Climate Change and Infrastructure Engineering:
Moving Towards a New Curriculum

Prepared by the Canadian Standards Association

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Table of Contents

1 EXECUTIVE SUMMARY 6

2 INTRODUCTION 11

3 GENERAL METHODOLOGY 16

4 IDENTIFICATION OF HIGH PRIORITY TOPICS 18

5 BUILDING A FRAMEWORK FOR A NEW CURRICULUM THAT INCLUDES CLIMATE CHANGE 29

5.1 Identification of Climate Change research 29

5.2 Assessing the existing education curricula 32

5.3 Assessing awareness and use by engineers 36

6 RECOMMENDED EDUCATIONAL DELIVERY METHODS 43

7 KEY FINDINGS AND NEXT STEPS 67

8 APPENDICES 70

APPENDIX A - SURVEY QUESTIONS 70

APPENDIX B – Survey results 74

APPENDIX C Catalogue of References (Body of Knowledge) 82

APPENDIX D – National Occupational Classification Details 119

9 TABLES

Table # 1: High Priority Topics for inclusion within University Undergraduate Engineering Curriculum……………………….....20

Table # 2: Proposed Framework for University Undergraduate Curriculum……………………………………………………………49

Table #3: Proposed Framework for Continuing Education……………....53

10 FIGURES

Figure #1 : Positioning the Project……………………………..…………….. **11**

Figure #2a : Project Methodology ……..….…………………….………..….. .. **13**

Figure #2b: Facilitating Codes & Standards Development…..................... **13**

Figure#3: Project Work Breakdown Structure ……..………………..……….. **17**

Figure #4: The proposed Climate Change Body of Knowledge for Infrastructure Engineers………………………………………….. **30**

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1 Executive Summary

Introduction
Historical climatic patterns are no longer reliable predictors for future climatic patterns. As this global trend of a more uncertain and changing climate continues to unfold, Canada's engineering community has a responsibility to ensure that it delivers appropriate responses and solutions. This is important across all engineering disciplines, and is especially important within the field of built infrastructure engineering.

The long term durability and resilience of much of Canada's built infrastructure is predicated on engineers having a solid understanding of the conditions that it will face over its useful life, including climatic factors. "Built Infrastructure" is a broad topic in itself. As it relates to this project, it includes the categories of, buildings, energy, transportation, and water.

The public expects that services provided by built infrastructure will continue uninterrupted. Although media coverage of catastrophic events occasionally puts a spotlight on the state of Canada's infrastructure, for the most part, it has proven to be reliable and safe to the point where it is often taken for granted.

Yet currently, there are significant knowledge gaps about how climate change issues will affect the practice of infrastructure engineering, and this has implications for built infrastructure. This special project, undertaken by the Canadian Standards Association (CSA), makes an assessment of, and recommends how to expand engineering curricula, both in universities and in continuing education programs, to reduce this knowledge gap over time. Integration of already-available knowledge in this topic area into mainstream engineering education and practice will increase the preparedness of Canadian infrastructure engineers to address the potentially damaging effects of climate change.

Identification of high priority topics for engineers
In order to determine the most essential topic areas that would form the basis of a useful curriculum for engineering students and practitioners, CSA conferred with experts and leaders from the fields of engineering, sustainability, and climate science. Additional consultations were conducted with individual university educators and practicing infrastructure engineering specialists. The topics and curriculum framework that evolved out of these consultations is believed to be a useful and pragmatic step toward advancing the engineering community's understanding of how to consider and address climate change issues within day-to-day engineering work.

For university students, topics are recommended that, for the most part, emphasize non-technical issues. One theme that ran through discussions with some experts was the importance of creativity. Accordingly, it was recommended that the focus for educating students should be on developing their ability to provide solutions when traditional methods are no longer valid. A working knowledge of risk analysis was identified as the highest priority topic for university curricula.

Further consultation with experts and individual infrastructure practitioners produced a wide array of other topics that are also important for practicing engineers including those that recognize the specialized nature of each infrastructure category. Most of the high priority technical issues that were identified for practicing engineers were related to extreme weather and its unique effects on different kinds of infrastructure. General topics, such as knowledge of infrastructure finance and decision-making processes, public policy, and emergency preparedness and response, were found to be applicable to all infrastructure specialties.

Present-state of Climate Change Education
It was also important to establish a baseline, or present-state for Climate Change education. CSA examined the course offerings for eight Canadian universities in order to develop an objective measure of engineering graduates' current, baseline knowledge of climate change and infrastructure issues. Course descriptions were searched for references to the key broad topics that were considered to be important. While climate change, for one, is not entirely overlooked as an area of study generally, it was very rarely featured in courses offered through engineering faculties specifically. Other topics that help enhance engineers' expertise with climate change issues – risk management, engineering economics and decision-making, and sustainability issues chief among them – were more prevalent in course descriptions, although coverage varied widely by university. Additionally, climate change issues were not covered in any of the three continuing education programs investigated by CSA. The lack of available comprehensive teaching of climate change in universities and continuing education programs implies a gap in the current level of knowledge among mainstream engineers and students.

Survey of practicing engineers
CSA also conducted an independent survey, aimed at Canada's professional engineers. The results of this survey were analyzed within the context of this project to assess:
- Awareness of climate change issues as they relate to real-life engineering practice,
- Familiarity with the identified high priority topics and,
- Familiarity with tools and techniques that are considered to be important.

A majority of engineers agree that global climate change will affect their practice; however, very few routinely consider climate change currently, and most claim they require more information before integrating climate change in their day-to-day engineering decisions. Confirming the findings of the review of university course descriptions, most respondents also agreed that several additional climate change and infrastructure topics need to be included in the engineering curriculum, in order to equip future graduates with the necessary tools for addressing climate change in practice.

Framework for changes to engineering curricula
Through primary research with education and industry professionals, as well as examinations of the current body of knowledge, CSA found that the best approach for delivering information to students and professionals is one that is methodologically

flexible, with topics arranged into modules. This ensures that engineers have convenient access to information that is pertinent to their field of study or practice. Furthermore, course materials should be developed by experts on their respective subject matter, and should be updated as knowledge on climate change and infrastructure engineering continues to evolve and change. The educational modules recommended for students are:

- Risk
- Climate change science
- Public policy and regulatory frameworks: role of codes and standards
- Psychology decisions, perceptions and behaviour
- Decision-making processes: economic, environmental, and social cost-benefit analysis
- Climate change impacts and adaptations.

The modules for practicing engineers are:

- Water infrastructure
- Buildings infrastructure
- Transportation infrastructure
- Energy infrastructure – electricity generation
- Energy infrastructure – electricity transmission and distribution
- Northern infrastructure
- Multi-discipline engineering
- General – not engineering specific.

Key findings and next steps

Here are the key findings as a result of this project:

- There is an already available body of knowledge on climate change responses for built infrastructure and it is expected that this knowledge-base will continue to evolve and improve over time. The framework proposed in this report will help to accelerate this existing knowledge into mainstream practice. In many specific areas of built infrastructure however, the research on climate change has not yet reached a point where it can be applied with confidence by the mainstream of practicing engineers. Further evidence that proposed solutions are practical, along with additional advances in the 'state-of-the-art', will be required in some areas.

- There seems to be a significant gap between what engineers presently know and what they would need to know to deal with Climate Change issues more effectively. This has implications for undergraduate curriculum, as well as for continuing education and ongoing professional development for practicing engineers. While most infrastructure engineers already accept that Climate Change will affect their practice in the future, very few are currently factoring Climate Change into their infrastructure decisions now. This has significant implications for built infrastructure, recognizing that the useful design life often exceeds 50 years for many categories of built infrastructure.

