CANADIAN ENGINEERING

GRAND CHALLENGES

CANADIAN ENGINEERING GRAND CHALLENGES (2020-2030):

INSPIRING ACTION TO IMPROVE LIFE FOR CANADIANS AND THE WORLD

Engineering Deans Canada | Doyennes et doyens d'**ingénierie** Canada

CANADIAN ENGINEERING GRAND CHALLENGES (2020-2030):

INSPIRING ACTION TO IMPROVE LIFE FOR CANADIANS AND THE WORLD

PRELUDE[1]

At the heart of the assessment is a stark warning. Human activity is putting such strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted. The provision of food, fresh water, energy, and materials to a growing population has come at considerable cost to the complex systems of plants, animals, and biological processes that make the planet habitable. Above all, protection of these assets can no longer be seen as an optional extra, to be considered once more pressing concerns such as wealth creation or national security have been dealt with. Nearly two-thirds of the services provided by nature to humankind are found to be in decline worldwide. In effect, the benefits reaped from our engineering of the planet have been achieved by running down natural capital assets. – Millennium Ecosystem Assessment, Living beyond Our Means

BACKGROUND:

The United Nations' 17 Sustainable Development Goals (SDGs) are our world's call to action on the most pressing challenges and opportunities facing humanity and our natural world. Recognizing the critical role that engineers play as technological leaders and stewards, the Canadian Engineering Profession and the Engineering Dean's Canada (EDC) council believe that our profession has a pressing responsibility to address these challenges with urgency. This document articulates this responsibility and presents a call to action.

The "Grand Challenge" concept has been developed and refined over the past century by a range of individuals and organizations, starting with the German mathematician David Hilbert in 1900 who provided a list of 23 unsolved problems in mathematics that he felt all mathematicians should focus their attention on over the next few decades. Since then, many groups have used a Grand Challenges approach to focus, galvanize, and inspire their respective professions.

Most conceptualizations of Grand Challenges stress that they are a delimited set of high-level aspirations that reflect broad, integrative problems of deep societal importance, where solutions are imaginable but the path to a solution is as yet unclear.

PROCESS:

At the Engineering Dean's Canada (EDC) meeting at the University of Prince Edward Island (UPEI) in June 2017, the idea of creating a series of Grand Engineering Challenges for the Canadian engineering community to work on was presented. These challenges would be global, but have a uniquely Canadian context.

Although Grand Engineering Challenges had been articulated by the US National Academy

[1] Taken from the Natural Assets and Human Well-Being Report https://www.millenniumassessment.org/documents/document.429.aspx.pdf

of Engineering in 2008, many Canadian Deans felt that the Canadian engineering community needed to develop "made in Canada" engineering challenges that reflected the unique characteristics of our people, our natural landscape and the challenges we face as Canadians.

The Deans believed that articulating the challenges in this manner would help influence the thoughts and actions of engineering education, research and outreach on the most compelling and important societal issues facing Canada and Canadians. These challenges would be relevant over the next decade and present problems for which engineering solutions could be imagined to improve Canadian Life.

At its core, each Grand Challenge we have identified is a broad but discrete concept where engineering expertise and leadership can be brought to bear on bold new ideas and engineering innovations that will improve Canadian life.

As Deans, we believe this will also provide us with invaluable opportunities for our engineering students, both undergraduate and graduate, and faculty members to engage with large complex and socially motivated problems that inherently require an understanding of multiple perspectives and disciplines.

As engineers, we design and construct new structures, processes, and products that influence how people live and how our world, including our natural environment, is transformed. The obligations and responsibilities associated with this activity are significant and require our engineering students and faculty members to be able to critically reflect on the impact our work has on people and how they live, as well as our natural environment and resources.

Students who work on Canadian Engineering Grand Challenges will collaborate with people from other engineering disciplines and other fields to understand and benefit from different perspectives and manage competing needs. A deep appreciation and respect for the knowledge of other disciplines is essential to ensure that solutions proposed to grand challenges are co-created in partnership, fully engaging the insights and experiences of others.

The 'Challenges' will greatly test our students as they have no obvious solution and will require abstract thinking, creativity, systems thinking, and multi-faceted problem-solving approaches. We need to build capacity in the profession of engineering for grappling with "wicked problems" and developing solutions that weigh diverse impacts – technical, environmental, social, cultural, economic, financial - and reflect a deep understanding and appreciation for global responsibility.

This engagement will develop new competencies and attributes among those who participate. Specific attributes may include:

1. The ability to design and create: Effective solutions to complex problems requires deep engagement with stakeholders, not only at the outset when defining the problem is particularly important, but also throughout the creative and design process, as well as both during and after implementation. Active listening, mindful conversation and embracing vulnerability are crucial to success.
2. The insight to integrate and solve: Appropriate and effective solutions to grand challenges can only be achieved through the integration of multiple points of view and knowledge from a wide array of disciplines, systems thinking at a broad level, the balancing of competing constraints that are both technical and social, the careful mitigation of risks, and a deep commitment to understand and take responsibility for the intended and potential unintended effects of our work.
3. The value of business and innovation: Grand challenges require the adoption of viable, socially responsible business models that put stakeholders first to develop successful and sustainable solutions that work over the long term and deliver value to both shareholders and stakeholders alike. The adoption of such models can create entrepreneurial opportunities that can empower others and realize very positive social impact.
4. The practice of being multicultural and diverse: Respectful and open engagement with cultural differences requires openness, curiosity, and listening. This is not always easy or comfortable but leads to essential understanding and meaningful progress towards solutions.
5. Commitment to community: Serving people and community through a more collaborative practice of engineering is the vision offered by the Canadian Engineering Grand Challenge project. This requires a deep social consciousness and motivation to address societal problems, often gained through community service learning.

6. Championing environmental stewardship: Identifying ways in which engineers and engineering projects can contribute to a healthy and sustainable environment in concert with sustainable, long-term employment and economic prosperity.

Through the EDC public policy committee a plan was initiated in 2019 to identify and articulate pertinent Grand Engineering Challenges for Canada that are rooted in the United Nations (UN) Sustainable Development Goals (SDG's) and agreed upon across the Canadian engineering community, represented by EDC, the Canadian Academy of Engineering (CAE) and Engineers Canada.

We believe that the Canadian Engineering Grand Challenges that we have articulated should:

- Lift our engineering profession's collective problem-solving sights,
- Inspire engineering professionals and students to solve these problems together but also with other disciplines,
- Galvanize the broader public's imaginations, and
- Focus Canadian engineering efforts over at least a decade.

We hope that this report and our commitment stimulates further ideas and opportunities and partnerships for actions and collaboration so that, together, Canadian engineering can play a fuller role in tackling the world's SDGs by 2030.

This document is endorsed and supported by Engineering Deans Canada (EDC) as well as the Canadian Federation of Engineering Students (CFES). We consider this a "living" document that we will continue to change and adjust over time. One example of this is the continuing and on-going acknowledgement of the disproportionate effect climate change has and will have on certain vulnerable populations in Canada. A second example is the need to engage in a meaningful way with the challenges faced by our Indigenous communities, including the development of protocols for consultations which lead to clarity around free, prior and informed consent.

