Research to establish dedicated innovation and training spaces within Wastewater Treatment Plants

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Disclaimer

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This project was conducted under the mentorship of Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Metro Vancouver or the University of British Columbia.

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Territory Acknowledgement

The author acknowledges that the work for this project took place on the unceded ancestral lands of the xwməθkwəy̓əm (Musqueam), Skwxwú7mesh (Squamish), Stó:lō and Səl̓ílwətaʔ/Selilwitulh (Tsleil- Waututh) Nations.

Executive Summary

This report aims to study the potential of establishing an innovation, training, and optimization space (ITO) within the wastewater treatment plants operated by Metro Vancouver. The report summarizes the surveys and interviews targeting around 20 municipalities to understand the incentives and obstacles of pursuing innovation and research in municipal wastewater treatment. The report also outlines some business and operation models of ITOs or similar institutions that can be used as references.

Most municipalities have undertaken pilot projects and have established partnerships with industry or academia. Additionally, most municipalities have a dedicated group responsible for innovation and research. All municipalities recognize the benefits and potential of the ITO. However, most municipalities were unaware of ITOs, which limited their planning and innovation and highlighted a lack of knowledge sharing among municipalities. Additionally, organizations face various obstacles such as cost, staff time, and regulatory environment for the innovation initiatives of municipalities. The organizational structure also prevents municipalities from making innovative decisions. Only a minority of the respondents have conducted plant scale testing, suggesting the need for deeper cooperation with the private sector.

Metro Vancouver is currently running the Annacis Research Centre (ARC) along its five WWTPs. Similar to municipalities participating in the survey, Metro Vancouver has excellent potential to set up an ITO for cost reduction, treatment improvement, and training and serve as a magnet for innovation. Moving forward, Metro Vancouver needs to consider the limitations of staff time, organization structure, and improvement of the regulatory environment. Furthermore, it will be beneficial to establish a framework for knowledge sharing with other municipalities. It will also be helpful to deepen cooperation and partnership with the private sector and engage in knowledge-sharing with other municipalities in future planning for the ITOs.

Background

Municipal wastewater is one of the largest sources of pollution to surface water in Canada. Before being released to the environment, wastewater needs to be treated. A higher level of wastewater treatment leads to a cleaner effluent and a smaller impact on the environment (*Municipal Wastewater Treatment*, 2020). Metro Vancouver operates five wastewater treatment plants and a regional sewer system that process over 1 billion litres of wastewater every day. Wastewater is treated using either primary or secondary or treatment processes (Metro Vancouver)

Wastewater treatment research, technology and operation development are often limited by lab-scale testing. As a result, industry and academia have great interest in conducting research with laboratory/testing space with access to continuous wastewater flow. An integrated research and testing centre within municipal wastewater treatment plants (WWTPs), such as Annacis Research Centre (ARC), offers enormous potential for conducting research and promoting innovative solutions for wastewater treatment that contribute to improvement of wastewater treatment effectiveness and efficiency, reduction of cost, and preservation of water resources. These centres also promote collaboration between public sector and universities and industry partners. Various public and private utilities have explored the possibility and potential of investing in a dedicated and integrated research and testing facility within the WWTPs. Integrating and dedicated ITOs at WWTPs may reduce the cost, complexity, and timeline of pilot-scale projects, anchor partnerships with universities and industry, and be an educational "learning ecosystem" for plant operators, engineers, and researchers.

A dedicated and integrated ITO within the municipal WWTP has the potential to improve the wastewater treatment operation in terms of improving treatment effectiveness and operator training, and reducing the need for temporary pilot infrastructure and/or reusing test beds, which can lead to reduction in human resources. Retrofitting existing WWTP or creating "Greenfield" test sites, in which no utilities, input and output streams and commodities, may present higher cost and discourage operation optimization. The study aims to explore potential opportunities, in both engineering and economic perspective, created by ITO spaces within WWTP.

The study aims to explore potential opportunities, from both engineering and economic perspectives, created by ITO spaces. The objectives of this project were to:

- Identify domestic and international utilities with strong innovation portfolios or "innovative utilities", including identifying which have dedicated pilot testing facilities.
- Develop and collect measureable input (e.g., a survey and literature review) on the desired attributes of laboratory/test spaces embedded in WWTPs for possible tenants, including university researchers, industry partners, plant operators, and plant engineers.
- Identify and rank specific process locations within WWTPs where ITO space would be of greatest benefit to sustainability and operation, consider the benefits based on unit process emissions, energy consumption via literature review.
- Summarize key business factors influencing the cost of pilot projects conducted in dedicated ITO spaces in comparison to the use of Greenfield sites using 3-5 case studies. Case studies may be found in literature or via discussion with public utilities.

- Summarize the state of test facilities or business models, at the previously identified "innovative utilities", through literature search and the support of Metro Vancouver.

Definitions

ITOs

Innovation, Training, Optimization spaces (ITOs) refers to dedicated and integrated research spaces, possibly distributed around municipal wastewater treatment plants.

Municipal WWTPs/WRRF

According to the Environmental Protection Agency (USEPA), a municipal wastewater treatment plant (WWTP) or Water Resource Recovery Facilities (WRRF) is a series of treatment processes used to remove contaminants and pollutants from domestic, business, and industrial wastewater collected in city sewers and transported to a centralized wastewater treatment system such as a publicly owned treatment works (United States Environmental Protection Agency, 2022). Some organizations have referred to its WWTP as the Water Resource Recovery Facility.

Annacis Research Centre (ARC)

Annacis Research Centre (ARC) is a modern, sustainable water resource recovery research facility, and event venue located on Annacis Island, in Delta, BC. The facility is adjacent to the municipal WWTP operated by Metro Vancouver. The main purpose of ARC is to provide research space for the exploration of water resource recovery, wastewater technology and pilot projects that need to work with wastewater streams or available potable water

Capital cost

The total of the purchasing price (excluding the cost of land), the part of legal, accounting, engineering, and other fees, that relate to buying or constructing (not including part that applies to land), the cost of additions or improvements after acquire the property, and soft costs related to construction, renovating or altering the property (*Government of Canada*, 2019)

Operation and Maintenance Cost

Direct operating and maintenance costs related to the initiative.

Greenfield

A temporary, non-dedicated test location which has not previously been built on. Greenfield sites require all services and support infrastructure to be provided.

Brownfield

A temporary, non-dedicated test location based upon abandoned treatment processes.

MGD

Wastewater flow rate expressed in millions of gallons per day.

Pilot Project

A small scale preliminary testing project aims to collect information and data.

ACWA

Advancing Canadian Water Asset (ACWA) is a partnership between The City of Calgary and the University of Calgary that supports research and development, knowledge transfer, de-risking and piloting of leading-edge water, stormwater and wastewater treatment technologies. ACWA's infrastructure is embedded within the City of Calgary’s Pine Creek Wastewater Treatment facility. ACWA is an initiative of the Urban Alliance, a strategic partnership between The City of Calgary and the University of Calgary.

Methods

This project has mainly performed two research methodologies: literature review and survey. First, the literature review aims to identify the municipalities similar to Metro Vancouver and interested in innovation. Second, the study developed survey questions to be distributed to around 60 WWTP operators, managers, engineers, and policymakers. The survey questions aim to identify municipalities' incentives and obstacles to pursuing an ITO space. For municipalities with an ITO or similar institution, the survey seeks to understand the processes, operation, maintenance, sustainability, improvement in treatment, and cost-benefit of the ITO.

The survey consists of three sections: introduction, general, and barriers to innovation. The introduction section allows participants to identify themselves and their preferred methods for conducting the surveys. The following section covers general questions related to testing within the municipal wastewater treatment plants:

- Whether the organization conduct pilot testing
- When testing a new technology/process, what kind of facilities do you use
- If applicable, how long has your organization had the test facility?
- What is the scale of testing conducted?