- Climate Change should be considered as one of many stressors or factors that infrastructure engineers will need to consider in the future, and should not be considered in isolation. Here is a list of typical factors that affect infrastructure:
    - More uncertain, or more frequent extremes in climatic conditions
    - Service delivery – changes to level of service required, or loads and capacity
    - Inadequate maintenance
    - Public health and safety issues
    - Environmental issues
    - Changes in demographics and other population characteristics
    - Institutions and how they are organized
    - Security
    - Availability of funding - access to capital
    - Local social factors
    - Stability of local and regional political situations.

- Infrastructure engineers acknowledge that they need much more knowledge if they are to incorporate Climate Change into their practice. Practicing engineers do not feel the current university curriculum sufficiently prepares students to deal with Climate Change, and recommend additions to the curriculum to better prepare them. Additionally, they recognize they are also not sufficiently prepared and believe they should seek more knowledge.

- Climate Change represents a relatively new challenge for most engineering disciplines. Therefore, the emphasis on preparing engineers to deal with the effects of a changing climate should be concerned with giving them the tools and foundation to apply their engineering knowledge in a new way. Risk assessment and risk management are examples of important topics that will play a greater role in future engineering decision-making.

- Engineering faculties should be given the flexibility to customize the delivery of Climate Change content to university students in a way the best suits their department structures, course offerings, and priorities, as long as a minimum level of coverage is assured. This implies a modular approach that allows for the unique teaching, research and organizational philosophy of each institution to be preserved. Each institution would therefore determine and adapt their curriculum with the optimal combination of new courses, course components, projects and problems.

- While much of the education required needs to be developed and instilled at the university curriculum level, efforts must be made to also build awareness with practising engineers through alternative sources such as distance learning, workshops, papers and continuing education courses. Because of the broad range of engineering disciplines, and the high degree of specialty within disciplines, every effort must also be made to create a flexible modular approach that can be tailored to meet specific Climate Change educational needs.

- Removal of systemic barriers will also help to accelerate the integration of climate change considerations into mainstream engineering practice. For example, codes and standards have a profound influence on engineering decision-making. Codes and standards developers and stakeholders have further work to do, so as to ensure that Canada's complex network of codes and standards enable rather than inhibit climate change responses and solutions. Furthermore, there was evidence that at least some decision-makers don't yet support or require climate change issues to be considered as part of technical decision-making. This also has implications for how effectively engineers can address climate change issues in their day-to-day work.

Implementation

While implementation of the education recommendations lies outside of the scope of this project, these actions should be considered as next steps:

1. A formal consultation with the Canadian Engineering Accreditation Board and the provincial/territorial associations/orders regarding implementation of these recommendations for universities. This consultation will focus on the need for Climate Change to be mentioned specifically in their accreditation criteria.

2. Further consultation with the Deans of engineering and science faculties to discuss how the findings could be implemented.

3. Discussions on how Engineering faculties can partner with Science or Business faculties and others to deliver Climate Change courses/materials.

4. Development of course and teaching materials for implementation with universities and continuing education providers. This project provides a basic framework for addressing engineering topics from a Climate Change perspective. More detail work is necessary, such as estimating the number of instruction hours per module, assessing how to balance this additional coursework with existing demands on students and instructors, as well as to determine where courses need to be sub-divided into smaller components.

5. Conduct pilot projects with selected education providers, using a limited number of modules to further test and evolve the proposed educational framework.

6. Consider a certificate/diploma program and/or incorporate the Climate Change topics into existing specialized certificates and diplomas in the various areas of infrastructure engineering. This would further facilitate a higher level of Climate Change knowledge amongst practicing infrastructure engineers.

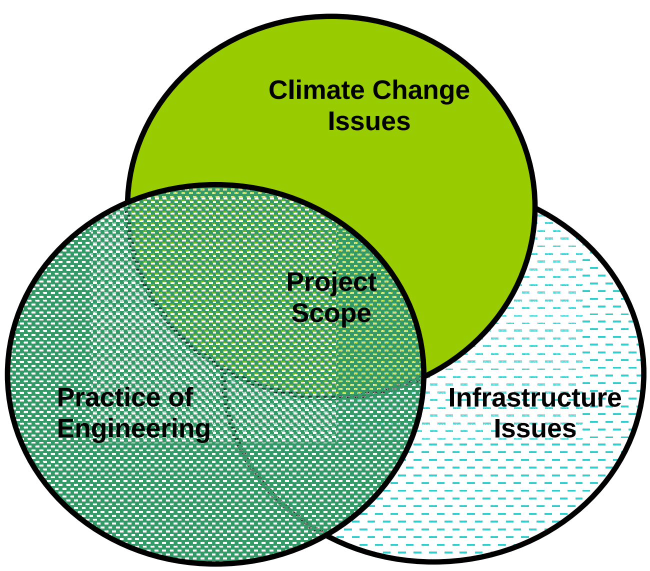
2 INTRODUCTION

This project was initiated by the Canadian Standards Association (CSA) to examine the current state of knowledge of climate change issues and responses amongst practising infrastructure engineers. Furthermore, it examines the current level of awareness and use of such knowledge in their day-to-day work. Finally, it establishes a baseline for the present-state of climate change topics within engineering curricula, and looks at what needs to be done in order to make improvements.

Canada's engineering community has a profound impact on the development of Canada's urban and rural infrastructure. The profession shares a responsibility for ensuring that Canada's built infrastructure is resilient and sustainable. This includes buildings, energy and transportation structures such as roads and bridges, as well as water, wastewater and storm water systems. Increasingly, extreme weather events, warmer temperatures, melting permafrost, more intense precipitation and droughts are all having a significant impact on urban and rural areas across Canada. The effects of these climate change events on built infrastructure are one of the many stressors and factors to consider.

The primary objective of this project is to conduct an assessment on how to expand Canadian university engineering curriculum and continuing education programs to include know-how on climate change responses and solutions for built infrastructure. Where climate change, infrastructure and the practice of engineering intersect, there are opportunities to build specialized knowledge and likely as well, knowledge gaps that need to be overcome. *Figure 1* illustrates this concept.

A key assumption is that there is an existing body of knowledge on climate change for built infrastructure, and that much of this knowledge has not yet made its way into mainstream use by infrastructure engineers in their day-to-day decision-making. The results indicate that this assumption is valid, and therefore, this gap between what is already known, and what is used, has significant implications for Canada's built infrastructure.



Figure# 1 Positioning the Project

Another key part of the work-product from this project are recommendations on the most effective methods for accelerating into the mainstream, the knowledge necessary in order for infrastructure engineers to consider climate change in their day-to-day work. Knowledge transfer and education for this emerging issue will lead to a better-prepared engineering community.

This special project was conducted by the Canadian Standards Association as one of many required tactics toward facilitating more resilient and adaptable built infrastructure over the long term. The ultimate goal is to ensure that technical codes and standards for built infrastructure adequately address climate change issues. CSA has approximately 9,000 volunteer experts who make significant contributions to technical standards. Many of these technical standards are either directly or indirectly related to physical infrastructure and many of the volunteer experts are practising engineers.

The four main project outcomes are:

- Identifying and prioritizing specific topics for knowledge transfer
- Establishing a measure of the present-state awareness and knowledge (i.e, establish a baseline) of these priority topics amongst infrastructure engineers
- Describing the available body of knowledge in important topic areas
- Identifying and recommending the most effective delivery methods for transferring this knowledge to engineering practitioners and students

The overall methodology is illustrated in Figure 2a. It starts with the identification of issues and high priority topics. Next, the already-available body of knowledge related to climate change was identified. Equally important to the project, results of a national survey were analyzed in order to establish the present-state or baseline for the existing awareness and use of this knowledge in the day-to-day decision-making by infrastructure engineers. Concurrent with this step as well, an assessment was made of to what extent, high priority Climate Change topics and knowledge areas are already included within university and continuing education curricula.

