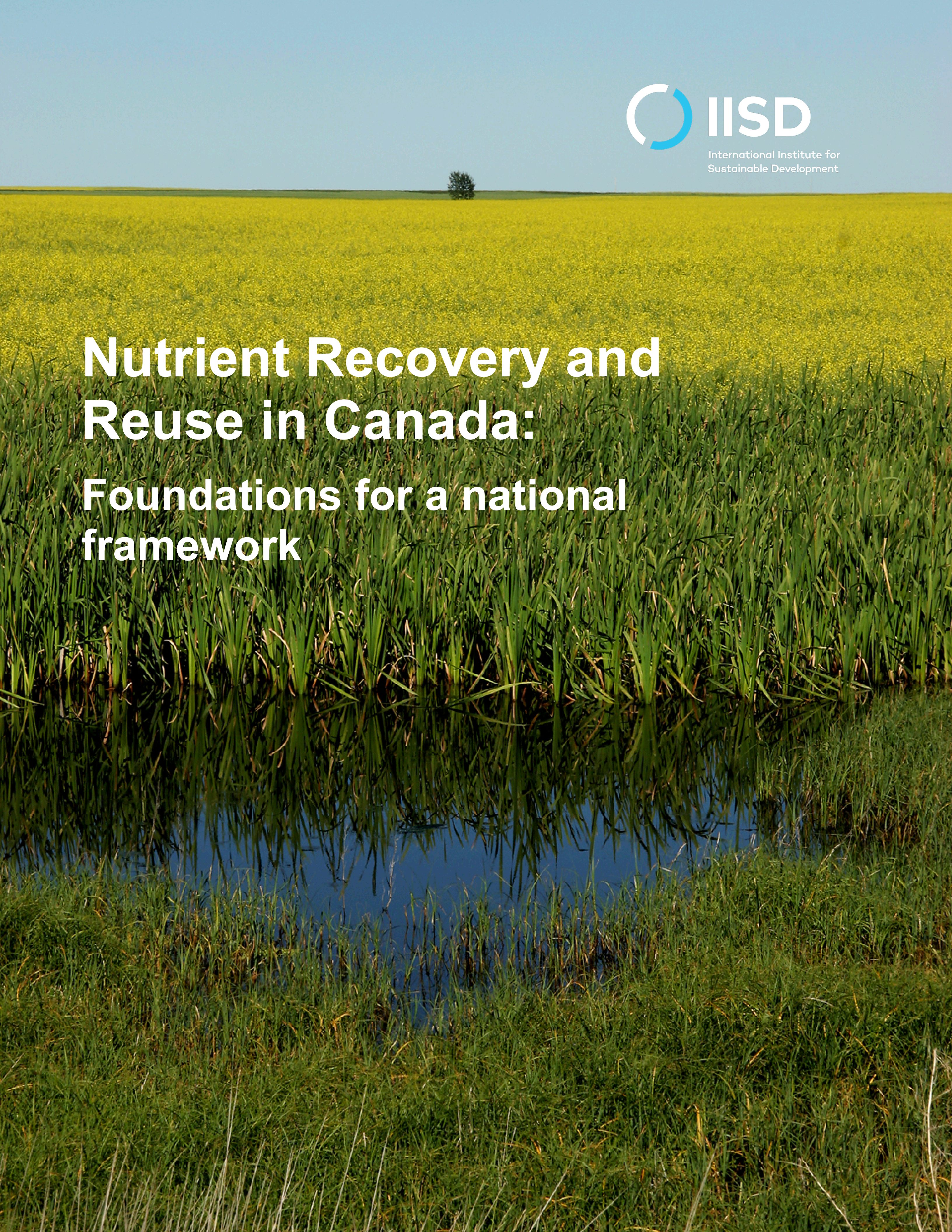

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International Institute for Sustainable Development

Nutrient Recovery and Reuse in Canada:

Foundations for a national framework

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EXECUTIVE SUMMARY

Introduction

Phosphorus (P) is a non-renewable, non-substitutable resource required for agricultural fertilizer and directly linked to **global food security**. It is also used in other industries and in many common consumer products, such as lithium batteries. Phosphate resources are finite. Canada currently heavily relies on foreign imports of commercial phosphate. While future shocks to the nutrient supply chain may be a decade or more away, proactive behavioural and infrastructure actions are required to ensure a seamless transition to ensure long-term food security. Simultaneously, P also poses **major environmental issues** through the eutrophication of lakes such as Erie, Winnipeg, Ontario and many inland lakes. Prudent cost-effective management of P is linked closely with **soil health** and soil carbon, nitrogen (N) management, biogas, biofuels and food waste.

The European Union (EU) has identified P as a "**critical resource**" and established the European Sustainable Phosphorus Platform (ESPP) of 35 industry, government and academic partners who network regularly to advance recovery technologies, practices and policies. The Sustainable Phosphorus Alliance, based in the United States and established in 2014, promotes P recovery and reuse (PRR) in North America.

This report outlines a **framework** for nutrient recovery and reuse (NRR) in Canada and includes results of the National Nutrient Reuse and Recovery (NNRR) Forum held March 8, 2018, in Toronto, as well as insights from research and discussions among government staff, academia and other experts.

Drivers

Future scarcity of supply, **abundance** in environmental systems (eutrophication) and **cost increases** of P are identified as the key drivers of PRR. Decreasing high-quality global reserves, a dependency on imports, vulnerability of potential manufacturing and supply chain disruptions are cited as indicators of future scarcity. Increasing populations, intensive agriculture and lack of watershed management are resulting in leakage of nutrients into many waterbodies, causing algae issues. In 2007/08, the price of rock phosphate increased and more than doubled the farm gate price of P fertilizer. While prices did stabilize, future price shocks can threaten food security. Higher prices will lead to market development for recovered products.

The Forum

The NNRR Forum was organized by the International Institute for Sustainable Development with the former Ontario Ministry of the Environment and Climate Change (now the Ministry of the Environment, Conservation and Parks), Environment and Climate Change Canada (ECCC) and the Everglades Foundation. The forum brought together over 80 stakeholders to review current recovery activities in Canada: to identify opportunities for new technologies and programs, to broaden the network of support for NRR and to identify ways to implement adaptive technologies to address P loading to Lake Erie, Lake Ontario and inland lakes. The forum included talks by 18 Canadian and international experts, a panel dialogue and breakout discussion tables. While the forum scope was NRR, the primary focus was on PRR.

The forum identified key gaps, including the need to understand: 1) the critical importance of P and that supplies are limited by quantity, quality and accessibility; 2) Canadian P flows to target key sectors and areas; 3) coordination between government departments; and 4) business cases and market instruments for P technologies and programs. Key barriers identified included: short-term thinking by decision makers, new innovation risks and costs, development of the new markets, and raising awareness among farmers, farming associations and regulators.

A full summary of the *Interim Forum Report*, video and slide deck presentations can be found at https://iisd.org/event/national-nutrient-reuse-and-recovery-forum

The forum and report identified many PRR initiatives and challenges. For example:

- Several Canadian companies successfully undertake P recovery; where the driver for P recovery is the reduction of municipal costs for sewage discharge operational costs.
- A Canadian company produces struvite generated from anaerobic digestion of food waste, as a side product of feed-in tariff subsidies for gas generation.
- A Canadian Food Inspection Agency-approved fertilizer from wastewater treatment plant biosolids is currently produced in proactive Ontario municipalities (Guelph, St. Thomas, Elora).
- Laval University's BioEngine Research team supports integrated nutrient and energy recovery from waste and has a geo-spatial tool based on biorefinery location, technology and end-user input.
- Quebec has phased in a ban on incineration and disposal of organics to landfills by 2022, and a CAD 650 million subsidy supports waste valorization projects such as anaerobic digestion and composting.
- The Lake Winnipeg Bioeconomy Project demonstrates nonpoint source nutrient recycling through biomass harvest for energy and biomaterial products.
- The USD 10 million George Barley Water Prize for P removal from fresh water, with USD 170,000 for P recovery, is a current incentive for recovery technologies.
- An NSERC chair for nutrient recovery is under development.
- The Lake Erie Action Plan cites an action to explore opportunities to adopt innovation technologies that encourage PRR.

The report also outlines key aspects to support the future Canadian Nutrient Recovery and Reuse Framework, including communication objectives; messages, audiences and methods; a review of global nutrient platforms; and draft goals and outcomes. Recovery and reuse technologies and best management practices (BMPs) were reviewed within the four source categories of urban and rural point and nonpoint sources of P. Potential funding sources and incentives were presented.

Key Opportunities in Agriculture, Rural/Urban Linkages

The forum and report emphasize the important roles of farmers, as primary generators and users of nutrients; of cities, for managing and recovering P from wastewater and municipal food waste; of researchers and industry, in collaborating to develop new practices and technologies and for governments in developing policies and programs.

Key opportunities to improve P recovery in agriculture were outlined both at the forum and in the report. These include investments in manure processing, precision agriculture and the economic, as well as environmental, benefits of soil health and production sustainability with the addition of organic materials. Most agricultural operations are effectively recycling today; however, there are localized hot spots (e.g., high concentrations of livestock and legacy P in soils) that warrant management actions. A key research and development issue is to find practical ways to move excess manure or subcomponents (e.g., liquid and separated solids) of manure from areas of livestock concentration to the non-livestock farms. This would maximize both the economic and agronomic benefits of all parties in addition to introducing methods to better distribute manure (e.g., neighbourhood nutrient/manure management strategies and planning). The continuing trend to concentrate livestock production onto fewer and larger farms increases the technical and transportation barriers to recycling manure nutrients directly onto farmland. Thus, there may be advantages for these operations to utilize technologies to extract nutrients in more concentrated forms for export to other areas.

A key step is to work closely with farmers and farm associations to ensure the recovered products meet their needs and that economically feasible, measurable linkages to water quality, N management, energy, soil carbon, biogas, contaminants and food safety are addressed in the PRR strategy.

Moving Forward in Building a Canadian Nutrient Recovery and Reuse Framework

The forum stakeholders and subsequent analysis endorses the development of a Canadian Nutrient Framework to coordinate NRR in Canada. **Long-term food security**, **soil health**, **water quality** and **job creation**, as part of the new circular economy, were identified as key outcomes. Collaborative partnerships are required, with industry, academia, government and non-governmental organizations to support demonstration and pilot projects to share risk and build the circular economy.

Pilot and demonstration projects with partners were identified as important components moving forward. This report outlines existing and proposed pilot projects and projects that support the development of a Canadian Nutrient Framework. It includes:

- A **National Nutrient Recovery and Reuse Framework Working Group** to refine objectives and outcomes, develop metrics and a budget.
- McGill University's development of the **Phosphorus Hub** to "Feed the World," which provides a web forum for P awareness and information collaboration.[1]
- **The Lake Erie Action Plan** states that Canada and Ontario will work with partners to explore opportunities to adopt innovative technologies that encourage PRR. Currently, ECCC is undertaking a study to **recover P from a wastewater treatment plant** in partnership with the Region of Waterloo. Monitoring from this project will be conducted to assess performance and to engage other municipalities and farmers in the Lake Erie basin to promote broader uptake.
- **Neighbourhood manure management** partnerships are under development with the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and Agriculture and Agri-Food Canada (AAFC).
- A **strategic fertilizer project** has been initiated to further understanding of supply/demand issues and map out roles and responsibilities for nutrient cycling that engages key federal and provincial departments including AAFC, ECCC, Statistics Canada and OMAFRA.

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[1] See: https://www.phosphorushub.com/

Recommendations for a Canadian Nutrient Recovery and Reuse Framework

This report outlines four pillars for the Canadian Nutrient Recovery and Reuse Framework to meet the objectives of food security, soil health and water quality within a circular economy. Key recommendations are outlined below.

Pillar 1: Develop an Information/Communication/Education Strategy:

1. Develop regional P flow maps.
2. Recognize P nationally as a critical resource in an Education Strategy.
3. Determine the social cost of P, including the economic cost of doing nothing.
4. Develop Phosphorus Footprint and Carbon–Nitrogen–Phosphorus (CNP) links.
   Benefits: Proactive management of P and key base information assembled.

Pillar 2: Develop a Strategy for Coordination of Network and Research:

1. Build a Canadian Nutrient Network: include government, industry, academia, non-governmental organizations.
   Benefits: Facilitate new approaches/innovations and nutrient circular economy partners.
2. Appoint NSERC Nutrient Recovery Chair: coordinate academia, users and industry.
   Benefits: Ensure scientific collaboration and end-user involvement, avoid duplication, and support new Canadian approaches and technologies.
3. Develop Transportation: e.g., neighbourhood nutrient/manure management
   Benefit: Link manure from intense livestock operations with nutrient crop needs.
4. Develop a Fertilizer Strategy: review fertilizer supply/use issues, set roles, responsibilities and actions for long-term supply stability.
   Benefit: Proactive agricultural fertilizer decision making for long-term food security.

Pillar 3: Support Technologies and BMPs:

1. Develop "concept-to-market" programs for NRR.
2. Examine urban food/organic waste recovery opportunities and quality issues.
3. Review agriculture improvements to existing technologies and BMPs.
   Benefit: Support Canadian farmers and companies for long-term fertilizer security.

Pillar 4: Develop Market and Policy Instruments:

1. Develop business cases for private and public funding partners (e.g., wastewater recovery).
2. Use models of diffusion, such as the Rogers diffusion model, to develop a strategy to speed innovation, product development and adoption of new technologies.

3. Examine policy and regulatory incentives, such as bans on organics in landfills, P offsetting that might include credits for P recovery, banning garburators and/or incentives for composting food and organic wastes.
   *Benefits**:** Increase use of PRR practices/technologies and job creation.*

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LIST OF ACRONYMS AND ABBREVIATIONS

AAFC	Agriculture and Agri-Food Canada
BMP	best management practice
C	carbon
ECCC	Environment and Climate Change Canada
ECN	European Compost Network
EIP-AGR	Agricultural European Innovation Partnership
ESPP	European Sustainable Phosphorus Platform
EU	European Union
DSS	decision-support system
FTW	floating treatment wetlands
GHG	greenhouse gas
GPRI	Global Phosphorus Research Initiative
K	potassium
MECP	(Ontario) Ministry of the Environment, Conservation and Parks (previously MOECC)
MOECC	(Ontario) Ministry of the Environment and Climate Change Resources
N	nitrogen
NNRR	National Nutrient Recovery and Reuse (Forum)
NP	Nutrient Platform
NRR	nutrient recovery and reuse
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
P	phosphorus
PRR	phosphorus recovery and reuse
R&D	research and development
RNPS	rural nonpoint source
RPS	rural point source
SCP	social cost of phosphorus
SOC	soil organic carbon
SPA	Sustainable Phosphorus Alliance
TMDL	total maximum daily load
UNPS	urban nonpoint source
UPS	urban point source
US EPA	U.S. Environmental Protection Agency
WRRP	water resource recovery plant
WWTP	wastewater treatment plant (now often referred to as WRRP)

1. INTRODUCTION

With growing concern over the current rates of resource extraction needed to meet increasing global population demand, it is clear that resource depletion can no longer be sustained in its current form. Nitrogen (N), phosphorus (P) and carbon (C) are critical to the agricultural sector and global food security, but inappropriate management of these nutrients has had huge impacts on the environment and economic security. Leakage of these nutrients from agriculture and urban sources into the environment disrupts aquatic food webs, causes eutrophication and reduced water quality, and adds C to the atmosphere, ultimately contributing to climate change effects. Circular economy concepts, where resources are recycled, recovered and reused for as long as possible—in contrast to the traditional linear economy where nutrients are used once and disposed of—will need to become accepted practice globally. The water–food–energy nexus clearly demonstrates water, food and energy security are inextricably linked. Disruption of one impacts the other. Clear steps must be taken toward sustainable nutrient management, reuse and recycling to prevent the continued degradation of water and air quality, soil health and agricultural sustainability.

In 2013, the EU identified P as a "Critical Resource" and established a Phosphorus Platform (today, it is a nutrient platform with a primary focus still on P) of 35 industry, government and academic partners who network regularly to advance recovery technologies, practices and policies. Canada currently does not have a known national policy to support nutrient recovery and reuse (NRR). An overarching recommendation is to recognize P specifically as a limited strategic resource. The numerous benefits are articulated in this report, and such a policy would enable P recovery and reuse (PRR) within a sustainable national NRR framework, much as the EU has done. N and P are naturally occurring nutrients. N is the most abundant element in the air, and C, N and P are natural parts of the soil and water ecosystems. N, P and C are all essential nutrients to all living organisms, including plants, animals, and human populations.

While nitrogen is renewable, P is a non-renewable, non-substitutable resource required for agricultural fertilizer and directly linked to global food security. It is also used in other industries in many common consumer products, such as lithium batteries, which increases demand for finite supplies of rock phosphate. Canada currently relies on foreign imports of P. While shocks to the nutrient supply chain may be a decade or more away, prudent behavioural and infrastructure changes require a similar time frame to ensure a seamless transition to a circular system to recycle this key critical resource. Simultaneously, P also poses major environmental issues through the eutrophication of lakes such as Erie, Winnipeg, Ontario and many inland lakes. Effective management of P in its use, recovery and reuse has direct impacts not only on agricultural resilience, lake health and water quality but also on soil health and soil organic C reserves, C emissions and N management. It also has implications for biogas, biofuels and other high-value bioproducts.

While N and C are freely available in the atmosphere, P has been directly linked to impacts caused by eutrophication and algae blooms in freshwater lake systems. For these reasons, P emerges as more relevant in the initial discourse on NRR, as well as the recent National Nutrient Recovery and Reuse (NNRR) forum that forms the basis of this report. This is also reflected in Europe's NRR strategies, which are a decade ahead of Canada. While PRR was the initial focus in Europe, N and organic C are emerging as important nutrients due to their role in soil health.

It would be beneficial for Canada to take similar action and recognize P as a critical strategic resource. If Canada were to establish an effective policy toward P and NRR and coordinate a national NRR network, it would provide buffers for future P supply shocks. This report was developed to contextualize the need for NRR in Canada, specifically the importance of PRR, and will provide greater clarity on the following:

- What are the specific elements of NRR in Canada?
- What are the issues and opportunities surrounding PRR in Canada?
- What are the actions that led to the development of NRR in Europe and the EU Sustainable Phosphorus Platform?
- What actions could support the development of NRR in Canada?

1.1 Nutrient Cycling and Implications for Management

Nitrogen is one of the most abundant elements in Earth's atmosphere, hydrosphere and biosphere; however, most natural forms of N are nonreactive and not readily available to be taken up (Galloway et al., 2003). The various forms of N naturally transfer throughout the environment through processes of N fixation, ammonification, assimilation, nitrification and denitrification. Atmospheric nitrogen (N_2) is converted into ammonia (NH_3/NH_4+) through bacterial fixation, which undergoes nitrification to form nitrate (NO_3-) from soil bacteria under aerobic conditions. Atmospheric nitrogen can also be converted to nitrate (NO_3-) under high-energy events, such as volcanic eruptions, lightning or industrial combustion. Denitrification occurs when anaerobic bacteria convert NO_3- to N_2, beginning the cycle again. In the geosphere and hydrosphere, plants uptake ammonia and nitrates through assimilation, forming important proteins and nucleic acids that can then be consumed by animals. Ammonification converts organic N compounds (e.g., proteins or amino acids) to ammonia, which can then undergo further assimilation or nitrification (Fowler et al., 2013).

The natural N cycle has been accelerated and altered by human activities, particularly high-energy industrial activities and intensive agriculture that produce and release nitrogen oxides (NO_x), and ammonia (NH_3/NH_4+). The release of nitrogen oxides and ammonia into the atmosphere results in greenhouse gases (GHGs) altering atmospheric composition, specifically disrupting the ozone layer, causing climate change (Gillenwater, 2010). It also results in N deposition on Earth causing smog, acid rain, acidification and increased nutrient availability in aquatic ecosystems (U.S. Environmental Protection Agency (US EPA), 2017a). While industrial production of N fertilizer and release of N compounds into the environment have disrupted the natural cycle of N, the production and use of fertilizer has been essential to sustaining food production for the ever-expanding human population (Gruber & Galloway, 2008).

Due to its role in plant growth, agriculture and food health, and its critical role in climate change, nitrogen reuse and recovery is an important targeted response. Opportunities for recovery and reuse are likely highest from high-energy industrial activities. Biomass assimilates a number of nutrients and provides another opportunity for reuse and recovery of nutrients *including* N.

Carbon is another of the most abundant elements on Earth and is present in all living organisms. The natural C cycle includes respiration, combustion, photosynthesis and decomposition. Carbon enters the atmosphere as carbon dioxide (CO_2) through respiration and combustion. Photosynthesis converts carbon dioxide into carbohydrates in plants, which then release oxygen available for respiration. The decomposition of organisms releases carbon dioxide back into the atmosphere, beginning the cycle again. Soil organic carbon (SOC) concentrations can affect soil health and soil behaviour, including its ability to retain moisture and other nutrients. As a result, managing SOC has become a priority in the context of soil health, nutrient management and, increasingly, climate change mitigation.

Human activities have had a massive impact on the C cycle through population expansion, deforestation and fossil fuel burning. Carbon dioxide is the largest GHG contributor to the atmosphere (Rice & Reed, 2007) and, paired with methane and nitrous oxide, is causing severe disruption to atmospheric composition, contributing to climate change.

