Environment and Climate Change Canada
Environnement et Changement climatique Canada

CANADA'S PLASTICS SCIENCE AGENDA

Canada

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CONTEXT

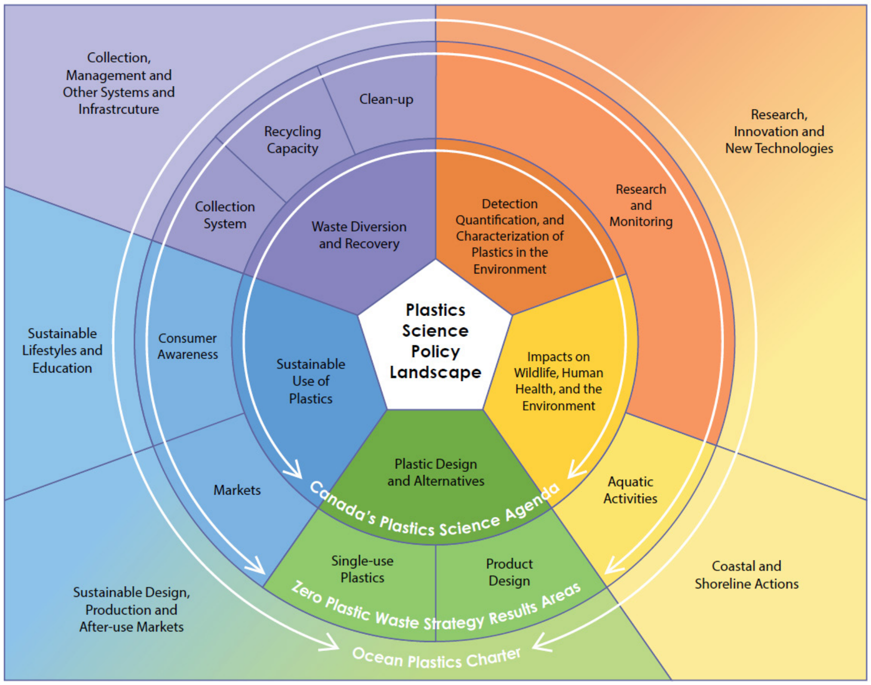
Plastics play an important role in the everyday lives of Canadians. As an affordable and versatile material, plastics are found in a wide range of personal and industrial products, such as pharmaceuticals, food packaging, textiles, and construction materials. However, plastic pollution is found almost everywhere on the planet, including uninhabited pristine environments, and is impacting the environment, wildlife, and potentially human health. Plastics overflow our landfills and incinerators, litter our parks and streets, and crowd our rivers, lakes, and oceans. Plastic pollution has become one of the greatest global challenges of our time, and we have reached a defining moment and urgent action is needed.

The Government of Canada has taken an action-oriented leadership approach to addressing plastic waste and pollution. As part of its 2018 G7 presidency, it spearheaded the Ocean Plastics Charter, which contains commitments and targets aimed at stopping plastic waste and the flow of plastics into the environment. Work on this front is continuing through the G7 and Canada continues to play an active role in advancing international collaborative efforts on plastics.

Domestically, the Government worked with provinces and territories through the Canadian Council of Ministers of the Environment (CCME) to develop the Canada-wide Strategy on Zero Plastic Waste, which Ministers approved in principle in November 2018. The Strategy contains ten results areas that span the lifecycle of plastics, from product design to collection and recycling to clean-up. It also includes a specific focus on effective research and monitoring systems to inform decision making and measure performance.

The Government also launched both the G7 and Canada's Plastics Challenges in September 2018, which were designed to help drive Canadian companies to find new ways to reduce plastic waste by rethinking how plastic is made, used, transported, removed from the environment, and recycled across its lifecycle. Additionally, to reduce the amount of plastic microbeads entering Canadian freshwater and marine ecosystems, Canada prohibited the manufacture and import of all toiletries that contain plastic microbeads as of July 1, 2018, with entry into force of the complete ban on July 1, 2019.

Canada's actions on plastics will contribute to moving the country towards a circular economy, keeping plastics and plastic products in use as long as possible, maximizing their value, and closing the loop in terms of resource use by reducing, reusing, repairing, remanufacturing, recycling, and composting plastics or, if no other option exists, recovering energy at their end of life. This will keep all plastics in the economy and out of landfills and the environment, which will result in significant environmental, socio-economic, and health benefits for Canadians.



Canada's Plastics Science Agenda in the context of the broader plastics science policy landscape

Continuing to advance science is critical to effectively address plastic pollution and support the development of a circular plastics economy. World-class, robust science informs evidence-based decisions, helps spur innovation, and enables tracking of progress. The environmental and wildlife health impacts of large plastic debris (macroplastics) are often observable; however, the environmental and health effects of micro- and nanoplastics are less understood. Although there are knowledge gaps in plastics science, the urgency of the plastic pollution challenge requires that science and policy evolve rapidly. As plastics science advances, it will better inform policy development and improve the ability to track the effectiveness of actions taken. Despite research undertaken by governments, academia, industry, and non-governmental organizations across Canada, much of this important work is fragmented and inconsistent, creating a patchwork of information.

Canada's Plastics Science Agenda (CaPSA) addresses this challenge by identifying opportunities for current and future research across a range of disciplines. Work under these priority research areas will strengthen the plastics-related evidence base for decision-making and help build a circular plastics economy that protects the environment and human health. CaPSA represents a framework of mission-critical, multi-disciplinary science needs. It is positioned to inform science and research investments for detecting plastics in the environment, understanding and mitigating potential impacts on wildlife, human health, and the environment, and advancing sustainable plastic production, recycling, and recovery. CaPSA spans the lifecycle of plastics and adopts a comprehensive approach that will provide the evidence base needed to accelerate the transition to sustainable design and develop innovative recycling and recovery approaches.

CaPSA is a reflection of discussions held with a wide range of partners, including science and policy experts from federal, provincial, and territorial governments, academia, Indigenous organizations, and industry. These discussions include two fora held in November 2018 (*Best Brains Exchange on the Ecological and Human Health Fate and Effects of Microplastic Pollution* and the *Canadian Science Symposium on Plastics*), a stocktaking of federal scientific activities, and additional direct engagement with a range of partners.