Figure 2b shows conceptually, how over a period of time, continuous improvements to engineering curriculum facilitates better codes and standards.

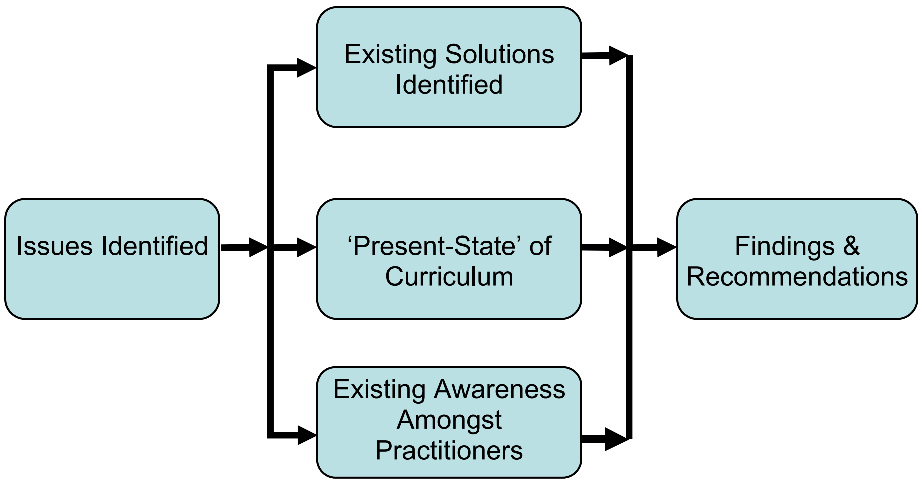


Figure # 2a Project Methodology

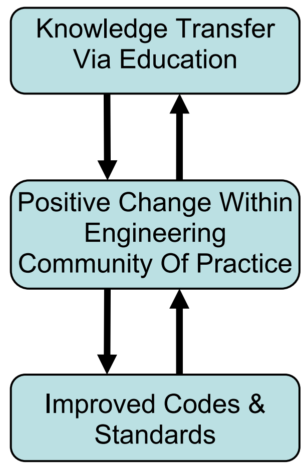


Figure # 2b Facilitating Codes & Standards Development

The project work-product is directed towards the full spectrum of the engineering profession - engineering students and practising engineers. The two audiences were considered separately. Experts in infrastructure engineering were consulted, and as well, experts from other fields that are also important to climate change were also consulted. This included climate scientists and sustainability experts. These consultations helped to shape the overall project direction, and as well, established specific lines of enquiry and assumptions to validate.

For the purposes of this project, infrastructure was categorized into four main groups:

- Buildings infrastructure (primarily commercial, municipal, and industrial structures, building envelope, geotechnical, building systems)
- Transportation infrastructure (primarily roads, highways and associated drainage systems, runways)
- Energy infrastructure (primarily transmission and distribution systems and hydro-electric generation)
- Water infrastructure (primarily physical assets employed in storm-water management, drinking water, wastewater, flood control, erosion)

NOTE: *A related category that was also considered was infrastructure issues specific to Canada's Northern Regions.*

Many researchers and commentators have expanded the meaning of "infrastructure" to include other domains such as agriculture, communications, public health, culture and tourism, intellectual wealth, etc. These domains are excluded, except where it is indirectly included via the consideration of one or more of the categories of built infrastructure that were defined above.

A flexible, modular framework for the inclusion of climate change topics within curricula is also provided. The report begins with the identification high priority topics. Some are non-technical areas that are considered to be essential as they help to put highly specialized engineering and technology topics into a broader context. This serves as the basis for the areas that should be covered in any education initiative.

This is followed by a sampling of the scholarly body of knowledge on these priority topics. This bibliography is a starting point for building a foundation for the overall content. Next is a measure of the present-state of climate change knowledge delivery to students and as well, to what extent practitioners use climate change knowledge in their day-to-day decision making. Analysis of the results from a national survey of engineers, conducted in the spring of 2007, serves as the primary means for describing the present-state baseline for practitioners. A review of university course calendars and descriptors, as well as continuing education offerings was augmented by interviews with engineering educators. These serve as the basis for evaluating the present-state of climate change topics within engineering curricula.

Finally, the recommendations on the content, approach, and delivery methods to expand engineering knowledge and awareness of relevant issues, responses and technical solutions are presented.

Project Scope

Interviews with experts were conducted in order to further evolve assumptions. This resulted in the following overall framework for the project:

- General topics would be considered in addition to specialized engineering subject areas. The rationale for this is based on the belief that engineers should be aware of more than just the technical requirements of their specialty if they are to provide comprehensive solutions for built infrastructure. Climate Change as an issue in particular, has more than just technical dimensions.

- Climate change issues were categorized into lines of enquiry as follows:
    - Understanding the impact of climate change on built infrastructure
    - Adapting built infrastructure to the impacts of climate change
    - Climate Change Mitigation as related to the identified categories of built infrastructure

Major tasks were outlined in Figure 2a and 2b.

1. Identify and prioritize specific topics and issues related to Climate Change and built infrastructure
2. Describe as fully as possible, the already-available body of knowledge that is available for each category of built infrastructure.

3. Measure the present-state of awareness of Climate Change issues and available knowledge, as well as the extent to which it is used in day-to-day decision-making by infrastructure engineers. Also, describe to what extent, Climate Change issues and solutions are already included in university and continuing education curricula aimed at infrastructure engineers.
4. Identify gaps and areas for improvement related to the delivery of Climate Change knowledge to infrastructure engineering practitioners and undergraduate students

3 General Methodology

A core team of CSA staff, augmented by external contractors and specialists were employed. The basic methodology used throughout the project was to conduct primary or secondary research, develop assumptions, test the assumptions with a group of volunteer experts, and then confirm the consensus of the experts through additional expert consultation and/or survey work.

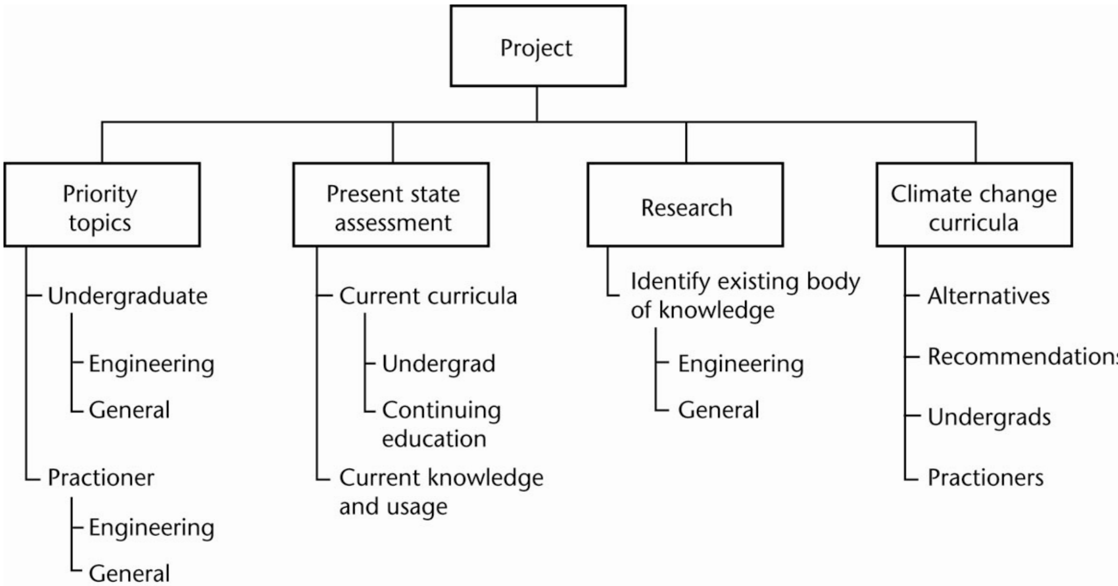
CSA sought input from a variety of engineering disciplines, scientific specialties and non-technical areas. Experts in various areas of practice from all regions of Canada were engaged.

