IRENA VIRTUAL EDITION
INNOVATION DAY 2022

IRENA INNOVATION DAY: CANADA

SUMMARY OF KEY INSIGHTS FROM THE DISCUSSIONS

EVENT OVERVIEW

Building on IRENA's biennial Innovation Weeks, **IRENA Innovation Days** take place in different countries and regions around the world and aim to connect national, regional and international innovators and policymakers to share their experiences and showcase emerging innovations to inspire broader and faster uptake of renewable energy. To date, Innovation Days have been held in Uruguay, Thailand and Turkey.

4 sessions	30 expert speakers	Over 300 participants	Over 60 countries including Canada

On 23 and 24 March 2022, over 300 delegates from the IRENA's member countries gathered virtually for the **fourth IRENA Innovation Day**, which was organized jointly with Natural Resources Canada (NRCan). Discussions spanned two days. On day 1, they focused on the decarbonisation of the power sector while on day 2 on the decarbonisation of end-use sectors. Discussions aimed to ensure attendees acquired a better understanding of what is happening, what is possible and what needs to be explored further to decarbonise power and end-use sectors. Panels showcased examples of innovative approaches that are being explored in Canada and are helping to address the system's needs while highlighting some innovative solutions from around the world that could be valuable to Canada. Panellists jointly identified and discussed gaps and opportunities in a new energy landscape.

Discussions drew upon the experiences of governments and innovative companies across Canada and further afield, and built upon global insights captured in IRENA's reports including Innovation landscape for a renewable-powered future, Innovation Outlook: Smart charging for electric vehicles, Renewable solutions for refugee settlements, Quality Infrastructure for Smart Mini-Grids, Reaching Zero with Renewables, Capturing Carbon, Green Hydrogen Cost Reduction and the upcoming report Innovation Landscape for Smart electrification of end-use sectors.

OPENING REMARKS

The event was opened by **Francesco La Camera,** IRENA's Director General and **John Aldag**, Member of Parliament and Chair of the Standing Committee on **Natural Resources Canada.**

Their remarks acknowledged the successes of capacity-breaking deployments of renewables globally and their continual cost decline but underlined major challenges in integrating renewables and energy-related technologies at a mass scale in energy systems. The scene was set around the central role the innovations play in tackling these challenges, and how innovations cannot be just about technology but require a more systemic approach, where technology is combined with novel business models, innovative regulations and market design, digitalisation and more optimised system operation; and how these solutions must then be implemented coherently through careful planning and smart policymaking.

They welcomed the IRENA Innovation Day: Canada as a way to connect a diverse mix of experts, policymakers, and innovators from Canada with the international IRENA community for a two-way exchange about challenges and innovative solutions to decarbonise power and end-use sectors. They acknowledged Canada's global leadership in clean energy with many commitments and efforts to clean energy that predisposed the event for insightful discussions between public and private stakeholders on their work in transforming the energy system through innovation and collaboration.

DAY 1: INNOVATIVE SOLUTIONS TO DECARBONIZE THE POWER SECTOR

SESSION 1: MINI-GRIDS OF THE FUTURE

Renewable energy mini-grids are a form of integrated energy infrastructure with distributed energy generation resources and loads. They provide the autonomous capability to satisfy electricity demand through local generation, mainly from distributed renewable energy sources. They can be also connected to the main grid. The session explored innovative solutions in off-grid, remote areas and islands, including interconnecting mini-grids together or with the main grid to increase their resilience and reliability, allow the integration of higher shares of renewable electricity and in turn decrease costs. The panel was **moderated by Dr Emanuele Taibi**, IRENA's lead analyst in the Power Sector Transformation strategies team. Two scene-setting presentations opened the session:

The global perspective: Aakarshan Vaid (Associate Programme Officer, Power System Flexibility (REmap), IRENA)

