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REPORT

Transatlantic hydrogen trade

Challenges and opportunities for Germany and Canada

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Executive Summary

Germany and Canada have both published ambitious hydrogen strategies and made hydrogen key to their bilateral cooperation with the establishment of the Canadian-German Hydrogen Working Group. This paper aims to support the Working Group by discussing the opportunities and challenges of transatlantic hydrogen trade as well as how the Canadian-German Energy Partnership can support the establishment of transatlantic hydrogen trade.

A look at Germany's and Canada's hydrogen strategies reveals complementary interests. To decarbonise the hard-to-abate sectors of its economy, Germany will have to rely largely on hydrogen imports in the future. As recent analyses have shown, Canada could be a particularly promising hydrogen supplier. Its Atlantic provinces such as Newfoundland and Labrador, which lie comparatively close to Europe and possess a renewable energy potential outweighing domestic energy needs, have a particular advantage for green hydrogen production and export.

For Canada, green hydrogen offers a new export opportunity for its energy sector in a world progressing towards climate neutrality. The country could capitalise on its energy sector's strength, infrastructure and skilled workforce to export green hydrogen to Germany and Europe, diversifying its market beyond traditional energy products and partners. The pursuit of export opportunities can in turn accelerate the ramp-up of Canada's domestic hydrogen economy. In addition, there are beneficial side effects of transatlantic hydrogen trade for technological and market developments and European energy security.

Still, there are a number of challenges for hydrogen trade between Canada and Germany. First of all, for the simultaneous ramp-up of supply and demand to succeed, government support through financing and coordination is needed. While both countries have put forward support measures for hydrogen, there is potential for further cooperation on the establishment of a supportive and coherent regulatory framework for transatlantic trade.

Second, the infrastructure required for shipping hydrogen and its derivatives across the Atlantic, including transmission power lines, pipelines, storage facilities, port equipment for conversion and reconversion, and dedicated vessels, will need to be rolled out. This will require public financing, not least for the hydrogen shipping technologies still to be commercialised. Further, cross-border cooperation on infrastructure planning and licensing will be key for Canadian provinces, and also for Germany within the EU.

Third, relevant stakeholders from both countries, including energy and hydrogen producers, technology providers, gas grid operators, ports, maritime shipping companies, and importers and consumers, will need to be brought together. This would not only help to conclude supply contracts, but also to identify mutually-beneficial linkages and synergies in the supply chain and to bring down costs for hydrogen and its applications. Further, these stakeholders require better information about hydrogen funding opportunities and technical standards.

Fourth, standard-setting and certification is required to prove that traded hydrogen products are low-carbon, climate-neutral and eventually sustainable. As a foundation for building up an open market for transatlantic hydrogen trade, then, Canada, Germany and the EU need to closely cooperate on the development of emission and sustainability standards and certification for hydrogen. Potential incompatibilities of Canadian product with upcoming EU sustainability requirements for hydrogen need to be assessed and responded to accordingly.

For Germany and Canada to realise their opportunity for the joint development of a long-lasting, mutually-beneficial hydrogen trade relationship, it is recommended that both countries further intensify their bilateral hydrogen cooperation. A number of action items for the Energy Partnership are suggested in the last chapter.

1 Introduction: Canadian-German hydrogen cooperation

Germany and Canada are emerging as frontrunners in the development of a hydrogen economy. Both countries have published national hydrogen strategies, with ambitious visions for hydrogen production, trade and end-use. Hydrogen is also a key field of bilateral cooperation within the Canadian-German Energy Partnership, which was established in March 2021 following the signing of a Memorandum of Understanding by the then Minister for Economic Affairs and Energy (BMWi), Peter Altmaier, and the then Minister for Natural Resources (NRCan), Seamus O'Regan.

In December 2021, the Canadian-German Hydrogen Working Group, with representatives from government, industry, civil society and research institutes, convened for the first time to identify priority areas for Canadian-German bilateral cooperation on hydrogen. In February 2022, the Hydrogen Working group met again to focus on potential hydrogen trade between Canada and Germany. This paper has been written in preparation for that meeting, aiming to structure the discussion on transatlantic hydrogen trade, describe the key opportunities and challenges for both Germany and Canada, and articulate how the Energy Partnership can support collective hydrogen efforts.