The final sections cover the barriers and incentives to innovation in municipal wastewater treatment:

- Does your organization have a dedicated innovation department or group?
- From 1-5, how would you rank your innovation portfolio? (e.g. innovation department, actively engaged with innovation/tech.)
- Does your organization have a dedicated and integrated testing facility?
- If you answered "yes" to the questions above, how many members does the dedicated innovation department have?
- If your organization has a dedicated and integrated testing facility, could you describe the processes of the facility? How large is the facility?
- If your organization has a dedicated and integrated testing facility, how many unit processes does the testing facility have?
- If your organization has a dedicated and integrated testing facility, what commodities are tested and what are the purpose and objective of the testing?
- Do successful pilot projects become permanent?
- What happens to equipment once testing is completed?
- How often does your organization partner with other organizations for research and development projects? (e.g. universities, private company)
- What promotes innovation at your organization? (Options: Cost reduction; Public pressure; Internal initiative; sustainability and environmental objectives; Champions of innovation; Supportive Board/Management)
- What prevents innovation at your organization? (Options: Cost and financing; Risk and risk aversion; Regulatory compliance; Space; Staff Time; Staff/department technical capacity; Current business model)

- Where do you see value in a dedicated testing facility? (Option: None, For enabling pilot project, For process optimization, For training; Reducing the need for temporary pilot infrastructure; Data collection; Reduced capital/O&M costs than Greenfield; Overcome limitations of modelling)
- What processes are your top priority for improvements (1=high, 5-low) (Processes: Primary treatment; Secondary treatment; Tertiary treatment; Solids handling; Wet weather treatment)
- What processes would benefit from integrated test beds? (Options: Primary treatment; Secondary treatment; Tertiary treatment; Solids handling; Wet weather treatment)
- Would you be willing to discuss a case study? (If yes, you will be contacted by Joshua)

Results

Among 60 organizations that are contacted, 20 participants have responded to the survey, with 3 participants opted to discuss a case study.

<u>Section 1: General questions</u>

The survey invited 65 municipalities to participate in the survey. Twenty participants have participated in the survey, with 3 participants willing to discuss a case study.

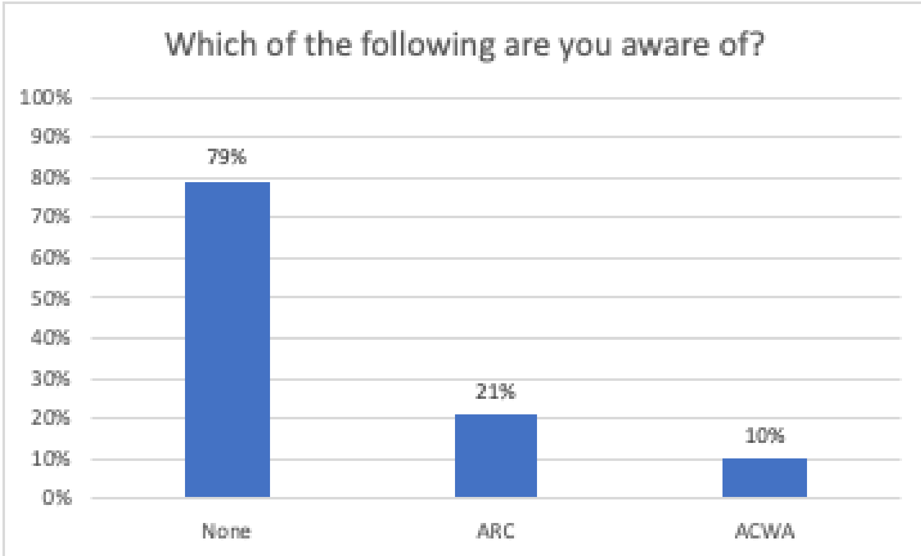

Figure 1: Awareness of existing ITOs

All organizations that take part in the survey undertake pilot projects. Among those organizations undertaking pilot projects, around half of participants only focus on process improvement, while the rest of the participants' partner with academia/industry partners. The results show a modest interest in cultivating relationships with academia and industry partners. However, all participants see the values of pilot projects and use them for process improvement, indicating considerable potential for the use of ITOs.

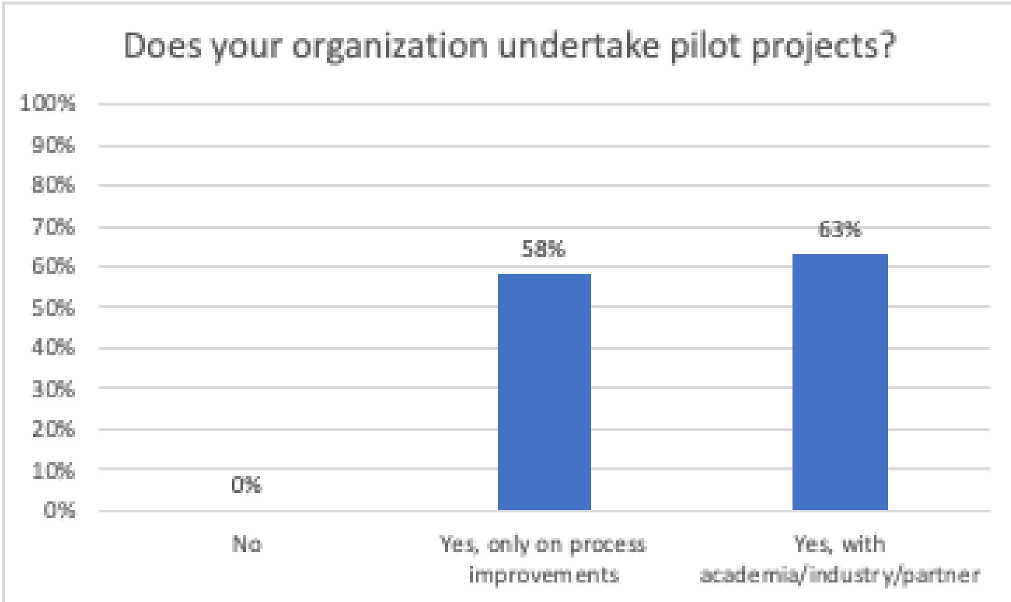

Figure 2: The pilot projects undertaken by municipalities

When testing a new technology/process, most organizations retrofit existing processes or conduct testing on Greenfield sites. However, most testing is less comprehensive and smaller than plant-based testing.

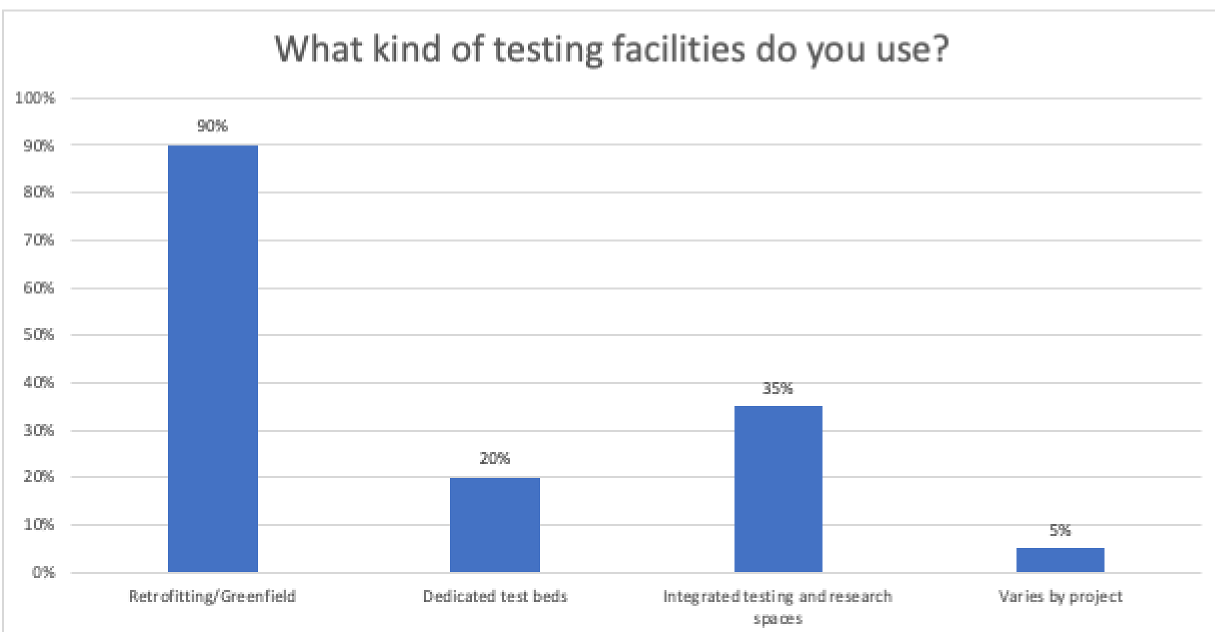

Figure 3: Type of testing facility

As for the test facility's duration, most respondents have run the testing facility for more than 5 years but less than 20 years, indicating a usual pattern for municipal infrastructure.

