NATIONAL NUTRIENT REUSE AND RECOVERY FORUM

March 8, 2018, Toronto, ON

Workshop Summary Report for Participants

IISD
International Institute for Sustainable Development

EXECUTIVE SUMMARY

PERSPECTIVES

Tom Kaszas, Director, Partnerships Branch at the Ontario Ministry of Environment and Climate Change, captured the phosphorus dilemma in his opening remarks at the National Nutrient Recovery Forum: “We are not talking about the food security risk we face due to our need to rely on imported phosphorus fertilizers in Canada.” Phosphorus recovery as a food security policy priority has not matured significantly since a 2014 workshop at Ryerson University last focused Canadian attention on the subject.

Although the principle that phosphorus has a dual characteristic as a pollutant and scarce resource is now well accepted in scientific literature, the dominant policy interest in phosphorus remains in regulating its discharge into aquatic ecosystems to reduce eutrophication. That situation is unlikely to change in the short to medium term in Canada, as phosphorus-driven eutrophication is a chronic, high-visibility environmental and political problem. Phosphorus scarcity is relatively low risk in the short term and, in the absence of evidence that *doing nothing* is costly, the issue will tend to be ignored by policy-makers. Elevating phosphorus scarcity as a priority environmental and geopolitical policy issue will motivate attention on recovery and reuse, but it will require a sophisticated strategy that leverages policy attention on climate change and lake eutrophication. The circular economy narrative will also be an important opportunity to motivate phosphorus recovery, as 30 per cent of the entire waste stream by mass is organic and contains phosphorus, much of it recoverable.

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 phosphorus removal from a freshwater ecosystem; a secondary USD 170,000 prize will be given to the team that demonstrates efficient reuse of removed phosphorus. The Barley Prize is motivated by the USD 12 billion cleanup cost of Lake Okeechobee, and greater than USD 3 trillion cleanup cost ascribed to phosphorus pollution globally: the cost of *doing nothing* in this case is clearly articulated.

Two international organizations have emerged to promote phosphorus sustainability: the European Sustainable Phosphorus Platform (ESPP), an independent non-governmental organization, and the Sustainable Phosphorus Alliance (SPA) based at Arizona State University. Both the ESPP and the SPA advocate for phosphorus recycling as biofertilizers from point sources (biosolids) and from processed manure products, and are active with research and development (R&D) projects that demonstrate the viability and co-benefits of applying recovered phosphorus to land. The ESPP has had success demonstrating that biofertilizers comply with phyto-sanitary standards and can be a European Union-certified product. The greater success for the ESPP may come if new European Union (EU) fertilizer regulations require the use of some fraction of recycled phosphorus, rather than simply permitting the use of recovered phosphorus. The phosphorus recovery agenda is generally more advanced in the EU than in North America. Although there is no accepted scarcity cost of phosphorus, phosphate rock is in on the EU list of critical raw materials that forms part of the 2018 EU Circular Economy Package. Recognizing rock phosphate as a critical scarce material will continue to drive phosphorus recovery in the EU.

KEY OPPORTUNITIES IN AGRICULTURE

Key opportunities to improve phosphorus recovery in agriculture involve investments in manure processing. Overall manure production continues to increase in Canada with livestock numbers. Manure production is also undergoing geographic intensification. Manure processing at its simplest involves separating the liquid and solid fractions of manure, applying the volatile liquid fraction safely and processing the solid fraction either on-farm or off-farm. By composting or anaerobic digestion (AD), processed manure improves soil health benefits and climate resilience and decreases the mobility of phosphorus through runoff. Increased soil organic carbon (SOC) is a key co-benefit of well-managed manure applications. Manure handling, processing and regional ("neighbourhood") manure management strategies are key R&D activities that will improve phosphorus recovery; pilot projects should focus on cost, yield comparisons with conventional fertilizers, phyto-sanitary compliance and life-cycle greenhouse gas (GHG) mitigation co-benefits. Costs should be consistently assessed as $/kg of phosphorus recovered and should also consider the value of SOC and life-cycle GHG emission reductions. The objective is a simple comparative assessment enabling policy-makers to understand the full value proposition of investing in phosphorus recycling. Until phosphorus externality costs are widely accepted, the economic rationale for improved manure management may be justified based on its carbon sequestration and GHG mitigation co-benefits.

A key R&D issue is the practical potential to process manure into a product of sufficient quality, quantity and consistency to enter the commercial fertilizer market. The potential to link on-farm and regional manure management with precision agriculture principles and methods also deserves examination through pilot projects.

KEY CANADIAN INNOVATIONS

Several Canadian companies have demonstrated world-class technological leadership in phosphorus recovery from wastewater treatment plants, including Ostara Nutrient Recovery Technologies and Lystek International Inc. Stormfisher Environmental is demonstrating phosphorus recovery from AD in plants designed to process food waste, another key resource stream within the circular economy.

Ostara cost-effectively recovers phosphorus from wastewater as struvite, a slow-release mineral fertilizer. Stormfisher Environmental has commercialized AD for food waste and dairy operations that produce a biofertilizer co-product. For both Ostara and Stormfisher, recovered phosphorus is not the key economic driver. For Ostara, the system benefit defines the business case: reduced chemical inputs, sludge handling, reduced ammonia load and Crystal Green fertilizer sales. Stormfisher markets itself as an electric utility, as 60 per cent of its revenue derives from renewable natural gas generation, which commands a climate-friendly premium in the Ontario market. Only 1 per cent of Stormfisher's revenues derive from biofertilizer sales. Lystek Inc. uses a thermos-mechanical process to extract a Canadian Food Inspection Agency-certified liquid biofertilizer from wastewater and co-products that optimize wastewater treatment plant (WWTP) performance. Demand for Lystek's fertilizer product, *Lystegro,* is strong and based on its agronomic performance.

Perhaps the most impressive feature of these Canadian companies is that they have succeeded in the absence of policies that incentivize the use of recovered phosphorus. Such policies would accelerate their growth and increase the total volume of recovered phosphorus. The AD technology demonstrated by Stormfisher is another notable Canadian success. The growth of the AD industry has relied on attractive feed-in tariffs for derived renewable natural gas. An incentive on recycled phosphorus from AD plants would accelerate what could be a billion-dollar industry in Ontario alone. The optimal location of AD plants to efficiently process food waste and manure is an important regional planning issue. Investing in a network of AD plants carries many sustainable development co-benefits, including rural job creation and GHG emission reductions.

Other important Canadian phosphorus management innovations include the Lake Simcoe phosphorus offset program and the Lake Winnipeg Bioeconomy Project, which demonstrate, respectively, the use of an economic instrument for incentivizing phosphorus interception and hydraulic interception to control non-point phosphorus runoff. Non-point phosphorus is widely understood as the dominant source of phosphorus responsible for eutrophication and harmful algal blooms (HABs). Non-point loading events are episodic and coincide with high precipitation events projected to become more frequent with climate change. The Lake Winnipeg Bioeconomy Project has won national and international awards for demonstrating that non-point phosphorus interception and recovery using phyto-remediation and biomass harvesting is feasible and low cost.

A major Canadian innovation opportunity lies in recognizing that a complete phosphorus recovery solution requires non-point interception methods; essentially, Canada could promote a watershed-based multi-barrier approach that encourages recycled biofertilizers, precision application and the hydraulic interception of residual runoff phosphorus. The multi-barrier approach would also leverage highly innovative circular economy systems (BioEngine) research at Laval University. Such a portfolio of policies, practices, technology and system optimization defines a new cleantech space where Canada could assert leadership.

The danger in not prioritizing non-point phosphorus is technical and political. Non-point phosphorus is the largest unmanaged flow of phosphorus to the environment and a key resource stream. If this phosphorus flow is neglected and HABs persist, and indeed become more frequent with climate change impacts, the R&D invested in upstream technologies and pilot projects may be perceived as misspent.

