APPENDIX E

Beneficial Reuse of Biosolids Jurisdictional Review

Final Report

Prepared For
Capital Regional District
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Project Number
EDI: 17N0110, CRD: 17-1907
August 2017

Down to Earth Biology

EDI ENVIRONMENTAL DYNAMICS INC.

EXECUTIVE SUMMARY

EDI Environmental Dynamics Inc. (EDI) was contracted by the Capital Regional District (CRD) to undertake a project entitled: Beneficial Reuse of Biosolids Jurisdictional Review to present examples of how other jurisdictions produce and use Class A biosolids.

The CRD is in the process of advancing efforts to design, construct, and operate a regional wastewater treatment plant. As the regulator for the project, the Province of British Columbia requested the CRD to conduct a jurisdictional review "of how similar-sized and larger municipalities within British Columbia, North America, and further abroad, successfully and beneficially reuse biosolids." This jurisdictional review was undertaken to support a more informed biosolids option assessment for CRD wastewater treatment and Integrated Resource Management projects, and meet the Province of BC request. As specified in the letter from the Province dated November 18, 2016, the beneficial reuse option selected by the CRD for their treated biosolids must meet the requirements for beneficial use specified in the Canadian Council of Ministers of the Environment 'Canada-Wide Approach for the Management of Wastewater Biosolids'.

This jurisdictional review identified a series of well-established programs, some of which have been in existence for decades. The review also identified a series of emerging techniques being advanced. Earlier this year, the theme for the Water Environmental Federation (WEF) Residuals and Biosolids Conference held in Washington State was, 'The Future of Biosolids and Bioenergy'. The conference included presentations on new technology and emerging trends in biosolids management in North America. A number of case studies demonstrating emerging technologies and trends presented at the conference, are summarized in Table 1.

Biosolids are processed, reused, or disposed of in a variety of ways worldwide. The most prevalent biosolid management option in many regions of the world, including North America, is land application (GMSC and UN-Habitat 2008, BCWWA 2016, EPA 2017). Biosolids can be applied to land for a variety of purposes, such as aiding plant growth on agricultural or forestry lands, improving soil health in land reclamation (e.g., mining) and restoration projects, and providing landfill closure material. The processing of biosolids for land application is highly variable, including aerobic or anaerobic digestion, alkaline stabilization, and thermal drying.

This report presents examples of the techniques being used by other jurisdictions, starting closest to the CRD, and expanding outwards. This approach enables the discussion of biosolids generation and management techniques that fall under the British Columbia Organic Material Recycling Regulations (OMRR), and similar regulatory regimes, expanding to areas whether the regulations may be different.

In this jurisdictional review, information was compiled for 15 jurisdictions with established biosolids programs. Jurisdictions were selected with the intent to present a diversity of Class A biosolids product processing types, end uses, and marketing strategies used in North America. British Columbian jurisdictions include some of the larger communities in the province and aim to highlight the different Class A processing and beneficial use options used. Other Canadian jurisdictions presented highlight well-established Class A biosolids programs of similar or larger-sized cities located across the country. Jurisdictions presented from the United States of America (USA) were selected based on factors such as regional proximity, coastal location, biosolids processing techniques and end uses, and the availability of information. For each jurisdiction, Table 2 provides a summary of the biosolids product name, treatment process, project initiation date, applicable regulations, and use of the biosolids.

Table 1. Jurisdictional summary of emerging trends and technologies in sewage sludge and biosolids management discussed. Includes case studies presented at the 2017 WEF Residuals and Biosolids Conference.

Jurisdiction	Emerging Trend	Project Stage	End Products Produced	Beneficial Uses
Grand Junction, Colorado	Biogas utilization – fuel	Operational	Natural gas vehicle fuel	Compression of renewable natural gas to fuel 46 city vehicles including garbage trucks and dump trucks.
City of Portland, Oregon	Biogas utilization – fuel	Construction summer 2017	Renewable natural gas, Class A Biosolids fertilizer	Export of renewable natural gas, compressed natural gas for municipal vehicle fleet, and agricultural fertilizer.
City of Calgary, Alberta	Thermal hydrolysis	Design phase	Biogas, Class B Biosolids	Increased biosolids processing capacity, increased biogas production, and land application of Class B biosolids as fertilizer.
Avonmouth, England	Biological hydrolysis	Operational	Biogas, Class A Biosolids	Increased biosolids processing capacity, increased biogas production, sale of excess electricity generated from biogas to the grid, and agricultural fertilizer.
City of Raleigh, North Carolina	Biodiesel production	Operational	Class A and B Biosolids, Biodiesel	Use of Class A and B biosolids to improve growth of sunflower and soybean crops to be converted to biodiesel to fuel farm equipment on location.
Anchorage, Alaska	Gasification	Pilot study	Syngas, Ash	Energy savings of biosolids disposal costs, reduced greenhouse gas emissions, and significant waste volume reduction.
City of Lebanon, Tennessee	Gasification	Operational	Syngas, Biochar	Energy savings, reduced greenhouse gas emissions, cost savings associated with waste transportation, significant waste volume reduction, and marketable soil amendment product.
District of Delta Diablo, California	Gasification	Evaluation and site selection	Syngas, Ash	Syngas converted to enough energy to make facility self-sufficient, reduced greenhouse gas emissions, and significant waste volume reduction.
District of Delta Diablo, California	Pyrolysis	Evaluation and site selection	Pygas, Biochar	Pygas converted to enough energy to make facility self-sufficient, reduced greenhouse gas emissions, significant waste volume reduction, and valuable soil amendment.
Silicon Valley Clean Water, California	Pyrolysis	Construction	Pygas, Biochar	Pygas converted to enough energy to make facility self-sufficient, significant waste volume reduction, reduced greenhouse gas emissions, and valuable soil amendment.
Cleveland, Ohio	Fluidized bed incineration	Operational	Heat and Steam to Energy, Ash	Heat captured from process drives energy generation through steam turbine, process supported by energy generated, reduced greenhouse gas emissions, and waste volume reduction.

Table 2. Summary of Class A biosolids management programs discussed in jurisdictional review.

Jurisdiction	Product Name	Biosolids Treatment	Program Initiation	Percentage of Class A Product Produced	Applicable Regulations	Beneficial Reuse of Biosolids
British Columbia						
Metro Vancouver Regional District	Nutrifor	Thermophilic anaerobic digestion	1991	80	BC OMRR, Federal Fertilizers Act	Mine reclamation, landfill closure and reclamation, regional reclamation projects, regional landscaping projects, forest fertilization, and ranch land fertilization.
City of Kelowna / City of Vernon	Ogogrow	Aerated static pile composting	1995 (2006)	100	BC OMRR, Federal Fertilizers Act	Commercial landscaping, residential gardening, nurseries and orchards, and landfill closure.
Comox/Strathcona Regional District	SkyRocket	Aerated static pile composting	2007	100	BC OMRR, Federal Fertilizers Act	Commercial landscaping, residential gardening, nurseries and orchards, slope stabilization project, and local reclamation projects.
Nanaimo Regional District	-	Mesophilic and Thermophilic anaerobic digestion	1991	30	BC OMRR, Federal Fertilizers Act	Forest fertilization.
Saanich Peninsula	PenGrow	RDF Lime-pasteurization	2008 to 2011	5	BC OMRR, Federal Fertilizers Act	Residential gardening and landscaping.
Other Canadian Jurisdictions						
City of Edmonton, AB	Second Nature	Co-composting with residential organic waste	2002	80	Federal Fertilizers Act; Provincial Application	Horticulture, agriculture, nurseries, commercial landscaping, residential gardening, city reclamation and enhancement projects.
Niagara Region, ON	Niagara N-Rich	N-Viro alkaline-stabilization	2007	50	ON Nutrient Management Act; Federal Fertilizers Act	Agricultural fertilizer.
City of Toronto, ON	-	Thermal drying; N-Viro alkaline-stabilization	2007	75	ON Nutrient Management Act; Federal Fertilizers Act	Agricultural fertilizer, mine reclamation.

Jurisdiction	Product Name	Biosolids Treatment	Program Initiation	Percentage of Class A Product Produced	Applicable Regulations	Beneficial Reuse of Biosolids
Greater Moncton, NB	Gardener's Gold	Composting - GORE Cover System	2008	100	CAN/BNQ 0413-200/2005; Federal Fertilizers Act	Commercial landscaping, municipal parks and horticultural activities, residential gardening.
City of Halifax, NS	Halifax N-Rich	N-Viro alkaline-stabilization	2007	100	Federal Fertilizers Act	Agricultural fertilizer and municipal horticultural activities.
United States of America						
King County, WA	GroCo	Aerated static pile composting	1976	2	US EPA Part 503 Biosolids Rule, Washington State Compost Standards	Residential gardening and landscaping, commercial landscaping, and forestry road reclamation.
City of Tacoma, WA	TAGRO	Duel digestion, composting	1990	100	US EPA Part 503 Biosolids Rule, Washington State Compost Standards	Urban community gardens, residential gardening, commercial landscaping, forest fertilization, and agriculture.
Pierce County, WA	SoundGRO	Thermal drying	2006	100	US EPA Part 503 Biosolids Rule, Dept.of Agriculture – Commercial Fertilizer	Agriculture, commercial and residential landscaping.
City of Raleigh, NC	Raleigh-Plus	Lime-stabilization, composting	2006	90	US EPA Part 503 Biosolids Rule	Agriculture, commercial landscaping, residential gardening, and biodiesel production.
Boston, MA	Bay State Fertilizer	Thermal drying	1991	100	US EPA Part 503 Biosolids Rule, Dept.of Agriculture – Commercial Fertilizer	Agriculture and fuel for cement kilns.

Broad biosolids management trends occurring elsewhere in the world, including the European Union (EU), Australia, New Zealand and Japan were also reviewed and presented as high-level summaries. Despite support from the European Commission on recycling biosolids to land, provided they do not pose any health or environmental threats, the acceptance of biosolids land application among different European countries varies considerably. The dominant methods of biosolids treatment/utilization in the EU includes application to agricultural lands (e.g., United Kingdom, Spain), composting and other land application options (e.g., Finland), landfilling (e.g., Greece, Malta), and incineration (e.g. Netherlands) (Fonts et al. 2012, Evan 2012, LRCS 2016). Overall, approximately 37% of biosolids are recycled to agricultural land in the EU; however the application rates range between member countries from the United Kingdom at 92% to the Netherlands and Greece with very minimal to no land application (Evans 2012, Panter and Barber 2017). Other European countries, outside of the EU, also highlight the range of biosolids management strategies utilized on the continent, from Norway which land applies 80% of biosolids produced, to Switzerland, which primarily incinerates biosolids due to a ban on agricultural land application (Evan 2012).

Australia supports the land application of biosolids and beneficially reuses approximately 64% of biosolids through agricultural land application annually, with 23% used in composting, forestry and land reclamation projects and 11% disposed of in landfill or stockpiled (ANZBP 2016a). New Zealand's most prominent biosolids management strategy is currently landfilling (61%), however biosolids vermicomposting has increased steadily in recent years (Quintern and Morely 2017). Japan, on the other hand, relies heavily on thermal processing, particularly incineration, for biosolids management as it is a densely populated country with comparably little opportunity for biosolids land application (GMCS and UN-Habitat 2008). The country has instead focused on generating energy as a beneficial use of biosolids processing (GMCS and UN-Habitat 2008).

This report is not intended to provide recommendations for the CRD or the Province of BC, but simply provide examples of biosolids approaches being used by other jurisdictions. A detailed reference list and websites are provided for readers to further explore specific examples. It should be noted that while recent and relevant information from a broad range of jurisdictions is presented, any claims these jurisdictions have made and results reported, have not been substantiated.

Overall, there are many useful examples of the biosolids treatment processes and applications being used by jurisdictions across BC, the rest of Canada, the US, and further afield internationally. These jurisdictions demonstrate a range of ideas that the CRD may wish to further investigate.

ACKNOWLEDGEMENTS

Most of the information for this jurisdictional review was compiled through a review of online and written sources. Telephone communication was undertaken with a select number of biosolids producers for clarity.

We would like to thank the individuals contacted by telephone who shared their time and knowledge with the study team to enhance the information presented in this report.

AUTHORSHIP

This report was prepared by EDI Environmental Dynamics Inc. Staff who contributed to this project include:

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1 INTRODUCTION

EDI Environmental Dynamics Inc. (EDI) was contracted by the Capital Regional District (CRD) to undertake a project entitled: Beneficial Reuse of Biosolids Jurisdictional Review to present examples of how other jurisdictions produce and use Class A biosolids.

The CRD is in the process of advancing efforts to design, construct, and operate a regional wastewater treatment plant. As the regulator for the project, the Province of British Columbia requested the CRD conduct a jurisdictional review "of how similar-sized and larger municipalities within British Columbia (BC), North America, and further abroad, successfully and beneficially reuse biosolids." This jurisdictional review was undertaken to support a more informed biosolids option assessment for CRD wastewater treatment and Integrated Resource Management projects, and meet the Province of BC requirement. As specified in the letter from the Province dated November 18, 2016, the beneficial reuse option selected by the CRD for their treated biosolids must meet the requirements for beneficial use specified in the Canadian Council of Ministers of the Environment 'Canada-Wide Approach for the Management of Wastewater Biosolids'. At the request of Province of British Columbia, the study team worked through the CRD with requests for information.

Biosolids management is a global issue, and different approaches are being used around the world. This report presents examples of the techniques being used, starting with jurisdictions closest to the CRD, and expanding outwards. This approach enables the discussion of biosolids generation and management techniques that fall under the BC Organic Material Recycling Regulations (OMRR), and similar regulatory regimes, expanding to areas whether the regulations may be different.

This report begins with an overview of biosolids in Section 2, followed by a summary of the BC OMRR and the Canadian Council of Ministers of the Environment (CCME) guidance document for the use of municipal biosolids in Section 3.

Biosolids processing and beneficial reuse is an evolving field, with new approaches, techniques, and technologies continuously emerging. Section 4 presents a summary of emerging trends, primarily related to biosolids to fuel and energy.

The jurisdictional review, focused on Class A biosolids programs, is presented in Sections 5 and 6. The results are written in paragraph form, rather than table format, to share more complete examples. The results are presented by region, including:

- British Columbia
- Canada
- United States, and
- International

The information presented in this report was compiled from available online sources, including websites, and the academic literature. These sources are presented in Section 8. Some telephone-based discussions were undertaken, to confirm information, and gain further detail.

Throughout the report, metric measurements of the volumes processed and products produced are presented when they were available. However, due to the different processes used, wet and dry conversions factors, and the use of Imperial measures in some jurisdictions, not all measures are metric.

This report is not intended to provide recommendations for the CRD or the Province of BC, but simply examples of approaches being used by other comparable jurisdictions. A detailed reference list is provided for readers to further explore specific examples. However, it should be noted that while recent and relevant information from a broad range of jurisdictions is presented, any claims made and results reported have not been substantiated.

1.1 JURISDICTIONAL REVIEW APPROACH

The approach for the jurisdictional review was to identify municipalities within British Columbia, other parts of Canada, North America, and globally that successfully and beneficially reused biosolids, primarily through Class A programs.

The jurisdictions selected are intended to present a diversity of biosolids treatment types, end uses and marketing strategies, focusing primarily on Class A programs. As some of the jurisdictions reviewed process and beneficially reuse multiple biosolids products, including Class B biosolids, these products are also discussed where applicable. Case studies in British Columbia focus on some of the larger communities in the province, and highlight the different processing and beneficial use options for Class A products use in the province. Other Canadian jurisdictions presented aimed to highlight well-established Class A biosolids programs of similar or larger sized jurisdictions located across the country. Jurisdictions in the United States were selected based on regional proximity or coastal location, diversity of biosolids processing techniques and end uses, and availability of information.

The inclusion of jurisdictions with well-established Class A programs that are evolving their programs through biosolids product enhancement or biosolids-to-energy options was also a consideration for the review. For all jurisdictions, the availability of information related to the biosolids program was an important deciding factor for inclusion.

Broad biosolids management trends occurring elsewhere in the world, including the European Union, Australia, New Zealand and Japan were reviewed. The information presented is a high level summary, as differences in classification and regulatory regimes make comparisons with North American jurisdictions more challenging.

The 2017 WEF Residuals and Biosolids Conference Proceedings were also reviewed to identify jurisdictions in North America that are currently investigating or implementing emerging biosolids processing technologies and beneficial use options.

Overall, information for this report was gathered from a variety of sources, including:

- Online searches and literature reviews of known, established Class A biosolids programs
- Review of information from municipal wastewater treatment plants, wastewater treatment associations, and biosolids land application programs. Key words included, but were not limited to: biosolids, beneficial use, Class A, biosolids compost, soil amendment, fertilizers, wastewater treatment plant, agricultural land application, energy recovery, biogas, pyrolysis, gasification and biochar
- Proceedings of the 2017 WEF Residuals and Biosolids Conference, Seattle Washington
- Beneficial Use of Municipal Wastewater Residuals - Biosolids (Vasileski 2007)
- A Review of the Current Legislative Framework for Wastewater Biosolids (CCME 2010)
- Land Application of Biosolids – Issue Analysis Paper and Position Statement (BCWWA 2016)
- Guidance Document for the Beneficial Use of Municipal Biosolids, Municipal Sludge and Treated Septage (CCME 2012)
- Biosolids Risk Assessment and Literature Review Update (Golder Associates 2014)
- Applicable Provincial and Federal Review

2 BIOSOLIDS BACKGROUND

2.1 WHAT ARE BIOSOLIDS

Biosolids are nutrient-rich organic materials derived from the treatment of sewage at a wastewater treatment facility (MoE 2017, USEPA 2017). Biosolids originate as sewage sludge which is the major solids component that results from the wastewater treatment process. Sewage sludge is commonly processed into biosolids using elevated temperature and biological processes (i.e., aerobic and anaerobic digestion) over an extended duration to stabilize the organic material and significantly reduce pathogen content and vector attraction (BCWWA 2016, MoE 2017). Biosolids may be dewatered to various degrees prior to reuse to achieve the following types: thickened (12% solid content), dewatered (18 to 30% solid content) and dried (50 to 90% solid content) (BCWWA 2016).

There is variation worldwide, and even within countries, in how biosolids are classified. The terms sewage sludge and biosolids are often used interchangeably, but some jurisdictions and regulations have distinguished biosolids from raw sewage sludge in that biosolids undergo additional treatment and processing prior to reuse (e.g., MoE 2017). For the purposes of this review, the term biosolids is used in the more restrictive definition, and refers to sewage sludge that has been treated. This review aimed for the consistent use of these terms throughout the document, however where unclear, the terminology used by the literature source was retained.

In Canada, provinces and territories have defined different classes or categories of biosolids based on various quality criteria, including heavy metal load and pathogen reduction techniques (CCME 2012b). In British Columbia, depending on the type and extent of treatment, biosolids can be produced as either Class A or Class B. British Columbia's Organic Matter Recycling Regulations (OMRR) outlines biosolids class requirements through quality criteria for pathogens, specifically fecal coliforms, and trace elements (MoE 2017). Class A biosolids undergo more extensive treatment and stabilization, targeted at pathogen removal, compared to Class B biosolids (e.g., anaerobic digestion, alkaline stabilization). Class A biosolids products are also lower in trace metal content due to the addition of additives during the treatment process such as lime, sand, or wood waste (Stantec 2011). As Class A biosolids are subject to more stringent quality criteria, they have less restrictive land application requirements than Class B biosolids due to their lower risk (BCWWA 2016, MoE 2017).

2.2 BIOSOLIDS PROCESSING AND BENEFICIAL REUSE

Biosolids are processed and managed in a variety of ways worldwide. The most prevalent biosolids management option in many regions of the world, including North America, is land application (GMSC and UN-Habitat 2008, BCWWA 2016, EPA 2017). Biosolids bound for land application can be processed in variety of ways, including aerobic or anaerobic digestion, alkaline stabilization and thermal drying. Biosolids are applied to land for a variety of different beneficial purposes, such as aiding plant growth on agricultural and forestry lands, improving soils health in land reclamation (e.g., mining) and restoration projects, and providing landfill closure material to reduce methane emissions. Biosolids can also be used as an ingredient in soil conditioning products such as composts and landscaping soils, which are commonly used in urban landscaping, domestic gardening and municipal parks (CCME 2012b).