A look at Germany's and Canada's hydrogen strategies reveals the largely complementary interests and needs of the two countries when it comes to hydrogen. Germany, as Europe's largest economy with a strong industrial sector, sees hydrogen as a key element in its energy transition, especially in hard-to-abate sectors such as steel and chemicals, maritime transport and aviation, as well as for seasonal electricity storage (BMWK 2020). To establish a domestic hydrogen market and promote international cooperation, Germany developed and released its national hydrogen strategy in June 2020. The strategy favours green hydrogen produced from renewable electricity for Germany's energy transition. In terms of domestic electrolysis capacity, the Federal government has set a target for 10 GW by 2030 (Bundesregierung 2021). Meeting this target would still, however, be insufficient to meet the forecasted demand of 90-110 TWh by 2030, with 70-75% having to be supplied by imports.

In the long-term, Germany will have to rely to a large extent on hydrogen imports due to its limited renewable energy potential (Piria et al. 2021). It is estimated that Germany will be the largest importer of hydrogen in the EU (WEC 2021). That is why Germany is seeking international hydrogen partnerships with countries with significant potential for hydrogen production and export such as Canada and has made available € 2 billion in funding for international hydrogen projects. Canada, too, has identified hydrogen as key energy technology on its way to climate neutrality. *A Hydrogen Strategy for Canada*, released in December 2020, outlines the role that hydrogen can play in contributing to Canada's 2030 climate objectives and net-zero target for 2050. Some key opportunities identified in the Strategy include: becoming one of the three largest global producers for low-carbon hydrogen; meeting 31% of its final energy demand with hydrogen, to be primarily used in heating, as an industry feedstock, in heavy duty, rail and maritime transport and electricity storage (NRCan 2020). Importantly, the strategy also aims for "Canada to become a supplier of choice to the world for clean hydrogen and the technologies to use it" (GoC 2021). Germany is identified as a key target market. Recent regional hydrogen blueprints on the West and East Coast further underline Canada's interest and opportunities in exporting hydrogen.

Germany and Canada have the potential to form a long-term and mutually-benefitting hydrogen trade relationship. The following chapters will take a closer look at the opportunities and challenges of transatlantic hydrogen trade and propose several actions, with which the Energy Partnership could support the build-up of such a Canadian-German trade relationship.

2 Opportunities of Canadian-German hydrogen trade

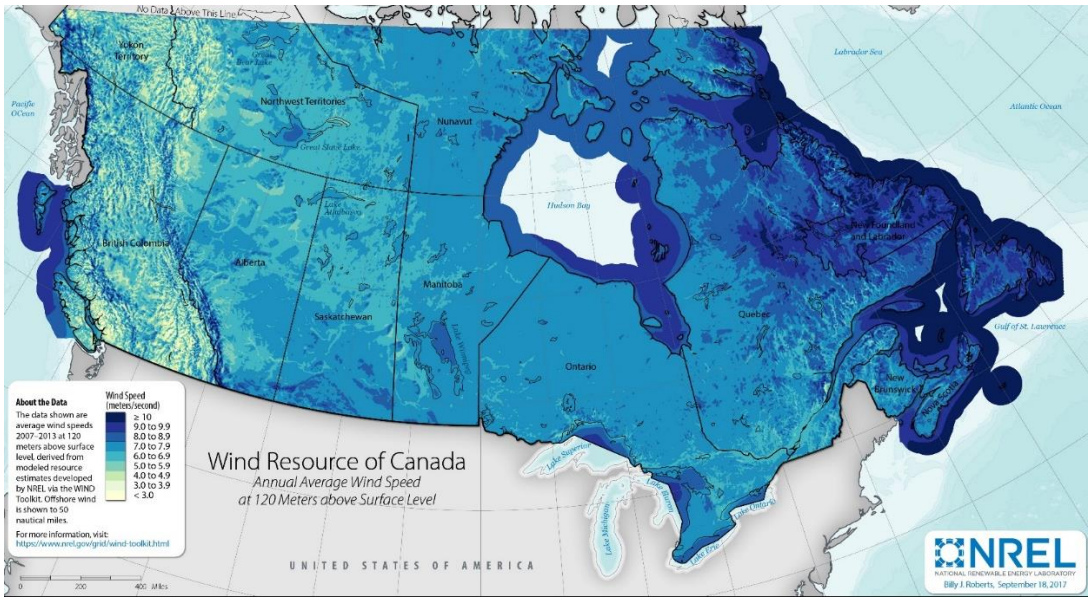
2.1 Canadian hydrogen could diversify Germany's import mix