Photosynthesis through plants is responsible for a large proportion of C use globally. Decomposing biomass releases C into the soil, where C-rich soils enable binding with other nutrients and water to create the best conditions for plant growth. As global soils are essential for sustainable agriculture and contain 2–3 times higher amounts of C than the atmosphere, a key focus of C management must address the improvement of soil C retention. Specific practices include the prevention of deforestation, restoration of pastures and degraded forests, growth of crops and legumes that accelerate nutrient capture, and conservation tillage.

Phosphorus is an essential macronutrient, essential for all forms of life, a critical input for agriculture and therefore a key commodity in the global food security chain. It is a naturally occurring element found in the Earth's rock crust in raw forms, and it is not always available for extraction. Natural runoff and sediments containing P are transformed into rock formations over millions of years, and P rock deposits available for mining are concentrated in regions where P has bioaccumulated slowly over time. In a natural P cycle, soluble P salts are released from rocks through weathering and taken up by plants and animals as necessary for growth. P is returned to the soil through senescence and decay of dead plant material and residues, in a form that is readily available for plant uptake and growth.

Today, the P cycle is driven by anthropogenic activities: development, mining and agriculture (Fillippelli, 2014). P is mined from rock phosphate and blended with other nutrients to fertilize plants. Fertilizer from mined P sources, and the spreading of manure, provide nutrients necessary for production of food crops and other agricultural products, including livestock feed.

Biological absorption of P is a complex chain of chemical reactions that is affected by temperature. In both soil and water, cold temperatures reduce the release and diffusion of P. The practice of adding a small amount of available phosphorus (PO_4^{3-}) to compensate for a temperature-induced deficiency improves yield and crop quality. Over time, crop production reduces the net reserve of P in soil if it is not replenished through additions of P from mineral fertilizers or manure.

Thus, for food security, additional P is required because the soil-bound P reserve is both exhaustible and not continuously biologically accessible. Marketability of recovered P from waste streams and manure should be focused on highly available and quick-release formulations for seasonal use as well as slower-release forms to augment deficits in soil reserve of P.

Without proper water and land management activities, P lost from agricultural land can become one of the biggest sources of P in waterways and aquatic ecosystems. Phosphorus is also transported by wind when particulate-bound P is picked up by the wind and transported to the surface of waterbodies. Too much P accumulation over time causes lake eutrophication and, consequently, algae blooms. Proper land and nutrient management provide an opportunity to capture, recycle and reuse this P.

With the acceleration of population growth, there is a growing need for food and agricultural products that rely heavily on commercial P for fertilization. As P cannot be either created or substituted, and as the limited supply of commercial rock phosphate is declining in quality, the need for PRR becomes increasingly relevant to meet the growing demands for a consistent high-quality source of phosphate for commercial fertilizers.

1.2 Phosphorus: Critical resource and environmental pollutant

The majority of the world's P comes from limited supplies of rock phosphate, mined from only a few global regions. Based on estimates, global supplies of rock phosphate amount to 71,000,000 tonnes (U.S. Geological Survey, 2012). While these numbers are still under debate, what is clear is that the availability of global P supplies are finite and limited, signifying a serious future risk to global food security.

Along with being a critical nutrient for growth and food production, P in excessive amounts is also an environmental pollutant that causes eutrophication and overgrowth of nuisance plant species and algae. Rapid growth and expansion of urban and rural activities are driving the use and release of P, leading to negative downstream impacts. The abundance of P in soils from fertilizer application, livestock manure and wastewater runoff are leaching into downstream freshwater ecosystems, causing eutrophication (Fillippelli, 2014). In watersheds, P loads are from four major sources: urban point sources (UPS) such as municipal wastewater treatment plants; rural point sources (RPS) such as wastewater lagoons and manure storage operations; urban nonpoint sources (UNPS); and rural nonpoint sources (RNPS), including landscape runoff. These are sources are discussed in some detail in Section 1.4 of this report.

P loads in watersheds vary based on a number of physical factors, such as topography, rainfall patterns, tributaries, elevations, orientation of the lake, size of the lake and tributaries—and, of course, the land-use practices in a given watershed. The Lake Simcoe Protection Plan, for example, and its related Phosphorus Reduction Strategy clarify the sources of P loads into Lake Simcoe (Table 1).

Table 1. Sources and categories of P loads in the Lake Simcoe basin

Sources of P loads	Amount (%)	Category
Sewage treatment plants (STPs)	7%	UPS
Septics	6%	RPS
Holland Marsh and smaller polders	4%	RNPS
Watershed streams	56%	RNPS and UNPS including stormwater collection ponds
Atmosphere	27%	

Source: Ministry of Environment and Climate Change, 2010.

These proportions differ significantly for different lakes based on physical watershed characteristics, such as eutrophication of surface waters, as one of the most prevalent and problematic water quality issues globally (Anderson, Glibert, & Burkholder, 2002; Ansari & Gill, 2015; Carpenter et al., 1998). It is caused by the over-enrichment of nutrients, specifically P, and can cause increased productivity in algae, vegetation and bacterial communities, anoxic conditions and unfavourable conditions for other forms of aquatic life (Cordell, 1998). Limiting P will significantly reduce eutrophication of these waterbodies while conserving this vital, limited nutrient to optimize food security needs.

1.3 Drivers of PRR

Due to its dual role as critical resource with limited quantity of good quality supply and prevalent environmental pollutant, major drivers for PRR include its scarcity as a resource, its overabundance in water systems leading to water pollution and increasing cost.

1.3.1 Scarcity

One of the major drivers of developing PRR technologies is that P is a finite resource and cannot be replaced by any other element or combination of elements. Agricultural fertilizers are the largest users of P, but it also plays a critical role in the manufacture of livestock feed, batteries, auto parts and many other products.

Commercial phosphate found in rock deposits is one of three main components for commercial fertilizers. Globally, there are large reserves of rock phosphate (with the biggest deposits in northwestern Africa), but commercial development of these reserves appears to be limited. The deposits of highest quality and easiest access are dwindling, so the process of extracting P in the form and quality needed for agriculture is getting more difficult.

World consumption of P is growing and is expected to increase from 43.7 million tonnes in 2015 to 48.2 million tonnes in 2019 (U.S. Geological Survey, 2016). Currently, Canada imports close to 100 per cent of its P requirements. Risks to future P supplies that may result in "P shocks" include:

- Political instability in areas with large P reserves
- Low phosphate concentrations in P rock deposits, increasing the price and difficulty of phosphate extraction
- Contamination of P rock with heavy metals like cadmium
- Transportation logistics from phosphate mines to shipping facilities.

Dwindling global reserves, a dependency on imports, vulnerability to potential manufacturing and supply chain disruptions (resulting in pricing instability for end users) makes PRR a priority for Canada.

1.3.2 Abundance

Increasing populations, intensive agriculture and a lack of watershed management and infrastructure are causing an overabundance of nutrients in many waterbodies across the world. The US EPA describes nutrient pollution as "one of America's most widespread, costly, and challenging environmental problems" (US EPA, 2017b). A Canadian national watershed report by WWF (2017) highlighted that 42 of 67 sub-watersheds across Canada with available water quality data have "fair" or "poor" water quality. Effects of nutrient overloading in lakes range from increased biomass, to composition change in aquatic food webs, to decreases in water transparency and oxygen levels, to declining fish populations, to toxic algal blooms that can cause death in animals and health issues in humans. In addition, broader impacts of eutrophication include loss of fish productivity and declining fisheries, reduced recreation, and reduced lakefront property values.

While reducing nutrient loads to waterways has become a policy priority for parts of Canada, (e.g., Great Lakes, Lake Simcoe and Lake Winnipeg), NRR in particular is still not considered a high priority within this context. In Europe, P has been identified as a key resource for food security, and this policy drives PRR in the EU.

1.3.3 Increasing Cost

Increasing efforts associated with mining rock phosphate are resulting in increased overall costs of P. Scarcity of quality commercial P and potential market shocks play a significant role in incenting PRR within a national context, as demonstrated by the price shock of 2007. Heightened demand for P-based fertilizers and a shortage of P production in 2007/08 led to an 800 per cent increase in the price of raw rock phosphate (Schroder, 2010), which more than doubled the farm gate price of P fertilizer. While prices did eventually stabilize, such price shocks significantly threaten food security, particularly in developing countries.

Farmers in Canada invest close to CAD 5 billion in fertilizers each year. Increasing concerns about soil health, resource sustainability and environmental quality, and the increasing momentum of emissions can enable accelerated efforts on PRR within the context of a national NRR platform. A focus on PRR can alleviate risks due to increasing prices and price shocks and enable Canada to become a leader in PRR, while maintaining food security, water quality and economic stability.

1.4 Sources of Phosphorus Contamination

Current management actions to combat eutrophication focus on point sources of P (e.g., wastewater treatment facilities), as well as nonpoint sources from rural landscapes and urban areas, particularly in the vicinity of waterbodies.

1.4.1 Urban Point Sources (UPS)

Point sources in urban areas primarily comprise wastewater treatment plants (WWTPs), also known as Water Resource Recovery Plants (WRRPs), that concentrate and treat a combination of human sewage, urban surface runoff and other wastewater from within municipal boundaries (e.g., sewersheds). WWTPs vary across Canada in size, technology, regulatory context and receiving wastewaters. Many coastal areas in Canada do not remove nutrients. Most WWTPs in Canada can be categorized into three types (Oleszkiewicz, Kruk, Devlin, Lashkarizadeh, & Yuan, 2015):

- Municipalities in Eastern Canada tend to employ conventional activated sludge with extended aeration for removal of organic pollutants. Many of these plants remove P using chemical precipitation processes.
- Municipalities in Western Canada, including the Prairies and central BC, tend to use biological processes that remove both N and P. In biological nutrient removal processes, P is trapped in bacterial cells, can be easily extracted and recovered later, and is fully bioavailable in land application.

- Some communities (often with smaller populations of under 3,000) use treatment lagoons (or septic systems) without targeted removal of N or P. Lagoons in Ontario will often add chemicals to remove P, in batches or at the discharge point. Some lagoons will have a filtration system added on. Some lagoons have ammonia (total ammonia nitrogen) limits and technologies to remove it. These are not specifically addressed in this report.

1.4.2 Urban Nonpoint Sources (UNPS)

UNPSs can include stormwater runoff or overflow from sewers during heavy precipitation events (e.g., flash flooding or major storm events). Impervious surfaces in towns and cities, such as streets, parking lots, roofs and driveways, carry rainwater and water polluted with animal and plant waste, lawn fertilizers and other sources of nutrients into collection waterways (e.g., through sewers, ditches, pathways and roads). The nutrient loads from this runoff typically intensify in times of rainfall and flooding.

Many UNPSs discharge directly into streams and rivers through storm sewers. Some areas are collected in stormwater retention ponds or stormwater management facilities, and others are integrated into domestic wastewater systems via combined sewer overflows and carried to WWTPs through surface and underground drains. Collecting the polluted waters and applying BMPs and technologies that incorporate PRR practices to address these sources may be challenging, but it is possible through improved monitoring, improved catchment management and better combined sewer overflow systems. As previously noted, exposed soils from lands under development within close proximity of the west shore of a waterbody may also be providing significant airborne P loading, like in the Lake Simcoe watershed. UNPSs of P are often poorly understood or monitored. Exceptions include the City of Toronto, which monitors P loads to Lake Ontario and has data for several years.

1.4.3 Rural Point Sources (RPS)

RPSs are facilities that collect and treat rural and agricultural wastes. These wastes could include, for example, spill from manure storages at intensive animal husbandry operations. Animal manures and other organic wastes contain tremendous amounts of the nutrients (N, P and potassium[K]), micronutrients and are a good source of organic matter to improve soil quality. Over 145 million tonnes of manure is produced annually in Canada, presenting a significant opportunity for PRR. Intensified livestock operation has produced an increasingly large volume of manure geographically concentrated in three major clusters located in central and southern Alberta, southwestern Ontario and southeastern Quebec. These clusters consist of 10 sub-watersheds that are mostly intensified with manure production, with six located in Ontario, two in Quebec and another two in Alberta. In addition, there are smaller clusters of high production in southern Manitoba and Prince Edward Island. It is worth noting that there are other local hotspots that are currently impacting their local aquatic ecosystems in various provinces, including BC, Manitoba, Ontario and Quebec. In many cases, excess runoff and insufficient dilution results in declining water quality and algal blooms in lakes. There is significant crossover into RNPSs, as over 80 per cent of the manure is applied to agricultural fields.

RPSs such as intensive livestock operators are subject to regulatory processes and BMPs that require them to manage their nutrient emissions (e.g., a farm operation in Ontario may have a nutrient management plan subject to Ontario's Nutrient Management Act). As a result, a range of research exists for nutrient management more generally from these sources, but the emphasis has not been specifically on reuse and recovery. Reuse and recovery from these sources may also be limited due to infrastructure needs, high costs and limitation of technology.

1.4.4 Rural Nonpoint Source (RNPS)

The agricultural sector in Canada applies fertilizers (including P) for plant growth. Large precipitation events enable runoff of excess P from agricultural lands and concentrates these in receiving waterbodies. These, RNPSs constitute a large contribution of P to downstream ecosystems in predominantly rural watersheds. Nonpoint sources include agricultural activities and other land-use alterations on the landscape. Agriculture is the largest nonpoint source P polluter resulting in water quality degradation (US EPA, 2017b). In the Lake Winnipeg watershed, which spans 1 million square kilometres largely across Prairie Canada, it is estimated that the majority of nutrients in this eutrophic lake come from nonpoint sources, predominantly in rural agricultural areas. In the Canadian portion of the Lake Erie basin, manure P accounts for 52 per cent of the P applied to agricultural soils and has been a major contributor to P loading to the waterbody (Han, Allan, & Bosch, 2012).

Part of the P loading stems from manure application to meet the N requirements of grain crops, so there is P build-up in soils because the animal manures contain more P than the crop needs (Zhang, Tan, Wang, Daneshfar, & Welacky, 2018). 4R Nutrient Stewardship that includes manure as well as mineral fertilizer avoids this issue. A range of BMPs have been created to manage nutrient runoff and include wetland management, water retention and filtration, riparian buffers, biomass harvesting, etc. While many of these BMPs focus on nutrient management and efficiency, their contribution to nutrient efficiency for plant growth is in part a PRR strategy.

2. NATIONAL NUTRIENT REUSE AND RECOVERY (NNRR) FORUM

2.1 Overview

On March 8, 2018, IISD hosted the National Nutrient Reuse and Recovery (NNRR) Forum in partnership with Environment and Climate Change Canada (ECCC) and the Ontario Ministry of the Environment and Climate Change (MOECC) in Toronto. This forum built on the momentum of previous forums related to NRR in Canada. A couple of these forums are highlighted in Appendix 3 of this report.

The workshop featured speakers from the MOECC who set the policy context as well as eminent Canadian academics and researchers, representatives of existing nutrient platforms described in this report, a representative from Ontario's Environmental Commissioner's office, the Regional Municipality of York, and the CFO of the Lake Simcoe Region Conservation Authority, as well as representatives from private sector technology companies. While the workshop referred to nutrients generally, many speakers focused on P recovery, which is widely accepted as the predominant nutrient for recovery and reuse due to its limited commercial supply, vital food security implications and its predominant role in eutrophication impacts to receiving waterbodies. The regional context for the workshop was in part a focus on Ontario's circular economy legislation and the new Lake Erie Action Plan presented by MOECC, but it did also present scenarios in various regions of Canada where other drivers for PRR and nutrient management factors are present (e.g., BC, Quebec and Manitoba).

- A complete audio and video recording of the workshop can be found here: https://www.youtube.com/watch?v=_zq5ntMag1I
- All the presentations are available here: https://www.dropbox.com/sh/p2in930otvr875v/AACM9zvyRj-mK9eGhsYiBaa4a?dl=0

The overall context of the forum was captured by keynote speaker Don Mavinic, who provided three main drivers for the focus on P recovery:

- P is a scarce and strategic resource critical to world food security and the long-term security of P supply is uncertain.
- P is an environmental pollutant when present in excess amounts and the key nutrient responsible for aquatic ecosystem eutrophication within the western basin of Lake Erie.
- P is physically conserved and can be recycled indefinitely. Unlike N, P does not have an atmospheric sink, therefore it can be traced and accounted for in terrestrial ecosystems, using mass-balance methods. P is applied as an agricultural fertilizer and can be found in agricultural soils, plant biomass, food products, human and animal waste, by-products of wastewater processing, landfills (in organic wastes or sewage sludge), or in the

sediments (both land and air borne) and the water columns of lakes and rivers in dissolved or particulate form.

2.2 NNRR Forum Objectives and Format

The objectives of the 2018 NNRR Forum were to:

- Increase awareness of Canadian and international NRR efforts.
- Broaden the reuse/recovery industry, government and research partnerships.
- Identify ways to complement adaptive technologies to address nutrient loading on priority lakes, including Lake Ontario, Lake Erie and inland lakes (e.g., Lake Simcoe).
- Assess key challenges and opportunities for Canadian leadership in NRR.

The workshop comprised three main sessions:

1. Setting the stage for nutrient recovery.
2. Providing a Canadian context to the discussions and highlighting nutrient initiatives and opportunities.
3. Providing agricultural (rural) and urban perspectives related to technologies and economic instruments.

The final agenda of the NNRR Forum is included as Appendix 1 of this document.

Very brief presentation and discussion highlights are provided below. Insights from the presentations and discussions are incorporated in the following section on the four main pillars. In addition, a detailed workshop summary report of the NNRR Forum is provided in the interim report (IISD, 2018).

2.2.1 Morning Presentations

Tom Kaszas, Director, Partnerships Branch, MOECC, introduced the dual nature of P as a valuable resource and an environmental pollutant. He talked about global supplies and imminent scarcity and set the context around opportunities in a variety of contexts, including WRRPs/WWTPs.

Madhu Malhotra, MOECC, introduced the Lake Erie Action Plan, launched to address issues related to lake eutrophication. She explained the immediate and broader impacts of eutrophication, including economic and human health impacts. She highlighted specific actions established under the action plan that enable PRR, such as that the Action Plan would "explore opportunities to adopt innovative technologies that encourage PRR".

Ellen Schwartzel, Deputy Commissioner, Ontario Environmental Commissioners Office, provided remarks.

Dr. James Elser, Director of the Sustainable Phosphorus Alliance (SPA), described SPA's mandate and functions and its role contributing to policy-relevant technical research related to NRR in North America. He welcomed Canadian partners to join the SPA.

Dr. Don Mavinic, Keynote speaker from UBC, highlighted the widespread eutrophication problems associated with P overloading. He presented struvite as a product of mature technology for recycling P from WWTPs/WRRPs. He also emphasized the positive influence of climate change policy instruments as a means to NRR.

Dr. Céline, Vaneeckhaute from Laval University, presented on NRR in Quebec. She stressed the importance of spatiotemporal decision-support systems to plan the circular economy, based on optimized biorefinery location, biorefining technology and end-product distribution, and the importance of policy drivers such as the ban on organic waste in Quebec.

Chris Thornton, Manager, European Sustainable Phosphorus Platform (ESPP), presented the ESPP with respect to the EU policy context in which the ESPP operates and highlighted key ESPP process and outcome successes. He highlighted ESPP's role in coordination, research, technology enabling and communications. ESPP is the longest-running and most successful NRR platform in the world.

Kathleen McTavish and Ryan Carlow presented the results of their 4th year capstone project in Environmental Sciences at the University of Guelph in 2016. They estimated the flow of P throughout the Ontario economy, developing an integrated P systems flow map. Among their key observations were that agriculture drives the major P inputs to the Ontario economy as seed, fertilizer and feed. Additional analysis and understanding of P flows is necessary moving forward.

Richard Grosshans, International Institute for Sustainable Development (IISD), presented the Lake Winnipeg Bioeconomy Project as an example of nonpoint source nutrient interception and recycling based on water retention and biomass harvesting for energy and biomaterial products. This successful multi-year project demonstrates cost-effective outcomes related to water quality, nutrient recovery, GHG offsets and flood mitigation.

Phil Dick, OMAFRA, presented the watershed perspective on P loading, including the location, temperature and timing of P availability in Lake Erie within the context of the algal life cycle. He demonstrated watershed analysis to better understand the challenges and role of NRR as a systems approach.

2.2.2 Lunchtime Panel Discussion

A lunch panel comprising Mavinic, Vaneeckhaute and Dick from OMAFRA addressed the following four pillars/issues that were delved into in more detail in the afternoon round table discussions with all stakeholders:

- **A need for information** to recognize the value of nutrients in the circular economy.
- Support for **coordination** of strategic actions on research, supply/demand and logistical issues.
- Support for Canadian recovery/reuse **technology** solutions
- Support for economic and market instruments and **policy** incentives

2.2.3 Afternoon Presentations

Tiequan Zhang, Research Scientist from Agriculture and Agri-Food Canada Harrow Research and Development Center, presented on agricultural nutrient loading hotspots in Canada, identifying six in Ontario, two in Alberta and another two in Quebec, and their implications. Zhang provided a comprehensive overview of manure-based nutrient loading in Canada, noting that animal manure is an important resource with potential for PRR.