Anaerobic respiration, a common biosolids processing option in land application programs, produces biogas that can also be can be captured and used in heating or electrical production at wastewater treatment facilities, thereby generating an additional beneficial use stream (Vasileski 2007, NACWA 2010).

Another common biosolids management option is incineration. The ash generated through biosolids incineration is commonly landfilled, but can be used as a fertilizer supplement or in industrial processes, such as cement manufacturing (CCME 2012b). Dried biosolids can also be used as a combustible fuel (i.e., coal substitute) in power and cement plants (GMSC and UN-Habitat 2008, CCME 2012b, Evan et al. 2012).

Gasification and pyrolysis process are beginning to be used as the desire to recover greater amounts of energy from sewage sludge and biosolids treatment grows. These processes significantly reduce biosolids volume, produce fewer emissions than incineration, generate process gas that can be captured and converted to energy, and produce an ash/biochar with potential for beneficial reuse as a soil amendment (CCME 2012b, Liu et al. 2017).

Combustion processes (incineration and gasification) are also considered a beneficial reuse of sewage sludge and biosolids by the CCME if the process meets relevant jurisdictional air quality standards, there is a positive energy balance through the combustion of the residuals, there is significant ash recovery and utilization, and there is low stack emissions of nitrous oxide and other contaminants (CCME 2012b).

Table 3 presents a summary of biosolids processing and reuse options.

Table 3. Review of biosolids processing and reuse options.

Management option	Description
Energy capture	Biogas generated during the anaerobic digestion (~60% methane) of sewage sludge in the production of biosolids can be captured and used in boilers at facilities, converted to energy using combined heat and power engines, or cleaned and converted to natural gas (NACWA 2010). Gasification and Pyrolysis also produce process gas (syngas and pygas) that can be captured and converted into usable energy or fuel (NACWA 2010, CCME 2012b).
Gasification	Thermochemically converts biosolids at elevated temperature (500-1,500°C) into ash and process gas (referred to as 'syngas') consisting of hydrogen gas, carbon monoxide, and methane with minor contributions of carbon dioxide and nitrogen gas. Syngas can be captured and converted into energy, or further refined for use in gas engines or in the production of synthetic biofuels. The ash generated can have value as a soil amendment or can be landfilled. In North America, gasifiers typically utilize additional feedstocks in combination with biosolids (CCME 2012b, NACWA 2010).
Pyrolysis	Thermochemical decomposition of biosolids at elevated temperatures (500-800°C), in the absence of oxygen, into process gas (referred to as 'pygas'), py-oil and biochar. Pygas can be captured and converted to energy, while biochar can be used as a valuable soil amendment (NACWA 2010, Liu et al. 2017).
Biodiesel production	Biosolids are spread onto soils used to grow oil-seed crops that are converted into biodiesel. Biosolids application improves soil productivity and enhances plant growth and yield, thereby improving biodiesel outputs (City of Raleigh 2017b).

Management option	Description
Agriculture	Biosolids are spread or incorporated through disking or sub-surface injection into agricultural soils used to grow food crops or livestock forage materials. This use improves soil productivity and thus enhances plant growth, reducing the need for chemical fertilizers (CCME 2012b). Class A and Class B biosolids are used, ranging from thickened Class B (13% dry solids) to dried Class A pellet products (90% dry solids).
Horticulture - Compost	Dewatered raw sludge or digested biosolids are composted, typically with other organic material, such as wood chips or food waste, to produce a product that is used for a variety of applications, including urban landscaping, domestic and community gardening, and municipal park application. Composting can be conducted in open air, in-vessel, or under synthetic covers. The systems can be static, or dynamic, where the compost is turned to redistribute moisture, re-establish porosity, and introduce oxygen into the system (CCME 2012b).
Forestry	Biosolids are spread on plantations, cut blocks, and woodlots to enhance tree growth rates and biomass, increasing the likelihood of natural tree seeding through improved soil quality and increased water holding capacity, and improved long-term productivity through increasing organic matter concentration (Nanaimo Biosolids 2017a).
Land reclamation	Biosolids used in reclamation projects to aid in developing productive soils with improved nutrients and water holding capacity. The application of biosolids increases organic matter and nutrient content of otherwise organic and nutrient-poor mineral soils (Larney and Angers 2012). They act as a tool to re-vegetate, reduce the bioavailability of toxic substance, re-generate the soil layer and improve slope stability (CCME 2012b). In BC, biosolids are commonly used in mine reclamation projects where they are often mixed with tailings. Biosolids are also used in the reclamation of gravel pits and degraded industrial sites.
Incineration	Combustion of biosolids as a means to reduce volume (up to 75%). Incineration of sewage sludge or biosolids occurs in two steps, drying the solids and the combustion of the volatile fraction of the solids. Combustion can only occur once sufficient water has been removed. The incineration process converts sewage sludge or biosolids into ash that is usually landfilled, but can also be used as a component in cement manufacturing (Vasileski 2007, CCME 2012b).
Landfill disposal	Disposal of municipal solid waste in landfills. There is increasing pressure to phase out the disposal of biosolids in landfills, due to concerns about leachate and greenhouse gas emissions, as well as concerns that limited space is being taken up by a product with beneficial reuse potential. However, biosolids and biosolids products can be beneficially used as a landfill cover material which can significantly reduce landfill methane emissions (Metro Vancouver 2016).

As of 2008, GMSC and UN-Habitat found that application of biosolids to land was the dominant biosolids management option in use in the highest-income countries, and was steadily increasing worldwide. A literature review of the beneficial uses of municipal biosolids completed by Vasileski (2007) found that approximately 75% of examples applied biosolids to land, including agriculture, land reclamation, forestry, composting, and landscaping, while 12% incinerated biosolids and 7% disposed of biosolids in landfills.

In Canada, the CCME has developed a 'Canada-Wide Approach for the Management of Wastewater Biosolids' (CCME 2012a) and a supporting 'Guidance Document for the Beneficial Use of Municipal Biosolids, Municipal Sludge and Treated Septage' (CCME 2012b). Currently, approximately 50% of biosolids in Canada are applied to land (CWWA 2012), while the remainder are incinerated or landfilled (GMSC and UN-Habitat 2008). Wastewater residual management is regulated on a provincial/territorial basis, with the type of regulatory mechanism varying across the country (CCME 2012b).

Land application of biosolids is not currently permitted in Newfoundland and Labrador, while only biosolids meeting Category A requirements, as outlined in the Guidelines for Compost Quality (2005), can be land applied in New Brunswick (CCME 2010). The land application of biosolids to fertilize fruit, vegetables and pasture land (current season), including home gardens, is prohibited in Quebec unless certified by the Bureau de normalization du Quebec (BNQ). Conversely, other provinces, including Alberta, British Columbia, Ontario, and Nova Scotia permit the land application of Class A and B biosolids and compost in accordance with applicable regulations (CCME 2010). Further, Quebec has enacted a green tax on each ton of sewage sludge/biosolids that is landfilled or incinerated, while Nova Scotia has prohibited the landfilling of organic material (CCME 2010). The disposal of biosolids is becoming less accepted throughout Canada as landfill tipping fees increase, landfill availability decreases, and an understanding that disposal does not capitalize on the resources contained in biosolids grows (CCME 2012b).

Similar to the CCME, the US EPA has stated that biosolids are an important resource that can, and should be safely used for purposes such as soil conditioning in agriculture and horticulture, and for reclaiming and re-vegetating areas disturbed by mining and waste disposal activities (USEPA 1994, USEPA 2017). The National Academy of Sciences has reviewed current practices, public health concerns, and regulator standards, and has concluded that "the use of these materials in the production of crops for human consumption when practiced in accordance with existing federal guidelines and regulations, presents negligible risk to the consumer, to crop production, and to the environment"(USEPA 2017). Biosolids are regulated under the EPA Part 503 Biosolids Rule (USEPA 2017). Approximately 50% of all biosolids in the US are applied to land, with land application occurring in all 50 states (GMCS and UN-Habitat 2008, USEPA 2017). Land applied biosolids are used on less than one percent of the nation's agricultural land (USEPA 2017). Aside from land application, approximately 22% of sewage sludge/biosolids are incinerated and 17% are disposed of in landfills, with the remainder going to other uses (GMCS and UN-Habitat 2008).

Although land application is supported at the federal level in the US, is it banned or limited in a number of counties (Deslauriers 2017, Slaughter 2017). In Northern California for example, between 50% and 90% of the biosolids produced are either used as alternative daily cover at a landfill or disposed of at a landfill depending on weather conditions. California is now requiring increased waste diversion from landfills, with recent legislation being passed that requires 75% diversion of organic waste (including biosolids used as alternative daily cover) from landfills by 2025 (Deslauriers 2017). In the US, there has been recent litigation that supports the land application of biosolids in California, Pennsylvania, Virginia, North Carolina, and Maryland where courts have upheld the primacy of state over local biosolids regulations (Slaughter 2017).

The opinion of the European Commission is that the use of biosolids on agricultural soils as a fertilizer is the best environmental option provided that it does not pose any threat to the environment, as well as to animal and human health (Smith 2009). Despite the support for recycling biosolids to land, the acceptance of this practice among different European countries varies considerably. The dominant methods of biosolids treatment/utilization includes land application to agricultural lands (e.g., United Kingdom, Spain), composting and land application (e.g., Finland), landfilling (e.g., Greece, Malta), and incineration (e.g. Netherlands) (Fonts et al. 2012, Evan 2012, LRCS 2016). Overall, approximately 37% of biosolids are recycled to agricultural land, however the value ranges between member countries from the UK at 92% to the Netherlands and Greece with very minimal to no land application (Evans 2012, Panter and Barber 2017). During the past decade, the UK has shifted more and more towards the land application of anaerobically digested biosolids and has closed many incineration and thermal drying facilities (Panter and

Barber 2017). Conversely, the Netherlands has made regulatory requirements for metal concentrations in biosolids bound for land application so stringent that it is almost impossible for municipal biosolids to comply, thereby freeing up land for the large quantities of livestock manure produced in the country (Evan 2012). Consequently the Netherlands incinerates most of its biosolids at facilities both within and outside of the country (GMSC and UN-Habitat 2008, Wiechmann et al. 2013).

Australia beneficially reuses approximately 64% of biosolids through agricultural land application annually, with 23% used in composting, forestry and land reclamation projects and 11% disposed of in landfill or stockpiled (ANZBP 2016a). Conversely, Japan relies heavily on thermal processing, particularly incineration, for biosolids management as it is a densely populated country with comparably little opportunity for biosolids land application (GMCS and UN-Habitat 2008). The country has instead focused on generating energy as a beneficial use of biosolids processing (GMCS and UN-Habitat 2008)

Although there is fair amount of support internationally for the land application of biosolids, there are also concerns about the potential effects of contaminants in biosolids on human health and the environment. Due to these concerns, some jurisdictions have chosen to incinerate or landfill their biosolids so as to avoid the potential risks associated with land applying biosolids. Switzerland, for example, banned the use of biosolids in agriculture in 2005 due to concerns over potentially toxic substances and harmful micro-organisms (Smith 2009, Evan 2012). Similarly, the Capitol Regional District in BC ended the production, storage and distribution of biosolids for land application at all regional facilities and parks and removed support for agricultural land application due to concerns that farmland could be polluted by pharmaceuticals and heavy metals (CRD 2011a).

First Nations and other residents of the Nicola Valley, BC, have also raised concerns over the potential for contamination of the Nicola River and a community well from biosolids use in rangelands and compost operations. In 2015, the five First Nations of the Nicola Valley signed a moratorium on the importation and land use of biosolids within the valley pending the outcome of a scientific review (refer to Section 5.1.1).

In Canada, the CCME encourages jurisdictions to consider adopting a continuous improvement philosophy and remain up-to-date with respect to biosolids research. This includes the consideration of new information, emerging technologies and greenhouse gas implications in the decision-making process to ensure a robust selection of appropriate technology and opportunities for beneficial use (CCME 2012b). In the US, the National Biosolids Partnership (NBP) has developed a voluntary Biosolids Management Program which is based on internationally recognized standards for an Environmental Management System (similar to ISO 14001; WEF 2017). The Program requires continuous improvement to develop, implement, and monitor environmentally sustainable practices and assists wastewater organizations in ensuring that they are efficient, responsive and protective of human and health and the environment. Organizations that have chosen to become certified by the NBP collectively manage more than 12% of the biosolids in the country (WEF 2017).

2.3 OVERVIEW OF BENEFITS AND CONCERNS RELATED TO BIOSOLIDS USE

Biosolids are nutrient-rich organic material that can be utilized as a soil conditioner or fertilizer to improve physical, chemical, and biological properties of soils (Lu et al. 2012). Biosolids can improve overall soil quality, including soil tilth, water storage capacity, nutrient retention, soil carbon sequestration, and improve conditions for soil biota (BCWWA 2016, Lu et al. 2012). Besides improving soil quality, biosolids application can supplement or replace commercial fertilizers, as biosolids additions can increase total soil nitrogen concentration and extractable phosphorus in comparison with fertilizers (Brown et al. 2011, Lu et al. 2012). As organic matter can be lost through land management processes such as livestock grazing, agriculture, and forestry, applying biosolids provides a way to put organic matter and nutrients back into the system. Alkaline-stabilized biosolids can also be used as liming material in agricultural settings to alleviate soil acidity (NEBRA 2004, Lu et al. 2012).

The utilization of biosolids in amending degraded soils, such as mine tailings, disturbed urban soils, and landfill cover soils to establish vegetation is increasing (Lu et al. 2012). The high organic matter content in biosolids can also be utilized to remediate sites previously contaminated with trace metals by binding and converting the metals to less soluble fractions (Basta et al. 2001, Brown et al. 2003). Biosolids are used by land managers throughout the world in agriculture, forestry, and mining as they have been shown to improve crop yield, forage quality, and vegetation establishment.

Although the benefits of applying biosolids to land are well understood, there are also potential risks. Most of these risks, such as those associated with nutrients, metals, and pathogens are well studied and understood, and are managed through storage, application, and monitoring regulatory compliance (BCWWA 2016, CCME 2012b). In BC, efforts to limit exposure to potentially harmful substances, includes requiring oversight by a qualified professional, minimizing public access to the treated areas, assigning setbacks from water sources, and mandatory wait periods for product harvest or grazing post- application for Class B biosolids (MoE 2017; refer to Section 3.1 for further information on BCs OMRR).

There are some potential risks however, such as those associated with emerging substances of concern (ESOC) that continue to be an evolving area of research (Hydromantis 2010, LRCS 2016). As such, these contaminants in sewage sludge and biosolids have become a focus of research in Canada and abroad. ESOCs include hormones, edocrine-disrupting chemicals, and pharmaceuticals and personal care products (PPCPs), and legacy organic contaminants include substances such as dioxins, polycyclic aromatic hydrocarbons (PAHs) and phthalates. These substances are largely introduced in municipal waste streams from anthropogenic sources. A growing body of evidence indicates a wide range of contaminants are ubiquitous in municipal biosolids at low concentrations (Hydromantis 2009, 2010, USEPA 2009).

Due to the growing interest in ESOCs in biosolids, the CCME commissioned a literature review to document the occurrence of a wide range of contaminants in biosolids, as well as a sampling study to focus on treatment process effectiveness in lowering concentrations of ESOCs (Hydromantis 2009, 2010). Contaminants considered by the review included industrial chemicals, flame retardants, hormones, and PPCPs, among others. The study tested biosolids produced at 11 different sites across Canada and found that 14 of 71 pharmaceutical, alkylphenolic, and fragrance compounds tested for were found in detectable concentrations in more than 75% (greater than 9 of 11 sites) of the treated biosolids samples likely to be applied to land (Hydromantis 2010). The type and concentrations of contaminants identified during the study were similar to results found during the 2009 US Targeted National Sewage Sludge Survey (Hydromantis 2010). They also found biological treatment processes to be more efficient in reducing the concentration of ESOCs than non-biological processes. Of the biological treatment processes investigated, aerobic composting was more effective in reducing the concentration of ESOCs than mesophilic anaerobic digestion, which was more effective than autothermal aerobic digestion. Of the physical processes, the N-Viro alkaline stabilisation process appeared to most effective (Hydromantis 2010). A review of other studies suggests that biosolids treatment processes can decrease concentrations of certain contaminants; however some contaminants can persist or increase in concentration (Hydromantis 2009, CCME 2012b). A sampling study to measure legacy organics and emerging substances of concern is also being completed as part of the review of BCs OMRR, and is expected to be released in the summer of 2017 (MoE 2017).

A recent review by Ryerson University investigating the risks associated with land application of biosolids found that, in general, currently available evidence suggests that the risk posed by ESOCs can be considered low for the general public, particularly when compared to the risk posed in different contexts (e.g., human exposure to flame retardants is more likely to occur from a domestic source than from agricultural products grown in biosolids-amended soil). The review found that ESOCs had little to no negative impact on test plants, insects, bacteria and fungi present in agricultural land. The review also acknowledges the lack of data in this area of study and that the potential impact to public and environmental health is still not well understood (Ryerson University, 2015, BCWWA 2016).

Continued research is likely to contribute to a better understanding of the risks associated with ESOCs and legacy organics from the land application of biosolids, as well as an understanding on how treatment processes can reduce their concentrations. Another important aspect in the reduction of contaminants in biosolids is source reduction initiatives. Currently, source control and treatment initiatives are not generally in place for these contaminants, with the exception of pharmaceuticals, where some jurisdictions have developed pharmaceutical take-back programs (CCME 2012b). The British Columbia Medications Return Program, administered by the Health Products Stewardship Association, for example, provides a means for citizens to return unused and expired medication, reducing disposal into the wastewater stream (HPSA 2014, LRCS 2016).

The Capital Regional District has established a Regional Source Control Program to augment their sewer use bylaw. The CRD has developed several industry-specific Codes of Practice to improve the quality of industrial wastewater discharges into the municipal wastewater collection system, such a Code of Practice targeting the dental industry which requires the installation of dental amalgam separators in dental offices to reducing mercury loading (CCME 2012). King County is another jurisdiction with a source control program that requires industries to remove potentially toxic materials from their wastewater before discharging it to the sewer system (King County 2016a). Controlling contaminants at the source, where possible, is an effective way to improve the quality of biosolids.

3 BIOSOLIDS POLICY AND REGULATIONS

3.1 PROVINCIAL REGULATIONS

In BC, the land application of municipal biosolids is regulated by the British Columbia Ministry of Environment (MoE) through the Organic Matter Recycling Regulations (OMRR). The OMRR was enacted in 2002 to regulate, in part, the production, distribution, sale, storage, use, and land application of biosolids and compost, and is enabled under the *Environmental Management Act* (administered by the MoE) and the *Public Health Act* (administered by the Ministry of Health) (CCME 2010). Land applied biosolids within the Agricultural Land Reserve are considered through the *Agricultural Land Commission Act* (BCWWA 2016).

The purpose of the OMRR is to facilitate the recycling of organic material through land application and composting while protecting human health and the environment. During development of the regulation, a significant amount of knowledge and risk assessment information developed from other jurisdictions was used, including the US EPA biosolids risk assessment. The OMRR is a results-based regulation that provides a set of standards that users must abide by to be considered in compliance (CCME 2010, BCWWA 2016).

The MoE has produced a number of guidance documents to assist in ensuring compliance, including the Compost Facility Requirements Guideline (2004) and the Land Application Guidelines for the Organic Matter Recycling Regulation and the Soil Amendment Code of Practice: Best Management Practices (2008). As noted in Section 2, there are other management options for biosolids, including use in waste-to-energy processes (e.g., biogas capture and utilization) which are not covered under the OMRR. Typically, the authorization of these activities is captured under site-specific authorizations under the *Environmental Management Act* (BCWWA 2016).

