Innovation Roadmap:

Mission Integrated Biorefineries

Executive Summary

The Mission Innovation Integrated Biorefineries Mission offers the opportunity to leverage international expertise and collaboration to support the development of bio-based Sustainable Fuels, Chemicals, and Materials (SFCM) which will be essential to reduce greenhouse gas emissions, improve supply chain resiliency and diversification, and support the global transition to a net-zero economy, with a goal of replacing 10% of fossil-based feedstock for fuels, chemicals and materials with sustainable alternatives by 2030. Therefore this roadmap serves as a guide to identify gaps and challenges in current biorefining value chains, prioritize key actions to support the Mission, as well as guide the Mission's overall path in achieving its goal.

To support the development of the Innovation Roadmap, participating members conducted an exhaustive analysis of existing domestic policies, programs, projects, and roadmaps to identify gaps in program and policy support for integrated biorefining. Using this analysis and input from domestic stakeholders, this Innovation Roadmap highlights eight key actions the Mission will take to help guide the pillars and achieve the Mission's goals. They include:

1) Improving support for Research, Design and Development (RD&D) through workshops to identify key challenges and solutions for biorefining technologies and conversion processes;
2) Developing a research initiative to support RD&D on new uses of biomass feedstock and end-product to improve co-processing;
3) Supporting energy efficiency and/or conversion process efficiency at existing pilot and demonstration plants to support uptake of technology, demonstrate technological viability, and support efforts to commercialize projects with cost-reductions;
4) Reviewing and comparing domestic biorefining legislation and regulations to reduce administrative burden for industry and more easily facilitate the transition to commercial operations;
5) Developing an integrated biorefinery business plan/framework in collaboration with industry to fast-track commercialization by improving awareness of business model types, helping de-risk investments, and enabling new pilots and demonstrations;
6) Developing internationally recognized standards to support biorefining processes, technology and end-product up-take, and market demand;
7) Developing internationally recognized sustainability criteria for biorefining processes and end-products to improve consumer and investor confidence in end-products;
8) Developing and harmonizing a life-cycle analysis (LCA) methodology for biorefineries to improve greenhouse gas emission reporting and comparability between biorefining processes and end-products;

All actions will start in the next sprint with a priority for action 1.

Contents

1. Introduction

The Mission

Launched in November 2021 as part of Mission Innovation 2.0[1], **the Mission Innovation Integrated Biorefineries Mission** offers the opportunity to leverage international expertise and collaboration to support the development of bio-based Sustainable Fuels, Chemicals, and Materials (SFCM) which will be essential to reduce greenhouse gas emissions, improve supply chain resiliency and diversification, and support the global transition to a net-zero economy.

However, while bio-based SFCMs are essential to global decarbonization and a sustainable future, they remain expensive to manufacture and difficult to attract large-scale investment needed to manufacture them competitively. Therefore, the goal of the **Mission Integrated Biorefineries[2]** is to develop and demonstrate innovative solutions to accelerate the commercialization of integrated biorefineries with a target of replacing 10% of fossil-based feedstock with low-carbon, sustainable bio-based fuels, chemicals and materials by 2030.[3,4,5] To do so will require replacing fossil-based energy, chemicals, and materials by an estimated 9 exajoule (EJ) fossil input equivalent.[6]

Therefore, the Mission will seek to support the development of integrated biorefineries, defined as a facility for the integrated and sustainable processing of biomass into a spectrum of marketable products and energy,[7] to maximize the production of bio-based SFCMs. Improving the technological innovation and cost-competitiveness of integrated biorefineries can help increase production capacity of bio-based SFCMs through co-processing and manufacturing of multiple end-products using one or more feedstocks and conversion processes. This in turn will reduce manufacturing costs, improve feedstock-use and manufacturing sustainability.

Cross-sectoral collaboration and coordination will be required to support this Mission and will require active participation from industry, government, and academia, through public-private collaboration and partnerships. Brazil, Canada, the European Commission (EC), the United Kingdom (UK), India, and the Netherlands will work together to share their expertise and resources to accelerate the development of integrated biorefineries. These members in the Mission will advance this work simultaneously through three pillars:

1. Research, development and demonstration (RD&D) that focuses on technologies and processes that improve both the cost competitiveness of bio-based SFCMs and the sustainability of their production.

