Integrated Biorefineries Mapping Results Summary

Introduction

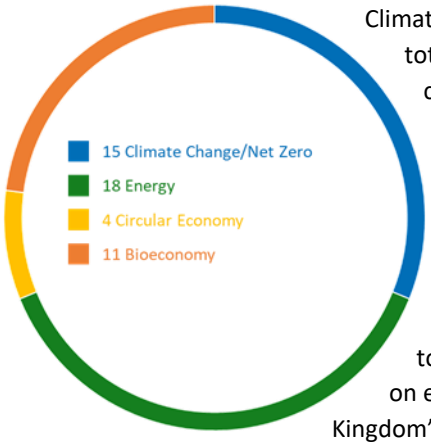
The Mission Innovation Integrated Biorefineries Mission's goal is to improve the cost-competitiveness of biorefining globally through accelerating research and development, supporting commercialization of pilot and demonstration level projects and improving standards and regulations to incent biorefinery development, with a target of replacing 10% of petroleum-based fuels, chemicals and materials with bio-based sustainable fuels, chemicals and materials by 2030.

To support this work, member countries from the Mission developed a database of existing domestic policies, funding programs and projects to identify both existing initiatives and current gaps. Member countries from the Mission submitted information on domestic policies, programs and projects to the activity lead (Canada) who compiled the information into an agreed upon excel database. This, along with consultation workshops being held domestically by each member country, will support the Mission's identification of key gaps and areas for actions to achieve the Mission's goal.

National Policies

A total of 48 biorefining related policies were identified by participating member countries.[1] These policies were then categorized across four policies areas: Climate Change/Net Zero; Energy/Energy Transition; The Circular Economy; and The Bioeconomy (See figure 1).

Figure 1: National Policies



Climate Change/Net Zero policies exist in almost every member country with a total of 15 policies focused on climate change and net-zero emissions commitments. These policies are a combination of national strategies for climate change mitigation and adaptation (e.g. Canada's Emissions Reduction Plan; European Green Deal), and domestic legislation enshrining government commitments to achieve specific greenhouse gas emission reductions by 2030 and 2050 (e.g. The Netherlands' National Climate Agreement; Brazil's National Policy on Climate Change).

Energy/Energy Transition policies exist in every member country, with a total of 18 across all member countries. These policies are primarily focused on emissions reductions in heavy emitting industries (e.g. The United Kingdom's Build Back Greener Strategy; the European Union's Sustainable and Smart Mobility Strategy; Brazil's Ten Year Energy Plan) and supporting low-carbon fuel production (e.g. India's National Biofuels Policy; Canada's Clean Fuel Regulations) .

Circular Economy policies exist in Canada, Brazil and the European Union, with a total of four across these three member countries. These policies focus primarily on waste reduction and materials substitution (e.g. Canada's Strategy on Zero Plastic Waste; Brazil's Circular Economy Route; European Union's Circular Economy Action Plan and Zero Pollution Action Plan).

[1] Member countries submitted domestic policies they felt were most closely aligned with biorefining as biorefining is a new and emerging industry and very few countries have biorefining specific policies. In most cases biorefining is one component of broader climate change and energy transition policies and strategies.

Bioeconomy policies exist in almost every member country, with a total of 11 across all member countries. These policies focus on the entire value chain, and more specifically, how bio-based alternatives can provide renewable, sustainable and low-carbon fuels, materials and chemicals (e.g. The Netherland's Strategic Vision for Implementation of Biomass; The United Kingdom's Biomass Policy Statement).

National Programs

A total of 30 domestic biorefining related programs[2] were identified by participating member countries. These programs range from supporting specific biorefining and bioeconomy initiatives (e.g. Brazil's Innova Bio, India's Sustainable Alternative Towards Affordable Transportation; Canada's Clean Fuels Fund), to broader energy and circular economy programs that include biorefining as one type of initiative that could be funded by the program (e.g. The Netherlands' Small Innovation Stimulation Fund; the United Kingdom's Innovate UK program; the European Union's Horizon Europe program and Invest EU program). The programs identified also provide support to biorefining projects across the entire technology readiness level (TRL) spectrum, using several different financial policies to support program implementation.

To identify potential funding gaps in existing member country programs, these programs were categorized by TRL and by the types of financial policies used to implement them. Four categories were used to categorize project TRL[3]: Research and Development (TRL 3-5); Pilot and Demonstration (TRL 6-8); Deployment/Commercialization (TRL 9); and Combination (i.e. programs that support one or more TRL categories). Financial policies were categorized across four categories[4]: Feed-in Tariff/Premium; Grants and Subsidies; Loans and Loan Guarantees; Combination (i.e. one or more financial policies used to support program implementation).