Under OMRR, MoE requires a Land Application Plan (LAP) for the land application of biosolids. The LAP must describe the application site, the quality of the receiving soils, the class of biosolids being applied, the rate of biosolids application, and applicable setback distances. Additional information required includes biosolids stockpiling, site signage, and environmental monitoring requirements. Post application soil quality standards contained in the regulation are based on the land use (e.g., agricultural land, industrial land), soil pH, and other site-specific factors unique to the application site. The OMRR follows the 'professional reliance' model, therefore a Qualified Professional (QP) is required to produce and validate the LAP. A LAP is required for Class A and B biosolids and Class B compost, while Class A compost and Biosolids Growing Medium (Topsoil products) do not require a LAP (CCME 2010, BCWWA 2016).

Prior to the application of biosolids, notification must be given to the BC Ministry of Environment Director (except for Class A composts and growing medium), the medical health officer (before land application to agricultural land or in a watershed), and the Provincial Agricultural Land Commission (before land application within the agricultural land reserve). Upon review of the LAP, site-specific standards or management practices or other conditions may be specified by these parties. The landfilling and/or incineration of biosolids requires approval from the MoE Environmental Protection Division (CCME 2010).

The MoE is currently undertaking a comprehensive review of the OMRR, for the following purposes: a) to ensure the regulation remains protective of the environment and human health by reflecting advances in science and current practices, b) to support MoE's targets for reduction of organic waste disposal, and c) to align with BC's goal to reduce GHG emissions from waste (MoE 2017). Topics to be considered during the review include the opportunity for increased public transparency, improved facilitation of organics recycling, notification requirements for First Nations, and increased clarity regarding regulatory requirements (MoE 2016a). MoE invited feedback from stakeholders, First Nations, and interested parties on a set of proposed policies to update the regulation. MoE expects to amend and implement the revised regulation in 2017 (MoE 2016a).

In light of recent concerns over the impacts of land applied biosolids, MoE assembled a technical working group to conduct a scientific review of the subject. The scientific review resulted in a literature review and soil sampling study, both released in 2016 [A literature review of risks relevant to the use of biosolids and compost from biosolids with relevance to the Nicola Valley, BC (LRCS 2016); Biosolids Sampling Project – Results and Analysis (MoE 2016b)]. MoE is currently conducting a biosolids sampling study to measure various potential contaminants including legacy organics and ESOC, which is anticipated for release in 2017.

The MoE is evaluating the option of requiring that wastewater treatment plants perform periodic testing of their biosolids for select contaminants, including legacy organics and ESOCs (MoE 2017). MoE is also conducting a risk assessment on the potential effects of biosolids land application on wildlife, including birds, and large mammals (MoE 2017). The results of the scientific review will inform the current review of the OMRR regulation.

3.2 FEDERAL POLICY

The Canadian Council of Ministers of the Environment (CCME) is comprised of the environment ministers from federal, provincial, and territorial governments. The CCME provides national guidelines for the beneficial use of biosolids through the Canada-wide Approach for the Management of Wastewater Biosolids. The Approach and the supporting "Guidance Document for the Beneficial Use of Municipal Biosolids, Municipal Sludge and Treated Septage" presents best management practices and encourages the beneficial use and sound management of municipal biosolids across the country (CCME 2012a). The management principles central to the approach are:

- Municipal biosolids, municipal sludge, and treated septage contain valuable nutrients and organic matter that can be recycled or recovered as energy.
- Adequate source reduction and treatment of municipal sludge and septage should effectively reduce pathogens, trace metals, vector attraction, odours, and other substances of concern.
- The beneficial use of municipal biosolids, municipal sludge, and treated septage should minimize net greenhouse gas emissions.

- Beneficial uses and sound management practices of municipal biosolids, municipal sludge, and treated septage must adhere to all applicable safety, quality, and management standards, requirements, and guidelines (CCME 2012a).

The CCME developed Guidelines for Compost Quality in 2005. The compost guidelines include two compost categories (A and B), which are based on safety criteria, including foreign matter, maturity, pathogens and pathogen indicators, and trace elements. The CCME guideline allows for the unrestricted use of compost that meets Category A criteria, whereas Category B compost has a restricted use allowance and may require additional control when deemed necessary by a province or territory. The compost guidelines apply to compost produced from any organic feedstock as determined by regulatory agencies (CCME 2010).

The Fertilizers Act and Regulations, administered by the Canadian Food Inspection Agency (CFIA), regulates the sale and import of biosolids products intended for use as a fertilizer or soil amendment. However, it does not regulate the production, use (including land application), disposal, or non-sale distribution (e.g., give away programs) of fertilizers and soil supplements, including biosolids products (CCME 2010).

Within Canada, provinces manage the maintenance and operation of wastewater treatment and/or composting facilities, and also the processing, use, and disposal of biosolids including land application, through provincial/territorial acts and regulations. For further information on the regulations of other provinces and territories refer to the CCME document, "A Review of the Canadian Legislation Framework for Wastewater Biosolids" (2010).

4 EMERGING TRENDS IN BIOSOLIDS REUSE

Policies and regulations regarding the land application of biosolids have been established in many regions of the world, including Canada, the US, and the United Kingdom. In countries where land application of biosolids is a common reuse option, there is an increasing shift towards the production of higher quality biosolids products, particularly transitioning from Class B to Class A biosolids programs. This is because Class A biosolids programs show more promise in meeting sustainability and public outreach goals in increasingly sensitive political climates, while providing more versatile distribution options (Clark et al. 2017, Newell 2017). Class A biosolids programs can take many forms, with products ranging from compost to dried pellets (refer to Section 5 for Class A biosolids program case studies).

There is a growing desire by many municipal wastewater treatment utilities to not only generate biosolids products for beneficial reuse, but to also make wastewater treatment plants energy neutral. This desire is fueled by the increased cost of power and fuel, as well as changing targets and stricter regulations for greenhouse gas emissions. The use of anaerobic digestion to process biosolids is becoming increasingly common throughout the world (Vasileski 2007, Deslauriers 2017). The biogas generated through anaerobic digestion is also increasingly being captured and converted to energy, for use by wastewater treatment plants, or fuel (e.g., compressed renewable natural gas) (Vasileski 2007, Deslauriers 2017, Panter and Barber 2017). Additionally, thermal processing options such as gasification and pyrolysis, which are being used in countries such as Germany and Japan, are now emerging processes in North America. These biosolids processing options produce process gas that can be converted into energy, while producing a potentially beneficial biochar or ash product and fewer emissions than incineration (CCME 2012b).

In 2017, the theme for the Water Environmental Federation (WEF) Residuals and Biosolids Conference held in Washington State was, 'The Future of Biosolids and Bioenergy'. The conference included presentations on new technology and emerging trends in biosolids management in North America. Case studies presented at the conference are summarized below to highlight how jurisdictions are integrating emerging technologies into their biosolids programs.

4.1 BIODESIEL PRODUCTION

In recent years, there has been increasing interest in biodiesel as a renewable alternative to fossil fuels. Biodiesel is produced from either animal or vegetable fats, which are converted to a combustible methyl ester fuel by a process known as transesterification (Mekhilef et al. 2011, Crawford et al. 2012). Commonly, plant species with a high content of oil in the seed (oilseeds) such as soy and canola are used as biodiesel feedstocks. There is interest from some municipal biosolids programs to use biosolids fertilizers to grow biodiesel crops to fuel municipal vehicle fleets or farm equipment. Fuel crop production on valuable agricultural land however, is not without some controversy (Pimental et al. 2009). Research into methods to produce biodiesel without occupying arable land is ongoing (Crawford et al. 2012).

4.1.1 CITY OF RALEIGH, NORTH CAROLINA

The City of Raleigh Public Utilities Department's Neuse River Resource Recovery Facility provides wastewater treatment to Raleigh and six surrounding communities. The Neuse facility produces approximately 40 dry tons of aerobically digested biosolids per day (McDilda 2009, City of Raleigh 2016a). Approximately 10% of the aerobically digested biosolids remain as Class B biosolids and are liquid land applied; about 55% are converted to a Class A biosolids fertilizer, named Raleigh-Plus, through a lime-stabilization process; and the remaining 35% are mixed with woodchips and composted by an independent company (McDilda 2009). Refer to Section 5.3.4 for a detailed summary of the City of Raleigh's biosolids beneficial reuse program.

In 2010, the City of Raleigh expanded their biosolids program to incorporate the production of biodiesel to fuel farming equipment (City of Raleigh 2016b). The City received funds under a state grant ("Priority 2: Civic and Small-scale Biofuels") to better understand the costs and benefits associated with biofuel production on municipal lands. A pilot study was initiated in 2010 to determine if sunflower was a viable crop for the production of biodiesel. The City planted 27 acres of sunflowers fertilized with effluent irrigation and Class A and B biosolids applications. The City produced 4,762 litres of biodiesel from processing the sunflower seeds, though third party, Piedmont Biofuels Inc. (City of Raleigh 2016b). An important lesson learned was the unanticipated cost of crushing seed and lack of available local processors and associated transportation costs. It was originally thought that a biodiesel processor would be built in an existing building at the Neuse facility, however escalating costs for retrofitting a building with the necessary utilities combined with transportation costs resulted in the decision to pursue a mobile processor (City of Raleigh 2016b).

The City purchased a 46-foot-long trailer and installed a mobile biodiesel production system. The City, through a competitive bid process, awarded New Earth Fabricators a contract for the design, fabrication, and necessary training for a mobile processor. The Mobile Biofuel Processor cost approximately US $178,350, excluding staff resources, and was funded through an initial state grant and additional funding from the City's Sustainability Fund and Public Utilities Department (City of Raleigh 2016b). The trailer can produce biodiesel on-site in any location and is also useful as a demonstration tool for educational purposes (City of Raleigh 2016b).

Currently, the department uses between 49,000 and 95,000 litres of diesel fuel annually to power the equipment it uses to farm land (Rodgers 2016). The City did a study in association with the Biofuel Center of North Carolina, NC State, and some other partners which estimated that with the City's current farming practices and crop production they are capable of producing 74,950 litres of biodiesel per year. The City did a study in association with the Biofuel Center of North Carolina, NC State, and some other partners which estimated that with the City's current farming practices and crop production they are capable of producing 74,950 litres of biodiesel per year.

During the summer of 2016, staff at the Neuse facility expected a 3,000 bushel sunflower harvest for the fall, with a soybean harvest to follow. Soybeans were expected to be pressed and converted into biodiesel as early as spring 2017 (City of Raleigh 2016c). The city is looking forward to increased production of biofuel over time for use in their farming equipment. The city provides biodiesel program updates to interested citizens through the City of Raleigh's Biosolids Program Facebook page (City of Raleigh 2016c).

4.2 BIOGAS UTILIZATION

The anaerobic digestion of sewage sludge to produce stabilized, low pathogen content biosolids is a common pre-treatment at wastewater treatment plants worldwide (Vasileski 2007). Following anaerobic digestion, biosolids can be dewatered and land applied or directed into further biosolids processing options such as thermal drying, composting or alkaline stabilization. Over the past decade, biogas utilization from the anaerobic digestion process has become a high priority and major component of energy recovery in both large-scale and small-scale wastewater treatment facilities. Initially, the utilization of biogas energy recovery focused on combined heat and power (CHP) systems, also known as co-generation (NACWA 2010). However, advances in gas cleaning technologies are now providing an alternative to electricity and heat generation in the form of renewable natural gas (RNG) production (Le et al. 2017). In North America, there are a number of projects underway that convert excess biogas, not required for the energy needs of the facility, into RNG for sale to a gas utility or use in natural gas fuelled vehicles. In addition to the examples below, refer to Section 5.3.4 for the City of Raleigh's biogas utilization plan.

4.2.1 CITY OF PORTLAND, OREGON

Portland's Columbia Boulevard Wastewater Treatment Plant has been in operation since the early 1950's and now serves most of Portland, with a population of more than 600,000 people (City of Portland 2017a). Since 1990, the city has applied biosolids to dryland pasture, dryland small grains, and irrigated small grains at Madison Ranches near Echo, Oregon. In 2010, the city also began applying some of its biosolids on farmland near Wasco in Sherman County. The farmers pay a fee for the biosolids and these funds support biosolids studies at Oregon State University (City of Portland 2017a). Portland uses anaerobic digestion to stabilize their biosolids (15 days at 95˚C) prior to land application. Through the anaerobic digestion process, the Plant produces 600 million cubic feet of biogas annually (55-65% methane content) (City of Portland 2017b, Han et al. 2017). Currently, more than three quarters of the biogas is captured and beneficially used, while the remaining amount is flared. Biogas is used in boilers for digester heating and various heating uses onsite (16%), in co-generation systems to offset power usage (41%), and is sold untreated to a nearby roofing manufacturing facility (20%) (Han et al. 2017).

The City of Portland has a goal to become a leading city in green energy and sustainability. One initiative the City has committed to is using biogas capture and beneficial use from wastewater treatment. In 2009, the Plant installed two 850 kilowatt GE/Jenbacher engine-generators (co-generation) with a total generating capacity of 1.7 megawatts, which now supplies approximately 40% of the plant's electrical needs (City of Portland 2017b). The biogas used for co-generation is treated to remove hydrogen sulfide, moisture, and siloxane, to meet required engine specifications. In 2011, Portland participated in an Oregon Department of Energy biogas feasibility study, which evaluated the feasibility for biogas use at wastewater treatment plants in Oregon (Han et al. 2017).

The recommendations for the Columbia Boulevard Wastewater Treatment Plant were to consider adding co-generation capacity and also consider producing renewable Compressed Natural Gas (Han et al. 2017). These recommendations were used in the development of the Biogas utilization/upgrade project, which started in 2013, originally as a cogeneration expansion project, with the intention of evaluating other options for biogas use. Over time, the project became a Renewable Natural Gas (RNG) to vehicle fuel project due to the economics and benefits of offsetting fossil based vehicle fuel (Han et al. 2017).

The overall goals for the Biogas utilization/upgrade project included devising a plan that:

1. made best beneficial use of remaining biogas
2. maximized ratepayers' benefits
3. optimized return on investment with best balance of risk and reward, and
4. aligned with the City's goals, policies, and Climate Action Plan (Han et al. 2017).

With these goals in mind, the City hired a consulting firm to perform a triple-bottom line analysis (financial, environmental, and social) for various alternative uses of the biogas, including co-generation expansion, biogas treatment for vehicle use, biogas treatment for sale to industry, and biogas use in biosolids drying. The analysis indicated that the best beneficial use of the flared biogas is for it to be used for vehicle fuel. A regional factor that affected the analysis was that Oregon's electrical grid emission intensity is low due to availability of hydropower and renewables, thus renewable energy though co-generation was not as compelling, compared to renewable fuel (Han et al. 2017).

After determining the direction of the project, many challenges still remained as there is currently no infrastructure and market for RNG in the Pacific Northwest. Early concepts included building commercial fueling stations and trucking RNG to retailers and wholesalers, however there were too many associated logistical and access challenges (Han et al. 2017). The City approached a local distribution company, NW Natural, for a partnership on pipeline injection and RNG delivery. Once RNG is injected into the NW Natural pipeline, it can be transported though a vast pipeline network, including out of state. It is anticipated that RNG will be sold to out-of-state markets initially as there is no RNG vehicle fuel market or infrastructure in Oregon. However, the city plans to develop a local market over time to keep the consumption of renewable and sustainable energy local (Han et al. 2017). To this end, the City is going to build a Renewable Compressed Natural Gas (RCNG) fueling station onsite for some vehicles in its fleet. The City is also considering organic wastes, primarily food waste, as additional feedstocks to augment biogas production, which will improve the project return on investment (Han et al. 2017).

The project is expected to cost US $11 million (City of Portland 2015). In 2015, the City secured an ODOE Alternative Vehicle Fuel Infrastructure tax credit for approximately US $1.6 million to offset costs. It is anticipated that construction of the biogas treatment facility will start in summer 2017, with RNG available in the fall 2018 (Han et al. 2017).

4.2.2 GRAND JUNCTION, COLORADO

The Persigo Wastewater Treatment Plant, jointly owned by the City of Grand Junction and Mesa County, Colorado, serves a population of approximately 60,000 people. The Plant treats approximately 31 million litres of wastewater daily through two anaerobic digestion tanks (primary and secondary treatment) (City of Grand Junction 2016). Until recently, biogas captured from the anaerobic digestion process was flared. In 2014, after many years of planning, city officials contracted BioCNG LLC to design, build, and operate a system to capture, collect, and purify biogas to create renewable natural gas (RNG) for use as vehicle fuel (City of Grand Junction 2016). As part of the project, BioCNG also designed and installed an option to preferentially use biogas in the WWTP digester boiler instead of natural gas, thereby saving on treatment plant operating costs, while also producing a low emissions vehicle fuel (Tetra Tech 2017).

The biogas-to-fuel project, Colorado's first, began operations in the spring of 2015. Approximately 1,740 gasoline litre equivalents are produced daily and piped 10 kilometers to an existing Compressed Natural Gas (CNG) fueling station (City of Grand Junction 2016). The CNG fuel, which achieves greenhouse gas emission reductions of 80% or more compared to gasoline or diesel, is then used to fuel municipal natural gas vehicles. As of summer 2016, 46 vehicles were being powered by the natural gas fuel including garbage trucks, dump trucks, pick-ups, and sedans, as well as 10 Grand Valley Transit regional buses, which already had natural gas engines installed (City of Grand Junction 2016). It is estimated that the project will eliminate the equivalent of approximately 636,000 litres of gasoline and diesel per year. The primary drivers for the project were fuel savings and the long-term fixed costs of renewable CNG fuel versus diesel and environmental credits generated under the EPA's Renewable Fuel Standard. The total project cost, including the installation of the needed pipeline infrastructure, was approximately US $2.8 million with an estimated payback period of seven to nine years (City of Grand Junction 2016, Day 2016). The project was funded in part by a $500,000 state grant from the Colorado Department of Local Affairs (Day 2016). The utility will charge US $1.50 per gallon to the city until the project is paid off, after which the price will be renegotiated to provide long-term savings at a stable price (Day 2016). In 2015, the project received a Natural Gas Vehicles for America Industry Achievement Award (Tetra Tech 2017).

A biosolids composting pilot program began in 2000 to divert biosolids produced through anaerobic digestion at the Persigo Plant from the local landfill. The program experienced some initial challenges, but after visiting other successful composting facilities, arrived at a productive composting formula (MCPC 2001). Mesa County ran the biosolids composting program from 2005 to 2010, when the program was discontinued because of problems with public perception, odour complaints, and a lack of market for the compost (McIntyre 2015, Mesa County 2017).

4.3 THERMAL HYDROLYSIS / BIOLOGICAL HYDROLYSIS

The desire to improve wastewater treatment plant operational sustainability has also led some utilities to explore options to increase the biogas generation from their anaerobic digesters. A number of pre-treatment processes can be used in conjunction with anaerobic digestion to improve digestion performance and enhance energy recovery from biogas (Peters et al. 2017, Theodoulou et al. 2017). Thermal hydrolysis, for example, is a two-stage pre-treatment process combining high-pressure boiling of wastewater sludge followed by a rapid decompression. The combined action makes the sludge more biodegradable, increases digester organic loading rates, produces more biogas, increases the de-waterability of the sludge, and sterilizes the sludge improving pathogen reduction (Peters et al. 2017).

4.3.1 CALGARY, ALBERTA

Bonnybrook Wastewater Treatment Plant is the largest of Calgary's three wastewater treatment plants, with capacity to treat the wastewater from approximately one million people (City of Calgary 2017). Over the past few decades, Calgary's population has steadily increased. To address this growth, the City must expand its wastewater treatment capacity. Currently, the treatment plant manages sewage sludge through mesophilic anaerobic digestion to produce stabilized biosolids and biogas. The digested biosolids are stored in storage lagoons during the year and used in the Calgro Class B biosolids agricultural land application program during the summer months (Peters et al. 2017). Biosolids generation at the Plant is estimated to increase from the current volume of 18,000 to 23,000 tonnes dry solids per year to 35,000 tonnes dry solids per year by 2030 to 2035. However surrounding agricultural lands can only accept biosolids at a rate of 11,500 to 22,000 tonnes dry solids per year. The City is currently constructing a dewatering facility at the Bonnybrook Plant and an off-site composting facility to address the shortfall between biosolids generation and Class B biosolids land application capacity (Peters et al. 2017). Biogas generated through digestion is captured and used in a combined heat and power (CHP) system to generate energy for the plant (Peters et al. 2017).