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[1] Mission Innovation. (2022). *Mission Innovation*. http://mission-innovation.net/.
[2] Mission Innovation. (2022). *Integrated Biorefineries Mission*. http://mission-innovation.net/missions/integrated-biorefineries-mission/.
[3] The Mission's goals are based on the International Energy Agency's *Net Zero by 2050* analysis and the NOVA Institute's *Turning of the Tap for Fossil Carbon* analysis.
[4] International Energy Agency. (2021). *Net Zero by 2050*. International Energy Agency. https://www.iea.org/reports/net-zero-by-2050
[5]Ferdinand Kähler et. Al. (2021). *Turning Off the Tap for Fossil Carbon*. NOVA Institut. https://renewable-carbon.eu/publications/product/turning-off-the-tap-for-fossil-carbon-future-prospects-for-a-global-chemical-and-derived-material-sector-based-on-renewable-carbon/.
[6] The total amount of green carbon needed to reach the additional 10% fossil carbon reduction MI goal is calculated by adding the targets of the member countries. The total amount of low-carbon energy that is needed equates to 9.1 EJ carbon equivalent. The total available biomass globally is 100 - 150 EJ/y (see annex 4)
[7] This definition comes from the International Energy Agency Bioenergy Task 42. https://www.ieabioenergy.com/wp-content/uploads/2013/10/Task-42-Booklet.pdf

2. Pilot scale demonstrations that support new and novel technologies and facilitate cost-competitive manufacturing of bio-based SFCMs.
3. Regulatory and policy support through coordination and collaboration with government, academia, industry and other stakeholders to identify challenges in biorefining and develop supportive policy and regulatory environments for bio-based SFCM production.

In order to support the Mission's goals and advance work across these three pillars, Mission members will also work closely with one another and domestic stakeholders, other Missions, the Mission Innovation Innovation Platform, and other international initiatives (i.e. International Energy Agency; IEA Bioenergy TCP Task42, Clean Energy Ministerial Biofuture Initiative and Campaign; the International Renewable Energy Agency).

The Innovation Roadmap

To support the development of the Innovation Roadmap, which will guide the Mission's pillars and progress towards its goal, participating members reviewed existing domestic policies, programs, and projects to identify gaps in program and policy support for integrated biorefining. This analysis was also supplemented with domestic consultation workshops, where participating members held national stakeholder workshops to hear from stakeholders about current challenges and how the Mission could support the development of domestic biorefining value chains.

Using this analysis and input from domestic stakeholders, this Innovation Roadmap highlights eight key actions the Mission can take to help guide the pillars and achieve the Mission's goal. They are outlined in the last chapter of the Roadmap.

While these actions have been identified as a result of the Mission's analysis, it is anticipated that further action will be required as the Mission develops. Future collaboration with other Missions and research and innovation initiatives is anticipated as well.

What follows is an overview of existing gaps in current program and policy support for biorefining, as well as existing biorefinery, or biorefinery-related, domestic roadmaps. The three common themes found from the Mission's preliminary analysis are reviewed, followed by areas for collaboration with other Missions and initiatives. The roadmap ends with the key actions the Mission will take to support the pillars and progress towards the Mission's goal.

2. Existing Biorefining Programs, Policies and Projects

To support the development of the Innovation Roadmap and the Mission's key actions, participating members developed a database of domestic biorefining related policies, funding programs and projects.[8] Members also held domestic consultation workshops to identify existing gaps and barriers in their respective biorefining value chains and for which the Mission could help support.

National Policies and Roadmaps

A total of 48 biorefining related policies were identified by participating member countries. These policies were then categorized across four policies areas: Climate Change/Net Zero; Energy/Energy Transition; The Circular Economy; and The Bioeconomy. Just under three-quarters (73%) of biorefining related policies and strategies identified by member countries are focused on supporting climate change mitigation, adaptation, and reaching greenhouse gas reduction targets by specified dates, as well as their country's energy transition with a specific focus on heavy emitting industries

[8] These policies, programs and projects, as well as the database summary and analysis can be found in Annex1 and 2 of this roadmap.

and supporting low-carbon fuel production. However, there is limited support from domestic policies for biorefining and the production of bio-based SFCMs, as just over one quarter (27%) of the policies identified are focused specifically on biomass and circularity (e.g. circular bioeconomy and circular economy policies). This is also consistent with domestic innovation roadmaps[9] (see table 1), where low-carbon fuels have primarily been the focus.