- **Global installed capacity for off-grid renewable mini-grids with a high potential for grid connection amounts to 4.2 GW.**
- **When connected to the main grid, mini-grids provide numerous services** ranging from ancillary services, flexibility, and the integration of distributed energy resources. Benefits for consumers include improved reliability of supply, clean energy access, revenues and savings.
- **Mini-grids with assured quality can enable resilient energy systems for small islands,** but require a different set of standards and codes. After Hurricane Maria in 2017, Puerto Rico developed regulations for mini-grids. The 2018 regulations identify the applicable codes and standards and define 'renewable microgrids' as those that can generate 75 % of their energy from renewable energy resources.
- **In refugee settlements, mini-grids are key to increasing the use of renewable and providing reliable access to clean electricity.** The solutions that provide various benefits include solar lighting kits, solar home systems, mini-grids with solar PV and battery storage, solar water pumping and grid-connected renewables.
- **A lack of energy data is a major obstacle to more effective planning and operation of renewable mini-grids.** Cost-efficient, easily available energy loggers are crucial to properly measure renewable energy systems' performance. Data on household income is equally important in shaping market-based cash assistance and scaling up the energy supply for communities relying on mini-grids.
- **Considerable synergies can be gained from international collaboration.** Such collaborations can be between the public and private sectors and specialised agencies.

Canadian perspective: Kathleen Lombardi (Science and Technology Advisor, NRCan)

- **Almost 300 remote communities and industrial sites across Canada are not connected to the North American grid.** These communities rely entirely on diesel for heat and electricity generation. Two-thirds are Indigenous communities.
- **The integration of renewables into mini-grids is key and requires a holistic approach with adequate policy support.** Successful integration of renewables requires all stakeholders included in decision making with assumed roles: communities as co-decision makers and project leaders, utility companies purchasing and providing reliable power, regulators setting policies and overseeing energy pricing and local and federal governments managing natural resources and providing funding.

» **Community ownership of renewable energy assets is critical in generating long-term economic benefits** through revenue and employment and **promoting energy sovereignty**. **Community leadership models** can enable innovative ownership and business models for such projects.

The following **panellists** joined the discussion:

- **Shane André**, Director of Energy Branch, Yukon Government
- **Peter Kirby**, President and CEO of Taku River Tlingit Corporations
- **Louise Mathu**, Lead consultant of Gennis Consulting
- **Tammy Riel**, Director of Three Nations Energy

Highlights from the discussion:

» **Renewable-based mini-grids in remote communities offer multiple benefits** including lower volatility vis-a-vis fossil fuel prices, diminished diesel dependence, higher resiliency of power systems and improved affordability.

» **The roles of energy actors have changed.** The role of utilities changed from being a sole energy provider to becoming a backbone of the system and enabler. New players traditionally not consulted for energy matters, such as communities, are becoming parts of new partnerships.

» **Mini-grids can foster community empowerment & self-sufficiency while providing opportunities for skill development and creating local jobs.** Consumers are empowered through their involvement in energy production, with several examples from the Yukon northern community, Taku River Tlingit Projects and Fort Chipewyan community.

- Taku River Tlingit First Nation's renewable energy projects provide long-term revenue and allow the development and promotion of sustainable resource management, GHG reductions and affordable energy. This results in self-sufficiency and improved and reliable energy access with opportunities for skill development.
- By owning a solar farm, Fort Chipewyan has provided economic opportunities and built knowledge about renewable energy. The partnership has led to several memorandums of understanding leading to more partnerships with ATCO Group (a group of Canadian Utility companies) and other groups. This enables the development of new innovative solutions to old problems as well as the opportunity to enjoy enhanced socio-economic benefits including training for the local communities.

» **Technology innovation is a key enabler for a rapid expansion of electricity access in remote communities.** Micro-hydropower systems, solar PV systems, energy storage technologies and digital technologies are defined as key areas of development. **Energy storage technologies** provide the required flexibility. **Digital technologies** such as remote monitoring of local mini-grids provide a great benefit in terms of safety, security and lower operating costs.

» **Mini-grid applications can help integrate higher shares of renewables into the grid but require a holistic approach to innovation and an adequate policy framework to succeed.** Far-reaching innovations in clean energy technologies must be accompanied by innovations in regulations and a strong engagement between public authorities, local communities and the private sector. Successful cases in Canada and Africa where innovative regulation allowing mini-grids to become electricity providers unlocked innovative business models with IPPs and PPAs combined with Community Ownership models.

» **International collaboration and exchange of best practices is an important catalyst in scaling-up renewable solutions for energy access globally.** Such collaboration is needed between countries and regions across the world.

