SMART CONSTRUCTION BUSINESS CASE

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Date:
Nov 5, 2018

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1. Challenge Overview

1.1 Industry Background

The Canadian construction industry represents a major component of Canada's economy. Statistics Canada (STC) data indicates the industry provided 1.4 million direct jobs in 2015 in almost 352,500 firms and contributed about $117 billion to Canada's GDP[1]. Following two years of contraction, the Canadian construction industry rebounded in 2017, registering an annual growth of 3.1% in real terms. This momentum is expected to continue in 2018, with annual growth of 2.6% in real terms, driven by government efforts to stimulate the economy through investment in public infrastructure and energy projects[2]. As an example, PCL's solar energy division is securing increasing amounts of work in solar facility/infrastructure construction.

The construction industry is responsible for environmental impacts including air emissions, waste generation, and the use of land, energy and water. According to a March 2017 study, the Canadian construction industry produced over 6,000 mega tonnes of CO2 in 2015, with Alberta contributing over 1,000 mega tonnes. Like the rest of Canadian industry, the construction industry is increasingly aware of the need for accurate data on production, energy use, and greenhouse gas emissions. A component of PCL's challenge, further described below, is to deploy IoT (Internet of Things) sensor technology solutions enabling real-time capture of such data. Due to the diverse nature of the construction industry, no physical measures of output (akin to single product industries such as steel where outputs can be added across companies) currently exist. It is also noted in Canadian and US research that energy consumption and carbon emission calculations rely on sparse data and extrapolations -- and likely underestimate the industry's actual energy usage and CO2 emissions by half. Canadian Construction Innovations (CCI), Canada Green Building Council (CaGBC) and others are working to improve the availability of construction energy and production data at a more detailed level.

1.2 Move to Net Zero Buildings

The term Net Zero refers to a variety of sustainability related aspects including energy, carbon, and water. In general, it means the building produces enough of a given resource like energy to offset the amounts that are used in its operation. In May 2017, Canada Green Building Council (CaGBC) was the first GBC to launch a dedicated Zero Carbon Building Standard, making carbon emissions the key indicator for building performance. Developed through extensive consultation with representatives from over 50 industry organizations, utilities, governments and companies across Canada, CaGBC is also working with 16 of Canada's most sustainable projects in the Zero Carbon Building Pilot Program, which will inform further development of the Standard and accompanying resources and education.

The drive to reduce energy and carbon use in buildings is forcing the industry to think beyond the operational life of the building to include recognition of the energy inputs that go into resource extraction, materials manufacture, transportation, installation and construction, building demolition, deconstruction and reuse. For buildings designed to meet current codes, the energy used during

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[1] Data are from Statistics Canada: CANSIM Table 379-0031 (GDP in $2007), Table 383-0031 (labour statistics), and Innovation, Science and Economic Development Canada (establishments).

[2] ReportBuyer.com. "Construction in Canada – Key Trends and Opportunities to 2022 (May 2018)". Available at https://www.reportbuyer.com/product/4927587/construction-in-canada-key-trends-and-opportunities-to-2022.html.

operation of the building far exceeds the energy used to construct the building. With net zero energy and high efficiency buildings, the energy used during construction becomes a significant factor in the life cycle energy use of the building. Shrivastava and Chini provide an example project to illustrate this fact. It shows that while construction site energy use comprises about 1% of the life cycle energy of a traditional building, it can comprise up to 18% of a net zero building[4].

1.3 Re-Work

Re-work in the construction industry is frequent and well known on most construction projects globally. It drains productivity, energy efficiency, profitability and timeliness of project delivery for both contractors and owners. Re-work adds to overall energy consumption during construction because building something twice can double the energy usage. The causes of rework are very well known: design and construction changes; errors and omissions; change requests; inferior construction quality resulting from uncontrolled environmental conditions; project enhancements; operability changes; fabrication changes and errors, etc. The Navigant Construction Forum™ has reported that average rework on projects can cost between 7.25% and 10.89% of total construction cost (when both direct and indirect costs are included) and increases the schedule (project delay) by approximately 9.8% of the planned project time.[3]

Rework also results from improper control of environmental factors like temperature, humidity and barometric pressure that, if not controlled, impair the quality of the finished product (e.g. concrete slabs, millwork). These factors are difficult to precisely measure, predict and control on a job site, especially when the building envelope is incomplete. This challenge is compounded by the fact that temporary heating, cooling, ventilation, and lighting systems on a construction site are typically managed with manual controls and simple timers incapable of reacting to actual environmental conditions. Re-building portions of the work results in needless waste of materials that often go to a landfill, additional energy use/ CO_2 emission on the job site to condition spaces and running equipment/ machinery/lighting beyond the normal project schedule.