Table 1: Domestic Biorefining Related Roadmaps

Country	Roadmap (click for link)	Year	Focus
Brazil	IEA Roadmap Biofuels (input, not their roadmap)	2017	Low-carbon fuels
Canada	Roadmap for biojet in Canada (internal doc)	2020	Low-carbon fuels
	Forest Bioeconomy Framework	2017	Circular bioeconomy
	Hydrogen Strategy	2020	Low-carbon fuels
	Advanced Biofuels Strategy	2019	Low-carbon fuels
European Union	EERA Strategic Research and Innovation Agenda	2021	Low-carbon energy
	Biobased Industries Vision	2012	Low-carbon chemicals
	Strategic Energy Technology Plan	2018	Low-carbon energy
	Bioeconomy Strategy	2018	Circular bioeconomy
	Strategic Research and innovation Agenda	2016	Low-carbon fuels
The Netherlands	MMIP-6 Biorefineries Roadmap		Biorefining
The United Kingdom	The Biorefinery Roadmap for Scotland	2017	Biorefining
India	Roadmap for Ethanol Blending in India 2020-2025	2021	Low-carbon fuels

Key gaps also exist in policies and roadmaps that seek to support broader industrial symbiosis and value chain integration. This was consistent in both reviewing current policies and frameworks and in comments received from domestic industry stakeholders during consultation workshops. Such policies and roadmaps will be important for driving and improving feedstock accessibility, availability, and quality across sectors, as well as leveraging potential cross-sectoral investments in biorefining. In addition, domestic industry stakeholders identified that industrial symbiosis and value chain integration policies and strategies would likely boost investor confidence in biorefining and bio-based SCFM production, as strategic policies and roadmaps support market development, improve investor confidence, and signal forthcoming regulatory and financial support for stakeholders.

