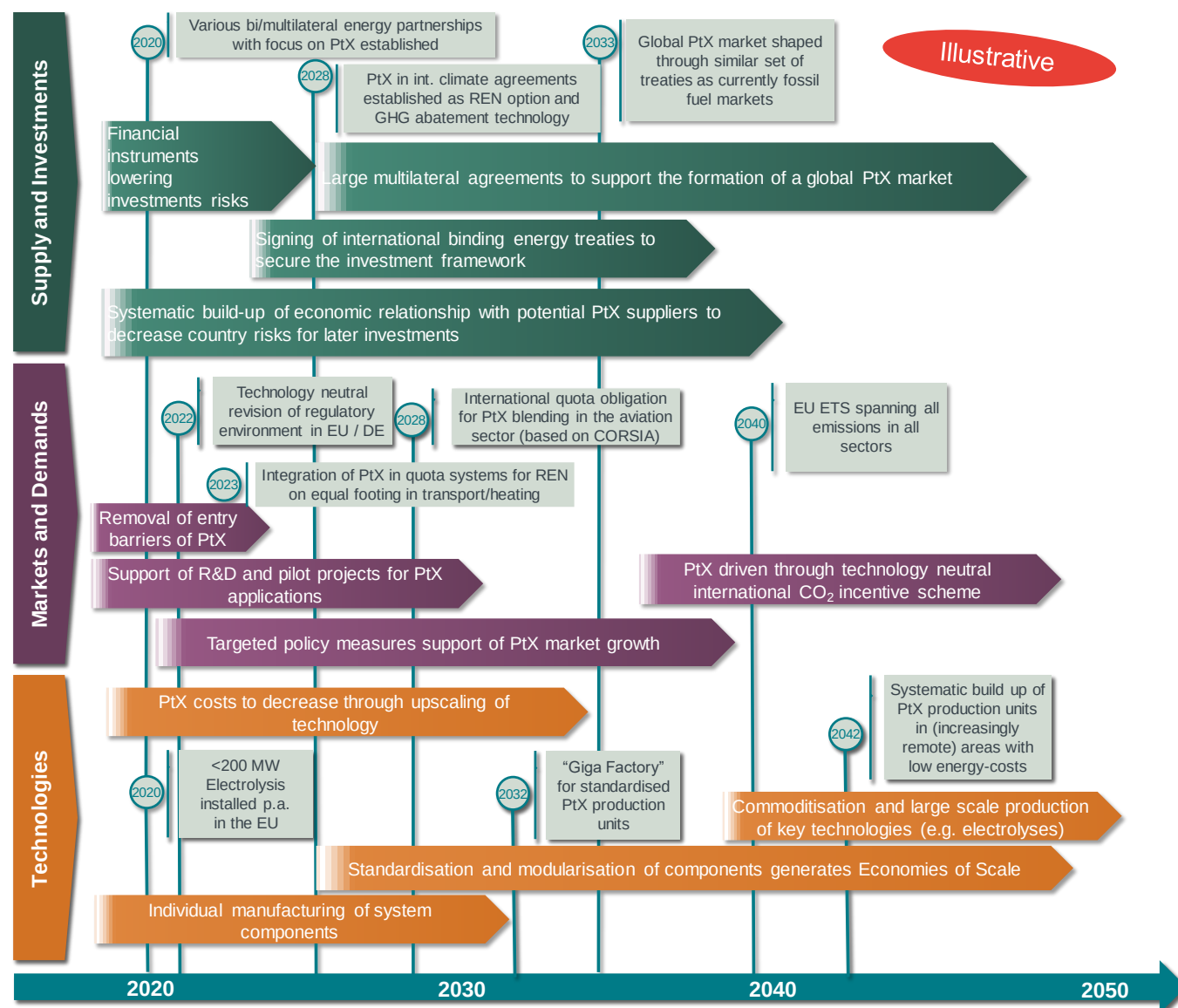
- Pushing for **legally binding Energy Agreements/Treaties** can be a stepwise approach for an improved investment climate. PtX should be part of the political agenda of multilateral negotiations such as UNFCCC conferences as well as energy and climate agreements. The Energy Charter Treaty could be promoted with an increasing number of states as only around 50 countries have so far signed and ratified the treaty – this would be an important step in the right direction.
- **Standards for PtX imports** and the establishment of **regional / global monitoring and certification schemes** to guarantee that sustainability and social standards are met. This can raise the trust in global PtX markets and ensures that the green value of PtX can be captured on a global scale.
- Evaluating **financial support to mitigate risks** – governments and state authorities can (temporarily) support investments in green PtX in foreign countries. This aims at lowering potential financial barriers related to country risks, e.g. by granting state guarantees or specific loans.
- **Strategic diplomatic support** can foster the establishment of relevant relationships and set up first projects.

Timing and complex interdependencies require a coordinated approach to developing an international PtX market

In addition to the necessary steps outlined within each pillar, there is a need for coordinated action across the development stages of each pillar. Policy makers therefore need to facilitate and support the development in all areas in parallel (see Figure 3):

- The development and scaling up of the required technologies could be facilitated through direct R&D support. More importantly, creating early opportunities and business cases can help to develop, apply and test the required applications in pilot project and niche markets.
- Effective climate change policies and/or suitable incentives (e.g. crediting of PtX on renewable energy and/or CO₂-targets) will ensure the validation and certification of PtX products and support the market development.
- Investments in production capacities should be fostered through a general favourable investment environment and a prospect for future business models.

With increasing maturity and growth of the PtX market, policy should aim towards international integration and move from more technology-specific policies towards a more generic approach to provide a level playing field for all carbon-neutral technologies, including PtX.

Figure 3 The three pillars of an international PtX roadmap

Source: Frontier Economics.