Just over half the programs (57%) identified by member countries support research and development (TRL 3-5), and commercial projects (TRL 9). Of the programs supporting projects at multiple TRLs (i.e. combination) five of the seven programs support research and development (TRL 3-5), and pilot and demonstration (TRL 6-8) projects, while the other two programs in this category support pilot and demonstration (TRL 6-8), and commercial projects (TRL 9) (See figure 2).[5]

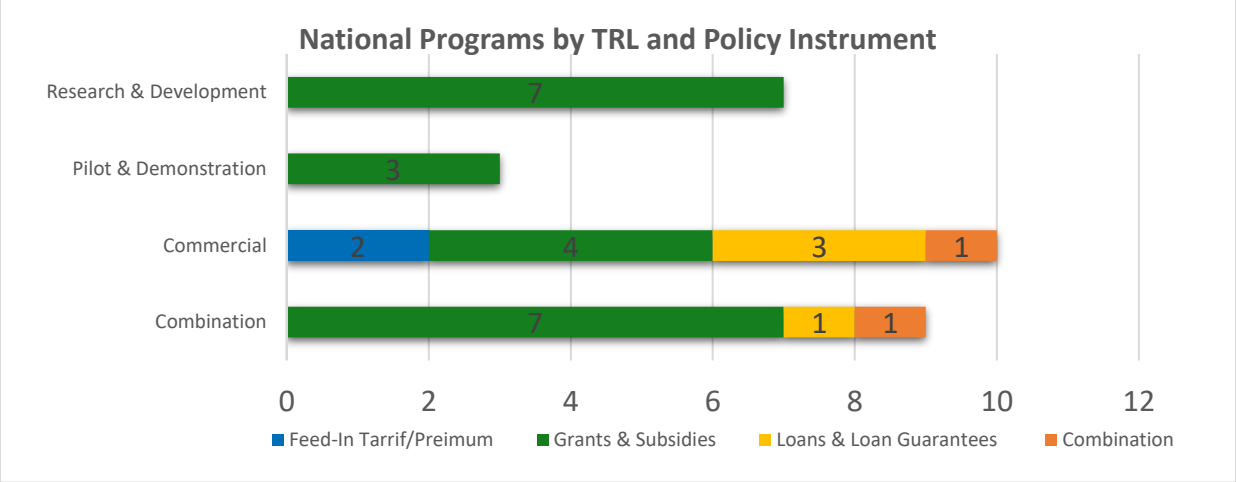


Figure 2: National Programs by TRL and Financial Policy

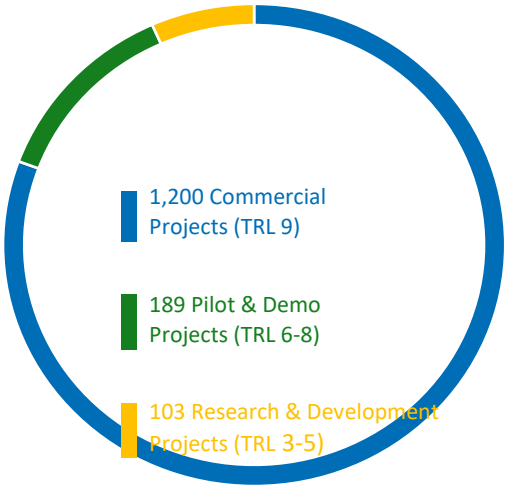
Just under half of the programs identified (48%) use grants and subsidies to support projects, with grants and subsidies being the only financial policy used to support research and demonstration (TRL 3-5), and pilot and

[2] Member countries submitted domestic programs they felt were most closely aligned with biorefining.
[3] The TRL categories used in the development of the database were collectively decided upon by member countries.
[4] The Financial policies use din the development of the data base were collectively defined by member countries.
[5] No financial policy was identified for one program, therefore figure 2 only shows 29 domestic programs.

demonstration projects (TRL 6-8). Three programs use loans and loan guarantees to support commercial projects (TRL 9), and two programs use feed-in tariffs/premiums to support commercial projects. Programs that support projects at more than one TRL (i.e. combination) primarily use grants and subsidies (78%).

National Biorefining Projects

A total of 1,492 biorefining projects[6,7,8] across the TRL spectrum were identified by participating member countries. Of these projects 80% are commercial projects (TRL 9), 13% pilot and demonstration projects (TRL 6-8), and 7% research and development projects (TRL 3-5) (See figure 3).



Broken down by participating member countries, the European Union (consisting of 27 member countries) is home to 90% of all biorefining projects which includes 97% of all commercial projects (TRL 9), 71% of pilot and demo projects (TRL 6-8) and 41% of research and development projects (TRL 3-5).