Session 2: Innovative Hydropower Solutions for a Clean, Reliable and Flexible Grid

Hydropower is a cost-effective electricity source. It offers high efficiency, operational flexibility and low operating and generation costs. As one of the oldest and largest sources of renewable energy, hydropower is a mature and extremely flexible electricity generation technology while being continually renewable, owing to the recurring nature of the hydrologic cycle. Discussions in this session explored the innovative solutions in hydropower and pumped storage hydropower (PSH) to maximise its contribution to the grid, integrate and balance higher shares of variable renewables by offering a unique range of system services including provision of inertia, operation reserves, load following and time-shifting to long-duration storage. The panel was **moderated by Roland Roesch**, Deputy Director of IRENA's Innovation and Technology Centre. The session was opened with two scene-setting presentations:

The global perspective: Carlos Ruiz (Associate Programme Officer, Renewable Technology, IRENA)

- **To get to net-zero by 2050, conventional and pumped storage hydropower capacity must more than double**. Currently, around 1.3 TW of hydropower is in place, which grew by 70% in the past 20 years. Compared to the growth of solar (440x) or wind (15x), growth in hydropower is small.
- **Not all new capacity has to come from new hydropower projects.** Some capacity will come from **retrofits and refurbishments** which offer the **opportunity to innovate, introduce new technologies and modernize** plants in a way that fits today's power system. Any new projects should be developed under **transparent sustainability criteria.**
- **With the higher shares of variable renewable, the role of hydropower has changed** from being a source of baseload generation to being used as **peaking capacity and a source of ancillary services**.
- **A large investment is needed** and this will only be **possible if policies and markets that appropriately value the wide range of hydro services are put in place**. Under 1.5°C scenario, around USD 85 billion per year investment is needed for conventional hydropower, and almost USD 9 billion per year investment is needed for pumped storage hydropower.
- To address and discuss these issues with its member countries and interested stakeholders, **IRENA has established the Collaborative Framework on Hydropower. As a key country** in this Collaborative Framework, **Canada** shares their best practices and challenges and encourages other countries to follow this suit.

The Canadian perspective: Thomas Levy (Senior Science and Technology Advisor, NRCan)

- **Hydropower plays a key role in power generation in Canada** representing 60% of total generation and in some provinces over 90%. Small hydro (<50MW) represents around 5%. Globally, Canada is the 3rd largest hydropower producer.
- **With an increase of variable renewables in the power system, the value of hydropower will be in providing system flexibility including across regional grids**. For example, Minnesota Power reached 50% renewables in 2021 with Canadian hydropower. Hydropower will play a decarbonisation role and in providing flexibility in grids of Eastern Canada through Natural Resource Canada's project Atlantic Regional Transmission Loop.
- **To further explore the value of hydropower flexibility across North American countries and regions, Natural Resources Canada and the U.S. Department of Energy launched the NARIS** (North American Renewable Integration Study) project**.** The project focuses on the modernisation of grid operation, and directly identified the role of hydropower. According to the outcomes of the study, **hydropower flexibility could bring multiple benefits** in terms of annual operation cost reduction of up to USD 2.3 billion, renewable generation curtailment reduction, mitigation of emissions from thermal generation and emissions from the power system by a further 1.3%.

The following **panellists** joined the discussion:

- **Viviane Aubin,** Engineer, Hydro-Québec
- **André Dagenais**, Network Planning Engineer, Hydro-Québec
- **Chelsea Donelon**, Manager – Energy Innovation, TransAlta
- **Rebecca Ellis**, Energy Policy Manager, International Hydropower Association
- **David Havard**, Head of Product Marketing, General Electric Renewable Energy

Highlights from the discussion:

» **Conventional and pumped storage hydropower offer cost-effective and highly efficient energy supply, capacity and flexibility services that are critical for the integration of higher shares of variable renewables and the overall energy transition.** These include ancillary services, the ability to quickly respond to demand loads, enabling renewable energy integration, providing storage and reducing overall system costs. Its services are becoming increasingly valuable and vast amounts of new hydro capacity will be needed by 2050 to meet decarbonisation targets.

» The increase in value is currently not being reflected in the market in many cases, making it clear that **innovative policies, business models and market mechanisms that appropriately reward the full range of hydropower services are a priority.**

» **Increasing shares of variable renewables are bringing changes to power system dynamics, affecting the role of hydropower assets,** requiring more frequent operation start-ups and shutdowns and a wider operational range. Technology is advancing rapidly to mitigate possible negative effects with new operating regimes as most of the hydropower assets were not designed to operate under these dynamic conditions. The **use of big data and wider deployment of digital technologies** can support new turbines to operate under these demanding operational conditions and pave the way for improvements also in terms of sustainability. **GE Renewables** presented a case study where they managed to expand the operating range of a PSH plant without the need for new equipment, through new sensory and simulation technologies.