While Germany will reduce its overall energy imports on the way to climate neutrality, it will in the long-term, due to its limited renewable energy potential and high population density, still have to rely on imports for a substantial share of its energy needs (Piria et al. 2021). In the coming decades, these energy imports will have to become climate-neutral and, more broadly, sustainable – with climate-neutral hydrogen and its derivatives making up a substantial share of the import mix.

For Germany and the EU as a whole, it would be cheapest to import hydrogen via pipeline from neighbouring countries and regions such as the UK, Norway, Northern Africa, the Ukraine and Northern Africa (Wang et al. 2020). However, the build-up of cross-border hydrogen pipelines will face long lead times due to the need for transnational political coordination as well as financing and permitting issues. Further, as Germany's and Europe's energy crisis following the Russian invasion of Ukraine has painfully shown, pipelines carry geopolitical and energy security risks by locking in trade relationships. The potential for cost competitive climate-neutral hydrogen in some of the neighbouring countries is also limited. Thus, Germany and the EU would benefit from a diversified pool of hydrogen suppliers, which can ensure long-term availability, affordability and sustainability of hydrogen supply (Piria et al. 2021).

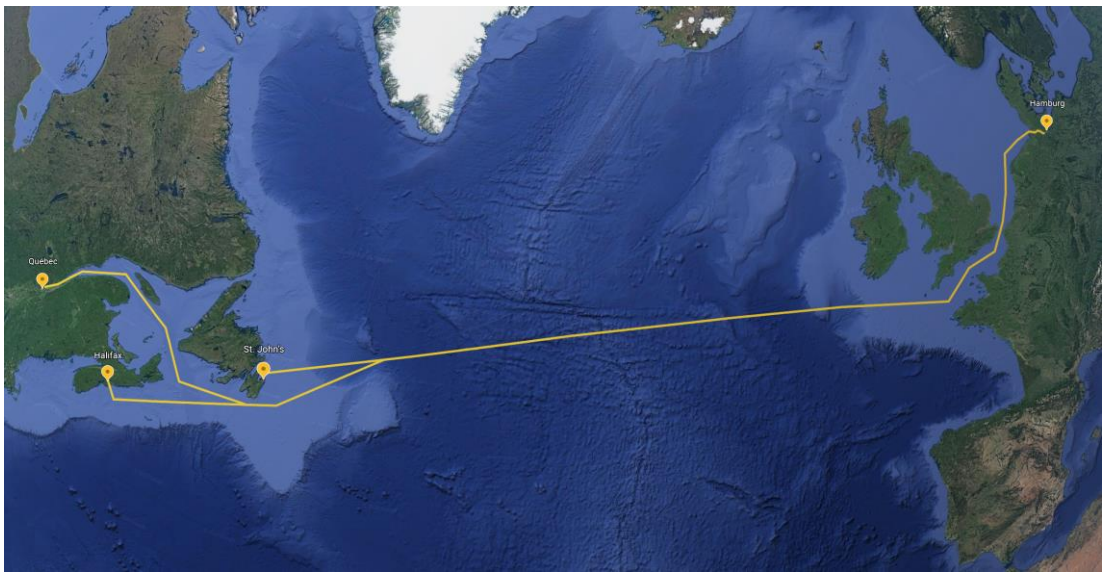
Similar to today's natural gas trade, such diversification can be achieved by importing some share of hydrogen or its derivatives (e.g. ammonia) via ships. In this context, Canada could be a particularly attractive hydrogen supplier for Germany, as has been shown by various studies (Teichmann et al. 2021; Jensterle et al. 2020). Eastern Canada, with a renewable energy potential that largely exceeds its own energy needs, has an advantage for green hydrogen production (Teichmann et al. 2021, Barrington-Leigh und Ouliaris 2016). This is especially the case in Atlantic provinces such as Newfoundland and Labrador, with enormous potential for onshore and offshore wind (see Figure 1). This potential could be leveraged for the export of green hydrogen to foreign markets such as Germany, where it could contribute to decarbonisation in a cost-competitive manner.