CANADIAN ENGINEERING GRAND CHALLENGES

After a brainstorming session in May 2019 attended by many Canadian Deans, six areas were identified that we believe best position Canadian engineering to make a collective difference. **All six areas are rooted in the climate crisis we face and can be related to the UN SDGs, and include:**

1) Resilient infrastructure,

2) Access to affordable, reliable and sustainable energy,

3) Access to safe water in all communities,

4) Inclusive, safe, and sustainable cities,

5) Inclusive and sustainable industrialization, and

6) Access to affordable and inclusive STEM education.

Figure 1 shows how each of these challenge areas maps onto the UN SDGs.

Figure 1 – Proposed area of focus for each Canadian Engineering Grand Challenge for 2020-2030 and UN SDGs that the challenge impacts.

As Deans, we are energized by this collaborative opportunity and believe that these six

identified challenges will focus the thoughts and actions of our engineering community on the most compelling and critical issues facing Canada and Canadians today and over the next decade. This will also allow us to galvanize our engineering students and faculty to work towards solutions for these critical issues as a way to best contribute as a community to help address the UN SDGs.

Each grand challenge is a broad but discrete concept, where engineering expertise and leadership can be brought to bear on bold new ideas and engineering innovations that will improve Canadian life.

There are many benefits to doing this together, as it will provide an ideal platform to illustrate how engineers can work together to improve Canadian life and offer a way to engage the public's imagination about the role engineers play in their own lives.

RESILIENT INFRASTRUCTURE

CONTRIBUTOR(S): AVID N. BRISTOW (UNIVERSITY OF VICTORIA)

RESILIENT INFRASTRUCTURE

CANADIAN ENGINEERING GRAND CHALLENGES

APPENDIX A
DESCRIPTION OF EACH GRAND CHALLENGE

A) BACKGROUND

Infrastructure is key for a prosperous Canada. When fit for purpose it enables economic productivity; supports a healthy lifestyle and can address issues of social inequality. Infrastructure, however, is at risk in Canada. For instance, a panel of experts from across the country, however, has recently graded infrastructure as the area in Canada most at risk due to climate change [1]. Second to infrastructure was coastal communities whose unique reliance on infrastructure that is reaching or exceeding its useful life is essential to their management of climate risks. The reasons for these rankings are apparent when risk is broken down into likelihood and consequence. Infrastructure and buildings are designed to withstand certain stresses and increasingly those stresses are changing due to climate change. This is increasing the likelihood of damaging events such as those of the Alberta floods in 2010 and 2013. Consequence of infrastructure damage and failures, on the other hand, is significant in that when infrastructure fails it can disrupt everything from homes to businesses. This dependency relationship between infrastructure and other areas is a key issue when it comes to risks facing Canada.

There are a range of hazards, beyond just those related to climate change that further imperil infrastructure and the services it provides. For instance, more than one-third of municipal infrastructure in Canada was rated as being in a fair, poor or very poor condition in 2019 [2]. This represents a significant amount of infrastructure that needs to be upgraded or replaced to continue to meet the needs of Canadians. Some of the impacts of these deficits include water quality issues and poor road conditions. Other hazards that infrastructure face in Canada that are causing ongoing impacts include wildfires, earthquakes, storms and stresses due to changing demographics and urban densification. Experience tells us that no infrastructure can be completely immune to these hazards; power, water and wastewater, transportation, communications and specialized facilities of a variety of types have and are expected to continue to experience the effects of hazardous events.

Resilient infrastructure is a broad term used to mean those infrastructures that are robust to the effects of hazards, can recover quickly from disruptions, and be suitably adapted to changing and uncertain conditions, such as climate change. To make headway on the challenges facing infrastructure requires continued action from infrastructure operators and further development and implementation of a wide variety of targeted strategies aimed at increasing resilience of our infrastructure to specific consequences.

B) ROADBLOCKS

Existing and mounting stressors in the form of large disasters, such as floods and wildfires, result in costly and devastating results that inhibit our ability

References:

[1] https://cca-reports.ca/wp-content/uploads/2019/07/Report-Canada-top-climate-change-risks.pdf

[2] http://canadianinfrastructure.ca/downloads/canadian-infrastructure-report-card-2019.pdf

to invest in the future as we work just to get back to where we were before disaster struck.

Sometimes the best options to increase infrastructure resilience can be painful – such as moving away from places of high risk.

The hazards infrastructure face, in particular those impacted by climate, are increasingly uncertain and depend a great deal on how successful worldwide actions are in mitigating global environmental changes.

Informed and responsible decision making that looks at the whole value of infrastructure throughout its life is essential but is challenged by the sometimes hidden role of infrastructure. Infrastructure can seem invisible until it stops working as desired. This can challenge our perception of the value of investing in infrastructure refurbishment and expansion. The result of insufficient investment can cause further burdens in that delays in making upgrades often leads to even greater costs in the long run.

Fundamentally, infrastructure is essential for healthy communities and economies. Though difficult, it is important that we all start to understand the full value infrastructure investments have across all areas of Canadian society.

C) CHALLENGES

To make the investments that ensure that infrastructure provides for the needs of Canadian communities and the economy with minimal disruptions and a high level of service in the face of changing and uncertain hazards.

D) POTENTIAL BENEFITS FOR CANADA

- Enhanced reliability and level of service to Canadians and the economy
- Greater economic benefits over the long-term for society and infrastructure operators
- Safer and stronger communities

E) PRIORITY AREAS IN CANADA

- Managing and prioritizing risks from all hazards, with an emphasis on regional risks and specific hazards where appropriate (e.g., flooding, sea-level rise, age of infrastructure)
- Upgrading aging stocks of infrastructure (e.g. water pipes as well as upgrading infrastructure plans in all sectors)
- Long-term and strategic infrastructure plans with a range of stable funding and finance options that account for the whole-life value of infrastructure in both large and small communities
- A serious approach to data collection, management and data analytics so that investments can be made where needed
- Transit infrastructure – cities are getting bigger, and low income populations have limited opportunities for travel
- Infrastructure is largely influenced by the public sector. Alternative forms of financing need to be investigated including looking into models of public-private partnerships. Small communities are lacking financing ability, in particular
- Transforming infrastructure (especially energy, water, and wastewater) for a changing climate and to meet desirable service levels more generally
- Exploring real time data collection and develop technologies to create “smart” infrastructure systems
- Provide incentives to develop and implement innovative alternative types of infrastructure to achieve more effective levels of service
- Advocate more transportation demand management strategies to achieve more efficient and effective use of our roads and highway infrastructures. For example, require large commercial/industrial vehicles to travel only during off-peak traffic periods, discourage the use of single occupancy vehicles, etc.

AFFORDABLE AND SUSTAINABLE ENERGY

CANADIAN ENGINEERING GRAND CHALLENGES

ACCESS TO AFFORDABLE, RELIABLE, AND SUSTAINABLE ENERGY

CONTRIBUTORS: THOMAS ADAMS AND JAKE NEACE (MCMASTER UNIVERSITY)

A) BACKGROUND

Energy is a critically important facet of the Canadian social and economic landscape. Canadian households use significant amounts of energy to heat and cool their homes, heat water, and run appliances such as lighting, stoves, refrigerators, air conditioners, televisions, and computers. Having a relatively sparse landscape, Canadian residents and industries consume significant amounts of energy through the use of passenger and commercial vehicles. Canada's energy sector is also a substantial driver of the Canadian economy, contributing to over 11% to the national the gross domestic product (GDP) [R5].