Figure 4: How long have municipalities had the test facility

As for the scale of testing, only a minority of the respondents have conducted plant scale testing, suggesting a lack of infrastructure and awareness of the potential of ITOs.

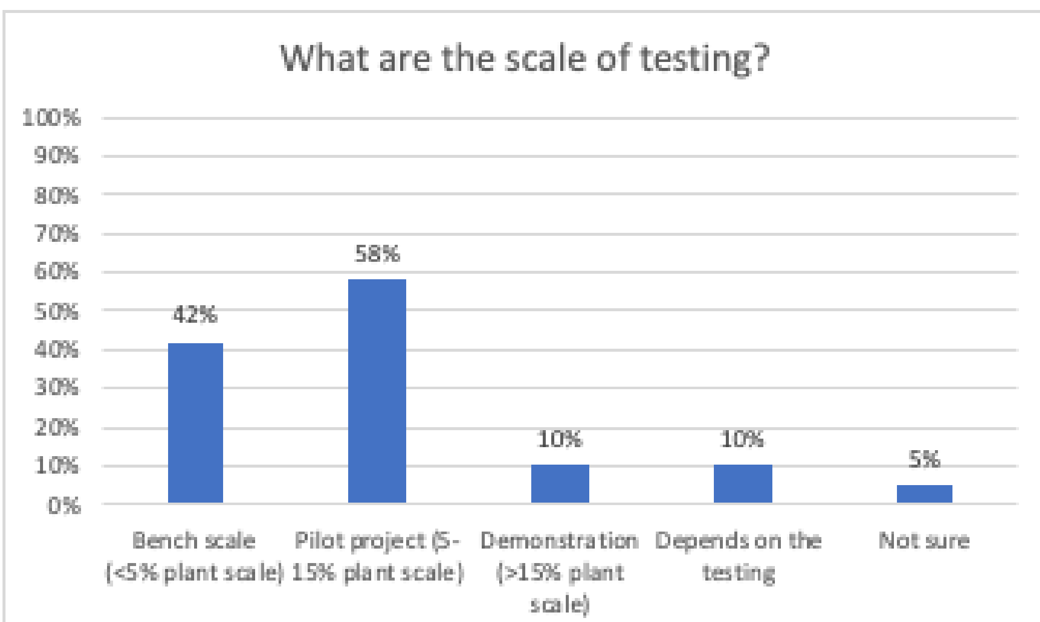

Figure 5: Scale of testing (Bench scale, Pilot project, Demonstration)

Section 2: Evaluating incentives and challenges for innovation in organizations

Among 19 responses, most municipalities have a dedicated innovation department or group. Most participants responded yes on whether their organization has a testing facility. On average, the dedicated innovation department of organizations has five employees. However, most municipalities do not see themselves as innovative, as indicated by the self-ranking of innovation portfolios.

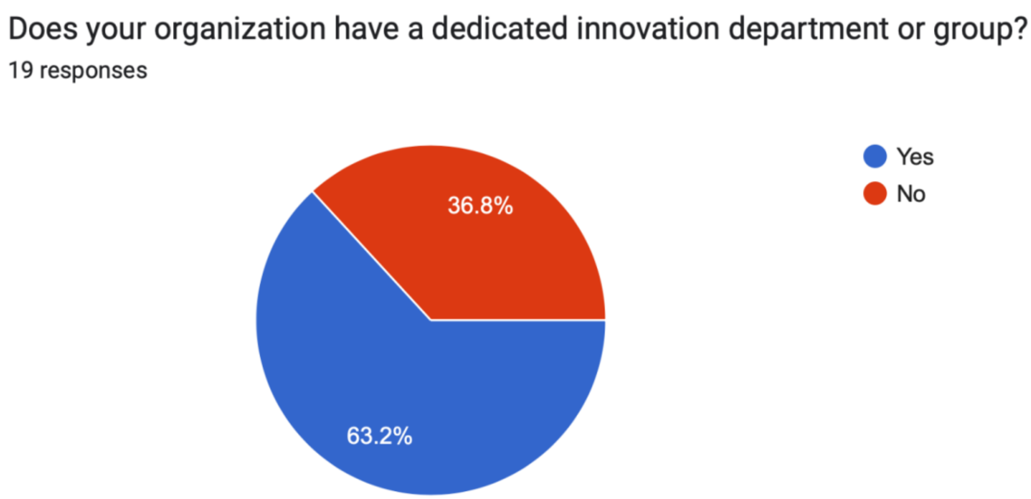

Figure 6: Percentage of municipalities that have a dedicated innovation department/group

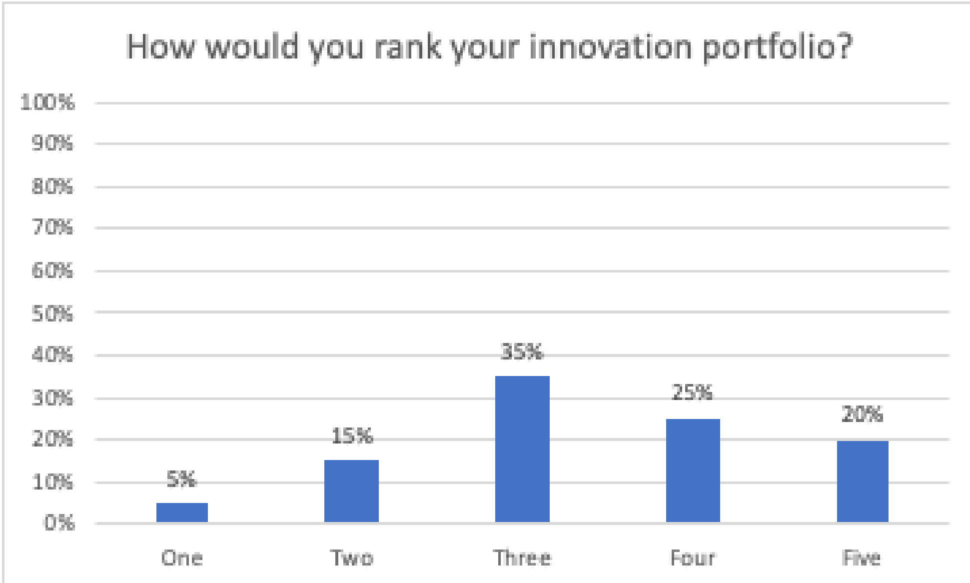

Figure 7: Self-ranking by municipalities of its innovation portfolio (One = non-existence, Five = Extensive innovation as more than 5 pilot projects annually)

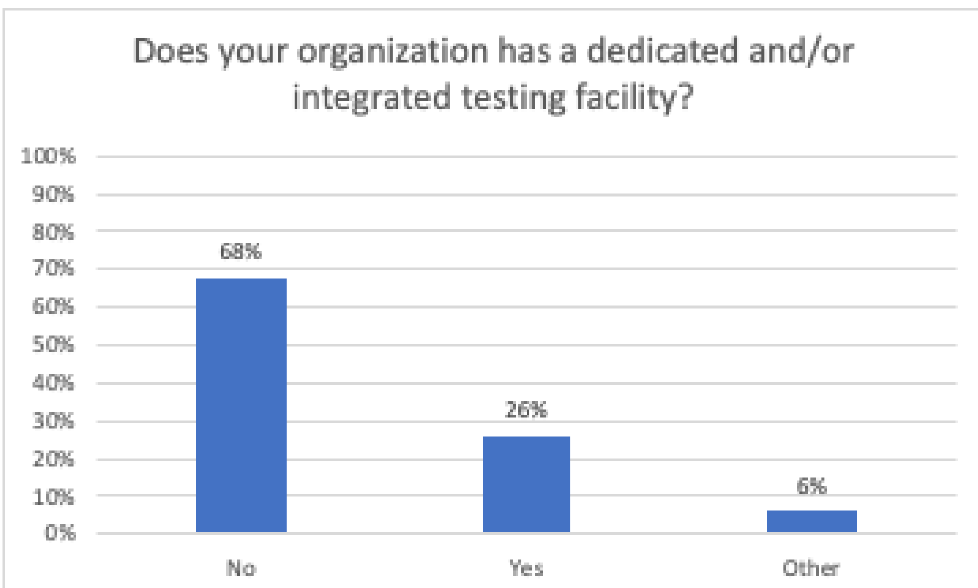

Figure 8: Percentage of municipalities that have a dedicated and/or integrated testing facility