[9] See annex 3 for more details

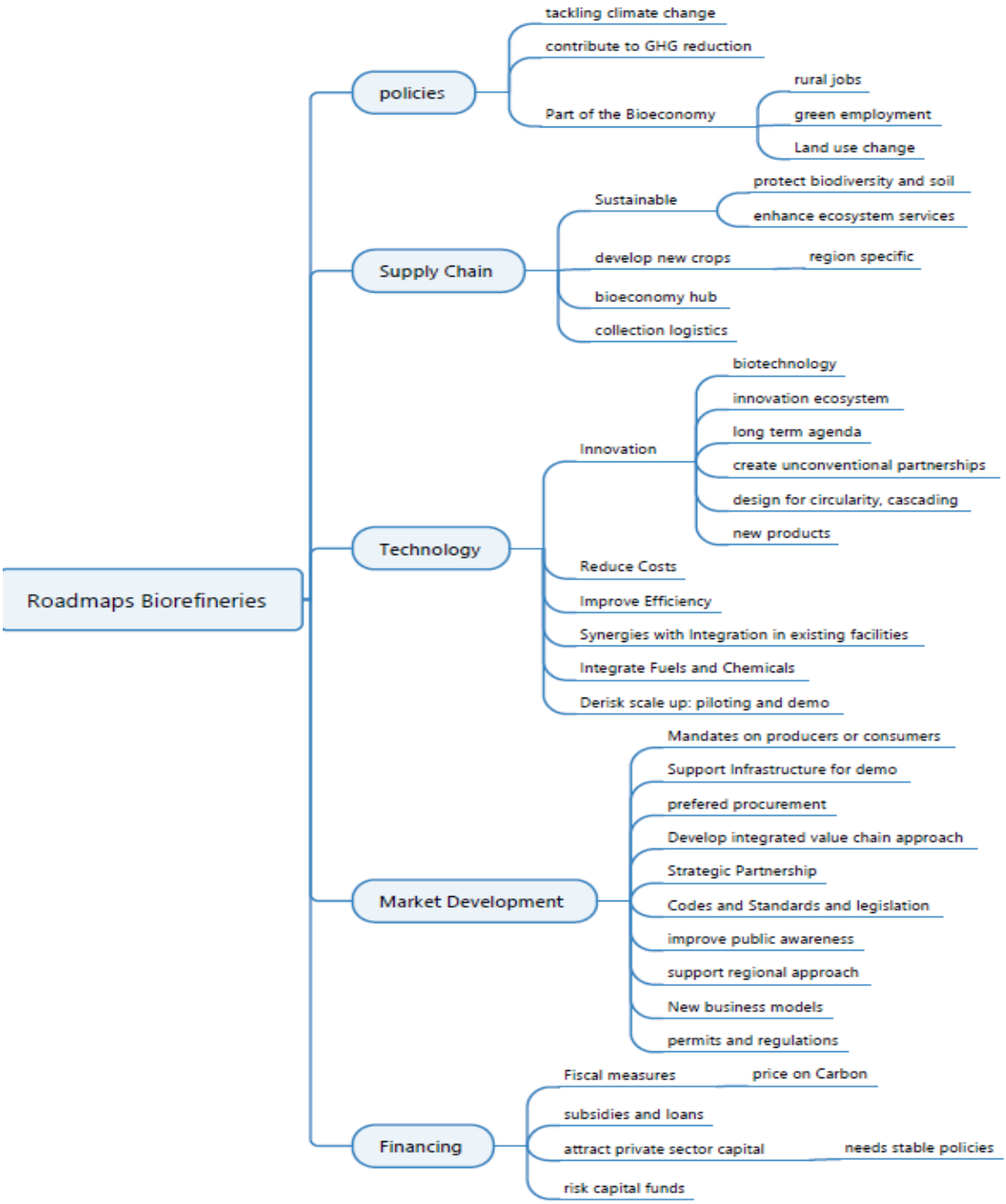

Figure 1 common topics in roadmaps

National Programs

A total of 30 domestic biorefining related programs were identified by participating member countries. Just over half of these programs (57%) provide support to research and development (Technology Readiness Level [TRL] 3-5) and commercial projects (TRL 9). However, while pilot and demonstration projects (TRL 6-8) did receive some support when programs have broad funding criteria, they do receive significantly less support from targeted funding programs (10%). This is also consistent with feedback received from domestic industrial stakeholders, who highlighted that pilot and demonstration projects typically experience the most difficulty in overcoming barriers to scale

up operations and commercialize (e.g. capital expenditures, operational expenditures, achieving scales of economy, investor confidence, and market size).

The most commonly used financial policies to support these programs were grants and subsidies - even when taking into account the technical maturity of projects (i.e. TRL spectrum). Loans and loan-guarantees are only used in programs targeting support for commercial projects (TRL 9). However, while large financial investments are required to overcome capital expenses, a range of different financial policies could be used to support commercialization of biorefineries. For example, investment tax credits or tax rebates could be used to support ongoing investments or retrofits to existing facilities, reducing capital expenses for investors, while wage and training subsidies could be used to support necessary upskilling to improve the cost-competitiveness and operations of biorefining facilities. Stakeholders also identified that while funding for capital expenses is important to support projects, stable financial support for operating expenditures (i.e. OPEX), especially in less technically mature projects as they develop more efficient processes, could support early stages of biorefining projects.

Non-funding programs and initiatives, such as government procurement which can both provide stability for new markets and grow demand for bioproducts, were identified consistently by domestic industrial stakeholders as another mechanism to support biorefining development. Another key gap in programs identified by stakeholders, was the lack of program design to incentivize collaboration between stakeholders across the biorefining value chain. This could be done either by making multi-stakeholder collaboration a requirement or disbursing additional funding for meeting this criteria.

National Projects

A non-exhaustive list of about 1,500 biorefining projects were identified by participating member countries.[10] The majority of projects are found in the European Union and the Netherlands (95%), with almost all commercial projects from Mission members found in the European Union (97%). Nonetheless, there is a greater share of less technically mature projects (i.e. TRL 6-8; TRL 3-5) found in other member countries, with the Netherlands, Canada and India making up a quarter (25%) of pilot and demonstration projects (TRL 6-8), and the United Kingdom, Canada and India making up over one-third (36%) of research and development projects (TRL 3-5).

Agricultural feedstocks make up the majority of feedstocks used across all projects (53%), followed by a combination of other feedstocks such as municipal solid wastes, energy crops and starches and woody biomass. The share of these feedstocks also increases in less-technically mature projects (i.e. TRL 6-8; TRL 3-5), which suggests that new and emerging types of technologies, and/or accessibility to, and availability of, feedstock is improving to allow for the use of these feedstocks to be more economically competitive. However, large gaps exist between these four types of feedstocks as well as algae and marine feedstocks, animal waste, and waste oils.

Biofuels and biochemicals make up almost all end-products produced by identified projects (90%), with less technically mature projects (i.e. TRL 6-8; TRL 3-5) more likely to produce advanced biomaterials. This gap was identified by industrial stakeholders as well during consultation workshops, where a number of stakeholders suggested that current government policies focusing on biofuels production could develop challenges for supporting the broader biochemical and advanced biomaterial market and therefore could limit investments in biorefining (i.e. limit potential

[10] All member countries recognize that this is not an exhaustive list of all biorefining projects from each country and that a number of projects may have been missed in the initial analysis, as well as recognize that a number of projects in all member countries are either planned, soon to be developed or become commercial following this initial analysis.

diversification of end-products). Some also highlighted policies supporting production of other materials would support the broader biorefining value chain. However, there are projects demonstrating the co-production of multiple products demonstrating the viability of integrated biorefineries. In addition, policies supporting materials substitution and reducing embedded carbon in consumer products and the built environment could also help to support marketing and consumer awareness of the environmental benefits of advanced biomaterials leading to increased demand for them and broader development of biomaterials production. This in turn would also further support the business case for integrated biorefineries.