PCL's major challenge is to develop and deploy rugged, low-cost, reusable, industrial-grade IoT (Internet of Things) sensors capable of measuring/monitoring job site energy consumption (along with other environmental factors including temperature/humidity, worker location, equipment and material movement) and streaming raw sensor data, via an internet-connected gateway, to a system (i.e. PCL's Job Site Insights) that:

a) ingests IoT sensor data and, along with other relevant data including project schedules, cost estimates, weather forecasts, progressing data and BIM (building information management) models, analytically (e.g. via machine learning models) optimizes, forecasts and regulates job site energy consumption and other job site conditions including worker location/safety, equipment/machinery movement and construction material logistics/handling;

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[3] Dougherty, James M., Hughes, Nigel & Zack, James G. Jr. "The Impact of Rework on Construction & Some Practical Remedies." *Navigant Construction Forum™*. Navigant Consulting, Inc., August 2012. Print.

[4] Shrivastava, Sandeep, Chini, Abdol, "Estimating Energy Consumption During Construction of Buildings: A Contractor's Perspective." Rinker School of Building Construction, University of Florida, Gainesville, FL, USA, January 2011

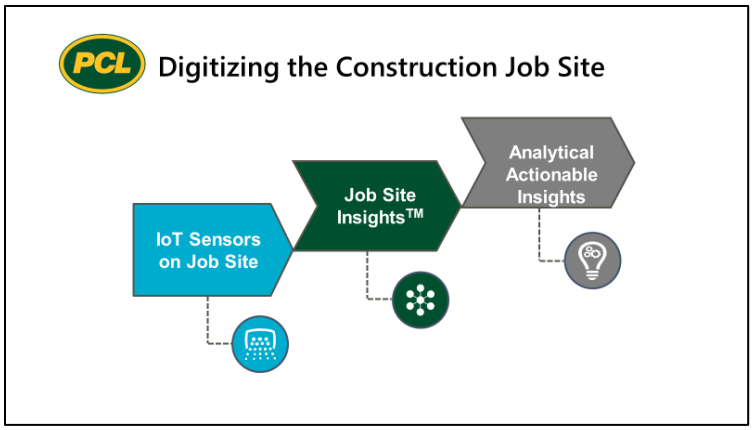

Figure 1 - Job Site Insights Analytics

b) in response to the machine learning/optimization models' outputs, intelligently controls/regulates the job site equipment (e.g. heaters, temporary lighting) consuming energy to achieve optimal/reduced energy consumption/carbon emissions.

1.4 Energy Efficiency

PCL and the construction industry must do a better job of managing energy resources. The construction industry uses significant amounts of energy to build, illuminate, and temporarily condition buildings and infrastructure projects.

Energy on a construction site is provided by gasoline and diesel fuel, electricity, and propane/natural gas. Of these energy sources, electricity and diesel fuel are responsible for the greatest total air emissions. Electricity from the grid is often used to power site lights, elevators, and trailers. On-site diesel fuel is often used to power task lighting, air compressors, pumps, heaters, fans, dehumidifiers and large equipment such as bulldozers, excavators, mobile and tower cranes, generators, and other powered equipment. Generators are used to provide power for more immediate electricity needs like lighting, welding and other hand tools, reaching areas of the site to which it is difficult to supply "grid electricity" and for which excess demand cannot be met by an electricity grid hookup. Sites demanding a significant amount of welding require this type of flexible electricity and thus often require on-site diesel generators.

This equipment is necessary to complete a construction project, yet little thought has been given as to how to operate and power this equipment in an efficient manner. The challenge is to identify inefficient energy consumption on PCL's projects.