Figure 1: Wind resources of Canada (NREL 2017)



There are several other reasons why Canada could become an attractive hydrogen supplier for Germany. Already today, Eastern Canada has hydropower overcapacities and very low electricity prices, which could benefit a green hydrogen market ramp-up (Teichmann et al. 2021). The Canadian market further benefits from a highly-skilled energy workforce, with existing expertise in producing various vectors for hydrogen export (e.g. ammonia, methanol). The country's high political stability and reliable administration results in low capital costs and high investor confidence. Further, the shipping distance to Europe is relatively short, when compared to other potential hydrogen-exporting countries (see Figure 2). Eastern Canadian ports are closer to Hamburg and Rotterdam than ports in the Eastern Mediterranean, the Red Sea and the Persian Gulf, let alone Southern Africa or South America.

Figure 2: Shipping route from Eastern Canadian ports to Hamburg (Google Earth 2022)



Further, transatlantic hydrogen trade would offer security for investors and consumers alike, especially when compared to trade routes in geopolitical sensitive regions of the world. In addition, there are sustainability advantages to Canadian hydrogen, given the country's abundant freshwater resources and very large areas at low risk for biodiversity conflicts.

2.2 Hydrogen as a new export opportunity for Canada's economy

Canada is one of the largest energy exporters in the world – of crude oil, natural gas, uranium, coal and electricity. Its energy sector is vital to its economy: energy exports make up 18% of total Canadian exports, the energy sector as a whole contributes 8.1% or C$168 billion to Canada's GDP (NRCan 2021). At the same time, global energy markets are changing as the international community is stepping up its ambition to tackle climate change. The IEA foresees global fossil fuel consumption as set to decline substantially in the future, as more and more countries progress towards climate neutrality, with the market share of alternative energy sources and carriers continuing to rise (IEA 2021).

These market developments provide Canada with the opportunity to capitalise on its energy sector's strengths, including its resource and infrastructure assets and highly-skilled workforce, in order to diversify its market beyond traditional energy products and partners and produce alternative energy products such as hydrogen and its derivatives for foreign markets such as Germany. As an advantage for Canada, the market for alternative energy products such as hydrogen will continue to grow in the future. Germany will become increasingly reliant on climate neutral hydrogen imports for its energy supply as the country progresses towards

net-zero. Moreover, it can be expected that an increasing number of countries will get interested in importing hydrogen or its derivatives via ship, as they try to diversify their pool of energy suppliers in a climate-neutral world. At the same time, the pursuit of opportunities in international hydrogen trade can accelerate the ramp-up of Canada's domestic hydrogen market, helping with decarbonisation at home and opening up new opportunities for Canadian industry and businesses.

With respect to hydrogen, Canada is already a frontrunner. It is one of the ten largest hydrogen producers worldwide and leading in the development of hydrogen technologies such as fuel cells and electrolysers (NRCan 2020). Canada is further endowed with large energy resources – both fossil and renewable – which allow for the production and export of hydrogen from various sources. However, from the point of view of becoming a hydrogen supplier to Germany, Canada's main strength are the very favourable conditions for green hydrogen production in the Eastern and Atlantic provinces. This is because Canada's blue hydrogen potential is centred thousands of kilometres away from the Atlantic Coast, and Germany has politically committed to focus on green hydrogen as the only sustainable solution for its energy transition in the long-term (BMWK 2020).

Next to its great potential for hydrogen production, Canada also benefits from an existing energy infrastructure on its East Coast, including for the export of ammonia, which may be utilised or adapted in the near future for the export of hydrogen and its derivatives to Europe.

2.3 Further benefits for the international community

A Canadian-German partnership on hydrogen trade could have beneficial spill over effects, which accrue not only to Canada and Germany but also to other countries and the international community as a whole. For example, establishing a trade chain will help ramp-up the international market for hydrogen or derived products traded via ship and speed up the development of involved technologies (e.g. for conversion and reconversion of hydrogen, shipping), which will contribute to economies of scale and the reduction of overall production and shipping costs.