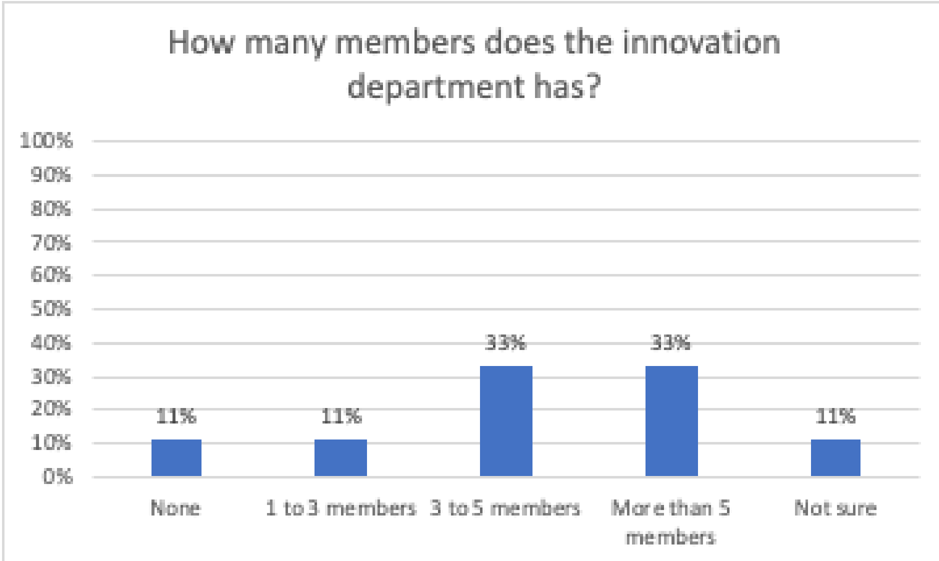

Figure 9: Number of members under the dedicated innovation department (None, 1 to 3 members, 3 to 5 members, more than 5 members, not sure)

A majority of organizations do not have a dedicated and/or integrated testing facility, suggesting that municipalities lack knowledge sharing platforms and awareness despite most respondents having seen the value of pilot projects. As for the organizations that have a dedicated innovation department, most departments employ more than three members.

Figure 10: Number of unit processes included in the testing facility

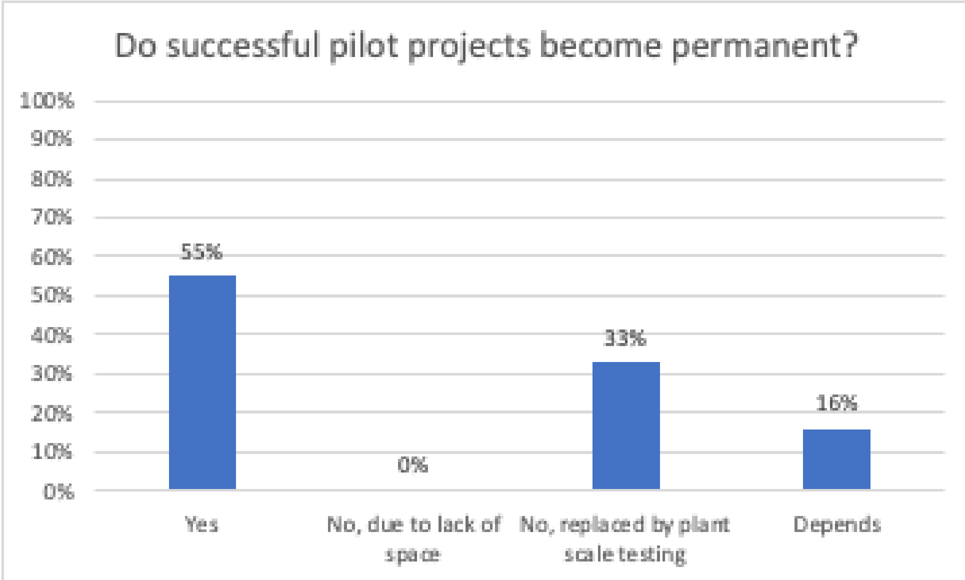

Figure 11: Whether successful pilot projects become permanent

As for what happens to the equipment once the test is completed, most participants answered "Owned and re-used", suggesting most municipalities are performing projects with sustainability and economic initiatives in mind.

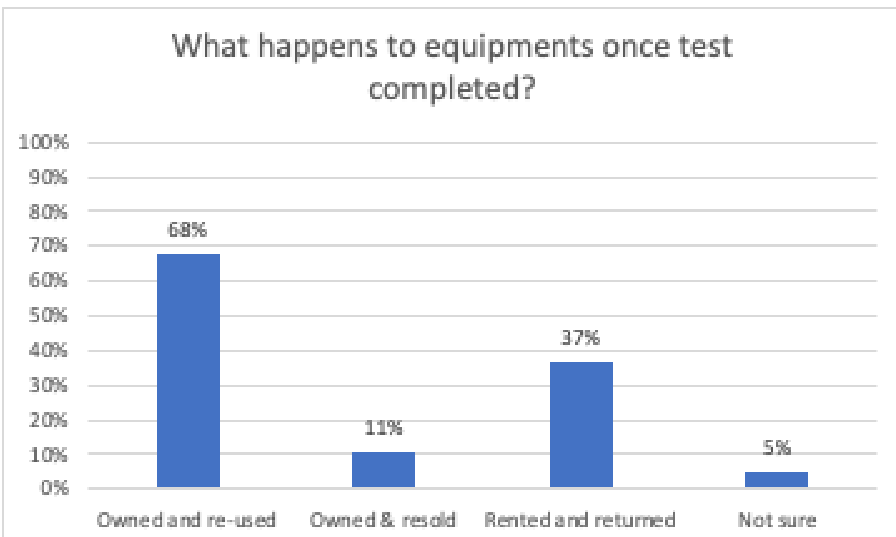

Figure 12: Post-usage of testing equipment

An overwhelming majority of organizations partner with other organizations for research and development projects, suggesting a significant potential to be explored by ITOs. However, it is worth noting that only a minority of those who partner undertake pilot projects with other organizations, suggesting a limitation with the current partnership with other organizations for research and development projects.

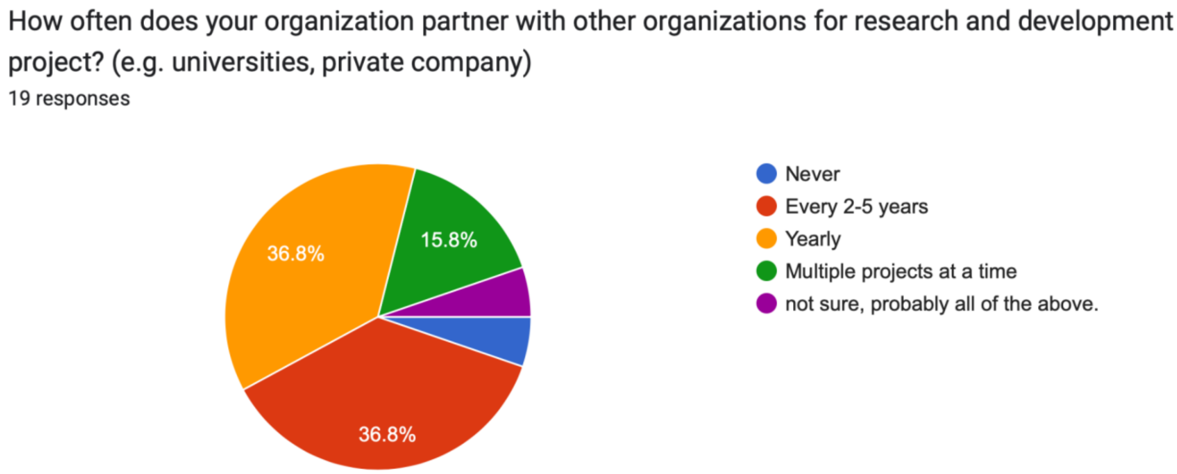

Figure 13: Status of partnership

Most municipalities recognize the value of innovation, particularly in fulfilling sustainability and environmental initiatives and cost reduction. Most organizations also identified the benefits of establishing an ITO for enabling pilot projects, process optimization, overcoming the limitation of modelling, training, etc. At the same time, financial restraints, staff time, risk aversion, and regulatory compliance prevent organizations from pursuing innovation.