The table below, from the March 2017 study Energy Use and Related Data: Canadian Construction Industry 1990 – 2015 (http://www.cca-acc.com/wp-content/uploads/2017/02/Report.pdf), prepared by the Canadian Industrial Energy End-use Data and Analysis Center (CIEEDAC) for the Canadian Construction Association, quantifies the construction industry's 2015 energy consumption and C02 emissions. It is important to note the study excluded electrical grid energy and its associated CO2 emissions.

Province	Energy Demand		CO_2 Emissions		Construction GDP	
	TJ	% of Total	Tonnes	% of Total	2007 $Million	% of Total
Atlantic	6,923	7.5	522,526	8.7	5,442	4.6
Québec	16,084	17.5	1,002,549	16.7	18,917	16.2
Ontario	27,058	29.4	1,795,053	29.9	36,326	31.0
Manitoba	6,598	7.2	412,618	6.9	4,204	3.6
Saskatchewan	10,413	11.3	705,677	11.8	4,571	3.9
Alberta	16,537	18.0	1,047,483	17.5	29,649	25.3
British Columbia	8,202	8.9	543,244	9.1	17,269	14.7
Territories	165	0.2	11,425	0.2	743	0.6
Total	**91,980**		**6,040,575**		**117,121**	

Sources: STC RESD, CANSIM Table 379-0031.

Figure 2: Construction Sector Energy Demand, CO2 Emissions & Production Data by Province, 2015

In some cases, general contractors are often not directly concerned with the cost of site energy during construction since it is often passed on to the project's owner. Nonetheless, efficient energy management, reducing CO_2 emissions and energy cost reduction benefit all construction stakeholders. Site energy is managed by the general contractor who also controls the activities and scheduling on the job site. On large PCL job sites there can be dozens of subcontractors and thousands of laborers working simultaneously. The temporary lighting, heating, cooling, and ventilation systems used by the industry are almost exclusively based on manual controls or simple timers to turn systems on or off during certain times of the day.

2 SMART Construction Technology Challenge

While PCL recognizes the economic and environmental value of smart buildings, smart construction is equally important. By enabling real-time data capture and analytics regarding the condition of a job site, PCL realizes better environmental stewardship, job-site safety, operational efficiencies, productivity, quality and profitability at the face of the job site.

PCL's Job Site Insights (JSI) platform, developed by PCL's Business Technology group, is the technical backbone of PCL's challenge to develop and deploy IoT-based job site sensors and machine learning/advanced analytics models that measure and minimize job site energy consumption and CO2 emissions. JSI is built upon Microsoft's Azure cloud platform and was recently announced in several publications, news articles and videos.

Engineering News Record article on Job Site Insights™: https://www.enr.com/articles/45584-analytics-platform-aims-to-get-the-most-out-of-site-sensors

Microsoft Job Site Insights™ Article/Video: https://customers.microsoft.com/en-us/story/pcl-construction-professional-services-azure

As illustrated in the diagram below, JSI is PCL's platform for ingesting job site sensor data, storing the data and making it available for PCL's systems and applications requiring such data, including analytics and machine learning solutions.

PCL's challenge is two-fold:

1. Build and deploy rugged/impact resistant low-cost sensors capable of, in optimal form factor(s), capturing a wide variety of job site conditions including temperature, humidity, barometric pressure, vibration, electrical energy consumption, daylight harvesting and vacancy/occupancy. This list is not exhaustive. The sensor's form factor must be capable of a "plug and play" approach to adding sensors; for example, as sensor technology advances or new sensors become available, the sensor should be capable of "plugging into" the form factor. The sensors must be able to transmit/receive through diverse construction materials (e.g. concrete walls), have long-life batteries and are installed/configured easily and quickly by construction personnel.

2. Create and deploy machine learning and advanced analytic models that optimize and contribute to lean construction practices, including efficient energy management and CO2 reduction.