3. Innovation Roadmap of Mission Integrated Biorefineries

The review of existing policies, programs, projects, and roadmaps, as well as consultations with domestic stakeholders, demonstrates that while several important steps have been taken in the right direction, a few key gaps still create barriers for fully supporting integrated biorefinery development, improving their cost competitiveness, and increasing the production of bio-based SFCMs. These include:

- Supporting biorefining RD&D across short, medium and long-term objectives;
- Accelerating support for pilot and demonstration level biorefining projects to support the transition to commercial operations, and improve their cost-competitiveness and financial viability;
- Improving policy and market conditions to de-risk and improve investor confidence needed in the sector, support value chain integration, and provide policy and regulatory certainty to support market growth.

What follows is a more detailed outline of these key gaps as well as what issues requiring further research, funding, and policy support to address them. It is also likely that steps to address them will need to be carried out in parallel with one another as all three key gaps are interlinked and interdependent meaning that actions to address issues in one area will either directly or indirectly have implications on addressing issues in another area.

Research, Design and Development

To achieve cost-competitive bio-based SFCMs, ongoing RD&D is required, focusing on three areas across the biorefining value chain:

1. Biomass supply (e.g. selection of feedstocks, planting rotations, sustainability, waste recovery) and logistics (e.g. harvesting, collection, storage, transport);
2. Conversion processes (e.g. chemical catalysis, bio catalysis, thermochemistry, and their use in combination);
3. End-products and markets.

Research topics will have both short-term and long-term applications.

Biomass Supply:

RD&D on biomass accessibility, availability, transportation, conversion and treatment, and processing will be important to ensure sustainable and consistent supply of feedstock for biorefineries, as well as build investor confidence in integrated biorefineries. Further RD&D will need to focus on:

- New and emerging feedstocks (e.g. algae; aquatic feedstocks, wastes, residues);

- Onsite treatment and processing to improve local availability of feedstock and transportation costs;
- Plant breeding, planting and harvesting to improve feedstock growth, sustainability and resiliency to climate change;
- Soil health and ecosystem impact from feedstocks;
- Integrated cropping and rotational harvesting to improve feedstock availability and sustainability;
- Feedstock sustainability criteria and certification.

Conversion Processes:

RD&D on biomass conversion processes, and relevant technology, will be important for reducing OPEX and manufacturing costs of bio-based SFCMs, as well as making integrated biorefineries cost-competitive with traditional petroleum-based refineries and end-products. Further RD&D will need to focus on:

- Processes that can co-produce multiple high-value end-products (e.g. biochemical co-production) to improve biorefining revenues and profitability;
- Processes that increase energy and feedstock-use efficiency to reduce OPEX costs;
- Improving quality of end-products (e.g. biofuels with better drop-in capacity);
- Catalysts and bio-catalysts for conversion processes specific to biomass conversion;
- Advancing fermentation technologies;
- Microbial biosynthesis, biophotolysis and auto fermentation, algae or cyanobacteria for the production of the fuels (alkanes, hydrogen, or ethanol, respectively);
- Use of advanced synthetic biology approaches for bio-based SFCM production;
- Chemo-enzymatic pathways to improve the production capacity of high-value chemicals;
- Thermochemical and thermolytic processes to advanced biofuels and biochemical manufacturing;
- Upgrading sugars and amino acids to improve end-product production.

End-products and Markets:

Research and analysis on end-products and markets will be important for growing and diversifying demand for bio-based SFCMs which will increase profitability of integrated biorefineries, as well as support co-production of bio-based SFCMs. Further research and analysis will need to focus on:

- Improving existing quality and availability of bio-based SFCMs;
- End-product quality and sustainability to demonstrate viability of bio-based SFCMs;
- Identifying successful business models and practices;
- Consumer and market demand for bio-based alternatives to design successful integrated biorefinery business models;
- Cross-sectoral collaboration and innovation ecosystems that build resilient biorefining value chains.

Pilots and Demonstrations

Accelerating support for pilot and demonstration-level biorefining projects will be important to de-risk investments and demonstrate new and innovative technology to improve cost-competitiveness. Pilot and demonstration-level integrated biorefineries will also be launch-pads for commercializing technologies and end-products and therefore will be vital in supporting both domestic targets (see table 2 for examples of domestic low-carbon fuel targets) and the Mission's overall goal.