As part of the City's planned plant expansion, increased sludge handling capabilities are required in part due to the greater volume of waste solids generated by the expanded plant. A number of alternatives for solids stream treatment were considered during Conceptual Design phase and evaluated using a triple-bottom-line assessment (Peters et al. 2017). Economic and non-economic considerations were included in the assessment, including reliability, operations and maintenance factors, and future proofing (ability to move to a Class A biosolids product in the future). Three solids handling alternatives were short-listed, including:

1. conventional mesophilic anaerobic digestion
2. acid gas digestion, and
3. thermal hydrolysis of the secondary sludge.

Of these options, thermal hydrolysis process (THP) of secondary sludge presented the most significant advantages in increasing solids treatment capacity for the plant (Peters et al. 2017).

One of the key reasons that thermal hydrolysis of secondary sludge was chosen, instead of thermal hydrolysis of both primary and secondary sludge, is that Class A biosolids are not currently required for land application programs in Calgary (Peters et al. 2017). Additionally, thermal hydrolysis of secondary sludge only requires a smaller, less costly facility while still realizing most of the benefits of thermal hydrolysis of the plant's sludge. These benefits include reduced sludge viscosity, pathogen reduction, increased volatile solids reduction, increased biogas production and, increased de-waterability of digested sludge. An additional key advantage is the elimination of the need for future digesters when considering expansions over the short and longer term (Peters et al. 2017). The addition of the process allows two small digesters and one large digester at the plant to be put into retirement which could accommodate future loads as the city grows. The thermal hydrolysis option is also readily reconfigurable to produce Class A biosolids should regulations for land application change, thereby providing process flexibility. Following a thorough analysis of potential venders, Cambi (CambiTHP) was selected as the successful thermal hydrolysis supplier. While there are many thermal hydrolysis systems in operation in the world, particularly in Europe, there are no comparable references in Canada. Detailed design of the project began in August 2016 and is expected to be completed in the summer of 2017 (Peters et al. 2017).

4.3.2 AVONMOUTH, ENGLAND

Biological hydrolysis is an anaerobic digestion enhancement technology, primarily used in England, that can be retrofit into existing wastewater treatment plants or included in the construction of new plants to increase anaerobic digester efficiency. Primary motivators for plants to install biological hydrolysis systems include:

1. maximizing digester efficiency, allowing for plant capacity expansion with existing anaerobic digestion infrastructure,
2. increasing biogas production with existing infrastructure to produce electricity through combined heat and power systems to supply plant electricity needs, and
3. producing an enhanced biosolids product that achieves up to a six-log reduction in pathogen content (Theodoulou et al. 2017).

The Avonmouth Wastewater Treatment Plant implemented biological hydrolysis in 2008. Prior to the installation, the plant was treating its own sewage sludge and sludge from neighbouring facilities. However only 51% of the total sewage sludge treated was anaerobically digested (Theodoulou et al. 2017). A series of upgrades at the plant, including the biological hydrolysis system installation, resulted in the entire sludge volume being treated through existing anaerobic digestion infrastructure in addition to the co-digestion of 40,000 wet tonnes per year of pre-processed food waste. The biological hydrolysis system enables close to double the digester organic loading rate than their previous system.

The increase in sludge digestions, paired with the addition of the digestion of 40,000 wet tonnes of food waste per year, resulted in a tripling of the biogas produced (Theodoulou et al. 2017). This increase was aided by the fact that the biogas yield from food waste is between 1.5 to 2 times higher than that of municipal sewage sludge. The increased biogas production enables the plant to make up to 5.75 MW of renewable energy through its combined heat and power engines. For example, prior to the biological hydrolysis install, the plant digested 18,360 dry tonnes of sludge per year and produced 1,900 kW of renewable electricity. After the install, the plant digested 36,000 dry tonnes of sludge and 40,000 tonnes of food waste per year and produced 5,750 kW of renewable electricity (Theodoulou et al. 2017).

In this example, the addition of biological hydrolysis in the plant's treatment process enabled the plant to import both additional wastewater sludge and food waste into the anaerobic digestion process stream using existing infrastructure. The digestion of the additional organics produced sufficient biogas to convert enough renewable electricity to supply the electrical requirements of the plant, leaving some excess, which is sold to the national grid (Theodoulou et al. 2017). The biological hydrolysis process also aids in pathogen load reduction in the resulting biosolids. As is the prevalent practice in Britain, biosolids produced through the biological hydrolysis and anaerobic digestion treatment process are dewatered and beneficially reused through agricultural land application.

4.4 GASIFICATION

There is growing interest in gasification as a means to significantly reduce biosolids volume while producing renewable energy and reducing fossil fuel consumption. The gasification of sewage sludge or biosolids produces syngas which can be converted into an energy source and ash/char, while producing significantly fewer emissions than conventional combustion processes, such as incineration (NACWA 2010). The ash or a biochar produced can be disposed of in landfills or potentially used as soil amendment (CCME 2012b). The use of gasification at wastewater treatment facilities is relatively new in North America, with a number of pilot studies undertaken since 2003 and continuing to present day (Jones 2017). Although a few exclusive sewage sludge gasifiers are in use (e.g., Balingen, Germany), most gasification systems utilize multiple feedstocks, such as biosolids, wood waste, and residential solid waste (e.g., City of Lebanon, Tennessee).

4.4.1 ANCHORAGE, ALASKA

The John M. Asplund Wastewater Treatment Facility located in Anchorage, Alaska treats wastewater from the City of Anchorage, sewage sludge trucked in from other nearby treatment plants, and the wastes from nearby fish processing plants (Jones 2017). The Facility processes dewatered primary sludge in a multi-hearth incinerator, which is fired with natural gas, and the resulting ash is disposed of in landfill. Due to the facility's age, the Anchorage Water and Wastewater Utility will soon be deciding on whether to replace several worn incinerator components, or to replace the incinerator entirely.

Under the US Sewage Sludge Incineration Rule (SSI Rule), upgrading or installing a new incinerator will trigger more stringent stack exhaust emissions standards (Jones 2017). The manpower and emissions testing associated with achieving compliance with the existing air emissions permit for the incinerator already represents a significant cost to the utility, and those costs are only expected to increase under more stringent emissions standards.

As a result, the city began looking at treatment alternatives to incineration. Other common treatment options, such as anaerobic digestion and composting, are not practical for Alaska due the cold climate and remote community locations (Jones 2017). To this end, the city is considering sewage sludge gasification as a viable alternative to incineration, which is not subject to the SSI Rule. Gasification provides a treatment alternative that reduces waste volume to a similar extent as incineration, while also producing cleaner air emissions and syngas that can be used to generate heat and electricity for the treatment facility (Jones 2017).

In the pursuit of gasification as an alternative to incineration, the City of Anchorage is conducting a full scale trial on an operational gasifier in Balingen, Germany (fluidized bed gasifier) to measure the yield of syngas and heat energy per pound of Anchorage biosolids (Jones 2017). For the study, the Utility rented a pilot scale multi-tray dryer from Wyssmont, which processes dewatered sludge cake and produces a product that is 90% dry solids. Once dried, the sludge was loaded into plastic lined supersacks and shipped to Germany. A team of engineers from Anchorage are currently in Germany conducting the gasifier testing (Jones 2017). It was decided that full scale testing was the most appropriate way to predict the performance of a sewage sludge gasifer processing Anchorage's sewage sludge. The testing will quantify the energy generation potential of the gasifier and provide a better understand of emission characteristics. This data will be used in the development of economic and practical recommendations regarding the installation of a gasifier at the treatment facility (Jones 2017).

Currently, there are no gasifiers in the United States that operate only on sewage sludge. Other operational gasifiers require the addition of other feedstock materials, such as wood waste, waste plastics, or solid waste (Jones 2017). The successful implementation of a sewage sludge gasifier in Anchorage would be expected to offer significant energy savings, while producing cleaner air emissions. It would also provide a North American example for other municipalities looking to eliminate their incinerators in favour of gasification.

Balingen, Germany: The fluidized-bed gasification demonstration plant, manufactured by Kopf, was constructed in 2002 at Balingen's Wastewater Treatment Plant to process digested sludge and recover energy. The fluidized-bed gasifier operates only on sewage sludge (Jones 2017). In 2010, the plant was rebuilt to accommodate a larger throughput (Judex et al. 2012). Kopf gasification technology combines a solar drying unit, fluidized bed gasification unit, gas engine unit for energy recovery, and post combustion chamber for burning excess syngas. The solar drying unit dries wet digested sludge to a solid content of between 70 and 85% over two to eight weeks, depending on weather. The Balingen Plant processes approximately 160 to 180 kg of dry digested sewage sludge per hour, and produces approximately 85 kg of ash and 300 m^3 of exhaust per hour. Approximately 0.5 kWh of electricity is produced per kg of total solids processed, with 0.1 kWh per kg of total solids processed used for the gasification process and the remaining 0.4 kWh is used by the plant (USEPA 2012). Ash generated during the gasification process is used as a bed material or is used in a variety of other ways such as road filling (Judex et al. 2012).

4.4.2 CITY OF LEBANON, TENNESSEE

The City of Lebanon, Tennessee, is located 40 km east of Nashville and has a population of approximately 28,600 people. As an expansion of the city-wide 'Think Green - Think Clean Initiative', the City of Lebanon has recently completed the construction of a waste-to-energy system sited at the City's wastewater treatment plant (City of Lebanon 2017, Snyder 2017). The new system will consolidate three waste streams, including biosolids, wood waste, and used tires, and convert it into electricity for use at the treatment plant. The new waste-to-energy system combines a biomass gasification system with thermal oxidation and an Organic Rankine Cycle (ORC) power generator to produce electrical power with emission levels comparable to natural gas combustion (Snyder 2017).

The downdraft gasifier used in the system was designed, engineered, and installed by Aries Clean Energy (formerly PHG Energy), a Tennessee-based company. The gasifier can accommodate a broad range of feedstock giving the City flexibility in handling its waste streams over its 25 year operating life. Initially, the feedstock for the system will be 10% biosolids, 10% tires, and 80% wood waste (Snyder 2017). The thermal oxidizer used in the system includes an attached hot water heater that transfers the energy from the thermal oxidizer's exhaust flue stream into a closed loop circulating stream of hot water. The hot water stream carries the heat energy into the ORC generator, where it drives the ORC's closed-loop power generation (Snyder 2017). Aside from the syngas, the gasification process also creates biochar. Approximately 32 tons of biosolids, tires, and wood waste will be processed daily, producing approximately 1.6 tonnes of biochar (Snyder 2017).

Prior to the completion of the waste-to-energy project, the City disposed of approximately 3 tons of anaerobically digested biosolids per day through land application and disposed of 27 tons per day of wood waste at the regional landfill. At these volumes, more than 1,680 round trips per year were needed to dispose of these waste streams via truck (Snyder 2017). The City's wastewater treatment plant also used energy from a municipal electrical distribution utility at an average cost of $0.10/KW. The new waste-to-energy system should conservatively generate 748MW-hrs annually, yielding approximately US $75,000 per year in electrical energy savings. The shutdown of the advanced thermophilic anaerobic digestion system will also contribute an additional US $175,000 per year in electricity savings. It is expected that US $248,000 per year will be saved through removal of costs associated with landfill tipping fees, labour, and fuel costs required for biosolids land application. The City also plans to add an additional revenue stream, through marketing the biochar as a soil amendment (Snyder 2017).

Overall, the waste-energy gasification project is expected to provide the City of Lebanon with a net savings of US $300,000 annually, and at least US $6 million during its operational lifetime, through avoiding costs and gaining operational efficiencies, while simultaneously meeting the goals of the Tennessee Department of Environment and Conservation Energy Program (Synder 2017).

4.4.3 DISTRICT OF DELTA DIABLO, CALIFORNIA

The District of Delta Diablo provides water resource recovery services for the City of Antioch, the City of Pittsburg, and the unincorporated community of Bay Point, California, serving a population of close to 200,000 (Delta Diablo 2017). The District treats sewage sludge generated through the wastewater treatment process via anaerobic digestion and centrifuge dewatering prior to land application as a biosolids fertilizer.

The district is the lead agency of the Bay Area Biosolids to Energy Coalition (Delta Diablo 2017). One of the main goals of the Bay Area Biosolids to Energy Coalition is to harness the energy in the biosolids and convert it to electricity and other useful energy products (Delta Diablo 2017). To this end, Delta Diablo, in partnership with Mt. Diablo Resource Recovery, is in the process of evaluating Aries Clean Energy's (formerly PHG Energy) downdraft gasification technology to determine project size, phasing, optimal feedstock ratios, and needed support infrastructure (Deslauriers 2017). The technology is similar to that used by the City of Lebanon, Tennessee. The District is evaluating project locations and working towards obtaining an air permit for the gasification technology (Deslauriers 2017). It is estimated that total project costs, from planning and design to construction will be approximately US $10 million.

Initially, the Gasifier system will process 7,750 tons of wood waste per year (1 truck/day) and 2,480 wet tons per year of biosolids (25% of Delta Diablo biosolids) and the syngas generated will be converted into approximately 467 KW of electricity. The energy generated by the gasification process, paired with the energy generated through anaerobic digestion, will eliminate the need for additional energy inputs at the treatment plant and will reduce greenhouse gas emissions by 85% (Bay Area Biosolids 2016a, Deslauriers 2017). The process will reduce biosolids volume by up to 93% and will produce a char product (Bay Area Biosolids 2016).

4.5 PYROLYSIS

Pyrolysis is an emerging technology in biosolids management that has been found to minimize air emissions and remove pathogens and pollutants, while generating syngas that can be converted to energy and biochar, a soil amendment (Liu et al. 2017). While there are still few examples of biosolid pyrolysis projects in North America, there is recognition that biosolids can serve as a renewable energy source to offset energy requirements at waste treatment facilities. Pyrolysis projects, such as those being investigated by the Bay Area Biosolids to Energy Coalition are aiming to provide viable, year-long alternatives to land application programs that go beyond biosolids-to-energy goals by also seeking to recycle biochar back into the environment (Deslauriers 2017).

4.5.1 DISTRICT OF DELTA DIABLO, CALIFORNIA

The District of Delta Diablo provides water resource recovery services for a population of approximately 200,000 people (Delta Diablo 2017). The District is the lead agency in the Bay Area to Biosolids Coalition, a collaborative effort to create options for local sustainable biosolids management (Delta Diablo 2017). In addition to investigating gasification as a biosolids management option (refer to Section 4.4.3), Delta Diablo, in partnership with Mt. Diablo Resource Recovery, is also evaluating Anaergia's pyrolysis technology to determine sizing, phasing, and needed support infrastructure (Anaeriga 2016, Deslauriers 2017).

The goal of the Delta Diablo pyrolysis project is to divert food waste from the landfill and convert it into clean energy and fertilizer using co-digestion, biosolids drying, and low temperature pyrolysis (Anaeriga 2016). An Anaergia's Organics Extrustion Press would sort food waste from municipal solid waste at Mt. Diablo Resource Recovery, creating a clean and digestible feedstock for anaerobic digestion. This feedstock would be trucked to Delta Diablo where it would be co-digested with municipal wastewater sludge to create biogas and biosolids (Anaeriga 2016).

Biogas produced during the anaerobic digestion process would be captured and converted to electricity. The digested biosolids would be processed through a low temperature dryer/pyrolysis system to produce a Class A biochar fertilizer product and bio oil. The bio oil would be fed back continuously to the digesters to create additional energy or stockpiled to generate energy during peak demand periods (Anaeriga 2016).

The project is anticipated to process 33 tons of anaerobically digested biosolids per day and 80 tons of food/organic waste per day into a Class A high-nutrient biochar fertilizer product and 2.2 MW of electricity. This would result in diverting 22,880 tons of food and organic wastes from landfills, reducing greenhouse gas emissions, and producing enough electricity to take Delta Diablo off the grid (Anaeriga 2016, Deslauriers 2017).

4.5.2 SILICON VALLEY CLEAN WATER, CALIFORNIA

Silicon Valley Clean Water is a Joint Power of Authority governed by four jurisdictions (Redwood City, West Bay Sanitary District, City of San Carlos, City of Belmont) that serves more than 200,000 people and businesses (SVCW 2012). Silicon Valley Clean Water's Wastewater Conveyance System takes wastewater from each jurisdiction collection system and transfers it to the wastewater treatment plant located in Redwood City. The plant processes sewage sludge generated during wastewater treatment though anaerobic digestion, producing biosolids. The biogas produced during the digestion process is captured and converted into electricity used by the plant (SVCW 2012).

Biosolids are dried by either rotary press or solar drying and used as an agricultural soil conditioner, a feedstock for composting, or daily cover at a landfill (SVCW 2012). The Silicon Valley Clean Water is a member agency of the Bay Area Biosolids Coalition which has a goal of better harnessing the energy in the biosolids and converting it to electricity and other useful energy products. To this end, Silicon Valley Clean Water has partnered with BioForceTech Corporation to develop a clean, green, sustainable method of handling biosolids using biosolids drying and pyrolysis. Goals of the project include maximizing energy potential from biosolids, reducing biosolids transportation by 90%, and producing a high value biochar soil amendment (Bay Area Biosolids 2016b).

After more than two years of successful pilot studies, a 10-year service agreement was executed between Silicon Valley Clean Water and BioForceTech Corporation in 2016, for the construction of a full-scale facility that will treat 7,000 wet tons of biosolids per year (Bay Area Biosolids 2016b; BioForceTech 2017). The estimated cost for the project, from planning to construction and start-up is US $9.9 million. The facility is under construction and start-up is anticipated in spring 2017, when approximately half of the biosolids produced by the treatment plant will be delivered to the new facility (Deslauriers 2017). Once delivered, the biosolids will be dried using BioForceTech's innovative BioDryer process, which requires 70% less heat energy and 50% less electrical energy than a gas dryer. Afterwards, the dried biosolids will be processed via pyrolysis which produces syngas and biochar as byproducts, decreasing biosolids volume by up to 90% (BioForceTech 2017, Deslauriers 2017). The syngas will be captured and converted into heat and electricity for the facility, while the biochar is anticipated to be sold in bulk as a soil amendment (BioForceTech 2017).

4.6 INCINERATION

Incineration is commonly thought of as an environmentally unfriendly biosolids processing option due to high energy input requirements, high greenhouse gas emissions, and an ash product which is most commonly landfilled, thereby not returning useful nutrients in biosolids back to the environment. Recently, however, incineration is being viewed as a more attractive process by some jurisdictions as technical and process improvements become available, such as more efficient heat recovery and power generation. Modern incineration systems are being designed to achieve strict emission limits while also being energy efficient (Hancock et al. 2017, CIMA 2016a).

The City of Toronto has recently chosen to replace their aging incineration facility at the Highland Creek Treatment Plant with new Fluidized Bed Incinerators paired with state-of-the-art emissions scrubbing technology (refer to Section 5.2.3; CIMA 2016a).

4.6.1 CLEVELAND, OHIO

The Southerly Wastewater Treatment Center, owned and operated by the North East Ohio Regional Sewer District, serves more than 600,000 people living in the greater Cleveland area. Prior to recent upgrades at the center, four multiple hearth incinerators, powered by natural gas, were used to incinerate the District's biosolids (Hancock et al. 2017). In the early 2000's, the District decided that it wanted to replace its multiple hearth incinerators with three Fluidized Bed Incinerators coupled with a heat recovery system. The new system would also include a new chemical conditioning system and nine new high solids dewatering centrifuges. In 2008, the district assembled an expert panel to review and provide comment on their Residuals Study (2005) and Biosolids Handling and Incinerator Project Proposal (2007) (NEORSD 2008). The panel believed that fluidized bed incineration with waste heat recovery was the most viable, cost-effective, and environmentally friendly long-term biosolids management option for the District (NEORSD 2008, Hancock et al. 2017).

The District estimated that a fluidized bed incineration system with waste-heat recovery would result in US $1 million in savings per year compared to the existing system by reducing the natural gas consumption by 98%. Initial construction costs were estimated to be between US $90 - $120 million. It was expected that selling electricity to a utility at $0.03/kwh would result in a payback period of 20 to 25 years (Hancock et al. 2017). During the design process, it was decided to add a steam turbine with power-generation capability to the system. The waste heat produced during the fluidized bed incineration would heat water to generate steam, which would power a turbine. It was estimated the turbine could generate approximately 3 MW of electricity, enough to satisfy the electrical needs of the new incineration system. This energy-recovery system added approximately $20 million to the project costs, however the payback period for the project was estimated to be 11 years when using the generated power on-site, instead of selling it to a utility (NEORSD 2008, Hancock et al. 2017). A $0.07/kWh savings was projected based on using power generated by the turbine on-site, instead of purchasing power from a utility (Hancock et al. 2017).