Participants included public and private sector infrastructure experts, academics, scientific researchers, NGO associates, and social science specialists. A partial list of the agencies represented includes Engineers Canada, the Public Infrastructure Engineering Vulnerability Committee (PIEVC), Engineers Canada's Environment and Sustainability Group, the Canadian Climate Impacts and Adaptation Research Network (C-CIARN), Environment Canada, Natural Resources Canada, Public Works and Government Services Canada, and the provincial and territorial professional engineering associations.

The success of this project relied on gathering information from individuals in multiple disciplines such as civil, mechanical, and electrical engineering; climatology; sociology; urban ecology; and public administration.

Subject matter experts were recruited to act in a voluntary advisory capacity for content development and analysis. The experts were chosen based on their national and/or international reputations, peer recommendations, and their availability and interest in the project.

Depending on the circumstances and project phase, the primary forms of consultation included an expert panel forum and individual interviews. The choice of group and interview formats was based on the most efficient use of volunteer time and the project schedule. The overall work breakdown structure for the project is shown in Figure #3.



Figure#3 Project Work Breakdown Structure.

4 IDENTIFICATION OF HIGH PRIORITY TOPICS

Introduction

Both undergraduate university students, as well as practising engineers were considered. It was essential to identify topics that would be relevant to the broadest possible cross-section of the identified infrastructure engineering disciplines and sub-disciplines.

As discussed earlier, the scope of work was set to include technical lines of inquiry that obviously come under the sphere of professional engineering, but also to include issues beyond science and technology that are also important for engineers to understand. It has been recognized that infrastructure engineers don't always work in isolation. Increasingly, decision-making is done by multi-functional and multi-disciplinary teams, where engineers work with other functional groups such as finance, planning, legal and policy-makers. Technical decision-making is only one dimension in the design, delivery and operation of built infrastructure. There are broader considerations such as:

- Social and cultural considerations
- Economic considerations
- Public policy and political direction
- Operations and maintenance (or deficiencies in operations and maintenance)
- Considerations such as public security, emergency preparedness and response
- Risk management and continuity of service

Methodology for the Identification of High Priority Topics

A series of interviews were conducted, some with individuals and others in groups. These are summarized below.

<u>Expert Panel Teleconference to establish assumptions related to priority topics for Students and Practitioners</u>
An expert panel of thought leaders from engineering, climate science and sustainability backgrounds was recruited to help determine priority topics for knowledge transfer to engineering students and engineering practitioners. The experts were chosen based on a number of criteria:

- Knowledge of issues such as climate change, engineering practice, and sustainable communities
- Regional diversity
- A cross-section of interests
- Acknowledged expertise in their fields

A series of preliminary questions was formulated to form the starting point for the expert panel discussion. These questions also formed the basis for future consultations with engineering practitioners.

The results generated by this expert panel were arrived at by consensus. The expert panel results were verified through consultation with expert practising engineers and/or university educators from Canadian engineering schools. Verification was also conducted through an online opinion survey that will be discussed later in this report.

University Educator Interviews for Student Priority Topics

CSA conducted one-on-one interviews with five university educators from Canadian engineering schools to verify the expert panel recommendations for university students. The university instructors were chosen through recommendations by their colleagues or by CSA staff. The university educators were asked to comment on the importance of the topics and their relevance to the engineering curriculum.

Expert Practitioner Interviews for Practitioner Priority Topics

CSA conducted interviews and small group teleconferences with a diverse body of infrastructure experts to determine primarily infrastructure-specific priority topics for engineers relating to climate change. This group was also asked to verify or add to the more general priorities topics determined by the expert panel.

One-on-one interviews were held with over 15 infrastructure experts working in each of the identified major asset categories. The volunteers were chosen so as to achieve regional as well as asset category representation. The choice of group and interview formats was based on the most efficient use of volunteer time and schedule.

Consensus was determined by consolidating results and asking the experts to review, comment, and confirm the results. Verification of expert practitioner results was attained by asking additional experts outside of the group to verify the results.

Identification of High Priority Topics for Engineering Students

Priority topics for engineering students were identified by posing the following questions to the expert panel and a pilot group from Engineers Canada:

1. If you could choose only one thing to add to the university engineering curriculum in the area of climate change and/or climate change and infrastructure, what would it be? Please be as specific as possible. (Examples that came out of experiments with this question are: the science of climate change, the effects of climate change on structures, and the application of design codes and standards to include climate change.)
2. If you could choose up to 3 more areas, what would they be?

The priority topics were verified through university instructor consultation. The resulting high priority topics are shown in Table #1.

Table # 1: High Priority Topics for inclusion within University undergraduate engineering Curriculum

TOPIC	DESCRIPTION & RATIONALE
Climate change science	Students should be provided with the fundamental science behind climate change. This will help them put any further climate change content into context.
Climate change impacts and adaptations	Engineers have a profound effect on the sustainability of infrastructure and will be expected to provide recommendations and solutions relating to climate change. Solutions may include mitigating greenhouse gas (ghg) emissions as well as looking at some of the emerging tools for adapting infrastructure for the impacts of climate change.
Risk	A thorough knowledge of the tools and techniques of modern risk management has become essential. Additionally, knowledge of the processes and concepts of vulnerability assessments is an emerging necessity. These tools and techniques are essential to infrastructure engineers because built infrastructure is often designed with a useful life of many decades.
Decision-making processes: Economic, Environmental and Social cost-benefit analysis	The useful life of built infrastructure often spans many decades. Essential knowledge areas are: infrastructure economics including topics such as financial planning, revenue and cash-flow projections, budgeting for ongoing maintenance and repair costs; assessment of environmental impacts; contemporary techniques of total lifecycle asset management, lifecycle assessment, consideration of environmental 'footprint'; social costs and service delivery requirements and expectations.
Public policy and related regulatory frameworks: role of codes and standards	The regulatory framework for infrastructure is complex and has a profound impact on how and where climate change solutions can be integrated into the day-to-day decision-making. An in-depth understanding of regulatory frameworks, as well as codes and standard development, helps to ensure that the development and use of innovative engineering responses and solutions by the mainstream of practitioners occurs once such innovations have been appropriately tested and proven.
Psychology - decisions, perceptions, and behaviour	Engineers are key decision-makers and should be aware of how people evaluate evidence, how they determine risks, and how biases, past experiences, peer pressure, and needs can affect their decisions and behaviour.

Discussion on University Curriculum needs

For engineering students, many of the topics that were initially highlighted as high priority touched on topics that are not exclusively related to engineering, as well as on the need to develop soft skills. This may have something to do with the makeup of the expert panel participants, but it also indicates an opinion that preparing engineering students to deal with the effects of climate change is about more than specialized engineering knowledge. For engineers to effectively respond to climate change, science and technology knowledge must be augmented with topics from other subject areas such as risk management, working on teams, social, economic and environmental impacts of technical decisions, and communications skills as well.