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ACRONYMS AND ABBREVIATIONS

AAFC	Agriculture and Agri-Food Canada
AD	anaerobic digestion
CFIA	Canadian Food Inspection Agency
ECCC	Environment and Climate Change Canada
ESPP	European Sustainable Phosphorus Platform
EU	European Union
GHG	greenhouse gas
HAB	harmful algal bloom
IISD	International Institute for Sustainable Development
LID	low-impact development
LSPOP	Lake Simcoe Phosphorus Offset Program
MOECC	Ontario Ministry of the Environment and Climate Change
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
R&D	research and development
SCC	social cost of carbon
SOC	soil organic carbon
SPA	Sustainable Phosphorus Alliance
UBC	University of British Columbia
WRRP	Water Resource Recovery Plants
WWTP	Wastewater treatment plant

1 OVERVIEW

On March 8, 2018, the International Institute for Sustainable Development (IISD) hosted the National Nutrient Reuse and Recovery Forum in partnership with Environment and Climate Change Canada (ECCC) and the Ontario Ministry of the Environment and Climate Change (MOECC).

The workshop featured speakers from MOECC to set the policy context as well as eminent Canadian academics, leading practitioners from Europe and the United States, research scientist from government and academia, and representatives from private sector technology companies involved in nutrient recycling. Although the workshop title referred to nutrients, most presentations focused specifically on phosphorus recovery. Ontario's circular economy legislation and the new Lake Erie Action Plan presented by MOECC provided regional context for reviving interest in phosphorus recovery. The key reasons for the phosphorus focus were reiterated by the MOECC representatives and the keynote speaker, Don Mavinic:

- Phosphorus is a scarce and strategic resource critical to world food security, and the long-term security of phosphorus supply is uncertain.
- Phosphorus is a deleterious substance when present in excess amounts, and the key nutrient responsible for aquatic ecosystem eutrophication. The Western Basin of Lake Erie is a compelling regional example.
- Phosphorus is physically conserved and can be recycled infinitely. Unlike nitrogen, phosphorus does not have an atmospheric sink; therefore, it can be traced and accounted for in terrestrial ecosystems using mass-balance methods. Phosphorus applied as an agricultural fertilizer (its key input to the economy) will be found in agricultural soils, plant biomass, food products, human and animal waste streams, by-products of wastewater processing, in landfills (sequestered in organic wastes or sewage sludge), or in the sediments (both land and airborne) and in the water column of lakes and rivers in dissolved or particulate form.

The presence of excess phosphorus in aquatic ecosystems is the most damaging end point, as unmanaged inputs to lakes and rivers create two negative externalities: the loss of phosphorus as a strategic resource for food production and the input of a pollutant responsible for aquatic ecosystem eutrophication. From a sustainable development perspective, the oversupply of phosphorus to aquatic ecosystems represents three market failures: (i) the uncertain and disputed monopoly of virtually all of the world's supply of commercial phosphorus, (ii) the omission of its scarcity value as a critical input to world food security and (iii) its environmental externality cost as a eutrophying pollutant.

Progressive jurisdictions such as Ontario have identified phosphorus impacts on lakes, particularly Lake Erie, since the 1970s and have focused on point source phosphorus removal from primarily wastewater treatment plants and household detergents. Non-point sources of phosphorus—primarily from exposed land surfaces (both urban and agricultural lands)—are a major phosphorus management challenge and now the dominant phosphorus loading mechanism for major Canadian lakes such as Erie and Winnipeg, which creates another technically challenging set of nutrient management problems.

Canadian research led by the University of British Columbia (UBC) and now commercialized by Ostara Nutrient Recovery Inc. demonstrates that phosphorus recycling is technically viable and that markets exist for the recovered product, demonstrating that "closing the loop" is possible. The fundamental intent of the workshop was to take stock of technology and policy best practices, and to develop a Canadian strategy for optimizing phosphorus management with a focus on nutrient (primarily phosphorus) recovery and reuse.

2 BACKGROUND

The March 8, 2018 workshop reprises earlier efforts to advance nutrient recycling as a policy priority, beginning with a 2012 webinar sponsored by the Canadian Council of Ministers of the Environment Nutrient Team on Nutrient Recovery. A June 19, 2014 workshop at Ryerson University entitled Phosphorus as a Resource: Sustainable Solutions for Infrastructure, Food Security and the Environment identified the following key barriers to advancing coordinated phosphorus management in Canada and North America:

- A lack of knowledge of the need to recognize phosphorus as a resource.
- Lack of coordination for governance, technology and research focused on phosphorus recovery/reuse.
- The absence of market-based instruments.
- Phosphorus recovery/reuse linkage to the broader nutrient/energy/water nexus.

A Canadian Phosphorus Platform, comparable to the European Sustainable Phosphorus Platform (ESPP) did not emerge from the 2014 Workshop, nor did clear Canadian institutional leadership on this file. However, significant progress has been made in Canada and internationally, which should be assessed to rejuvenate interest in asserting Canadian leadership in this field and build on a legacy of Canadian research excellence, including:

- Definitive limnological evidence that phosphorus controls freshwater eutrophication, based on pioneering whole-ecosystem research in the early 1970s at Lake 227 in the Experimental Lakes Area (ELA) located in northwestern Ontario. ELA was operated by the Canadian Department of Fisheries and Oceans from 1968 to 2013, at which time it was transferred to the Winnipeg-based IISD.
- The emergence of cleantech firm Ostara Nutrient Recovery Technologies Inc. from the UBC Department of Civil Engineering; the first to commercialize phosphorus recycling.

3 WORKSHOP OBJECTIVES

The objectives of the 2018 National Nutrient Reuse and Recovery Forum were to:

- Increase awareness of Canadian and international nutrient reuse and recovery efforts.
- Broaden the reuse/recovery industry and government research partnerships.
- Identify ways to implement 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 nutrient reuse and recovery.

The workshop objectives were largely met, though the key challenges noted in the 2014 workshop prominently re-surfaced, however, with more clarity on how they could be addressed.

4 MORNING PRESENTATIONS

James Elser, Director of the Sustainable Phosphorus Alliance (SPA) discussed SPA's mandate, "to catalyze the implementation of technical, organizational, and institutional innovations to advance phosphorus sustainability in North America." Dr. Elser introduced SPA and its members and described its key functions: facilitating networking among players across the phosphorus value chain, hosting an annual conference (Phosphorus Forum), various outreach activities including technical webinars and newsletters, managing working groups (including on biosolids and manure management), contributing policy-relevant technical research, and representing North American interests in international networks including the European Sustainable Phosphorus Platform (ESPP). Dr. Elser also presented SPA-associated research, including:

- U.S. phosphorus flow mapping work.[1]
- Soil-test phosphorus results for North America from the International Plant Nutrition Institute, showing that, for Ontario and the U.S. Great Lakes riparian states, the majority of soil phosphorus test are above critical levels, indicating a surplus.
- Continental U.S. phosphorus imbalance mapping.[2]

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[1] Suh, S. & Yee, S. (2011). Phosphorus use-efficiency of agriculture and food system in the US. *Chemosphere*, *84*(6), 806–813.
[2] Jarvie, H. P., Sharpley, A. N., Flaten, D., Kleinman, P. J., Jenkins, A., & Simmons, T. (2015). The pivotal role of phosphorus in a resilient water–energy–food security nexus. *Journal of Environmental Quality*, *44*(4), 1049–1062. doi:10.2134/jeq2015.01.0030

Jarvie et al. (2015) also includes this key information regarding the non-point phosphorus loading mechanisms responsible for Lake Erie eutrophication, exacerbated by a climate change impact—the increase in the intensity and frequency of storm events:

> Over the last decade, the re-eutrophication of Lake Erie has been directly linked to increasing fluxes of dissolved P from the major tributaries including the Maumee and Sandusky Rivers (Michalak et al., 2013; Baker et al., 2014; Kane et al., 2014; Scavia et al., 2014; Smith et al., 2015b). Between the early 1980s and mid-1990s, land in these watersheds was converted to no-tillage to reduce soil erosion and P losses. Initially, no-till was highly effective in decreasing total P losses (Baker and Richards, 2002; Richards et al., 2009). However, river dissolved P fluxes started to rise in the early 2000s and have risen steadily since then, increasing the magnitude and frequency of nuisance and harmful algal blooms in Lake Erie (Baker et al., 2014; Kane et al., 2014; Scavia et al., 2014). As noted above, the effectiveness of no-till and the risks of dissolved P losses are often highly dependent on other land management practices. During this time, other drivers came into play: biofuel mandates increased demand for corn and soybean production, raising commodity prices. Higher prices encouraged farmers to install subsurface tile drains to improve yields. Tile drains increased hydrological connectivity, contributing source areas, and dissolved P flux transmission to the rivers (Richards et al., 2009; Smith et al., 2015a, 2015b). The rising dissolved P fluxes therefore likely reflect a combination of well-intended watershed management practices designed to improve water quality and secure farm profitability but that were poorly coordinated, probably exacerbated by an increase in the intensity and frequency of storm events (Sharpley et al., 2012).[3]