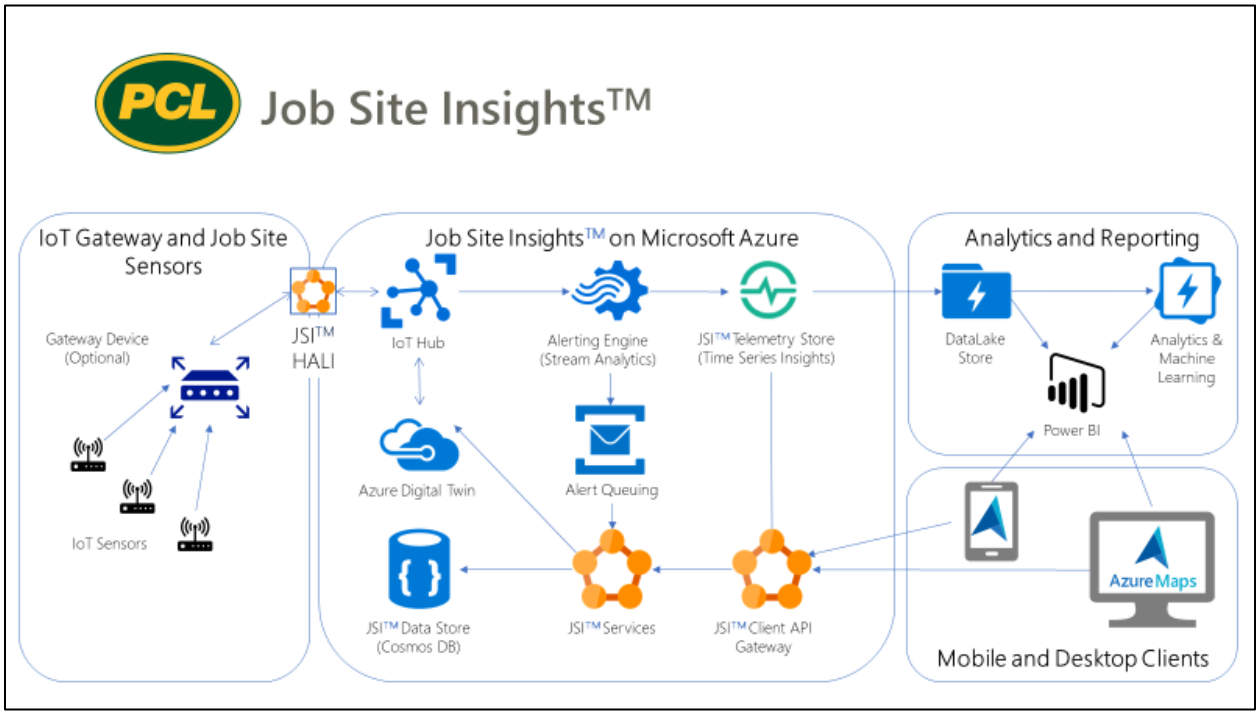

Figure 3 - PCL's Job Site Insights (JSI)

IoT Sensor Deployment Scenarios

- Deploy IoT sensors to measure/monitor job site conditions (e.g. temperature, worker activity, humidity, electrical energy consumption, lighting state and illumination levels, safety conditions) and cross reference the sensor data with other relevant data sources (e.g. project activity and work

schedules) to intelligently (via machine learning models and analytics) reduce (or turn off) energy consuming equipment (e.g. lighting) operation.

- Use temperature sensors to send signals/notifications to turn off heating when ambient temperatures match construction and material requirements (e.g. millwork construction requires strict temperature and humidity regulation).
- Use worker activity/occupancy sensors to turn off lighting in unoccupied areas while protecting workers with sufficient lighting levels.
- Deploy electrical current sensors on temporary jobsite electrical systems, equipment and machinery/tools to monitor loads and consumption of electricity.

2.1 Solution Characteristics

2.1.1 Sensor Technology

This challenge requires IoT sensors and data gateways for environmental sensing. The sensor system shall stream telemetry from a building site during construction and will include low power technologies, security, transport protocol, flood relays, radio technologies, gateway, and the ability to integrate directly with cloud computing platforms including Microsoft Azure.

The system shall stream sensor telemetry to PCL's Azure IoT Hub via the Internet through a gateway and shall automatically use flood network relaying nodes to aggregate wireless messages to a single gateway per construction site.

The sensor node will gather telemetry of the following:

- Temperature
- Humidity
- Barometric Pressure
- Battery voltage
- Radio signal strength
- Acceleration, shock, vibration
- Energy consumption

The sensor node shall wake periodically to receive downlink (cloud to sensor) messages and provide the latest sensor readings in uplink (sensor to cloud). The sensor node shall also wake asynchronously on a threshold-based acceleration event outside of its normal reporting period.