Energy use in society is a flow that begins with a source (e.g. coal, petroleum, uranium, the sun, the wind etc.) that may pass through several intermediate processes for refinement or conversion to a different form (e.g., electricity, diesel fuel, methane), before finally reaching a home, vehicle, or industrial plant, where it can be used.

The amount of personal energy consumed by each person in society can depend on several factors such as their geographic location, commuting patterns, typical climate exposure, and various desired qualities of life. For example, a significant contributor to Canadian energy consumption is that it is a first-world nation with a dramatically variable climate. Many of the most highly populated Canadian regions experience cold winters (thus requiring energy for heating) and hot summers (thus consuming energy for commercial and domestic cooling, which is a quality expected from most Canadian residents). For example, 99% of all direct GHG emissions from a Canadian home is from natural gas or heating oil combustion for heat, at a rate of about 1.3 tonnes of CO_2 equivalents (t CO_2 eq) per year per person, which is the third highest among G8 countries. [R1]. Indirect home emissions (for cooling and appliances) are primarily related to electricity use, the carbon intensity of which varies widely from Province to Province. Provinces like Manitoba, Quebec, and B.C. have electricity grids with very low carbon footprints (just 1.2 to 12/9 g CO_2/kWh) because they can exploit naturally available hydroelectric resources [R2]. Ontario has a relatively low carbon footprint (40 g CO_2/kWh) because it has augmented its hydroelectric power with nuclear energy. By comparison, Nova Scotia, New Brunswick, the Northwest Territories, and the Yukon have carbon footprints an order of magnitude higher in the 280 to 750 g CO_2/kWh range. This means that access to low-carbon electricity is not distributed evenly across the country.

Today, Canada is the largest per capita energy consumer in the world and consumes about 5 times more energy than the world average [R2], as shown in Figure 1. However, personal emissions of the average Canadian overall are often quite low. For example, the average emissions for electricity use in Canada is only 140 g CO_2/kWh [R2], compared to the US at 588 g CO_2/kWh, Mexico at 856 g CO_2/kWh, and China at 1064 g CO_2/kWh. Rather, the primary reason for Canada's high energy consumption per capita is because of our very large energy sector relative to our population, which produces 82% of Canada's GHG emissions [R3]. It is important to remember that our energy products are largely produced for export to meet world demands, not because the daily personal energy use of Canadian residents is unusually high compared to the rest of the world. However, it does mean that because so much energy consumption occurs inside our borders, it creates both a unique opportunity and a responsibility for us to reduce its environmental impact.

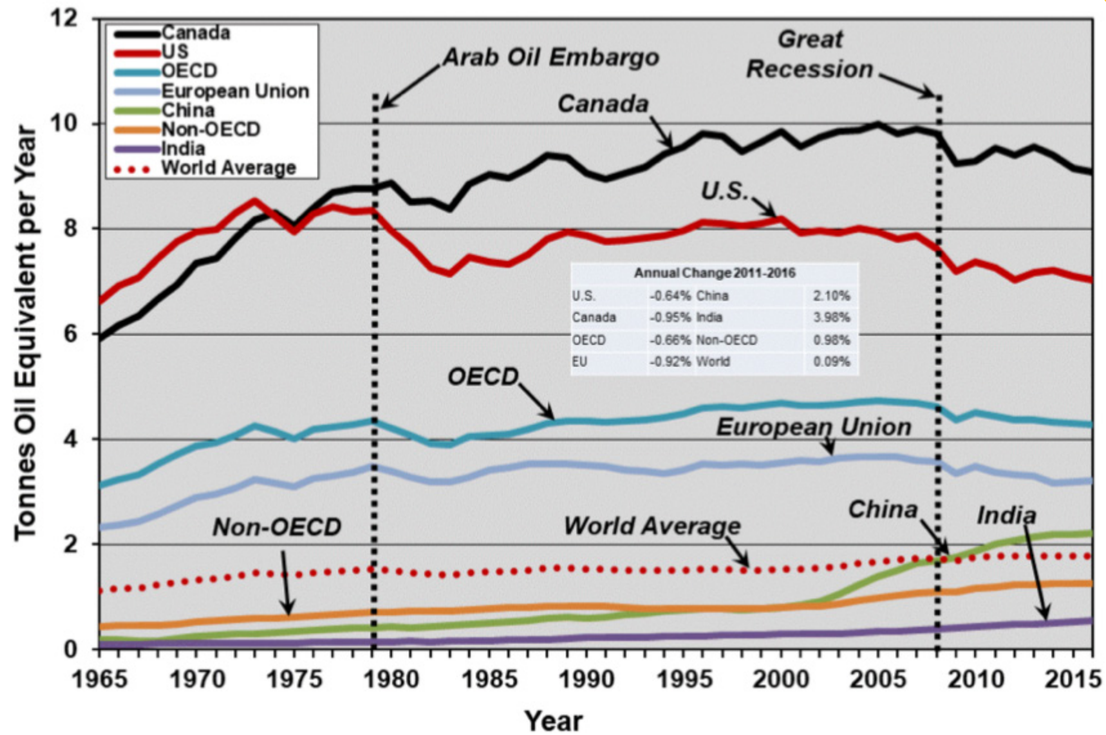

Figure 1: Per capita primary energy consumption by country from 1965 to 2016 [R2].

When it comes to Access to affordable, reliable, and sustainable energy, there are different considerations. As a highly developed nation, the vast majority of Canada's population has access to affordable, reliable, and modern energy services including grid electricity, heating, and transportation for almost all areas of their life (UN Sustainability Target 7.1). However, Canada's Northern communities are dispersed over a 4.5 million km2 area. The population of the Northwest Territories, the Yukon, and Nunavut not within the Whitehorse and Yellowknife urban areas is only about 69,000 or just 0.18% of Canada's total population. There are about 116 communities in this area (thus an average of less than 600 people per community) which qualify for the Nutrition North Canada program [R4], meaning that they are so isolated that access to food and energy is extremely difficult, including a severe lack of year-round rail, road, or sea access.

Most energy consumption in these areas is fossil-based, whether for electricity production (primarily through diesel generators), home heating (natural gas, or fuel oil), or transportation (primarily diesel and aviation fuel). These regions can expect to pay much higher amounts for fuel, with energy prices 2-3 times the cost of mainland Canada [R6]. Energy storage considerations are very important as well, since limited access means that in some cases, an entire year's supply of fuel must be stored on site or more. Thus, these areas are an obvious target for where Canada can improve upon its Accessibility to affordable and reliable energy.