Table 2: Member Country's Domestic Low-Carbon Fuel Targets and Commitments

	Sustainable Aviation Fuels (SAF)	Sustainable Marine Fuels	Low-Carbon Liquid Fuels	Low-Carbon Gaseous Fuels
The Netherlands	14% renewable in 2030		10% ethanol fuel blending mandate	Produce 1.6 billion m3 by 2030 (± 15.6 TWH)
India			20% ethanol blending by 2025-2026	SATAT program, 5000 facilities
Canada			5% biofuel blending mandate; 15% reduction in carbon intensity of liquid fuels (supported by fuel switching or blending) by 2030	
Brazil	Target forthcoming		Reduction in the carbon intensity of liquid fuels from 71.56 gCO2 eq/MJ to 65.56 gCO2 eq/MJ by 2031	Target forthcoming
The European Union	In 2030 SAF at least 5% of which synthetic aviation fuels share at least 0.7%	Reduce GHG emissions in marine transportation by 6% by 2030 and 75% in 2050 using low-carbon fuels	13% GHG reduction of which 2.2% from liquid fuels by 2030	REPower plan, target of 30 BCM in 2030 equal to 293 TWh
The United Kingdom	10% of aviation fuel SAF by 2030; 75% by 2050		Fuel suppliers must blend 15% of biofuels derived from waste feedstocks by 2030	Produce 35.8 Twh by 2030

Accelerating support for pilot and demonstration-level projects will need to focus on:

- Pilots and demonstrations using advanced marine feedstocks (e.g. algae and kelp) and different technologies to assess the viability of conversion pathways and competitiveness of end-products (e.g. transesterification to biodiesel, fermentation of algae to alcohols, hydrothermal liquefaction to bioliquid intermediates, anaerobic digestion to biomethane);
- Diversify pilots and demonstrations to begin producing high-value intermediaries/end-products (e.g. sugars and alcohols);
- Pilots and demonstrations focusing on integrating carbon capture utilization and sequestration (CCUS) technology to demonstrate technological viability and improve emissions reductions at biorefining facilities;
- Pilots and demonstrations that use multiple pathways to support end-product manufacturing (e.g. gasification through Fischer Tropsch and thermal processes through pyrolysis to create multiple biofuels);
- Increasing the use of waste and residue upgrading processes at pilots and demonstration-level to improve quality of intermediate and end-products.

Markets and Policy

Improving market conditions and developing policy that support biorefining development will be important to improve investor confidence needed to attract investment in the sector, support value chain integration and develop cost-competitive end-products.

Further support will need to focus on:

- Developing policy that supports decarbonizing embedded carbon in chemicals and materials in the same way current energy policies incentivize decarbonizing energy;
- Developing markets and demand for both intermediaries (e.g. bio-based sugars and alcohols) used to produce end-products, and end-products themselves (e.g bioplastic and renewable consumer packaging), so as to ensure that the entire value chain, regardless of what is produced, is profitable and viable;
- Improving investor confidence by developing regulations and policies that support de-risking investments (i.e. reduce concerns regarding stranded assets and biorefining profitability);
- Standardized and internationally recognized LCA and suitability criteria for end-products to improve consumer awareness and confidence in the sustainability and carbon intensity of end-products.
- Using mandates, such as those used for liquid biofuels[11], or environmental standards (i.e. carbon intensity of end-products) to provide stable demand for end-products to de-risk investment and improve integrated biorefineries profitability;
- Using government procurement strategies[12] to develop markets and grow demand for end-products, especially end-products from pilot and demonstration-level projects, and increase investor confidence in early investments in integrated biorefineries;
- Using financial tools and incentives to attract investment such as special purpose investment banks and funds[13], public-private innovation agencies[14] to support end-product RD&D and business development simultaneously, and green bonds[15] to provide access to funding for capital expenses and improve financial stability of early investments;

4. Collaboration

To achieve the Mission's goal and address key challenges, collaborating with other domestic and international initiatives will be essential. This will leverage international expertise and resources in addressing these challenges and progressing towards the Mission's goal.