The *Best Brains Exchange* allowed participants to discuss relevant scientific knowledge on microplastics and identify knowledge gaps regarding the health-related fate and effects of microplastic pollution. Similarly, the *Canadian Science Symposium on Plastics* was aimed at identifying priority science gaps and needs across various themes and proposing activities for moving forward. The federal stocktaking exercise provided a broader picture of plastics-related scientific research being performed and funded by the federal government. Finally, federal engagement with industry, provincial, territorial and Indigenous partners sought to collect input on the state of plastics science in their respective areas, as well as their perspectives on the actions needed to support the implementation of the CCME Canada-wide Strategy on Zero Plastic Waste.

CaPSA is a call to coordinated action on plastics science priorities. It is designed to help all Canadian researchers and research funders understand the key plastics science needs in Canada. By proposing several goals and activities that range from the short term to the longer term, it will also serve as a roadmap for guiding Canada's scientific efforts towards a zero plastic waste future, supporting the Canada-wide Strategy on Zero Plastic Waste and Action Plan, as well as Canada's commitments under the Ocean Plastics Charter.

PRIORITIES AND NEEDS

CaPSA builds on the plastics science already underway in Canada and internationally. Its framework represents the priority science needed to identify and address the effects of macro-, micro- and nanoplastic plastic pollution, and to achieve a circular economy for plastics. CaPSA's science goals and needs are categorized into five complementary themes, highlighting areas requiring more collective attention going forward. These five themes cover the entire lifecycle of plastics and are:

1. **Detection, quantification, and characterization of plastics**[1] **in the environment** – Harmonizing / standardizing the detection, monitoring, and characterization of the sources, pathways, concentrations, and fate of plastics in the environment.
2. **Impacts on wildlife, human health, and the environment** – Increasing understanding of the impacts of plastics on wildlife, human health, and the environment.
3. **Plastic design and alternatives** – Decreasing the environmental footprint of plastics by improving their design and enabling value recovery.
4. **Sustainable use of plastics** – Supporting the informed and responsible usage and sustainable management of plastics.
5. **Waste diversion and recovery** – Innovating to enhance the capture and value recovery of existing and future plastics.

[1] For the purpose of this document, references to plastics include macro-, micro- and nanoplastics, unless otherwise specified.

Currently, efforts are being made to address many of these needs. However, there is significant potential for collaboration and leadership among scientists—including all levels of government, academia and research institutes, non-profit and Indigenous organizations, and industry—to achieve the goals of the framework.

Theme 1: Detection, quantification, and characterization of plastics in the environment

Under Theme 1, the overarching goal is to **detect, quantify, and characterize the sources, pathways, concentrations, and fate of plastics in the environment**. Action under this theme will provide a strong foundation for work under Themes 2 through 5.

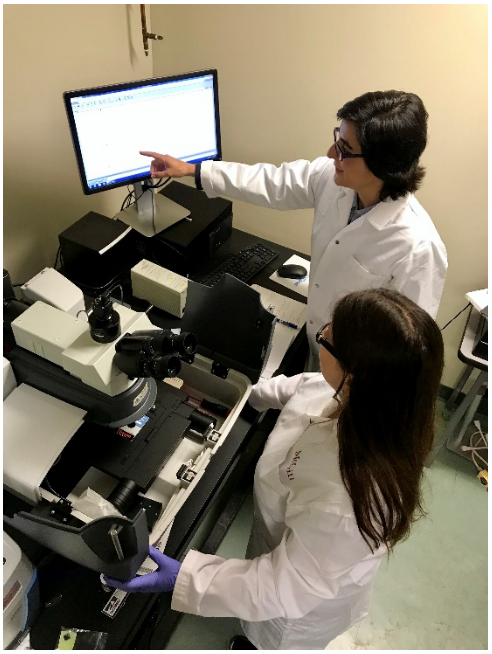
The **harmonization (and in some cases standardization) of methodologies and reference data** for the sampling, detection, quantification, analysis, and risk assessment for specific environmental compartments[2] will be fundamental in fulfilling this goal. It will contribute to reducing lab and field contamination and establishing quality control in research pursuits. While harmonization is critical to routine monitoring, flexible method development and application will still be necessary for emerging research on humans, wildlife, and environmental receptors.

These harmonized methodologies should ensure that data are accurate, representative, and reproducible, and should recognize that plastics behave differently across the ecosystems and environmental compartments in which they are found. These methods should also be complemented by a more robust understanding of the influence these environments have on plastics over their lifecycle (e.g., susceptibility to weathering). To compare research results across studies, track trends over time, and effectively assess cumulative environmental effects, the development and harmonization of methodologies and reference data is critical. Considering that plastics differ widely in terms of size, composition, and other characteristics, as well as the fact that new methodologies are being developed to fit monitoring and research questions, minimum reporting criteria should be established to facilitate comparability between studies (e.g., size, shape, polymer type, etc.). Finally, the contamination of samples is a significant challenge with respect to the quality and reliability of data given the ubiquity of plastics. As such, quality control and quality assurance procedures need to be developed and standardized for use by the plastics research community.

Methodological advancements in the study of plastics

Dr. Nathalie Tufenkji and her colleagues at McGill University are working to advance the methods used to study microplastics and nanoplastics to better understand the way these materials are formed and move through the environment, aggregate, and pick up other pollutants. For example, their work provides insights into the degradation of bulk plastics into smaller microplastic and nanoplastic fractions. Their work has also advanced toxicity studies by accounting for the various additives present in microplastics that are produced specifically for laboratory studies, which can skew the results.

[2] For the purpose of this document, "environmental compartments" will include air (indoor and outdoor), water (fresh and marine), soil, sediments, ice, and biota.



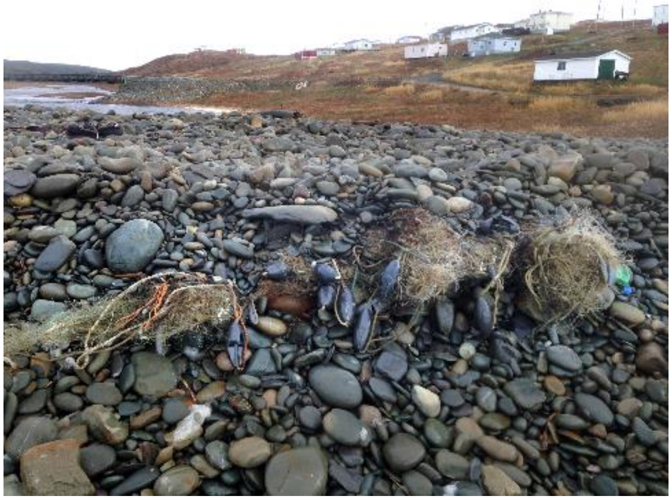
Dr. Nathalie Tufenkji in her lab with student Laura Hernandez (Photo courtesy of Raphaela Allgayer)

Harmonized and/or standardized methodologies can provide a foundation for increased **research efforts, monitoring, and modelling** to determine the types, concentrations, sources, distribution, transport, degradation, and fate of plastics across different environmental compartments. The examination of the fate of plastics in controlled environments that can mimic naturally occurring processes will be helpful in following plastic pollution over both shorter and longer timescales. In addition, taking a lifecycle view—from source to fate—will be key in producing a comprehensive picture of plastics and ultimately informing targeted action. This includes a more rigorous examination of large single-source sectors for aquatic plastics, such as fishing, and a focus on freshwater systems that transport plastics and are a significant source of plastics in the world's oceans.