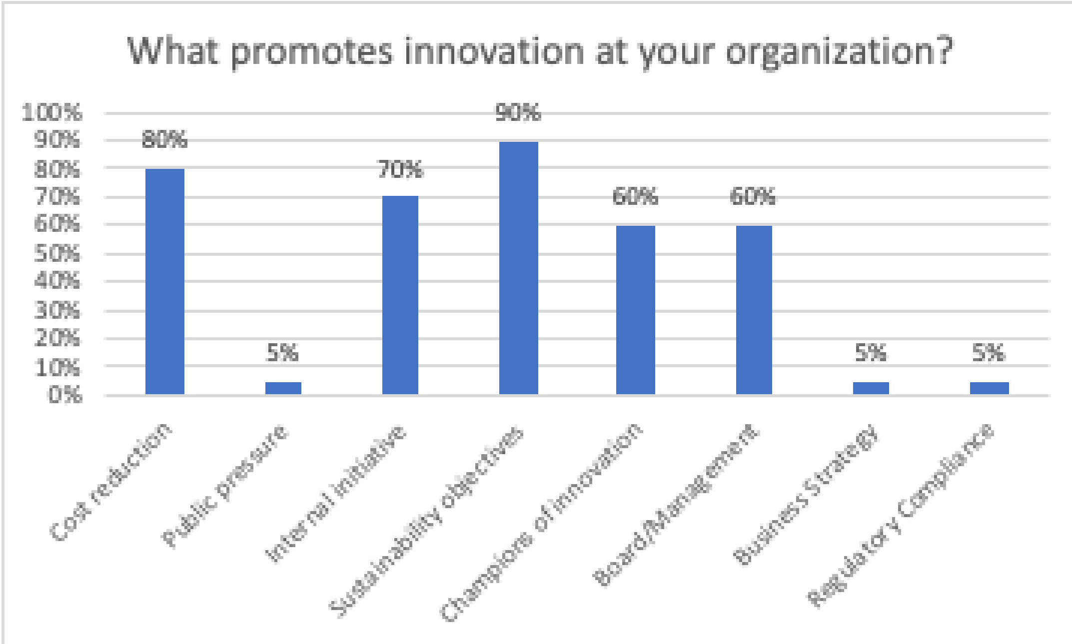

Figure 14a: Incentives for innovation

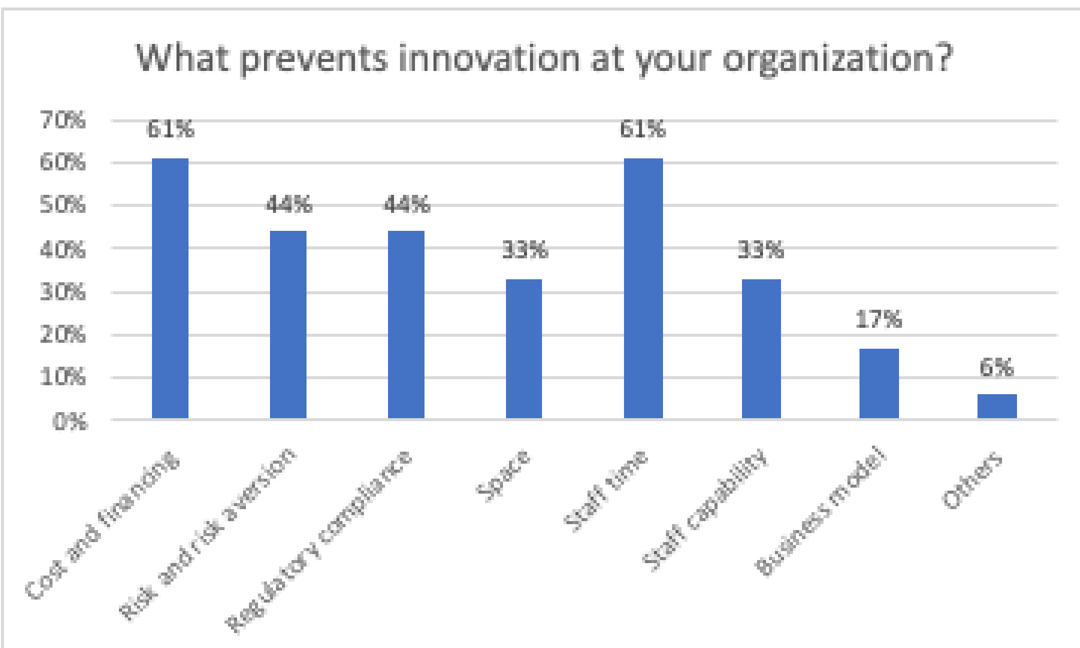

Figure 14b: Obstacles for innovation

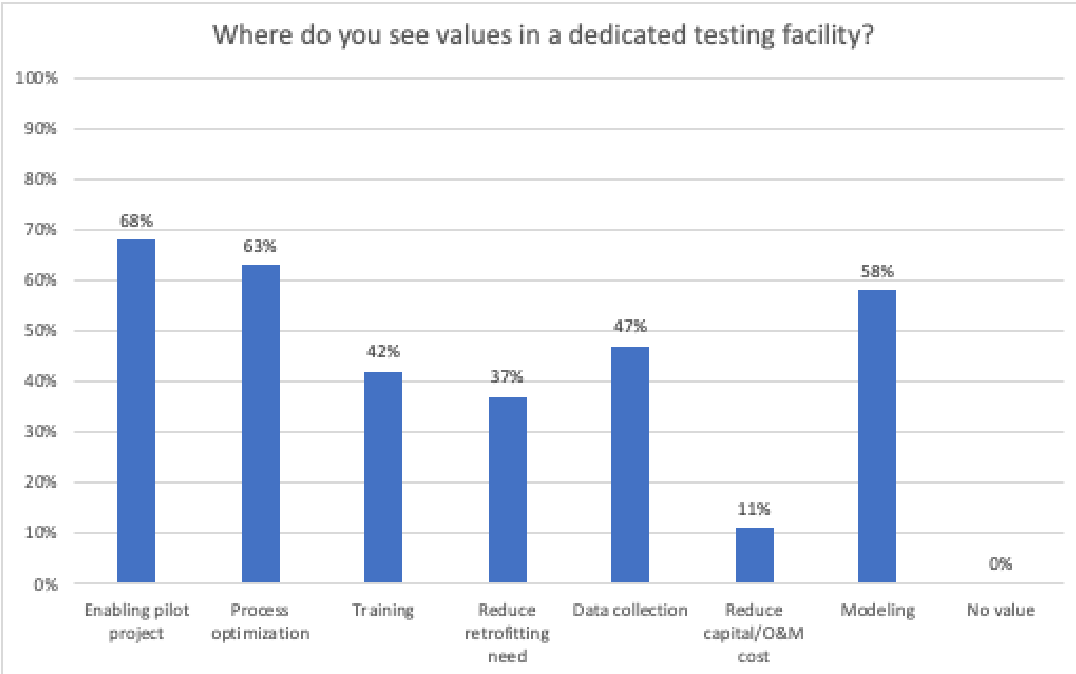

Figure 14c: Values in a dedicated testing facility

<u>Section 3: Evaluating the potentials for ITOs</u>

As for the priority for improvement of WWTPs, a majority of municipalities select secondary treatment as their top priority. Similarly, most municipalities desire secondary treatment as the process that would benefit most from establishing an integrated and dedicated test space.