The Netherlands and Canada are home to 8% of projects, which includes 2% of all commercial projects, 23% of pilot and demo projects, and 30% of research and development projects.

Brazil, India and the United Kingdom make up the remaining 2% of all projects. Brazil makes up the remaining 1% of commercial projects, while India accounts for the remaining 6% of pilot and demo projects. India and the United Kingdom are home to the remaining 29% of research and development projects.

Figure 3: Share of National Biorefining Projects by TRL

Project Feedstocks

Agricultural feedstocks make up the majority of feedstocks used across all projects (53%). Municipal solid waste, energy crops and starches, and woody biomass account for the next largest share of feedstocks used across all projects accounting for 42% of all feedstocks used. Algae and marine feedstocks, as well as waste oils, animal waste, and combined feedstock use, make up the remaining 5% of feedstocks used across projects (See figure 4).

[6] Member countries submitted domestic projects they felt best represented biorefining and/or were most closely aligned with biorefining. These projects were submitted and used to create a database of projects across member countries. The European Union's (EU) Biobased-Industry database (https://datam.jrc.ec.europa.eu/datam/mashup/BIOBASED_INDUSTRY/index.html) was used for their submission. To avoid potential double-counting of projects, the EU's chemical biorefineries data base was not used, as it is unclear as to whether or not these facilities are reported in the larger biobased industry database. Therefore, in an effort to reduce over-reporting only the EU Biobased Industry database was used.

[7] Projects do not include sawmills or pulp and paper mills. This filter was applied to the EU's Biobased-Indsurty database when compiling data for this analysis.

[8] 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.

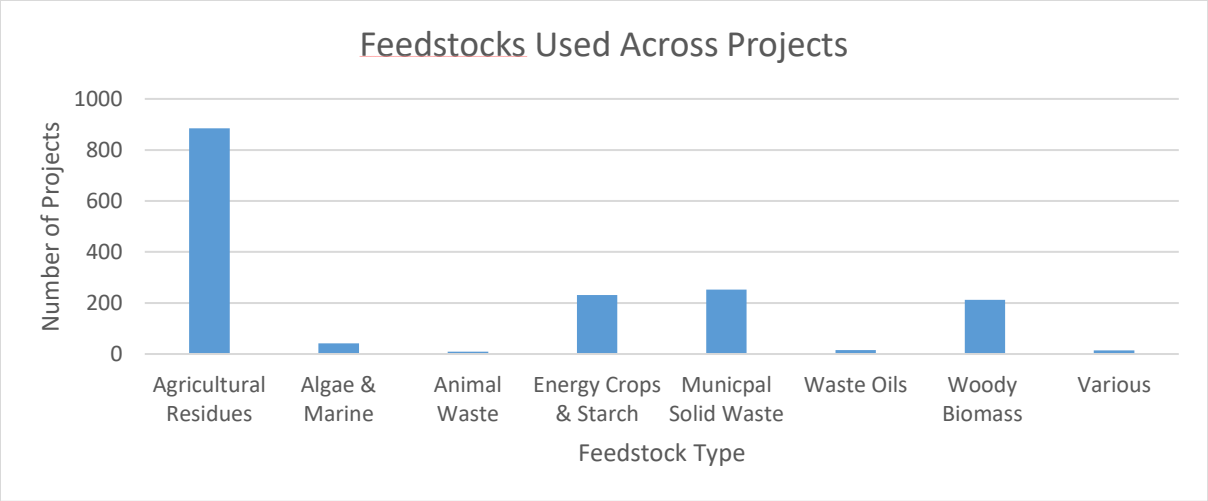


Figure 4: Feedstock Used Across Projects

Similar trends exist across research and development (TRL 3-5), pilot and demonstration (TRL 6-8), and commercial projects (TRL 9), with increasing shares of other feedstocks in less technically mature projects (See figure 5).