» **Canada has vast amounts of hydropower resources, yet some of the flexibility challenges are occurring in provinces that are aiming to phase out fossil fuel-based power plants with limited hydropower assets and/or inadequate grid interconnections.** Innovative projects such as WaterCharger Battery Storage Project, developed by **TransAlta** in Alberta, maximize the flexibility provision potential which is essential. **Hydro-Québec** aims to have its grids transmit hydroelectricity's flexibility to neighbouring jurisdictions. Their priorities include ways to maximize grid capacity, integrate variable renewables, finance new infrastructure, plan for evolving transmission needs, including time-dependent issues, and allow for vertical planning optimisation for all transmission grid users with new technology management strategies. This highlights the importance of regional integration and increased interconnection, and raises the issue of identifying innovative ways to finance the grid expansion needed to accommodate increased variable and distributed energy resources.

» **Pumped storage hydropower should be considered a key enabler of the energy transition as a proven energy storage technology.** It has the potential to offer grid services, which will be increasingly important with the phasing out of fossil fuel generation. The Pumped Storage Hydropower International Forum, led by the **International Hydropower Association**, offers reports and tools to help guide prospective installations across the globe.

» **Initiatives like the IRENA's Collaborative Framework on Hydropower provide an excellent platform to host such exchanges and accelerate progress**. Many countries are facing similar challenges including the necessity of long transmission lines. This opens the door for international cooperation and potentially an exchange of good practices to address similar types of challenges.

DAY 2: INNOVATIVE SOLUTIONS TO DECARBONISE THE END-USE SECTORS

SESSION 3: ADVANCEMENTS IN DECARBONISING ON-ROAD TRANSPORT

On-road transport plays a vital role in the world's economy by facilitating the movement of people and merchandise. Yet, it comes at a cost, as it is a major source of emissions given its current heavy reliance on fossil fuels. On-road transportation represents a sector with the lowest level of renewable energy use but with the largest potential. During the session, discussions explored some of the challenges and opportunities in technologies, enabling frameworks and business models in transitioning to low-carbon transport for the road freight segment and the needed infrastructure. The session was **moderated by Francisco Boshell**, Renewable Energy Technologies Standards and Quality Infrastructure Analyst from IRENA. First, the presentations on global and Canadian perspectives set the scene for the follow-up discussion:

The global perspective: Arina Anisie (Analyst, Renewable Energy Innovation for Developing Countries, IRENA)

- **To reach net-zero in the heavy-duty vehicles sector, three solutions are being discussed: battery EVs, fuel cell EVs and cars using advanced biofuels.** They come with various considerations: in terms of EVs, the battery weight, drive range and the impact on the power grid are being discussed; the efficiency, costs and available infrastructure are key considerations for the deployment of fuel cells EVs; while biofuels are dependent on feedstock availability and its sustainability. While there is a role for all three options, battery trucks are becoming the main solution in many countries.
- **Efficient adoption and integration of electric trucks are only feasible if energy authorities and grid operators consider charging infrastructure for EVs, including electric heavy-duty trucks, in their investment plans and long-term energy planning roadmaps.** This integrated planning is particularly critical as the bank battery of the power system may lie with the EVs. Under the 1.5°C scenario, by 2030 approximately 9 million electric trucks are projected to be on roads, offering 3.5 TWh battery capacity. This would increase to 60 million electric trucks by 2050 offering 24 TWh battery capacity, while the stationary utility storage capacity would be around 11 TWh.
- **Developing the charging infrastructure while considering the impact the extra load will have on the power grid is of great importance.** While most of the charging is foreseen to take place overnight at depots, en-route charging is essential to decrease range anxiety and to scale up to longer distances and wider employability of electric trucks. To decrease the extra load on the power grid at depots, national governments should adopt strategic approaches for a public fast-charging network for electric trucks and incentivise investments in en-route charging. Hybrid charging systems are also considered by several countries, combining stationary charging points with catenary charging in segments of highways with high traffic volume.
- **Energy storage systems and load management reduce the need for distribution grid and transformer expansion.** To manage peak demand, charging hubs should be combined with on-site renewable generation and stationary batteries.
- **The systemic approach to innovation is key to a successful decarbonisation strategy of heavy-duty vehicles.** This approach represents an enabling environment that includes innovation in infrastructure, business models, market design and regulations, and system operation and planning. Most importantly, all stakeholders from power and transport sectors need to co-operate and plan together for a smart integration approach. Numerous examples around the world already offer lessons learned and replicable solutions that combine innovations across these areas.