The project at the Southerly Center was designed to be completed in several phases, beginning in 2009 (NEORSD 2008). The new biosolids incineration system became fully operational in 2016. The Center now has three fluidized bed incinerators with three heat recovery systems producing superheated steam to generate power through a steam turbine, which is designed to handle two incinerators due to one incinerator being on stand-by during normal operation (Hancock et al. 2017). The turbine generates 2.4 MW when two incinerators are in operation with a 11,975 kg/hr (26,400 lb/hr) steam flow. Each fluidized bed incinerator has the capacity to incinerate 100 dry tons of biosolids per day. Flue gas from the incinerators after being used in steam generation is discharged into a wet scrubber to remove particulate and acid gases (e.g., SO2). Clean flue gas discharged from the wet scrubber flows through a mercury removal system prior to discharge (Hancock et al. 2017). Ash generated through the incineration process is landfilled (Dominak 2010).

The three fluidized bed incinerators were started, commissioned, and underwent performance testing between 2014 and 2016. All three incinerators satisfied the emission requirements listed in the air permit and project specifications. In 2015, the incinerators were retrofitted with the mercury removal system (SPC Gore technology) supplied by EnviroCare International to meet the Maximum Achievable Control Technology (MACT) emission limit (Hancock et al. 2017).

Table 4 Jurisdictional summary of emerging trends and technologies in sewage sludge and biosolids management, focused on case studies presented at the 2017 WEF Residuals and Biosolids Conference.

Jurisdiction	Emerging trend	Project Stage	End Products Produced	Beneficial Uses
Grand Junction, Colorado	Biogas utilization – fuel	Operational	Natural gas vehicle fuel	Compression of renewable natural gas to fuel 46 city vehicles including garbage trucks and dump trucks.
City of Portland, Oregon	Biogas utilization – fuel	Construction summer 2017	Renewable natural gas, Class A Biosolids fertilizer	Export of renewable natural gas, compressed natural gas for municipal vehicle fleet, and agricultural fertilizer.
City of Calgary, Alberta	Thermal hydrolysis	Design phase	Biogas, Class B Biosolids	Increased biosolids processing capacity, increased biogas production, and land application of Class B biosolids as fertilizer.
Avonmouth, England	Biological hydrolysis	Operational	Biogas, Class A Biosolids	Increased biosolids processing capacity, increased biogas production, sale of excess electricity generated from biogas to the grid, and agricultural fertilizer.
City of Raleigh, North Carolina	Biodiesel production	Operational	Class A and B Biosolids, Biodiesel	Use of Class A and B biosolids to improve growth of sunflower and soybean crops to be converted to biodiesel to fuel farm equipment on location.
Anchorage, Alaska	Gasification	Pilot study	Syngas, Ash	Energy savings of biosolids disposal costs, reduced greenhouse gas emissions, and significant waste volume reduction.
City of Lebanon, Tennessee	Gasification	Operational	Syngas, Biochar	Energy savings, reduced greenhouse gas emissions, cost savings associated with waste transportation, significant waste volume reduction, and marketable soil amendment product.
District of Delta Diablo, California	Gasification	Evaluation and site selection	Syngas, Ash	Syngas converted to enough energy to make facility self-sufficient, reduced greenhouse gas emissions, and significant waste volume reduction.
District of Delta Diablo, California	Pyrolysis	Evaluation and site selection	Pygas, Biochar	Pygas converted to enough energy to make facility self-sufficient, reduced greenhouse gas emissions, significant waste volume reduction, and valuable soil amendment.
Silicon Valley Clean Water, California	Pyrolysis	Construction	Pygas, Biochar	Pygas converted to enough energy to make facility self-sufficient, significant waste volume reduction, reduced greenhouse gas emissions, and valuable soil amendment.
Cleveland, Ohio	Fluidized bed incineration	Operational	Heat and Steam to Energy, Ash	Heat captured from process drives energy generation through steam turbine, process supported by energy generated, reduced greenhouse gas emissions, and waste volume reduction.

5 BENEFICIAL BIOSOLIDS REUSE – CASE STUDIES

5.1 BRITISH COLUMBIA

5.1.1 METRO VANCOUVER

Metro Vancouver has managed biosolids for beneficial use in the lower mainland since 1991, serving 23 municipal members and a total population of 2.4 million people. The Annacis Island Treatment Plant, the region's largest secondary treatment plant, processes approximately 80% of the region's biosolids (Metro Vancouver 2016). Following initial wastewater treatment at the plant, primary and secondary sludges are mixed and treated through thermophilic anaerobic digestion (55°C) for 22 days and dewatered in a centrifuge. The resulting biosolids (26-30% solids) are stored in hoppers until transferred to application sites (Force 2015).

The biosolids produced meets Class A standards and are used in a variety of land applications under the brand name Nutrifor. Metro Vancouver also produces a smaller amount of Class B biosolids through mesophilic digestion, at the region's Lulu Island and Lion's Gate treatment plants (Force 2015). Throughout the treatment process, Metro Vancouver tests the wastewater that will be turned into Nutrifor for metals and pathogens (Metro Vancouver 2016). Once Nutrifor is produced, it is tested again before leaving the facility to be sure it meets regulatory standards. Nutrifor conforms to BC OMRR regulations and the Fertilizers Act administered by the CFIA (Metro Vancouver 2016).

Metro Vancouver uses Nutrifor at its own facilities and parks and also partners with regional districts, mine operators, forestry workers, and others around British Columbia (Metro Vancouver 2016). Metro Vancouver has delivered more than one million tonnes of Nutrifor to a variety of different sites since it began producing biosolids (Ford 2016a). For more than 20 years, a large proportion of the biosolids produced have been delivered to BC mines for reclamation, where biosolids are typically mixed with overburden or tailings to improve soil productivity (refer to mining project example below).

Nutrifor products are also used in other regional reclamation projects. For example, Nutrifor products were used to help convert a 12 hectare gravel-pit in Abbotsford into a recreational park with hiking trails, lake, and marshy pond. The site is located over a sensitive aquifer; therefore Metro Vancouver conducted studies and continued monitoring to protect sensitive environmental site conditions. Studies indicate that the use of biosolids during reclamation had no negative effects on groundwater or surface water (Metro Vancouver 2016). Metro Vancouver also produces a biosolids landscaping soil (Nutrifor Landscaping Soil) made of biosolids, woodchips and sand, which has been used in numerous projects, including improvements to the Sea to Sky Highway and regional landscaping (Metro Vancouver 2016).

Nutrifor has been used in many landfill closures, including several landfills in the Thompson-Nicola region, resulting in a reduction of methane emissions (Metro Vancouver 2016). Nutrifor is also currently used in forest fertilization projects. In the past, Nutrifor products were used as a fertilizer for rangelands; however high resource costs, including monitoring, has eliminated that use in recent years (Golder Associates 2014).

Concern from the public and First Nations over the use of Metro Vancouver biosolids in rangeland fertilization and compost programs has arisen in recent years. First Nations and local residents in the Nicola Valley raised environmental and health concerns regarding the land application of biosolids. In 2015, the First Nations of the Nicola Valley enacted a moratorium on the importation of biosolids from the Lower Mainland and the Okanagan into the Nicola Valley until a stringent scientific review had taken place (CBC News 2015a, 2015b, Merritt Harold 2016, LRCS 2016; refer to Nicola Valley example below).

Although Metro Vancouver uses a variety of beneficial use options, it is becoming increasingly challenging to find places and programs to use its biosolids. Metro Vancouver practices source separation of food and yard wastes, therefore compost, which also needs space for land application, is becoming increasing abundant in the region. Additionally, it is anticipated that biosolids production in the region will increase substantially in 2020 and 2030 due to planned upgrades at the Lions Gate and Iona Island Wastewater Treatment Plants to secondary treatment (Ford 2016b). As a result, Metro Vancouver is currently conducting a feasibility study for a Biosolids Drying Facility at Annacis Island. The aim would be to dry biosolids using excess heat produced by cogeneration engines during the treatment process and then use the dried biosolids in a variety of ways, including as a fuel source (Ford 2016a, 2016b). Metro Vancouver is also working on a pilot hydrothermal processing facility project, which would convert sewage into biocrude, instead of biosolids, that would then be sold to an oil refinery (Saltman 2017).

Metro Vancouver's biosolids program received the 2010 Award of Excellence in Biosolids Management from the Northwest Biosolids Management Association and Pacific Northwest Clean Water Association. The region was recognized in 2012 by the National Biosolids Partnership for its work to align its biosolids management with the partnership's code of good practice (Metro Vancouver 2016).

Mine reclamation example using Nutrifor: Highland Valley Copper (Teck Resources)

Located near Logan Lake in south-central British Columbia, the Highland Valley Copper Mine is the largest active open-pit copper mine in Canada and among the largest copper mines worldwide. The mine has operated under different ownership structures since 1963, and is currently owned by Teck Resources. The site consists of 6,000 ha of disturbed land and reclamation has been conducted progressively during the life of the mine. Currently, more than 2,300 ha have been revegetated, representing approximately one-third of the site's total disturbance area.

Multiple area-specific reclamation and land use objectives are being targeted at the mine site including agriculture/rangeland, forest land, wildlife habitat, and aquatic habitat. Where possible, restorative actions are being applied that promote natural succession of native species through broadcast seeding and planting. An insufficient quantity of topsoil was salvaged to adequately cover the disturbed landscape; therefore, most revegetation efforts were being applied directly on tailings and overburden materials that have low organic content and limited mineral nutrients (Gardner et al. 2010, 2012).

Over the past 18 years, the mine's reclamation program has applied 380,000 wet tonnes of biosolids (primarily Class A biosolids originating from Metro Vancouver, as well as some Class B biosolids) to cover more than 700 ha of disturbed or reclaimed land (Teck 2012). In collaboration with Thomson River University and other collaborators, past and present research trials have proven beneficial for optimizing site preparations and application rates, and documenting both short- and long-term ecological performance. Soil, vegetation, and water quality monitoring programs are also in place to verify environmental compliance for metal exposure and run-off.

Application of biosolids has resulted in improved revegetation response, especially with agronomic grasses (J. Dickson, Pers.Comm.). Because end land use objectives have shifted toward enhancing natural/native biodiversity composition – reflecting a global trend in ecological restoration (MacDonald et al. 2016) – reclamation trials are currently combining and incorporating other surface preparations and treatments (e.g., application of coarse woody debris, biochar) to further facilitate the growth of native trees and shrubs. The Highland Valley Copper Partnership was awarded the 2008 British Columbia Jake McDonald Mine Reclamation award for reclamation achievement by the BC Technical and Research Committee on Reclamation.

Highland Valley Copper has temporarily discontinued its biosolids program due to concern expressed by Indigenous communities of the Nlaka'pamux Nation over stockpiling procedures and potential risk to the down-stream environment. An ongoing dialogue with the First Nations as well as additional research and monitoring actions are being used to explore and address these concerns and resume biosolids use.

Rangeland fertilization and composting in the Nicola Valley:

The Valley is home to five First Nations (Nooaitch, Lower Nicola, Shackan, Coldwater, and Upper Nicola bands), several large ranches, and the City of Merritt, which has a population of approximately 7,000 people (LRCS 2016). Biosolids have been used in the Valley to fertilize rangelands and reclaim mine sites for many years. In 2013 and 2014, for example, 31,000 dry tonnes of biosolids were incorporated into the remediation of mine sites and over 37,000 dry tonnes of biosolids that were utilized through agricultural land uses. The majority of these biosolids from Metro Vancouver, much of which was Class A biosolids (LRCS 2016).

In 2014, local First Nations became aware that biosolids were being deposited and stored at a composting facility in the Sunshine Valley. The facility is close to the Nooaitch Band's reserve and the Nicola River, which the Nooaitch, as well as other First Nation communities, draw water from. It was also identified that a second biosolids storage location was planned in the Dry Lake area, a 320-acre parcel of land that is near a 44-lot rural subdivision and a community well (CBC News 2015a). First Nations expressed concerns about the effects of biosolid land application on human health and the environment, particularly the potential for water contamination. First Nations and a local group of concerned citizens called 'Friends of the Nicola Valley' began protesting the deposition of biosolids and for several months maintained a blockade preventing trucks carrying biosolids from entering the area (CBC News 2015a). In May, 2015, the five Nicola Valley First Nations chiefs and their supporters protested at the B.C. legislature, calling on the government to stop the importation of biosolids into the region. The First Nations signed their own moratorium on the land use of all biosolids pending a scientific review (CBC News 2015b, Merritt Harold 2016).

In June 2015, the Province announced it would conduct a scientific review on the use of biosolids in the Nicola Valley. The scientific review was intended to focus on: 1) developing a monitoring and testing regime for biosolids in the Nicola Valley, 2) reviewing the effectiveness of the current requirement for a Land Application Plan, and 3) reviewing research on how biosolids impact wildlife and determining if any monitoring or testing is required. Information gained through the review process was to inform future measures to address issues and concerns regarding biosolids identified by the Nicola Valley First Nations and local residents (BC Gov News 2015). The following October, the provincial government and the five Nicola Valley First Nations signed an agreement (termed a 'collaborative engagement protocol'), to enable First Nations oversight and participation in the scientific review. In March 2016, a report titled 'A literature review of risks relevant to the use of biosolids and compost from biosolids with relevance to the Nicola Valley, BC' was prepared by Land Resource Consulting Services for the B.C. Ministry of the Environment, as part of the scientific review process, to evaluate the state-of-science in support of an assessment of the risk associated with the land application of biosolids in the Nicola Valley. An aim of the report was to identify knowledge gaps, provide recommendations and highlight best practices to reduce risk, such as the establishment of an organic contaminant monitoring program for biosolids being applied in the valley (LRCS 2016).

In April 2016, the five band chiefs of the Nicola Valley First Nations walked away from the scientific review after they felt that their participation in the study was relegated to the status of 'observers' (Merritt Harold 2016). An agreement regarding the land use of biosolids in the valley between the First Nations and the government has yet to be reached.

5.1.2 CITY OF KELOWNA/CITY OF VERNON

The City of Kelowna began producing and marketing biosolids compost in 1995 (G. Light, Pers.Comm.). Nearly a decade later, Kelowna partnered with the City of Vernon to create a regional compost facility capable of meeting the needs of both municipalities. The regional compost facility, located on the outskirts of Vernon, opened in 2006, and uses an advanced aerated static pile composting method. This method enables biosolids to be converted into Class A compost in approximately 80 days (City of Kelowna 2017a). Biosolids from the region's wastewater treatment facilities arrive by truck to the compost facility and are mixed with wood waste comprised of wood chips or hog fuel and wood ash. The facility uses batch mixers (Supreme Enviro Processor 900) to prepare the initial mix for active composting. Each batch contains 3,500 kg of biosolids, 15.25 m^3 of wood waste, and 350 to 500 kg of ash (G. Light, Pers.Comm). Once cured, the compost is screened to remove excess wood waste and tested for pH, metals, and pathogens, in compliance with provincial and federal guidelines. The resulting Class A compost is marketed under the brand, Ogogrow, as a soil amendment. Ogogrow conforms to BC OMRR regulations and the Fertilizers Act administered by the CFIA (City of Kelowna 2017a).

Ogogrow is sold in bulk quantities to local landscapers, nurseries, orchardists, and retail outlets. The cities have decided to work with compost distributors and landscape supply centers rather than being a direct competitor (G. Light, Pers.Comm.). The program has one costumer that typically comprises 50% of all sales (G. Light, Pers.Comm.). Ogogrow is often used to dress lawns, as a mulching medium or soil additive for flower beds and other landscaping uses, and is being used to cap the regional landfill (City of Kelowna 2017a, Nair 2017). Ogogrow sold out annually until 2011, when the facility started adding more wood to reduce odours (G. Light, Pers.Comm.).

The product is available at the Regional Compost Facility, the Glenmore Landfill, and at most nursery outlets in Kelowna for $31.43 per yard or $4.19 per bag (City of Kelowna 2017a). Product revenues are returned to the program to assist in the long-term economic sustainability of the facility. Since Kelowna's composting program partnered with the City of Vernon, they have sold approximately $550,000 worth of Ogogrow per year, which accounts for approximately 23% of the operating costs, noted as $2,350,000 per year (G. Light, Pers.Comm.).The facility has a biosolids processing capacity of 36,400 tonnes annually and typically produces approximately 28,500 tonnes of Ogogrow per year (City of Kelowna 2017b, G. Light, Pers.Comm.).

The product has developed a loyal customer base over the last decade and has been successful in the horticultural, landscaping, and home-use compost markets. However, recent increases in the region's population have resulted in the production of more compost than can be sold in existing markets. The City of Kelowna is currently undertaking a strategic review of their biosolids management program and is investigating technical solutions to address their growing compost surplus (Nair 2017, G. Light, Pers.Comm.). Solutions being reviewed include enhanced marketing, expansion into the regional reclamation market, thermal drying, chemical treatment, the addition of an anaerobic digester at the regional wastewater treatment facilities to decrease biosolids volume, and expansion of the composting facility. The cities have also considered incineration, but deemed that option too expensive (G. Light, Pers.Comm.). An online survey of possible waste management options was launched to include participation from Okanagan residents (City of Kelowna 2017c).

5.1.3 COMOX/STRATHCONA REGIONAL DISTRICT

Comox Strathcona Regional District opened their regional composting facility, located in Cumberland on Vancouver Island, in 2007. Before arriving at the regional composting facility, primary and secondary solids are blended and dewatered via centrifuge at the regional wastewater treatment plant. At the facility, the dewatered sewage sludge is treated to a Class A compost, marketed as a soil amendment under the name SkyRocket. The compost is produced using aerated static composting bunkers with a mix of 2.5 tonnes bulking agent (combination of yard waste and recycled overs) and 1.6 tonnes of dewatered sludge per batch. The mixture is adjusted as required during the various seasons to achieve a moisture content of 55-60% (Elliot 2009, Z. Berkey, Pers.Comm.). Clean and untreated wood is diverted from the regional landfill for use in the compost. Once mixed, the -sludge and wood waste are composted in aerated bunkers for 4 weeks, after which they are screened to half an inch to remove large woody pieces before being further cured and stored in windrows for up to 12 weeks (Elliot 2009, Z. Berkey, Pers.Comm.). SkyRocket is routinely tested for pathogens, pH, metals, and coliforms content. The Class A compost conforms to the BC OMRR and the Fertilizers Act administered by the CFIA (CVRD 2017).

SkyRocket compost is primarily sold to residential customers and local compost retailers, where it is typically blended with additional products prior to re-selling (Z. Berkey, Pers.Comm.). Over the last few years, a large portion of SkyRocket compost has been purchased by the landfill where is has been used as part of their capital project to decommission the existing landfill. In the past, SkyRocket has also been used in local land reclamation projects (e.g., reclamation of a local coal slag pile), slope stabilization projects, and in Ministry of Transportation roadside tree planting projects (Vasileski 2007, CVRD 2016). The compost is available from the Comox Valley Waste Management Centre and ranges in price from \$10 to \$21 per m^3 depending on the amount purchased (CVRD 2015). In 2016, the compost facility processed 5,284 metric tonnes of dewatered sludge and generated \$42,635 in revenue from compost sales (Z. Berkey, Pers.Comm.). The 2016 operating cost of the compost facility was \$396,425 (Z. Berkey, Pers.Comm.).

During the early years of production, the Regional District focused on public engagement to build support for the product within the community. Public outreach efforts included installing a demonstration garden at the Compost Education Center that provided comparisons of plant growth using different composts and topsoil types (Elliot 2009). The district also organized public plant measuring events, free compost bag giveaways, and local sales (e.g., "fill a truck for 20 bucks"). Although the sale of SkyRocket is relatively successful, the Regional District is still only able to remove about a quarter of the compost produced annually through residential and commercial sales (Z. Berkey, Pers.Comm.). Despite public education efforts, there was some initial push-back from the local community regarding the compost's safety for use in food gardening due to potential substances, such as ESOCs, that are not currently tested for (S. Valdal, Pers.Comm.). As a result, the program no longer endorses the use of SkyRocket on food gardens. Residential use has been growing however, largely by word-of-mouth (S. Valdal, Pers.Comm.).