Keynote speaker **Don Mavinic, recently retired from UBC,** emphasized our vulnerability to phosphorus supply interruption, with virtually all of the world's rock phosphate supply originating outside of Canada and mostly from the disputed area of Western Sahara. Dr. Mavinic highlighted mature technology for recycling phosphorus as struvite from WWTPs (now often referred to as Water Resource Recovery Plants [WRRPs]). Struvite is a mineralized form of phosphorus that can be used as a slow-release fertilizer with superior agronomic properties. Struvite recovery also offsets energy-intensive conventional fertilizer production and therefore generates greenhouse gas (GHG) emission credits, an example of the positive influence of climate change policy instruments in the absence of policy instruments designed specifically for nutrient recovery and a theme that recurred through several presentations.

Celine Vaneeckhaute from Laval University presented on Nutrient Recovery and Recycling in Quebec. Dr. Vaneeckhaute leads BioEngine, a research team on green process engineering and biorefineries that takes a systems-based approach to energy and nutrient recovery and recycling at a regional scale. Dr. Vaneeckhaute stressed the importance of spatio-temporal decision support systems to plan the circular economy, based on optimized biorefinery location, biorefining technology and end-product distribution. Dr. Vaneeckhaute also identified

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[3] Ibid.

the ban on organic waste incineration by 2022 as the key driver for organic waste recycling investments in Quebec, noting that Quebec City plans to produce 6.6 million m^3 of biomethane, 83 kt of solid biodigestates returned as organic fertilizer and—again noting the positive crossover with climate policy—9,500 tonnes of carbon dioxide equivalent (tCO_2e) emission offset credits annually. Quebec City will also invest in a technology to recover nitrogen from the resulting liquid digestate as concentrated ammonium sulfate.

Dr. Vaneeckhaute also presented a couple of other innovative resource-recovery projects that the BioEngine team is currently working on, such as the recovery of phosphorus for use as electrode material in lithium-ion batteries and the production of biodetergents from sewage sludge. Throughout these projects, the team applies an innovative quality-by-design approach adapted to resource recovery, combining process monitoring and advanced mathematical modelling to continuously achieve a stable and desired end-product quality given the temporal and spatial variability of the waste feedstock.

Chris Thornton, Manager of the ESPP, presented the ESPP in the context of the EU policy context in which it operates, as well as key ESPP policy and practice successes. The ESPP perspective is broad, encompassing phosphorus stewardship, global food security, the circular economy, environmental protection, and healthy diet and food safety. The ESPP is engaged in standards development, which supports emerging regulations and is also exploring the importance of organic carbon in agricultural soil amendments and practices. The ESPP functions as a member-driven boundary organization comprised of water- and waste-related industries, mineral and organic fertilizers and chemical companies, phosphorus recycling technology suppliers, national and regional governments, and research institutes. The ESPP responds to a set of mutually reinforcing and coherent EU policy signals, including the EU Water Framework Directive and rock phosphate's inclusion in both the 2014 EU list of critical raw materials and the 2015 EU Circular Economy Package, whose flagship initiative is fertilizer regulation. The ESPP claims among its successes that 54 per cent of circular economy consultation respondents cited bionutrients or phosphorus as priorities. The ESPP is heavily involved in developing EU standards to accelerate the use of recycled phosphorus in commercial organic and inorganic fertilizer products. Mr. Thornton cited many examples of commercial phosphorus recycling, including those involving Ostara's struvite production, as examples of the ESPP's success. The ESPP emphasizes "mediation rather than advocacy" enabling dialogue between stakeholders, shared policy proposal development, communication with regulators and an array of public communication products.

Kathleen McTavish and Ryan Carlow presented the results of their fourth-year capstone project in environmental sciences at the University of Guelph in 2016. Ms. McTavish and Mr. Carlow estimated the flow of phosphorus throughout the Ontario economy, developing an integrated phosphorus systems flow map. Among their key observations was that agriculture drives the major phosphorus inputs to the Ontario economy as seed, fertilizer, feed and pesticide. Ms. McTavish and Mr. Carlow also presented a wastewater and stormwater systems analysis, observing that most WRRPs do not use tertiary treatment, though it is becoming more common. Typically, 85 per cent of all suspended sediments and their adsorbed phosphorus are removed following secondary treatment, with the phosphorus rendered unrecoverable. Their agricultural systems analysis revealed that crops remove 200,000 tonnes of phosphorus annually in Ontario, with “unknown amounts lost to runoff and erosion.” Ms. McTavish and Mr. Carlow concluded that many phosphorus reuse and recycling opportunities exist throughout the phosphorus value chain.

Richard Grosshans of the International Institute for Sustainable Development (IISD) presented the Lake Winnipeg Bioeconomy Project as an example of non-point source nutrient interception and recycling based on multifunctional hydraulic interception and biomass harvesting for energy and biomaterial products. The system was developed as a response to Lake Winnipeg eutrophication, which is dominated by non-point source phosphorus loading. The multifunctional retention storage system is based on intercepting runoff events with hydraulic storage in small, relatively shallow reservoirs and then using the growth of plant biomass to sequester nutrients. *Typha spp* (common name: cattail or bulrush) demonstrates high productivity in such systems and is the species typically harvested for energy, biomaterial and nutrient recycling. The multifunctional retention storage approach can be interpreted as a climate adaptation strategy, as the dominant phosphorus loading events coincide with high-intensity rainfall events that are projected to become more frequent with climate change.

Two such systems are currently operational in the Lake Winnipeg basin: Pelly’s Lake (near Holland, MB) and North Ottawa, Minnesota (near Wahpeton, ND). Both systems use hydraulic control to de-water the reservoirs in the late summer and early fall, allowing biomass harvesting to take place with conventional agricultural equipment. Both systems show a positive habitat impact, with some evidence that songbirds and waterfowl counts in these managed systems exceed those in natural wetlands. The average harvest at Pelly’s Lake is 10 tonnes of biomass per hectare @ 1 kg P + 4 kg N per tonne of biomass. The economics of the system are highly favourable if the recovered phosphorus can be monetized, through a water quality trading credit for example. The initial market for the harvested biomass in Manitoba has been agricultural space heating driven by a ban on coal use as GHG mitigation policy. The multifunctional storage approach has several key implications, including:

- Phosphorus recycling can be bundled within a class of distributed infrastructure that has climate adaptation (water harvesting) and climate mitigation (sustainable biofuels) co-benefits.
- Phosphorus interception and recycling via biomass addresses a serious limitation within water quality trading systems with respect to the verifiability of non-point source phosphorus credits. Typically, regulated point sources within water quality trading systems have not used non-point source phosphorus credits, as these credits assume agriculturally beneficial management practices with uncertain and hard-to-verify

performance. U.S. researchers have recently proposed a nutrient assimilation credit based on biomass harvesting to provide a much more robust method for proving non-point phosphorus interception, as demonstrated in the Lake Winnipeg Bioeconomy Project.[4]

Phil Dick from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) presented a series of slides illustrating, from a watershed perspective, how the growth cycle of cyanobacteria is dependent on turbidity, temperature, location of phosphorus-enriched tributaries and timing of interception points in Lake Erie. In general, turbidity inhibits cyanobacteria filament growth, whereas temperature (e.g., two nuclear facilities' warm water discharges), timing and location of elevated phosphorus concentration/loading inputs promote initial germination and mature growth. Mr. Dick placed the overall context of his presentation within the Ontario Climate Action Plan. The presentation was to demonstrate the complexity of factors that contribute to a watershed analysis and a solution to phosphorus loading in Lake Erie, in order to understand how to address the challenges effectively, including the role of nutrient recovery.

5 PANEL DISCUSSION

A lunch panel comprising Dr. Mavinic, Dr. Vaneeckhaute and Mr. Dick addressed the following issues:

- **Information needs 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 financial incentives.