For example, collaborating with the Zero-Emission Shipping Mission and Clean Hydrogen Mission could help to identify new areas to support low-carbon fuel production while simultaneously supporting market demand for end-products. Likewise, partnership with the Carbon Dioxide Removal Mission could support carbon capture technology innovation (e.g. Bioenergy Carbon Capture Utilization and Storage) that could be used at integrated biorefineries to reduce emissions, while partnership with the Net-Zero Industries Mission could provide opportunities for cross-sectoral collaboration to develop net-zero value chains and grow demand for various bio-based SFCMs that

[11] Examples include: The European Union's Renewable Energy Directive; Brazil's Anhydrous Manadatory Blend in Gasoline; Canada's Clean Fuel Regulations; The United Kingdom's Transport Fuel Obligation; India's National Biofuel Policy

[12] Examples include: The United States Biopreferred Program; Canada's Green Government Strategy and Low Carbon Fuel Procurement Program

[13] Examples include: The United Kingdom's Green Investment Bank; Brazil's Development Bank

[14] Examples include: Finland's Technical Research Centre

[15] Examples include: The European Unions's NextGenerationEU green bonds to provide access to capital at a lower cost than most member states; Canada's green bonds to finance early-stage projects and programs.

could be used by various industries looking to reach net-zero emission targets. In addition, the Mission could look to work with Mission Innovation's Innovation Platform that has initiatives focusing on end-market development and low-carbon fuels.

The potential to work with other initiatives could also support progress towards the Mission's goal. For example, partnering with a number of the International Energy Agency Bioenergy TCP Tasks could leverage significant international expertise in sustainable biomass supply chains, conversion processes and pathways, as well as market development and trends. Collaboration with the Clean Energy Ministerial Biofutures Initiative and Campaign could also support integrated biorefinery commercialization and bio-based SFCM production by collaborating on joint-research projects or workshops and bringing together networks from across both initiatives to address key challenges across the biorefining value chain.

It is also anticipated that experts and industry leaders from each participating member country in the Mission will engage, collaborate and network extensively over the duration of the Mission. This will also include leveraging expertise and resources from domestic research and technical centers, industry consortiums, and government funded research centers to support the Mission's pillars and progress towards its goal.

5. Key Actions and Key Performance Indicators

To address key gaps identified by the analysis and support the commercialization of integrated biorefineries, several key actions to support the Mission's goal of replacing 10% of fossil-based feedstock for fuels, chemicals and materials with bio-based alternatives by 2030 have been identified. These key actions have been organized across the Mission's three pillars, with member countries working together where possible to support them, and the timeline for completing these key actions can found in figure 2.

Pillar 1: Research, Development and Demonstration

Objective: Support research, development and demonstration that focuses on technologies and processes that improves both the cost competitiveness of sustainable bio-based SFCMs and the sustainability of their production.

Technoeconomic Workshops (2022 – 2023)
Three technical workshops with leading researchers and industry leaders will be held to support networking and knowledge-sharing on important and relevant technologies, conversion processes and end-products, as well as identify areas for further research for which the Mission could support. These workshops include:

- Synfuels and chemicals from gasification
- Biofuels from enhanced fermentation processes
- Integrated biochemical and biofuel manufacturing processes

Research Initiative on New Uses for Biomass in Bio-based SFCM (2023 – 2026)
A RD&D initiative to improve the resource-use efficiency of biomass and the development of new end-products to support product diversification and profitability for integrated biorefineries. The initiative will seek to support new original research to broaden possible pathways for feedstock use and conversion to end-products.

Pillar 2: Pilots and Demonstration

Objective: Develop pilot-scale demonstrations that support new and novel technologies, and facilitates cost-competitive manufacturing of sustainable bio-based SFCMs.

Energy and Conversion Process Efficiency Program (2023 – 2027)
A funding program to support current pilot and demonstration projects to support energy efficiency and/or biomass conversion process efficiency retrofits with existing technology. This will support uptake of current technology, as well as demonstrate its viability, while also supporting cost reductions in pilot and demonstration facilities towards commercializing.

Review and Comparison of Domestic Biorefining Legislation and Regulations (2023 -2024)
A review and analysis of domestic biorefining legislation and regulations to identify commonalities and differences, and potential opportunities to reduce administrative and regulatory burden on industry.

Development of Biorefinery Business Plan/Framework (2023 – 2025)
Development of a business plan/framework, in collaboration with leading industry experts, to support companies in scaling-up pilot and demonstration projects and advancing to commercial production. This will help to de-risk biorefining business models by outlining important key performance indicators for new and emerging biorefining businesses looking to advance across the TRL and business development spectrum, as well as serve as an outline for how and where governments can support businesses, through funding and policy development, along the TRL spectrum.

Pillar 3: Policy and Regulatory Support

Objective: Provide regulatory and policy support through coordination and collaboration with government, academia, industry and other stakeholders to identify challenges in biorefining and develop supportive policy and regulatory environments for bio-based SCFM production.