The themes that ran through much of the discussion with the expert panel were change, the importance of working in cross-functional teams, and dealing with more uncertain future-states of weather and climate. The importance of creativity was also emphasized, as innovative thought processes and paradigm shifts are considered to be important paths toward future solutions. It was suggested that if engineering students could deal with these themes in an effective manner, then better, more effective technical solutions would follow naturally. Even for technical topics, the expert panel believed the focus for educating students should be more on the process of developing solutions rather than on the solutions themselves.

The engineering university instructors concurred in large part with the findings of the expert panel. All of the university instructors saw value in topics beyond the domain of engineering, and highlighted the point that engineers needed a wide understanding of broader issues that will help them implement their technical decisions. As might be expected however, the university instructors also emphasized the need to address topics that specifically relate to engineering disciplines such as transportation engineering and municipal engineering. They believed that students should know the latest research on how a changing climate may impact certain categories of infrastructure.

Energy efficiency is considered to be an important subject area related to the mitigation of greenhouse gases. Although greenhouse gas mitigation is a central and important dimension to the Climate Change issue, it was also noted that its consideration is less important to some of the disciplines associated with infrastructure engineering. In most cases, responding to Climate Change impacts, and increasing the focus on adapting built infrastructure plays a more important role. This is why the expert panel felt that addressing adaptations and impacts issues are essential elements.

The highest priority topic for the engineering university curriculum was the subject of risk in the context of Climate Change. ‘Risk’ is not a new concept, and many engineering disciplines already apply risk management tools and techniques. However, it was also recognized that the body of knowledge related to risk management as it applies in the context of Climate Change is still evolving. Climate Change researchers have introduced new concepts and vocabulary into the study of risk as it relates to Climate Change. For example, techniques such as vulnerability based approaches are considered to be essential elements within the study of Climate Change risk management.

'Risk' as a subject area includes: risk assessment, risk management, and risk communication. Risk can encompass public safety risk, economic risk, environmental risk, and serviceability risk. It can also encompass the qualitative, as well as quantitative assessment as to the degree to which a community's infrastructure and/or sub-components is 'vulnerable'. This entails looking beyond just the technology domain.

Many of the interviewees believed that knowledge of risk analysis should be a key professional competency. Recognizing that Climate Change is a dynamic subject area that entails predicting future outcomes that are uncertain, this knowledge area has become increasingly important, particularly for infrastructure engineers. A solid knowledge of the general approach to risk assessment and management is essential to decision-making related to Climate Change.

Identification of High Priority Topics for Engineering Practitioners

High priority topics for engineering practitioners were identified by posing a series of questions to a panel of experts, as well as to individual practising engineers:

1. If you could choose only one area where you think there is a gap in the engineering community's knowledge and awareness in the area of climate change and public infrastructure, what would it be? Please be as specific as possible. (Examples that came out of experiments with this question are: designing structures for climatic loads when historical records are no longer valid, best practices for storm water management, and design assumptions to use for electricity system planning.)
2. If you could choose up to 3 more areas, what would they be?

The identified topics and subject areas were categorized as either specific to one or more engineering disciplines, or applicable to all disciplines that deal with built infrastructure. The topics were then further categorized by infrastructure category. It is expected that most engineers should be knowledgeable about all of the general topics, and as well, to be knowledgeable about engineering topics that are applicable to all disciplines. However, there would be no need for an engineer to be knowledgeable about specific technical topics that are outside of their engineering specialty.

The high priority topics are categorized into subject areas and are outlined below:

<u>Multidiscipline engineering topics:</u>

1. Using climate change models and climate change model experts to integrate modeling into design at the local project level.

2. The application of design codes and standards, and the adaptation of codes and standards, in the face of more uncertainty about future weather impacts and climatic conditions.
3. Techniques for identifying and/or building in the potential to adapt infrastructure at intervals throughout its useful life.
4. Concepts, options, and technology for reducing greenhouse gas emissions
5. Asset management systems.
6. Importance and sourcing of accurate environmental data.
7. Land use planning for vulnerable areas and monitoring of vulnerable areas
8. The science behind climate change and the broad impacts of climate change on the physical environment.

<u>Water Topics:</u>

1. Impacts on storm water management due to precipitation from extreme weather events, and the potential adaptations that are available.
2. Impacts of climate change on the availability and sources of potable water, and potential and appropriate responses to ensure appropriate utilization and availability of potable water resources.
3. Available adaptations for coastal infrastructure for dealing with climate change-induced long-term sea level rise and/or short term storm surge from extreme weather events.
4. Impacts on built infrastructure from river flooding due to extreme weather events, and the implications for municipal planning.
5. Impacts of climate change on waste water infrastructure, and the implications for human health.
6. Decision support recommendations on how to properly prioritize solutions and responses to Climate Change, so as to ensure that water assets are appropriately adapted in a sustainable manner, recognizing constraints and the finite nature of economic and environmental resources.

<u>Buildings infrastructure topics:</u>

1. Knowledge of energy efficiency options within building mechanical systems and/or building envelope technology to mitigate carbon (ghg) emissions through reduced usage of energy.
2. Tools and techniques for evaluating and comparing ‘green’, ‘climate-friendly,’ or ‘sustainable’ building technologies and materials. For example, understanding various materials ratings systems, ‘cradle to cradle’ carbon footprints, total lifecycle assessment techniques. Although this field is still developing, it is essential that engineers have the skills to differentiate between marketing claims and actual results from the use of various materials and technology within buildings.
3. Impacts of climate change on the durability of buildings and building components, and methods to improve durability.

4. Methods for designing buildings for climatic loads when historical records are no longer predictive of future conditions or for situations where weather data is not available.

Transportation Infrastructure topics:

1. Impacts of extreme weather events on the drainage systems of roads, and available adaptations for existing drainage systems that may have become inadequate or will in future.
2. Available knowledge on asphalt design adaptations to improve durability due to variations in temperature caused by climate change.
3. Impacts of increasing, and more variability in temperatures on pavement performance.
4. Impacts of climate change on long-term fluctuations in water or moisture conditions affecting existing roads. This would include addressing the implications of seasonal load restrictions or winter weight premiums.
5. Methods for designing drainage structures, such as culverts and ditches, when historical moisture and precipitation data are no longer predictive of future conditions
6. Potential impacts of climate change-induced storm surge and river flooding on road embankments, and potential adaptations to limit or eliminate damage
7. Impacts of warming temperatures on pavement rutting, and adaptations to limit the effect.
8. Impacts of melting permafrost on new and existing roads, and related adaptations to address the problems
9. Emerging technology. For example, pervious/permeable/porous pavement technologies that can be incorporated into urban areas

Energy Infrastructure - Electricity Generation topics:

1. The expected local impact of climate change on long-term water supply, and variability of supply, as it relates to hydroelectric dams.
2. Approaches for the prediction of floods from extreme precipitation as it relates to hydroelectric dam safety.
3. The effect of climate change on demand patterns and the magnitude of peak energy demands.
4. The implications of a change in the energy supply mix if hydroelectric generation capacity is affected by changes in available water supply to dams and reservoirs.
5. The effects of increased air temperature and humidity on the output of gas turbine plants.
6. The effects of changes in wind strengths and patterns on the output of wind farms.
7. The risks to overall supply reliability and security due to changes in overall generating capacity as a result of Climate Change issues.