A transcript of panel discussion highlights between workshop facilitator Dr. Henry David (Hank) Venema from IISD and the panelists follows:

Venema: *The framing thoughts are: we don't know the supply shock will come, we suspect it will, but we don't know when. The main frame: given human behaviour, what are the proactive steps that we can take for the food security issue? The key questions are around information gaps. In your opinion, what are the key information gaps that can further nutrient recovery and reuse in Canada?*

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[4] Stephenson, K., & Shabman, L. (2017). Nutrient assimilation services for water quality credit trading programs: a comparative analysis with nonpoint source credits. *Coastal Management*, *45*(1), 24–43.

Mavinic: *I can think of two main things. The first gap is the importance of phosphorous and the need to repeat this message over and over: people are aware of global freshwater issues (scarcity, climate change, etc.), but people don't realize how important phosphorus is! In my opinion, you can't do business in life without both, you can't trade off one versus the other. You need to have fresh water and you need to have phosphorus. I find it challenging to educate politicians about this concept.*

The second gap is the recognition of a shortage of phosphate rock in the world: there is 70–120 years' worth of phosphate rock reserve around! However, lots of it might not be recoverable, or poor quality or not economically viable (examples: Jupiter, Florida; Peru).

Venema: *So the information gap here is: we don't understand the value of accessible recoverable recyclable phosphorus compared to the cost of low-grade raw resource.*

Vaneeckhaute (re: data issues): *The information is there, but data are spread between different stakeholders and not necessarily accessible. For example, for our nutrient portal [a decision support tool], we need data on phosphorus flows. We know different government departments and agencies have lots of data (e.g., nutrients, hotspots, etc.), but in most cases they aren't accessible. Therefore, there is absolutely a need for better coordination between governments and their departments to share the data and make them more accessible.*

Dick (re: business cases and market instruments for phosphorus technologies): *From an economic prospective, the gap is between reality and wishes. We need to work more on the business cases and market instruments of new technologies to shorten the timeline of adopting them. Consider carefully how to apply Roger's theory of the diffusion of innovations to encourage phosphorus recycling technologies and EU case studies encouraging innovation.*

Venema: *We need also to include the "scarcity value," as explained by Don [Mavinic], to have a complete business case and communicate the financial benefits of nutrient recovery to decision-makers. What are the things we need to put in place to support coordination of research technology development?*

Vaneeckhaute: *Creating sub-platforms across Canada to bring different stakeholders together to spread knowledge and facilitate coordination at the regional level and send representatives from these sub-platforms to the pan-Canadian and North American platforms. For example, in Quebec we have a smaller platform to reflect the local opportunities and challenges.*

Mavinic: *I echo Celine [Vaneeckhaute]'s point, and I disagree with Jim Elser: I think we need a platform in Canada.*

Venema: *What are the key barriers to developing new recovery technologies?*

Dick: *The risk level of the innovation side: proofing a new technology tends to have a high cost; it could be 25 per cent of the capital of the project.*

Mavinic: *I agree! The experience we had with Ostara was: "It's nice but so what?!" So we made it a private company, and we succeeded—but it wasn't easy. The problem is that recovery technologies are not as "sexy" as nano technology from an investor's point of view.*

Venema*: Do we need to target people like Bill Gates?*

Dick: *Yes. But first we do need to make the business case in a language that an accountant or CEO can understand, that would present net value and so on.*

Vaneeckhaute: *Another barrier is the development of the market: we need to raise awareness among farmers and farmers' associations as well as regulation makers.*

Mavinic: *Another barrier is the short-term thinking of decision-makers on all government levels. No one wants to do the long-term thinking, mainly because the life cycle of a politician is 3–5 years.*

Venema: *Is it possible to do an analysis similar to "social cost of carbon" to reinforce the business case of the nutrient recovery? And is that feasible?*

Dick: *I would argue against doing that before knowing what the economic opportunity is. Because you need to have the motivation to attract action by generally private sectors or perhaps the public sector that [could be] getting entrepreneurial. So, let's do the economic analysis first.*

Vaneeckhaute*: I think we do need to include it. I think we need to put it in mind when we do economic calculation. For example, indicators like sustainable return on investment do take into account social cost, environmental cost, etc.*

Intervention by Dr. Brad Bass (ECCC): *From an economic point, we do that. We do look at the total welfare. For example, we look at the impact of not acting on the total welfare of Lake Erie for about a 100-km zone from the shoreline. In some sense that $5 billion is really a social cost; it's a regional geographic social cost and not per kilogram.*

Vaneeckhaute: *Students, when they come to my class (third year – chemical engineering), they don't have any background on environmental studies or sustainability. I think this something needs to be taught at the high school level in order to have people really care about the future of the sustainability of the Earth.*

6 AFTERNOON PRESENTATIONS

Following the panel discussion and lunch, presentations resumed in the following sequence.

Tiequan Zhang, Agriculture and Agri-Food Canada (AAFC)-Harrow, presented on agricultural nutrient loading hotspots in Canada, identifying six in Ontario, two in Alberta and another two in Quebec, along with implications. Dr. Zhang provided a comprehensive overview of manure-based nutrient loading in Canada, illustrating that total manure production in Canada is approximately 150 million tonnes annually, increasing at about 500,000 tonnes per year. Despite this overall increase, according to StatsCan data, the number of watersheds in the highest nutrient loading category shows a decline between 2006 and 2011, suggesting that some overall geographical intensification may be occurring.

Dr. Zhang noted that animal manure is an important resource, containing substantial amounts of nutrients, including nitrogen, phosphorus, potassium, carbon, magnesium, iron, micro-nutrients, as well as organic carbon. Boosting SOC is increasingly regarded as a very important climate policy objective as it generates GHG mitigation, climate change resilience (adaptation) and soil health co-benefits.[5,6] Issues of manure-based phosphorus overload occur because the manure has higher concentrations of phosphorus compared to that actually needed by most crops, and producers generally apply manure to meet nitrogen requirements. Dr. Zhang cited 2002 data published in 2012 indicating that the Lake Erie riparian watersheds investigated in Canada had higher overall phosphorus loadings and higher manure-based phosphorus loading than U.S. watersheds. Eutrophication issues associated with the systematic over-application of phosphorus are exacerbated by the high bioavailability (high percentage of labile phosphorus) of some forms of manure application, particularly liquid pig, liquid dairy and solid beef. Manure composting can reduce the labile phosphorus percentage and decrease the fraction flushed downstream in dissolved or particulate form. Dr. Zhang proposed phosphorus-based beneficial management practices to increase soil production sustainability and resilience to climate change, and suggested using manures as a feedstock for fertilizer and methane production.

Keith Reid, AAFC, and Christine Brown, OMAFRA, presented on Circular Nutrient Economies – Agriculture Reality Check and discussed the realities of manure management from a producer perspective, citing high material handling costs due its bulky nature and application timing issues. Mr. Reid stressed that the simplest improved practice is separating manure solid and liquid fractions, with the solid fraction high in organic matter, organic (slow-release) nitrogen and phosphorus, and potentially exportable off-farm given its improved density. The liquid fraction is high in ammonium nitrogen (rapidly available but volatile) and potassium and

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[5] Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G. P., & Smith, P. (2016). Climate-smart soils. *Nature*, *532*(7597), 49.
[6] Minasny, B., Malone, B. P., Mcbratney, A. B., Angers, D. A., Arrouays, D., ... Winowiecki, L. (2017). Soil carbon 4 per mille. *Geoderma* 292 (2017): 59–86.

can be applied to forages (and presumably biomass crops). Liquid/solid separation equipment is relatively inexpensive, but its use creates two handling and storage issues, and the economics can be difficult to justify at a single farm level. Christine Brown stressed that the economics of manure separation would improve if both the liquid and solid fractions could be managed as a shared resource across several farms within a "neighbourhood nutrient management plan." Ms. Brown envisioned a centralized geospatial manure application planning function performed by a consultant and potentially optimized with precision agriculture techniques. An open question identified by the presenters concerned the potential for on-farm manure separation and processing to produce an end-product of sufficient quality, quantity and consistency to enter the commercial fertilizer market, an issue that applies generally to WWTPs and industrial phosphorus sources.