Access to sustainable energy is a different consideration. "Sustainable" energy, according to the triple-bottom-line of sustainability definition, means that energy must be not only environmentally sustainable, but economically and socially sustainable as well. For Canada, improving access to sustainable energy means improving our energy supply and access in all of these areas, but the details will differ depending on the circumstance. For example, reducing the carbon intensity of the power grid in Alberta may make a lot of sense because it is much higher than in the rest of mainland Canada, it is relatively large in volume, and electricity prices are currently on the lower end so any resulting electricity cost increases would not greatly restrict a typical Albertan's access to affordable electricity.

In Canada's North, it may be a different story. For example, Nunavut has the highest carbon electricity grid intensity in the country because they rely on diesel generators for 100% of their supply [R6], but the scale of generation is so small that they contribute a very tiny percentage to Canada's total carbon footprint. This means that this is not a wise place to invest money on technologies for the explicit purpose of CO_2 emissions reductions. Rather, investments that improve access in Canada's North should focus more on cost, reliability, and environmental factors not related to CO_2, such as particulates, smog, and water impacts. For example, it is possible for some remote communities in forested areas to use wood gasification technologies to produce dimethyl ether (DME), a clean burning diesel substitute that requires small modifications to existing diesel generators to use. Not only does this provide far greater access to a more reliable and sustainable source of energy (since it DME could be generated and stored on site using local resources), but DME burns more cleanly, with far lower soot, smog, NOx, and other emissions that are important to those living near the generators. However, the cost could be higher than diesel, but with a subsidy these regions could receive much better access to sustainable energy at minimum cost to the country as a whole.

B) ROADBLOCKS:

There are some key roadblocks to better access to reliable and sustainable energy. They include:

- Many small communities across Canada cannot be accessed year-round, are isolated from the larger population by long distances, and in some cases, are only accessible by plane. This is a major challenge for energy access, and it may not be feasible or desirable for these communities to be connected to the rest of Canada for the purposes of energy management. Instead, energy system improvements must be made within the tight constraints of these islanded energy systems. Climate and weather issues also play a major role in these communities which are typically located in extreme environments. This places major barriers on technology selection. For example, intermittent renewable sources, such as solar, are extremely difficult to incorporate effectively in these areas in a reliable way, especially in regions with limited to no sunlight for large parts of the year.
- It can be very difficult for funding organizations, investors, and policymakers to choose the right technologies to research, develop, and commercialize for sustainable energy purposes. There are many new, promising, and unproven technologies to choose from, and unfortunately the wrong technologies are sometimes promoted for a given situation due to hype, political ideology, or simply bad valuation methods. The development of analysis standards which can be used to objectively make technology selections on the basis of the best return on investment from an ecological viewpoint can significantly help key decision-makers to choose the best investments which will result in meaningful impacts in Canada.
- Current energy policies in Canada, such as the federal carbon tax, focus on controlling domestic carbon dioxide emissions, but do not take a holistic view of the problem. For example, a policy which taxes CO_2 emitted in Canada would most certainly reduce CO_2 emitted within our borders to some degree. However, without a CO_2 tax policy that considers imports and exports across our borders, the global impacts will be minimal. For example, Canadians import a very large portion of their manufactured goods from overseas, especially China, where the energy consumed to make those goods is extremely CO_2 intensive. Canadians are responsible for these CO_2 emissions as well, and only when the carbon tax policy considers this impact will Canadian behaviour truly change with regard to the environmental cost of carbon. Without a policy like this, there is nothing to prevent a carbon-intensive Canadian manufacturer who sells goods to Canadians to simply move its operations to a country without a carbon tax policy, and then export the goods to Canada again, thereby undercutting the point of the entire system. Manufacturers who choose to remain in Canada would then be at a disadvantage compared to a low cost, high polluting manufacturer.
- Energy storage is a major roadblock within our current infrastructure. For electricity, for example, there are an increasing number of occurrences when electricity grids need to sell electricity at a negative price, often to other jurisdictions. This can happen, for example, when renewables such as wind and solar happen to be producing a large amount of electricity during times of low demand, and doing so faster than can be stored. In other cases, wind farms can go months without producing a meaningful amount of electricity, particularly in hot dry summers. In general, as wind and solar energy grows to be a larger part of the mix, the energy storage capabilities of our system need to grow as well. This is one of the major technology advancements that will be required for

all Canadians to have access to reliable sustainable energy.

- A key roadblock is the transition of existing infrastructure. For example, for transportation fuels, it would be a major and very expensive transition to move the entire fleet of personal vehicles into hydrogen, electric, or alternative fuels. As such a transition occurs, access to sustainable energy may become very difficult for some Canadians who either cannot access new technologies or can no longer access the old ones, due to affordability or logistical issues. Some technology choices will be more difficult to transition than others, but we currently lack a comprehensive and meaningful plan which gradually transitions our infrastructure from fossil fuels to more sustainable alternatives, while maintaining accessibility.

C) CHALLENGES

"To ensure that our future energy system will be clean, safe, reliable, accessible and affordable for all Canadians"

In order to accomplish this, one of the best tools we can use is technoeconomic analysis of the eco-efficiency of the environmental actions: a way of determining the costs and benefits of environmental actions and the economic and environmental return on investment. With techniques such as this, we can determine where to spent our first $10 billion on these initiatives, where to then spend the second $10 billion, etc., by plucking the lowest hanging fruit first and focusing on the activities, technologies, and policies which will give us the greatest impact for a finite amount of money. In this evidence-driven way, we can determine how to best balance the different aspects of accessing reliable and sustainable energy for the country as a whole.

D) POTENTIAL BENEFITS FOR CANADA

- Highest eco-return on investment on environmental initiatives.
- Greater access to more advanced forms of energy in remote areas.
- Lower carbon footprint of energy services in populated and connected areas.
- Reduced worldwide CO_2 emissions at the lowest possible cost to Canadians.
- Technological and political solutions designed for Canadian political needs.
- Informed, managed, gradual, and equitable cultural change.

E) PRIORITY AREAS IN CANADA

- Identifying and investing in high quality and promising energy technologies using rigorous and standardized metrics
- Funding research and development in promising energy technologies throughout the entire research and development chain, especially pilot scale and first-of-a-kind ventures
- Cleaner methods of extracting, processing and utilizing hydrocarbon fuels, including reduced consumption of these fuels.
- Taking deliberate steps to make government aware of the identified challenges and offer cost-effective solutions/alternatives for government decisions and policies. For example, strongly advocate against urban sprawl.

References

R1. Milito AC, Gagnon G. Greenhouse gas emissions—A focus on Canadian households. *Statistics Canada Report*, Winter 2008, vol 2, no 4.

R2. Quan R, Vela C, Edwards B, Nadew M, Wilde C. Canada's Renewable Power Landscape – Energy Market Analysis 2017. *National Energy Board Report*. ISSN 2371-5804. (2017)

R3. Deng L, Adams TA II. Optimization of coke oven gas desulfurization and combined cycle power plant electricity generation. *Ind Eng Chem Res* 57:12816-12828 (2018).

R4. CIRNAC-ISC, Geomatics Services. Map of NNC Community eligibility as of April 1, 2019. (2019)

R5. Natural Resources Canada Energy Fact Book 2019-2020. ISSN 2370-3105 (July 2019)

R6.National Energy Board. Energy Use in Canada's North: An Overview of Yukon, Northwest Territories, and Nunavut – Energy Facts. (March 2011).