As the current landfill closure project is nearing completion, the Regional District is in the process of working on additional communications and outreach to improve sales. They are also in the detailed design process for a compost facility expansion and are looking at continuing with aerated static pile composting, but may include mass bed curing as part of the process (Z. Berkey, Pers.Comm.).

5.1.4 REGIONAL DISTRICT OF NANAIMO

The Regional District of Nanaimo (RDN) has been beneficially using biosolids in agriculture, landfill closures, mine reclamation, and forestry applications since 1999 (Nanaimo Biosolids 2017a). Forestry became the primary use in 2003 with the start of Vancouver Island University's (VIU) Forest Fertilization Program at Woodlot 020, located in the Flynfall Creek watershed. Through this program, the vast majority of the region's biosolids are diverted from the landfill through land application to improve tree growth (Nanaimo Biosolids 2017a). The RDN has four Pollution Control Centers, two of which process biosolids, including the Greater Nanaimo Pollution Control Center (GNPCC) and the French Creek Pollution Control Center (FCPCC). The GNPCC produces Class B biosolids through chemically enhanced primary treatment, stabilization via mesophilic anaerobic digestion (30 days at 38°C), and centrifuge dewatering. The FCPCC produced Class A biosolids through a trickling filter/solids contact secondary treatment process, stabilization using autothermal thermophilic aerobic digestion (10-12 days at 65˚C) and centrifuge dewatering (Nanaimo Biosolids 2017b). Once produced at the two facilities, biosolids are mixed with sand and are transported to the woodlot for stockpiling and application (Nanaimo Biosolids 2017b). The biosolids are tested regularly for metals and pathogens, in accordance with the BC OMRR (Nanaimo Biosolids 2017a, 2017b).

In 2013, a biosolids management program agreement was signed between the RDN, VIU, and the residuals consulting firm SYLVIS, to manage the region's biosolids though to 2017. Under the agreement, the RDN generates the biosolids, VIU maintains a research-focused role, and SYLVIS assumes operational responsibilities for biosolids application (Nanaimo Biosolids 2017a, SYLVIS 2017a). The program received the Northwest Biosolids Management Association's Excellence in Biosolids Management Award in 2013, for demonstrating a successful collaboration between a private company, a research institution, and a regional biosolids generator (Nanaimo Biosolids 2017a). The program produces approximately 4,200 tonnes of biosolids annually. In 2016, 3,046 tonnes of biosolids were delivered to the VIU woodlot from GNPCC and 1,278 metric tonnes were delivered from the FCPCC (Nanaimo Biosolids 2017b).

VIU's Forest Fertilization Program was initiated to assess the beneficial use of biosolids in BC's coastal forest ecosystems (Nanaimo Biosolids 2017a). The woodlot is owned by TimberWest, and leased to VIU. The forest is composed of Douglas fir, lodgepole pine, and red alder, and historically had poor soil conditions that were limiting tree growth. The woodlot is an important educational tool for VIU, with students engaged in various research activities related to all aspects of biosolids forest applications, as well as developing and practicing skills in surveying, timber cruising, and ecological assessment (Nanaimo Biosolids 2017a, 2017b). Since biosolids applications began, VIU researchers have documented dramatic increases in tree growth at the woodlot site, ranging from 50% to 400%. Ground water studies have also found that biosolids applications have not impacted groundwater quality in wells located in the region (Nanaimo Biosolids 2017a, 2017b). Biosolids applications are completed in accordance with the Land Application Plan, including setbacks from potable water sources, water bodies, roads, and highways (Nanaimo Biosolids 2017a, 2017b).

As woodlots are also popular outdoor recreation areas (primarily mountain biking and hiking) the program does restrict public access to application areas and posts signs and maps on roads and paths and uses online advising the public where biosolids have been applied. VIU works with the local mountain bike club to avoid the mountain bike trail network (Nanaimo Biosolids 2017a, 2017b). The RDN host regular Open Houses for the public at its Pollution Control Centres to provide an opportunity to tour the facilities, learn about recent upgrades, and ask questions (Nanaimo Biosolids 2017a).

5.1.5 CAPITAL REGIONAL DISTRICT – SAANICH PENINSULA

In 2008, following the completion of a successful pilot study, the Saanich Peninsula Wastewater Treatment Plant began its biosolids beneficial use program. The plant, which serves the municipalities of North Saanich, Central Saanich, and Sidney produced a Class A biosolids product named PenGrow for use as a soil amendment in residential gardening and landscaping. The plant used a propriety lime-pasteurization process called RDP, which stabilizes dewatered undigested sewage sludge by raising the pH to 12.5 through lime addition and pasteurizing by heating biosolids above 70°C for 30 minutes. The resulting product was then cured for a minimum of four to six weeks. The resulting Class A PenGrow product conformed to BC OMRR regulations and the Fertilizers Act administered by the CFIA (CRD 2009).

The initial PenGrow pilot study included 20 homeowners who used the biosolids product on their lawns and gardens. Homeowner feedback was positive, which resulted in the establishment of a PenGrow self-help station at the regional Hartland landfill. Based on the success of the pilot program, the plant initially planned to produce 300 tonnes of PenGrow and distribute it to the public for free from the landfill, before potentially expanding to include distribution at three municipal public works yards (SPWWTP 2009). The biosolids product was well received. However, some issues were identified during the early stages of production, including limited product availability, and a dislike of the product's colour. The lime pasteurization process causes the biosolids to appear light in colour which gardeners found off-putting (CRD 2009). Due to the lack of available space for storing and curing the product at Hartland landfill, the production of PenGrow never exceeded 180 tonnes per year. Therefore, the majority of the dewatered sludge produced by the plant (approximately 3,000 tonnes) were landfilled. The program did steadily grow over time, with over 1,000 customers using the product during its last year (CRD 2011b).

In the summer of 2011, the PenGrow Program was put on hold following a decision by the regional government, the Capital Regional District (CRD), to end the production, storage, and distribution of biosolids for land application at all CRD facilities and parks, including the Hartland landfill (CRD 2012a). The ban was based on concerns that farmland and the food grown on it could be polluted by pharmaceuticals and heavy metals in biosolids (CRD 2011a). Following the decision, the Saanich Peninsula Wastewater Commission tried unsuccessfully to find an alternative beneficial use for its biosolids through a nationally advertised expression of interest aimed at companies involved in biosolids management and utilization (CRD 2012a). Since the PenGrow program was halted, all sewage sludges generated by the plant have been disposed of as controlled waste at the Hartland landfill (CRD 2012b).

5.2 OTHER CANADIAN JURISDICTIONS

5.2.1 CITY OF EDMONTON, ALBERTA

In Edmonton, approximately 22,500 tonnes of biosolids are composted or applied to land annually. The majority of Edmonton's biosolids are produced by the Gold Bar Wastewater Treatment Plant which stabilizes biosolids through conventional mesophilic anaerobic digestion (EPCOR 2017, Szoke and Suarez 2017). A portion of the biogas generated by the digestion process is captured and used in the boiler system to heat the plant's buildings and digesters (EPCOR 2017). Following treatment, the stabilized biosolids are handled by the City of Edmonton's Waste Management Branch, who either apply the biosolids on agricultural fields through the NutriGold program or use it as an input for the city's co-composter (EPCOR 2017). The NutriGold Program was first established in 1978 and has since applied over 496,000 dry tonnes of Class B biosolids to local farmland to reduce the use of chemical fertilizers. The Edmonton Compost Facility, a biosolids and organic waste co-composting operation, was opened in 2002. The facility is the largest of its kind in North America (occupies an area of 38,690 m^2) and can process up to 200,000 tonnes of residential waste and 25,000 dry tonnes of biosolids each year (City of Edmonton 2017a). The facility co-composts de-watered biosolids together with residential solid waste or woodchips to produce a Class A compost product, marketed under the brand Second Nature. The compost conforms to the Fertilizers Act administered by the CFIA.

Second Nature is sold as a horticultural and agricultural product and is used by farmers, nurseries, landscapers, city parks, and roadside enhancement projects. Second Nature is also sold directly for residential use at many local gardening stores (e.g., Canadian Tire). Three grades of compost are available for purchase, including: a finely screened turf-grade product for lawns and sports fields; a garden mix grade designed to help bind the soil, provide better aeration and provide stable, long term nutrient release; and an erosion control grade that can be applied as a blanket or in filter socks (Inglis Environmental 2017).

The NutriGold and the co-composting programs have been successful, however due to logistical constraints and increasing biosolids production, they do not currently use the total annual production (SYLVIS 2013a). The City of Edmonton hired a consultant, SYLVIS, to investigate new biosolids land application options for the region. SYLVIS identified mine reclamation (refer to example below), marginal land improvement, and biomass production as potential options to augment the city's beneficial use programs. A two-year demonstration project at the Alberta Pacific Forest Industries (Al-Pac) poplar plantation site was designed to determine the effect of biosolids applications on poplar growth. Tree mensuration, soil, and water monitoring data from the project indicated that application of biosolids to marginal land to improve poplar growth (biomass) was a productive use of biosolids (SYLVIS 2013b). Additionally, another demonstration project has applied biosolids to vacant land with poor soil conditions, adjacent to the Beaver Regional Landfill, to grow a short-rotation willow crop (willow coppice) which is intended to provide a secure source of woodchips for the city's composing program while increasing in-situ organic soil development through willow root mass production. The program was initiated in 2013 with biosolids land application, followed by willow planting in 2014 (Beaver Municipal Solutions 2013, Breau 2013).

In addition to diversifying land application programs, the City will be adding an Anaerobic Digestion Facility at the Edmonton Waste Management Centre in 2018 (City of Edmonton 2017b). The Anaerobic Digestion Facility is a partnership between the City of Edmonton and the University of Alberta and will expand the City's organic waste processing capacity, while producing biogas to create renewable energy in the form of electricity and heat (City of Edmonton 2017b). Additionally, the Gold Bar Wastewater Treatment Plant recently completed a review of Biogas-to-Energy technologies that could increase the plant's operational efficiency through future plant upgrades (Szoke and Suarez 2017). Currently, biogas not used in the Plant's boilers is flared, and represents an opportunity to integrate a more cost-effective technology. The review found that a reciprocating engine generator combined heat and power (CHP) solution to be the best Biogas-to-Energy technology for implementation at the plant. Other alternatives considered included cleaning biogas to produce biomethane for use in natural gas for use in fleet vehicles and liquefied renewable natural gas for efficient storage, transportation, and export (Szoke and Suarez 2017).

Mine reclamation example: Genesee Mine (Westmoreland Coal Company)

Located in Warburg, central Alberta, the Genesee Mine is an active surface strip coal mine which has been operating since 1988 by Westmoreland Coal Company and Capital Power Corp. The mine site consists of approximately 7,250 ha of permitted operating area and averages 5 million tonnes of annual production.

Multiple reclamation end land use objectives are being targeted at the mine site, depending on location, including agricultural cultivation and rangeland, forest land, wildlife habitat, and aquatic habitat. So far, approximately 600 hectares have been reclaimed.

In 2010, SYLVIS Environmental, in collaboration with EPCOR, was retained by the Edmonton Waste Management Centre of Excellence (EWMCE) to assess application options for Edmonton region biosolids. The Genesee Mine was selected as a research trial area to demonstrate biosolids application, originating from EPCOR's Clover Bar Waste Management Facility, and scalability in post-mining land reclamation. One of the initiatives of the two-year project was to demonstrate the use of biosolids as a temporary topsoil substitute on areas of the mine where agricultural crops had been seeded directly in subsoil (SYLVIS 2017b; NRCan 2017).

Genesee Mine was awarded the 2008 Alberta Chamber of Resources Major Reclamation Award for achievement in land reclamation. The site has been used for soil assessment field training by the Faculty of Extension at the University of Alberta in collaboration with Paragon Soil and Environmental Consulting.

5.2.2 NIAGARA REGION, ONTARIO

Ontario's Niagara Region is a regional municipality that encompasses five cities, five towns, and two townships, with a population of 430,000 residents (Walker Industries 2014a). Approximately 10 years ago, the Region undertook a biosolids master planning project to diversify biosolids use. Up to that point, Class B biosolids were entirely liquid land-applied to farmland as a fertilizer, following treatment via anaerobic digestion at the region's many wastewater treatment plants (Niagara Region 2017). A joint venture between Walker Environmental Group and N-Viro Systems Canada was chosen by the region to construct and operate a centralized biosolids processing facility (Gunn 2015, Houle 2015). The Thorold Biosolids Facility became fully operational in 2007 (Walker Industries 2014a, Gunn 2015).

Approximately half of the Class B liquid biosolids produced by the region are still land-applied at Ministry of Environment approved agricultural sites (Houle 2015). The remainder is mechanically dewatered and converted into a Class A biosolids soil amendment product at the Thorold Facility using the patented N-Viro alkaline-stabilization process (Niagara Region 2017). The facility buys its alkaline agent, a byproduct of cement production, from a regional cement plant that was previously landfilling the substance (Gunn 2015, Houle 2015). During the biosolids product curing process, samples are taken every hour to test for pH and pathogens. The product is also tested biweekly for all restricted heavy metals and pathogens (Gunn 2015). The process yields a Class A biosolids product marketed under the name Niagara N-Rich. It is approved for use as a fertilizer or soil amendment by the CFIA.

Niagara N-Rich is sold to large farm fertilizer distributors who sell the Class A biosolid product and the direct application service to farmers in Ontario. Most of the product is sold to neighboring regions where the province's large cash-crop farms are located. Niagara N-Rich is well received by consumers for agricultural use and has required little marketing to date (Gunn 2015). The facility is also working with a contractor, a mining company, and university researchers to look for more uses for the product, such as mine reclamation and reforestation (Gunn 2015).

The facility processes 26,000 tonnes of treated Class B biosolids annually, most of which are from the region, and produces approximately 35,000 tonnes of the Class A Niagara N-Rich soil amendment per year (Walker Industries 2014a). The product is sold for approximately $10 per tonne (Gunn 2015). In 2014, Walker Environmental acquired N-Viro and became the sole owner of the facility, operating under a contract with the regional government. The Niagara Region pays Walker Environmental to process the Class A biosolids; however they split the net revenue from sales of the N-Rich product. The operation received the Exemplary Biosolids Management Award from the Water Environment Association of Ontario in 2014 (Walker Industries 2014a).

5.2.3 CITY OF TORONTO, ONTARIO

All of Toronto's biosolids are treated at two facilities. The Ashbridges Bay Treatment Plant treats approximately 78% of the city's biosolids and the Highland Creek Treatment Plant treats the remainder (City of Toronto 2017a). The Ashbridges Bay Treatment Plant is the largest secondary wastewater treatment plant in Canada, servicing an area of approximately 25,000 ha, and a population of 1,524,000 people (Toronto Water 2016).

In 2007, the City commissioned a pelletizer facility to begin production of a Class A biosolids fertilizer product, as part of a beneficial biosolid use program diversification effort aimed at lowering operation costs and addressing environmental constraints (Toronto Water 2015). Prior to the upgrade, the facility's management strategy included incineration and land application of Class B biosolids. The Highland Creek Treatment Plant currently incinerates all of its biosolids. The ash produced by the incineration process is disposed in a landfill or recycled in cement manufacturing (City of Toronto, 2017b).

At the Ashbridges Plant, the solids generated through primary and secondary wastewater treatment are anaerobically digested in the mesophilic temperature range (34-38°C for 23 days) and dewatered by centrifuge. The biogas produced during digestion is captured and is used to heat the Plant which aids in reducing operating costs. The resulting biosolids (approximately 27% dry solid) are either transferred to the pelletizer facility onsite, transferred to another jurisdiction for lime stabilization treatment (e.g., Niagara Region), or loaded into trucks for disposal via the Class B land application program (Toronto Water 2016, 2017). The pelletizer facility uses the Seghers indirect drying system, referred to as the Pelletech Process, which involves heating biosolids in a dryer to evaporate water content to produce a finished Class A biosolid product that is at least 90% dry solid (RVA 2017). The resulting Class A biosolids pellets are dust-free, low-odour, and have a long storage life (City of Toronto 2017b). The operation and maintenance of the pelletizer facility and marketing of pellets is managed by an outside contractor, Veolia Water. The City has been testing biosolids for nutrient, metals, and pathogens at the Ashbridge plant on a regular basis for more than a decade and consistently meets regulatory standards. Toronto's biosolid products and land application programs conform to Ontario's Nutrient Management Act and the Fertilizers Act administered by the CFIA (City of Toronto 2017c).

Biosolids generated at the plant are managed by the City in a number of ways, including agricultural land application and mine reclamation. Up until 2015, a portion of the City's biosolids were also landfilled, however efforts to eliminate that disposal option have been successful (Toronto Water 2016). In 2016, the plant managed a total of 147,733 wet tonnes of biosolids. Fourty-nine percent of biosolids were processed by the pelletizer and sold as a Class A biosolids fertilizer. Twenty-four percent of biosolids (Class B) were sent to approved agricultural land application sites in Ontario. Twenty-six percent of biosolids were further treated through alkaline stabilization off-site by licensed external biosolids service providers and used as a Class A soil amendment (e.g., Niagara Region). The resulting two percent of biosolids were used at mine reclamation sites in the province (Toronto Water 2017).

Upgrades required at the Highland Creek Treatment Plant recently prompted a study of viable biosolids management options, including: 1) conversion to fluidized bed incineration, 2) construction of a truck loading facility and added digester capacity to haul biosolids off-site for beneficial use and/or disposal, and 3) construction of an on-site biosolids dryer to produce and transport pellets for beneficial use (CIMA 2016a, 2016b). Public comments collected during the study showed strong support for modernizing the existing incineration facility, strong opposition to additional truck traffic, and concerns about the health impacts of land application of biosolids or biosolids pellets. The study also found that the modern state-of the-art incineration option would be the lowest emitter of greenhouse gases, would have the lowest noise, odour, and traffic impact on the community, and would have the lowest capital and operating costs (CIMA 2016). Taking all aspects of the study into consideration, fluidized bed incineration with state-of-the-art emissions scrubbing technology was identified as the preferred approach for the future of the facility (CIMA 2016). Ash generated by the new incineration facility would continue to be hauled off-site for disposal in the City's Green Lane Landfill, however it is noted that ash reuse is viable option to be assessed during implementation. The new facility would also take advantage of the fuel value of feed materials, recovering energy to generate electricity, mechanically drive blowers or for process, and building heat at the plant (CIMA 2016a, 2016b).

5.2.4 GREATER MONCTON, NEW BRUNSWICK

In 2008, the Greater Moncton Sewerage Commission, serving the communities of Moncton, Dieppe, and Riverview, opened a biosolids composting facility to provide a more environmentally sustainable method of biosolids disposal than its existing landfilling practice. In 2014, the commission changed its legal corporate name to the Greater Moncton Wastewater Commission (GMWC) (TransAqua 2016). The composting process used by the GMWC combines bottom aeration and a proprietary cover system referred to as the GORE Cover System. The compost produced at the facility is made using biosolids and by-products from the forestry industry (bark, sawdust, and wood chips), as well as hay, straw, and silage from the farming community and green waste from yard cleaning (TransAqua 2017a). The initial mixture is two parts of green waste to one part of biosolids by volume. The composting process takes approximately one year and compost stockpiles are screened and tested for metals and pathogens prior to sale (TransAqua 2017a, K. Rice, Pers.Comm.). Prior to arrival at the composting facility, sewage sludge is treated at the wastewater treatment facility into lime-stabilized biosolids, which involves conditioning with liquid lime, dewatering by high-speed centrifuges, followed by the addition of dry lime (TransAqua 2017a). In 2016, 11,311 tonnes of biosolids were shipped to the Composting Facility for processing. The composting system produces Type "AA" compost in accordance with the BNQ (Bureau de normalisation du Québec) CAN/BNQ 0413-200/2005, 2005 edition and also fully complies with the established limits of Category A Compost set by the CCME (TransAqua 2017a).