Melodie Naja, Chief Scientist for The Everglades Foundation, presented on the Everglades' George Barley Water Prize, which will present a USD 10 million Grand Prize to the eventual first place winner from among the top 10 technology teams currently competing in Phase 3 of 4 phases. The objective is to remove (and recover) phosphorus from fresh water, and the Phase 3 cold weather portion of the overall competition is being held at the Holland Marsh test site in Ontario.

The George Barley prize, named after the founder of the Everglades Foundation, is motivated by the very large estimated cleanup costs of Lake Okeechobee (over USD 12 billion), and of phosphorus pollution generally (over USD 3 trillion), and by the need for "innovation, creativity, and a breakthrough solution." The George Barley prize will be awarded to the team that can demonstrate the most efficient phosphorus removal, with a top-up Phoenix Prize of USD 170,000 to the team that demonstrates the most efficient by-product using the recovered phosphorus. The current round of competition is taking place at the Holland Marsh, Lake Ontario. The qualifying and currently competing teams are: Blue X green (University of Idaho, United States); ECONSE (Canada); ESSRE/RePleNish (United States); Global Phosphate Solutions (United States); GreenWater Solution (United States); Phosphex (University of Waterloo, Canada); USGS, Leetown Science Center (United States); Wetsus NaFRAd (the Netherlands) and ZeroPhos (China).

Brandon Moffatt, Stormfisher Environmental Ltd., presented on- and off-farm anaerobic digesters and digestate reuse, including what prompted innovation, future issues and opportunities. Mr. Moffat introduced Stormfisher's London, ON plant, a 2.8 MW biogas production plant based on AD and processing 100 kt of organic food processing wastes: vegetables, meat, grains, dairy, restaurant scraps and grease trap waste, institutional waste from cafeterias and campuses, food distribution and grocery store waste, packaged food, liquid organic waste and beverage waste. The plant provides sustainable disposal services for food processors. Stormfisher Environmental describes itself as an electric utility company foremost, as 60 per cent of its revenues derive from electricity generation based on biogas, 39 per cent from food processor tipping fees and only 1 per cent from a dry 5-4-2 bio-fertilizer product produced on-site from digestate and dried with waste process heat.

The AD market has been driven by the favourable feed-in tariff on renewable natural gas, and Mr. Moffat believes that a carbon price will be central to the continued growth of the industry, as the market does not yet sufficiently value the nutrient and soil health benefit of recycled biofertilizers. Mr. Moffat noted that Ontario currently has approximately 30 other AD facilities throughout the province, mostly on large dairy farms processing dairy waste, some of which also accept local food waste and co-mingle with the on-farm waste stream. Mr. Moffat noted that importing local food waste to farm-based ADs represents an on-farm nutrient surplus that requires some form of optimized redistribution. Approximately 32 per cent of Ontario's total waste stream (3.8 Mt) is organic and could be processed by AD, equivalent to approximately 35 times the London, ON plant representing an investment of USD 500 million to USD 1 billion within the next 10 years; however, the siting and biofertilizer co-product utilization require careful analysis. Large, centrally located AD plants are uneconomic because of the high transportation cost associated with trucking organic wastes with high water content. The geographic distribution of livestock and human populations is quite different; therefore, Mr. Moffat foresees a decentralized AD plant network serving livestock waste streams, and a network serving urban food processing streams.

A key challenge for the growth of the AD industry is markets that fully recognize the biofertilizer co-product value, particularly its high organic matter and significant soil health benefits, such as phosphorus and water retention. Mr. Moffat presented an excellent circular economy diagram depicting the idealized flow of energy and nutrients, illustrated below. The take-away point from a nutrient recovery perspective is that, for the circular economy to flourish, the flow of biofertilizers back to agriculture will need to be optimized both in terms of higher demand by agricultural producers for their superior agronomics and optimal application technologies such as those that support the 4R principles for nutrient stewardship: right source, right rate, right time and right place. Mr. Moffat regards carbon credits associated with the use biofertilizers as a key policy enabler.

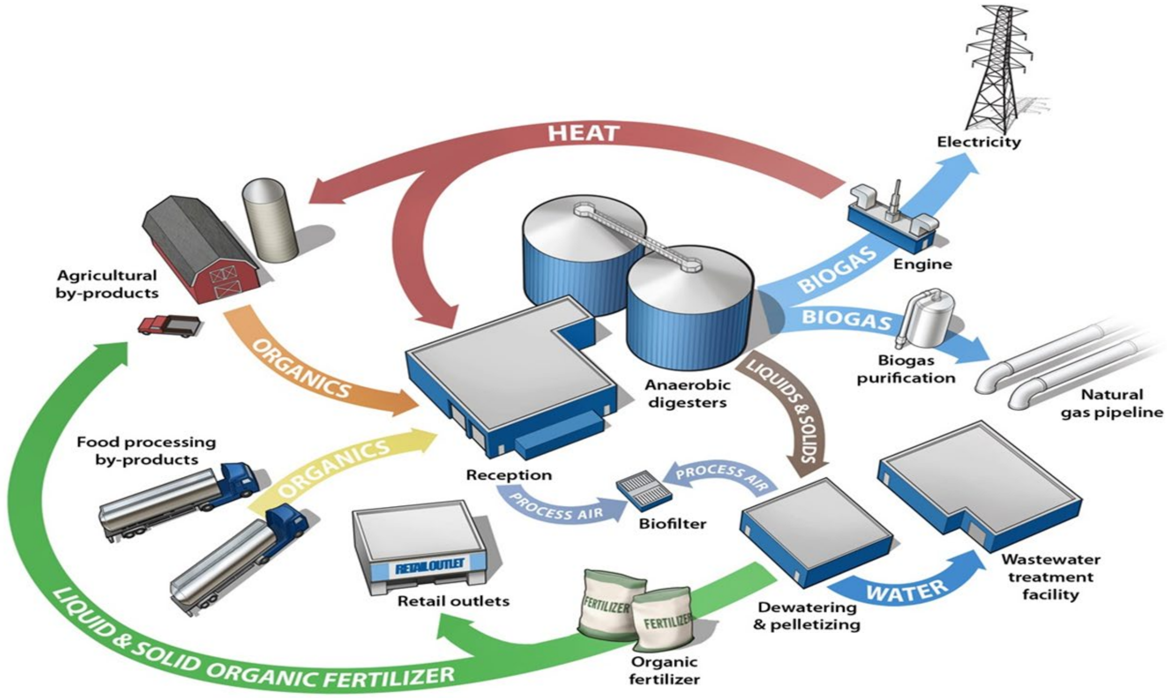

Figure 1: StormFisher's Biogas Value Chain
Source: http://www.stormfisher.com

Mr. Mike Dougherty, Director of Product Development at Lystek International Inc., presented on Lystek's technology, products and markets. Lystek emerged as a startup from the University of Waterloo and was then purchased by the Tomlinson Group of Companies. Lystek derives its name from cell *lysis* the process of cell membrane breakdown. 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, represented in this diagram of Lystek optimized WWTP.

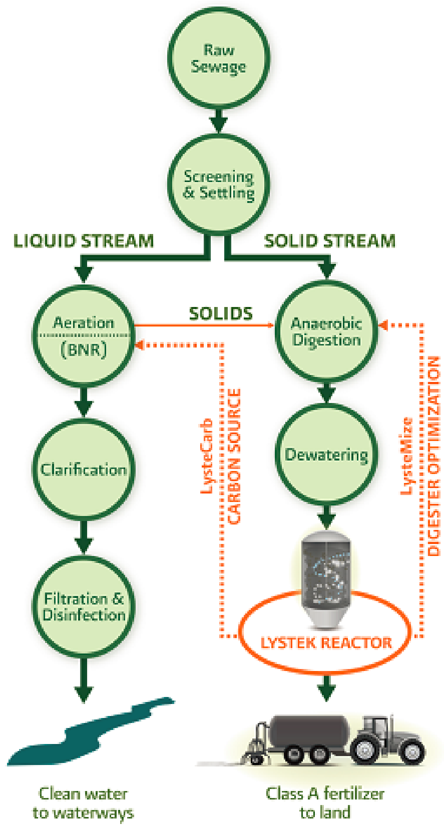

Figure 2: LysteMize®& LysteCarb® Optimize digesters & BNR Systems
Source: https://lystek.com/solutions/lystemize-wwtp-optimization

A Lystek reactor produces LysteCarb® to add a high-carbon source to the biological nutrient removal stage of a WWTP, *a* Lystemize® co-product stream that optimizes AD and Lystegro®, a federally registered biofertilizer product recognized by the Canadian Food Inspection Agency (CFIA) (Canada) and Class A EQ (United States). Mr. Dougherty discussed agricultural field trials demonstrating that *Lystegro* produces equal or better yields than commercial fertilizer. Lystek has commercial markets in Ontario, California and Saskatchewan. Mr. Dougherty then illustrated agricultural examples of top-dressing and soil-injection methods for applying Lystegro®. Lystek works with CFIA to ensure that its product is registered as a fertilizer based on nutrient and toxicity testing. Lystegro® provides organic matter and soil health co-benefits, with increasing appreciation by producers.