The flood network relaying nodes shall include message reliability mechanisms suitable for concrete high-rise buildings.

Sensor batteries: The batteries shall have a minimum life of 5 years; target 10 years. The battery life is highly dependent on the size of battery (cost) and the period of telemetry. The lifetimes indicated assume 1 message per minute, 24 hours per day, with a CR123A 3V lithium cell.

The sensor form factor ideally measures 60 x 60 x 25 mm or less and its enclosure must be appropriate for simple (and easy) adhesive or single screw mounting. The form factor's material must be able to

survive UV, water spray (IPx5), humidity, temperature, dust (IP6x) and VOC exposure; that is, it is rugged and durable to survive harsh construction job site conditions, particularly cold Canadian climate conditions.

The sensor and gateway technology shall meet jurisdictional, provincial and federal safety codes, such as Underwriter Laboratory certifications, pertaining to such electrical and radio-frequency equipment.

2.1.2 Analytics/Artificial Intelligence/Machine Learning

PCL's challenge includes the use of advanced analytics and machine learning models to measure, forecast, predict and optimize/control job site factors that positively influence lean construction practices (e.g. reduce or eliminate re-work), cost savings, efficiencies, worker safety and energy consumption/CO2 emissions. In addition to sensor data, PCL's analytics challenge could also include data from project schedules, cost estimates, design documents, progressing data, BIM models and external sources including weather forecasts. This data could be leveraged to provide more significant datasets with greater dimensionality and breadth through techniques like natural language processing to build new features to better guide machine learning model performance to deliver better results. PCL seeks to engage Alberta-based machine learning and artificial intelligence expertise (which Edmonton institutions, in particular, has earned international recognition for) to develop optimization and control models.

2.1.3 Desired Impacts

1. The construction industry and building owners benefit from reducing job site energy use and resulting carbon emissions by working smarter and reducing rework. The province and the environment benefit from reductions in greenhouse gas emissions across the construction industry.
2. The development of a platform that measures, forecasts and optimizes energy use from disparate construction activities and the entire project is a significant outcome of this challenge. This will be a revolutionary advancement since PCL and others in the industry are currently dependent on systems that have limited or no tracking or monitoring capabilities.
3. Through the development of artificial intelligence and machine learning solutions, material progress is expected to be made on understanding root causes, predictive factors, and data collection gaps of energy use and rework that beneficially informs the construction industry and building owners on core insights and required data collection and process improvements. The construction industry, as indicated in the various research references in this document, lacks a robust data collection and analysis mechanism for capturing accurate and meaningful data to create actionable insights related to energy and CO2 reduction.
4. The sensors could remain in completed buildings and provide features of a smart building. Smart IOT-sensor-equipped buildings attract tenants (allowing owners to remain competitive), differentiate owners from other developers and increase the productivity and engagement levels of a building's occupants.
5. PCL's challenge, if addressed, will lower energy consumption, reduce waste and decrease its carbon footprint.

3 Market Assessment

According to the Alberta Government 2018 industry profiles published in February 2018, the Construction Industry employs the 2nd highest number of Alberta workers at 10.5% (Health Care and Social Assistance Industry employs 12%) of the total workforce with over 90% employed by SMEs. Over the last 10 years, total construction jobs in Alberta increased by 42,900 from 2007. As industry momentum builds in our province over the next 10 years, an increase of 17.8% jobs is projected adding 8,300 net new jobs by 2027. During this period 40,000 skilled workers will be retiring and 38,300 new employees are also estimated to enter this industry.

Construction demands in Alberta were forecast to decline this year (2018) but divergent trends have emerged between residential and non-residential construction markets, and there are signs of a broader recovery ahead. Over the 2018–2027 scenario period, Alberta engineering construction and commercial sectors are forecast to resume growing at a modest level next year followed by slightly higher growth-rate beginning in 2024 as anticipated renewed oil and gas investment returns.