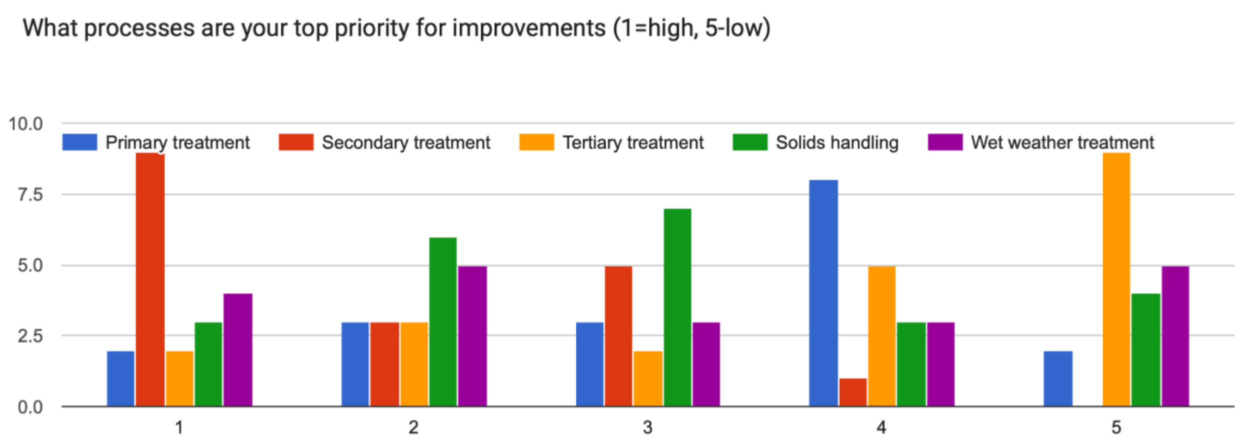

Figure 15a: Top priority for improvements

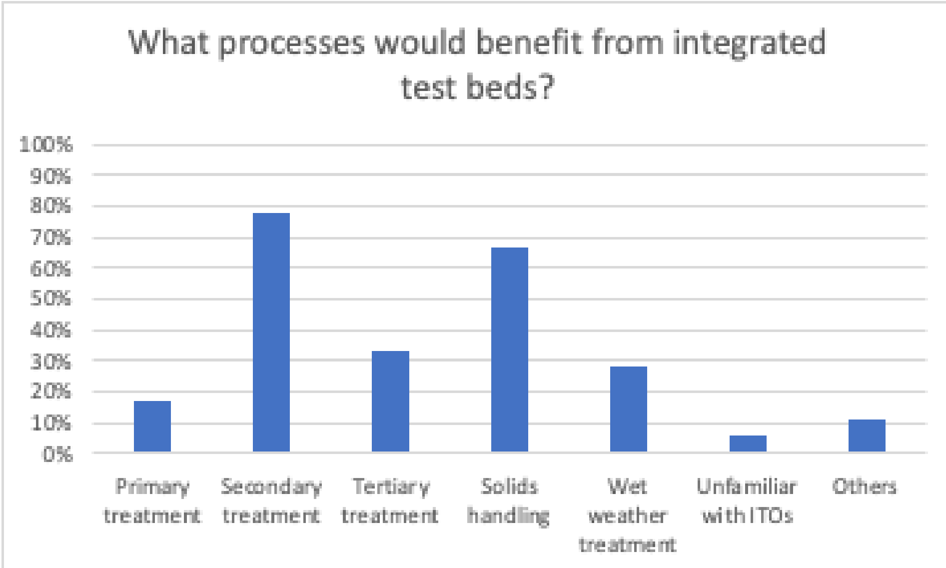

Figure 15b: Processes that would benefit most from integrated test beds

Case study:

Case Study 1: A drainage service

The Wastewater Treatment Plant, operated by A Services, is located in the Capital Region of the province. The G wastewater treatment plant is one of North America's most innovative wastewater treatment operations. More than 200,000 million tons of sewage are treated by the WWTP annually. The treatment process of the WWTP consists of pre-treatment, primary treatment, enhanced primary treatment (for stormwater flows), solid handling (via digestion), secondary treatment, and tertiary treatment (membrane filtration and UV disinfection). The treatment Plant is ISO 14001 and OHSAS 18001 certified. The organization emphasizes innovative processes such as membrane filtration to reduce environmental impact. Additionally, utilizing biogas has enabled the WWTP to recover approximately $200,000 in annual fuel savings. Furthermore, the plant is investing in odours control.

The WWTP serves approximately 800,000 residents. The plant is currently undergoing expansion and upgrading.

- Peak primary treatment capacity: 200 MGD
- Peak secondary/tertiary treatment capacity: >90 MGD
- Headworks (grit removal and screening) capacity: >260 MGD
- Combined digester (8 anaerobic digesters that treat sludge) capacity: 14MGD
- Biogas produced (average per year): 11 million m3

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Figure 16: Wastewater Treatment Plant treatment process operated by A ([redacted])

A service undertakes pilot projects with academia and industry partners. The facilities relied on both retrofitting existing processes, and a plant integrated testing and research facility, which has been operated for between 5 years to 20 years. The plant-based testing and research facility incorporates less than 10% of facility capacity with more than multiple treatment processes. The main commodities tested are primary and secondary treatment. After testing, the equipment is owned and reused, owned and resold, or rented. Despite partnering with other organizations for research and development projects yearly, the organization does not have a dedicated innovation department or group. Innovation initiatives are generated and managed internally by departmental sub-groups.

A considers cost reduction, internal initiative, sustainability, and environmental objects as the main incentives for innovation. On the other hand, the obstacles to innovation are risk and risk aversion, staff time, and the current business model. The top priority for improvement for E is secondary treatment.

According to the interview, the utility owned a pilot testing facility in partnership with the provincial university. The plant is currently upgrading its secondary treatment and is now undergoing testing in the pilot plant. The plant is also conducting research with the state university. In terms of education and training, the plant trains its employees using simulation rather than conducting training in the pilot plant.

The business model of A (a public-owned utility enterprise) enables the company to develop a close relationship with the regulatory authorities. However, the manager believed that municipal wastewater tends to be conservative in adopting innovative technologies and initiatives such as ITOs. The utility also takes a cautious approach to cost and finance and evaluates return on investment carefully before implementation of the investment.

Case Study 2: B Region Wastewater Program

In cooperation with local municipalities, the B Region Wastewater Program aims to provide communities with environmental protection by treating wastewater. Currently, 11 WWTPs are under operation under B Region.

The organization partners with industry and academia for research every 2-5 years. The B Region Wastewater Program identified cost reduction, public pressure, internal initiative, sustainability, and environmental objectives, champions of innovation, and supportive Board/Management as incentives for innovation. However, the innovation initiative of the organization also faces obstacles, including cost and financing, regulatory compliance, staff time, and staff/department technical capacity.

The study included an interview with the associate Director of Wastewater Operations, Maintenance, and Lab Services from B Region Wastewater Program. The director shares a few examples of innovative initiatives. B Region has taken several initiatives to amend and upgrade the secondary treatment of its 11 WWTPs. The process involves cooperation with consultants, researchers, and internal testing in laboratories of WWTPs. According to the interview, the positive relationship and communication between regulators and municipalities help provide flexibility and assurance for innovation. The director also pointed out that a plant integrated training and research centre would be ideal, although potentially limited by cost and finance.

Case Study 3: C Council Environmental Services

C Council Environmental Services is a local government office located in the upper midwestern region of the United States. The C Council treats wastewater for more than 100 cities and townships with around 2.5 million people in the metro area. The utility own, operate, and maintain the regional wastewater collection and treatment system, which includes:

- >630 miles of regional sanitary sewers
- >220 metering stations

- 61 lift stations
- 9 wastewater treatment facilities

C service collects and treats an average of 250 MGD of wastewater; almost 70% of this is being processed at the B Wastewater Treatment Plant in the city. The total amount of wastewater treated in 2021 was around 80 billion gallons. Located on one of North America's longest rivers and largest drainage systems, the C Plant is the largest wastewater treatment facility in its state. When it opened in the 1930s, it was one of the first WWTP discharges to the adjacent river. The C Plant treats an average of around 172 MGD of wastewater. The WWTP has an advanced secondary treatment process with chlorination/dechlorination ([redacted]).