Rachel Lee, Regional Technical Sales Manager at Ostara Nutrient Recovery Technologies Inc., presented Ostara phosphorus recovery technology, first describing their market penetration as first-movers in the phosphorus recycling space with 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 nutrient recovery systems. Ms. Lee provided a global context regarding the benefit of phosphorus recycling as a rational response to global phosphorus supply insecurity and widespread aquatic eutrophication. Ostara's initial market is municipal WWTP, and it anticipates new markets in fertilizer process water processing, livestock waste, food and beverage processing, and biofuels processing.

Ms. Lee presented Core Technology: The Pearl® Reactor, which uses two input streams: a blend of post-digestion dewatering liquor, WASSTRIP® (Waste Activated Sludge Stripping to Remove Internal Phosphorus) and magnesium. The nutrient-rich influent and WASSTRIP® feed come into the bottom of the fluidized bed up-flow reactor. Chemicals are then added to create ideal reaction conditions with supersaturated magnesium at the proper pH. Reactor contents are recycled and treated effluent flows from the top of the reactor. Periodically, an operator will start a harvest cycle to harvest Crystal Green, the commercially valuable struvite product. Crystal Green crystals can be harvested at 0.9 to 4.5 mm diameter for different fertilizer blending applications. Ms. Lee presented the business case for a 50 million gallons per day (MGD) WWTP as a USD 6.5 million CapEx on Ostara technology with about a 5-year capital payback based on reduced chemical inputs, sludge handling, reduced ammonia load plus Crystal Green sales.

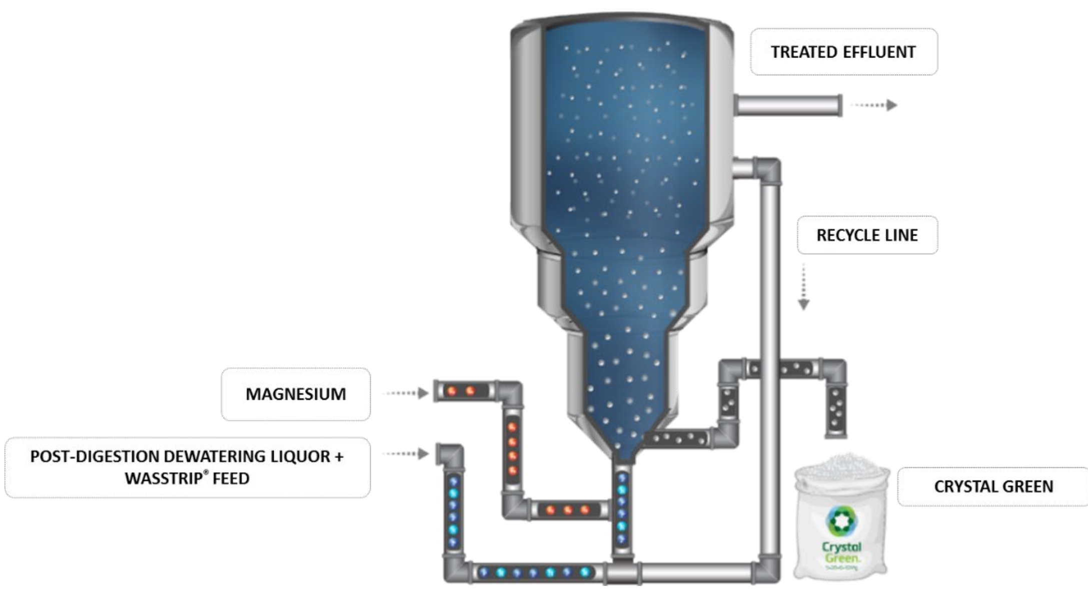

Figure 3: Ostara's Pearl® Process
Source: http://ostara.com/nutrient-management-solutions/

Theresa MacIntyre-Morris, York Region and Ann Huber from the 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. Water reuse is relatively common in other parts of the world where water scarcity and drought are more frequent risks, but uncommon in Ontario. The Lake Simcoe eutrophication issues and the Lake Simcoe action plan motivate York region's interest in alternative methods to reduce phosphorus loads to Lake Simcoe. Ms. MacIntyre-Morris noted that York region's GHG intensity was decreasing in all sectors except for water and wastewater treatment, because more expensive and energy-intensive tertiary treatment technologies, such as membranes and reverse osmosis, are coming online to provide lower phosphorus effluent levels. Treating secondary treatment effluent as a resource for biomass (sod) production potentially provides equal or better phosphorus removal and avoids tertiary treatment energy inputs. Ms. Huber described the soil column measurement methods that would be deployed at the irrigated sod test plot, using previous research on greenhouse nutrient feedwater as an analog.

Ms. MacIntyre-Morris fielded one comment after the presentation from Randy Moffat of Stormfisher Environmental, who observed that the increasing energy intensity of WWTPs could be addressed by increasing their organic (food waste) load, thereby increasing the energy yield from anaerobic digestion, potentially allowing net-zero-GHG-emission WWTPs and food processors constrained by the low availability of AD capacity. Ms. MacIntyre-Morris noted that she was not aware of such an initiative within the York Region Master Plan, suggesting that the potential for circular economy system optimization is high and that solutions are still being sought in silos.

Mr. Michael Walters, CAO of the Lake Simcoe Region, presented the Lake Simcoe Phosphorus Offset Program (LSPOP) as a key program of the Lake Simcoe Region Conservation Authority. The long-term average total phosphorus loading on Lake Simcoe is about 90 tonnes/year and the ecological target is 44 tonnes/year. WWTPs—noted as water pollution control plants (WPCPs) in the figure below—have reduced their phosphorus loading significantly in recent years by employing advanced and energy-intensive tertiary treatment technology. WPCPs are now a minor contributor to overall Lake Simcoe loading. The LSPOP targets the largest loading sources: tributaries, and more specifically stormwater runoff, which is the major tributary loading mechanism.

The high demand for residential development in the Lake Simcoe watershed creates an opportunity to levy a development charge on new residential developments that is used to offset the incremental phosphorus loading caused by development. The fundamental principle underlying the offsetting system is that new developments should induce zero increase in total phosphorus loading and that developers can achieve zero loading by purchasing offsets "to fix the sins of the past" that improve the performance of existing developed areas with uncontrolled stormwater runoff. Mr. Walters illustrated the offset mechanism with reference to a specific new

9.2 ha (176 lot) residential development that increases the impervious area by 45 per cent and thereby increases phosphorus export by 13.8 kg/year. By employing low-impact development (LID) measures to control stormwater runoff, loading can be reduced to 3.5 kg/year that must be offset. The LSPOP uses a 2.5:1 offset ratio to account for uncertainties; therefore, the net offset requirement is 3.5 * 2.5 = 8.8 kg/year. The developer is then charged an offset fee of CAD 35,000/kg phosphorus, resulting in a net development charge of CAD 308,000, which is used to purchase LID stormwater management in previously uncontrolled contributing areas. The effective development charge is CAD 1,750/lot, a minor cost when the developed lot is worth CAD 600,000–800,000. Mr. Walters also noted that the co-benefits of stormwater LIDs are numerous, including: improved groundwater recharge, improved climate resilience and overall improved development aesthetics.