Technology such as cloud-based software, integrated collaboration, and mobile project management is transforming the industry everywhere and those who cannot keep up, will likely not survive. It plays a key role in increasing competitiveness of Alberta construction firms. First, it helps attract workers while the Alberta construction industry transitions to a smaller workforce and focuses on maintaining high worker skill levels as retirees are replaced over the next decade. Second, it helps firms compete for new projects locally and globally by offering new construction processes and products such as Net Zero and smart buildings. And thirdly, during the construction process, technology helps companies focus on increasing efficiency, reducing negative environmental factors and, reducing costs through reduced waste and energy usage.

From an environmental aspect, Alberta is positioned to become a national leader in increasing productivity while reducing emissions as the chart below illustrates.[4] There is an opportunity for Alberta to become an exporter of construction technology that focuses on environmental sustainability.

	Energy & Emissions Intensities Calculations, 2015	
Province	Energy Intensity TJ/ $GDP	CO_2 Emission Intensity T CO_2/ $GDP
Atlantic	1.07	96.02
Québec	0.85	53
Ontario	0.74	49.42
Manitoba	1.57	98.14
Saskatchewan	2.28	154.4
Alberta	0.56	35.33
British Columbi	0.47	31.46
Territories	0.22	15.37

Figure 4: Energy & Emission Intensities are CIEEDAC calculations based on CANSIM Table 379-0031.

[4] Griffin, Bradford & Bennett, Michelle. "Energy Use and Related Data: Canadian Construction Industry 1990 to 2015" Prepared for: Canadian Construction Association. Canadian Industrial Energy End-use Data and Analysis Centre Simon Fraser University, Burnaby, BC. March, 2017. Print.

4 Industry Sponsor Overview

4.1 PCL Background

Headquartered in Edmonton, Alberta, PCL (www.pcl.com) is a privately-held and employee-owned group of independent construction companies operating in Canada, the United States, Australia and the Caribbean within the civil infrastructure, heavy industrial and buildings markets.

As a large general contractor, PCL works on hundreds of projects at any given time and the cumulative energy consumption/ costs are substantial. PCL estimates that it spends $200-$300 million in energy consumption across its construction projects in North America. Refer to the graphic below.