Energy Infrastructure - Transmission and Distribution topics:

1. The impact of climate change on localized climatic loads, particularly ice and wind, as it relates to transmission and distribution wires and structures.
2. Adaptations for transmission system components that are sensitive to higher temperatures.
3. Impacts of higher temperature on transmission and distribution systems.
4. Expectations for changes in system demands, particularly due to increasing summer heat, and its effect on transmission and distribution system design.
5. Measures to ensure more reliability and robustness in transmission and distribution systems to contend with extreme storms or disasters.

Topics related to Northern Infrastructure:

1. Dealing with the effect of melting permafrost on new and existing buildings and transportation structures.
2. Anticipated impacts that are unique to Northern communities and responses to them.
3. The implications of later freeze and earlier thaw in water transportation routes because of climate change.
4. Winter roads impacts and adaptations due to rising temperatures and a shorter useful season.
5. The effect on the lives of Northern populations, and the way they use infrastructure because of changes to historical snow and ice conditions.
6. Potential impacts on Northern roads from additional volumes of water from mountain streams and melting glaciers.

Important General Topics:
Practicing infrastructure engineers should have a solid understanding of the general topics listed here. They are drawn from the fields of general management, planning, probability and statistics, law and public policy. These topics, are considered to be important for all infrastructure engineering disciplines

1. Risk topics - as they relate to infrastructure engineering decisions in the context of Climate Change issues. This includes:
   a. Probabilistic and quantitative methods for the analysis of Climate Change issues and risks.
   b. Qualitative methods for the analysis of Climate Change risks and responses
   c. Political and public policy considerations in Climate Change risk management
   d. Areas related to risk and Climate change: safety, economics, serviceability, levels of service, social and cultural impacts.
   e. Methods to deal with the lack of clear-cut solutions to complex issues such as Climate Change. This would include developing cases whereby

engineers can gain experience in looking at problems and viewing solutions more as a range of possibilities as opposed to a finite solution.

f. Vulnerability assessments/vulnerability-based approaches and techniques

2. Planning processes
   a. The role of multi-discipline, multifunctional cooperation in infrastructure planning
   b. Frameworks for looking at climate change and other infrastructure issues.
   c. Integrating climate change responses into planning processes
   d. The principles of scenario-planning and analysis

3. Legal and Regulatory issues
   a. Understanding the legal and ethical responsibilities for infrastructure engineers (duty of care) as it applies to Climate Change issues.

4. Emergency preparedness and response
   a. Identifying critical infrastructure vulnerabilities due to Climate Change
   b. Contingency-planning principles and practices
   c. Addressing infrastructure failures and preventive measures

5. Integrated decision-making processes – this includes the economic, environmental and social dimensions to decision-making related to major capital infrastructure projects:
   a. Understanding the financial elements of infrastructure decision-making
   b. Tools and techniques for the consideration and integration of social and environmental costs as part of cost-benefit assessments of built infrastructure investments
   c. Principles of life-cycle costing, lifecycle assessment and life-cycle analysis. Consideration for the total lifecycle within capital asset planning and decision-making. This relates to the different phases of built infrastructure's lifecycle;
      - design/build phase
      - operations/maintenance phase
      - repair/rehabilitate phase
      - decommission/dismantle or divest phase
   d. Social implications and related considerations as part of Climate Change response planning for built infrastructure, and implications for the public and industry.
   e. Addressing systemic barriers (public and private sector) to the acceptance of innovative technology
   f. Value analysis – holistic techniques for integrating financial cost-benefits, as well as the social and environmental cost-benefits into decision-making
   g. The effect on public health as a result of climate change and the effects of engineering infrastructure decisions on public health issues
   h. The relationship between Climate Change issues and Sustainability issues

Discussion on Continuing Education aimed at practicing engineers

As is the case with most professions, there are many specialized sub-disciplines within the field of engineering. Engineers are very often specialists by necessity. The complexity required to design, maintain, plan, or construct various infrastructures often requires a significant amount of specialized knowledge. Therefore, the high priority topics for engineering practitioners are wide-ranging and often very specialized.

The topics the expert panel identified previously during their teleconference were primarily general topics rather than infrastructure specific topics. This is consistent with their view that the emphasis for educating engineers should be in giving them the tools and background to apply their existing technical knowledge in a new way. There was agreement amongst all stakeholders that there was a need for engineers to have in-depth knowledge of a range of general issues. Engineering decisions affect social, cultural, and economic activities, and non-technical considerations often affect technical decisions. While agreeing with the expert panel on the non-technical priorities, many of the expert practitioners who were interviewed also believe that practising engineers should be well-informed about advances in the technical state-of-the-art within their specialty area.

Many of the priority-technical topics identified for practitioners are related to extreme weather events. Infrastructure is often most at risk when extreme design values are exceeded. Since historical records may no longer be predictive of future behaviour, there is real concern among many within the engineering community that the more extreme weather conditions expected with climate change are not being sufficiently consider. Practising engineers are also concerned with the potential for infrastructure failures, and anything that could lead to sudden infrastructure failures is likely to be a high priority with them.

A common theme voiced by many expert practitioners was that climate change introduced a new problem into the practice of engineering because of the uncertainty in predicting future conditions. Usually, engineers can count on a combination of codes and standards, best practices, historical climatic records, or previous experience. Many engineers do not feel the engineering community is adequately prepared for decision-making in an atmosphere of increased uncertainty and more frequent change. Many of the high priority topics relate to better preparing engineers do address more uncertain future states in their day-to-day decision-making.

Many practitioners expressed frustration that it was often difficult to persuade decision-makers to accept engineering solutions that are innovative, or focussed on life-cycle cost rather than initial capital cost. They provided many examples where private sector owners or government leaders had chosen a conventional solution, with the lowest initial capital cost as a key deciding factor, rather than the engineer's recommended solution. To effectively support decision-makers, engineers need to have sufficient knowledge of how capital budgeting decisions are made, and how alternative tendering processes and methods of cost analysis may be more appropriate to deliver better solutions or more optimal solutions over the long-term.

5 BUILDING A FRAMEWORK FOR A NEW CURRICULUM THAT INCLUDES CLIMATE CHANGE

There were three tasks that had to be accomplished in order to conduct the gap analysis that would ultimately lead to the recommendations regarding changes to existing curricula:

a. Identify existing and relevant Climate Change research that is useful to infrastructure engineers;
b. Analyze the extent to which high priority Climate Change topics are already included within curricula;
c. Analyze the extent to which relevant and useful Climate Change research is actually utilized by practising infrastructure engineers within their day-to-day decision-making.

A discussion of the methodology and results for each of these three tasks follows below.

5.1 Identification of Climate Change research – Framing the body of knowledge

Introduction

As previously mention, one of the primary assumptions behind this project is that there is an existing body of relevant research, related to Climate Change, that would be useful to infrastructure engineers, but that has not yet become part of their day-to-day practice.

Although research related to Climate Change is expected to evolve much further, many of the experts who were interviewed believe that in many cases it is already sufficiently developed to be useful to practising engineers immediately. Therefore, a catalogue of known, existing research was constructed.

Methodology

A list of known researchers in the climate change field was developed. These researchers were approached and asked to, “Describe the peer-reviewed and/or body of knowledge that already exists, that addresses infrastructure/climate change issues and, that would be appropriate for professional engineers to use.” It was CSA’s view that in the course of their own work, many of the volunteer experts interviewed, had developed, or were aware of most of the existing useful research that was being sought out.