The Canadian perspective: René-Pierre Allard (Senior Technical Advisor, NRCan)

- **Road transport is the largest contributor to Canada's overall transportation sector emissions** with circa 2.5 million Medium and Heavy-Duty Vehicles (MHDVs) on the roads.

- **To drive down emissions from existing fleets and technologies, retrofits and fuel efficiency improvements will be critical to attracting investments**. Canada's government is also focusing on ways to encourage demand for zero-emission (ZE) MHDVs and their local manufacturing and supply chain, carbon pricing, greenhouse gas emissions and fuel standard regulations.
- **The Canadian government introduced various programmes to incentivize investments in ZE-MHDVs.** The government introduced a 100% tax write-off for business investments in eligible ZEVs, Energy Efficiency Program, Green Freight Assessment Program, Zero-Emission Transit Fund, Zero-Emission Buses Initiative, ZEVIP (ZEV infrastructure program), ZEV Awareness Initiative, with funds for RD&D.
- **Canada sees particularly three zero-emission MHDCs emerging: battery EVs, fuel cells EVs and plug-in hybrid EVs.** The speed of their deployment depends on cooperation between public and private, national and local stakeholders.
- **Several barriers hinder ZEVs adoption in Canada** particularly high initial capital costs, uncertainties related to benefits, low level of technological readiness, unclear operational and integration costs and concerns regarding safety, maintenance, and reliability.

The following **panellists** joined the discussion:

- **Hussein Basma,** Associate Researcher, International Council on Clean Transportation
- **Mathieu Larivière**, Senior Manager from Natural Resources Canada
- **Amanda Mesluk**, Senior Manager Industry Development, Alberta Motor Transport Association
- **Josipa Petrunic**, President and CEO, Canadian Urban Transit Research and Innovation Consortium

<u>Highlights from the discussion:</u>

- **Economic viability is a key metric for fleet owners and operators when pursuing decarbonisation pathways for MHDVs.** ZEVs are still more expensive than conventional vehicles, but associated indirect costs (operation and maintenance, refuelling, etc.) are needed to be incorporated into the equation as well. There is a high level of variability in terms of profitability of the business cases for electric fleets between different regions of Canada due to differences in electricity prices. Supporting policies constitute the key incentive in their market uptake, especially through economic incentives. Net-zero battery-electric trucks are expected to be economically viable before 2030, even without policy incentives.
- In terms of competitiveness, **in the EU, BEVs (Battery EVs) are leading the market and market development in Canada is likely to follow a similar pathway.**
- **Real-world data collection and analysis in the transport sector is becoming increasingly important and can be facilitated by digital technologies.** Real-world emission data and vehicle performance data provide considerable added value for the market readiness of clean transportation technologies. Data collection at this stage is crucial to increase confidence among policymakers.
- **For successful smart charging strategies, a systemic approach to innovation is far-reaching.** Most of the technology is available today, but innovations in regulations, business models, system operation and planning are lagging. More support is needed to unlock the EVs' market potential and enhance their integration into the power system. Government programmes for effective benchmarking, labour training and public and private sectors collaboration must be put in place.
- **In some parts of Canada, the use of green hydrogen for medium and heavy-duty trucks has substantial potential compared to other transport sub-sectors.** Several projects are already coming online in Alberta in the area of hydrogen fuel cell heavy-duty vehicles. Cross-sectoral collaborations in the engineering, design and other aspects are key in developing the climate-resilient assets that advance the market adoption. Building the demand for green hydrogen must be a key focus but depends on the production cost of renewable hydrogen. Policies to close the price gap between green and grey/blue hydrogen such as carbon pricing should be adopted to mitigate financial risks.

» **Depending on local conditions, the adoption of BEVs and hydrogen fuel cell trucks will differ.** Some OEMs (Original Equipment Manufacturers) believe BEVs are enough to satisfy market needs, while others believe hydrogen fuel cell trucks would be needed for applications with very large driving ranges.