Further, an effort to deploy Canada's renewable energy potential can benefit not only decarbonisation in Canada and in Germany, but also in other hydrogen-importing European countries as well as in the United States.

Last but not least, beyond the opportunities for economic growth and climate mitigation, Canadian hydrogen exports could contribute to the energy security of Germany and the European market as a whole, further strengthening the transatlantic alliance and decreasing Europe's reliance on energy imports from geopolitically volatile countries and regions.

3 Challenges for Canadian-German hydrogen trade

3.1 Supporting the market ramp-up and reducing investment risks

The hydrogen market ramp-up will require large investments on the supply and demand side as well as in infrastructure. Producers ask for a certain degree of certainty about future hydrogen demand. At the same time, climate-neutral hydrogen will for some time remain more expensive than traditional emission-intensive energy sources and carriers, hindering the uptake by end-users such as industry. Indeed, the whole hydrogen value chain including production, storage, transport and end-use will have to scale up simultaneously in order for the market ramp-up to succeed. This will require support and coordination by government at various parts of the value chain.

Both Germany and Canada have put forward support schemes for hydrogen. With its "Low-carbon and Zero-emissions Fuels Fund", Canada has made available C$1.5 billion in funding for low-carbon fuels including hydrogen. Germany has put forward €2 billion in international hydrogen funding. Most notably, it has launched the H2Global initiative – a double-auction scheme for supporting green hydrogen import projects – and it has presented a funding guideline to support the green hydrogen market ramp-up abroad.

In order to remove regulatory barriers as well as to reduce risks for investment in transatlantic hydrogen trade, Germany (and the EU) and Canada need to cooperate on establishing a supportive regulatory framework for hydrogen production, transatlantic trade and demand. Germany and Canada could benefit from exchanging experiences on the development of their respective hydrogen value chains and support schemes, aiming to exploit synergies and to create a framework that is conducive to appropriate investments on both sides of the Atlantic.

In terms of hydrogen support measures, different policy instruments, including for the supply side (PPA-like supply contracts, investment subsidies) and the demand side (Carbon Contracts for Difference, quotas), have been put forward. In order for such measures to be effective, regulatory frameworks will need to follow a coherent and coordinated approach, integrating different policy targets. For instance, long-term contract guarantees for hydrogen suppliers will have to be balanced with the consumers' preference to change one's supplier in the light of price developments.

3.2 Infrastructure roll-out and commercialising hydrogen shipping

Next to upscaling supply and demand, the energy infrastructure required for shipping hydrogen or its derivatives across the Atlantic needs to be simultaneously built up. This would include pipelines from production sites in Canada to its East Coast's harbours, and from European harbours to demand centres in Germany and elsewhere. For green hydrogen, also transmission power lines from renewable electricity production sites to electrolysers located near harbours could be built. Further, storage facilities and port equipment for conversion and reconversion (of hydrogen into hydrogen carrier technologies and vice versa) would be required on both sides of the Atlantic as well as, of course, the dedicated vessels for shipping.

As of today, various hydrogen carrier technologies are being discussed for long-distance shipping, including liquified hydrogen, ammonia, methanol and liquid organic hydrogen carriers (LOHC) (Brändle et al. 2020). For all shipping technologies, the costs for conversion and reconversion (including for the LOHC liquid for LOHC-based transport) are highest, making up around 60-80% of total transport costs for a 10.000km distance (Wang et al. 2021).

Studies indicate that shipping ammonia or hydrogen stored in LOHCs will probably be the most cost-efficient options in the short- and medium term (IEA 2019; Wang et al. 2021; Roland Berger 2021). However, which carrier will outcompete others in terms of costs also depends on the required end-use form of hydrogen. For users that need pure hydrogen (e.g. for applications such as fuel cells), some expect liquid hydrogen to become competitive in the long-term, as significant cost reductions in liquification and shipping are possible (IEA 2019; ERIA 2019; Roland Berger 2021). If ammonia is used directly as fuel or feedstock in the import country, it could have an advantage over other carriers in the long-term (Wjayanta et al. 2020).