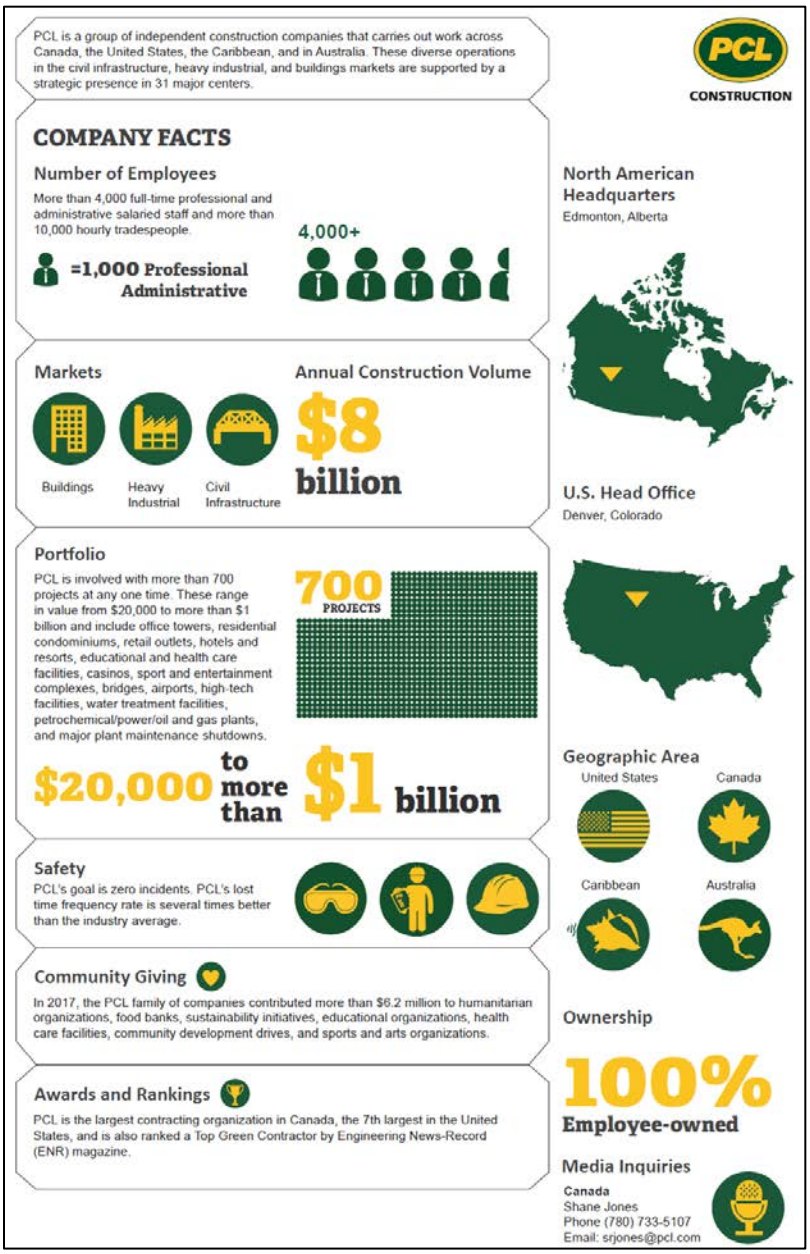

Figure 5 - PCL Facts & Figures

5 Challenge Process

The application process for this Challenge will take place in three stages:

Stage I: Opportunity Identification

This stage is open to the public and will require Applicants to submit an Expression Of Interest (EOI). The EOI will be used to assess and identify opportunities that align with the challenge, have a clear competitive advantage, have a viable path to market and will have a significant impact in Alberta within a reasonable timeframe.

Stage II: Corporate and Capital Readiness

This stage is by invitation only, with successful participants selected from Stage 1. Applicants will be required to submit their up-to-date year-end financial statements, a 5-year financial forecast and a basic business plan.

Stage III: Go-to-Market Plan

This stage is by invitation only, with successful participants selected from Stage 2. Applicants will be required to submit a proposal outlining the development/demonstration of their technology in collaboration with the appropriate partners, including academia or other industry, as well as letters of support (if applicable).

6 Evaluation Criteria

The scope of this challenge is focused on supporting the development and demonstration of technology solutions for managing, measuring and reducing energy used during the construction process. The solution provider must be a qualified Alberta SME and should have the capability of supporting their product through its lifetime (design, parts, maintenance, training, etc.). Ideally, the SME has experience in the Canadian construction industry. If the SME does not have in-depth expertise in all key areas of sensor development and machine learning, PCL will accept sub-contracting or partnership relationships in order to develop and deliver a comprehensive and robust solution.

Broadly, the evaluation criteria will focus on the opportunity, potential impact, and feasibility

The Opportunity

Market: The optimal solution and provider will be strongly positioned to address a clearly characterized and quantifiable market that is significant both in Alberta and globally.

Technology: The optimal solution will be sufficiently developed to ensure a timeline to demonstration in a commercial building of less than 1 year.

Business: The optimal solution will be commercialized by an Alberta SME with the experience, expertise, planning and financial resources to realize the potential of the technology as well as the capacity to

support the product through its lifetime (design, parts, maintenance, training, etc.). PCL seeks to have license fee free use rights to the technology.

The Impact

Alberta: The impact to Alberta will need to be significant, measurable and timely. This impact may be related to social well-being and/or economic development through new venture creation, manufacturing facilities and/or direct supply-chain growth and maturation.

SME: Growth is expected in the form of increased revenue, new export market/customer acquisition, recruitment and retention of highly skilled workers, and follow-on investment.

Environment: The technology must provide the opportunity to measure and reduce energy inputs that go into resource extraction, materials manufacture, transportation of materials and labour to job sites, installation and construction, building demolition, deconstruction and reuse and thereby reducing sufficient GHGs to meet net zero energy and high efficiency building standards.

Project Feasibility

Data ownership: PCL must own IoT sensor-produced data and it will not pay subscription fees to access its own data; the data produced by IoT sensors will be streamed to, and stored on, PCL's Microsoft Azure cloud tenant and is the sole property of PCL.

Outcomes: The project must be outcome-focused with appropriate milestones, timelines, and resource allocations.

Support: The project must have the appropriate supports in place, including partners and financing needed to ensure success.