Applying a variety of research and monitoring techniques and methods will help develop **reliable modelling tools** for identifying sources of plastics and predicting their degradation and fate. Using space-based earth observation technologies and measuring and modelling the transport and fate of plastics will also help identify hotspots for plastic pollution, including geographic accumulation zones and species with high accumulation rates. Overall, increased research, monitoring, and modelling will produce a better understanding of plastic pollution hotspots, and the levels of exposure for organisms and humans. This will guide the assessment of environmental and health risks under Theme 2, and inform future research and action.

Regional state of knowledge report

Dr. Max Liboiron and her colleagues at Memorial University are working on a report addressing the state of knowledge for plastic pollution in Newfoundland and Labrador. Their report will obtain, coordinate, and analyze all available data on plastic pollution in the province, enabling new analyses and visualizations and identifying areas of interest and intervention. Ultimately, the report is aimed at providing policy-makers, rights holders, and stakeholders with the information they need to make informed decisions regarding plastic pollution. This project builds on strong community collaborations and training and is an example of how to effectively work with local Indigenous and Inuit communities in research efforts.



Shoreline plastics, Newfoundland and Labrador (Photo courtesy of Dr. Max Liboiron)

An important aspect of monitoring techniques is their contribution to **measuring the effectiveness of existing and proposed regulatory actions, and other policies and actions designed to tackle plastic pollution**. This area is particularly critical as plastic pollution continues to garner significant global attention and momentum, and with the acceleration of the development and implementation of policies relating to plastic pollution reduction. Science must play a fundamental role in developing, examining, adjusting, and validating current and future policies and actions.

Theme 2: Impacts on wildlife, human health, and the environment

Under Theme 2, the overarching goal is to increase **understanding of the impacts of plastics on wildlife, human health, and the environment**. Health extends beyond the absence of disease or harm, and includes the capacity of organisms for resilience in the face of environmental stress caused by plastic pollution, and cumulative effects from other stressors.

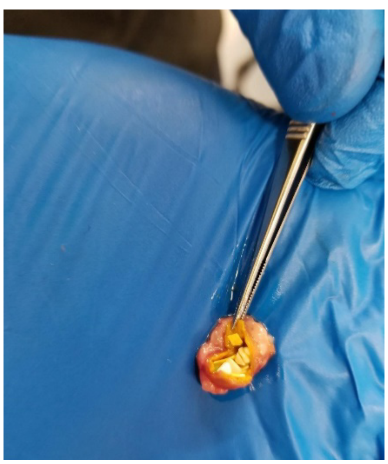
Understanding the characteristics of plastics exposure, and thus its potential effects, is crucial. Science related to the **exposure and occurrence of plastics** in humans, wildlife, and the environment will provide an improved understanding of where plastics originate and how they travel through the environment to organisms. Similarly, science to **characterize the hazard** posed by plastics will highlight which subpopulations may be more sensitive. To characterize the hazards posed by plastics, knowledge of the composition of plastics in food (including traditional subsistence foods), drinking water, and the environment is needed to inform appropriate toxicological studies (e.g., relevant ecological concentrations, appropriate polymers). Properly characterizing both exposure and hazard is essential for identifying subpopulations at risk of reaching a level of exposure where adverse effects may occur.

Understanding the role seabirds play in spreading microplastics

Ongoing collaborative research under the Northern Contaminants Program has been exploring the vulnerability of northern marine bird species to marine plastic pollution. New work from the research team—led by Drs. Jennifer Provencher (Environment and Climate Change Canada) and Mark Mallory (Acadia University)—is looking into how seabirds, in addition to ingesting plastics, might also spread microplastics in the environment through their guano. The researchers are analyzing air, water, sediment, mussel, and seabird samples collected by local Inuit community members in the areas around seabird colonies in order to understand how microplastics are distributed and move through Arctic ecosystems. The project also includes strong contributions from traditional knowledge.

In addition to the possible direct physical effects of plastic exposure, we know that plastics can also act as **vectors for chemical contaminant exposure** for both plastic-derived chemicals and environmental pollutants. Plastics can release chemicals used in their production, such as plasticizers, flame-retardants, and UV stabilizers, some of which have been linked to endocrine-disrupting activity and other adverse effects. Plastics have also been associated with a high capacity to pick up other chemicals present in the environment, such as persistent organic pollutants (POPs) and trace metals, as well as biological contaminants such as bacteria and viruses. The extent to which plastics pick up and release contaminants depends on the type, size, and shape of plastic, its chemical properties, and the environmental conditions present, including the characteristics of an exposed organism. This growing field of research on the interactive effects of plastics with other pollutants will inform the range of health effects attributable to plastic pollution in wildlife and humans, and impacts on the environment, with a focus on both the organism and population levels.

Research campsite close to a seabird colony (Photo courtesy of Dr. Cody Dey)



Stomach of a Leach's storm petrel containing plastic (Photo courtesy of Dr. Jennifer Provencher)

There are several other priority research areas related to the impacts of plastics on human and wildlife health and the environment. Efforts to advance and harmonize methods (Theme 1) are fundamental to making progress in these priority areas. These additional priority research areas include mechanisms of transport (including through food webs), individual-, population-, and community-level effects, and short- and long-term studies to understand the acute and chronic effects of plastics. Monitoring programs focused on key sentinel species could provide an ongoing indicator of wildlife health, human health risks, and environmental impacts. Finally, research into the human health effects of plastics should include the mental health and socio-cultural impacts resulting from the contamination of country foods and from wildlife being harmed by plastic pollution, in recognition of the relationship to the land that exists in Indigenous, northern, and remote communities.

Theme 3: Plastic design and alternatives

Under Theme 3, the overarching goal is to **decrease the environmental footprint of plastics, including improving their design and enabling value recovery (e.g., reuse, repair, remanufacturing, recycling, and composting)**.