To build the transport and storage infrastructure necessary for transatlantic trade with hydrogen and its derivatives, government support will be essential on both sides of the Atlantic. This will have to include public financing for infrastructure projects such as pipelines and export/import terminals. Due to the uncertainty with regard to the technical and economic feasibility of different shipping methods, government funding should specifically target the promotion of research, development and deployment of shipping technologies.

Further, governments need to support through sub- and transnational coordination on planning and licensing of hydrogen infrastructure. Given Germany's central geographical location in Europe, it will have to further develop its ongoing collaboration with its European neighbours and other EU Member States in establishing a hydrogen transport network. Within Canada, the provinces will have to coordinate should inter-provincial pipelines to Eastern Canadian ports need to be built. However, export and import terminals should lie as close to producers and end-users as possible, given the lower marginal cost of shipping compared to building additional pipelines (Wang et al. 2021). Further, it needs to be assessed to what extent the existing energy infrastructure (e.g. existing natural gas pipeline network, methanol and ammonia tankers) may be utilised or repurposed for transporting hydrogen or its derivatives.

3.3 Better connecting and informing Canadian & German stakeholders

As a precondition for the establishment of transatlantic hydrogen trade, private stakeholders in Canada and Germany relevant for such a trade relationship need to identify and connect with each other. These stakeholders include energy and hydrogen producers in Canada, technology providers, gas grid operators, ports, maritime shipping companies, as well as importers and consumers of hydrogen in Germany. Connecting these stakeholders would have benefits beyond the conclusion of supply contracts. Through close cooperation, Canadian and German businesses could align their supply chains, make use of mutually-beneficial linkages and exploit synergies, bringing down costs for hydrogen and its applications while mitigating disruptions. Despite these obvious advantages of collaboration, prior exchanges within the Canadian-German Hydrogen Working Group have pointed to the need for helping Canadian and German companies with identifying key stakeholders in the hydrogen ecosystem in each other's countries.

First working group discussions have also identified an information gap in Canadian and German industry when it comes to project funding opportunities. Stakeholders reported the need for guidance on what funding mechanisms are available in Canada and Germany for hydrogen projects, how they may potentially be combined for cross-funding, what kind of projects (and at which technology readiness levels) as well as which organisations would be eligible for funding, and what the timelines are for implementation, as prescribed by respective funding scheme. A further information gap identified in working group discussions was the regulatory uncertainty when it comes to technical standards for the quality and security of hydrogen, as well as the required procedures for monitoring, reporting and verification.

3.4 Sustainability and reaching climate targets

While hydrogen is emission-free at the point of end-use, its production and transport today is associated with significant GHG emissions (IEA 2022). In the long term, only hydrogen, whose entire life-cycle is carbon-neutral, can help countries around the world to meet their climate neutrality targets.

For green hydrogen, this means that only renewable electricity may be used for electrolysis production. There are further sustainability dimensions of green hydrogen, including the additionality of renewable electricity used for hydrogen exports (so that it does not compete with local decarbonisation), but also water supply, land use, socio-economic impacts and transport (Heinemann and Mendelevitch 2021). If hydrogen is (partly) produced with nuclear energy, the GHG emission intensity of the entire nuclear fuel chain as well as the impacts and risks associated with nuclear waste disposal and the operation of the nuclear supply chain must be taken into account.

For fossil-based hydrogen, emission-intensity will depend on the methane emission intensity, the CO_2 capture rate as well as fugitive CO_2 emissions at the storage site. Recent assessments indicate that blue hydrogen can approximate the low emission intensity of green hydrogen only if very low rates of methane leakage of less than 1% and carbon capture rates of at least 93% are accomplished (Bauer et al. 2021). There are further sustainability challenges associated with fossil-based hydrogen, most importantly the land use impacts of upstream production, including the seismic and water risks posed by fracking.