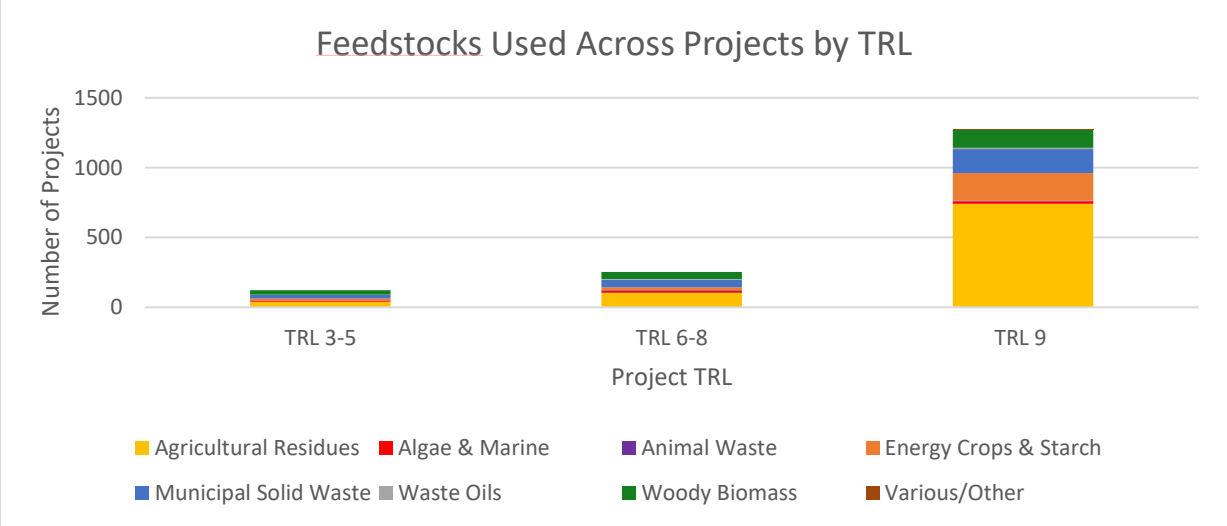


Figure 5: Feedstocks Used Across Projects by TRL

Agriculture feedstocks make up the majority of feedstocks used in commercial projects (TRL 9) (58%), followed by energy crops and starches (15%), municipal solid wastes (14%), and woody biomass (10%) projects. Waste oils and animal waste are the least used feedstocks (Under 1%).

Agriculture feedstocks are the largest share of feedstocks used in pilot and demonstration projects (TRL 6-8) (41%), followed by municipal solid waste (21%), woody biomass (20%), and energy crops and starch (9%). Waste oils and animal waste are the least used feedstocks (4%).

Agriculture feedstocks are the largest share of feedstocks used in research and development projects (TRL 3-5), followed closely by woody biomass (27%) and municipal solid waste (22%). Energy crops and starches, algae and marine feedstocks, and other/various feedstocks also make up just over a quarter of feedstocks (29%). Waste oils are the least used feedstocks (under 1%).

Project End-products

Biofuels (46%) and biochemical (44%) make up almost all end-products produced, or intended to be produced from less mature projects (i.e. TRL 3-5), across all projects (See figure 6). Biomaterials make up the remaining 10%.

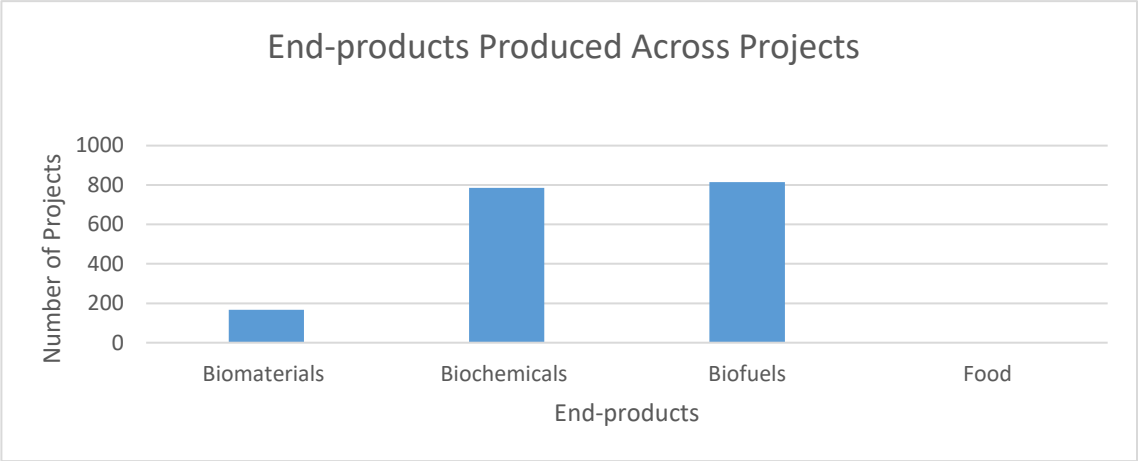


Figure 6: End-products Produced Across Projects

Similar trends exist across research and development (TRL 3-5), pilot and demonstration (TRL 6-8), and commercial projects (TRL 9), with biochemicals making up a slightly higher share in less technically mature projects (See figure 7).