Keith Reid & Christine Brown, from AAFC and OMAFRA respectively, presented "Circular Nutrient Economies – Agriculture Reality Check" and discussed the realities of manure management from a producer perspective, citing high material handling costs due to its bulky nature, as well as application timing issues. Specific opportunities, such as neighbourhood nutrient planning models, were highlighted.

Melodie Naja, Chief Scientist for The Everglades Foundation, presented on the Everglades' George Barley Water Prize, a USD 10 million Grand Prize motivated by the very large estimated cleanup costs of Lake Okeechobee (>USD 12 billion), of P pollution generally (>USD 3 trillion), and of the need for "innovation, creativity, and a breakthrough solution."

Brandon Moffatt, StormFisher Environmental Ltd., presented on- and off-farm anaerobic digesters and digestate reuse, including current and potential drivers of innovation such as Ontario's feed-in tariff program and renewable natural gas production/costs of C. He presented on StormFisher's London, ON plant that processes food and institutional waste and produces energy based on biogas. He highlighted the role of the 4R Stewardship Program in conjunction with the Ontario Healthy Soils Framework as a framework for soil health and food security.

Mike Dougherty, Director of Product Development at Lystek International Inc., presented Lystek's technology, products and markets. Lystek's processing technology involves thermal hydrolysis, heating, pH adjustment and high-speed shearing to disrupt biosolid cell membranes to produce lysate—essentially a homogenous, low viscosity, pathogen-free bio-slurry that is then processed into three products, including fertilizer, contributing to increased soil C and soil health.

Rachel Lee, Regional Technical Sales Manager at Ostara Nutrient Recovery Technologies Inc., presented Ostara P-recovery technology, first describing their market penetration as first-movers in the P recycling space. Currently, there are 14 proprietary Operational Pearl® systems worldwide, 17 KT annual fertilizer production, 400,000 hours of Pearl® system operational experience and 11 million people serviced by Ostara's nutrient recovery system.

Theresa MacIntyre-Morris, York Region, and Dr. Ann Huber, Soil Research Group, presented on a two-year pilot project applying recycled wastewater for irrigated sod production to demonstrate an alternative to tertiary wastewater treatment.

Michael Walters, CAO of the Lake Simcoe Region Conservation Authority, presented the Lake Simcoe Phosphorus Offset Program (LSPOP) as a key program of the Lake Simcoe Region Conservation Authority. He presented the long-term average total P loading on Lake Simcoe and the ecological target and highlighted WWTPs/WPCPs as having reduced their P loading significantly by employing advanced and energy-intensive tertiary treatment technology.

2.2.4 Afternoon Table Discussions

In the final session of the workshop, participants from industry, academia, government and non-governmental organizations were divided into Working Group Tables to answer questions related to the same four pillars from the morning discussion panel. More details on these discussions are provided in the workshop report (IISD, 2018). High-level insights included:

1. The need for information and recognition of the value of information and of a circular nutrient economy (P/N), and the recognition of other high-value products within the context of a coordinated strategy.
2. Support for Strategic Coordination – research (e.g., funding, pilot projects); logistical issues (e.g., transportation from source to market); and identification of process, supply and nutrient-demand issues (e.g., P).
3. Support for a coordinated Canadian recovery/reuse technology solution strategy – applied (from concept to market).
4. Support for identification and coordination of economic and market instruments and financial incentives (e.g., P offsetting/water quality trading, subsidies, GHG credits, percentage of recycled nutrient requirements, area-wide cumulative multiple farm nutrient management plan strategies, etc.).

Overarching Insights

Some overarching insights evolving from the workshop were:

- The need for a comprehensive, user-friendly communications/education strategy required for a circular economy and P recovery for all sectors to recognize the value of recovery.
- A concrete action plan focused on NRR, with an initial primary focus on PRR, must include pilot implementation projects that demonstrate true value and guidance for replication. These pilot projects should have similar measures of success to create a verifiable approach for monitoring and achieving success.
- A Canadian network similar to the European Sustainable P Platform (which is in fact a nutrient platform) is welcomed by NNRR participants, and a Canadian nutrient platform must consider active coordination between governments, academia/researchers, non-governmental organizations (NGOs), private sector innovators and end users. More details on this platform are provided in Section 3.2 of this report.

Other opportunities/barriers identified at the NNRR are in the interim workshop report (IISD, 2018). Specific opportunities that arose from the afternoon working group discussions included:

- The need for incentives or subsidies to ensure that NRR actions are incorporated as a transition to a circular economy system with an underlying emphasis on climate change and green infrastructure support.
- Highlighted funding opportunities, including the NSERC Research Chair (recovery and industrial), AAFC industry, Canadian Agricultural partnerships and municipality-based green infrastructure funds. There may also be funding opportunities under the Canada–Ontario Agreement in support of the Lake Erie Action Plan.

Four main pillars were reinforced through discussions and presentations at the NNRR Forum as well as related research and review conducted by IISD. These pillars are described in greater detail in Section 3 of this report. Key pillars/issues and outcomes/action items identified include:

1. **Pillar/Issue: A need for an information/communication/education strategy**

   Key outcomes/actions identified: P recognized federally as a critical resource; a communication strategy related to PRR, including the strategic value of P and its stewardship; better public and targeted messaging around opportunities related to PRR.

2. **Pillar/Issue: A need for coordination**

   Key outcomes/actions identified: Need for a Canadian nutrient platform, particularly engaging provinces, research coordination, focus on manure transportation and neighbourhood nutrient planning, as well as a long-term fertilizer strategy related to supply and demand. Means to engage government, researchers, private sector, end users and others.

3. **Pillar/Issue: A need for support for technologies**

Key outcomes/actions identified: Enable replication of technologies and BMPs on PRR through incentives, support and the development of markets. Create follow-up on the George Barley Water Prize and target early adopters. Consider information on technology adoption provided by Roger's diffusion model.

4. **Pillar/Issues: A need for markets and economic incentives**

   Key outcomes/actions identified: Need for policy drivers to enable markets, incent innovation and reduce cost barriers; examples of policy mechanisms include subsidies related to PRR; regulations enabling offsets; and other market mechanisms.

3. FOUR PILLARS FOR A PRR APPROACH

This section compiles insights on the four pillars previously identified and reinforced at the NNRR Forum (2018), along with complementary research.

3.1 Information/Communications/Education for PRR

One of the key needs identified at the NNRR Forum was the need for education and communication, on not only the essential nature of P for human existence (sustainable food production, long-term soil health, manufacturing, etc.), but also education on the scarcity and finite nature of the existing global supply of high-quality rock phosphate. It has been estimated that there are limited years of commercial phosphate supply left in the world. Moreover, much of this supply may not be recoverable due to its poor quality, contaminated nature, or the expense to excavate the material. Canada currently imports 100 per cent of commercial rock phosphate and is therefore vulnerable when world shortages/disruptions begin to develop. Much more needs to be done to educate agricultural producers, consumers, manufacturers and decision makers about the scarcity of the resource, as well as the clear and urgent need to begin recovering waste P to ensure a sustainable food supply for future generations. A proactive strategy would be to ensure that Canada moves toward higher efficiency and better NRR/PRR systems. This section provides recommended approaches to enhance PRR through education and communication strategies primarily within the context of overall soil health and interaction with other nutrients in the foreseeable future. A new resource in Canada is the Phosphorus Hub, managed by Dr. Sidney Omelon's Phosphorus Lab at McGill University, which connects with groups and individuals and focuses on information about feeding the world while protecting the environment.[2]

Educating stakeholders and decision makers within all levels of government about the importance of nutrient management, and in particular P, is key to facilitating the establishment of sustainable nutrient recovery framework within a reasonable time frame. It is also essential to better understand existing P flows within our economy. Whether it is initial use of commercial P or the places where waste streams contain P concentrations, it is important to know the P cycle in our society in order to educate and inform others of true possibilities and barriers to PRR.

Some insights related to communications and education came through the presentations and discussions of the NNRR Forum. Mavinic emphasized, for example, the first gap as a lack of information about the importance of P and the need to repeat this message again and again. If people understand the importance of P in addition to its role in food security and freshwater quality problems, it might start getting incorporated into decision making. Similarly, Vaneeckhaute highlighted the data issues related to this topic and the need for a portal where data and information related to P sources and hot spots would give rise to opportunities and

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[2] www.phosphorushub.com

action. Dick highlighted the need for a business case and communications oriented to accountants and CEOs that demonstrate net present value and payback required to accelerate private sector investment. Performance measurement tools such as the Rogers diffusion model are useful for tracking the adoption of economically viable technologies for determining a seamless sunset for program support. Education and communication were also highlighted as a means to raise awareness among urban residents, farmers, engineers and others less involved in environmental management or sustainable development. NNRR Forum discussions also highlighted the need for a comprehensive user-friendly communication/education strategy required for a circular economy, P recovery and for all sectors.

Evidence and experience in Europe and elsewhere would suggest that bringing groups of stakeholders, including industry, government, academia and others, together under a coordinating body such as the ESPP can be an effective mechanism for communication and education. Models of this approach in Canada include efforts currently underway in Quebec with the establishment of the Nutrient Stakeholder Platform, established in response to Quebec policy on organic waste management (Vaneeckhaute, 2018), including about CAD 650 million in subsidies for development of anaerobic digestion as a means to address organic waste issues and create economic opportunities for PRR and other NRR possibilities. Europe is also building a model through the work of the ESPP and a host of other nutrient recovery platforms/organizations operating locally and more globally. The ESPP is comprised of a broad stakeholder group and has developed an array of public communication products to help achieve their goals.

Canada should undertake an in-depth review of these communication products to determine which have been most effective in Europe in order to shortlist candidates for adoption in this country. The Québec Policy on Residual Materials reflects the provincial government's commitment to building a green economy as they seek to create a "waste-free society." This goal will be in part achieved by ensuring all stakeholders are responsible for residual materials management. There is a clear need to communicate the risks of P shortages and benefits associated with the implementation of PRR technologies and BMPs. The 2014 Sustainable Solutions for Infrastructure, Food Security and the Environment Workshop that took place at Ryerson University, Toronto, identified four priorities for an initial Action Plan of Engagement (Trudeau, 2014). The key knowledge gap, "lack of knowledge of the need to recognize P as a resource," was recognized as one of those four action plan priorities. It remains a key action plan item today.

3.1.1 Key Initiatives and Messages in a Comprehensive PRR Communications Plan

- **Change public perception/mindset shift:** Change mindset related to nutrients from "waste" to "resource." This is critical to bringing awareness to the general population and decision makers of the importance of and need to conserve P supplies and implement PRR strategies. This includes a clear message that **wasting P harms the environment.** A number of specific messages and means are described below.

- **P flows and value of reused and recovered P:** In 2015, OMAFRA, in partnership with ECCC and with MOECC (now Ministry of the Environment, Conservation and Parks) conducted an assessment of P flows in Ontario. The assessment revealed five areas of required research: (i) the impact of precision agriculture on P flows; (ii) the impact of soil management on P flows (manure, drainage tile, slope and cover management); (iii) the volume of P available from agricultural sources (manure and biomass); (iv) the volume of P available from organic wastes (e.g., food processing and municipal solid wastes); and (v) the volume of P available from wastewater flows (municipal and industrial discharge).
- A clear description of **environment benefits associated with PRR,** including: reduced GHG emissions/C credits; reduced nutrient losses to the environment; and reduced need for nutrient application due to improved efficiency of products produced (i.e., slow release). This could also include messaging around the **societal benefits of PRR,** including increased food security and decreased transporting costs. Consideration should be given to including messaging around the **societal risks of a do-nothing approach,** including: (i) increased food costs, (ii) potential food shortages, (iii) accelerated GHG emissions/climate change impacts and (iv) water quality deterioration. It will also be important to clearly articulate to the public, stakeholders and decision makers the **economic risks of a do-nothing approach** to Canada in the event of a P shortage, including reduced production and export of Canadian agricultural goods and a shortage and/or increased cost of essential manufactured items (e.g., lithium batteries in cell phones and other electronic products).
- There is a general lack of awareness of the value of accessible, recoverable nutrients, and in particular P, compared to the less accessible, more contaminated supplies that remain to be mined. P buyers will need to buy more P source rock as the percentage of phosphorus pentoxide (P_2O_5) declines in the remaining supplies in rapidly reducing world supplies. Mavinic spoke to the current information gap on the scarcity of supply during the NNRR Forum (IISD, 2018). In addition, the **safety of recovered P** must also be clearly communicated to improve public acceptability related to the safety of using fertilizer produced from organic waste streams (i.e., human and animal waste streams) for food production. This should include communication on the standards and quality testing that is in place for reused and recovered P.
- **Food security/risk mitigation benefits:** Communication needs to clearly articulate the economic and social impacts of a catastrophic event such as an unexpected rapid decline or total absence of rock phosphate imported into Canada. Severe shortages of P fertilizer availability will result in significant declines in food production in Canada and impact countries dependent on the Canadian food market. These messages need to emphasize the importance of developing a reliable "homegrown" P supply to ensure food security into the future.

- **Circular economy benefits:** Clear messaging around the benefits of a circular economy will be important, explaining that this covers the nutrient cycle from production to consumption, to waste management and to markets for secondary raw materials. In a circular economy, the value of products and materials is maintained for as long as possible and waste and resource use are minimized. This can contribute to innovation, growth and job creation—all important elements of expanding economies.

  Messaging should focus on aspects of PRR related to such things as: (i) accessing a local supply of fertilizer rather than depending on imported products, (ii) profitability of PRR and (iii) potential for yield enhancement from specific nutrient products.

  There is a need to communicate using **business case models for PRR**, using successful existing examples whenever possible. These communication tools should carefully consider all costs and cost savings with the implementation of PRR technology and BMPs, including any anticipated increased cost of commercial P as a result of declining rock phosphate quantity and quality.

  The economic benefits of PRR include: (i) development of green technology that can be exported worldwide and (2) production of "green fertilizer" that can be sold locally and exported globally as current rock phosphate supplies decline and the demand for "green fertilizer" expands.

- **Monitoring, understanding and communicating our P footprint:** Following in the steps of the C footprint efforts, individuals, businesses and industries could be educated to understand their nutrient footprint. Understanding their own contribution will help in finding opportunities to close the nutrient cycle and manage households, farms and businesses more sustainably.

- **Communications and education around a range of green technology options:** Many jurisdictions do not have municipal organic collection or composting programs. Similarly, few jurisdictions regulate the use of garburators, and/or incent composting. Education is needed on the importance and value of direct composting rather than disposing of food waste into wastewater treatment systems through garburators or to landfills with household garbage. As well, green wastewater treatment technologies such as the use of composting toilets and greywater recycling can be effective means to recover and recycle P.

3.1.2 Target Audiences and Methods

In addition to the messaging highlighted above, targeted strategies are needed to improve understanding and adoption of PRR means and technology. It is recommended that the following target audiences and methods be considered in any NRR communications strategy:

1. **Internal and interagency government communications:** There is a need for enhanced communication between levels of government and between government departments to not only share data related to the P stream but also to work together to develop integrated innovation approaches to PRR. Most pertinent departments involve those

related to environment, agriculture and technology. Multidisciplinary, interagency and interdepartmental teams need to review and revise policies, regulatory framework, incentives, etc., and to move the PRR agenda forward in a coordinated approach. See additional discussion under sections 3.2 and 3.4 of this report on these pillars.

2. **Conferences and workshops with experts:** Continue to engage professionals through conferences, workshops, webinars, etc., to enhance coordination and communication between those already engaged in aspects of PRR to create the foundations of a Canadian Nutrient Platform. In addition, such events could also involve those researchers and industry representatives and stakeholders who are not engaged in Canadian Nutrient Platform initiatives. At the NNRR Forum, James Elser, Director of the SPA, highlighted the role of a nutrient platform to facilitate networking among players across the P value chain, hosting an annual P forum, various outreach activities including technical webinars and newsletters, managing working groups (including on biosolids and manure management) contributing policy-relevant research and representing North American interests in international networks.

3. **Building public support:** To support adoption of PRR technologies, especially in areas with dense populations, it will be key to involve citizens, allowing bottom-up input into innovations to complement any top-down approaches such as implementing technological changes. By increasing awareness on the need for a circular economy and sustainable P management, public support for these innovations will be higher and the use of reused and recovered P products will become attractive and acceptable. This will also help garner political support for NRR programs, policies and regulations. For example, **food labelling** for P content would enable consumers to make informed decisions regarding their dietary P footprint for both health and environmental considerations.

4. **Integrating PRR knowledge and skills into the workforce:** To achieve a circular economy with full adoption of PRR, different sectors of society must be educated and trained to support relevant efforts. PRR crosses a vast and diverse set of career paths: farming, manufacturing, chemical engineering, technology development and economics. Educational institutions need to integrate the concepts of a circular economy, sustainability and specifically PRR into academic and technical training programs to enable a skilled working population to help close the nutrient cycle broadly across society, including plumbers, landscapers and scientists. Identifying these skill sets and integrating them in our educational training programs will play a significant role in adopting and advancing sustainable development opportunities related to PRR.

5. **Communication publications and social media tools:** The ESPP is a successful nutrient platform discussed in some detail in Section 3.2 of this report. Modelled after the

success of the *ESPP SCOPE Newsletter* and ESPP's eNews,[3] consideration should be given to developing a communication product that would help communicate awareness and inspire action on PRR in Canada and globally. Specific stakeholder resource and communication materials may be required, including materials for non-technical audience, which would focus information and guidance on PRR for the general public and others implementing practices on a more local/individual level.

[3] SCOPE newsletter can be found here: https://phosphorusplatform.eu/scope-in-print/past-issues; ESPP eNews can be found here: https://phosphorusplatform.eu/scope-in-print/enews

Summary: Information/Communications/Education for PRR

Key Objectives of a Strategic Communications Strategy for PRR:

- An overarching understanding of the importance of nutrients, specifically P, its role in food security, water quality and the need for management, reuse and recovery. Additionally, a change in the perception of P from "nutrient waste" to "nutrient resource."
- A better understanding of P flows, including existing data/information and conducting analysis to identify key opportunities for PRR, within the context of a circular economy and water quality management.
- An understanding of crosscutting and sector-specific messaging for the different sources of P: UPS, UNPS, RPS and RNPS.
- Understanding, adoption and implementation based on knowledge, information and data.
- Best practice in PRR and NRR are well known and act as models for Canada.

Key Messaging in a Communications Strategy

- P flows, value of reused and recovered P, and strategic drivers of PRR.
- Circular economy, water quality and climate mitigation are opportunities for PRR.
- Need for Canadian PRR based on risk of global supplies, need for food security and impact of nutrient overloading.
- Support for P footprint thinking across sectors.
- Environmental benefits from NRR and particularly PRR.
- Economic opportunities of nutrient recovery, as well as the economic risks of a "do-nothing approach."
- Potential for agricultural yield enhancement.

Target Audiences:

- Government levels and departments; academics and experts; end users—particularly in agriculture and industry; public, students and youth, innovators and entrepreneurs.

Communications Means and Tools:

- A Canadian Nutrient Platform (proposed).
- Workshops, conferences and webinars.
- Policy briefs and targeted communications to integrate the concepts of PRR into a circular economy, sustainability and watershed management strategies.
- Training materials and curricula for a range of academic and technical training programs.

3.2 Coordination of Research and Actions Related to NRR

A key theme emerging from relevant literature, the 2018 NNRR Forum and the 2014 Sustainable Solutions for Infrastructure, Food Security and the Environment Workshop (Trudeau, 2014) is the need for a strong, coherent, coordinated approach to advance progress on

Canadian PRR. One of four action plans for engagement strategies emerging from the 2014 workshop was "lack of coordination for governance, technology and research focused on recycling."

At the NNRR Forum (IISD, 2018), organizers identified the option of creating a Canadian version of the ESPP as a key priority to advance PRR. Significant knowledge and experience can be gained from existing nutrient/P platforms that have already advanced the thinking and actions on sustainable P management in Europe and elsewhere. The following section will provide examples of coordinated approaches and activities supporting NRR with a specific emphasis on PRR. This section will also provide thoughts on coordination related to a sustainable P platform in Canada. One action item identified at the NNRR Forum was to create a working group to assess and analyze what is needed to create a Canadian nutrient platform within the context of the existing platforms (e.g., ESPP and SPA). A critical starting point would include provincial representation, in the context of nutrient management and water quality management as illustrative driving forces.

The P recovery agenda is generally more advanced in the EU than in Canada. The two P sustainability platforms that are most widely known in Canada are the ESPP and the SPA. The ESPP is a thriving communications node, focused on bringing together "companies and stakeholders to address the Phosphorus Challenge and its opportunities" (Elser, 2018). The ESPP platform serves to nucleate a wide range of stakeholders across the EU, and its content is also available to the global community. ESPP attributes much of its success to the streamlined organization and its focus on being the leading edge for access to emerging legislation, existing and emerging NRR technology, and soil health implications for end users. These approaches mean that ESPP plays a crucial role in effectively communicating all things nutrient and PRR related. The SPA, based at Arizona State University, is a nonprofit organization that brings together public and private sector organizations from across the P value chain to make P use more sustainable. SPA is expanding beyond being just a research organization and developing other tools that are relevant to all stakeholders and members.

3.2.1 Coordination Platforms at Local, Regional and Global Scales

The following provides examples of relevant coordination models that are operating on local, regional and global scales around the world.