Innovation in the **design and manufacturing of plastic resins, additives, and products** is ongoing, and there are thousands of different plastics and plastic-containing products on the market. Plastics and plastic products are often developed to meet specific performance requirements, such as to increase strength and durability, extend the shelf life of perishable food, or reduce transportation- and manufacturing-related greenhouse gas emissions by reducing their size and weight. These are important objectives to inform plastic design; however, meeting our goals will also require **introducing zero plastic waste principles and incentives into innovation and design**. A circular economy for plastics will require that these principles be a primary focus, along with other critical goals, such as climate change mitigation and resilience.

Achieving zero plastic waste starts from the beginning of the design process, and should be informed by data that assesses the health and environmental impacts of plastics across their entire lifecycle. This includes knowledge of the impacts of plastics, additives, alternative feedstocks, and manufacturing processes. It also includes insights derived from analyzing the plastic production and waste streams, as well as knowledge of end-of-life options for future value recovery. Better understanding of which plastic products are commonly found in the environment, such as microparticles from textiles or tire wear, can also inform product design to prevent unintended leakage and enhance value recovery.

Taken together, these insights can help inform the development of sustainable plastics and plastic products, support innovation, and inform business decision making at the earliest stages of product development. Market analysis on the reusability, reparability, refurbishment, remanufacturing, and recyclability of different plastics can also support business decisions related to product design. Incentivizing and promoting this holistic approach can help minimize unintended consequences (e.g., shifting environmental or health impacts from one category to another), support a circular plastics economy, and **focus research investments towards Canada's zero plastic waste goals**.

To further advance the sustainable design of plastics and plastic products, research is needed on the development of **alternative products that provide the beneficial functions of plastics while also reducing negative environmental and health impacts**. This can include use of alternative feedstocks like recycled materials, methane, forestry and food product wastes, and biomass, where validated by a comprehensive lifecycle assessment.

Innovation in bioplastic production

Dr. Trevor Charles, a microbiologist from the University of Waterloo and the company Metagenom Bio, has been conducting research on bioplastics. More specifically, his innovative research explores ways to use bacteria to convert waste such as methane to bioplastics. In producing these bioplastics, the method also makes use of a readily abundant waste product—and powerful greenhouse gas—from sources like landfills and wastewater treatment systems.

Further work is also needed to address difficult-to-recycle plastics, including those produced with additives such as dyes, hardening or softening agents, or flame-retardants, which can affect the recyclability, value, or safety of the recycled product. Designing plastics to reduce waste and enable circularity includes using chemistries that will enhance recyclability and reduce the use of potentially hazardous substances that could lead to human health and environmental risks. It also includes building on the concept of “safe-by-design.”

Sustainable design strategies for achieving zero plastic waste also include designing products for durability (e.g., longer use, less fragmentation during use), disassembly for reuse and repair, refurbishment, and remanufacturing into new products.

The development of new plastic resins, additives, and products is driven by industry. However, there are opportunities for science to play a supporting role in **advancing sustainable design**. This includes considering how design relates to risks (e.g., fragmentation, greenhouse gas emissions, exposure to hazardous substances) and how it can reduce waste and enhance value recovery. Zero waste goals and the analysis of lifecycle impacts should be priorities for collaboration and investment in the research and development of new plastics. The federal government and key partners also have a role to play in encouraging the development of scientific expertise in Canada, in order to build the capacity needed to provide scientific support for reaching Canada’s zero plastic waste goals. In support of CaPSA, the federal government will work with science collaborators, other organizations, and networks to leverage funding across sectors and accelerate sustainable plastic innovations to enable zero plastic waste solutions.

Theme 4: Sustainable use of plastics

Under Theme 4, the overarching goal is to **support the informed usage and sustainable management of plastics by all sectors, including industry, and citizens**. Understanding the benefits and impacts of plastics, as well as business and consumer motivations and behaviours, will help to inform their responsible use.

In most cases, the social sciences that will support progress in this area are newer and less developed than the natural sciences. They are, however, key to the successful implementation of policies to reduce plastic waste and pollution.

Research to **support behavioural change targeting industry and consumers** will encourage these groups to adopt sound practices for the consumption and management of plastic resources. It will provide the knowledge base to support efforts to treat plastics as a valuable resource and meet the ambitious plastic waste reduction targets laid out in the Ocean Plastics Charter. Leveraging and enhancing the participation of industry and consumers—with the help of research to understand their motivations, attitudes, and beliefs surrounding plastics—is vital to increasing the circularity of the plastics economy. Areas of focus may include: research into the effectiveness of behavioural interventions aimed at extending the useful life of plastics; encouraging the purchase of recycled, remanufactured, and alternative products; and encouraging the sound and sustainable use and disposal of plastic products. Additional areas of focus should include behavioural insights related to industry, in order to understand the drivers and mechanisms of plastic use and function along the value chain, as well as the barriers and opportunities related to adopting more sustainable practices.

Using behavioural interventions to reduce plastic waste

Ocean Wise—a Vancouver-based non-profit active in promoting global ocean conservation through research, education, and engagement—has been working to mitigate plastic pollution through its Plastic Wise campaign. To assess the impact of this campaign and understand what sort of behavioural interventions are most effective in reducing plastic waste, Dr. Jiaying Zhao and colleagues from the University of British Columbia's Department of Psychology partnered with Ocean Wise to explore several different poster-style interventions in an office environment. These interventions ranged from simplified recycling signage to images of marine animals trapped in plastic waste to an invitation to sign a pledge to protect ocean life from plastic pollution. The study findings showed that animal images, combined with better recycling instructions, were most effective. Insights like these can help reduce plastic pollution by effectively targeting daily individual behaviours.

Similarly, **knowledge mobilization and science communication** are key components in supporting **informed decision making concerning the use, management, and disposal** of products containing plastic. The systems to manage plastic products are widespread and diverse, as are the effects of plastic pollution. Science must therefore consistently integrate knowledge specific to the local context from a variety of stakeholders. Similarly, scientific results must be effectively communicated across the same range of expertise and local contexts. In addition, understanding the current level of knowledge among administrations, industries, and consumers regarding the urgency and scale of the plastics problem, as well as the actions that can be taken, is needed to inform future interventions.