SAFE WATER IN OUR COMMUNITIES

CANADIAN ENGINEERING GRAND CHALLENGES

APPENDIX A
DESCRIPTION OF EACH GRAND CHALLENGE

ACCESS TO SAFE WATER IN ALL COMMUNITIES

CONTRIBUTORS: ED MCBEAN (UNIVERSITY OF GUELPH), MADJID MOHSENI (UNIVERSITY OF BRITISH COLUMBIA), BOB ANDREWS (UNIVERSITY OF TORONTO) AND GRAHAM GAGNON (DALHOUSIE UNIVERSITY)

A) BACKGROUND

Water is life. Provision of safe water is considered a basic human right, as described in the UN Sustainable Development Goals (SDG#6). Issues of flooding, water scarcity, and invasive biological contaminants, are examples of issues that threaten the ability to provide safe water to a community and are further heightened through climate change.

Generally, Canada has an abundance of water; it has 0.5 per cent of the world's population but seven per cent of the world's renewable freshwater supply. However, Canadian freshwater systems are under significant strain due to climate change, aging infrastructure and contamination.

The quality of drinking water supplies in rural and Indigenous communities has become severely degraded in recent decades leading to **more than 100 drinking water advisories for reserves in Canada as of 2015**, forcing some Indigenous communities to **boil water, arrange for water delivery via truck, or haul it from a water filling station** [1].

Canada's population is very urbanized (82% of its population live in communities with 20,000 or more people). There exists a wide range of differences as a result of size of community since available expenditures influence the functionality of strategies/responses to delivery of safe water. Examples of the difficulty to provide safe water to consumers include the quality and quantity of the source water, water treatment, distribution of the treated water, water quality monitoring, and alarm in response to detection of failure to deliver safe water. The complexity of ensuring safe water delivery is clearly multi-faceted.

Temporal and spatial variability of water issues is enormous and potential failure modes are huge in number, which all contribute to the challenges of providing safe water to communities. As one example of the issues, 28% of the watermains in North America are over 50 years old and nearing their estimated end-of-service life. Pipe breaks across North America are increasing, with a 27% increase in pipe breaks over the last six years. Watermain failure is a major concern for every water utility. Watermain breaks disrupt customer service, result in water and revenue loss, and create the potential for contaminants to enter the water distribution system.

Dimensions of risk and uncertainty are enormous and complicated (e.g. regarding climate change, we must make decisions on investments today, to provide for circumstances in the future that are not known with any certainty). Possibilities of terrorism and cybersecurity exist. The challenges are also

References:

[1] https://canadians.org/fn-water

great for small/remote and Indigenous communities which cannot manage complicated systems (cost and oversight of operations).

To make headway in these challenging dimensions, promising directions involve the building in of the factors that collect, manage and implement data in real-time, and to incorporate risk assessment methodologies which are proactive, rather than reactive. This approach will bring key issues to the forefront and promote a proactive approach to drinking water safety.

B) ROADBLOCKS

Many Canadians have a myth of water abundance. Unlike the situation of potholes in the road where the evidence is encountered on a daily basis, as long as water comes out of the tap, water supply is out-of-sight, and out-of-mind. The price that Canadian consumers pay for water is low but these same consumers resist any change that would raise the price. However, the water distribution pipes for many cities across the country are reaching their expected lifespan. Without collection of appropriate data on potential pipe breaks, guidance on how to most efficiently repair/replace pipes is challenged but many municipalities have not been assembling appropriate databases that will allow efficiency in making decisions on upgrades/ repair; this has to change.

Generally, provision of safe water has continued to be delivered to many, but there have been significant challenges for small urban and Indigenous communities. High rates of boil water advisories have continued. From 2004 to 2014, 400 out of 618 Indigenous communities experienced at least one drinking water advisory. It has been very difficult to provide sufficient, appropriate water treatment systems, and retain the necessary trained and experienced operators, etc. for remote and small water systems.

Additional examples of roadblocks include:

(i) The potential for severe water shortages (e.g. as a result of climate change and glacier depletion) in the prairies and in the north will influence the ability to respond to increased water demands for urban and industrial activities. Will fracking cause irreversible damages?

(ii) Data for planning purposes for water supply issues are currently limited in northern Canada, and identifying how the situation will change in response to climate change makes the issues even more challenging;

(iii) Shrinking mid-sized communities throughout Canada, are resulting in shrinking tax bases, resulting in less money to pay for upgrades;

(iv) The potential for transboundary movement of water is a major concern. There are already examples of water being removed to cities outside the Great Lakes watershed, and such pressures will continue to increase as the aquifers (e.g. the Ogallala) in the USA become depleted;

(v) Understanding which of the 5000 new chemicals introduced into the commercial/ residential sector each year will prove to be major concerns, including those for which our water and wastewater systems are not generally designed with consideration of their removal of these chemicals. Which ones will become the "polychlorinated biphenyl of the future", the lubricant that was incredibly good for its intended purpose but disastrous for human and environmental health?

(vi) How to plan for decisions to abate climate change impacts, when investments are being made decades before the conditions that may arise? The ranges of uncertainties are huge.

C) CHALLENGES

Canada is a highly urbanized country (82% of the citizens live in communities of 20,000 population or more) but the country is also very large, and climate variations across Canada are enormous. Many challenges exist, particularly (but not exclusively) in relation to the ability to provide safe water to smaller communities. The availability of data to assess the risks are limited; risks of vulnerability in the provision of safe water are extremely broad, resulting in issues of 'how to deal with "surprises"'. Redundancy is difficult in a country so large, and varied in conditions.

Pressures for transboundary water movement into the US will continue to increase as the pressures will intensify.

Canada needs to greatly encourage data collection, for without data collection, the bases upon which to make decisions will be limiting. Much can be learned and managed, if the right types of data are available and in these technological decades, the potential to expand the assembly of data is enormous but the 'learning curve' is substantial. The speed of computers is now measured in terms of peta flops. 'peta flops' now allow 1000 trillion operations per second, and hence the adoption of strategies to vastly collect, and manage/manipulate data to facilitate the making of better decisions through use of AI approaches is enormous – but, the challenge to instill the need to collect useful data begins now. Satellite assemblies, sensor technologies, data telemetry, etc. – there are many dimensions of data which exist which can help to improve our decisions.

Canada's water demands are large. In Ontario, as an example, we use 260 Litres/cap/day but in Europe, usage is 150 Litres/cap/day. If we use less water, there is less income to the providers of water which may result in insufficient revenue to provide the innovations needed to keep pace. The price of water does not reflect its value.

D) POTENTIAL BENEFITS FOR CANADA

The challenges of providing safe water to remote and small communities are now widely recognized. There are sizable funds being made available by the Canadian government to improve the situation, but are they sufficient and being used effectively? Further, costs and knowledge of water quality issues (e.g. arising from mine tailings) are providing improved insights and opportunities to improve delivery of safe water.