The LSPOP also puts the Lake Winnipeg Bioeconomy Project (the morning presentation by Dr. Grosshans) in context and implies a high potential for rural LIDs based on multifunctional storage. The LSPOP uses a CAD 5,000/kg phosphorus charge, whereas Dr Grosshans used a CAD $50/kg phosphorus credit to demonstrate the cost-effectiveness of multifunctional storage for rural non-point source nutrient recycling.

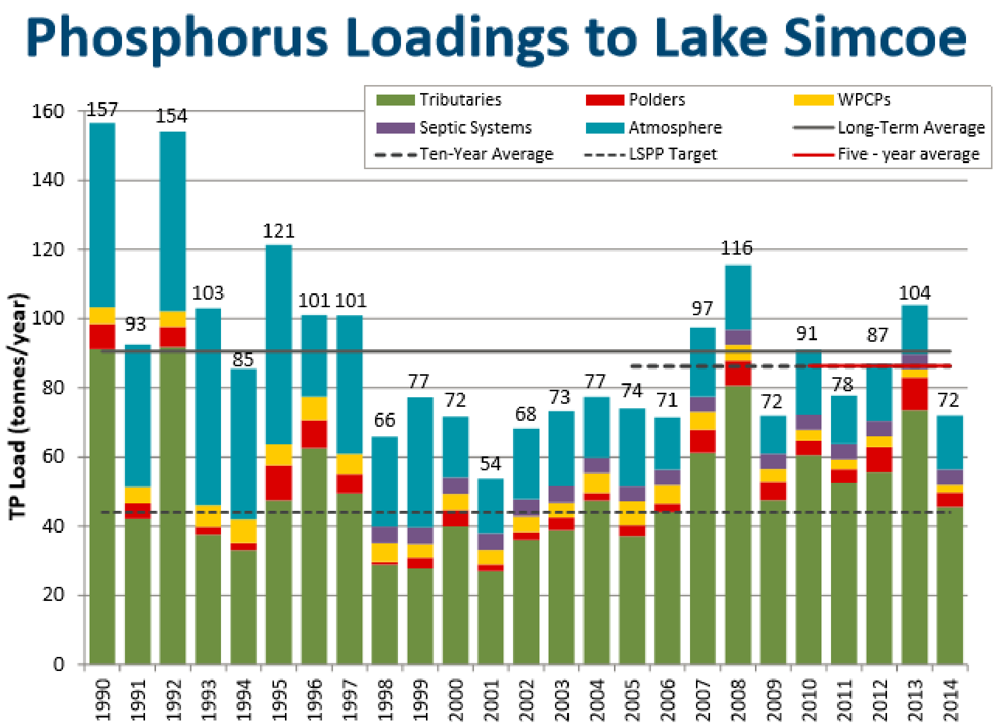

Figure 4. Phosphorus loadings to Lake Simcoe

Source: LSRCA Presentation, Nutrient Reuse and Recovery Forum, 2018

7 AFTERNOON ROUND TABLE DISCUSSION: PRELIMINARY SCAN

The final session of the workshop took a round table discussion with reportage format. Participants from industry, academia, government and non-government organizations were divided into working group tables to answer four main question topic areas. In some cases, more than two tables addressed the same topic area. The preliminary scan recorded here will be further analyzed and prioritized.

We wish to thank this assembly of high-level experts who brought years of experience and expertise to contribute to the Action Plan moving forward.

A) Need for information and recognition of the value of a circular nutrient economy (phosphorus/nitrogen) 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, phosphorus transport.
- Need for a comprehensive user-friendly communication/education strategy required for circular economy, phosphorus recovery, for all sectors to recognize value (e.g., Lystek case study), politicians, inter-sector meetings, field trips. Linkages to nitrogen, carbon 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., phosphorus) demand issues

Research Coordination

- Need for cohesive, long-term network and goals across all resource streams of phosphorus reuse/recovery.
- Top targeted research areas: holistic decision-making tools, legacy phosphorus 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., phosphorus flows, temperature/flow cycles). User-driven research. Involve key universities (including but not limited to Laval, McGill, University of Manitoba, University of Calgary, UBC), 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 useable 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 (CFIA), 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., phosphorous offsetting/water quality trading, subsidies, GHG credits, % of recycled nutrient requirement, area-wide/cumulative multiple farm nutrient management plan/strategy, etc.)

- Need understanding of phosphorus 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); non-point source (e.g., using biomass to quantify amount of phosphorus).
- 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.

8 RECOMMENDATIONS

1. **The most important recommendation for advancing nutrient recovery and reuse concerns is establishing the economic cost of *doing nothing*,** essentially the social cost of phosphorus (SCP), analogous to the social cost of carbon (SCC), which underlies the principle of carbon taxation and incentives for renewable energy. The SCP is the sum of its scarcity cost and its eutrophication cost. The SCP is the policy analog to listing rock phosphate as a critical scarce material, as in the EU, and would provide the continued justification for technology and pilot project investment. Phosphorus supply stability is a legitimate medium- to long-term concern; the scarcity value of phosphorus could be estimated as the societal willingness to pay to acquire alternative supply (through recycling for example) in the case of conventional supply interruption. The other component of the SCP is the normalized ($/kg) eutrophication cost, which is end-point (typically lake basin) specific, aspects of which are currently under study at ECCC.

   The opportunity for sustaining political and investor commitment to nutrient reuse and recovery will occur in the aftermath of an HAB episode, with communications to the effect that the key pollutant, phosphorus, is actually a scarce and strategic resource and its misuse causes environmental pollution—both of which have an economic cost to society.

2. **The circular economy**. Nutrient reuse and recovery provide a powerful storyline for advancing the circular economy that can be harnessed to show case Canadian innovation in pursuit of a zero-waste society and global food security. Specific recommended actions within the Strategy for a Waste-Free Ontario: Building the Circular Economy in particular that relate to regulations and incentives for biofertilizers and extended commercial fertilizer producer responsibilities are the following:

- Action 13: Improve and establish environmental standards to provide a level playing field and a strong foundation for markets.
- Action 14: Use green procurement practices to build market demand for recovered materials.
- Action 15: Implement disposal bans to direct materials to end-markets.
- Action 16: Responsibility to ensure waste reduction, value creation and effective recycling systems. Municipal support through integrated waste management approaches.

3. **R&D activities and pilot projects** should focus on cost, yield comparisons with conventional fertilizers, phyto-sanitary compliance and life-cycle GHG mitigation co-benefits. Costs should be consistently assessed as $/kg of phosphorus recovered and should also consider the value of SOC and life-cycle GHG emission reductions. The objective is a simple comparative assessment enabling policy-makers to understand the full value proposition of investing in phosphorus recycling. Until phosphorus externality costs are widely accepted, the economic rationale for improved manure management may be justified based on its carbon sequestration and GHG mitigation co-benefits.

4. **Innovation: establish a unique Canadian brand associated with nutrient reuse and recovery and differentiate from the ESPP and the SPA.** A major Canadian innovation opportunity lies in recognizing that a complete phosphorus recovery solution requires non-point interception methods; essentially, Canada could promote a watershed-based multi-barrier approach that encourages recycled bio-fertilizers, their precision application and hydraulic interception of residual runoff phosphorus. Non-point phosphorus is the most difficult, largest source and most environmentally damaging cause of eutrophication. Low- cost, multifunctional non-point phosphorus interception using natural infrastructure has been proven in Canada (e.g., the Lake Winnipeg Bioeconomy Project), which marks a major Canadian innovation and creates a strong synergy with the CAD 180 billion, 12-year federal Investing in Canada infrastructure investment strategy. The multi-barrier Canadian brand should leverage highly innovative circular economy systems (BioEngine) research at Laval University. Such a portfolio of policies, practices, technology and system optimization defines a new cleantech space where Canada could assert leadership.

5. **Detailed recommendations for the Canadian nutrient management platform.** A strong consensus exists for a unique Canadian Nutrient Management Platform networked with and building upon the successes of the Sustainable Phosphorus Alliance and the European Sustainable Phosphorus Platform. The Canadian Platform should leverage unique Canadian research and technology assets, and link strongly to circular economy and large ecosystem protection (lake basin) narratives. The Canadian Platform should be designed as a national cleantech asset with domestic and international knowledge export and economic development value.