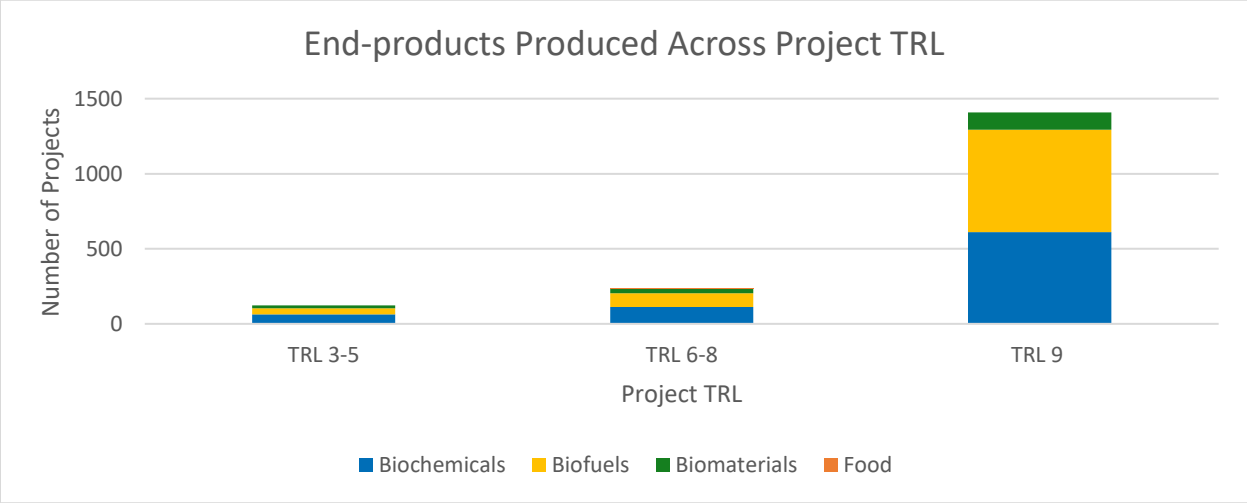


Figure 7: End-products Produced Across Project TRL

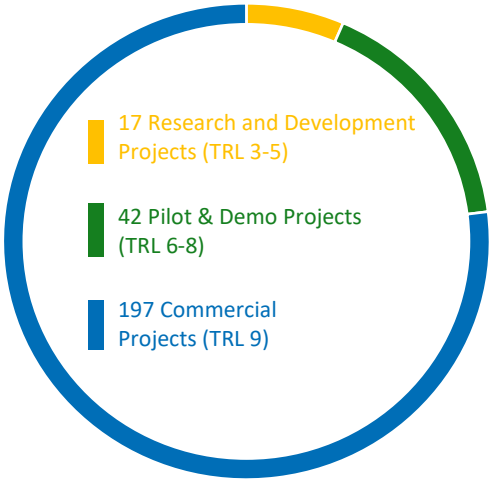
Biofuels are the primary end-product produced (49%) in commercial projects (TRL 9), followed by biochemicals (43%) and biomaterials (8%).

Biochemicals are the primary end-product produced (47%) in pilot and demonstration projects (TRL 6-8), followed by biofuels (38%) and biomaterials (13%).

Biochemicals make up the majority of end-products intended to be produced (52%) in research and development projects (TRL 3-5), followed by biofuels (32%) and biomaterials (16%).

Co-producing Projects

A total of 256 co-producing projects, those producing one or more end-products, were identified by participating member countries. Of these projects 77% are commercial projects (TRL 9), 16% pilot and demonstration projects (TRL 6-8), and 7% research and development projects (TRL 3-5) (See figure 8).



Broken down by country the European Union is home to 98% of commercial projects (TRL 9), 79% of pilot and demonstration projects (TRL6-8), and 43% of research and development projects (TRL 3-5).

The Netherlands and Canada are home to the remaining 2% of commercial projects (TRL 9). The Netherlands and India make up the remaining 21% of co-producing pilot and demonstration projects (TRL 6-8).

The United Kingdom, India and the Netherlands are home to the remaining co-production research and development projects (TRL 3-5), with 26% located in the United Kingdom, 13% in The Netherlands and 4% in India.

Figure 8: National Co-producing Projects by TRL

Agricultural residues make up the majority of feedstocks used across co-production projects (53%), followed by wood biomass (20%), and municipal solid waste (17%). Animal waste and algae and marine feedstocks are the least used feedstocks in co-production projects (under 4%) (See figure 9).