While we have problems and roadblocks, Canadians benefit from an educated populace and recognize many of the challenges related to delivery of safe water to consumers, and Canadians with these skillsets have extensive expertise to market our knowledge to the world. Researchers in Canada have been instrumental in developing technologies that have international benefits, as well as benefits to Canadians. It is noted that it continues to be a challenge to protect Canadian-developed intellectual property, and takeovers of Canadian innovations by large multinationals are widely evident. Examples of Canadian benefits arising from Canadian expertise and research, include new sensors and new technology ideas to telemeter data, and new water treatment technologies. For example, the potential exists to use sensor technologies to monitor water quality and then to provide guidance to remote/small communities; this represents an opportunity to decrease the challenges of providing safe water. As well, the potential exists to provide communication and internet 'whiteboards' to facilitate collective learning amongst operators in remote locations,
on how to deal with specific water issues.

While research is showing that climate change will result in more intensive storms and earlier snowmelt making it difficult to abate/reduce flooding, there are many involved in research that will provide guidance on how to best respond to these conditions.

Further, because Canadians have been proactive in protecting our water, we have the expertise that establishes our leadership in global water economy; this is an opportunity for Canada to promote its expertise on the matter.

E) PRIORITY AREAS

Suggested priority areas include:

(i) Climate change creates challenges for sustainability so ignoring climate change would be disastrous. We must continue to refine strategies to respond/protect against climate change impacts on our ability to deliver safe water;

(ii) Decreasing Canada's vulnerability regarding provision of safe water to all communities, will benefit greatly from improved data collection and management. Sensor technologies, data availability and management programs, and telemetry of data to identify issues, have undergone enormous evolution in recent years. It is noted, however, that 'big data' isn't of value unless it is 'useful data' so improved data collection must be carefully managed and implemented;

(iii) Canada needs to proactively adopt AI, to manage the data and make the huge amount of data gathered useful. Sensor technologies need to be more robust and reliable and there should be more opportunities for the regulators to accept and approve the data/results from remote sensors. Currently, the regulatory structure is very conservative and slow in their acceptance/approval of innovative solutions, and this is an impediment to innovation in the water sector (particularly regarding remote monitoring);

(iv) Canada needs to integrate data streams for improved decision-making. The opportunities to collect the 'right' data must be facilitated to overcome 'resistance to change' at municipality levels, both large and small. Municipalities tend to be focused on meeting constrained budgets and not thinking sufficiently about planning for the future. There needs to be more co-ordination amongst municipalities so collectively, we can ensure the right data are collected. Further, investments, once a strategy for assembly of data has been made, become very difficult to change, to adjust to a different strategy should a new strategy become available. Measures to improve uniformity or actions to facilitate transition to new strategies would be very helpful;

(v) Adoption of a proactive approach, rather than a reactive one, is important to undertake to ensure the health and safety of Canadians and identify where vulnerabilities merit the most attention. A proactive approach that identifies vulnerabilities such as has been adopted in Alberta, has significant merit since their drinking water safety plans lead the reviewer of a water supply system through the array of potential failure modes. The nature of this guidance can be extremely valuable as guidance on how a water supply system may fail.

(vi) Communities and operators, particularly for small urban and Indigenous communities, must be re-empowered, and have access to the needed information and budget to improve the management of their systems. This needs to include access to information, their peers, and experts, to ensure responses to issues are quickly and efficiently adopted. The use of internet for expanding the learning and education of operators – digital platforms for networking and learning (if adopted and implemented properly) can be very valuable for small communities;

(vii) Canada must move to adaptive water treatment technologies. Examples include UVLEDs; new materials have the ability to transform the water industry but industry must be allowed to adapt accordingly;

(viii) The development of source water protection (SWP) plans provides the means to provide a basis for protection of the integrity of a water supply system. However, the development of an SWP is challenging for small urban and Indigenous communities and utilization of an SWP program should be extended beyond Ontario.

SAFE AND SUSTAINABLE CITIES

CANADIAN ENGINEERING GRAND CHALLENGES

INCLUSIVE, SAFE, AND SUSTAINABLE CITIES

CONTRIBUTORS: CHRIS KENNEDY (UNIVERSITY OF VICTORIA), NADINE IBRAHIM (UNIVERSITY OF WATERLOO), CAM CHURCHILL (MCMASTER UNIVERSITY

A) BACKGROUND

Cities are home to over 80% of Canadians – and are the arenas where many of Canada's toughest environmental and socio-economic challenges play out. Complex environmental stresses, including climate change and global biodiversity loss, amongst others, intersect with social challenges of widening inequality, and changing demographics in cities. The 'design' of cities has substantial impacts on human health, linked to car-dependent lifestyles. Addressing these challenges will necessitate changes to the ways that engineers participate in the planning of urban infrastructure and development of urban technologies more broadly.

The multitude of urban issues needing input from the engineering profession include:

- Adapting cities to extreme weather events resulting from climate change
- Reducing greenhouse gas emissions from cities
- Providing a greater diversity of transportation modes in cities, with affordable access for lower income communities. Also, the implementation of effective transportation demand management strategies can reduce the volume of inefficient single occupancy vehicles
- Creating safer cities, eliminating traffic accident
- Creating healthy cities, designed to promote physically active lifestyles
- Creating inclusive cities, that includes aging populations with varying community needs, as people live longer and need to remain mobile
- Planning for investment in infrastructure to support growing and aging populations, and to manage aging infrastructure

Addressing these challenges requires transformation of energy and material use in Canadian cities and fundamental changes to transportation planning. To mitigate greenhouse gas emissions, cities need to replace fossil fuels with carbon-free electricity and biofuels. Provision of local-scale power generation, use of cogeneration and energy storage will also be important for making cities more resilient to shocks – due to extreme weather events or other causes – so they can rapidly rebound. A combination of better land-use planning, clever design and application of new technologies can help to support a greater choice of urban transportation modes. This includes improved design for active transportation – walking and cycling – as well as enhanced public transit and electrification of vehicles; and adaptive reuse of existing materials, structures and buildings.

B) ROADBLOCKS

Transformation of Canadians cities is hindered by 'lock-in' to infrastructure systems, modes of planning; and cultural and institutional ways of thinking. Infrastructure systems are developed over decadal timescales, and are slow to change. Part of the challenge is that institutions, including municipal agencies, utilities and the engineering profession become used to modes of operation. There are opportunities for change; deterioration of aging urban infrastructure, for example, provides challenges for maintaining services, but also opportunity for alternatives. Yet cities are complex creations, and influencing their evolution requires understanding on micro and macro scales from multiple perspectives. Decision-making on large urban infrastructure projects are heavily reliant on political will and political agendas, which risk missing long-term effects, and compromise future generations.

C) CHALLENGES

"Canadian engineers need to provide technical expertise, ingenuity and leadership, working with interdisciplinary teams and multiple stakeholders in transforming Canadian cities."

Problems today and in the future, such as recovering from the aftermath of extreme weather events, are not only of a clearly defined technical nature, but imply many other disciplines to work together to rebound and resume normal activities. Engineers can lead these efforts because of their training in critical-thinking, problem-solving, teamwork, i.e., to be the bridge among disciplines.