Finally, achieving zero plastic waste will have significant impacts for Canada's economic sectors. Gathering data and developing approaches to **quantify the economic impacts of a market transition to a circular economy for plastics** is crucial to informing its adoption by Canadian industry, consumers, and public administrations. In addition, understanding the barriers to market entry for innovative plastics and plastic products can also inform policies that incentivize the retention of plastics in the economy. Areas of research may include the development of economic modelling tools for the plastics economy, as well as cost-benefit analyses of different policy approaches to achieve zero plastic waste. Additionally, ongoing monitoring and reporting on the flow of plastics in the Canadian economy will help assess progress toward a circular plastics economy.

Facilitating research in these areas would provide strong foundational knowledge to ensure **informed usage and sustainable management of plastics by all Canadians**. Supporting the development of the social sciences relevant to moving towards a zero plastic waste economy will be crucial to the development of successful intervention strategies that are tailored to the Canadian context.

Theme 5: Waste diversion and recovery

Under Theme 5, the overarching goal is to **enhance the capture and value recovery of existing and future plastics**.

Science can support the development of mechanisms and technologies to increase the capture of used plastic products and prevent their leakage into the environment. Improving the capture of plastics will require a **better understanding of the current practices and opportunities for innovation**, particularly in sectors that produce large amounts of plastic waste. This includes, for example, the Industrial, Commercial, and Institutional (ICI), Construction, Renovation, and Demolition (CRD), and automotive sectors. A better understanding of how all sectors produce, use, collect, sort, and dispose of plastics is needed. This will inform the development of innovative systems, best practices, and incentives to improve diversion and enable value recovery, including the prevention of pellet and scrap loss during manufacturing or recycling.

Waste recovery facilities in Canada primarily use manual sorting of waste streams, which could be improved by digitalization. Additional research is needed for **advanced identification methods and sorting technology**, such as artificial intelligence, which will facilitate recyclability and value recovery by increasing the quantity and quality of useable feedstock from secondary materials. Science will also be needed to determine the feasibility and efficacy of scaling technological innovations throughout Canada, including for use in northern and remote areas.

Importantly, science is needed towards **more complete recovery of plastics from key entry points into the environment**, such as microfibers lost to the environment through wastewater and its by-products. For plastics that have already been lost to the environment, technology and innovation are needed to **collect and process plastic debris** from terrestrial and aquatic environments, such as fishing gear.

Following plastics throughout their lifecycle

Researchers at Polytechnique Montréal are working to identify and analyze the possible pathways that a particular product or material, like plastic, could take from its production to its disposal. The research, led by Drs. Sophie Bernard and Jean-Marc Frayret, will provide insight into why certain products do not always follow the intended pathway. The idea is to identify the ideal pathway, considering both the product's environmental and management costs, and then locate potential points of friction (e.g., gaps in policy, technology, market structure) that would push it off this path. Additional work is being done on the potential use and adoption of a tool for the traceability of materials and products. This tool could use new technologies like blockchain to provide key information about a product's impact (e.g., emissions, material consumption, end-of-life treatment) at each step in the value chain, and would support better decision making by consumers, industry, and governments.

Value recovery of captured plastic products includes repair, reuse, remanufacturing, refurbishment, recycling, and energy recovery (in order of desirability according to the CCME waste management hierarchy). Science can support advancements in recycling, composting, and conversion of plastics to fuel and energy, and will build on and complement work on the design of plastics (Theme 3).

Technologies to recycle plastics are in development, and can either be mechanically or chemically based. There is a need to better understand the use of these technologies at different scales and in different settings in terms of their efficacy, readiness, and optimal use throughout Canada. In addition, the other environmental consequences of these technologies should be properly evaluated, such as the energy- and water-intensive nature of some chemical recycling methods. Research is also needed on different recycling technologies to create a feedstock that can be recycled multiple times without a decrease in quality.

For plastic products that are designed to be **compostable**, additional research is needed to improve the technologies for identifying, sorting, and processing them, as well as research to improve the performance of the products themselves. In addition, research is needed on the biodegradability of these products in the natural environment and their potential contribution to plastic pollution and marine litter. This includes facilitating access to larger-scale facilities where laboratory results can be validated, ensuring there are no unintended consequences when these new compostable products move into real-world applications.

Converting plastics into fuel and energy is another area where research is needed, particularly in terms of undertaking these activities in an environmentally and economically responsible manner (e.g., technologies for fuels from landfill-diverted waste, plastics combustion in cement kilns). Focused research will help identify potential plastic feedstocks through economic and lifecycle analyses, develop the technologies needed to convert existing and future feedstocks into energy, and understand the fate of chemicals, such as POPs, in order to safely and responsibly convert plastics into energy.

Plastics science and northern realities

Plastics science in northern, Arctic, and remote communities intersects with many urgent social, cultural, environmental, and economic issues. For instance, access to clean drinking water in many of these communities remains a challenge, and residents must frequently rely on bottled water. In addition, country foods play an important role in promoting cultural identity and reducing food insecurity and reliance on food shipped from southern Canada, which is often expensive and of poor nutritional value. As the science on the wildlife and potential human health impacts of plastics advances (e.g., plastics in bottled water and country foods), there will be implications for Indigenous communities to be considered alongside basic infrastructure and food security issues.

In addition, northern and remote communities have different priorities for science that supports waste diversion and recovery, again tied to infrastructure issues. For example, proper waste disposal and recycling facilities that are viable in these communities will be a priority in order to keep plastic out of the environment. This work will also be informed by science related to detection aimed at determining where the various plastics present in northern communities originated (e.g., local sources versus long-range transport).

Given the isolation and vulnerability of many of these communities, it is vital that research efforts involve local communities and governance, and include a strong education, training, and capacity-building component. This will ensure community members have the skills and knowledge needed to make decisions based on the information being generated about plastics in their unique environment. An example of collaboration and community-based research is a project funded by the Northern Contaminants Program called "Community monitoring of plastic pollution in wild food and environments in Nunatsiavut." Through this project, Inuit organizations and university professors are working together to raise awareness about marine debris and microplastics pollution while training Inuit participants in a northern community to be co-researchers and lead sampling efforts.

HOW WE GET THERE

Canada is a global leader in plastics science, with significant work happening across the five key themes of the framework, and with participation from many sectors. Much of this work is fragmented, however, creating a patchwork of information and efforts. Mechanisms for collaboration, knowledge mobilization, and capacity building must be leveraged to increase coordination and best utilize resources and expertise to address all the priority research areas of the framework.

It will be critical for scientists and funders to **consider the priority science needs outlined in this agenda**, and how research can contribute to achieving the science goals in a way that is **aligned with ongoing initiatives**. A targeted multi-faceted approach to plastics science in Canada will address priority knowledge gaps, enhance capacity, capitalize on opportunities for innovation and growth, and provide the required evidence base to support sound decision making, including potential new regulations, policies, and programs.