1. **The ESPP:** Much can be learned from the success and progress achieved by the ESPP. This organization was formed in March 2013 through a declaration,[4] signed by over 150 organizations after the first European Sustainable Phosphorus Conference. ESPP ensures knowledge sharing, experience transfer and networking for opportunities in the field of P management; facilitates discussions between the market, stakeholders and regulators;

[4] Joint declaration for the launch of a European Phosphorus Platform. See: https://phosphorusplatform.eu/images/download/Joint_declaration.pdf

addresses standards and regulatory obstacles; contributes to policy proposals; circulates information through newsletters, websites, conferences and publications; promotes Platform Members' activities; and contributes to defining a long-term vision for P sustainability in Europe. Additionally, the ESPP is also engaged in other nutrients such as N and organic C as they relate to soil health for the agricultural sector.

ESPP members[5] cover a wide range of actors across the whole value chain of P stewardship: P mining and processing; water and waste treatment; food, feed and agriculture; P reuse and recycling; innovation and technology providers; knowledge institutions; NGOs and governmental organizations.

2. **The SPA:** The mission of the SPA[6] is to be North America's central forum and advocate for the sustainable use, recovery and recycling of P in the food system. According to Elser (2018), their values are stated as: "(1) Objectivity: Decisions and actions are based in the best available science; (2) Stewardship: Supporting the implementation of technologies and practices that benefit ecosystems and not ones that facilitate their deterioration; and (3) Inclusivity: Seeking buy-in from diverse stakeholders about best policies and practices." The SPA provides a venue where member organizations can share experiences, network, and develop and implement solutions to P sustainability challenges. Ostara, the Water Research Foundation and the Water Environment Federation are among the current partners in this initiative. Listed membership benefits include the opportunity to:

    - Network with diverse organizations from across the P value chain.
    - Participate in technical webinars on important P management issues.
    - Attend annual stakeholder meetings centred on P sustainability.
    - Partake in projects that tackle technical, legislative, institutional and societal hurdles to implementing P management innovations.
    - Obtain discounts to select P-related events.
    - Gain recognition among regulators, investors and the public as a leader in P sustainability.

    At the NNRR Forum, James Elser, Director of the SPA, provided an overview of the SPA and discussed some of the key North American P issues requiring attention. Elser indicated that the SPA is broad enough in its mandate to address sustainable use, recovery and recycling of P in the United States, Canada and Mexico, and extended an invitation to workshop participants to join the SPA, rather than creating another similar organization that is specific to Canada. Clearly there are benefits to both approaches.

[5] For a member list and to see how to become a member, go to: https://phosphorusplatform.eu/espp-members
[6] For more information on the SPA, go to: https://phosphorusalliance.org/

A detailed listing and descriptions of a number of global nutrient platforms are provided in Appendix 6 of this report.

3.2.2 The Need for a Canadian Nutrient Platform to Address PRR

Canada has not yet taken steps to organize and share resources around the complex issues of nutrient flow quantification, use efficiency and recycling (Ross & Omelon, 2018). It seems that P research/action in Canada typically involves academic institutions, government and research organizations clustered around the subject of preventing eutrophication, often around a specific body of water, but there is no central point of cohesion for these initiatives. Clearly there is a need to identify these groups and start discussions around galvanizing a larger, coordinated Canadian effort on PRR. This need was clearly reinforced at the NNRR Forum.

In Ross and Omelon's June 2018 paper, *Canada: Playing Catch-up on Phosphorus Policy*, they identify the key Canadian agencies, institutions, interest groups and industries that are involved in work within the P cycle: (1) AAFC; (2) Canadian Agri-Food Policy Institute (CAPI); (3) Canadian Association of Water Quality (CAWQ); (4), Circular Economy Innovation Laboratory (CEIL); (5) Canadian Municipal Water Consortium (CMWC); (6) Canadian Water Network (CWN); (7) Environment and Climate Change Canada (ECCC); (8) Global Affairs Canada (GAC);(9) Lake Winnipeg Foundation (LWF); (10) National Zero Water Council (NZWC); (11) Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA); (12) Ontario MOECC; (13) Phosphorus Research Coordination Network (P-RCN); (14) Sustainable Phosphorus Alliance (SPA); (15) Waste Free Ontario Act (WFOA); (15) Agrium-Potash Corp (Nutrien); (16) Ostara; (17) Western Sahara Resource Watch – The Congregation of the Sisters of Mercy of Newfoundland; (18) Conservation Ontario; (19) University of Guelph- Food Institute; (20) University of British Columbia; (21) McGill University; (22) University of Ottawa; (23) Polytechnique; (24) Ryerson University; and (25) the University of Manitoba. Some of these institutions are narrow in their focus, while others cover a broader range of the P chain. These agencies and others identified at the NNRR Forum should be considered as potential partners of a Canadian PRR Alliance.

The 2014 Phosphorus as a Resource: Sustainable Solutions for Infrastructure, Food Security and the Environment Workshop (Ryerson University)[7] identified four priorities for an initial Action Plan of Engagement (Trudeau, 2014), including that a coordinated and comprehensive approach to P management is needed. A formal platform, modelled on the ESPP and other nutrient platforms, could serve to bring together government, researchers, industry, farmers and other end users and stakeholders (e.g., Indigenous Peoples and environmental NGOs) while raising the profile of the P issue and allowing mutual trust to develop among the various players. It was thought that this could assist in the development of a long-term vision for closed-loop P

[7] To read the *Proceedings and Initial Action Plan for Engagement* of the workshop, go to: https://www.ryerson.ca/content/dam/water/2014/PhosphorusRecoveryReuse/ProceedingsFinal_2014%20(5).pdf

management in Canada and North America. A platform could also help promote collaboration among researchers, and with end users of technologies, to create synergistic approaches while reducing duplicated efforts.

The need for a Canadian nutrient platform was discussed at the NNRR Forum (2018). Panel participants were asked to identify the top three things needed to improve PRR coordination in Canada. Discussions were around:

- **Coordinated Decision-Support Strategies:**
    - To accelerate enabling policies, replicable technologies and broader action in PRR, coordinate research and development (R&D) toward optimization tools/decision-support tools to highlight the best strategies for waste collection, waste treatment, nutrient recovery mechanisms and end-product distribution. This also related to actions under the markets and policies of this report.
    - Rather than developing PRR technologies and then trying to find a market for the products, develop coordinated and focused product development. Nutrient recovery technology development must focus on end-user needs and developing specific nutrient products that are needed and are of more beneficial/higher quality than traditional nutrient products (e.g., slow release, more economical, more accessible, etc.).

- **Agriculture and Cities as Key Players in a Coordinated P Cycling Strategy:** Just as federal and provincial government agencies need to play critical roles in PRR, it is important to recognize the strategic role that specific sectors such as agriculture and municipalities can play in this strategy. Farmers are the final recipients of PRR and depend on P supply for improved productivity. They emerged from the NNRR Forum as engaged and active participants in any PRR strategy moving forward.

  Urban sustainability practices aimed at social equality, resource use reduction and a clean local environment are key components of a circular economy, and cities are well positioned to influence actions and behaviours. Actions such as limiting residential fertilizer use and composting programs can be good examples of P management strategies led by municipal governments. Urban gardening/agriculture encourages low technology P reuse and contributes to reducing food waste. This local nutrient recycling creates a buffer capacity for urban food security. Cities, including WWTPs, can play a critical role in waste management education and food production planning as part of a holistic approach to reducing landfills and decreasing resource use. Metson and Bennett's (2015) research in Canada has demonstrated that urban agriculture can be a valuable pathway to improve urban PRR. Cities may be one of the most important players, and hence should be key players in a coordinated in PRR approach in Canada.

- **Multidisciplinary Approach Needed for Coordinated PRR**: Pellerin et al. (2014) argues that future research on PRR should span multiple disciplines, including social and natural sciences, and implement multidisciplinary projects. In addition to understanding P dynamics at micro and meso-scales, there is an increasing need to identify drivers of P flows in the agricultural sector, and more broadly in society and model the P cycle at large scales (regional, national, continental and global levels). This integrated approach will provide the appropriate framework to determine critical flows, processes and factors and to assess how individual and combined innovative strategies can improve PRR in society. This will enable interactions with other issues to be assessed, such as food safety and C and N cycles (Pellerin et al., 2014). A key take away from the NNRR Forum was the willingness of agriculture sector participants to continue to engage in working groups.

- **Supporting Innovation:** Coordination has a critical role in supporting innovation, such as through the George Barley Water Prize,[8] to develop P removal and recovery technology of P from fresh water. A component of the prize includes a grand prize of USD 170,000, the Phoenix Prize, to a contestant who can demonstrate the greatest value from their by-products while still cost-effectively removing P. Winning teams ensure that the winning technology works under variable conditions (flows, climate, cost, sustainability/environmentally safe, scales and the ability of the technology to recover by-products). This competition is now at pilot stage and is being conducted in Holland Marsh, Ontario. The competition allows for additional prizes for processes that effectively recover by-products to reduce the cost of technology. Final decision on the winners is expected in November 2020.

  This approach is an excellent way to support and inspire innovation for new PRR technologies and may be an important strategy to support future innovated technologies for Canada for both point and nonpoint source waste streams in urban and rural environments.

[8] For more information on the George Barley Water Prize, see: https://barleyprize.org/

Summary: Coordination of Research and Actions related to PRR

Establish a Canadian Nutrient Platform as a central point of cohesion in Canada for NRR initiatives, building on the progress made by other nutrient platforms (e.g., ESPP, SPA) globally. The EU has identified phosphorus as a "Critical Resource."

A key function of coordination would be to share best practice applicable in different sectors and geographies, specifically UPS, UNPS, RPS and RNPS. For example, RPS (e.g., animal manure) can be processed and applied through a neighbourhood nutrient management plan with crop farming/farmers as the end users. Specific questions can focus on how P can be recycled and reused in ways different than commercial fertilizer application.

Policy aspects—such as standards for end products, incentives and economic instruments for innovation and technology and the coordination of programs and BMPs—require coordination.

Who needs to be included on the Canadian Nutrient platform?

- Use the platform to bring together politicians, governments (federal, provincial and municipal) and associated agencies like conservation authorities, researchers, industry, farmers, other end users and other stakeholders to raise the profile of PRR and NRR and allow mutual trust to develop among the various players. Provincial or regional representation is considered critical in this effort (e.g. Atlantic provinces could be a regional hub).
- Ross and Omelon (2018) identify the key Canadian agencies, institutions, interest groups and industries that are involved in work within the phosphorus cycle. These are listed on page 26 of this report.

Goals and Outcomes of Coordination

- A Canadian nutrient platform could strive to have Canadians working together to achieve sustainable use, reuse and management of phosphorus to ensure food security, soil health and environmental quality are maintained. The platform could serve to support coordination efforts and establish key working alliances between all levels of government and stakeholders to facilitate:
  - Collective understanding of P flows in the agricultural sector, and more broadly in society and at large scales (regional, national, continental and global levels).
  - Coordination of education and communication strategies and collation of data.
  - Networking between diverse organizations from across the P value chain.
  - Technical information exchanges to ensure scientific collaboration and new Canadian approaches/technologies, and to provide technology sector a focus point for business development.
  - Prioritization of research and technology development/focused product development/inspiring innovation.
  - Coordinated input into regulatory frameworks.
  - Recognition of the Canadian Nutrient Platform among regulators, investors, stakeholders and the public, as a leader in P sustainability.
  - Raise the profile of Canadian PRR and liaise with other platforms and forums.
  - Coordinate mechanisms such as food labelling, nutrient footprint and other ideas highlighted in other sections of this document.
  - Provide a comprehensive Canada-wide database on nutrient flow on a national scale.
  - Enable long-term thinking/planning by decision makers (including coordinated regulation and standards development).
  - Transportation and costs associated with trucking organic wastes.
  - Fertilizer use, efficiency and recovered biofertilizers are strong candidates for priority research.

3.3 Technology and BMPs for PRR

Canada has made good efforts to start to lessen dependency on P imports using a variety of actions and technologies. In rural landscapes, this includes realigning P use to more precisely match crop and animal requirements, reducing nonpoint P runoff losses, reusing P from manure and residues more effectively, using more P-efficient cropping systems, direct use of P-rich by-products as fertilizers, improvement of fertilizer and manure recommendations, and application techniques. In urban landscapes, PRR efforts have focused on recycling P from municipal and industrial wastewater, implementation of green infrastructure to better manage nutrients in stormwater and some programs on better household organic waste management.

Concerted effort is needed to reduce Canada's dependency on P rock imports. Today, there are emerging and existing technologies and BMPs to recover P from a diverse range of sources using innovative physical, chemical and biological methods. The applicability of PRR actions is dependent on several factors, including the regulatory framework, access to raw materials, final product market accessibility, political considerations and economic drivers (costs, availability of partnerships, incentives, etc.).

Ross and Omelon (2018) report on Ostara, a Canadian company founded at the University of British Columbia that is currently selling P recovery technology from municipal wastewater treatment plants in Canada. Ostara's Pearl® process currently produces struvite in Saskatoon and Edmonton. In contrast, eight processes are operating in the United States and three are operating in Europe. The Ostara process produces an ammonium–magnesium–phosphate mineral called struvite that meets the fertilizer specifications of the Canadian Food Inspection Agency and is marketed as Crystal Green®.[9] It is used as a special additive in other fertilizers and is marketed for golf courses; however, it is not widely available in Canada. Moving forward, key considerations around struvite products should include cost considerations and how struvite can be incorporated into the existing commercial fertilizer manufacturing process. Ross and Omelon (2018) identify that a barrier for recycled P fertilizer adoption in the Canadian market seems to be availability rather than regulations prohibiting its use, as is the case in the EU. Cost might be added as another critical barrier in Canada.

Cordell and White (2013) present a comprehensive classification of all potential P supply and demand-side measures to meet long-term P needs for food production. Examples range from increasing efficiency in the agricultural and mining sector to developing technologies for recovering P from urine and food waste.

Adoption of new PRR technology and their associated products will be partly governed by Canada's provincial and federal regulatory framework. Ross and Omelon (2018) provide a discussion on Canadian and European regulations pertaining to recovered and reused P,

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[9] For more information on Crystal Green® see: http://crystalgreen.com/

identifying some of the progress achieved on this front. Similarly, broader PRR policy is required in Europe as well as Canada.

In 2014 ESPP developed an inventory of P recycling literature that was published between 2010 and 2014 and compiled by Wetsus & ESPP (2014). This comprehensive inventory provides citations, a description of the types of technologies, the waste streams that are treated, products recovered and a brief overview of the abstract for each of these published papers.

Significant work lies ahead to track new developments in nutrient recovery technology and finding ways to support new Canadian nutrient recycling technologies. This will include evaluation of technical and economic performance to produce integrated cost curve information for public sector investment planning, similar to the well-known McKinsey cost curve for GHG mitigation technology that provides a quantitative basis for discussions about what actions would be most effective in delivering emission reductions (McKinsey & Company, 2013). A major policy-relevant value-add to such cost curve information will be the inclusion of key climate externalities associated with nutrient recycling: GHG emissions and SOC. Higher-cost technologies may have offsetting benefits with respect to reduced GHG emissions and improved organic matter, which can be monetized as SOC credits.

The ESPP website contains a compiled list of P recovery technologies from wastewater streams around the globe (Wetsus & ESPP, 2017). The inventory lists 28 technologies, along with the location and operator of the plants. The inventory also lists when the plants became operational and the recovered material or product from each of those facilities. Further investigations are necessary to determine which of these technologies would have application in Canada.

3.3.1 Application of Technologies to Rural and Urban Point and Nonpoint Sources

The following section highlights some of the existing and emerging technologies discussed during the NNRR Forum, as well as other technologies that may have good application in the Canadian landscape, and in particular, the Lake Erie watershed. Table 2 categorizes these technologies based on their applicability in addressing UPS, UNPS, RPS and/or RNPS. It is noteworthy that many technologies today are focused on P management, while recovery and reuse are only recently emerging or in research stages.

Table 2. A summary of PRR (or P management) technologies and BMPs applicable to rural and urban, point and nonpoint sources

PRR Tech and BMPs	Point Source (with source of information)	Nonpoint Source (with source of information)	References
Rural	• Pyrolysis [2] • Microwave treatment of manure [4,5] • Manure composting[33] • Manure liquid/solid separation[33] • Wash water treatment systems for vegetable farms[28] • Ion exchange nanotechnology (pig manure to lithium ion battery material)[16] • Constructed wetlands [35]	• Water storage/nutrient uptake/biomass harvesting [3] • Precision feeding of ruminants/removing excess P from feeds.[40] • Precision application of farm nutrients[41, 43, 44, 45,] • Utilization of legacy P in soils [49] • Controlled tile drainage with storage and reuse/irrigation[34, 46, 48]. • Agricultural runoff capture • Constructed wetlands [35, 47] • Nutrient neighbourhoods[35]	2: Sun et al. (2017) 3: Grosshans et al. (2014) 4: Chan et al. (2013) 5: Srinivasan, Liao, & Lo (2016) 6: Cullen, Baur, & Schauer (2013) 7: Ostara (2018) 8: Vaneeckhaute (2018a) 10: Moffat (2018) 16: Vaneeckhaute (2018b) 19: Lystek Inc. (2018) 20: LSRCA (n. d. a) 21: MECP (2012) 22: Lake Simcoe Region Conservation Authority (2017b) 24: Lu, & Stofella (2012) 28: OMAFRA (2017) 29: Anand & Apul (2014) 31: Vaneeckhaute, & Weinberg (2017) 32: MECP (2003) 33: Zhang (2018) 34: Sunohara et al. (2016) 35: Real Agriculture (2018) 40: Cerosaletti, Fox, & Chase (2004) 41: Haneklaus, Panten, Lilienthal, & Schnugh (2010) 42: RRFB Nova Scotia (n.d.) 43: Hao et al. (2018) 44: Wang, Zhang, Hu, & Tan (2016) 45: Hao et al. (2015) 46: Tan and Zhang (2011) 47: Tan et al. (2007) 48: Zhang, Tan, Welacky, & Wang (2017) 49: Zhang et al. (2014, 2018)
Urban	• Low-temp pyrolysis [2] • Ostara/struvite generation /waste-activated sludge stripping (Ostara WASSTRIP®) and Pearl® technologies [6,7] • Lystek International Inc. wastewater biosolid and organic waste digester [19] • Ion exchange nanotechnology[8, 31] • StormFisher anaerobic digesters for food waste and biogas generation[10]. • Composting toilets/urine collection [29] • Backyard or community composting programs[42] • Wastewater reclamation and reuse/effluent irrigation [21,] • Land application of biosolids from sewage sludge[24] • Constructed wetlands [35]	• Biomass harvesting [3] • Urban stormwater runoff capture [32] • Phosphorus offsetting [10, 20, 22] • Urban agriculture & composting[13] • Constructed wetlands [35] • Green roofs and LID	

Note: superscript numbers refer to the associated source in the right column. Full references provided at the end of this report.

The following section provides a brief overview of technologies and BMPs related to P management, as well as PRR technologies identified in the table above.

3.3.2 Prominent PRR Technologies and BMPs (Application to UPS, UNPS, RPS and RNPS)

Point sources of nutrients concentrate waste and nutrients and offer unique opportunities for PRR technologies. Urban centres concentrate large volumes of P through municipal and industrial point source waste collection and treatment systems. P in urban areas also originates from nonpoint sources such as stormwater runoff from lawns and construction sites. Opportunities exist to recover and recycle the nutrients and prevent these from entering waterways and accelerating the eutrophication processes. However, the levels of treatment attained at WWTPs (a key UPS being considered for this research) are quite diverse, based on size, regulations and receiving waters (Oleszkiewicz, 2015). RPSs include large livestock operations that collect and manage animal waste.

Nonpoint sources include agricultural landscapes and urban stormwater collection and present other unique challenges and opportunities related to the collection, concentration and recovery of nutrients. Agricultural systems that integrate crops and livestock can enhance ecosystem services by improving nutrient cycling efficiency, reliance on renewable natural resources and soil health while maintaining or improving economic outcomes. Integrated crop–livestock systems may provide adaptable solutions to the sustainability challenges of declining P reserves, combining RPS- and RNPS-related technologies and BMPs toward mutual benefit.

The following section of this report describes and highlights several key PRR technologies that can be more broadly applied across Canada.

1. **Ostara (UPS):** Vancouver-based Ostara nutrient management technologies (WASSTRIP® and PEARL®) recovers nutrients, including P and N, from municipal and industrial wastewater streams, and transforms them into a continuous-release struvite fertilizer marketed as Crystal Green®. They have 17 plants worldwide, two located in Canada, generating 19,000 tonnes of fertilizer annually (Ostara, 2018). At the NNRR Forum, Rachel Lee of Ostara Nutrient Management Technology explained that 14 facilities in North America and Europe produce 17,000 tonnes of fertilizer (Crystal Green®) per year. Crystal Green® is acid soluble (rather than water soluble), therefore it does not runoff like traditional fertilizer (Lee, 2018). The developers are looking at ways to maximize needs for the both the wastewater and the fertilizer end users. This technology can be applied to wastewater and agricultural waste and can be adapted for other organic waste treatment processes. With an investment of CAD 6 million to build, it has a return on investment of approximately five years for municipal wastewater plants, primarily due to reduced costs in biosolids management, including potential reduction in energy costs.