- Capacity: >250 MGD
- Discharges to: River
- Communities served: >60
- Population served: 1.8 million
- Interceptors to plant: > 380 miles
- Average flows: 170-200 MGD

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Figure 17: WWTP operated by C service ([redacted])

C has a dedicated innovation group with five members, a research and development laboratory, and on-site testing facilities. As for the testing facilities, the organization builds pilot and bench systems as needed but does not have permanent unit processes. According to the survey, the organization undertakes pilot projects using dedicated test beds but only focuses on process improvement. C has identified cost and financing, risk and risk aversion, regulatory compliance, and staff time as the main obstacles to pursuing innovation while identifying cost reduction, internal initiative, sustainability, and environmental objectives as incentives for innovation. The organization partners with other organizations for research development every 2-5 years. The C identified wet weather treatment as the top area for improvement.

Case Study 4: D Water Services

D Water Services is a water resources management utility serving over 600,000 people in an urban region in the Pacific Northwest region of the Western United States. The utility operates a wastewater network of more than 3000 km of sewer pipes and 44 pump stations. The network transports the water to one of the four water resource recovery facilities for treatment before returning to the adjacent river to be reused.

The interview features the plant operator from R Water Resource Recovery Facility. The treatment process consists of a preliminary process, primary treatment, secondary treatment, solids recovery, tertiary treatment, and disinfection. The facility currently lacks an integrated and dedicated research and training space. As a result, the facility conducts testing with scales ranging from bench to plant scales. Most of the testing and training is performed in the facility's lab. Additionally, some testing and training are conducted in a sister plant.

The largest municipal nutrient recovery facility started operating at the R Facility in 2012. The utility partnered with the private sector to develop technology, known as proprietary technology, that directly removes and diverts ammonia and phosphorus to a reactor to be converted into fertilizer. This process reduces the operation cost and reduces the risk of forming struvite. The amount of energy required for creating fertilizer is estimated as one-seventh of energy needed for a conventional fertilizer. Therefore, the recovery facility can generate revenue and reduce energy usage.

The facility has developed a positive relationship with the regulators. As a result, the operator believed that the service can overcome the challenges associated with the regulatory environment. The facility also overcomes cost and financing issues with its innovation initiative and financial resource. The facility is also supported by a vital human resource, with an adequate number of newly hired interns and permanent staff fulfilling the innovation task.

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Figure 18: R Facility [redacted]

- Capacity: >30 MGD
- Discharges to: D River
- Population served: 300,000
- Recycles more than 18 dry tons of biosolids daily for use as a soil amendment

- Produces approximately 300 tons of fertilizer

Researchers

The study also included some interviews and questionnaires with wastewater researchers from UBC. All researchers conduct less than plant scale testing, and around half of the researcher partners were involved in projects with municipal wastewater treatment plants every 1-5 years. Researchers have identified enabling pilot projects, process optimization, training, reduced cost for setting up temporary structures, and cooperation between academia and the public sector as benefits of having an ITO.

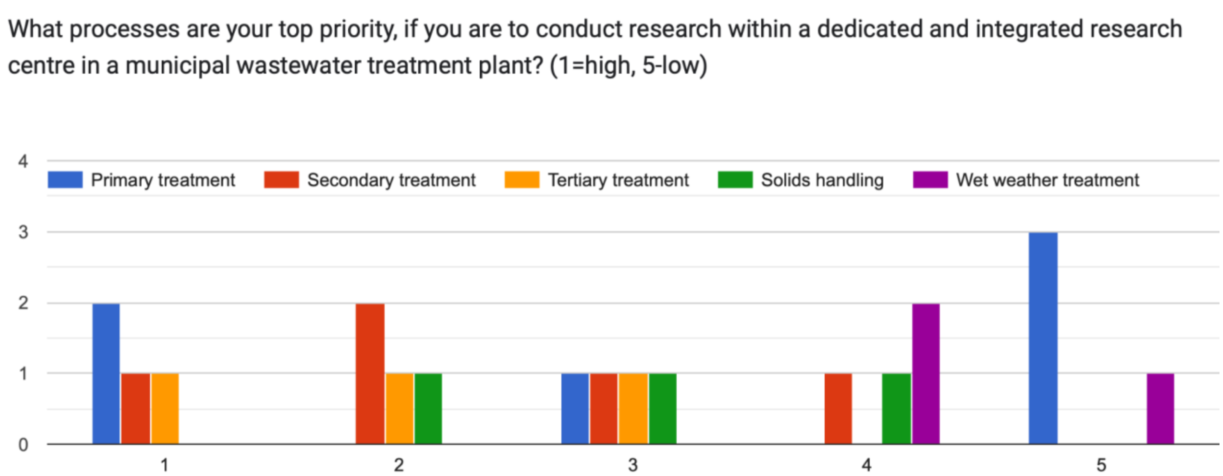

Figure 19: What processes are top priority for researchers (One = high, Five = low)

Similar to municipalities, most researchers identified primary and secondary treatment as the top priority if they are to conduct research in an ITO. In addition, researchers identified tertiary treatment, solids handling, and secondary treatment as significant areas of potential improvement from cooperation with ITOs.

Analysis:

Previous studies have shown that municipalities across North America generally desire innovation due to a combination of public pressure, cost reduction, and reputation (ASCE, 2017).. In addition, innovation can also lead to cooperation between municipalities. The Water Environment Federation (WEF) has recognized 39 water utilities for innovation in operation and communities. The 39 water utilities have transformed from a conventional municipal WWTP into a resource recovery centre and leader in the overall sustainability and resilience of the communities. In addition, The US Environmental Protection Agency (EPA) concluded that there is growing momentum to address traditional and emerging threats to the nation's water resources through innovative technology.

Studies found in literature have shown that although municipalities desire to pursue innovation, some are hesitant due to various factors. For example, regulation is an important factor for utilities considering innovation while the strongest barriers to innovation are found within regulatory relationships and the regulatory environment (Sherman et al. 2020). Therefore, itt is crucial to support resources, knowledge, capacity, and programs to the regulation to navigate the relational and contextual barriers to taking risks. A study by Scotland's Centre of Expertise for Waters summarized the key barriers and drivers for adopting innovations in water and wastewater utilities. The study identified four key barriers to innovations in water and wastewater utilities: operational (e.g., perceptions on the fitness of purpose for innovation, timescales), legal (e.g., demand for compliance, approvals process, other legal issues), Financial (e.g., costs of innovation, no incentives to innovate), and technical (e.g., feasibility of use, performance, lack of accredited supplies or equipment). (O'Keeffe & Gilmour, 2018)

Deloitte released a study summarizing lessons learned from adopting government agencies to address environmental issues. These lessons include cooperation between agencies and justifications, risk management and reduction, and operation sustainability (Chew, 2021). The report also recommends creating specific targets and integrating targets with current practices. As shown in case A, the lack of partnership and frameworks that enable knowledge-sharing and cooperation between municipalities prevents municipalities from adopting innovative approaches.

According to a study by OECD, the past environmental policy and practice are often limited by the capture of government policies by special interests (OECD, 2022). Based on its innovation studies, the OECD also concludes that policy instruments should be "fine-tuned to the circumstances in which sociotechnical change processes occur and tip the balance." Specifically, the paper argues that the government should create policies that are "explicitly concerned with technical change" and be concerned with institutional arrangements beyond the details of policy instruments. The paper concludes that various responsibilities by different stakeholders and policymakers are needed. (OECD, 2022)

Most municipalities are unaware of ARC or ACWA, which indicates a lack of awareness of establishing ITOs in Canada. Despite general interest and initiatives in pursuing innovation, the lack of references may prevent municipalities from pursuing ITOs in their organization. Additionally, based on the interview and responses from municipalities, the concept of ITOs require further clarification.

A majority of municipalities undertake pilot projects and regularly partner with academia and industry partners, with around equal amounts of only focusing on process improvements versus partnering with academia/industry partners. However, most municipalities only rely on retrofitting existing testing processes. Additionally, most municipalities have maintained the same business and operation model for more than five years, and most of the municipalities focus on bench scale and pilot projects. The results show that although most municipalities have a department or group responsible for innovation and have the potential to develop demands for establishing research and training institutions, few have established one.