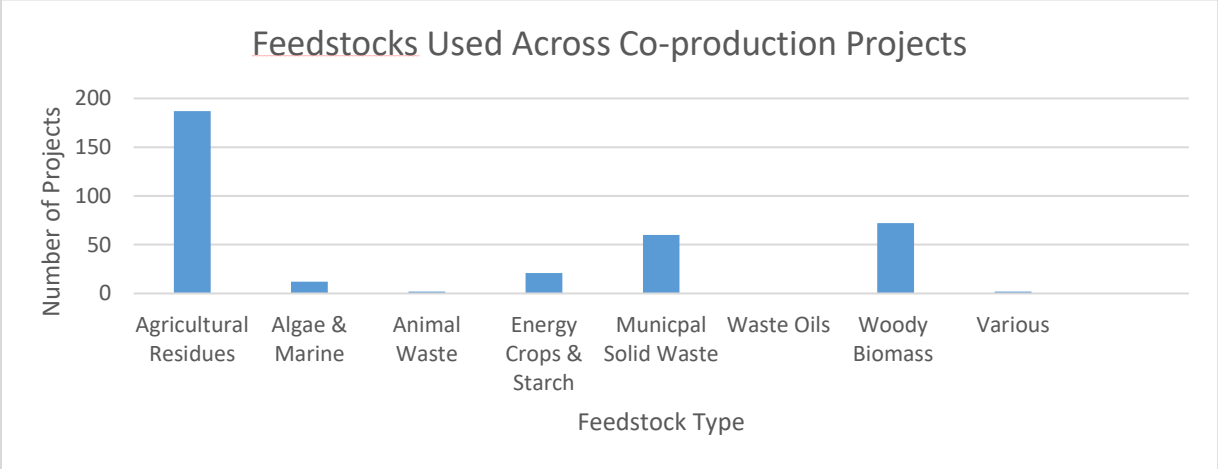


Figure 9: Feedstocks used Across Co-production Projects

Similar trends exist across research and development (TRL 3-5), pilot and demonstration (TRL 6-8), and commercial (TRL 9) co-production projects, with increasing shares of other feedstocks used in less technically mature biorefining projects (See figure 10).

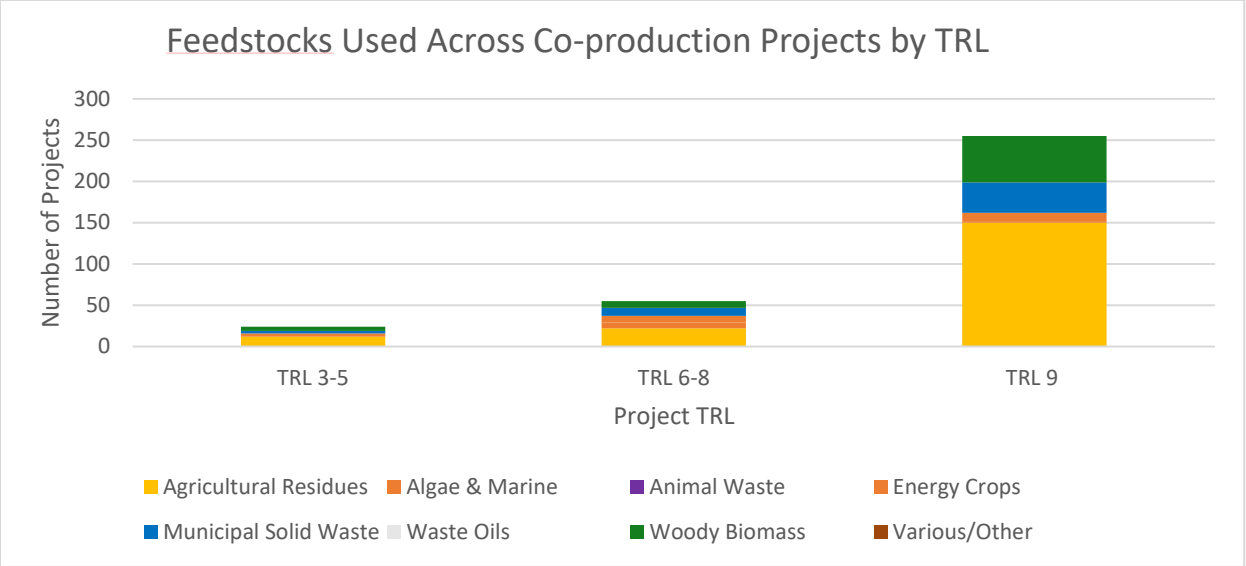


Figure 10: Feedstocks Used Across Co-production Projects by TRL

Agriculture feedstocks make up the majority of feedstocks used in commercial (TRL 9) co-production projects (59%), followed by woody biomass (22%), and municipal solid waste (15%). Algae and marine feedtsocks are the least used feedstocks (under 1%).

Agriculture feedstocks are the largest share of feedstocks used in pilot and demonstration (TRL 6-8) co-production projects (40%), followed by municipal solid waste (18%), woody biomass (15%), and energy crops and starches (15%). Algae and marine are the least used but follow very closely behind woody biomass and energy crops and starches (12%).