Engineering education today is more technical and more specialized, whereas the training for future engineers needs to adapt to the challenges of the future. The junior engineers of 2050 would start their undergraduate studies in 2040, so we are perhaps looking ahead at education 20 years from now. More pressing, engineers entering university in the next decade will be the leaders in their fields by 2050, which gives us only a ten-year time horizon to consider how might we change how and what we teach, and what technical knowledge and skills will still be essential in the future and which will have changed.

D) POTENTIAL BENEFITS FOR CANADA

- Creation of safer, heathier, livable cities with higher quality urban environments.
- Effective transportation networks that meet the needs of pedestrians, cyclists, transit users, motorists and the movement of goods.
- More diverse, vibrant urban economies with higher level of access to opportunities for all.
- Leveraging the economic power of skilled workers and immigrant populations for more inclusive cities, socially and economically.

E) PRIORITY AREAS IN CANADA

- Provide greater choice of transportation modes, through development of urban strategies and technologies that overcome the low densities and challenging climates of Canadian cities.
- Increased electrification of energy uses in cities, taking advantage of low-carbon electricity in most Canadian provinces. More progressive government regulations and policies are needed to incentify the provision of more electrical infrastructures for the direct use of consumers.
- Enhancing the resilience of Canadian cities to climate change and other stresses.
- Provide innovative infrastructure planning and design to meet sustainability and resilience objectives.
- Technological stewardship that calls on those who create and influence technology to step into a greater responsible leadership role, to not only solve problems, but to also contribute to society.
- All of the above will never be effectively implemented without political will. Engineers can influence political decision makers and better still, become decision makers to ensure that these priority areas will be implemented.

SUSTAINABLE INDUSTRIALIZATION

CANADIAN ENGINEERING GRAND CHALLENGES

INCLUSIVE AND SUSTAINABLE INDUSTRIALIZATION

CONTRIBUTORS: M.A. WELLS (UNIVERSITY OF GUELPH), YAOYAO FIONA ZHAO (MCGILL UNIVERSITY) AND SYLVAIN COULOMBE (MCGILL UNIVERSITY)

A) BACKGROUND

Inclusive and sustainable industrial development depends on achieving long-term economic prosperity from industrial activities while minimizing resource use and safeguarding our natural environment. Inclusive industrialization ensures that industrial development in Canada and internationally offers equal opportunities to everyone and ensures an equitable distribution of the benefits from industrialization. Technological progress is vital in this process and can mobilize and contribute to the energy-efficiency of our industries and minimize the use of our natural resources or waste generated.

In Canada, it was at the beginning of the 19th century where our economic activities were transformed from being primarily agriculture and natural resources based to manufacturing and services. During this transformation, activities shifted from rural cottage industries to urban industrial pursuits. This transformation from a largely agricultural and extractive economy to one that engaged in manufacturing was propelled by the shift from wind to steam power, and the embrace of new transportation technologies. Today manufacturing is a cornerstone of Canada's modern economy. Accounting for approximately $174 billion of our Gross Domestic Product (GDP), manufacturing represents more than 10% of Canada's total GDP [1]. What is more, manufacturers export more than $354 billion each year, representing 68% of all of Canada's merchandise exports [1].

The idea of a circular economy (Figure 1) is an alternative to the predominant linear "take-make-use-dispose" economy of production (manufacturing) and consumption or use of the products. Regenerative by design, the circular economy keeps products, components and materials at their highest utility and value, at all times. Its aim is to decouple the creation of wealth from the consumption of raw material resources by making it more profitable for a company (and an economy) to recover, regenerate and reuse than to draw on virgin resources. Although increasing the circularity of economies is desirable, high levels of circularity are aspirational; currently the global economy is about 6% circular [2].

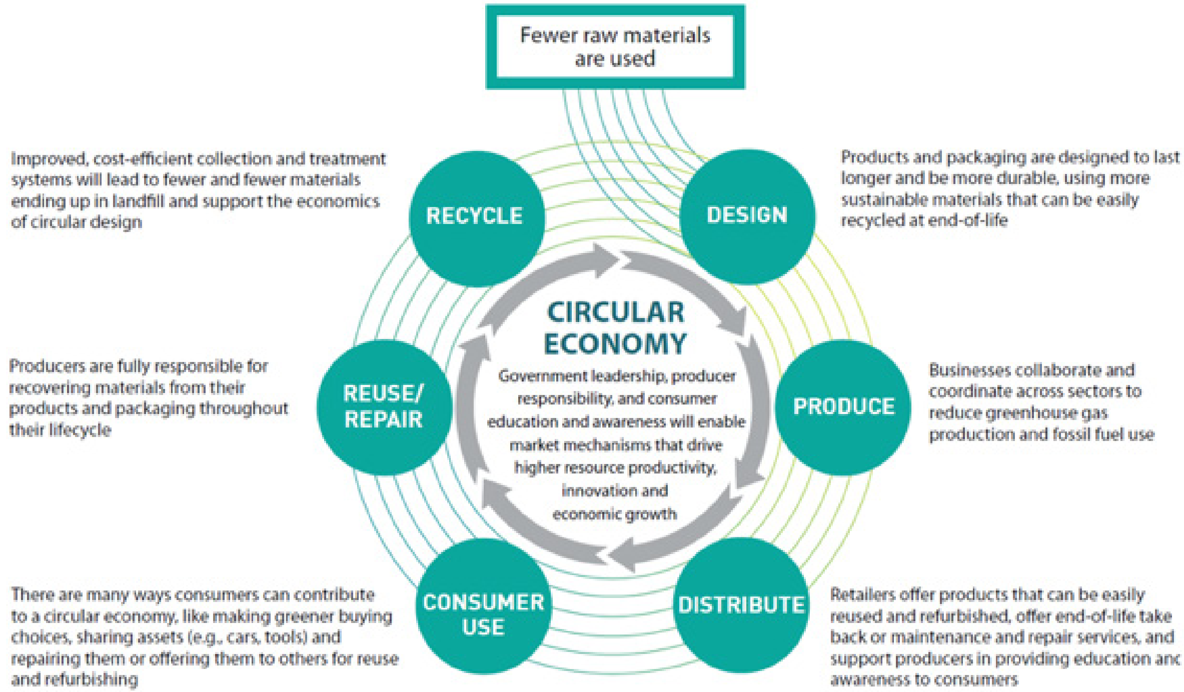

Figure 1 – Schematic showing the elements of a circular economy [3].

In practice this translates into:

- Preventing waste through new and innovative business models or through improved design (eco-design) – either for disassembly, upgradeability or for longevity;
- Maximizing the continuation of a product's life through enhanced re-use, repair or remanufacture; and
- Improving end-of-life processing and resource recovery.

In the future, Canada needs to position itself as a leader in sustainable industrialization or eco-production and eco-manufacturing by encouraging the wider adoption of circular approaches to industrialization.