Despite seven municipalities having claimed to have an integrated and/or dedicated testing facility, closer examination reviews that the majority of the facilities either do not have access to continuous wastewater or are incapable of conducting plant-scaled testing and training. Municipalities may not have explored the full potential of these facilities, mainly due to cost and staff time limitations, as well as the business model and structure of these facilities. As the interview with the CWS has revealed, although many WWTPs have adopted innovative technology, the municipal wastewater industry tends to be conservative in adopting innovation initiatives, often due to risk and risk aversion.

Among municipalities that report having integrated and dedicated testing facilities, only a minority of facilities have more than 3 unit processes, suggesting that the size and capacity of the facilities are likely limited. Most of the testing facilities focus on primary and secondary treatment. The result resembles the initial literature search that only a few facilities can conduct plant scale testing or fulfill the definition of ITOs.

Limitations of cost, financing and staff time are the most significant obstacles preventing municipalities from pursuing innovation. Lack of funding is widely acknowledged as the main obstacle for municipalities WWTP to pursue innovation (The American Society of Civil Engineers (ASCE, 2017). In the United States, public utilities are often forced to share more of the financial burden regarding innovation (Parker, 1988). In particular, a dedicated and integrated ITO requires significant capital investment and operation and maintenance expenses. A closer economic analysis of ARC can help Metro Vancouver to assess the feasibility of new ITOs. However, other articles point out that increasing research and testing capacity is widely recognized as the most significant avenue for adopting innovation by public utilities and regulators (Cantor et al., 2021). As the survey shows, most municipalities recognize that a dedicated and integrated facility can be beneficial in enabling pilot projects, process optimization, and overcoming modelling limitations. The survey conducted has shown that municipalities with an innovation department or team tend to have more comprehensive testing, research, and training activities. Moving forward, human resource allocation may prove to be one of the most effective directions to study when planning an ITO. Cooperation and partnership between municipality, industry, and academia are helpful for the acquisition of qualified staff. As shown by the case of the R facility, the revenue, energy saving, and carbon credit generated by the establishment of new facilities can be the main incentives for municipalities.

Additionally, some municipalities identified "Regulatory Compliance" as their main obstacle to pursuing innovation. Indeed, other studies have pointed out the importance of communication between utilities and regulators in pursuing innovation and that utilities and regulators share similar objectives in pursuing innovation. (Cantor et al., 2021; Sherman et al., 2020). In general, rather than regulation, WWTPs across North America have identified regulatory relationships (regulatory requirements, regulators and relationships, the broader regulatory environment) and factors related to the broader regulatory environment as barriers to innovation (Sherman et al., 2020). The connection, as shown by case study A, ensures smooth communication and flexibility necessary to pursue innovative solutions and initiatives.

Metro Vancouver is currently running five wastewater treatment plants that process around 220 MGD of wastewater and a regional network of sewers and pump stations. In addition, Metro Vancouver has adopted its Integrated Liquid Waste and Resource Management Plan. Under the plan, Metro Vancouver is upgrading its Iona Island wastewater island treatment plant and other environmental assessment and monitoring programs. Metro Vancouver is also building a new North Shore Treatment Plant, which will replace Lions Gate wastewater treatment plant. Metro Vancouver is also eying to incorporate tertiary treatment in its WWTPs (Metro Vancouver, 2022).

- Capacity: 220 MGD
- Population served: 2,700,000

Figure 20: Metro Vancouver Liquid Waste System Map (Metro Vancouver, 2022)

Currently, Metro Vancouver relied on retrofitting existing processes within WWTPs and establishing pilot testing plants for its upgrading and expansion projects. Metro Vancouver has established a team of professionals that is in charge of research, training, and education initiatives and related projects. In addition, Metro Vancouver has partnered with academia and industry partners to engage in various research and development projects.

The Annacis Research Centre (ARC) was built by Metro Vancouver and the governments of British Columbia and Canada. Many of ARC's projects focus on reducing environmental impacts and reducing costs for utilities and the communities they serve. The centre's secondary purpose is to provide a modern, affordable, eco-friendly option for meeting rooms and event space rentals (Metro Vancouver, 2022).

Figure 21: Annacis Research Centre (ARC) (Metro Vancouver)

The study shows that it is critical for Metro Vancouver to consider the incentives and limitations surrounding the ITO in the following pillars: sustainability, staff availability, finance, and partnership.

Regarding staff availability, limitations can be partly offset by having ITO incorporate education and training into its objective. During the interview and survey, most municipalities do not seem to explore the full potential of their existing testing and research facility for training purposes. For example, A service only conducts training in the form of simulation rather than having employees participate in the full-scale operation in its sister plant that is used for pilot tests. The B Region does seek partnership with the private sector and its research facility and has established its on-site testing facility. However, its staff does not conduct training and education in its plant. Most of the innovation department/group appears to have only 1-2 employees, and as a result, the limitation of staff can prevent innovation. Incorporating education and training elements into the ITO can largely offset the limitations around staff time.

Cost and finance are other important considerations and limitations for establishing ITOs. For example, the D Water Service has established the largest municipal nutrient recovery facility. According to the interview, the revenue generated from the recovery facility has further encouraged innovation and research in other areas such as odour control, secondary treatment, and plant upgrade. The interview with E has shown, the conservative business model and organizational structure of municipal WWTPs may prevent the adoption of ITOs.
Partnership with the private sector can overset the organization or staff time limitation. For example, the B service has started to plan on upgrading its secondary treatment to MBBR. It has established a relationship with consultants who have the knowledge and resources that can benefit its secondary treatment upgrade. The B Region only had a limited on-site lab, while it relied on performing research in partnership with the private sector. Therefore, having a constructive collaboration with the private sector in establishing ITOs can be an option in the future. In innovation, the public sector has much potential to learn and adopt from the private sector, with the connections built by organizations and platforms such as Open North, Evergreen, and Municipal Innovation Exchange (Linthorne & Thompson, 2019).

Various respondents have recognized the "business as usual" mindset in the municipal wastewater sector as a limitation to adopting innovative approaches such as ITOs. It is important to clearly outline the area of research interest and education objectives and how the research and training can benefit the municipalities in terms of reducing operation and maintenance cost, and improving treatment effectiveness in the planning phase of the ITOs. As recognized by various municipalities during the interview, it will be difficult to obtain funding from municipalities for non-practical projects, such as the treatment technology that are still under development. In those cases, partnership with the private sector and academia can provide additional support for research and development. As shown in the study, most municipalities are interested in exploring innovative technology and processes in primary, secondary, and solid handlings. Therefore, some municipalities have partnered with other organizations and set up a committee or group to break down their internal barriers and encourage a "safe-to-fail" culture. This would be limited to innovation and training, while maintaining consistent and fail-free core service (i.e. treatment). It also assisted its staff in connecting internally and externally with the right people to discuss potential new solutions, processes, and technologies. This strategy has helped various organizations identify its existing problems, and provide more incentives for innovation (Chattha & Chong, 2018).

Municipalities may also encourage innovation by making their data and resources accessible to its staff and other municipalities and seeking public engagement. Municipalities may also need new funding opportunities and agreements, including foundation partners, nonprofit partners, academia, and business, to offset the limitations in cost and finance (Burstein et al., 2015). The ITOs can be a potential public engagement platform for Metro Vancouver to explore.

Conclusions and recommendations

Municipalities have overwhelmingly supported the idea of establishing an ITO and as the survey showed, recognize the value in establishing ITOs. However, only a few have established or planned an ITO similar structure. In addition to the overall conservative nature of the municipal wastewater industry, most municipalities are unaware of Metro Vancouver's ARC and City of Calgary's ACWA and how these facilities have contributed to the wastewater treatment effectiveness, cost reduction, and sustainability policy requirements. Municipalities are also concerned with limitations of staff time, finance, and the regulatory environment.

Cooperation and partnership are essential components in establishing ITOs in the future. Cooperating with the private sector in establishing an ITO can offset many obstacles. In addition, engagement with other municipalities is also helpful. As shown in the study, various municipalities have taken initiative to pursue innovation and can be used as helpful reference for Metro Vancouver. Building a positive relationship with regulators is another vital point in establishing an ITO. It is also important to consider allocating more human resources to support innovation.

Metro Vancouver has engaged in various engineering projects that require pilot testing, research, education, training, and partnership. Further study is needed to examine the previous pilot project, training, and cooperation with the private sector to identify areas of improvement. The previous project pilot, testing, and staff education can be an important reference for the ITOs.

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