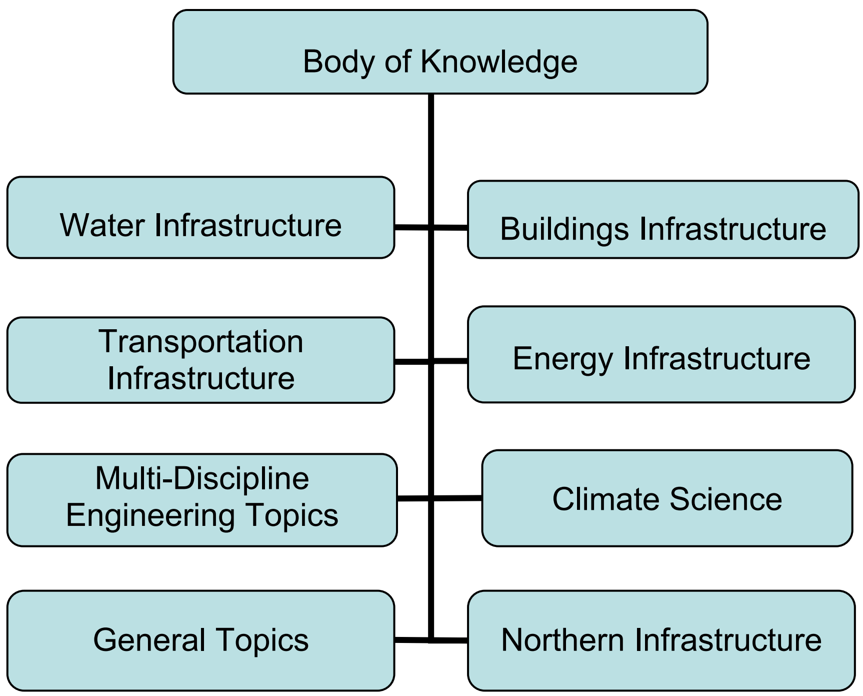
Some of the experts that were solicited for research references advised that references should not be restricted to only academic grade, peer-reviewed research. It was believed by many, that some of the 'grey' literature that exists (i.e. research that has not been peer-reviewed with the same rigour as academic research), is still valuable in many cases. It was pointed out that good quality Climate Change research is often conducted outside of Canada's core academic and university network.

Framework for the Climate Change Body of Knowledge for infrastructure engineers

The catalogue of references that forms the basis for the proposed body of existing, relevant Climate Change/infrastructure engineering body of knowledge is contained in Appendix C.

This body of knowledge is subdivided by major infrastructure category. Also, references that can be categorized as non-engineering or 'general' subject areas are clustered around a few specific topics. *Figure 4* shows the major subject area headings for the proposed body of knowledge.

Figure # 4 The proposed Climate Change Body of Knowledge for infrastructure engineers



Integration of subject areas and addressing cross-linkages between specialties
There are many cross-linkages between the different topic areas and classifications. Specialists sometimes think within a narrow range, and as well, engineers responsible for built infrastructure often work within departmental 'silos', unaware of potentially

useful information within other departmental silos. While this is sometimes necessary to constrain the scope of planning and design processes in the interest of ‘getting it done’, it can also have negative effects, particularly in terms of built infrastructure. Engineers should understand that a decision in one area, will typically also affect other areas.

Climate Change curriculum developers will have to consider how to integrate specialized, but related knowledge areas. This will entail touching upon the linkages and related topics that are peripheral to a specific specialty area.

This proposed body of knowledge serves as a starting point for a more in-depth search for suitable content, in preparation of specific courseware.

5.2 Assessing the existing education curricula

Assessing the existing undergraduate and continuing education curricula

Introduction

An undergraduate engineering education is a primary source of an engineer's knowledge. Therefore, the extent to which educators are presently presenting and teaching topics that relate to Climate Change within the undergraduate engineering curriculum serves as an important measure of the present-state baseline. Also, since most infrastructure engineers will engage in further professional development after graduation, a review of existing continuing education offerings for topics related to Climate Change adds another dimension toward establishing the present-state baseline.

Methodology

The online course calendars from a sample of eight universities from across Canada were examined to see whether there was evidence that universities were already addressing high priority climate change topics. The previously identified priority topics or themes for engineering students were used as the basis for a search of the course descriptions. It was recognized that course descriptions are not exhaustive, and it is still possible that some of the universities sampled, do address the high priority issues although they are not explicit within a published course description. Despite this limitation, it is believed that this assessment technique is a useful indicator – individual institutions can use the same technique to conduct a more in-depth and comprehensive self-assessment.

The following university course calendars were examined:

- Carleton University
- Concordia University
- Memorial University of Newfoundland
- University of Calgary
- University of Alberta
- University of Waterloo
- McGill University
- Dalhousie University

Three continuing education providers were chosen from among the providers that are recognized by the Engineering Institute of Canada, as providers of continuing education courses for engineers. These education providers were then contacted and asked whether they were currently offering any courses that relate to Climate Change or climate change as it relates to built infrastructure.

The following continuing education providers were contacted:
Centre for Transportation and Planning
EPIC Educational Programs Innovations Centre
HEC Ecole des Hautes Etudes Commerciales

Findings —Undergraduate curriculum

The findings are grouped by topic.

Climate Change Science, Impacts, Adaptations
Of the eight universities examined, two universities identified climate change in the course descriptions for the Engineering Faculty. One university offered four courses that included climate change material. That university offered a course on Energy and Environmental Systems in their General program that covered climate change mitigation solutions. They offered three other courses supplied by the Environmental and Geomatics departments that covered monitoring of climate change, the impacts of climate change, or mitigation of climate change.

For the other university, the civil engineering department offered a course in environmental engineering that covered climate change science and climate change impacts. While not specifically identified as climate change-related, some engineering faculties offer course content to specific disciplines on renewable energy sources that could be considered climate change-related.

All of the universities examined offered climate change material in some of their other faculties. The coverage in these other faculties ranged from a minimum of some coverage on the impacts of climate change in an Earth Sciences course, to nine courses covering climate change material in the Economics, Environmental Studies, Biology, Earth and Atmospheric Sciences, and Business faculties.

Five universities reported full courses in other faculties that were specifically about climate change. They came from the following faculties' departments: Science–Earth Science, Environmental Studies, Arts–Economics, Science-Atmospheric & Oceanic Sciences, Science-Oceanography, Science- Physics and Atmospheric Science, and Social Sciences-Geography.

Risk
All of the Engineering Faculties at the eight universities examined covered risk assessment or risk management to some degree. However, the level of detail, and the extensiveness of coverage, varied widely. Six of the universities offered courses specific to risk, three of which offered the courses in specific engineering disciplines only. In fact, most of the universities offered risk course material within the engineering disciplines that traditionally engage in decisions involving risk. There was no evidence that risks that are specifically associated with climate change is covered at any of the universities, although three of the universities referred to risk relating to the environment and sustainability.

Codes and Standards
Understanding how to utilize and interpret codes and standards is essential for many disciplines of engineering. Also, understanding both the benefits, as well as the limitations of codes and standards, is important when dealing with climate change issues. The coverage of codes and standards in engineering courses tends to be about specific codes that relate to the course content. Only one of the universities specifically mentioned how standards are developed and kept up to date. Individual instructors may be providing more in-depth coverage on the role of codes and standards. Equally important are discussions on how engineers should address issues that are not sufficiently covered in an existing code or standard – laying out the rational process that engineers must follow in order to test that their solution will be acceptable. It is also important to emphasize that written technical guidance, whether it is a handbook, best practice or standard, are intended to facilitate an engineer's professional judgement, rather than to supersede it.

Engineering Economics
All of the engineering faculties offer courses related to engineering economics. Five of the eight universities offered courses in economics for engineers to all disciplines. Three universities offered courses to individual disciplines only. Of the courses offered to all disciplines, none specifically identified climate change, lifecycle costing, or environmental considerations. However, two of the general courses mentioned either social decision-making or intangible benefits.