1. Collaboration

Collaboration between federal departments and agencies, other levels of government, academia, industry, non-governmental organizations, Indigenous groups, and international organizations on plastics science is ongoing, and is amplified through the implementation of CaPSA. A cornerstone principle of CaPSA is that plastics science and research should combine **expertise from multiple sectors and disciplines**, wherever possible.

The ***Canadian Science Symposium on Plastics*** (November 2018) brought together federal government representatives and academic experts on plastics science to identify and prioritize key gaps, and propose activities to move forward. This forum also provided a venue to build networks and partnerships and connect science and policy experts. Given its success and the interest expressed by attendees, this Symposium will be a **regular event** that can be focused on **sharing results on specific plastics science questions**. Following the expert advice from the last Symposium, the next Symposium will focus on a foundational priority: the **development of harmonized methods and reference data** for the detection, quantification, and characterization of plastics across environmental compartments.

Interdisciplinarity and collaboration across all research sectors in Canada will help enhance Canada's plastics science capacity. For example, Health Canada, McGill University, the University of Toronto, and Environment and Climate Change Canada have an opportunity to work together to develop methods for the quantification and characterization of microplastics in environmental compartments, including water, soil, and food. The project aims to develop new, more advanced, and reliable techniques for identifying and quantifying microplastics in various media. The outcomes of this project will help better understand human exposure to microplastics and will inform risk assessment approaches and risk management strategies, as warranted.

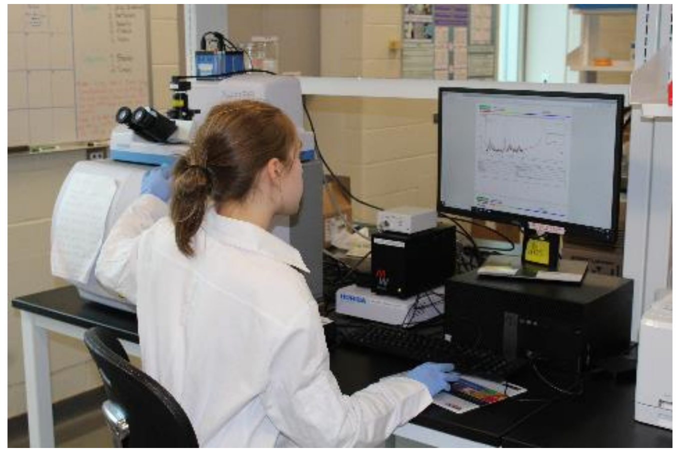
Collecting zooplankton from the CCGS Amundsen (Photo courtesy of Dr. Liisa Jantunen)

Bringing the research community together in deliberate ways can serve to increase coordination and collaboration. Moving beyond regular workshops, researchers can be drawn together through funding programs that prioritize and incentivize collaboration, both within Canada and internationally. **Coordination can also be enabled through data sharing** across research communities, through a central repository for current, planned, and completed work across disciplines and sectors, or through the creation of working groups or communities of practice that focus on specific problems in a holistic way. Existing networks and programs (e.g., Northern Contaminants Program) can also be leveraged by, for example, expanding existing monitoring efforts to include microplastics. In addition, innovative approaches to problem solving implemented elsewhere can be emulated in Canada. One notable example is an international collaborative effort to standardize methodologies between laboratories, supported by an interlaboratory network.[3] This type of approach could be adapted to the Canadian context and used to address priority research questions.

On sustainable design and waste, more efforts can be made to bring together scientists, engineers, lifecycle analysis experts, and municipalities, as well as social and economic scientists, to work together on scoping out product development or waste conversion solutions. The goals in the Ocean Plastics Charter create an incentive for collaboration, and creating nimble research networks can help mobilize diverse expertise around a particular innovation or plastic pollution mitigation strategy.

[3] The QUASIMEME/NORMAN Interlaboratory Study on the Analysis of Microplastics in Environmental Matrices.

There is an opportunity to build on the many community-led cleanup activities already taking place across the country, integrating a **citizen science** angle to contribute to monitoring efforts. These types of activities are particularly well suited to the monitoring of large plastic debris, and should address land, freshwater and marine coasts, and nearshore areas. An existing example is the Great Canadian Shoreline Cleanup, delivered by Ocean Wise and World Wildlife Fund Canada. As part of this initiative, any Canadian can participate in a cleanup and the collected materials are tracked, providing information on the most prevalent types of plastic litter. An added benefit of this type of program is an increased awareness of plastic pollution among Canadians.



Lara Werbowski uses a Raman spectrometer in the Rochman Lab (Photo courtesy of Cole Brookson)

Bridging science and action to tackle plastic pollution

Dr. Chelsea Rochman and her research lab at the University of Toronto are working to understand the sources, fate, and impact of pollutants on aquatic ecosystems, with a focus on plastics. Their work includes a strong commitment to collaboration and knowledge mobilization, and they frequently partner with non-profit organizations and governments to ensure policies and actions to mitigate plastic pollution are informed by science. Dr. Rochman's lab is also active in outreach efforts, engaging the public in events like their annual #CleanUpTheDon event, where community members help clean up the Don River and learn about plastic pollution. These cleanup events also provide Dr. Rochman's lab with important data to inform their research efforts and future action.

2. Knowledge mobilization

Knowledge mobilization is another principle for CaPSA, to ensure that research investments and outputs have an impact on actions to reduce plastic waste, mitigate plastic pollution, and achieve circularity. There are critical knowledge gaps that must be addressed in order to better support evidence-based decision making and, given that this emerging issue is evolving rapidly, research will need to advance in tandem with policy and infrastructure planning.

There is a need to **connect researchers from a wide range of disciplines, policy-makers at all levels of government, and key influencers in other sectors** in innovative ways, creating linkages between scientists and the users of science. Sharing data through accessible mechanisms is one means of doing this, as access to data can help inform decision making. This could include monitoring data that is accessible to decision-makers and communities, or information on emerging Canadian innovations that can be utilized by industry or in recycling infrastructure. Many **open data** platforms already exist or are in development, but no platform specific to plastics research exists. There have been calls internationally, through the G7 and the United Nations Environment Assembly, for example, to facilitate access to data on plastic pollution. The federal government is committed to continued cooperation with the Chief Science Advisors of the G7 and the European Union to advance scientific understanding and information sharing related to microplastics. The federal government can also play an important role in building a data-sharing community among researchers, and in raising awareness of the various platforms that could be used to share data.