2. **Pyrolysis (UPS & RPS):** Pyrolysis can be conducted using small-sized stoves to industrial-scale pyrolysis equipment to produce biochar and has great potential to be integrated into waste management such as sanitation of human excreta and animal manure (Sun et al., 2017) Potential feedstocks for pyrolysis include animal manure and human excreta and high-P plants grown on P-enriched sites such as P mines, agricultural soils, stormwater basins and P

polluted lakes. Such captured P can be reused from the produced P-enriched biochar by being directly used as a soil amendment or by chemical retrieval of P. The development of biochar technology and available data provide fundamental scientific evidence for the feasibility of pyrolysis for nutrient recovery. However, public acceptance requires that it must be easy to handle, with low economic investment, and be effective. This points directly to the future development of advanced pyrolysis technology, identification of alternative high-feedstocks, and exploration of additional values for biochar. A pilot project involving pyrolysis in California is described in Section 3.4 of this document, highlighting the resulting self-sufficiency and value addition for a dairy farm.

3. **Ion Exchange Nanotechnology (UPS):** Hybrid ion exchange (HIX) nanotechnology has successfully been applied at scale to recover nutrients from a variety of wastewaters (Vaneeckhaute & Weinberg, 2017). The resulting product after recovery and reconcentration is a N–P–K liquid fertilizer, 3–0.28–3, which is being used for hydroponic lettuce growing. Ion Exchange Nanotechnology is also being investigated for harvesting P for the rapidly expanding lithium battery production market (Vaneeckhaute, 2018).

4. **StormFisher – Food Waste Nutrient Recovery and Reuse/Digestate Technology (UPS):** StormFisher offers a technology solution for waste management of organic waste from Ontario's food processors, food retailers and waste haulers. StormFisher processes up to 100,000 tonnes of organic material per year from Ontario's food producers and food retailers and turns it into renewable energy and fertilizer. An original driver was Ontario's feed-in tariff program. Looking ahead, renewable natural gas production and the cost of C might help drive the process. They work directly with waste generators and haulers to offer an organic waste management solution (solids, packaged materials, liquids and retail food waste). At the NNRR Forum, Moffat (2018) reported that there is 3.7 million tonnes of organic waste that could be processed by this technology in Ontario to support the circular economy. This technology needs to be located near urban centres where the waste is generated, but this is not often desirable to the public. Fertilizer outputs can be transported to rural areas, and biogas can be used in either rural or urban settings. At this time, the company is making fertilizer as a cost avoidance mechanism, as there is not yet the market for this fertilizer.

5. **Lystek International Inc. – Wastewater Biosolid and Organic Waste Digester (UP):** Lystek International Inc. is an organic materials recovery firm that is processing wastewater biosolids and organic waste into fertilizers and other multi-purpose products. The Lystegro product provides co-benefits related to soil health. Lystek reports that they are assisting clients in reducing waste, costs, odours and GHG emissions through their biosolids and organics management systems. Their fertilizer products are federally registered in Canada. Their treatment system is also being used to optimize the performance of digesters and biological nutrient removal systems by reducing overall volumes and increasing biogas production for green energy.

6. **Wastewater Reclamation and Reuse/Effluent Irrigation (UPS):** During the NNRR Forum, Theresa MacIntyre-Morris (York Region) discussed the work being done around Lake Simcoe using wastewater effluent as a fertilizer on non-food crops (e.g., sod). The effluent being used currently is low in P content but has N levels that support sod growth. The Ontario Minister of the Environment (2012) provides guidance on water reclamation and reuse in its *Water and Energy Conservation Guidance Manual for Sewage Works*. The manual reports that the main barrier to reuse programs is usually the lack of community support, as well as insufficient communication of the benefits and feasibility of effluent irrigation. The manual also presents a comparison of the level of treatment and the economic, social and environmental factors, for various wastewater reuse options.

7. **Biosolid Application to Agricultural Land (UPS, RNPS)**: Application of biosolids to land provides several benefits, including enhancing soil organic matter and nutrients, However, caution needs to be exercised when biosolids are repeatedly or heavily applied as heavy metals, organic pollutants and pathogens in biosolids, though at low concentration, may pose a threat to the environment and animal and human health with time (Lu et al., 2012). A review of land application of biosolids in the United States (Lu et al., 2012) compiles research and regulation efforts regarding land application of biosolids, including forms, types and nutrient values of biosolids, environmental and health concerns, and related BMPs for reducing the impact of biosolid application, with emphasis on its land application in agriculture. The researchers recommend that community-specific outreach programs addressing public risk are needed to enhance adoption of this PRR strategy.

8. **Urban Stormwater Runoff Management/Phosphorus Offsetting for Stormwater Management (UNPS):** The *Stormwater Management Planning and Design Manual* prepared by the MECP (2003) provides a good overview of various stormwater BMPs that will work to mitigate the impacts of urban development. Common lot level and conveyance control BMPs include: rooftop storage, parking lot storage, superpipe storage, reduced lot grading, roof leader to ponding area, roof leader to soakaway pit, infiltration trench, grassed swales, pervious pipes, pervious catch basins, vegetated filter strips/rain gardens, natural buffer strips and rooftop gardens. In addition, common end-of-pipe stormwater control measures include: wet pond and artificial wetland, dry pond, infiltration basin, filters footnote, oil/grit separators. Most BMPs remain focused on P removal and management and must be further analyzed for PRR applications. Contamination of P and low concentration in stormwater from PRR would need to be taken into account for effective reuse.

9. **Composting Toilets/Urine Collection Systems (UPS):** There are barriers to the adoption of composting toilets and urine collection systems. There is a general lack of awareness of this technology, and the public may not easily adopt the technology because of perceived odour and maintenance issues. Composting toilets can require the user to be more active in managing their waste compared to conventional toilets. Maintenance requirements such as turning of the compost, addition of bulking agents and emptying the chamber may be

unacceptable for some users. There are also no clear and uniform regulations related to composting toilets. Existing regulations can either prevent the sole installation of the toilet or the application of compost and can become a barrier to use of composting toilets (Anand & Apul, 2014). These barriers will need to be addressed before composting toilets can take their place as a sustainable sanitation approach in developed countries. Assessments related to life-cycle costing, safety of compost material and the effectiveness of nutrient recycling of composting toilets is limited in the literature but would be helpful in evaluating this technology as a sustainable alternative to centralized water-based sanitation. Although composting toilets are generally not seen as tools for NRR, they can serve a function of diverting nutrients from traditional waste streams that may impact waterways.

10. **Backyard/Community Composting (UPS, UNPS):** Many jurisdictions have not yet implemented full organic waste collection programs, and the public must make the choice to either landfill organic household food waste along with their other household garbage or undertake a backyard or community composting. Composting organic wastes and returning nutrients to gardens are valuable ways to reduce the purchase of commercial fertilizers and help close the loop on P recycling. Treadwell, Clark and Bennett (2018) conducted a simulation of P flows through Montreal's food and waste systems. The researchers found that that over 80 per cent of P imported onto the island ends up in landfill, 17 per cent flows to the Saint Lawrence River and less than 3 per cent is available for recycling. This research demonstrated the significant potential to recover P from both wastewater and solid organic waste on the island of Montreal and to reduce P flows to landfill by up to 95 per cent. Given that existing policies in Montreal support organic waste diversion and wastewater treatment, information gained through their study can be utilized to make P policy and management decisions that fit readily into these current policies. Composting toilets are primarily used in rural cottage areas, where there are restrictions to septic system and holding tank installations.

11. **Composting Agricultural Waste (RPS and RNPS):** At the 2018 NNRR Forum, Zhang reported that annual animal manure production in Canada is approximately 146 million tonnes (Zhang, 2018). This manure can serve as a valuable resource if applied appropriately, adding P, N, K, calcium, magnesium and sulphur micronutrients and organic C to farmland; however, if lost to waterways, it can cause significant deterioration to lakes and other waterbodies. Challenges facing this technology are that manure is being produced in areas that are already high in soil P, and further application is restricted. In addition, manure production and crop needs are not often synchronized, there is a shortage of storage facilities, transportation costs are high and the public has concerns about odours and potential for pathogens. However, Zhang also reported that there are many opportunities and advantages to applying manure to land. In addition to supplying essential highly bioavailable nutrients, it can improve soil quality and health. Composting can reduce labile P and decrease the risk of dissolved and particulate P being lost downstream (Zhang, 2018). A new approach of P-based

manure and compost application can sustain crop yields, while reducing the risk of losing P to water resources (Wang et al., 2016; Zhang et al. 2018).

12. **Neighbourhood Nutrient Management Planning (RPS and RNPS):** Neighbourhood nutrient planning is another PRR tool that can assist producers with livestock operations in their efforts to management manure efficiently (Real Agriculture, 2018). The concept helps connect manure producers with grain farmers who may benefit from accessing and recycling manure-based nutrients for crop production. A third-party nutrient manager or a 4RNutrient Stewardship[10] consultant would coordinate the planning through mapping, manure analyses and soil testing.

13. **Manure Liquid/Solid Separation Application (RPS):** Manure separation makes reuse of component nutrients much simpler, as storage and transportation costs are much reduced. This requires appropriate equipment, storage and a market to sell/dispose of the manure economically. The neighbourhood nutrient planning approach is needed so nutrient application can be done efficiently and effectively as explained above (Brown & Reid, 2018). Key opportunities to improve PRR in agriculture involve investments in manure processing and precision application. Ensuring technology and innovation for transporting manure from areas of intensive livestock facilities to areas where fertilizers may be required for crop production can improve manure management and component NRR.

14. **Controlled Tile Drainage, Storage and Reuse (RNPS/RPS):** Controlled drainage is a BMP in which the tile drainage outlet is managed in order to regulate and reduce drain flow volume and nutrient loads to waterbodies (Tan, & Zhang, 2011; Tan et al., 2007). Research results on nutrient losses through tiled fields versus untiled fields have been variable, particularly for P movement within these drainage systems. Sunohara et al. (2016) compared conventional tile drainage versus controlled tile drainage in eastern Ontario over nine growing seasons, not accounting for losses during spring freshet. This research found a significant reduction in nutrients (58 per cent for total P) in the controlled tile drainage sites. In addition, yields for corn and soybeans were better under controlled drainage. Controlled tiled drainage can hold water in the root zone where nutrients can be taken up. It also permits the option to divert drainage water to holding ponds where the water and associated nutrients can be reused through sub-irrigation back through the tile drainage system or through above-ground irrigation technology (Tan, & Zhang, 2011). This technology has potential for application in specific agricultural regions of Canada with appropriate soil and landscape conditions.

15. **Water Retention, Nutrient Uptake and Biomass Harvesting (RNPS)**: Biomass harvesting can intercept nonpoint source nutrients in rural landscapes. IISD developed biomass harvesting practices through projects in Manitoba and North Dakota to capture

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[10] For more information on 4R Nutrient Stewardship, see: https://www.nutrientstewardship.com/

nutrients, enable bioenergy and biomaterial use, and improve habitat. Nutrient capture and reuse from nonpoint sources has been accomplished in projects located in both Manitoba and North Dakota. Both systems use hydraulic control to dewater reservoirs in late summer and early fall, allowing for biomass (*Typha spp*) harvesting with conventional equipment. The economics of the system are highly favourable if the recovered P can be monetized, through a water quality trading credit for example. The initial market for the harvested biomass in Manitoba has been a solid fuel for space heating driven by a ban on the use of coal for heating as a GHG mitigation policy. P interception and recycling via biomass provides verifiable sources of P reduction, which is particularly relevant for offset mechanisms.

16. **Constructed Wetlands (UPS, UNPS, RPS, RNPS):** The use of wetlands for bioremediation to capture and remove contaminants and nutrients is widely practised around the world to treat wastewater and stormwater runoff. Wetlands rely on natural processes to biologically filter water as it passes through shallow areas of dense aquatic vegetation and permeable bottom soils. Constructed wetlands are treatment systems that use natural processes involving wetland vegetation, soils and their associated microbial assemblages to improve water quality. Several agencies, including the US EPA, provide guidance on the design, construction, operation and maintenance of constructed wetlands (e.g., US EPA, 2016). Ashutosh, Kumar, & Sharma (2011) report that constructed wetlands provide the conditions for the interconversion of all forms of P. With careful designing and planning, constructed wetlands can efficiently remove varieties of inorganic and organic nutrients from domestic and industrial wastewaters. The cost of design and construction can be considerably lower than other conventional wastewater treatment options. Harvesting biomass in constructed wetlands and reusing those accumulated nutrients serves to close the nutrient cycle in these systems.

17. **Floating Treatment Wetlands (FTWs) for Nutrient and Contaminant Treatment in Urban and Rural Storm Water Ponds (UPS, UNPS, RPS, RNPS):** FTWs, or islands, are artificial platforms that allow aquatic emergent plants to grow in water that is typically too deep for wetlands. Their roots spread through the floating islands and down into the water, creating dense columns of roots with lots of surface area. Not only do the plants take up nutrients and contaminants themselves, the plant roots and floating island material provides extensive surface area for microbes to grow, forming a layer of biofilm. The biofilm is where the majority of nutrient uptake and degradation occurs in an FTW system. The unique nature of the FTW ecosystem gives the potential to capture nutrients and transform common pollutants into harmless by-products. Removal of the biomass is critical for complete removal of the extracted P and provides an opportunity for PRR.

18. **Wash Water Treatment Systems for Vegetable Farms (RPS/RNPS):** Fruit- and vegetable-packing facilities use water to move, cool and wash the produce. OMAFRA (2017) has developed a *Vegetable and Fruit Washwater Treatment Manual* that provides vegetable and fruit packers with a strategy to select and manage washwater treatment equipment based

on a water management plan. Washwater often contains soil, plant material and other debris that contributes to suspended solids and dissolved nutrient loads. The manual is designed to help producers manage washwater so that it will not impact nearby water supplies or the quality and shelf life of the produce. OMAFRA estimates there are up to 2,000 growers in Ontario who may wash produce on the farm. Management options include: (i) land application (irrigation or spreading on cropland), (i) treatment and reuse within the facility, (iii) on-site treatment and discharge and (iv) haulage to a nearby waste water treatment facility.

Apart from those described here, there are a number of BMPs, particularly for RNPs. These include, for example, precision feeding of ruminants (Cerosaletti et al., 2004), removing excess P from feed and precision application of farm nutrients. Current BMPs are not focused specifically on PRR, but rather just on reduction of nutrient emissions. Efforts in the future could be on enabling PRR in these BMPs where appropriate.

Summary: Technology and Best Management Practices Related to PRR

- Canada has made good efforts to lessen dependency on P imports in both urban and rural waste streams, although clearly more needs to be done to ensure Canada will secure critical supplies of essential plant nutrients.
- Ostara and Lystek International are two Canadian-based companies currently producing fertilizer from wastewater/organic wastes and contributing to PRR in Canada.
- Several other technologies and BMPs exist to recover nutrients from rural and urban point source waste streams. These include pyrolysis, ion exchange nanotechnology, digestate technology, effluent irrigation, biosolid application to agricultural land, anaerobic digestion, manure and organic waste composting.
- Nonpoint source-related technologies and BMPs with an emphasis on P management include: water storage in association with biomass harvesting, constructed and floating treatment wetlands, nutrient neighbourhood planning, urban stormwater capture, controlled tile drainage, P offsetting, precision application of farm nutrients and precision feeding of ruminants.
- Opportunities exist for scaling existing and emerging technologies in other contexts and at different scales. Policy enablers, market incentives and R&D are required for this.
- A specific opportunity is in the context of developing solutions for logistical barriers such as transportation of bulky materials with a lower density of nutrients.
- Specific barriers include:
    - The implementation of policies, economic instruments/incentives to inspire and support new research and technology development for NRR by Canadian companies.
    - Innovative technology developers (both adopters and adapters) have a difficult time getting emerging technology approved and adopted because of multiple barriers (e.g., funding, regulatory permits, communications, etc.).
    - NRR is not "sexy" like other technology sectors.
    - Much more needs to be done to market end products to producers and others to ensure that these new products will be trusted and bought. Consider making standards for these new products so farmers (and other sectors that influence end-user decision makers such as the insurance industry) will feel confident that these products will meet their needs.
    - Policies and regulations need to enable innovation and, at a minimum, reduce barriers to innovation. The Netherlands provides good examples of enabling policies through mechanisms such as the Dutch Phosphate Value Chain Agreement and the Phosphate Platform.

3.4 Markets and Policy Instruments for PRR

The drivers of market innovation and development are different at each stage. In the case of P recovery, it has been suggested that "early stages of development are driven by legislation and technical feasibility while economic viability, environmental stability and social acceptance are the most important factors for full-scale implementation" (Stark, 2004, in Holmgren, Verstraete, & Cornel, n.d.). The challenge is that legislation in the absence of economic viability is a burden that inhibits adoption. Therefore, policies and other incentives need to recognize these stages.

A key economic driver for PRR in the past was P market conditions and foreign trade policies relevant to P trade. The 2008/09 financial crisis changed the price of rock phosphate dramatically and brought it closer to the much higher present levels. China imposed a 135 per cent export tariff on P rock in 2008 leading to a price peak of P and placing direct pressure as the biggest supplier on the global P market. This higher price paved the way for a variety of P-recovery initiatives. Due to increased demand, the uncertainty of available reserves of mineral P and China's export tariff, the price of P spiked eightfold from USD 50 per tonne to USD 400 per tonne in 2008. After this price peak, the price stabilized around USD 100 per tonne, twice as much as before the peak (de Boer et. al., 2018).

A current economic driver for PRR globally is the circular economy and policies supporting waste reduction and reused more broadly. The circular economy is restorative or regenerative by intention, and policies supporting circular economies include the European Commission's bioeconomy strategy (EU, 2012), which addresses the production of renewable biological resources and their conversion to bioproducts and bioenergy. There is an emphasis on waste management through research, policy and market mechanisms.

The Phosphorus as a Resource Workshop at Ryerson University (Trudeau, 2014) identified the lack of economic instruments as a key limitation related to PRR. At the NNRR Forum in Toronto (IISD, 2018), discussions highlighted the difficulty in communicating the real cost of business as usual. Wastewater treatment plant investments are unlikely to include P recycling technologies unless there is a transparent and **viable business case** for doing so—even though sludge disposal cost can be 50 per cent or more of the life-cycle costs of a new plant according to Mavinic (IISD, 2018). Technologies like Ostara demonstrate that the real driver is not the additional revenue from fertilizer, but in fact the reduced ongoing costs of operations and maintenance of the WWTP. Vaneeckhaute emphasized a society-wide perspective of "sustainable return on investment" for nutrient recycling technologies that accounts for the benefits of reduced pollutant loading and lower risk of food insecurity (IISD, 2018). Precedents exist for estimating the total societal cost of eutrophication for specific ecosystems of concern (e.g., Lake Erie), and these estimates can be used to encourage the development of market instruments. Precedents exist for estimating the total societal cost of eutrophication for specific ecosystems of concern (e.g., Lake Erie) and Mavinic promoted the value of credibly quantifying the scarcity value of P to communicate the public sector investment case for P recycling.

From a sustainable development perspective, the oversupply of P to aquatic ecosystems represents **three market failures** relevant to PRR: the uncertain and disputed monopoly of virtually all the world's supply of commercial P, the omission of its scarcity value as a critical input to world food security and its environmental externality cost as a pollutant.

One concept that was highlighted at the NNRR Forum was using the model of the social cost of C to capture and communicate the social cost of phosphorus (SCP). SCP would be the sum of the P eutrophication and scarcity externalities. This could be operationalized like costs were calculated for Lake Erie, where an ecological goods and services approach was used to assess the costs of eutrophication and *Cladophora,* and the non-market costs were estimated based on survey results of environmental valuation reported in the literature. SCP could then be monetized in ways similar to C taxes and incentivizing PRR analogous to incentives and R&D for renewable energy use. Bass highlighted this need at the NNRR Forum by suggesting we look at the regional geographic social cost and not just the per-kilogram cost (IISD, 2018). SCP could also assist in creating incentives for policy-makers. For example, since mining rock phosphate is a polluting process, SCP would incorporate environmental externalities in mining regions and help move toward higher efficiency and incenting PRR.

Phil Dick presented the Rogers diffusion model as a means to shorten the stakeholder adoption time cycle. It models the evolutionary path for emerging technologies and divides adopters into five different categories: innovators, early adopters, early majority, late majority and laggards. Considering the social factors underlying the movement from innovators through early adopters to an early majority will improve the design and roll-out of initiatives to encourage adoption of PRR technology.

Examples of early PRR adopters: WWTPs in Berlin, Germany, or "Berliner Wasserbetriebe," generate a revenue stream out of P recovery, even if it is yet only a small one. As more and more are following this idea in Europe, there will be a market for these recovered nutrients out of wastewater treatment plants. An early adopter in case of Lystek was Guelph, Ontario. Lystek established a relationship with the City of Guelph in 2006 and maintains this relationship till today. Lystek went through pilot-scale testing and proceeded to full commercialization with the City of Guelph as their first customer.