Agriculture feedstocks make up the majority of feedstocks used in research and development (TRL 3-5) co-production projects (50%), followed by woody biomass (21%). Municipal solid waste, energy crops and starches and algae and marine feedstocks make up the remaining feedstocks used (29%).

Biochemicals make up the majority of all end-products produced, or intended to be produced in less technically mature projects (i.e. TRL 3-5), across all projects (55%), followed by biofuels (30%), and biomaterials (%15) (See figure 11).

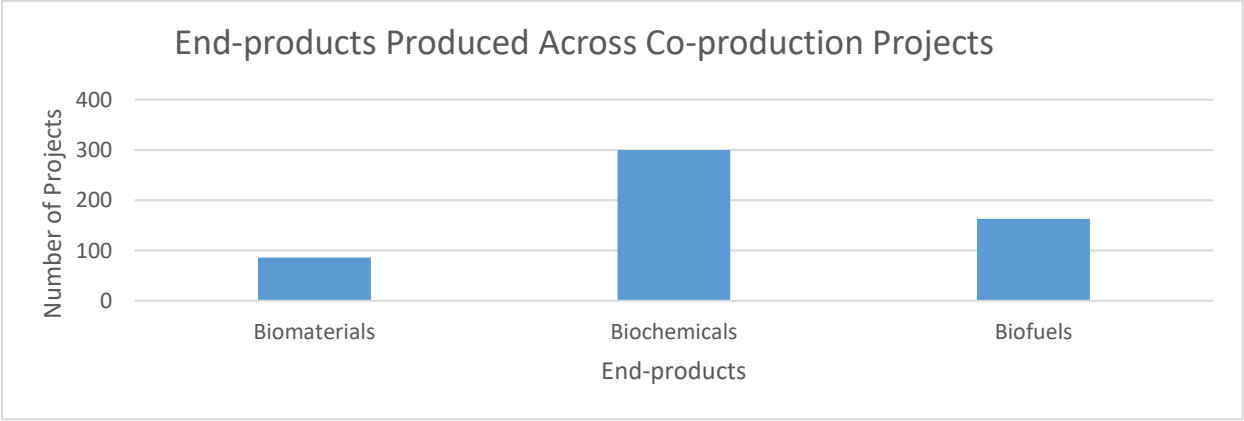


Figure 11: End-products Produced Across Co-production Projects

Similar trends exist across research and development (TRL 3-5), pilot and demonstration (TRL 6-8), and commercial (TRL 9) co-production projects, with biochemicals making up a slightly less higher share in less technically mature projects (i.e. TRL 3-5) (see figure 12).

Biochemicals make up the majority of end-products (58%) produced in commercial (TRL 9) co-production projects, followed by biofuels (27%), and biomaterials (15%)

Biochemicals are the primary end-product produced (48%) in pilot and demonstration (TRL 6-8) co-production projects, followed closely by biofuels (34%), and biomaterials (18%).

Biochemicals are the primary end-product intended to be produced (47%) in research and development (TRL 3-5) co-production projects, followed closely by biofuels (40%), and biomaterials (13%).