Session 4: Innovative Solutions to Decarbonise Iron and Steel Sector

Steel is a critical material for industrial development. The production is concentrated in a handful of countries, which makes it a strategically important industry for various countries. Discussions in this session explored pathways to accelerate the development and dissemination of renewables and enabling solutions, including technologies and processes, enabling frameworks and business models to decarbonise the iron and steel industry. The session was **moderated by Ted Todoschuk,** Board Chairman of the Canadian Carbonisation Research Association. Two scene-setting presentations opened the session:

The global perspective: Martina Lyons (Associate Programme Officer, Innovation and End-Use Sectors, IRENA)

» In 2020 **global steel production** amounted to **1 878 Mt**, with half of it coming from **China,** followed by EU27, India, Russia, the US and Japan. Canada produces 1% of global steel. The sector is a major energy and process-related CO_2 **emitter**, amounting to **8% of global** emissions. The majority of its energy use (up to 33 EJ/year) relies heavily on fossil fuels. **Renewables** play a **negligible** role of **5%.**

» **There is an important but limited role of energy and material efficiency in decarbonising the sector.** To reach net-zero, the focus should be on two decarbonisation pathways:

- **Green H_2-DRI (Direct Reduced Iron):** Need for **green H_2** for example by decoupling the iron from the steel production into areas of low-cost H_2. This would **reduce CO_2 emissions by 0.7 Gt per year. HYBRIT is the only green H2-DRI commercial plant** with several other projects in the pipeline.
- **CCS/CCU:** the advantage of its applicability to existing processes but emphasised a lack of deployed solutions and transportation and storage. The only example is the **DRI-EAF CCS plant in Abu Dhabi, there is no BF-BOF (Blast Furnace – Basic Oxygen Furnace) CCS plant.**

» Policymakers and industry recognise a **need to deploy H_2-DRI even with grey/blue H_2 but with a clear pathway to the green transition.**

The Canadian perspective: John Smiciklas (Interim Director, Canadian Steel Producers Association (CSPA))

» **The Canadian steel sector** is a **USD 15 billion industry**, a major job creator and represents critical suppliers to North American construction, energy, automotive and other manufacturing sectors.

» The Canadian steel sector emits **16 Mt of GHG emissions** accounting for **2% of Canada's GHG emissions**. Between 1990 and 2018, the sector reduced GHG emissions in absolute terms by 17%. Newly announced projects by ArcelorMittal Dofasco and Algoma will remove 6 Mt/year bringing emissions down to 10 Mt per year.

» In March 2020, **CSPA launched Climate Call to Action to achieve net-zero CO_2 emissions by 2050**. Canadian steel production is already amongst the lowest CO_2 intensity steel in the world both through BF-BOF and DRI-EAF (Direct Reduced Iron – Electric Arc Furnace) routes. New projects in the pipeline benefit from the financial support through the **federal Net-Zero Accelerator programme.**

» **CSPA and Natural Resources Canada launch a study to examine over 125 technologies across 4 pathways:** energy efficiency, GHG reductions, implementation of the technology roadmap within

the industry and net-zero technological roadmap to access the opportunities and gaps to be addressed by innovation across technologies, regulations and business models.

The following **panellists** joined the discussion:

- **Chad Cathcart,** Director of Research, Stelco
- **Kashif Rehman**, Director of Product Development and Technology, Algoma Steel
- **Ka Wing Ng**, Research Scientist, Canmet-Natural Resources Canada
- **Tony Valeri**, Vice President of Corporate Affairs, ArcelorMittal Dofasco
- **Jean-Pierre Birat**, CEO, IF Steelman

Highlights from the discussion:

» **The Canadian steel industry is on track to reduce its emissions intensity by more than 40% by 2035 and reach carbon neutrality by 2050.** Industry and government are pursuing several undertakings including RD&D efforts in achieving sustainable steel production by upgrading small blast furnaces, and coke batteries or investing in electricity co-generation projects.

» **Canadian steel companies and researchers explore five major complementary pathways to decarbonise the iron and steel sector.** These pathways are at different technology development stages. Energy and material efficiency, bioenergy and electrification or utilisation of waste heat are already considered mature technologies. Carbon capture, utilisation/storage and green H_2-DRI-EAF are both technically viable but are neither well-developed nor ready for a mass scale-up.