3.4.1 Examples of Policy and Incentives Applicable to PRR

Total maximum daily loads (TMDLs) under the US EPA's Clean Water Act: U.S. regulations prescribe TMDLs, or the maximum amount of a pollutant allowed to enter a waterbody such that it continues to maintain its water quality standards. TMDLs are calculated for specific pollutants and specific waterbodies in the context of impaired or polluted waters. In eutrophic systems such as the Chesapeake Bay, TMDLs have been set for nutrients, including P. While these regulations do not specifically target PRR, they do enable innovation, offset markets and other mechanisms that have implications for PRR.

Organic Waste Management in Quebec: Quebec has prioritized and invested in organic waste management over the decade or so. Quebec aimed at a 60 per cent reduction in its organic waste stream from entering landfills, incenting composting, bio methanation, valorization, value-added development of organic waste and other organic waste management components in the process. It has also invested CAD 650 million in anaerobic digestion. In addition, the province has banned the use of organic waste incineration and disposal by 2022, and these actions are anticipated to have lasting impacts for NRR/PRR.

Phosphorus Offsetting: Lake Simcoe stormwater management program is implementing stormwater management requirements to significantly reduce P sources from development sites and requiring offsetting for any P that does leave the site. This program is being used to implement treatment options to deal with nutrient export at an offset ratio of 2.5, or approximately CAD 2000 per lot in the Lake Simcoe Region Conservation Authority region. This offsetting program could serve as an important model for other jurisdictions looking for strategies to reduce impacts from both point and nonpoint stormwater runoff (Lake Simcoe Region Conservation Authority, 2017). Nutrient offsets are primarily a nutrient management mechanism; however, future design could consider incentive mechanisms for recycled and reused nutrients.

Some of the necessary preconditions to support P management initiatives that could be used to enable recovery and reuse are regulatory incentives. In case of the offsets management approach, certain regulatory and market preconditions are necessary in order for water quality offsetting to be a feasible alternative to traditional abatement means and technologies. These include:

1) **Regulatory cap on nutrients**: involves a regulatory agency setting and enforcing the limit (a cap) on pollutant discharges. An example is the TMDL system described earlier in this section applicable in certain U.S. waters.
2) **Economic:** existence of varying pollution reduction costs across discharges in the watershed. An offset mechanism is based on the premise that a high-cost nutrient reduction intervention might be replaced (or offset) through lower cost options. The cost differential for different options is therefore necessary to create offsets.

The combination of these two prerequisites is necessary to create demand for offsetting, and this combination is the main driver of most water quality trading programs examined in this report**.** A realistic and enforceable regulatory framework creates incentives for polluters to seek out cost-effective pollution control options (OECD, 2012, p. 88).

Funding: The Water Environment Research Federation (WERF) conducted a in 2013 that concluded that sufficient funding can help overcome barriers and that such investment can be derived from different sources. The public sector has a role in providing financial support for private sector investments, risk sharing in critical early phases and catalytic funding (BASD, 2011). "Survey respondents included a mention of the conservative, risk-averse nature of the industry that focuses less on growth opportunities and, thus, creates barriers for recovered resources. Another survey response emphasized the need for flexibility among regulators and decision makers as well, noting the lack of understanding among policy-makers about the needs and potential of technologies in the field of resource recovery" (Holmgren et al., n.d.).

Subsidies: Holmgren et al. (n.d.) highlights that the high start-up investments related to PRR technologies are often a barrier to adoption. In addition, many existing practices are subsidized in a variety of ways and act as competition for PRR technologies. The provision of subsidies or financial assistance into the R&D sector can level the playing field and enable recovery practices to enter the market. Subsidies can be targeted at any of the barriers identified in different parts of this report, including technology development, scale-up and replication, waste management logistics such as transportation, links to markets and bioenergy, and those related to coordination and the development of clusters and platforms.

Other relevant policy mechanisms in that could enable markets for PRR technology and application could include:

- Regulations related to field applications for uncomposted manure (UPS, RPS, RNPS).
- Stringent P reuse requirements at wastewater treatment plants, ensuring that biosolids are generated with technology that renders P bioavailable. (UPS).
- Regulations related to point source P emissions limit allowing for nutrient offsets or water quality trading (UPS, UNPS, RPS, RNPS). An additional design feature would be credits for reuse and recovery in the offset calculations.
- A recycled P-blending policy or regulation for commercial fertilizers.
- Incentives for fertilizer companies and fertilizer users to use recycled P.
- R&D on least cost NPS PRR.
- Climate change/GHG mitigation credits for nutrient capture.

Energy costs as incentives: For PRR technologies that enable energy generation, adoption might be more successful in areas with high electricity rates. In the United Kingdom when energy prices doubled during 2003–2006, on-site generation of energy from sludge was increased, endorsing the fact that rising energy costs act as incentives for energy recovery from waste (Holmgren et al., n.d).

The Dutch Phosphate Value Chain Agreement facilitated by the ESPP in 2011 called for a commitment to create a sustainable market for secondary recycled phosphates over the course of two years in the Netherlands. The agreement was signed by 20 industrial companies, knowledge institutions, government authorities and NGOs (de Boer et al., 2018).

Based on the scope of the NNRR Forum and related research, the policy and economic implications for a few PRR systems are described in sections below.

3.4.2 PRR from UPSs

PRR from WWTPs are becoming more common in Canada with the emerging viability of Ostara and Lystek technologies (these are explained in Section 3.3 of this paper). Based on existing research, the ability to sell recovered P is not the key economic driver for PRR. In the case of UPSs, the operating cost reductions related to the biological removal processes applied are the main incentive for the adoption of technologies. WWTPs aim for operational cost reduction without factoring in the value of recovered P sales. However, there is an overall return on investment and reduced maintenance that is attractive to decision makers and managers.

According to Oleszkiewicz et. al. (2015), the return on investment in plants currently recovering P from waste-activated sludge or anaerobically digested sludge liquor in North America varies between seven and 14 years and depends on criteria such as the severity of prior scaling, the improvement in dewaterability of sludge and the impact on stabilization of effluent P concentration.

It has been noted that the sale price of the recovered struvite is inadequate to justify struvite recovery on economic arguments alone. Instead, recovery in larger WWTPs is often driven by maintenance cost avoidance, where removing P limits damage caused by struvite precipitation in valves and pipes. Ostara nutrient recovery systems, operational in Canada, the United States and Europe, are based on the service of P removal rather than the sale and actual reuse of the product (Mayer et al., 2016).

Lystek is another PRR technology related to UPSs capable of converting biosolids and other organics into federally recognized biofertilizer products (Tomlinson, 2016). Focused on multiple benefits, the technology produces a safe biofertilizer. Lystek-based fertilizer is markedly less expensive than commercial fertilizers, with comparable N–P–K values and contains organic matter to rebuild the health of the soil over the long term. This technology also claims to be scalable to smaller treatment plants and possibly to RPSs.

For Lystek, there are two typical business models. The first is the capital purchase model in which the municipality or treatment plant operator pays for the installation, operates the facility and recovers the costs through maintenance savings, often within a 3–10-year payback period. In the second, the fee model, the business partner installs the P-recovery unit using the build–operate–own model through a long-term contract. The fee model saves the large upfront capital costs for facilities and instead charges only a monthly fee, which should be below the facility's existing struvite-related treatment costs. Both models can involve a P purchase agreement that allows the treatment plant to dispose of the unwanted struvite and the P recovery company to market it (Mayer et al., 2016).

3.4.3 PRR from RPSs

In rural areas, point source operations tend to be smaller; however, they are more prolific and together are responsible for a large portion of the P discharge into the environment. Therefore, the economics, scale and policy implications are different than in UPSs and nonpoint sources.

Sarvajayakesavalu et al. (2018) stress that PRR from small sewage plants in rural and semi-urban areas may not be economically feasible due to the low percentage of recovery and increased cost of technology. They posit that, given upfront costs of PRR technologies in point sources such as WWTPs, smaller facilities may need to rely on the application of biosolids or manure for agriculture as a simpler and cost-effective means of PRR.

Knowing what we know about UPS PRR, we can conclude that considering P reuse for RPSs will depend on the types of technology: for smaller operations compared to UPSs, the technology needs to have the ability to be scaled down. Lystek, for example, is scalable. They claim their system is designed to be small, simple to operate, easy to maintain and really easy to deploy. They are also able to "bolt on to existing infrastructure with little to no impact on what's already been there" (Lystek International Inc., n.d.).

Energy self-sufficiency through manure management: In California, the Scott Brothers Dairy Farms are demonstrating manure management and the production of the farm's diesel fuel using a "circle of energy" concept. Using funding support from the California Energy Commission, the pilot system first removes almost all suspended solids and 40 per cent of dissolved solids from the dairy's liquid manure. The solids then go into a pyrolysis gasifier and the resulting syngas is purified using a proven Fischer-Tropsch process, producing a sulphur-free renewable diesel product. Regulatory hurdles along the way included responding to the need for a structure to meet the California Environmental Quality Act (Hein, 2016). Policy opportunities included meeting the zero total dissolved solids mandate and salt loading restrictions in water quality regulations. This pilot project is demonstrating that PRR can assist in meeting energy self-sufficiency as well as value addition from RPSs.

3.4.4 PRR from RNPSs

Nonpoint P is the most difficult and largest source, as well as the most environmentally damaging cause of eutrophication. Low-cost, multifunctional nonpoint P interception using natural infrastructure has been proven in Canada (Grosshans et al., 2015) and could be effective when integrated with traditional built grey infrastructure. The Lake Winnipeg Bioeconomy Project received national and international recognition for demonstrating that nonpoint P interception and recovery using phytoremediation and biomass harvesting is feasible and low-cost. The economics of the system are favourable if the recovered P can be monetized, for example, through a water quality trading credit such as in Lake Simcoe or wetland restoration in New York. The initial market for harvested biomass in Manitoba is as a solid fuel for space heating, which was driven by a ban on the use of coal, implemented as a GHG mitigation policy.

Typically regulated point sources within water quality trading systems have not used nonpoint source P credits, as these credits assume agricultural BMPs with uncertain and hard-to-verify performance. U.S. researchers have recently proposed a nutrient assimilation credit (Stephenson & Shabman, 2015) based on biomass harvesting to provide a much more robust method for nonpoint P interception, which could be applied to the Lake Winnipeg Bioeconomy Project example.

Several new federal funding programs exist to support natural infrastructure projects, including the Investing in Canada Infrastructure Program and the Disaster Mitigation and Adaptation Fund.

Summary: Markets and Policy Instruments for PRR

- The lack of enabling policies, incentives and market-based instruments remains a key limitation related to PRR and was heavily reinforced at the NNRR Forum.
- The market price of P has been a critical driver of PRR in the past. Widespread knowledge of the finite supplies of P and its role in global food security can incent PRR in the future. There have already been precedents of unexpected price hikes that undermined the sector stability (an eightfold price increase from CAD 50 per tonne to CAD 400 per tonne in 2008). Phosphorus prices will need to be considered in any comprehensive NRR strategy.
- The financial indicator **"sustainable return on investment"** in PRR projects can capture the benefits of P recycling compared to P extraction, such as lower risk of food insecurity and reduced eutrophication in the waterbodies. Moreover, recovered P does not have to be mined, converted into a finished product and travel long distances. This may serve as incentive for potentially socially responsible investors in PRR.
- Enabling policies for PRR, including those relevant to **food security, circular economy,** waste reduction and reuse more broadly, and those targeting eutrophication in water systems.
- Regulatory incentives act as some of the necessary preconditions to support phosphorus management initiatives. Regulations related to field applications for uncomposted manure (UPS, RPS, RNPS) and stringent P reuse requirements at wastewater treatment plants.
- A clear business case for recycled P from WWTPs is needed, including that fact that sludge disposal cost can be 50 per cent or more of the life cycle costs of a new plant (IISD, 2018).
- Nutrient management regulations, regulators and decision makers need to understand the needs and potential of technologies in the field of resource recovery.
- High start-up investments related to PRR technologies are often a barrier to adoption. The provision of **subsidies or financial assistance into the research and development sector** can enable recovery practices.
- In addition, for PRR technologies that enable energy generation, adoption might be more successful in areas with high electricity rates.
- In practice, based on existing research into current technologies and their implementation at the wastewater treatment plants, **the ability to sell recovered P is not the key economic driver for PRR**. In the case of large-scale WWTPs, the main incentive for PRR is P removal, which limits damage caused by struvite precipitation in valves and pipes (for example, Ostara technology), thus reducing operational costs of the plant. The sale and actual reuse of the product has a secondary role.
- RNPS PRR has been successfully demonstrated by the **Lake Winnipeg Bioeconomy Project**. This project confirmed that nonpoint P interception and recovery using phyto-remediation and biomass harvesting is feasible and low-cost. Moreover, this process enables measuring P loads, which is useful for the water quality trading schemes.
- **The Rogers diffusion model of technology adoption** allows us to understand the stages of innovation adoption informing policies and implementation strategies for PRR projects. The model divides adopters into five different categories: innovators, early adopters, early majority, late majority and laggards. Each group's approach to technology adoption is different. This model allows us to look for the ways to shorten the stakeholder adoption cycle.
- **Specific regulations and incentives** such as against garburators and/or incentives for composting food and organic waste can help in achieving PRR objectives.

4. RECOMMENDATIONS FOR A CANADIAN PRR ACTION PLAN

A clear message from the NNRR Forum 2018 is the need for an integrated approach to NRR in Canada, with an initial emphasis specifically on PRR. Key Canadian priorities directly benefiting from PRR include reducing Canada's high dependence on imported P, improved soil health, food security, environmental protection, water quality, lake eutrophication and waste management. Explicitly articulating the drivers and outcomes of PRR (and NRR) is a critical requirement for a successful integrated Canadian strategy on NRR. Due to its dual nature as a critical resource and a pollutant, P offers an important solution to addressing linked water–energy–food security-related issues on a global basis. Clearly articulating P as a finite and valuable resource fundamental to agricultural production and global food security provides just one immediate and direct entry point for a broader and longer-term NRR strategy; the role of P in the growth of algal blooms provides another.

While many of the drivers of NRR, such as the dependency on imported P for food production, are not urgent, any shock to the nutrient supply system, from price fluctuations or supply scarcity, for example, could cause a sudden and severe impact on the production and the price of food. Anticipating such inevitable events, it is prudent to prepare and enable the conversion of research and best practices to demonstration, adoption, verification and application.

The NNRR Forum in Toronto reinforced the four key elements of an integrated action plan for PRR in Canada. The 80 participants who gathered from academia, industry, NGOs and government were asked key questions on what they thought were priority actions, and who would form the working groups and projects and pilots that would accelerate P-recovery strategies in Canada. The group and panel discussions provided informed suggestions and were further enhanced by research and inputs from a steering committee. As there is no single route to PRR in Canada, the four key pillars articulated through this research document were reinforced at this forum. Key insights and recommendations clustered around the four key pillars are provided below.

4.1 Strategic Information, Communications, Education Needs

A number of critical opportunities and gaps for changing mindsets and enabling PRR in Canada have been highlighted in this report. A strategic communications strategy would, above all, focus on achieving broader recognition of P as a commodity and resource critical for food security, its role in societal priorities, and the value and benefits of recycling, reuse and recovery for waste management and water quality.

To effectively and strategically target actions, we need to better understand the contexts and regions in Canada that have the most opportunities for PRR. Strengthening monitoring systems to ensure consistency, detail and open access will improve overall understanding of P sources and sinks. There is some potential to do this in the context of water quality and watersheds. The watershed report created by WWF (2017), for example, includes data on water pollution, specifically P-related pollution, as a prominent component. This could be expanded to include P sources and flows in the watershed, identifying priority areas across Canada. Targeted communications efforts could include mapping regional P levels and flows that would not only provide non-experts with a broad understanding of the imbalance, but also assist in the brokering of coordinated research and action for moving P from regions of excess to regions that require more to meet agricultural needs.

Beyond P, enabling a broader NRR strategy would need to include the value of NRR more broadly. This would also emphasize N and K as important agricultural fertilizers and the benefits of organic C for improved soil health and for mitigating climate change. A practical example of value was provided by Reid and Brown at the NNRR (2018), where they described the significant quantifiable benefits from applying manure to croplands and forage lands. They highlighted the specific benefits related to agricultural productivity as well as cost savings from PRR in the agricultural sector (IISD, 2018).

Sarvajayakesavalu et al. (2018) reinforces the need for an integrated approach that involves significant investment for developing social, economic and environmental analyses to evaluate the costs and benefits of scaling up PRR in the context of developing countries. They highlight the need for joint R&D programs between water, fertilizer and P industries. Specific aspects of research, such as P footprints, economic benefits of NRR/PRR and the cost of doing nothing, are recognized as potential priorities in ensuring a broader understanding of NRR/PRR as well as enabling strategic actions in the field.

These priorities, as well as target audiences and communications tools, are articulated in some detail in Section 3.2 of this document and summarized on page 32.

4.2 Strategy for Coordination of Research and Actions

With the challenge and complexity of rural and urban point and nonpoint sources of P, and the current and potential actions related to research, technology, communications and government programs, there is an expressed need to coordinate PRR (and NRR as possible) across Canada. Recommended components of coordination include the following four components: a Canadian nutrient platform, coordination of research, transportation of nutrient reserves in the agricultural sector and a fertilizer strategy.

4.2.1 A Canadian Nutrient Platform

A stand-alone Canadian nutrient platform is needed to coordinate efforts at multiple levels between experts and stakeholders in Canada. Such a Canadian platform would need to have representation from all Canadian provinces and strong linkages with the North America-based SPA. As well, associations with the larger ESPP and other international platforms would facilitate greater global coordination. A Canadian Phosphorus Alliance would focus on the sustainable use, reuse and management of P and all nutrients in Canada, emphasizing priorities for food security, soil health, waste management and environmental stewardship. The Phosphorus Hub at McGill University[11] might provide some early efforts in this direction.

A Canadian platform would include experts from federal and provincial governments, academia, researchers, NGOs, industry and other civil society groups. Ross and Omelon (2018) provide an initial list of potential organizations and experts in Section 3.2.2 of this report. Key insights from the ESPP and the SPA will provide important guidance for a Canadian nutrient platform, particularly on tools for engagement and messaging related to industry and government, as summarized in Section 3.2 of this report.

In addition, a Canadian Phosphorus Alliance would coordinate across regional hubs, which would coordinate the response to regional priorities and conditions. Regional hubs also provide an opportunity for participation by NGOs, farmers and others less involved in research, technology, policies and actions relevant to NRR specifically. Regional hubs are also seen as more likely to enable provincial participation, as well as academic participation from regional universities. Overall, a Canadian Phosphorus Alliance would enable national coordination of the four key pillars for (i) reinforcing improved communications; (ii) coordinated research and action; (iii) technology development replication and scaling; and (iv) government policies, incentives and markets.

4.2.2 Coordination of Research

There is already an active field of research related to nutrient management, use, reuse and recovery in Canada. Coordinating research is a priority for any PRR/NRR efforts in Canada to accelerate development, technology, best practice application, outcome measurements, and to establish Canada as a leader in NRR and PRR applications.

Greater research coordination would create opportunities for joint research proposals, to expand funding potential and future actions and outcomes. Coordinated research enables cross-sectoral and cross-regional actions, some of which were identified at the NNRR Forum, in previous forums and in the literature. Specifically, current technologies could be tested in other contexts and scales, lessons would be shared among researchers across government departments and academic institutions. More importantly, coordinated research would bring researchers and end users together toward practical applications of PRR actions.

4.2.3 Transportation of Nutrient Reserves in the Agricultural Sector

A key issue highlighted at the NNRR Forum, particularly in the agricultural sector, was transportation challenges related to transferring nutrients from regions of excess, such as in areas of intensive livestock operations or large urban municipalities, to areas with a need for nutrients to meet crop production. Such coordination might be achieved through a

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[11] Phosphorus Hub: https://www.phosphorushub.com/

neighbourhood nutrient planning effort where brokers connect those with too much nutrients with those with not enough nutrients and conduct the necessary paperwork and other actions to ensure sustainable manure management and as well as fertilization as needed.

Beyond such regional planning, transportation planning would also enable research on the nutrient concentration, load reduction and other priorities to enable agricultural nutrient management and NRR. Transportation costs and technology barriers related to rural nonpoint nutrient management would need to be considered in this aspect of coordination.

4.2.4. Fertilizer Strategy

Sufficient fertilizer production is essential to food production, and producers spend billions of dollars in Canada on fertilizer every year. The need to remain competitive has driven the popularization of best practices, such as precision fertilization through the 4R Nutrient Stewardship, promoting right rate, right source, right time and right placement (4R). Research has shown that crop P use efficiency in the year of application is relatively low, both from animal manures and chemical fertilizers, at less than 20 per cent. While the remainder might be taken up in subsequent years, there is a risk that field water discharge in runoff and tile drainage could increase nutrient loss from agricultural fields, affecting downstream waterbodies. Evidence shows that, in numerous eutrophic freshwater bodies in Canada, while the majority of the nutrients accumulate from agricultural landscapes, some of the most intensive impacts happen where agricultural and urban flows collide.

Some thought on the historic evolution of the current P issues and changes in P sources is also needed to address regional urban and agricultural leakages at watershed scales and to improve recapture and reuse. Prior to the 1990s, rock phosphate prevailed with a half-life of 18–19 years with a 5 per cent availability rate. With rock phosphate's persistent leakage and high rate of accumulation because of its long half-life, if a farmer needed 50 kg of available phosphate, they needed 1,000 kg of rock phosphate. Since the 1990s, activated phosphate is now 20 per cent available (a 4+ year half-life), therefore the farmer who needed 50 kg of active phosphate would now only need 225 kg. The farmer's cost for active phosphate has not changed much in 30 years, which could lead to over application, but they are now using much less, focusing on technology and precision farming for fertilizer applications while optimizing nutrient availability based on factors such as soil type, temperature and existing soil reserves.