Standards Development to Support Biorefining Processes & End-products (2024 – 2029)
Development of internationally recognized (ISO) and accredited standards for biorefining conversion processes and select end-products.

Development of Sustainability Criteria for Biorefineries (2023 – 2025)
Development of internationally recognized (ISO) and accredited sustainability criteria for biorefining processes and end-products jointly with the CEM Biofuture Initiative and others.

Development of Life Cycle Analysis Methodology for Biorefineries (2022 – 2025)
Development of an internationally recognized (ISO) and accredited life-cycle assessment methodology for biorefineries to assess the carbon intensity of biorefining processes and end-products.

Figure 2: Key Actions and Timelines

Pillar	ACTION	ACTIVITY	2022	2023	2024	2025	2026	2027	2028	2029	2030
RD&D	Technoeconomic Workshops	Synfuels & chemicals from gasification workshop									
		Biofuel from enhanced fermentation workshop									
		Integrated biochemical & biofuel processes workshop									
	Research Initiative on New Uses for Biomass in Bio-based SFCM	Review & consultation with technical experts of current initiatives & areas requiring new research									
		Call for projects to be funded by the Mission									
		Research									
Pilots & Demonstration	Energy & Conversion Process Efficiency Program	Review & consultation with technical experts to identify commercial ready technology for eligibility in program									
		Call for projects to be funded by the Mission									
		Funding awarded									
		Retrofits									
		Finalization of retrofits & reporting									
	Review & Comparison of National Biorefining Regulations / Legislation	Review & analysis of existing regulations/legislation in member countries									
		Data analysis document									
		Finalization of document									
	Development of Biorefinery Business Plan/Framework	Review & analysis of available business plans and/or operating biorefining models									
		Development of working group w. Mission's industry partners to support development of document									
		Drafting of business plan/framework in partnership w. industry partners									
		Finalizing business plan/framework									
Policy & Regulatory Support	Standards Development to Support Biorefining Processes & End-products	Review & analysis of existing biorefining conversion & bioproduct standards									
		Establishment of conversion process standards technical working group									
		Establishment of end-product standards technical working group									
		Domestic workshops									
		Drafting of standards									
		Review workshop(s)									
		Finalization of standards									
	Development of Sustainability Criteria for Biorefineries	Review & analysis of existing sustainability criteria for biorefineries									
		Preliminary workshop with Technical Experts									
		Development of criteria									
		Review workshop with technical experts									
		Finalization of criteria									
	Development of Life Cycle Analysis Methodology for Biorefineries	Review and analysis of existing LCA models									
		Preliminary workshop with technical experts									
		Development of methodology									
		Review workshop with technical experts									
		Finalization of methodology									

6. Key Performance Indicators (KPIs)

The key performance indicators have been developed and informed by the Mission's key actions and the timelines highlighted in the Gantt chart above. The KPI's will help ensure deliverables across the Mission's key actions and progress towards the Mission's goal.

The following KPI's have been identified for the Mission:

1. Reduction of fossil fuel use by up to 10% in 2030 compared to 2020 which equals an energy equivalent of 9 EJ.

2. At least 1 annual workshop hold, which may be held in conjunction with other international events, to continue to inform the direction of the Mission.

3. Minimum of $2M USD provided by each participating member country to support RD&D projects.

4. Financial commitment of at least $2M USD by each participating member country supports at least 10 RD&D projects.

5. Development of at least five new bio-based SFCMs within the first five years of the Mission.

6. At-least one-third of all projects includes one or more industrial stakeholders to promote collaboration and value chain integration.

7. At least one-fourth of the projects carried out between organizations from the member countries.

8. At least two new pilot and/or demonstration plants developed in each participating member country in collaboration with industrial stakeholders within the first five years of the Mission.

9. A least five domestic industrial partners identified in each participating member country to support Mission activities.

7. Conclusion

This Roadmap has identified key gaps and action to support the commercialization of integrated biorefineries. Most notably it will require the Mission to support RD&D over the short, medium and long-term; accelerate support for pilot and demonstration level biorefining projects to improve their cost-competitiveness and financial viability; and improve policy and market conditions to improve investor confidence, support value chain integration and provide policy and regulatory certainty required to accelerate market growth. The Mission's three pillars will address these key gaps, carrying out the eight key actions identified, and collectively support progress towards the Mission's goal of replacing 10% of fossil-based feedstock for fuels, chemicals and materials with bio-based SFCMs by 2030.

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Annexes: Background reports with all data:

A. Country reports
B. Mapping of Country information
C. Analysis of existing roadmaps
D. Background MI Mission Biorefineries goals