The resulting compost is used in the production of a number of products marketed under the brand name, Gardener's Gold (compost mulch, compost soil conditioner and topsoil) which are used by the general public, landscapers, nurseries, and local municipalities (TransAqua 2017b). The compost is made available to the public free of charge from self-loading bins. If customers require a small tractor to load their truck or trailer, a $15 per cubic yard fee is paid. The compost is also sold to landscapers and is provided to the Greater Moncton area municipalities for their horticultural activities.

In 2014, it was determined that commercialization of the compost was not feasible, as the capital investment for a bagging building and a bagging operation, based on the current market sale of the final product, was not a reasonable return on investment (K. Rice, Pers.Comm.). Recent examples of use the compost include the Dieppe and Riverview walking trails, the new City of Moncton track and field events field, and the Hildegard storm-water detention basins project. In 2016, 7,700 tonnes of Class A compost was produced and made available for sale, with public and commercial vendors being the primary users (TranAqua 2016).

The original system had a capacity to process 10,000 tonnes of biosolids mixed with 10,000 tonnes of wood waste for a total of 20,000 tonnes of input materials per year. An additional third concrete composting pad and an expansion of the asphalt curing pad was completed in 2016 to increase capacity for an additional 5,000 tonnes of biosolids and 5,000 tonnes of wood waste per year that will accommodate additional biosolids from the incorporation of a secondary treatment process in 2020, in compliance with new federal regulations (TransAqua 2016, 2017c). The new compost pad incorporates a new control and tracking system which will ensure full traceability of every compost lot that is put out to the market and facilitate data gathering of the product.

Since composting was initiated, the GMWC has distributed all of its compost products locally. Last year, 2016, was the best year to date with respect to participation from the public, commercial users, and municipalities (TransAqua 2016). No public opposition to the final compost product has been recorded (K. Rice. Pers.Comm.). The compost program, however, is a major expense to the city and is not expected be cost effective. Revenue for 2017 is projected at $56,000 while the annual operation costs, not including depreciation, is estimated to be $875,390. Since 2005, there has been approximately $15 million in capital investment, with the current value of the assets at just over $10 million (K. Rice, Pers.Comm.). TranAqua is currently measuring greenhouse gas emissions from the Wastewater Treatment Facility and Compost Facility to see if the treatment program is carbon neutral or even carbon rich as it pertains to a potential cap and trade system in New Brunswick. There have been requests from private companies to submit proposals to take over management of the facility, but the Commission has been happy to date with the program from the beneficial reuse angle and giving back to the community (K. Rice, Pers.Comm.). TransAqua is developing a Biosolids Management Strategy in 2017 where the Commission Board will determine to stay with the existing model or look at going in a different direction (K. Rice, Pers.Comm.).

5.2.5 HALIFAX, NOVA SCOTIA

Halifax's Biosolids program was initiated as a part of the Harbour Solutions Project in 2003. Until the opening of the Halifax Biosolids Processing Facility at Aerotech Park in 2007, the city sent approximately 90% of its sewage into the harbor. The facility is owned by Halifax Water and operated by Walker Industries (previously N-Viro Systems Canada Limited) (Hydromantis 2011). Municipal anaerobically digested and de-watered biosolids produced by Halifax Water's three wastewater treatment facilities (approximately 8,500 dry tonnes per year) are processed at the Biosolids Processing Facility using the patented N-Viro alkaline-stabilization process (Walker Industries 2014b). During the process biosolids are mixed with quick lime and cement kiln dust. The process yields a Class A biosolids product marketed under the name Halifax N-Rich

(Walker Industries 2014b). It is approved for use as a fertilizer product under the Fertilizers Act administered by the CFIA (City of Halifax 2014).

Halifax N-Rich is primarily sold to large farm fertilizer distributors (e.g., Truro Agromart) who sell the product as a soil amendment/fertilizer and liming agent to farmers in Nova Scotia (NEBRA 2014). In Nova Scotia, biosolid products are applied to pastureland and used in the production of animal feed like corn, soybean, cereals, and forages (CCME 2012b, Arora and Harz 2014). The Halifax N-Rich soil amendment product is of particular benefit as a liming agent as the soils in the region are acidic and the pH must be raised for crops to be successful. Farmers have found the product to be an economical and beneficial alternative to chemical fertilizers for appropriate crops (NEBRA 2014). Halifax N-Rich is also used by sod farmers who have reported that its use has resulted in improved germination and growth of the sod (CCME 2012b). The product is also used on Halifax Regional Municipality (HRM) properties as a soil amendment.

Halifax Water has faced some challenges with public perception (NEBRA 2010, Hydromantis 2011). In August 2010, a topsoil mixture of Halifax N-Rich, soil, and compost was used along a Halifax street resulting in a number of odour complaints. The complaints triggered Halifax Regional Council to place a moratorium on the use of the N-Rich product on HRM properties, and to request that Halifax Water conduct an independent third party review of the N-Viro soil amendment process (Hydromantis 2011). The review found Halifax's biosolids program was suitable in meeting all regulatory requirements (Hydromantis 2011) and the moratorium on biosolid use was lifted in October 2011 (Herald News 2011). Recommendations from the review included the establishment of tests on municipal property using N-Rich to track potential odour formation or dissipation, pH neutralization rates, effects on vegetative growth, to demonstrate to the public the safety and effectiveness of the product, and to establish a more enhanced public outreach program (Hydromantis 2011).

There has been considerable effort to improve the understanding and reputation of the N-Viro process and resulting N-Rich soil amendment by Halifax Water and Walker Industries, who acquired the operation in 2014. As a result, there has been little negative publicity in recent years (Walker Industries 2017). The facility processes up to 30,000 tonnes of biosolids annually and produces approximately 42,000 tonnes of Halifax N-Rich per year (Walker Industries 2014b). The product has found a loyal agricultural client base, resulting in pre-sales of the product before it is produced (Walker Industries 2017).

5.3 UNITED STATES OF AMERICA

5.3.1 KING COUNTY, WASHINGTON

The King County biosolids program began in 1973 and has since served as a leader in biosolids recycling in the United States. All of the biosolids generated by the region are processed to either Class A or B biosolid quality and applied to land through various partnerships and programs (King County 2016b). The regional wastewater treatment plants separate solids from wastewater and treat them through an anaerobic digestion process lasting several weeks. Biogas produced by the digesters is recovered and used as a source of energy for the treatment plants. Following digestion, the biosolids are de-watered in a centrifuge, producing a Class B biosolids product marketed under the brand name Loop. King County conducts monthly monitoring of nutrients, trace metals, organic pollutants, and pathogens in the product (King County 2016b).

In 1976, King County also began processing a Class A biosolids product named GroCo. King County currently contracts Sawdust Supply, a local company, to produce GroCo compost. At the composting facility, GroCo is produced by mixing one part Loop biosolids with three parts sawdust from local lumber mills. The mixture is piled into mounds and turned as needed during the year-long compost process. Every batch of compost is laboratory tested for nutrients, trace metals, organic pollutants, and pathogens to ensure it meets Class A Exceptional Quality standards for biosolids products and Washington State standards for composts (King County 2016b).

King County produces approximately 120,000 tons of Loop each year, the majority of which is used as fertilizer and soil amendment for agricultural crops in eastern Washington or commercial forests in east King County (King County 2016b). In 2011, 74% of Loop biosolids were used in farming, 25% were used in forestry, and just over 1% was used to produce GroCo (King County 2012). King County has a number of stable, long-time agricultural partners, who use Loop to grow a variety of crops including Boulder Park Inc., the largest farmer-owned biosolids cooperative in the country. Loop is also used to fertilize forest plantations in east King County (King County 2012, 2016b). King County's forestry projects are part of a program, initiated by the non-profit Mountains to Sound Greenway Trust, to protect and enhance forests and wildlife habitat along the scenic I-90 corridor east of Seattle. Forest sites are managed in accordance with state biosolids management guidelines, including monitoring of soils and streams. GroCo compost also has a loyal following of gardeners and landscapers that use it as a soil and lawn conditioner (King County 2016b). The product has also been used in the reclamation of forestry roads and landings (Vasileski 2007). GroCo is both bagged for individual sale and sold in bulk at the compost facility.

Since their biosolids program began, King County has worked extensively with local universities to develop and test biosolid processing and recycling methods. Numerous studies using Loop and GroCo have been completed, including peer-reviewed published studies, which have contributed to the development of new markets, testing/application methods and best management practices (King County 2012, 2016b). For example, forestry studies completed at the University of Washington have researched tree growth, soil enhancement, reclamation of degraded lands and carbon sequestration, attempting to understand the benefits of biosolid use in the forest environment (King County 2012, 2016b). Agriculture-based studies by

Washington State University have focused on building soil productivity, supporting local agriculture, protecting water quality, and facilitating organic waste recycling. Other studies include a partnership between Natural Selection Farms and the University of Washington which investigated the effectiveness of biosolids fertilizer for growing canola for biofuel production (King County 2012, 2016b). Recently, GroCo compost has also been studied as a potential beneficial component in urban bio-retention systems. Preliminary studies at the University of Washington have demonstrated that a combination of biosolids compost, woody debris, and drinking water treatment residuals can be effective at capturing and holding storm water and removing contaminants (King County 2012, Jay and Brown 2017).

A tenet of King County's biosolid management program has been to regularly re-evaluate the most appropriate strategies for biosolids management. In 2009, an analysis of alternative uses and market opportunities for biosolids in King County found that land application and composting was still the most cost-effective and reliable option (King County 2012, King County 2016b). The County, however, is committed to identifying and evaluating new and emerging technologies. For example, the wastewater treatment division participated in a Water Environment Research Foundation pilot study investigating combining organic wastes, such as food waste or restaurant grease, with sewage sludge ("co-digestion") to enhance biogas production. The County is also planning to track other promising technologies including biomass gasification, biochar production, and thermal hydrolysis (King County 2012).

5.3.2 TACOMA, WASHINGTON

Tacoma began producing biosolids products at their wastewater treatment plant in the early 1990's using a Duel Digestion System, comprised of aerobic thermophilic and anaerobic mesophilic digestion phases (Mendrey 2014). The Dual Digestion process produces methane, which is captured and used to heat the treatment plant. Between 1990 and 2003, Tacoma produced a Class A biosolids product marketed under the name TAGRO. With input from key customers, TAGRO Mix was developed as a soil amendment, consisting of 50% biosolids, 25% sawdust, and 25% screened sand (City of Tacoma 2017). In 2003, the treatment process was improved by introducing three levels of temperature phasing during the anaerobic digestion phase which eliminates virtually all odours from the resulting biosolids. This innovation led to the development of new TAGRO products, including a topsoil and mulch, which quickly expanded the local biosolid product use market (Eschborn et al. 2007). TAGRO topsoil, which is designed for both indoor and outdoor use, is a blend of 20% biosolids, 20% maple sawdust and 60% aged bark. TAGRO Liquid, a liquid product designed for use on agricultural and forestry lands, is also produced. All TAGRO products are rated as Class A Exceptional Quality by the U.S. Environmental Protection Agency (City of Tacoma 2017).

Tacoma's approach for the first ten years of the TAGRO program was to provide a public service. TARGO Mix was frequently given away to customers, with a charge for loading and delivery. With the introduction of the additional odour-free biosolids products in 2003, the program took on a more business-focus approach with the ultimate goal of becoming a profit center (Eschborn et al. 2007). As planned, the biosolids program is now operated as an independent profit center within the utility. Sales of TAGRO products have increased yearly, while associated costs of managing Tacoma's biosolids have decreased. The utility is not yet at a break-even point, but product sales substantially offset the costs of biosolids handling, production, and transportation such that the city has one of the lowest net costs for biosolids management in the Country (Eschborn et al. 2007, Brown et al. 2017). The City processes about 4,000 dry tons of biosolids per year, with biosolid product revenue generating more than US $850,000 in 2015 (Brown et al. 2017).

TAGRO products are used by local landscapers, farmers, forestry professionals, and the public. TAGRO products are commonly used by residents in home and community gardens. A demonstration garden at Tacoma's Central Wastewater Treatment Plant aims to show visitors how TAGRO products can benefit vegetable gardens (City of Toronto 2017). Most of the harvested produce from the garden has been donated to local food banks (Hodges Snyder et al. 2016). TAGRO is also used in both large and small community parks, as well as on sports fields, golf courses, and other public sites. Tacoma also provides educational opportunities through presentations with schools; civic and community groups; business groups; and garden clubs. TAGRO Mix sells for $10 per cubic yard and TAGRO Potting Soil sells for $30 per cubic yard or $15 for ½ cubic yard. A few buckets or containers full of potting soil can be purchased for $5, for customers who only need a small amount (City of Tacoma 2017). TAGRO products have a loyal following, with more than 4,500 customers using the product each year. In 2015, TARGO products were sold out by early summer (Brown et al. 2017).

Tacoma's biosolids program has won numerous awards since it began, including first and second place awards for the best biosolids program in the country (1995, 1996, and 1998) and the Technology Innovation or Development Activities Award (2004) from the Environmental Protection Agency (City of Tacoma 2017).

Urban horticulture example: Tacoma's Community Garden Project

Tacoma's success in building TAGROs use and reputation locally was in part due its use in the community garden development program. In 2007, the city made a goal to expand the existing community garden network (Brown et al. 2017). Available city-owned land was offered to potential gardeners with the materials needed to build the gardens provided free of charge. This included water for irrigation, construction materials to build raised beds, TAGRO potting soil and/or yard waste compost to fill the beds, and mulched wood to cover garden paths. The program, now called Harvest Pierce County (www.harvestpiercecounty.org), currently supports 46 gardens in the City of Tacoma, 18 of which have been set up on publically owned lands, and an additional 30 gardens in surrounding Pierce County (Hodges Snyder et al. 2016). This represents an increase of approximately 70 gardens since the program began. Harvest Pierce County provides dedicated staff and a wide range of programs, classes, resources, and giveaways to support the gardens (Hodges Snyder et al. 2016). As the community garden project grew, Tacoma also experienced increased sales of TAGRO products. The use of TAGRO products in community gardens provides opportunity for residents to experience the products resulting in positive word-of-mouth reviews and higher residential use (Brown et al. 2017).

5.3.3 PIERCE COUNTY, WASHINGTON

In 2001, Pierce County's Unified Sewer Plan set a goal to eliminate the land application of Class B biosolids (Northwest Biosolids 2015). The County's decision to transition to a Class A biosolids program developed from a growing appreciation of sustainability principles in local leadership combined with concerns related to the long-term risk management and poor public perception of Class B biosolids (Newell 2017). Up to that point, all of the County's biosolids were treated through anaerobic digestion to a Class B product standard and applied to land. Initially, Class B biosolids were transported to a strip mine for land reclamation purposes, however, use shifted over time towards agricultural application (Newell 2017). In 2006, Pierce County launched its new biosolids management program, with the opening of a new drying facility.

The facility, built next to the wastewater treatment plant for a cost of US $19 million, uses a drying and pelletization process to produce a Class A biosolids product marketed under the name SoundGRO. The plant receives anaerobically digested and dewatered biosolids from the wastewater treatment plant and processes them using an Andritz drum dryer. The drying drum consists of three concentric cylinders which the pellets pass through consecutively. After emerging from the drying process, the pellets (93% dry solid) are sorted, cooled and stored until needed (Pierce County 2017a). The entire treatment process is enclosed and biogas generated during anaerobic digestion is captured and reused by the facility. SoundGRO meets US EPA standard for Class A Exceptional Quality biosolids. It is also registered as a commercial fertilizer with the Department of Agriculture, which has enabled sales to other regions and states (Pierce County 2017a, Newell 2017).

SoundGRO is marketed for use in commercial, industrial, and residential landscapes. It is a dry pelletized product, similar to commercial fertilizers, making it different from other common biosolid products produced and sold in Washington (e.g. TAGRO and GroCo). SoundGRO is a slow release fertilizer with a low salt-index compared to chemical fertilizers; therefore it requires fewer applications per year and can be applied at any time of year, even during dry conditions (Pierce County 2017b). SoundGRO is well received by customers and sells out on a yearly basis. It is available for purchase in 1-tonne totes and individually wrapped bags. Large purchases are sold for US $85.95 per 1-ton tote, which includes pallet and loading costs. Individually wrapped bags are made available through a number of regional garden and hardware stores (Pierce County 2017b). Pierce County produces approximately 2,500 dry tons of SoundGRO fertilizer annually, generating approximately US $200,000 in sales revenue (Newell 2017).

5.3.4 CITY OF RALEIGH, NORTH CAROLINA

In 2002, the City of Raleigh's biosolids management program and its Neuse River Wastewater Treatment Plant underwent scrutiny due to program deficiencies, including an over-application of biosolids on city-owned farmland, resulting in fines and a loss of public trust (City of Raleigh 2016a). Following an in-depth review of the facility, the City decided to become a National Biosolids Partnership demonstration agency, and committed to the development and implementation of an Environmental Management System (EMS) for biosolids. Prior to the development of the EMS in 2006, Class B biosolids was the only product produced at the facility and land application was the only dispersal method used. A key in re-building a successful biosolids management program in the city has been the decision to diversify biosolids products and distribution. The City currently produces three biosolid products, a Class B product for agricultural land application, a Class A biosolids fertilizer, and a Class A compost (City of Raleigh 2016a).

The City of Raleigh Public Utilities Department's Neuse facility provides wastewater treatment to Raleigh and six surrounding communities. The Neuse facility produces approximately 40 dry tonnes of aerobically digested Class B biosolids per day (City of Raleigh 2016a). Approximately 10% of the aerobically digested solids remain as Class B biosolids and are liquid land applied. About 55% are converted to a Class A biosolids fertilizer, named Raleigh-Plus, through a lime-stabilization process. Raleigh-Plus is produced by dewatering digested biosolids (22% dry solids) using belt presses and mixing them with lime kiln dust using a Cemen Tech mixer (McDilda 2009). Laboratory tests are completed on both Class A and Class B biosolids to ensure regulatory compliance and to assist in application of the product at agronomic levels (McDilda 2009). The remainder of the Class B biosolids are transported to an independent operator that mixes the biosolids with woodchips to produce a Class A compost product (McDilda 2009).

The majority of Raleigh County's biosolids beneficial reuse is agricultural based. Class B biosolids are typically produced by the facility in the spring when farmers are preparing to plant corn, soybeans, and grain sorghum (McDilda, 2009, City of Raleigh 2017). The Class B biosolids are applied to approved private agricultural fields through ground injection or surface spraying and disking into the soil (McDilda 2009). Raleigh-Plus is sold and distributed primarily to farmers; however the product is also used on the Neuse facility grounds and on other institutional lands. The City's program delivers and provides farmers a pull-behind spreader to apply Raleigh-Plus as part of a low cost lease program (McDilda 2009). In 2016, the Neuse facility distributed 41,000 tons of Raleigh Plus to 102 farmers in 27 counties along with application on City of Raleigh permitted land (City of Raleigh 2017). Raleigh-Plus and Class B biosolids are also used to grow sunflowers and soybeans bound for the City's biodiesel program (refer to Section 4.1.1). The Class A compost product, produced by the composting facility, is distributed in bulk to local markets (City of Raleigh 2016b).

The Raleigh Public Utilities Department is aiming to improve its historical record as the largest energy user in the city, with the largest carbon footprint. In 2015, the City changed the name of the Neuse River Wastewater Treatment Plant to the Neuse River Resource Recovery Facility, reflecting the long term goal of converting the facility from an energy sink into an energy producer (Knight et al. 2017). Currently, biosolids generated during the treatment process are managed through a range of product streams with different characteristics and different levels of stabilization. The City is planning to change its biosolids management program by consolidating the existing stabilization processes into a single stabilization process utilizing thermal hydrolysis pre-treatment (CambiTHP) coupled with mesophilic anaerobic digestion to produce a Class A product from all of its residuals (Bullard et al. 2017). With the addition of anaerobic digestion, potential biogas utilization options were also considered for the Facility that could maximize the value of biogas while also providing sufficient heat for the thermal hydrolysis process. Following the outcome of feasibility studies, the City is planning to convert biogas to either compressed natural gas, to fuel the City's bus fleet, or to renewable natural gas for pipeline injection (Knight et al. 2017). The City is taking advantage of recent advances in gas upgrading technology that make biogas conversion to renewable or compression natural gas a viable alternative to more traditional combined heat and power applications. The City's Bioenergy Recovery Project is now in the detailed design phase and construction is expected to start in 2018 (Knight et al. 2017).