4.2.5 Decision-Support System for NRR

At Laval University in Quebec, under the coordination of Dr. Céline Vaneeckhaute and performed by the BioEngine research team on green process engineering and biorefineries, research is being performed on holistic optimization of integrated nutrient and energy recovery from waste.

BioEngine proposes a systems-based approach to resource recovery through the development of a spatiotemporal decision-support system (DSS), which is a user-friendly software tool that allows setting up optimal organic waste valorization chains, including energy and nutrient recovery and recycling, while targeting cost and GHG minimization and respecting regulatory and social constraints. Such a DSS enables optimal planning of the location, capacity and treatment scenario for organic waste valorization, as well as the collection of the waste sources to be treated and the distribution of the recovered end-products at minimum cost and environmental footprint, taking into account public nuisance and regulations in force. It also allows for optimal valorization of new industrial waste flows to be treated and can hence provide low-cost support to growing industries in Canada without the need for extensive experimental laboratory or pilot testing. Finally, the DSS can be valuable for the agricultural sector, since it allows for better adjustment of resource recovery strategies to end users of recovered products.

Overall, the DSS can improve the coordination between waste generation, treatment and end-product distribution across Canada. Such a portfolio of policies, practices, technologies and system optimizations define a new cleantech space where Canada could assert leadership. It is expected that the BioEngine research on DSS will result in significant benefits for the Canadian circular economy within three to five years.

Expected economic gains:

(1) A larger basis of local fertilizer supply in the country

(2) Greater profitability of waste treatment projects (anaerobic digestion, notably) through the establishment of a circular economy

(3) Higher yields of high-nutrient-demanding crops where environmental regulation limits nutrient application rates through increased nutrient-use efficiency

Expected environmental gains:

(1) Reduced GHG emissions through organic waste recycling (= regulatory requirement in Quebec from 2022 onwards)

(2) Less nutrient export from high-nutrient production zones at high risk for eutrophication

(3) Reduced nutrient application in high-nutrient-demanding cropping systems through increased nutrient-use efficiency and improved planning

Expected social gains:

(1) Establishment of closed links between urban and rural areas to support food security

(2) Reduced traffic and odour nuisance through optimization of logistics and treatment plant location

(3) Increased acceptability of waste recycling and agricultural activities

All of this is expected to spark a win–win–win situation for the environment, economy and society in Canada.

4.3 Support for Technology and BMPs for PRR in Canada

A "concept-to-market" strategy is required for the development, adoption, replication and scaling of new and existing technologies for PRR. As technologies are context specific, a strategy must first compile available technologies and communicate where and how they work. Solutions can include NRR from WWTPs, as well as 4R precision fertilizing. An initial listing of technologies relevant to the various sectors has been provided in Section 3.3 of this report. In addition to markets and applicability of technology, it is important to understand their associated risks, side effects, and long-term cost and implementation implications in order to improve broader adoption.

Several Canadian companies have demonstrated world-class technological leadership in nutrient (mostly P) recovery from wastewater treatment plants, including Ostara Nutrient Recovery Technologies and Lystek International Inc., while PRR from anaerobic digestion plants designed to process food waste is being demonstrated by StormFisher Environmental.

While new technology is one possible pathway for NRR in general, for the agricultural sector, improvements in existing technologies, BMPs, and improving process efficiencies are key for driving NRR in agriculture. Specific opportunities in the context of existing and new technologies are related to manure management and agricultural fertilizer technologies. Regional densification of intensive livestock operations results in large amounts of manure production with higher costs related to land application. A specific gap in manure handling, processing, separating solid from liquid, concentrating nutrients and manure transportation are all opportunities for technology and BMP improvements and development, as the market opportunities are currently high. Soil health and water quality are also key considerations in the context of developing appropriate technology. A related R&D opportunity is in finding ways to move excess components of manure from areas of livestock concentration to croplands with a nutrient deficit, particularly P.

4.4 Policy Instruments for PRR: Identifying and leveraging opportunities and funding in Canada

Presentations and discussions at the NNRR Forum highlighted the need for a variety of policy and market instruments to enable aspects of PRR across Canada. The forum also stressed the need for funding, incentives or subsidies to drive PRR in emphasizing the links of NRR to the circular economy, climate change and green infrastructure.

Potential funding opportunities could include NSERC Research Chairs (recovery and industrial), clusters or projects funded under the Canadian Agricultural Partnership (administered by AAFC), the Lake Winnipeg Basin Program, Genome Canada and municipal-based green infrastructure funds. There may also be funding opportunities under the Canada–Ontario Agreement in support of the Lake Erie Action Plan. Several new cross-disciplinary federal funding programs also exist to support research and applications in natural infrastructure, clean technology and climate adaptation projects, all of which have direct links to NRR. This includes the Investing in Canada Infrastructure Program (ICIP), the Disaster Mitigation and Adaptation Fund (DMAF), as well as the National Resources Canada Clean Growth Fund and other clean technology funds.

A few other examples of policies and instruments relevant to NRR/PRR are highlighted below and can be expanded for wider application.

The George Barley Water Prize from the Everglades Foundation neatly encapsulates the challenge: a USD 10 million prize will be awarded to the team that demonstrates cost-effective P removal from a freshwater ecosystem; a secondary USD 170,000 prize will be given to the team that demonstrates efficient reuse of removed P. The Barley Prize is motivated by the USD 12 billion cleanup cost of Lake Okeechobee, and the greater than USD 3 trillion cleanup cost ascribed to P pollution globally—the cost of *do-nothing* in this case is clearly articulated.

Ban on organic wastes, Quebec: The presentation by Vaneeckhaute (IISD, 2018) noted that the ban on organic waste incineration by 2022 was the key driver for organic waste recycling investments in Quebec (CAD 165 million was invested by the province). Quebec City plans to produce 6,600 m^3 of biomethane, with 83 kt of solid biodigestates returned as organic fertilizer. It recognizes the positive crossover with climate policy—9,500 tonnes of carbon dioxide equivalent in emission offset credits annually. Quebec City will also invest in technology to recover N from the resulting liquid digestate as concentrated ammonium sulphate.

Ontario's circular economy strategy provides policy incentive for waste management and reuse, particularly in an effort to mitigate climate change. The circular economy strategy "goes beyond recycling," with a goal to design for better recovery systems and to minimize the use of raw materials and energy through restorative processes. The strategy includes mention of "digestate and compost to recover nutrient and improve soil health." The strategy does not, however, explicitly identify P as an item of concern.

The Lake Erie Action Plan, launched in February 2018, focuses reducing nutrient loads from entering Lake Erie. One component of the action plan anticipated to have implications for PRR is the intent to explore opportunities to adopt innovative technologies that encourage PRR (ECCC & MOECC, 2018).

Manitoba's coal ban has, in part, incentivized the Lake Winnipeg Bioeconomy Project, as it has helped develop a local demand and market for biomass for use as a solid fuel to replace coal for rural heating needs. This has, in turn, created a market demand for novel biomass sources, such as cattail and other marsh grasses, which captures and removes P when harvested from water retention and drainage projects. Other drivers include the Lake Winnipeg Basin Program for nutrient management and a voluntary C offset market that helps fund biomass management projects.

These examples provide some guidance on efforts needed to drive, incent and regulate PRR-related actions in different sectors across Canada. Further discussion of policies and the specific studies that will help in replication processes are described in Section 3.4 of this document.

4.5 Existing and Proposed Pilots Under a Canadian PRR Strategy

There are a number of existing and proposed pilot, demonstration and research projects in the context of P management, PRR and NRR in Canada. Some of these initiatives are focused on pillars highlighted in this report and many target specific sectors such as UNPSs of nutrients. A non-extensive overview of these projects is provided in Table 3.

Table 3. Initial projects and pilots in a Canadian NRR strategy

Pillar P Source Sector	Project Title Lead (or Potential Lead) Funding	Objectives and Key Actions
Pillar: Coordination Sectors: All	**National Nutrient Recovery Strategy and five-year budget forecast** **Funding:** budget needs to be developed in coordination with strategy to inform funding sources	**Objectives:** Establish a working group to develop a strategy for a national nutrient recovery platform potentially based on regional hubs across Canada **Action:** Create a five-year plan and supporting budget to ensure development and sustainability of this initiative (like ESPP)
Pillar: Coordination Sectors: All	**User-driven Lake Erie or Lake Simcoe pilot, Ontario** **Lead:** TBD **Funding**: TBD	**Objectives:** To determine the scope of a regionally or watershed-based NRR platform that will focus primarily on PRR. Funding opportunities need to be identified first.
Pillar: Technology Sector: Urban, point source	**Lake Erie coordinated research project, Ontario** **Lead**: Ostara, ECCC, Region of Waterloo **Funding**: ECCC	**Objectives:** To reduce known sources of P loading to the Grand River watershed. **Actions**: The pilot will recover P from a wastewater treatment plant in the Region of Waterloo and will convert it to a slow-release fertilizer, to reduce P application and P loss from the farm. Monitoring will be conducted to assess performance and information will be used to engage other municipalities and farmers in the Lake Erie basin to promote broader uptake.

Pillar: Technology Sector: rural, nonpoint source	**Infrastructure support for the use of organic soil amendments with Ontario Pork Producers, Ontario** **Lead**: OMAFRA?; AAFC (Harrow Research and Development Centre , ON Pork Producers **Funding**: AAFC can be approached for funding support through AgriInnovate Program AgriScience Program Clusters, etc.	**Objectives**: To demonstrate a neighbourhood nutrient management effort to distribute nutrients from an area with high manure production to an area that is nutrient-deficit for agriculture. **Actions**: AAFC Harrow RDC has been conducting research on various forms of manure and compost vs. soil fertility, crop productivity and water quality. There are good opportunities to implement the neighbourhood nutrient management strategy through working with OMAFRA, ECCC and/or MOECC. In addition to Ontario Pork Producers and maybe OMAFRA, neighbourhood nutrient management plan to be developed cooperatively with livestock and cash crop farms. Ideally a third-party nutrient management or 4R consultant would complete the paperwork, with maps, crop rotation schedules, manure analyses and soil tests from cooperating farms.
Pillar: Technology Sectors: Urban and rural, nonpoint source	**Floating treatment wetlands for storm water treatment, Manitoba** **Lead**: IISD **Funding**: Various	**Objectives**: To demonstrate a successful and efficient means of water quality treatment for urban, rural and agricultural runoff. **Actions**: IISD has ongoing FTW research, two pilot-scale FTW deployments and has proposed a large-scale deployment of FTWs in old residential stormwater ponds across the City of Winnipeg to verify potential for water treatment. An FTW pilot can further explore biomass harvesting for PRR.
Pillars: Awareness, Coordination Sectors: All	**Strategic fertilizer supply/ demand, Ontario** **Lead**: **Funding**:	**Objectives**: To engage federal and provincial departments to examine the Canadian supply/demand issue in further detail. **Actions**: The project will engage key federal and provincial departments (including AAFC, ECCC, Statistics Canada and OMAFRA) to understand nutrient supply/demand issues in some detail. This study will also attempt to map out roles and responsibilities in the context of nutrient cycling and management. This project outlines key questions in relation to Ontario ministries responsible for job creation, economic development, environment and agriculture.
Pillars: Coordination, Technology	**Waste circular economy initiative** **Lead**: Céline Vaneeckhaute **Funding**: NSERC	

Pillar: Technology Sector: Urban, point source	**Effectiveness of struvite as a component of high-quality garden fertilizer** **Lead**: **Funding**:	
Pillars: Awareness, Coordination Sectors: All	**Phosphorus Hub** **Lead:** Jessica Ross **Funding:**	The Phosphorus Hub is managed by Dr. Sidney Omelon's Phosphorus Lab at McGill University. It creates a platform to connect with other groups and individuals who care about feeding the world while protecting the environment.
Pillar: Technology Sectors: rural, nonpoint source	**Constructed vertical wetlands** **Lead:** Environmental Science and Environmental Engineering, University of Guelph **Funding:**	**Objective:** To assess design options for a constructed wetland with a small footprint, incorporating technology and designs developed for living walls. **Actions:** Two reports have been completed on this constructed vertical wetland. The first report reviewed existing living wall technologies that could be compatible with a constructed wetland (Beasley, Liu, Maahs, MacRae, & Robinson, 2018). This report includes a recommended design option. The second report is an engineering assessment of the potential performance of this design at a specific location in the Lower Thames River Watershed. The analysis is based on modelling studies, not an actual prototype (Fischer, Patterson, Mantha, & MacMillan, 2018).
Pillar: Awareness, Coordination Sectors: All	**Communicating the value of P and PRR** **Lead:** Environmental Science, University of Guelph **Funding:**	**Objective:** To highlight the value of P, particularly in Ontario, the benefits of PRR and a strategy for increasing awareness about PRR and the available technologies. **Actions:** Describe the benefits of P and the benefits of PRR. Identify the potential audiences and clear messaging for these audiences on the value of P, PRR and linked policies such as the circular economy. Recommend a strategy to increase the effectiveness of the message in Ontario based on the social context of innovation adoption.

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APPENDIX 1: NNRR FORUM AGENDA

National Nutrient Reuse and Recovery Forum
Hosted by the International Institute for Sustainable Development
in partnership with ECCC and MOECC
Ontario Investment and Trade Centre, 250 Yonge Street, 35th Floor,
Thursday March 8, 2018

Registration – 8:30 am – Coffee Continental Breakfast

Welcome - Setting the stage 8:50 am - Dr Hank Venema, introductions

- MOECC – Tom Kaszas
- Lake Erie Action Plan – Madhu Malhotra/ Sandy George
- Ontario Environmental Commissioners Office – Ellen Schwartzel
- Sustainable Phosphorus Alliance – Dr. James Esler

Canadian Context, Nutrient Initiatives and Opportunities

Keynote Speaker: Dr. Don Mavinic, UBC

- Global, national and provincial perspectives through examples
- Fraser Valley dairy issues (e.g. leading recovery work from dairy cows, P recovery, energy and GHG factors)

Dr. Céline Vaneeckhaute, Laval University

- Leading nutrient recovery workshops/pilot projects in Quebec

Chris Thornton, European Sustainability Phosphorus Platform (ESPP)

- How the EU platform operates and key current projects to inspire us

Bio Break – 10:30 am – 10:45 am

Kathleen McTavish & Ryan Carlow, UofGuelph, Phil Dick, OMAFRA

- Identifying the status of P flows in Ontario
- Life-cycle temperature and nutrients

Dr Richard Grosshans, IISD

- P recovery from cattails, Lake Winnipeg Bioeconomy Project
- Manitoba livestock and phosphorus issues

PANEL DISCUSSION - 11:20 am – 12:00 pm

LUNCH 12:00 pm – 12:50 pm

Agricultural Perspectives: Rural and Urban; Technologies; Economic Instruments

TIequan Zhang, Ag Canada

- Agricultural hotspots in Canada

- Six in Ontario, two in Lake Erie Basin (description) and implications

Keith Reid, AAFC, & Christine Brown, OMAFRA

- Opportunities and challenges for agriculture's contribution to the circular nutrient economy
  - On-farm reuse of nutrients

Everglades Foundation

- George Barley Water Prize – top 10 technology teams compete for $10M grand prize in removing and recovering P from fresh water
- Holland Marsh Ontario cold temperature test site

Mike Dougherty, Lystek

- Circular economy success story drivers? Future issues and opportunities
- A commercialized treatment technology, biosolids/non-hazardous wastes

Bio Break – 2:05 – 2:20

Brandon Moffat, StormFisher Environmental Ltd.

- On and off-farm anaerobic digesters and digestate reuse
- What prompted invention? Future issues and opportunities

Rachel Lee, Ostara

- Recovery opportunities from urban and rural wastewater sources
- How Ostara evaluates business opportunities? Drivers? Future

Theresa MacIntyre-Morris & Ann Huber, York Region/SRG

- SRG (Treated wastewater application to sod farms), 2-year pilot
- Greenhouse Nutrient Feedwater, 4-year pilot

Mike Walters, LSRCA–LSPOP

- Lake Simcoe Region Conservation Authority to present on the pending Lake Simcoe Phosphorus Offsetting Program for Stormwater Works

GROUP DISCUSSION – 3:20 pm – 4:30 pm

Everglades Foundation Technology Competitors Tradeshow Event

Post-Forum Networking Event with Wine and Cheese Reception Hosted by the Everglades Foundation until 5:45 pm

APPENDIX 2: LIST OF FORUM PARTICIPANTS

No.	Last name	First name	Affiliation
1	Ahmed	Ramsha	MECP
2	Amiri	Andrew	Econse
3	Anderson	Barbara	Aquawaters & Associates
4	Balpataky	Katherine	Water Canada
5	Bass	Brad	AG Canada
6	Bilyea	Robert	MECP
7	Bobbie	Thoman	Walker Environmental
8	Boh	Michael	McGill University
9	Bonte-Gelok	Shelly	MECP
10	Brandon	Moffatt	Storm Fisher
11	Brown	Christine	OMAFRA
12	Carlow	Ryan	University of Waterloo
13	Ciosek	Amanda L	Ryerson University
14	Davy	Derek	Econse
15	Deprez	Mike	Walker Environmental
16	Dick	Phil	OMAFRA
17	Dougherty	Mike	Lystec
18	Elliott	Michael	CH2MHILL Canada Limited
19	Ellis	Lara	ALUS
20	Esler	Jim	SPA
21	Fretz	Laurie	University of British Columbia
22	Goel	Pradeep	MECP
23	Grosshans	Richard	International Institute for Sustainable Development
24	Haas	Christine	Renix
25	Hellebust	Andrew	Rivercourt Engineering Inc.
26	Huber	Ann	Soil Resource Group
27	Jamaludin	Zamry	BioEngine & Anaergia Inc
28	Johnston	Trish	WaterTap
29	Kanji	Rahim	SOWC
30	Karoubi	Shirin	MECP
31	Kaszas	Tom	MECP
32	Kerr	Nadine	City of Toronto
33	Kopansky	Mike	Miller Compost Ontario
34	Kuiper	Miriam	Wetus
35	Law	Aaron	MECP
36	Lee	Rachel	Ostara
37	Liu	Helen	University of Guelph
38	MacRae	Heather	University of Guelph
39	Malhotra	Madhu	MECP
40	Mavinic	Don	University of British Columbia
41	McCabe	Don	Soil Conservation Council of Canada
42	McMurray	Barb	MECP

43	Mctavish	Kathleen	Environment Canada
44	Meliton	Eric	TRCA
45	Mohieddin Abukhdeir	Nasser	University of Waterloo
46	Moller	Greg	University of Idaho
47	Morris	Theresa	York Region
48	Mott	Jody	Holland Marsh Growers' Association
49	Naja	Melodie	Everglades Foundation
50	Nalepa	Rachel	Environmental Commissioner of Ontario
51	Osborne	Kaitlyn	AG Canada
52	Osman	Hisham	IISD
53	Palfi	Viktoria	Global Affairs Canada
54	Palmer	Mark	Greenland Consulting Engineers
55	Pansini	Erica	University of Guelph
56	Parra	Loren	Everglades Foundation
57	Payne	Michael	Black Lake Environmental Biosolids
58	Quinton	Woods	Holland Marsh Growers Association
59	Reid	Keith	AG Canada
60	Ross	Jessica	University of Ottawa
61	Rozema	Eric	Rivercourt Engineering Inc.
62	Sandler	Michelle	MEDJCT
63	Sawyer	Derek	City of Toronto
64	Schankula	Tina	OFA
65	Schnell	Andre	MECP
66	Schumacher	Kyle	Miller Compost Ontario
67	Schwartzel	Ellen	Environmental Commissioner of Ontario
68	Skeates	Robin	MECP
69	Smith	Scott	Laurier University
70	Stammler	Katie	Conservation Ontario
71	Strain	CJ	University of Idaho
72	Ternier	Sabrina	MECP
73	Thornton	Christopher	ESPP
74	Tucker	clara	MECP
75	Tybinkowski	Mirek	MECP
76	Vaneeckhaute	Céline	Laval University
77	Venema	Hank	IISD
78	Walters	Mike	LSRCA
79	Xiang	Gao	ZeroPhos
80	Yasmin	Glanville	RSI
81	Zhang	Tiequan	AG Canada

APPENDIX 3: PANEL QUESTIONS AND DISCUSSION GROUPS

Morning Discussion Panel

Although shocks to the nutrient supply chain may be decades away, we understand that behavioural and infrastructure changes take that long.

Therefore, what key actions need to be put in place now to prepare proactively for the onset of insecurity in the crop nutrient supply?

KEY ACTIONS:

A) Need for Information and recognition of the value of a circular nutrient economy (P/N) and the recognition of other high-value products.

Key geographic areas of both nutrient oversupply and soil saturation and nutrient-deficient areas in Canada. Urban opportunities for reuse/recovery. Biosolids, rural linkages and challenges.