» **H_2-DRI-EAF**:

- Many steel companies are **transitioning from BOF to EAF steelmaking**. This will eliminate polluting cokemaking and reduce CO_2 emissions. Algoma and ArcelorMittal Dofasco have started the transition aiming to finalise it by 2029. This will reduce up to 70% of their GHG emissions.
- The **sufficient production of green H_2 in Canada is a challenge**. Industry and the government are working together to build necessary infrastructure including renewable and other low carbon electricity generation and transmission and H_2 supply chain. Ontario is at advantage with 96% of electricity generated from non-carbon emitting sources. With **power demand projected to increase substantially** by 1.5-times by 2030 and more than 3-times by 2050 with EVs and electric heating for building as major drivers driving electricity prices up, production of green H2 for iron production will be challenging.
- **Relocating the iron production to areas of iron ore mines and low-cost electricity can be a game-changer**, contributing to **significant CO_2 emissions reduction.** This approach has been explored in theory in the case of Australia.

» **CCS / CCU:** Stelco is at the forefront, but further exploration of storage and particularly CO_2 uses is necessary. There are currently no announced projects/plants.

» **Bioenergy**: NRCan's Canmet Laboratories, a leading federal R&D centre, explores the substitution of coal with renewable solid biocarbon in the existing iron and steel making processes, as a reducing agent and energy source. It comes with several limitations including a need to enhance biomass properties by pyrolysis, and continual reliance on fossil fuels as the current design of blast furnaces does not allow complete replacement of coal with biocarbon.

» **To reduce CO_2 emissions, electric arc furnaces can use steel scrap.** Its availability is currently limited by the long life span of steel products. Steel demand will keep growing coming also from emerging economies. In 2019 almost 800 Mt of steel scrap was available globally, and by 2050, it is expected to reach 1.3 billion tonnes.

- **These technology pathways have significant implications for infrastructure decisions.** Discussions among governments, utilities and industry on power transmission lines, hydrogen and CO_2 transport and storage need to be held in advance to avoid future bottlenecks.
- These **technological options must go hand in hand with system integration and optimization, systemic innovation** in business models and market design, and **strategies co-developed by public and private** actors. **International collaboration** cannot be neglected.
- Since 2004, **Europe launched several green steel projects, with the first one being ULCOS,** finance by the EU. These projects focus on the analysis of various technologies and processes between then and 2050 in terms of energy needs, CO_2 emissions and cost of production, which is oftentimes a critical bottleneck in pursuing those pathways.
- **Net-zero energy transition requires a multi-faceted approach.** This requires strategy, shared vision, goals and co-owned roadmaps developed by public and private/national and international stakeholders. The enabling conditions can secure new forms of energy including a demand-driven push to deliver energy that works for transforming industries. In this way, roadblocks can be identified along the pathways before reaching them. Large industries and governments, in partnership with energy providers, need to find the way forward and start executing projects. An inter-industrial, collaborative action is required to successfully achieve change.

CONCLUSIONS

Canadian stakeholders showcased remarkable progress in deploying innovative solutions to decarbonise their power and end-use sectors from innovative solutions for mini grids and hydropower, to various technology pathways to decarbonise on-road transport and the iron and steel sectors. Discussions with international stakeholders unsurprisingly uncovered how Canada faces similar challenges decarbonising and integrating higher shares of variable renewables.

Panellists acknowledged that innovative solutions tackling these challenges are enabled by technology innovations but considered that impactful solutions would require a **systemic approach** that is broader than technology and **combines technology innovations with innovations in business models, digitalisation, market design and system operation**. Whilst discussions acknowledged optimal combination of innovations is **country-specific**, speakers recognised **common challenges** intrinsic to the power systems globally:

- a **greater need for flexibility** of generation, transmission and system operations to maintain the balance between generation and load uncertainty;
- **greater use of big data and the broader deployment of digital technologies,** considering real-world data collection and analysis as the key to increasing the confidence of policymakers and providing added value for the market readiness of any technology and sector; and
- a **greater need for a mass scale-up of technologies in the end-use sectors** to seize new opportunities for various actors.

Participants emphasised the importance of creating opportunities for a diverse group of innovators and policymakers to gather, discuss challenges, and share insights into the deployment of various innovative solutions. As most countries are facing similar challenges in their journey to the decarbonization of end-use sectors and integration of variable renewables, international collaboration and exchange of best practices in implementing renewable energy solutions would accelerate the scale-up of those technological solutions globally. Global initiatives such as IRENA Innovation Days, IRENA Innovation Weeks and Collaborative Frameworks provide an excellent platform to host such exchanges and accelerate progress.