Knowledge mobilization fora can bring the research and policy communities together to increase the impact of federal investments in plastics science. Policy Ignite and the Canadian Science Policy Conference are two possible mechanisms that could be leveraged for sharing research results with a policy audience. Regular knowledge sharing could be planned and leveraged to include an objective of informing policy-makers of science outputs and discussing evolving needs. The multi-partner approach of the *North American Caribou Workshop* could also serve as a model.

Art as knowledge mobilization (Detail of "In The Belly Of The Whale" by Julie Sperling)

Stimulating new innovation and supporting technology deployment will also be an important part of achieving Canada's zero plastic waste goals. Challenge competitions, for example those coordinated by Innovative Solutions Canada, have already proven that they are helpful in addressing specific aspects of the plastic pollution problem. Policy objectives set by all levels of government to help reduce waste, increase the capture of plastics, and advance green procurement can also incentivize innovation and investments aligned with achieving greater circularity in the plastics economy.

In situations where specific questions or challenges need to be addressed, task teams can also be struck to **develop targeted science advice or collaborate on technical challenges** to try to rapidly synthesize knowledge and identify solutions. In these situations there is a well-scoped problem and a clear user of the resulting information. One example of this is the incident report the Canadian Wildlife Health Cooperative submitted to federal decision-makers to inform action in response to the 2017 right whale die-off. These incident reports could be explored as one way to mobilize critical knowledge in a targeted and applied manner, including insights into priority issues.

Finally, social media has been a powerful tool in raising awareness about plastic pollution and encouraging action among citizens. It can also play a role in sharing science and mobilizing knowledge. There is a **growing community of scientists using social media**, both as part of their research (e.g., sharing their work, keeping abreast of the latest research, expanding their networks, cross-pollinating between disciplines) and as a way to communicate their work to non-scientists. This momentum could be encouraged and leveraged to build and connect the plastics science community. Activities like “Ask A Scientist” or a plastics Twitter conference could be explored. Federally, the government could also explore developing a communications strategy for plastics science to help increase the impact of federally supported research.

3. Circular economy transition

The flow of materials and energy in the Canadian economy is mostly linear, as resources are extracted, transformed into products, and then disposed of as waste. In contrast, a circular economy aims to keep products and materials in use for as long as possible and to maximize their value. This system closes the loop in the use of natural resources by reducing, reusing, repairing, remanufacturing, recycling and composting materials or, if no other option exists, recovering energy at their end of life.

Plastics are an example of a lost value in the resource chain, with 91% either landfilled, incinerated, or lost to the environment in Canada today. To work towards fulfilling the objectives of the CCME’s Canada-wide Strategy on Zero Plastic Waste, the design, production, use, recovery, and adaptive recycling and reuse of most—and ideally all—plastic materials must be made sustainable through minimal or zero waste throughout the full lifecycle and value chain of products.

Science can further the transition to a circular economy for plastics by supporting informed substitution in the design of plastic resins, additives, and products; providing the analysis needed to support behavioural change interventions; and enhancing the mechanisms and technology for capture and value recovery of existing and future plastics.

A goal of CaPSA is for the principles of a circular economy to be advanced in any plastics-related research. An inventory of current federal investments related to plastics science highlighted that there may be additional opportunities to consider recyclability or compostability, where appropriate, in the early stages of product development when undertaking projects aimed at furthering other objectives (e.g., lightweighting cars to reduce greenhouse gas emissions, using bio-based polymers for the development of plastics materials). As part of its commitments to advancing circularity, the Government of Canada’s investments in science could further the principles of the circular economy in all projects or activities involving plastics materials, particularly by assuring that all materials are developed with comprehensive lifecycle analyses that fully consider the potential health and environmental risks of the products. It will also be important to gather lessons learned from the application of a circular economy lens to plastics in order to help inform its application to other materials and sectors. This could be accomplished, in part, by incorporating circular economy criteria into evaluation and monitoring efforts associated with applicable research initiatives.

4. Capacity building

According to a recent economic study commissioned by Environment and Climate Change Canada, Canadians throw away over 3 million tonnes of plastic waste every year. This represents an estimated lost economic opportunity of close to $8 billion per year in Canada. Moving towards a circular economy for plastics is a significant economic opportunity. Part of this shift will include a pull for **more capacity and expertise in Canada to perform research** on product development, recycling and recovery technologies, the socio-economic factors of market transition, and changes in plastic use and pollution in Canada.

Research funding through Canada's granting agencies and federal departments and agencies, for example, through jointly funded targeted calls on important themes, is one way to increase Canadian research capacity. This could include supporting multi-disciplinary projects to help develop the skills needed to address complex problems, or creating more opportunities for students to work in emerging areas of plastics science. The **Green Municipal Fund** is another avenue to harness and expand existing expertise to address specific plastic waste management problems at the municipal level. The **Science Horizons Youth Internship Program** is a federally supported program that helps to increase the workforce in science, technology, engineering, and mathematics (STEM) fields within the environmental and clean technology sectors. It is also important to build capacity by **involving local communities in research projects**. For instance, Ocean Wise's Ikaarvik program engages local youth, drawing on Inuit knowledge and science to address issues of local concern. The youth gain experience and skills that enable them not only to play a more active role in research being done in their communities, but also to better present community needs to researchers and communicate the research back to the community.

Other levels of government can also invest in STEM education and in supporting small and medium enterprises in Canada, which represent an area of significant potential job growth in the future circular plastics economy. Industry can also invest in research and development to support this science agenda. Through collaboration across different sectors and levels of government, **investment in research and development and skilled jobs will help increase capacity** to address the challenge of plastic pollution and Canada's zero plastic waste goals.

CONCLUSION

The Government of Canada has been a world leader on plastic pollution, through the Ocean Plastics Charter, the Canada-wide Strategy on Zero Plastic Waste and its corresponding Action Plan, the G7 and Canadian Plastic Innovation Challenge, the ban on microbeads, and a range of research and development initiatives, including support for on-the-ground initiatives and citizen science. In addition to leading by example, these initiatives are contributing to changing the way plastic products are manufactured, used, disposed of, and recovered, and are supplying important scientific knowledge to inform and support the decision- and policy-making that will shift Canada towards a circular plastics economy.

While government action and leadership is important, the scope and scale of the plastic pollution challenge will require collaborative and coordinated action across all sectors and regions, including all levels of government and Indigenous partners, industry, academia, the non-profit sector, and the general public. Science will be fundamental to informing this action, which is why the Government of Canada has worked with partners to produce Canada's Plastics Science Agenda.