Panel Question:

i) What are the three key information gaps (not including technologies) that could further nutrient reuse/recovery opportunities in Canada?
ii) How significant are urban nutrient loads (e.g., stormwater management, wastewater treatment) and what opportunities are there for urban capture, reuse/recovery?

B) Support for coordination of strategic actions – e.g., research (funding, pilot projects), identification of process, supply/demand issues, logistical issues (e.g., transportation).

Panel Question

i) What are three things we need to put in place to support coordination of research, technology development, transportation costs and long-term fertilizer supply for nutrient (P/N) reuse and recovery?

C) Support for Canadian recovery/reuse technology solutions – applied (concept to market).

Panel Question:

i) What is needed to support the development and adoption of new recovery technologies?

ii) What are the key barriers/opportunities to the development of new recovery technologies in Canada?

D) Support for economic and market instruments and financial incentives (e.g., P offsetting/water quality trading, subsidies, greenhouse gas (GHG) credits, percentage required for recycled, nutrient content, area-wide/cumulative nutrient management plan strategy, etc.)

Panel Question;

i) Do we need some standardized cost/externality analysis of P equivalent to carbon dioxide? For example, the influential social cost of carbon work led by the U.S. Department of Energy and adapted by ECCC for the purposes of setting carbon dioxide taxation levels.
ii) Should the P marginal abatement cost curve be constructed for various recycling technologies, similar to highly influential work on GHG mitigation cost curves done by the McKinsey & Company consulting group?
iii) What are the top existing and potential market instruments and or economic incentives to further P recovery?

Afternoon Round Table Discussion

A) Need for information and recognition of the value of a circular nutrient economy (P/N) and the recognition of other high-value products within the context of a Coordinated Strategy**.**

i) What are additional information gaps from the morning?
ii) Do the nutrient materials from the urban sources and current technologies fit the needs and wants of the farm community?
iii) What is the feasibility of recovering P from agriculture nonpoint source runoff in terms of available technology and the economics of recovery from the farm?
iv) Who are the specific key people/organizations you would choose for a working group to look at the information gaps?
v) Name three actions you would use to convince the rural community and urbanites of the value of manure biosolids, recycled materials?

B) Support for coordination of strategic actions – e.g., research (funding, pilot projects), logistical issues (e.g., transportation from source to market), and identification of process, supply and nutrient (e.g., P) demand issues

Research and Linkages to Technology Development

i) What are your top three priority areas of targeted research and the rationale?
ii) What are the key organizations/universities who you would choose to be part of a working group to coordinate research and discuss future priorities?

iii) What are the best options for funding? (e.g., Growing Forward? Food For Thought?, NSERC? Other? Longer-term government funding – COA?)
iv) Key pilot projects and linkages to technology development

Logistical Issues (e.g., Transportation)

v) What are the most effective and economical options for overcoming the challenge of moving bulky materials with low nutrient density (e.g., manure, biosolids) from generating locations to potential beneficial end use (e.g., processing, pipelines, composting, local trading)?
vi) What are the barriers to these options, and how might they be overcome?
vii) What are the key organizations you would chose to be part of a working group on this topic? Are their specific areas to consider pilot projects?

Process and Demand/Supply Issues
viii) Who would lead/collaborate in the development of a Canadian Fertilizer Strategy?

C) Support for a coordinated Canadian recovery/reuse technology solution strategy – applied (from concept to market).
i) What are the key adaptive technologies to address nutrient loading in Lake Ontario, Lake Erie and inland lakes/waterbodies?
ii) What are the key drivers, challenges and opportunities to development of new technologies?
iii) Are technologies adaptable between urban and rural situations (e.g., SWM, WWTP, hog, cattle, poultry)?
iv) Who would you engage in a working group going forward?

D) Support for identification and coordination of economic and market instruments and financial incentives (e.g., P offsetting/water quality trading, subsidies, GHG credits, percentage of recycled nutrient requirement, area-wide/cumulative multiple farm nutrient management plan strategy, etc.)?

i) What further tool development is needed for: 1) P offsetting 2) GHG tools to further support nutrient recovery?
ii) What are the key principles for a P trading system that will ensure that P emission reductions can be audited?
iii) What subsidies or tax incentives would support the use of recycled nutrients and co-products by farmers? Encourage the urban recovery of nutrients?
iv) Is recycled P tonnage the correct proxy indicator for circular economy function, or should it be some aggregate of P, N and C (like the way the human development index is based on life expectancy, income and literacy)? What is/are your top existing or potential market instrument(s) and/or economic incentives to further P recovery?
v) Who would we include in a working group to further develop these tools and outline the key items that they should address?
vi) What are core policy factors for developing the circular economy as a cleantech investment space?

APPENDIX 4: NNRR FORUM AFTERNOON ROUND TABLE DISCUSSION SUMMARY

Method: The participants from industry, academia, government and non-government organizations were divided into Working Group Tables to answer four main question groups. Several questions benefited from two tables addressing these questions. This appendix summarizes these discussions.

A) Need for information and recognition of the value of a circular nutrient economy (P/N) and the recognition of other high-value products within the context of a coordinated strategy

- Gaps in public understanding of the issue (scarcity, industrial value, waste value), policy integration between ministries, urban/rural, holistic approach, positive regulations, user-driven technologies, P transport.
- Need for a comprehensive user-friendly communication/education strategy required for circular economy, P recovery, for all sectors to recognize value (e.g., Lystek case study), politicians, inter-sector meetings, field trips. Linkages to N, C and food security, water protection, energy.
- A farmer-centric pilot that will address farmers' soil amendment needs from their perspective to include (but not limited to) quality, logistics, coordination between producer and farmers.

B) Support for strategic coordination – e.g., research (funding, pilot projects), logistical issues (transportation from source to market) and identification of process, supply and nutrient (e.g., P) demand issues

Research Coordination

- Need for cohesive, long-term network and goals across all resource streams of P reuse/recovery.
- Top targeted research areas: holistic decision-making tools, legacy P tracking, economic assessment/business plan, coordination between source and sink, more coordination between Agriculture Canada and ECCC.
- Coordination – overarching long-term objectives needed for Canadian nutrient platform. Local research hubs to tackle locally specific issues (e.g., P flows, temperature/flow cycles). User-driven research. Involve key universities (including but not limited to Laval, McGill, University of Manitoba, University of Calgary, University of British Columbia), AAFC research centres, farm associations, municipalities, provincial/federal governments, conservation authorities, the fertilizer industry and Global Water Futures.
- Future pilots could include local research hubs, extension of Barley Prize.
- Funding opportunities: NSERC Research Chairs, (recovery and industrial) AAFC industry, Canadian Agricultural Partnerships, municipality/university partnerships.

Logistical Issues (e.g., Transportation)

Challenges of moving bulky materials with low nutrient density (e.g., manure, biosolids).

- Disconnect – Products produced not necessarily what farmers want; need economically transportable products usable by farmers.
- Working group needs to include soil experts in building healthy soil from the farmer's perspective.
- Suggest infield/edge of farm and municipal drain technology funding for demo in Thames River.
- Identify opportunities to establish pipelines for liquid waste to processing plant—a more decentralized approach; add nutrients at the source to make the blend worth transporting; compost low-value biosolid waste (regulatory barrier).
- Promote research to look at other values within the waste stream.
- Establish a common language.
- Engage broader stakeholder base.
- Pilot project (blending, transportation, carbon credits, cost/benefit): existing digestors producing low-nutrient, low-density materials to be blended with organics to increase the value.
- Need to quantify the carbon credits methodology/protocol for organic amendments. Key organizations for working group – Ontario Ministry of Agriculture Food and Rural Affairs, Ontario Soil and Crop Improvement Association (OSCIA), Ontario Professional Contractors, Ontario Federation of Agriculture, Water Environment Association of Ontario, AAFC, Ministry of the Environment and Climate Change (MOECC), Ministry of Natural Resources and Forestry (MNRF), Canadian Food Inspection Agency, CAs, data experts.

C) Support for a coordinated Canadian recovery/reuse technology solution strategy – applied (from concept to market)

- Key adaptive technologies to address nutrient loading—one size does not fit all. Solutions include but not limited to Ostara current technology, bioreactors, beneficial management practices, 4R systems. Technologies being examined in George Barley Water Prize. Barriers include: uncertainty, risk, scalability, funding, side effects, perception issues, development of markets storage and transport
- Need demonstrations, centres of excellence, communication coordination, and collaboration between rural and urban.
- Key is to engage users early; wastewater should not be a last thought; waste as wealth.
- E.g., the Netherlands has sector tables on innovation agenda to coordinate between government, industry and research. Cost-sharing models, managing risk and sharing access to risk. Pilot to demo this in Canada/Ontario needed.
- End of waste legislation; write regulations in a positive manner. Need representatives from waste sectors to be part of working group moving forward.

D) Support for identification and coordination of economic and market instruments and financial incentives (e.g., P offsetting/water quality trading, subsidies, GHG credits, percentage of recycled nutrient

requirement, area-wide/cumulative multiple farm nutrient management plan/strategy, etc.)

- Need understanding of P offsets/trades and specifics such as trade ratios to meet challenge of cost-effective nutrient reuse and recovery (e.g., retrofitting storm water ponds not as effective as other options).
- Scenario framework needed for implementation (e.g., LID, stormwater ponds, hydraulic considerations); nonpoint source (e.g., using biomass to quantify amount of P).
- Subsidies could include carbon credits for local sustainable soil amendments or tax credits.
- Fertilizer company required to have certain percentage of nutrient recyclable /recycled products. Could get carbon credits.

APPENDIX 5: PREVIOUS EVENTS AND WORKSHOPS ON PRR IN CANADA

Ryerson, 2014: A workshop on P as a resource held at Ryerson University in 2014 (Trudeau, 2014) brought together nearly 150 participants and included talks by 15 Canadian and international experts and three breakout groups engaging participants in challenges, opportunities, potential partnerships and actions related to P recovery and reuse (PRR). An initial action plan for engagement was created based on elements identified at the workshop. This action plan was organized around four main pillars: (i) the need to recognize P as a resource; (ii) a lack of coordination for governance, technology and research around PRR; (iii) a need for supportive market mechanisms; and (iv) a need to link PRR to broader nutrient–energy–water security issues.

Canadian Council of Ministers of the Environment, 2012: A Canada-wide approach for the management of wastewater biosolids provided a policy statement "promoting the beneficial use of valuable resources such as nutrients, organic matter and energy contained within municipal biosolids, municipal sludge and treated septage. Beneficial uses should be based on sound management principles that include: consideration of resource value, strategies to minimize environmental and human health risks; strategies to minimize GHG emissions, and adherence to standards regulations or guidelines. Specific principles addressed the need to recover or recycle valuable nutrients from municipal biosolids, sludge and treated septage" (Canadian Council of Ministers of the Environment, 2012).

APPENDIX 6: GLOBAL NUTRIENT PLATFORMS

- **Nutrient Stakeholder Platform (Quebec):** Quebec has established a Nutrient Stakeholder Platform in response to the Québec Policy on Residual Materials,[12] which includes a ban on incineration of waste by 2022. The platform includes representation from government, agriculture, industry and other stakeholders to bring diverse interests together to educate stakeholders on the benefits of this policy related to the circular economy. It will focus on: establishing an increased local supply of fertilizer for food stability/security; increasing profitability through nutrient recovery and reuse (NRR); and increasing agriculture yields through highly effective nutrient products that also provide lower environmental risks. The project scope includes waste collection, waste treatment and end-product distribution.
- **Biorefine Cluster (Europe):** The Biorefine Cluster Europe[13] interconnects projects and people within the domain of bio-based resource recovery, striving to contribute to more sustainable resource management. This organization focuses on the biorefinery sector: the refinement of chemicals, materials, energy and products from bio-based waste streams. It can be subdivided into four categories: (i) bio-based waste streams as an input for the circular economy; (ii) bioprocesses; (iii) sustainable bioenergy production in its various shapes and forms; and (iv) resource recovery: extracting minerals, chemicals, water and materials from biomass. There are 26 countries, 600 people and 100 organizations involved in the network of the Biorefine Cluster.
- **European Compost Network (Europe):** The ECN is a European non-profit membership organization promoting sustainable recycling practices in composting, anaerobic digestion and other biological treatment processes of organic resources. This membership organization, with 70 members from 27 European countries, includes all European bio-waste organizations and their operating plants, research, policy-making, consultants and authorities. Via the member organizations, ECN represents more than 3,000 experts and plant operators with more than 30 million tonnes of biological waste treatment capacity. The network works with practitioners, researchers, technicians and policy-makers to deliver integrated organic waste recycling solutions to generate high-quality products for the benefit of the environment and the users of the recycled products.
- **Nutrient Platform (Netherlands):** The Nutrient Platform (NP),[14] founded in 2011, is a cross-sector network of Dutch organizations that are concerned about the global impact of the phosphate problem and the way in which nutrients are generally managed. Together with the Dutch government, the Nutrient Platform takes the responsibility to support organizations through the entire value chain to close the phosphate cycle. It builds on the

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[12] For more on this policy, see: http://www.environnement.gouv.qc.ca/matieres/pgmr/index_en.htm
[13] For more on the Biorefine Cluster, see: https://www.biorefine.eu/about
[14] For more on the Netherlands' Nutrient Platform, see: https://www.nutrientplatform.org/over-nutrient-platform/

special position that the Netherlands has, with its nutrient surplus, and uses a "learning by doing" approach. Due to a greater awareness of the need for NRR, the platform enables opportunities to apply knowledge and solutions in the Netherlands and internationally. Members have an important voice in determining activities and strategic decisions and the secretariat helps to implement the agreed action plan, facilitates communication between the members and coordinates the external communication. It is hosted by the Netherlands Water Partnership.

Benefits of NP membership include: participation in member meetings and other network events; access to contacts of the NP network; enhanced opportunities for projects; private newsletter with information, especially for NP members; direct access to government ministries with regard to law and regulation; influence on laws and regulations at the European level; access to information about financing and subsidy opportunities; branding on the NP website, newsletter, social media and iPad app; The Phosphorus Challenge; free use of NP logo and exclusive communication material from the international media campaign; and simplified access to the international nutrient market.

- **The Agricultural European Innovation Partnership (Europe):** The European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI)[15] works to foster competitive and sustainable farming and forestry that "achieves more and better from less." It contributes to ensuring a steady supply of food, feed and biomaterials, developing its work in harmony with the essential natural resources on which farming depends. The EIP-AGRI was launched in 2012 to contribute to the EU's Europe 2020 Strategy[16] for smart, sustainable and inclusive growth. This strategy sets the strengthening of research and innovation as one of its five main objectives and supports a new interactive approach to innovation. The EIP-AGRI pools funding streams to boost interactive innovation. Different types of available funding sources help get an agricultural innovation project started, such as the European Rural Development Policy[17] or the EU's research and innovation program Horizon 2020.[18] The EIP-AGRI contributes to integrating different funding streams so that they contribute to the same goal and mutually support results. It brings together innovation partners (farmers, advisers, researchers, businesses, non-governmental organizations and others) at the EU level and within the rural development programs in an EU-wide EIP network.

[15] For more on the EIP-AGRI, see: https://ec.europa.eu/eip/agriculture/en/about
[16] For more on the Europe 2020 Strategy, see: https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy-coordination/eu-economic-governance-monitoring-prevention-correction/european-semester/framework/europe-2020-strategy_en
[17] For more on the European Rural Development Agency, see: https://enrd.ec.europa.eu/policy-in-action/policy-framework_en
[18] Horizon 2020: https://ec.europa.eu/programmes/horizon2020/what-horizon-2020

Through the EIP-AGRI's interactive website, users can share innovative project ideas and practices, and information about research and innovation projects, including projects' results, by filling in the available e-forms. Various EIP-AGRI-related publications are available for download on the website, providing visitors with information on a wide range of topics. Future functionalities are planned for Operational Groups and European fund-managing authorities once the programs start. The EIP-AGRI website will aim to become a one-stop-shop for agricultural innovation in Europe and its EIP-AGRI Service Point offers a wide range of tools and services, which can help promote ideas and projects.[19] It also facilitates networking activities, enhancing communication, knowledge sharing and exchange through conferences, focus groups, workshops, seminars and publications.

- **Sustainable Phosphorus Platform e-Discussion Group (Global):** The Sustainable Phosphorus Platform e-Discussion Group is a Google Group open to anyone who wishes to join in on discussions related to P sustainability.[20] Initiator: European Sustainable Phosphorus Platform, managed by Arno Rosemarin/SEI with the North American Partnership for Phosphorus Sustainability & Global Phosphorus Research Initiative.
- **Flanders Nutrient Platform/Flanders Water Knowledge Centre (Belgium)**: The Flanders Nutrient Platform/Water Knowledge Centre[21] connects entrepreneurs, governments and researchers, and supports the acquisition and management of knowledge, promotes collaboration between all actors and stimulates the exchange of experience and knowledge for nutrient management. In addition, they collect and channel the needs of business owners, answering their questions or connecting them with product providers. The Flanders Water Knowledge Center is an independent division within VITO, a leading European independent research and technology organization in the areas of clean technology and sustainable development, addressing solutions for large societal challenges. The platform addresses nutrients available in manure, organic biowaste, wastewater sludge, etc., working to close the nutrient value chain.
- **The German Phosphorus Platform (Germany):** The objective of the German Phosphorus Platform (DPP)[22] is to bring together the knowledge and experience of participants from relevant industries, public and private organizations, and research and development facilities, with the objective of achieving the sustainable use of phosphorus. P usage management has been developed with combined efficiency, recycling and substitution

[19] EIP-AGRI Service Point: https://ec.europa.eu/eip/agriculture/en/about/service-point-eip-agri-network
[20] Access the Google Group here: https://groups.google.com/forum/#!forum/sustainablephosphorusplatform
[21] For more information on the centre, see: https://www.vlakwa.be/en/vlakwa/what-is-vlakwa/
[22] For more on the German Phosphorus Platform, see: https://www.deutsche-phosphor-plattform.de/

strategies, while also developing and promoting the sustainable consumption of P in Germany.

- **United Nations Global Partnership on Nutrient Management (Global):** The Global Partnership on Nutrient Management (GPNM)[23] is a response to the challenge of how to reduce the amount of excess nutrients in the global environment. The GPNM reflects a need for strategic global advocacy to trigger governments and stakeholders in moving toward lower N and P inputs to human activities. It provides a platform for governments, UN agencies, scientists and the private sector to forge a common agenda, mainstreaming best practices and integrated assessments. It also provides a space where countries and other stakeholders can forge more co-operative work across the variety of international and regional agencies dealing with nutrients and assessment work.
- **Global Phosphorus Research Initiative (Europe, Australia and North America):** The Global Phosphorus Research Initiative (GPRI)[24] is a collaboration between independent research institutes in Europe, Australia and North America. The GPRI undertakes independent, interdisciplinary research on global P security for future food production. In addition to research, the GPRI also facilitates networking, dialogue and awareness-raising among policy-makers, industry, scientists and the community on the implications of global P scarcity and possible sustainable solutions. The GPRI was co-founded in early 2008.
- **International Water Association Resource Recovery Cluster (Global):** The International Water Association Resource Recovery Cluster[25] aims to bring together R&D, water industry and materials users to promote economically and environmentally attractive approaches to resource recovery. The core issues of the Resource Recovery Cluster are to innovate science, technology and business to promote the recovery of resources from the drinking and used water treatment facilities. The strategic objectives of the Resource Recovery Cluster are:
    - To promote resource recovery from water and wastewater
    - To network on innovations of resource recovery through conferences, meetings, working groups and publications
    - To promote links with complementary organizations to find ways to build value chains
- **Leibniz ScienceCampus Phosphorus Research Rostock (Germany):** The goal of the Leibniz Science Campus Phosphorus Research Rostock (LSCPRR)[26] is interdisciplinary cooperation through a thematically oriented integrated network, to explore options for

[23] Global Partnership on Nutrient Management: https://wedocs.unep.org/bitstream/handle/20.500.11822/11996/GPNMRevisedDecember2014.pdf?sequence=1&isAllowed=y
[24] For more of the initiative, see: http://phosphorusfutures.net/global-research/
[25] See the Resource Recovery Cluster: http://phosphorusfutures.net/global-research/
[26] For more on the LSCPRR, see: https://wissenschaftscampus-rostock.de/about-us/goals-concept.html

the more sustainable management of P. The **concept** enables thematically focused, interdisciplinary cooperation between Leibniz Institutes and institutions of higher learning, as an equal, complementary regional partnership. It is a network of five Leibniz Institutes and the University of Rostock (Germany). From these partners, 45 Working Groups are conducting research on P-relevant subjects. The networks organize strategic research, promote interdisciplinary topics, projects and methods, raise the visibility of the participating locations and strengthen their research profile.

- **SusPhos (Europe):** SusPhos is a European training network that conducts systematic investigation of the eco-friendly production, smart use, recycling and commercial use of processes and materials that use P in a sustainable manner. This approach is aimed at providing insights into sustainable technologies as well as creating a platform for the training of young researchers in a collaborative setting. Currently, SusPhos educates several PhD and post-doc students at the interface of synthetic chemistry, catalysis, materials science, process chemistry, industrial P chemistry and technology transfer. SusPhos combines the complementary strengths of nine academic and three industrial (Arkema, DSM & Magpie Polymers) teams to promote and enable enforced cross-fertilization of enhanced research synergies between the market and the academic world and to enable effective technology transfer.

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