5.3.5 BOSTON, MASSACHUSETTS

In 1991, as part of the Boston Harbor Project, Boston began producing biosolids for beneficial use with the opening of the Quincy Residuals Processing Facility (MWRA 2016a, 2016b). The Boston Harbor Project was initiated in 1986 to improve the health of the Boston Harbour, which at the time was known as one of the dirtiest harbours in America (MWRA 2016b). For a century prior to the project's initiation, Boston's sewage received only limited treatment before being released into the harbour with the outgoing tide. Boston's primary treatment facility, the Deer Island Wastewater Treatment Plant, also received significant infrastructure upgrades as part of the project (MWRA 2016a, 2016b). The Massachusetts Water and Resources Authority (MWRA), which serves 61 metropolitan Boston communities, awarded the design, construction and operation of the biosolids processing facility to New England Fertilizer Company (NEFCO 2017a). NEFCO still owns and operates the Quincy facility today and is responsible for all biosolids product marketing and sales.

The Quincy facility uses thermal drying technology, including a rotary drying drum, to produce a Class A biosolids pellet product. Digested solids arrive at the facility via underwater pipe from the Deer Island Wastewater Treatment Plant, after which they are dewatered onsite and are treated through thermal drying and pellet processing before being sorted, cooled, and stored (NEFCO 2017a, 2017b). The product meets state and federal standards for biosolids fertilizers (MWRA 2016a).

NEFCO distributes the Class A biosolids pellets in bulk throughout the country, primarily for use as an agricultural fertilizer or fuel source (NEFCO 2017a). Selling the pelletized product in bulk enables larger agricultural operations to purchase high quality biosolids fertilizer at lower costs than traditional synthetic chemical fertilizers (MWRA 2016a, NEBRA 2017). NEFCO distributes approximately 80% of the product to other states for agricultural use or as an additive for various fertilizer blends. The remaining product is distributed as a fuel for cement kilns (O'Brien and Pawlowski 2011). Biosolids are increasingly being used as a renewable fuel source, most notably in cement kilns, as they provide a carbon-neutral substitute for coal. The amount of energy obtained from the biosolids product is greater than the amount of energy used to produce it and the ash generated in the process can be incorporated into the cement (NEFCO 2017c). A small portion of the product is also packaged and distributed throughout the New England region under the brand Bay State Fertilizer (MWRA 2016a). Since 1995, Bay State Fertilizer has been available for purchase by the public at local garden centers and nurseries and is also available in bulk purchase for landscapers and golf courses. Many communities within the Massachusetts Water and Resources Authority use the biosolid pellets on their municipal landscaping, parks, and athletic fields (MWRA 2016a).

Table 5. Summary of Class A biosolids management programs.

Jurisdiction	Product Name	Biosolids Treatment	Program Initiation	Percentage of Class A Product Produced	Applicable Regulations	Beneficial Reuse of Biosolids
British Columbia						
Metro Vancouver Regional District	Nutrifor	Thermophilic anaerobic digestion	1991	80	BC OMRR, Federal Fertilizers Act	Mine reclamation, landfill closure and reclamation, regional reclamation projects, regional landscaping projects, forest fertilization, and ranch land fertilization.
City of Kelowna / City of Vernon	Ogogrow	Aerated static pile composting	1995 (2006)	100	BC OMRR, Federal Fertilizers Act	Commercial landscaping, residential gardening, nurseries, orchards, and landfill closure.
Comox/Strathcona Regional District	SkyRocket	Aerated static pile composting	2007	100	BC OMRR, Federal Fertilizers Act	Commercial landscaping, residential gardening, nurseries and orchards, slope stabilization project, and local reclamation projects.
Nanaimo Regional District	-	Mesophilic and Thermophilic anaerobic digestion	1991	30	BC OMRR, Federal Fertilizers Act	Forest fertilization.
Saanich Peninsula	PenGrow	RDF Lime-pasteurization	2008 to 2011	5	BC OMRR, Federal Fertilizers Act	Residential gardening and landscaping.
Other Canadian Jurisdictions						
City of Edmonton, AB	Second Nature	Co-composting with residential organic waste	2002	80	Federal Fertilizers Act; Provincial Application	Horticulture, agriculture, nurseries, commercial landscaping, residential gardening, city reclamation and enhancement projects.
Niagara Region, ON	Niagara N-Rich	N-Viro alkaline-stabilization	2007	50	ON Nutrient Management Act; Federal Fertilizers Act	Agricultural fertilizer.

Jurisdiction	Product Name	Biosolids Treatment	Program Initiation	Percentage of Class A Product Produced	Applicable Regulations	Beneficial Reuse of Biosolids
City of Toronto, ON	-	Thermal drying; N-Viro alkaline-stabilization	2007	75	ON Nutrient Management Act; Federal Fertilizers Act	Agricultural fertilizer and mine reclamation.
Greater Moncton, NB	Gardener's Gold	Composting - GORE Cover System	2008	100	CAN/BNQ 0413-200/2005; Federal Fertilizers Act	Commercial landscaping, municipal parks and horticultural activities, and residential gardening.
City of Halifax, NS	Halifax N-Rich	N-Viro alkaline-stabilization	2007	100	Federal Fertilizers Act	Agricultural fertilizer, and municipal horticultural activities.
United States of America						
King County, WA	GroCo	Aerated static pile composting	1976	2	US EPA Part 503 Biosolids Rule, Washington State Compost Standards	Residential gardening and landscaping, commercial landscaping, and forestry road reclamation.
City of Tacoma, WA	TAGRO	Duel digestion, composting	1990	100	US EPA Part 503 Biosolids Rule, Washington State Compost Standards	Urban community gardens, residential gardening, commercial landscaping, forest fertilization, and agriculture.
Pierce County, WA	SoundGRO	Thermal drying	2006	100	US EPA Part 503 Biosolids Rule, Dept. of Agriculture – Commercial Fertilizer	Agriculture, commercial and residential landscaping.
City of Raleigh, NC	Raleigh-Plus	Lime-stabilization, composting	2006	90	US EPA Part 503 Biosolids Rule	Agriculture, commercial landscaping, residential gardening, and biodiesel production.
Boston, MA	Bay State Fertilizer	Thermal drying	1991	100	US EPA Part 503 Biosolids Rule, Dept. of Agriculture – Commercial Fertilizer	Agriculture and fuel for cement kilns.

6 INTERNATIONAL BIOSOLIDS MANAGEMENT

The treatment and disposal of biosolids, including beneficial use programs, varies considerably worldwide.

6.1 EUROPEAN UNION

The European Union (EU) comprises 28 countries with a combined population of more than 500 million people (Evan 2012). The processing and use of biosolids varies considerably across the EU, with the dominant processing/utilization methods including application to agricultural land; composting and other land applications; landfilling; and incineration (Evan 2012, Fonts et al. 2012). The average use of biosolids for agricultural land application within EU countries is approximately 37%, with some countries such as the Netherlands, Greece, and Romania applying no biosolids to agricultural land and other countries such as the United Kingdom, Spain, France, and Ireland using more than 50% of their biosolids in agricultural land application programs (Evans 2012). Countries within the EU are required to enact Regulations and Directives into their own national legislations. While Regulations must be transposed verbatim, Directives are minimum requirements. Relevant directives include the Sludge (use in agriculture) Directive (CEC, 1986), the Landfill Directive (CEC, 1999), and the Waste Incineration Directive (CEC, 2000). EU member states have chosen a range of measures and limits in the implementation of the EU Sludge (use in agriculture) Directive (Evan 2012). Within the EU, biogas and phosphate recovery appear to be areas of future interest (Evan 2012).

6.1.1 UNITED KINGDOM

The United Kingdom (UK) beneficially re-uses most of its biosolids in agricultural land application as it is recognized at the best practicable environmental option in most circumstances by the government (UK Water 2010, Panter and Barber 2017). During last decade, the UK has undergone a shift from energy intensive processes with high carbon footprints (incineration, thermal drying, and lime stabilization) to energy producing wastewater processing using advanced digestion paired with biosolids agricultural land application (Panter and Barber 2017). A combination of strict financial regulation, high energy costs, and renewable energy incentives have led the UK Water Industry to invest heavily in advanced anaerobic digestion. The UK has the highest proliferation of thermal hydrolysis plants anywhere in the world (21 full-scale facilities), that treat more than a quarter of sludge production, 1500 metric dry tonnes per day, and generate 60 MWs of electrical energy continuously (Panter and Barber 2017). They have developed sludge centres where anaerobic digestion of biosolids is centralized, which has made sludge pre-treatment more affordable, has increased solid loads at treatment plants promoting energy self-sufficiency through biogas capture, and has provided greater ability to enhance product quality. When all current development projects in the UK are complete, 92% of all sewage sludge will be digested with captured biogas used in combined heat and power generation. Currently, nearly all digested biosolids are applied to farmland, with recent increases in Class A biosolids production. Almost all thermal dryers and incinerators have been de-commissioned and lime stabilization is now rare (Panter and Barber 2017).

6.1.2 FRANCE

France is a major agricultural country in the EU, applying 65% of its biosolids to farmland in 2010 (Wiechmann et al. 2013). In 2002, following pressure from the water industry and from farmers, France developed an indemnity fund, administered by the national government and linked to a quality assurance program. The fund ensures that should there be adverse effects of land-applied biosolids, they will be remedied, which provided market confidence (Evans 2012). In 2004, new regulations for biosolids compost were signed into law (NFU 44095), which recognizes composted biosolids as a product instead of a waste material (Petroff and Brashear 2005). A substantial amount of biosolids are composted with green waste in France and land applied as compost (Evans 2012). An example is Mont De Marsan biosolids composting facility, which began operations in 2005 and uses agitated bay composting technology. The facility is designed to handle 50 wet tonnes per day of dewatered biosolids (15% dry solids) and 50 wet tonnes per day of ground yard trimmings (BDP Industries 2014). The mixture undergoes 21 days of active composting in bays to meet EU requirements for a premium grade compost material, followed by a minimum of 2 months of curing in windrows. The finished compost is marketed for local agricultural use (BDP Industries 2014).

6.1.3 GERMANY

Germany generates the largest amount of biosolids in the EU, with approximately two million tonnes of biosolids dry mass utilized or disposed of in 2010 (Wiechmann et al. 2013). During that year, approximately 50% of biosolids were incinerated through co-incineration or micro-incineration (including gasification installations), 30% of biosolids were applied to farmland, and 20% were managed via other methods, including composting and landscaping (Wiechmann et al. 2013). Biosolids use in agriculture is subject to federal legislation, with three states opposed to the use of biosolids, and eleven states in favor. Only biosolids from municipal sewage treatment plants can be used as fertilizer for conventional farm crops (Wiechmann et al. 2013). Germany has established a liability compensation fund to remedy problems that might arise from land application. The fund, which is not linked to any quality management system, was started voluntarily by some of the leading operators and later taken over by the federal government (BCB1, 1998) (Evan 2012).

The most abundant form of biosolids management is Germany is thermal processing; anaerobically digested biosolids are incinerated at mono-incineration plants, coal fired power plants, cement plants, and at certain waste incineration facilities (Judex et al. 2012, Wiechmann et al. 2013). Germany has approximately 20 sewage sludge mono-incineration plants with aggregate combustion capacity of 580,000 tonnes dry solids per year and seven private sector sewage sludge mono-incineration plants with aggregate combustion capacity of 830,000 tonnes of original sewage sludge per year (Wiechmann et al. 2013). Germany has several pilot and full-scale gasification facilities in operation, including Balingen and Mannheim (refer to Section 4.4.1). Aside from incineration in mono-incineration plants, biosolids are also disposed of through co-incineration, which occurs mainly as coal fired power plants, waste incineration plants, and cement plants (Jones 2012, Wiechmann et al. 2013). Consequently, Germany is a major supplier of incinerator technology. Considerations for the future of Germany's biosolids management program include transitioning from agricultural use of biosolids to the exclusive use of mono-incineration in conjunction with energy and phosphorous recovery, in an aim to avoid soil substance and contamination risks and also eliminate Germany's dependence on imported phosphorous (Wiechmann et al. 2013).

6.1.4 OTHER EUROPEAN COUNTRIES

Similar to France, Spain and Italy have taken the biosolids composting route to shift biosolids into a different legal framework than the national implementations of the Sludge Directive (Evan 2012). Norway, while not in the EU, quickly exceeded their official target to recycle 60% of biosolids to farmland, with 80% of biosolids applied to farmland or green areas in 2008 (Evan 2012).

The Netherlands, by contrast, has one of the lowest percentages of biosolid use in agriculture in the EU, as the Ministry of Agriculture set the limit values for metals in biosolids so low that it is challenging for biosolid products to comply. This keeps available land open to for the large qualities of livestock manure generated in the country (Evan 2012). The Netherlands incinerates most of its biosolids at facilities both within and outside of the country (GMSC and UN-Habitat 2008, Wiechmann et al. 2013).

Finland's Ministry of Agriculture has taken the same approach as the Netherlands; however the response has been to develop biosolids products for gardening, landscaping, and reclamation purposes instead of incineration. For example, Helisinki's Wastewater Treatment Plant anaerobically digests all of its sewage sludge (with biogas used for combined heat and power) and composts the resulting biosolids with sand, crushed biotite, stone and crushed limestone. The product is called Metsäpirtin Bio-Soil and it is sold largely to gardeners and landscapers (Evan 2012).

Switzerland banned the use of biosolids on farmland in 2005, over concerns about the potential consequences for human health and the environment of potentially toxic substances and harmful micro-organisms (FOEN 2003, Evan 2012, Smith 2009). The country co-incinerates much of its biosolids in either cement kilns or coal plants, with some biosolids applied to land in neighboring France. Greece and Malta have also chosen not to apply biosolids to land and use landfilling as their predominant disposal method (Mininni et al. 2015).

6.2 JAPAN

Like Germany, Japan also relies heavily on thermal processing (largely incineration) for biosolids management. The country produces over two million dry tonnes of biosolids annually and manages more than 70% through incineration (GMSC and UN-Habitat 2008). There are a number of different ways incineration ash is beneficially used, including incorporation in cement, soil improvement materials, and various construction materials such as paving stones and bricks (Vasileski 2007, GMSC and UN-Habitat 2008).

Wastewater treatment plants capture biogas from anaerobic digestion, as well as thermal energy from sewage and waste heat from the incineration process to provide heat and power to the treatment plants, as well as to external buildings (UN-Habitat and GMSC 2008). For example, the thermal energy captured from raw or treated sewage is used for regional air conditioning (Vasileski 2007). Technical developments have also facilitated the recovery of phosphorus from biosolids, through the crystallization of Magnesium Ammonium Phosphate method (Vasileski 2007). Japan is exploring other high-technology thermal treatments, such as gasification and pyrolosis, with the hope of obtaining more net energy from biosolids than standard incineration yields (GMSC and UN-Habitat 2008). To that end, the world's largest fully operational sewage sludge gasification facility is located in Tokyo (Jones 2017). Additionally, treatment plants occur in Hiroshima and Tokyo that pyrolyze up to 27,800 and 109,000 tonnes of dewatered sewage sludge per year, respectively, into pygas and biochar (IBI 2013). Japan's way forward in wastewater and biosolids treatment is to change wastewater treatment plants in urban centers into energy supply and material recycling stations. This is being achieved through improved efficiencies and energy savings at treatment plants, as well as maximizing energy recovery from biosolids and other local organic wastes, such as food waste (GMSC and UN-Habitat 2008).

6.3 AUSTRALIA AND NEW ZEALAND

In the southern hemisphere, Australia and New Zealand initiated the Australian and New Zealand Biosolids Partnership (ANZBP) in 2007, a member-based collaboration of utilities, consultants, academics and government bodies committed to the sustainable management of biosolids (ANZBP 2016b). The objectives of the partnership, among others, are to support engagement with the public and other stakeholders regarding biosolid management, support the biosolids industry on technical and regulatory policy matters and provide support services and information to members and the public (ANZBP 2016b).

In Australia, biosolids are usually regulated by the State environment protection authority or equivalent using the guidelines that apply in that State or Territory, or adopting those used in other States or national Guidelines. In New Zealand, the application of biosolids to land is carried out under the guidance of Territorial Authorities as per the provisions of Regional Plans. Most Australian State guidelines and the New Zealand national guidelines specify three or four treatment grades and two or three contaminant grades (ANZBP 2016c). In 2015, Australia produced approximately 310,000 dry tonnes of biosolids, with approximately 64% applied to agricultural land, 23% used in composting, forestry, and land reclamation projects, and 11% disposed of in landfill or stockpiled (ANZBP 2016a). In 2015, New Zealand produced approximately 77,000 dry tonnes of biosolids, with roughly 61% going to landfill, 18% discharged to the ocean, 9% applied to agricultural land, and 12% used in composting, land reclamation, or forestry (ANZBP 2016d).

A survey completed in 2010, assessing community attitudes to the use of biosolids found that 71% of respondents, most of which were Australian, felt positively towards the use of biosolids for various purposes, such as land application in agriculture or forestry, composting, and energy generation (ANZBP 2010).

Although, the majority of biosolids in New Zealand are disposed of in landfills, the country has developed a number of successful vermicomposting operations over the last decade (Quintern and Morley 2017). Vermicomposting has grown from processing 2,000 tonnes of biosolids in 2008, to approximately 200,000 tonnes in 2015. The process yields a highly valued fertilizer and soil conditioner known as vermicast for uses in agriculture, horticulture, nurseries and recreation areas (Hernandez et al. 2015, Joshi et al. 2015, Sinha et al. 2013, Quintern and Morley 2017). Hamilton City, for example, has a vermicomposting operation that serves a population of 153,000 and a diverse industrial footprint. Anaerobically digested, dewatered biosolids are transported to Tokoroa vermicomposting site where they are blended with other industrial wastes, and pulpmill solids from a cardboard recycling plant. The site operates on forestry blocks, vermicomposting approximately 90,000 wet tonnes of blended material annually. The site produces 30,000 tonnes of various vermicast products per year which is applied to crops, pastureland, orchards and nurseries (Quintern and Morley 2017).

7 CONCLUSIONS

Managing biosolids is an ongoing challenge for most jurisdictions around the world. As a result, innovative techniques and processes are continually being developed to the address health and environmental concerns, as well as issues related to managing the physical volume of biosolids. Over the past number of decades, many jurisdictions have shifted from treating biosolids as a waste product to a resource.

The CRD is advancing efforts to design, construct, and operate a wastewater treatment system. They have determined that the system will be designed to generate Class A biosolids. Based on this jurisdictional review, it is apparent that many different options are available to CRD planners and decision-makers.

Jurisdictional examples from BC, other parts of Canada, the US, and further abroad internationally highlights a range of existing programs using a variety of techniques. Some of the emerging biosolids and bioenergy process trends include:

- Biodiesel production
- Biogas utilization
- Thermal hydrolysis/biological hydrolysis pre-treatment
- Gasification
- Pyrolysis, and
- Incineration with energy capture

These techniques are showing great promise to address some of the common concerns associated with biosolids management, as well as opportunities to be innovative and creative.

Many jurisdictions also have established biosolids programs. Fifteen jurisdictional summaries from North America were presented, highlighting a range of biosolids treatments or combination of treatments, including:

- Aerobic digestion
- Mesophilic and thermophilic anaerobic digestion
- RDF Lime-pasteurization
- N-Viro alkaline-stabilization
- Thermal Drying
- Composting
  - Aerated static pile
  - Co-composting with residential organic waste
  - Bottom aeration with Gore Cover System

Some of the Class A biosolids products are used in:

- mine reclamation
- landfill closure, reclamation, and slope stabilization
- forest fertilization
- ranch land fertilization
- agriculture
- commercial, municipal, and residential landscaping
- industrial process feedstock

This report does not provide recommendations to the CRD. But hopefully, through the information contained in this report, a range of options are provided for consideration, and if appropriate, further exploration and research.

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