B) ROADBLOCKS

- Patterns of consumption are difficult to both measure and change for individuals
- Lack of knowledge or recognition by both consumers and producers on the energy, water and natural resources used to produce each product
- Individual apathy and lack of knowledge on recycling
- Products produced are complex (both in number of components and materials used, and integration) make it difficult to disassemble and recycle each individual component effectively
- Lack of legislation around products that are produced and end-of-life responsibilities
- Difficult to reconcile due to economic and industrial growth with environmental benefits
- Lack of data on how energy and material (resources) are used and flow in our Canadian industry
- Lack of regulatory framework and incentive programs that guide a sustainable economic development
- Need for recycling requires energy and hence has environmental impacts
- Loss of material quality during recycling is often degraded

C) CHALLENGES

"To reconcile the tension between industrialization and the manufacturing of products with the need to safeguard our environment and our natural resources"

D) POTENTIAL BENEFITS FOR CANADA

- Leader in sustainable industrialization and a circular economy
- Opportunities for Canadian businesses to lower input and manufacturing costs
- Create new jobs
- Leader in eco-design and production

E) PRIORITY AREAS IN CANADA

- Become a leader in the circular economy where waste products become input to produce other value-added products
- Improve our research and teaching on eco-design as well as ways to predict or forecast when an outcome that occurs is going to be later recognize as a large problem (i.e. microplastics)
- Suppress waste in all stages of industrialization and production
- Recycling and reuse of products we make
- Design for sustainability, recyclability and biodegradability of all the products we produce
- Life cycle analysis include both energy and water analysis of the products we produce
- Techniques to digitize and collect product use data in our daily lives and industrial practice that can be used for life cycle analysis
- Improve efficiency of resource use
- Extended producer responsibility for products which are manufactured and used
- More legislation and regulatory framework are needed to implement these priority areas

References:

[1] https://www.ic.gc.ca/eic/site/mfg-fab.nsf/eng/home

[2]*Willi Haas, Fridolin Krausmann, Dominik Wiedenhofer, and Markus Heinz*, "How Circular is the Global Economy? An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005, Journa of Industrial Ecology, Vol 19, No. 5, 2015, 765-777. https://onlinelibrary.wiley.com/doi/full/10.1111/jiec.122444

[3] https://www.ontario.ca/page/strategy-waste-free-ontario-building-circular-economy

APPENDIX A
DESCRIPTION OF EACH GRAND CHALLENGE

ACCESS TO AFFORDABLE AND INCLUSIVE STEM EDUCATION

CONTRIBUTORS: MARY WELLS AND VALERIE DAVIDSON (UNIVERSITY OF GUELPH), KIM JONES (MCMASTER UNIVERSITY)

A) BACKGROUND

In 1854 the first engineering school in Canada was established at King's College (now the University of New Brunswick). Other applied science courses were established by the 1870s at McGill and l'École polytechnique de Montréal and at the School of Practical Science (now part of the U of Toronto). Today, Canada has 44 institutions offering 279 engineering accredited programs and close to 85,000 engineering students who are enrolled in engineering programs. In 2017, close to 16,000 students graduated with an undergraduate engineering degree in Canada [1]. Although engineering education in Canada has grown substantially over the past 165 years in the breadth of programs we offer and the number of students who study engineering, there continues to be a lack of diversity in the student and faculty bodies. Today, female enrolment in engineering programs across Canada persists at 20 percent despite focussed efforts to close the gender gap over the past decade and female educators make up only 15% of the professoriate [1].

Across our engineering disciplines we see large differences in the participation of women with programs such as environmental and biomedical/biological being close to parity. In contrast traditional engineering disciplines such as mechanical, electrical, computer and software engineering are typically closer to 15%. A key factor related to this is that in high school, women are much less likely than men to take the required science courses (math, chemistry and physics) to ensure they are engineering ready and able to apply to study engineering at a post secondary institution. Of these required high school courses, physics has the least participation amongst men and women and the largest gender gap [2]. This is a critical issue in terms of economic growth for Canada and a recent McKinsey report [3] stated that Canada's key inequality indicators are women in Science, Technology, Engineering and Mathematics (STEM) education and the STEM workforce of which engineering is a significant part.

Another group of people who are significantly underrepresented in Canadian engineering programs are Indigenous students; while Indigenous peoples make up 4.9 per cent of the Canadian population (Statistics Canada, 2017), they only account for 1.2 per cent of total undergraduate enrolment in engineering programs [1].

In the Canadian engineering profession only 18% of our licensed professional engineers are women [4]. Engineers Canada is working to increase the representation of women within engineering through its 30 by 30 initiative. This initiative has a goal of raising the percentage of newly licensed engineers who are women to 30 per cent by the year 2030. This 30 by 30 initiative has received national support across all provinces and territories in Canada including our engineering regulators. According to a recent Mckinsey report, the most important levers for economic growth in Canada are adding more women to mining and technology and raising women's labour force participation [3]. This directly aligns with our goals of increasing the number of women in engineering.

B) ROADBLOCKS

Implicit biases lead to skepticism about the ability of people who are not traditionally associated with engineering to be successful. This can result in an environment that does not welcome or include people who are different from themselves.

People who are not typically associated as being engineers may also feel from a self-identity perspective that they cannot be their authenticate selves as an engineer and that they "do not fit in". People who feel this way often do not meet their latent potential and end up leaving the engineering profession.

The societal view of the role engineers play as utilitarian problem solvers versus technology innovators and leaders has hampered our ability to recruit a diversity and breadth of students from different background and with different interests into engineering programs.

Currently, we do not know much about the students who chose to study engineering (other than gender). For example, we do not have full demographic breakdowns for our students or knowledge of their socio-economic status. Hence it is difficult to fully understand what other groups of students we are not reaching.

Recognizing a trend of lowered support from governments across Canada towards higher education, how do we balance the financial sustainability of engineering education against the need to make it affordable for all students in the future. Today affordability and access to post-secondary education is very dependent on the socioeconomic status of a family and is a significant factor that affects what educational opportunities are considered.

C) CHALLENGES

"To ensure the role engineers play in society is well understood and that engineering becomes an affordable, accessible and welcoming destination and profession of choice for all students who are interested in it."

D) POTENTIAL BENEFITS FOR CANADA

- Diversity of thought which will benefit innovation into the future
- Greater economic benefits in the future (refer to the McKinsey report)
- Accessibility of engineering programs to everyone

E) PRIORITY AREAS IN CANADA

- Broader diversity of our Canadian engineering programs (women, indigenous peoples and other underrepresented groups)
- More socially-relevant and outward-facing engineering curricula that emphasizes multidisciplinary learning and societal impact
- A better understanding of the social psychology aspects involved for people who enter and persist in engineering programs
- Programs to ensure the affordability of our engineering programs in the future
- University Engineering Programs are relevant to young people and are sought after by students

References:

[1] https://engineerscanada.ca/publications/canadian-engineers-for-tomorrow-2017#total-undergraduate-student-enrolment

[2] https://www.design-engineering.com/features/engineering-gender-gap/

[3] https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Women%20matter/The%20power%20of%20parity%20Advancing%20womens%20equality%20in%20Canada/MGI-The-power-of-parity-Advancing-womens-equality-in-Canada-Executive-summary.ashx

[4] https://engineerscanada.ca/diversity/women-in-engineering/30-by-30

[5] http://higheredstrategy.com/wp-content/uploads/2019/08/HESA-Spec-2019-Final-Online-Version_Updated.pdf

[6] https://www150.statcan.gc.ca/n1/daily-quotidien/160907/dq160907a-eng.htm