Standard-setting and certification is meant to establish proof that hydrogen or its derivatives are either low-carbon, climate-neutral or even sustainable. Today, different jurisdictions as well as private certification agencies around the world have developed or are in the process of putting forward regulation, standards and schemes for the emission-intensity of hydrogen. In Germany, standards for hydrogen are regulated at EU level. The EU's Renewable Energy Directive sets standards for green hydrogen, with a delegated act detailing these standards expected to be released in early 2022. For low-carbon hydrogen (which includes blue), a first, broad definition has been proposed by the Commission in its gas package of December 2021. The delegated act specifying concrete standards for low-carbon hydrogen is not expected before 2024. Further, the EU methane emission regulation, proposed by the Commission in December 2021, will, once adopted, define detailed monitoring procedures for methane emissions. While the regulation will, according to the proposal, first apply only to facilities inside the EU, there are calls for extending its application to imports. And it can be expected that European industrial hydrogen consumers interested in demonstrating the low climate footprint of their product might also require their imports to follow these methane regulations.

Clarity and transparency on emission standards and sustainability criteria for hydrogen are key enablers of the market ramp-up of climate-neutral and low-carbon hydrogen. International hydrogen trade, such as between Canada and Germany, would do well out of a coordinated approach for standard-setting and certification. Because, before concluding any supply contracts, both Canadian producers looking to sell on the European market as well as importers and consumers in Germany interested in buying Canadian hydrogen will need to be sure that their trade product complies with European standards and can be counted towards their emission targets. In terms of blue hydrogen, potential incompatibilities of Canadian product with upcoming EU sustainability requirements for fossil-based hydrogen need to be assessed early and responded to accordingly.

Clearly then, as a foundation for building up an open and transparent market for transatlantic hydrogen trade, Canada, Germany and the EU should cooperate closely on the development of hydrogen standards and certification.

4 An agenda for cooperation on hydrogen

Germany and Canada share common interests and needs in the field of hydrogen, with an opportunity for the joint development of a long-lasting, mutually-beneficial hydrogen trade relationship. Thus, it is recommended that both countries further intensify their cooperation on hydrogen. The following recommendations for cooperation are divided in two categories: 1) high-level policy cooperation and 2) concrete activities and outputs of the Energy Partnership. The Hydrogen Working Group will discuss this proposed agenda and decide on which cooperation activities shall be proposed to the Energy Partnership's Steering Committee.

High-level policy cooperation

Germany and Canada should develop a policy agenda for facilitating the investments required in both their countries for establishing transatlantic trade with hydrogen and its derivatives. The goal could be to work towards a "German-Canadian Hydrogen Accord", with concrete commitments and milestones on the way to establishing a transatlantic trade relationship. Such an accord could include the following goals:

- Announcements of respective policy commitments to support the development of green hydrogen resources for the export to Germany/Europe (Canada) and to commit to hydrogen imports by ship as a means to secure a diversified hydrogen supply mix (Germany)
- Cooperation on advancing a supportive regulatory framework for hydrogen production and trade (including on emission standards and certification)
- Creating opportunities for co-funding (through both Canadian and German funding schemes) of hydrogen projects and hubs for industrial-scale production of green hydrogen in Canada and export to Germany/Europe
- Supporting individual hydrogen projects and their companies through practical assistance (e.g. helping with finding partners, guidance on funding opportunities, support with planning and licensing issues)

Concrete action items for the Canadian-German Energy Partnership could include:

- A joint workshop on emission standards and certification procedures for potential hydrogen producers and exporters in Canada and importers and consumers in Germany
- A B2B round table connecting stakeholders relevant for building up transatlantic hydrogen trade (including energy and hydrogen producers in Canada, technology providers, gas grid operators, ports, maritime shipping companies, as well as importers and consumers of hydrogen in Germany)
- A roundtable with Canadian and German ports, to promote cooperation on hydrogen trade and initiate proof of concept actions on decarbonising main nodal points (e.g. twinning Montreal and Hamburg)
- A workshop with Canadian and German ports on different hydrogen carrier technologies (liquid hydrogen, ammonia, LOHC), including on expected cost developments and practical implications and aiming at the coordination of investments in infrastructure to handle hydrogen or its derived products
- A who-is-who document mapping relevant stakeholders in the hydrogen ecosystems of Germany and Canada, to support businesses finding partners
- A dedicated LinkedIn Group for stakeholders relevant for building up transatlantic hydrogen trade, managed by the German Secretariat of the Energy Partnership
- A roadmap presenting hydrogen funding opportunities in Germany and Canada for projects at different technology readiness levels and different parts of the supply chain

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End Piece

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