IISD recommends a credible, national non-governmental science and policy agency with provincial, federal government and academic bona fides be tasked with coordinating the initiative, the first step of which will be establishing the following working groups:

- Economics and Policy Instruments
- Technology
- Data and Systems
- Strategic Intelligence, Government and Investor Relations
- Communications

8.1 ECONOMICS AND POLICY INSTRUMENTS

The Economics and Policy Instruments Working Group is tasked with quantifying the costs and benefits of nutrient reuse and recovery. Two key issues identified in 2014 were the weak knowledge base with respect to recognizing phosphorus as a resource and the absence of market-based instruments. Similarly, the 2018 panel highlighted the difficulty communicating to policy-makers and decision-makers the real cost of business as usual. Wastewater treatment plant investments are unlikely to include phosphorus recycling technologies unless there is a transparent business case for doing so—even though sludge disposal cost can be 50 per cent of the life-cycle costs of a new plant according to Dr. Mavinic. Dr. Vaneeckhaute emphasized a society-wide “sustainable return on investment” perspective for nutrient recycling technologies that accounts for the benefits of reduced pollutant loading and lower risk of food insecurity. Precedents exist for estimating the total societal cost of eutrophication for specific ecosystems of concern (Lake Erie), and Dr. Mavinic emphasized the value of credibly quantifying the scarcity value of phosphorus to communicate the public sector investment case for phosphorus recycling.

The sum of phosphorus eutrophication and scarcity externalities is analogous to the SCC—the use of the SCC has entrenched the principle of taxing carbon and therefore incentivized progressive renewable energy/energy conservation policies and R&D. Similarly, the positive interplay between science and economics, policy and regulatory focus, and investor interest will be crucial to growing nutrient recycling as a vibrant cleantech sector. A compelling economic case for nutrient recycling based on avoided externalities strengthens the political resolve for a strong regulatory and incentives framework, which increases investor attention to nutrient recycling R&D, which in turn has a positive feedback on political resolve to require phosphorus recycling.

An accepted “social cost of phosphorus” or an accepted methodology for calculating that cost regionally will accelerate the political acceptance of a sophisticated policy response using an array of policy instruments. The Economics and Policy Instruments Working Group will identify policy best practices and develop the expertise to design region-appropriate policy instruments.

Table 1 below illustrates a typical matrix of environmental policy instruments used in the context of climate change and carbon dioxide emission reductions.

Example policy instruments for phosphorus reuse and recovery could include:

- [restrictive, supply side] a restriction on field application of uncomposted manure, more stringent phosphorus reuse requirements at wastewater treatment plants.
- [supportive, supply side] a recycled phosphorus blending requirement on commercial fertilizers.
- [restrictive, demand side] water quality trading systems based on phosphorus targets.
- [supportive, demand-side] incentives for fertilizer companies to use recycled phosphorus; R&D on non-point phosphorus interception.

As an important caveat, the issue of phosphorus management is significantly more complex than carbon dioxide emission reductions and will inevitably require a portfolio of policy instruments, much like the public health objective of reduced smoking involves public education, taxes and physical restrictions.

Table 1: The Climate Policy Toolkit.[7]

Table 1 The climate policy toolkit

	Supply-side	Demand-side
Restrictive	*Restrictive supply-side climate policies* (e.g. FF subsidy reduction; FF supply tax; FF production quotas; FF supply ban/moratorium)	*Restrictive demand-side climate policies* (e.g. carbon tax; carbon cap-and trade; mandatory CO_2 emissions standards)
Supportive (of substitutes)	*Supportive supply-side climate policies* (e.g. direct government provision of low-carbon infrastructure; R&D subsidies; renewable energy feed-in-tariffs)	*Supportive demand-side climate policies* (e.g. government procurement policies; consumer subsidies for energy-efficient or low-emitting substitutes)

Notes: FF = fossil fuels. Shaded area represents the focus of this article; unshaded areas are those typically analysed in the comparative literature on climate policy instruments.

8.2 TECHNOLOGY

The Technology Working Group is responsible for assessing the state of technology for phosphorus reuse and recovery technologies, with the following categories and a non-exhaustive list of technology examples based on the National Nutrient Reuse and Recovery Forum.

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7 Fergus, G. & Denniss, R. F. (2018). Cutting both arms of the scissors: The economic and policy case for restrictive supply-side climate policies. *Climatic Change, 150,* 73-87

Urban Point

- Ostara (struvite production)
- Lystek
- Stormfisher Environmental (AD)

Urban Non-Point

- Urban LIDs (Lake Simcoe phosphorus Offsets Program)
- Urban wastewater recycling (turf, biomass production)

Rural Point

- Manure composting
- Manure separation
- "Nutrient neighbourhoods"

Rural Non-Point

- Tile drainage control and irrigation reuse
- Multifunctional storage with biomass (e.g., the Lake Winnipeg Bioeconomy Project)

Key functions of the Technology Working Group will be:

- Tracking developments in nutrient recovery and supporting new Canadian nutrient recycling technologies.
- Analyzing and testing technology "stacks"—the appropriate integration of individual technologies.
- Consistent evaluation of technical and economic performance to produce integrated cost curve information for public sector investment planning, similar to the well-known and regularly updated McKinsey cost curve for GHG mitigation technology. 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.

8.3 DATA AND SYSTEMS

The Data and Systems Working Group is inspired by the Laval University-based BioEngine research team on green process engineering and biorefineries. BioEngine takes a systems-based approach to energy and nutrient recovery and recycling and uses advanced spatio-temporal decision support to co-optimize biorefinery location, biorefining technology and end-product distribution. BioEngine also uses advanced control and optimization logic for end-product optimization.

Generalizing BioEngine principles to regional scale investment planning and integrating with non-point technology would be a fundamentally unique Canadian contribution to phosphorus reuse and recovery with high international relevance.

Scoping the potential application of "big data" such as LiDAR for geospatial and hydraulic analytics; drone technology for rapid distributed soil phosphorus testing; and artificial intelligence (AI) and machine learning for large network design and management is also within the remit of the Data and Systems Working Group.

The fundamental objective and capability within this pillar will be to assess regional nutrient management opportunities at a systems level (including data gaps) and develop optimized investment strategies based on portfolios of point and non-point technologies. The objectives of this pillar are to:

- Develop the capacity to diagnose and treat a regional issue (eutrophication) as a systems design problem and with a set of coordinated policy and technology recommendations.
- Diagnose and recommend the necessary informatics to support system-level solutions.
- Develop the analytics to support system-level investment.

8.4 STRATEGIC INTELLIGENCE: GOVERNMENT AND INVESTOR RELATIONS

The fundamental objective of this work group is to develop a strategic national narrative, to ensure high-level political support, and to position nutrient recycling technology and technology systems as a compelling cleantech investment space for domestic and international investors.

The recommended narrative to pursue is that Canada has unique, leading-edge expertise and technology for data-enabled large ecosystem (lake basin) protection based on unique system analytic capacity (BioEngine and its generalizations) and unique component technologies (e.g., Ostara, Lystek, StormFisher, the Lake Winnipeg Bioeconomy Project).

Key government-related workplan components within this pillar are:

- The critical assessment of how to expand markets for Canadian technologies with comparative advantage, for example by engaging with standards organizations like the International Organization for Standardization (ISO) to advance relevant international standards (e.g., ISO/TC 275 "sludge recovery, recycling, treatment and disposal").

- Assessing where Canada should build comparative advantage (e.g., geospatial analytics/natural infrastructure for non-point interception and reuse), promote relevant R&D and standards.
- Engage with key federal agencies outside the environment box such as Sustainable Development Technology Canada, Infrastructure Canada, Export Development Canada and the nascent Canadian Infrastructure Bank.
- Key investor-related workplan components are translating work within the Economic and Policy Working Group to develop a unified investment case for nutrient recycling technologies and large-basin protection based on:
- Conventional private sector investment principles.
- Best-practice investment principles using extended cost-benefit analysis, environmental, social and governance risk analysis and climate risk disclosure principles (as recommended by the Task Force on Climate-Related Financial Disclosure).
- For institutional investors: applications for sustainable finance for nutrient recycling and large-ecosystem protection (e.g., green bonds, climate bonds, environmental impact bonds).

8.5 COMMUNICATIONS

[TBD]

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