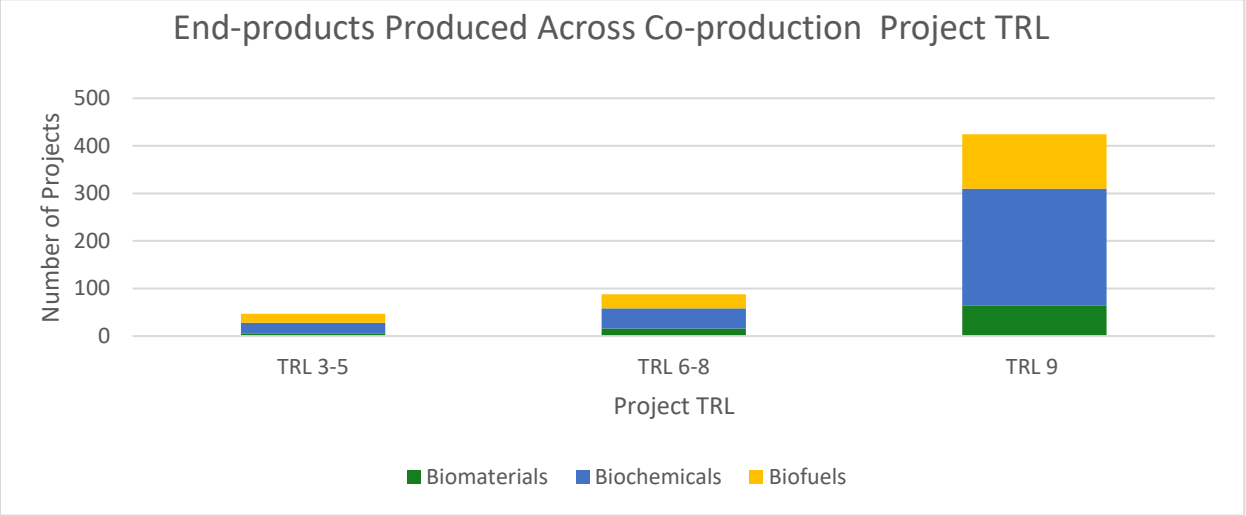


Figure 12: End-products Produced Across Co-Production Projects

Key Findings and Gaps

There are several key findings and gaps across policies, programs and projects submitted by member countries, which should inform the Mission's actions.

National Policies

Just under three-quarters (73%) of 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 and supporting low-carbon fuel production. However, greater legislative, policy, regulatory and strategic recognition is needed for the bioeconomy, and broader circular economy, as just over one quarter (27%) of the policies identified are focused on these areas. In addition, of the 11 bioeconomy related policies identified, only three are holistic strategic frameworks to support the growth of the bioeconomy (e.g. The Netherlands' Biomass 2030 Strategic Vision; the United Kingdom's Biomass Policy Statement; the European Union's A Sustainable Bioeconomy for Europe). Other bioeconomy related policies focus on components of the bioeconomy (e.g. Canadian Council of Forest Minister's Forest Bioeconomy Strategy), but not the broader bioeconomy itself.

Key gaps also exist in policies that seek to support broader industrial symbiosis and value chain integration across sectors. This will be important for driving, and improving, feedstock accessibility, availability and quality across sectors, as well as leverage potential cross-sectoral investments in biorefining. In addition

strategic industrial symbiosis and value chain integration policies will likely boost investor confidence in biorefining, as strategic policies support market development, reduce uncertainty and can signal forthcoming regulatory and financial support for industry.

National Programs

Just over half the programs (57%) identified by member countries provide support to research and development (TRL 3-5) and commercial projects (TRL 9) using grants and subsidies and loans and loan guarantees to implement these programs. In comparison, pilot and demonstration projects (TRL 6-8) receive less program support from dedicated programs (10%), but are likely to be receive additional support through funding programs that support a greater share of the TRL spectrum. Nonetheless, this gap in program support for demonstration projects (TRL 6-8) is significant, given that projects at this stage typically experience the most difficulty in overcoming barriers (i.e. The "Valley of Death") to scale up operations and commercialize (e.g. CAPEX costs; OPEX costs; achieving scales of economy; investor confidence).

Grants and subsidies are the most used financial policy across all programs, even for programs that support projects across the TRL spectrum (i.e. combined category). Grants and subsidies are also used most in less technically mature projects (i.e. TRL 3-5) while loan and loan guarantees are used only for commercial projects (TRL 9). While large financial investments are required to overcome capital expenses, a greater diversity of financial policies could be used to support program implementation, or used in new programs, to provide multiple pathways to support greater 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-competiveness and operations of biorefining facilities. Less financially oriented policies and programs could also complement programs financially supporting biorefinery projects, such as government procurement, to grow demand for bio-based alternatives.

National Projects

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 home to over one-third (36%) of research and development projects (TRL 3-5). Differences in the number of projects are likely a result of a number of challenges such as: technical and economic challenges to improve cost competiveness and compete with petroleum-based products; sociopolitical and sociocultural challenges regarding attitudes towards the use of bio-based feedstocks; policy and regulatory support to de-risk investment and provide investor certainty; and strategic policy and funding programs specifically targeting biomass supply chains and biorefining.

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 and algae and marine feedstocks, typically considered newer and emerging sources of feedstocks for biorefining, and animal waste and waste oils. The use of these feedstocks could be a result of accessibility, quality, quantity, economic probability and/or supply chain integration.

Biofuels and biochemicals make up almost all end-products produced (90%). This trend is consistent across all TRL projects, with some variation depending on the technical mature of projects. A significant gap exists between the production of biochemicals/biofuels and advanced biomaterials. Less technically mature projects (i.e. TRL 6-8; TRL 3-5) are more-likely to produce, or intend to produce, advanced biomaterials. The gap between these end-products could be a result of current government policies focusing on biofuels production rather than other end-products., which could develop challenges for supporting the broader biochemical and advanced biomaterial markets, therefore limiting investments in integrated biorefineries. Policies supporting materials substitution, and reducing embedded carbon in consumer products and the built environment, could also support more advanced biomaterial production and improved co-production of multiple end-products from biorefineries. However, there are a few projects demonstrating the co-production of multiple end-products and the viability of integrated biorefineries.