CaPSA is meant to amplify the impact of Canadian plastics science by providing a framework that identifies gaps in current knowledge and the science needed to fill them, as well as policy-relevant areas of focus. The hope is that CaPSA will encourage additional research in related areas of social and behavioural sciences, applied sciences and engineering, and beyond, inspire meaningful changes in consumer and industry behaviour, and inform policy and decision making at all levels.

The priority science needs identified in CaPSA begin with fundamental work to improve detection, sampling, and analysis of plastics across their lifecycle, as well as increased research, monitoring, and modelling to inform decision making and action. Building on this foundation, CaPSA also calls for a better understanding of the impacts of plastics on wildlife, human health, and the environment. In addition to addressing key methodological and health impact gaps, CaPSA identifies science needs that, once addressed, will contribute to decreasing the environmental footprint of plastics, as well as improving the capture and recovery of plastics, thereby working to address the problem before plastics enter the environment. There is also a strong social component to CaPSA, calling on the social and behavioural sciences to contribute knowledge and insights that can support behavioural change in industry and consumers. Taken together, the five themes identified under CaPSA will help drive science to support action across the entire lifecycle of plastics.

While Canada is a global leader in plastics science, much of the work underway is fragmented. It would benefit from increased collaboration, knowledge mobilization, and capacity building in order to increase coordination and make the best use of existing resources and expertise. CaPSA proposes several actions and models that could be explored in order to advance plastics science.

The call for action on plastic pollution is clear, and science will be fundamental to making meaningful progress on tackling this problem. CaPSA will serve as a guide for scientists and funders from all sectors, as they join efforts to advance the science needed to support action on plastic pollution.

ANNEX 1: CANADA'S PLASTICS SCIENCE AGENDA FRAMEWORK

Detection, quantification, and characterization of plastics in the environment	
Goal: *Detect, quantify, and characterize sources, pathways, and fate of plastics in the environment*	
Science needs to fulfill goal:	• Standardized methodologies and reference data for detection, sampling, analysis, and risk assessment across media, including consideration of cumulative environmental effects • Research, monitoring, and modelling to determine types, concentrations, sources, fate, distribution, transport, and degradation of plastics in air, soil, sediments, fresh and marine waters, and biota • Monitoring of plastics in the environment to measure the performance of existing and proposed regulatory actions and other risk management actions, as warranted
Existing federal contributions:	• Advancing sampling and characterization techniques (ECCC, NRC) • Understanding microplastic movement (dispersion modelling, deposition, movement through food webs) (NRC, DFO, CIRNAC) • Establishing environmental baselines (DFO) • Understanding microfiber sources and distribution in freshwater and marine environments and fish (DFO, ECCC) • Surveying and monitoring in key areas (e.g., coastal British Columbia, Gulf of St. Lawrence, Arctic) (DFO, PCA, ECCC, CIRNAC)
Impacts on wildlife, human health, and the environment	
Goal: *Understand the impacts of plastics on wildlife, human health, and the environment*	
Science needs to fulfill goal:	• Pathways, levels, and exposure in human, wildlife, and environmental receptors • Health effects on aquatic and terrestrial wildlife, humans, and effects on environmental receptors • Ecotoxicology of plastics as vectors for contaminant exposure
Existing federal contributions:	• Assessing and quantifying sources, exposure, and ingestion in key biota (e.g., seabirds) and ecosystems (e.g., Arctic, Great Lakes, Gulf of St. Lawrence) (DFO, ECCC) • Testing and monitoring drinking water (HC) and wild foods (CIRNAC) • Assessing the science of human health impacts from plastic exposure, including contribution to the World Health Organization report on health effects of microplastics in drinking water (HC) • Understanding the effects of microfibers in fish (DFO) • Monitoring and assessing effects of plastics on wildlife and other environmental receptors (e.g., seabirds, whales, fish, zooplankton, shellfish) (ECCC, DFO)
Plastic design and alternatives	
Goal: *Decrease the environmental footprint of plastics, including improved recyclability, value recovery, and compostability*	
Science needs to fulfill goal:	• Design of plastic resins, additives, and products towards improved recyclability, value recovery, and compostability, including incorporation of bio-based and/or recycled feedstocks • Lifecycle analysis of new products to minimize unintended consequences and to support a circular economy approach
Existing federal contributions:	• Research and development to decrease the environmental footprint of plastics, including alternatives to petroleum-based feedstocks and design for recyclability and compostability (NRC) • Advancing bio-based materials for commercial plastics, such as forestry products (NRC, NRCan, AAFC) • Developing smart food packaging (ECCC) • Reducing plastic construction waste (ECCC, NRC)
Sustainable use of plastics	
Goal: *Support informed usage and management of plastics*	
Science needs to fulfill goal:	• Analysis to support behavioural change interventions targeted to industry and consumers • Knowledge mobilization and science communication to support informed decision making, notably with regards to the use, management, and disposal of products containing plastic • Data, information, and approaches to quantify the economic impacts of plastic waste and its pollution by sector, and to inform and support market transition to a circular economy
Existing federal contributions:	• Reducing single-use plastics in government institutions (ECCC, TBS) • Building community solutions for marine plastic litter, particularly in arctic communities (ECCC, CIRNAC)
Waste diversion and recovery	
Goal: *Enhance capture and value recovery of existing and future plastics*	
Science needs to fulfill goal:	• Mechanisms and technology to prevent leakage, capture and recover plastics from the environment, and maximize value recovery of products, including improvement to infrastructure • Capture of plastics from key environmental entry points, including wastewater and its by-products • Assessment of effectiveness of capture and value recovery technologies and methods
Existing federal contributions:	• Evaluating mechanisms to recover value from different types of hard to recycle plastics (NRC) • Cleaning up marine plastic litter and developing ocean-to-plate plastic-free fisheries and aquaculture (DFO, PCA, ECCC) • Improving the recycling of mixed plastics (ECCC)

(List of departmental acronyms on following page)

List of departmental acronyms:

AAFC – Agriculture and Agri-Food Canada
CIRNAC – Crown-Indigenous Relations and Northern Affairs Canada
DFO – Fisheries and Oceans Canada
ECCC – Environment and Climate Change Canada
HC – Health Canada
NRC – National Research Council Canada
NRCan – Natural Resources Canada
PCA – Parks Canada Agency
TBS – Treasury Board Secretariat