Six of the eight universities cover lifecycle assessment in courses directed towards specific disciplines. Two universities, one in the Mechanical Engineering department and one in the Environmental Engineering department, offer stand-alone lifecycle assessment courses.

Sustainability
Sustainability is related to climate change, and courses that deal with sustainability offer an opportunity to discuss climate change issues. All engineering faculties cover sustainability and sustainable design in some way. Only one university offers a specific course on sustainability that is available to all disciplines. However, four other universities offer specific courses in sustainability either through the Civil, Environmental, or Mechanical Engineering departments.

Findings - Continuing Education providers

None of the continuing education providers contacted currently offers instruction relating to climate change for practising engineers. Continuing education providers primarily respond to requests from either their stakeholders or their target market. Currently, some of the providers believe that there is insufficient demand from their market for them to invest in developing climate change-related coursework. However, one of the providers was developing material on sustainable development. This could provide some coverage of the non-technical high priority Climate Change topics such as risk management and economic analysis in the context of environmental considerations. Also, one of the providers offers coursework that relates to energy efficiency and some mitigation-related technologies.

The fact that none of the continuing education providers included within the sample currently offers climate change material suggests that there is not yet widespread commercial demand for knowledge of climate change issues and its impact on engineered infrastructure.

It should be recognized that instructor-led lectures or seminars, which is the predominant delivery method for these continuing education providers, is not the only source of education for practising engineers. Continuing education can take many other forms such as workshops, conferences, on-the-job training, and published articles.

Summary

Educational content within university undergraduate engineering programs, as well as within the courseware of continuing education providers was assessed to establish a present-state baseline for Climate Change education delivery. Most Canadian universities take different approaches to undergraduate engineering curriculum. All undergraduate programs are accredited by the Canadian Engineering Accreditation Board. Continuing education providers base their offerings on stakeholder needs and their perception of market demand.

An examination of the calendars from a sample of eight engineering programs in Canada indicated that there is very little direct delivery of climate change content. There were no courses in the engineering programs specific to climate change, and few indications of climate change content in other courses. However, all of the universities examined offered some climate change-related content in other faculties, primarily in the Science and Business faculties.

Coverage on other topics that would help prepare engineering students to deal with climate change issues was more evident. Risk assessment and engineering economics were covered at least to some degree by all of the universities. However, the level and diversity of coverage varied by university and by department. Since coverage varied, not all engineering students that are involved in infrastructure receive content that would be sufficient to prepare them for dealing with climate change issues. Since economics, risk, and sustainability were interspersed through most of the programs, there are obviously opportunities to add climate change content to existing courses.

Engineers Canada, the national organization of the provincial and territorial engineering associations that regulate the practice of engineering in Canada, established the Canadian Engineering Accreditation Board (CEAB) to accredit Canadian undergraduate engineering programs. The CEAB is responsible for ensuring the engineering schools provide graduates with programs that meet or exceed minimum standards required to achieve registration in Canada. As part of its mandate, the CEAB also provides advice and recommendations to universities on curriculum content to satisfy accreditation requirements. An endorsement from the CEAB would be an essential step toward implementing a national effort to include more climate change-related material in the university undergraduate engineering curriculum.

An examination of three continuing education providers indicates providers to practising engineers are not regularly providing climate change content in their course offerings to engineers. Engineers who are looking for additional immediate information to help them to address Climate Change within their practice will need to look to other forms of education such as conferences or papers.

5.3 Assessing awareness and use by engineers

Analysis of results from a national survey of practising infrastructure engineers

Introduction

CSA conducted an independent national survey to determine practising engineers' attitudes, awareness, and familiarity with climate change as it impacts infrastructure.

The purpose of the survey was to:

- Understand the present level of awareness of the relationship between climate change issues and engineering practices
- Determine how acceptance of climate change affects engineering decisions today and in the future
- Determine the level of awareness of climate change impacts and solutions
- Identify knowledge gaps and opportunities for improvements to engineering education
- Explore educational options and preferences amongst practising engineers.

Methodology

The survey was aimed at all practising Canadian engineers registered with a provincial/territorial professional engineering association. All of the participating associations have responsibility for licensure of professional engineers within their jurisdiction. The survey was administered electronically, and was accessible in English or French via a link to the survey's URL. A listing of the survey questions can be found in Appendix A.

Respondents were self-selecting. By accessing the survey website, and responding to a pre-qualifying question, respondents participated on a first-come, first-served basis with quotas. Quotas were established both by category of specialization, as well as by region. This electronic survey was administered on behalf of CSA by an independent, third party research company (RIS Christie).

Participating provincial/territorial engineering associations made their members aware of this survey either via an e-newsletter or via e-mail. A link to the online survey website was provided in every case. Survey responses were gathered between April and June 2007. Ten provincial/territorial associations sent notifications of the survey to their members.

Survey Description

In total, 2,060 practising engineers participated from across Canada. The province or territory that respondents chose as their primary location of practice broke down as follows:

Region	Total # of respondents
British Columbia	226
Alberta	259
Manitoba	220
Ontario	517
Quebec	582
New Brunswick	123
Nova Scotia	63
Newfoundland	39
North Western Territories	19
Prince Edward Island	5
Other (Sask., Yukon)	7
Total	**2,060**

In situations where 50 responses or less were received, the results are not reported separately.

The breakdown of responses by infrastructure areas is as follows:
- Water (294 respondents)
- Transportation (250)
- Energy (340)
- Buildings (310)
- Other (866)

National results (aggregate of all responses) are accurate to within 2%, 19 times out of 20. Infrastructure category results are accurate to within a maximum of 6% (and in most cases much less), 19 times out of 20.

Margin of Error

Margin of error is a function of the sample size and the amount of variability within the sample. For example, the margin of error for a sample size of 100 is greater than for a sample size of 1000. The margin of error for a sample size of 100 where 50% of respondents choose an option is greater than the margin of error for the same sample size where only 5% choose that option. For this survey, CSA analyzed the results for lower sample sizes by considering the margin of error on a case-by-case basis taking into account the sample size and the response readings.

Findings

The results from the survey can be found in Appendix B.

Knowledge and Awareness

For many respondents, there seems to be a significant gap between what engineers presently know and what they would need to know to deal with climate change issues more effectively. This has implications for undergraduate engineering curriculum, as well as the continuing education and ongoing professional development of practicing engineers.

1. More than 4 of 5 engineers accept that climate change will affect their practice.

   There was strong indication within all four infrastructure sectors that climate change will have an effect on their decisions. When asked whether a changing climate will affect their engineering decisions in the near future, 82% of engineers surveyed said they “somewhat agreed” or “strongly agreed”. Percentages were relatively consistent across all sectors, with the highest percentages in Water and Buildings (88% and 87% respectively).

   When addressing specific industry sectors, variability ranged from 72% to 86%, with the Government sector showing the highest level of agreement and the Resources sector the lowest. Government agencies for their part face public pressure to consider climate change in their decisions. As a result, they may tend to be more proactive in promoting the impacts of climate change to employees and the public. The Resource industry (mining, oil and gas, forestry), on the other hand, is less disposed to believe that climate change will affect the sector to a large degree which may reflect concerns about potential economic consequences.

2. More than 4 of 5 engineers agree that reducing greenhouse gas emissions would lessen the magnitude of climate change in the future.

Depending on the infrastructure sector, agreement ranged from 80% to 87%, with Buildings ranking the highest and Energy the lowest. However, these results should not be considered specific to the engineering industry, as they reflect the opinions of the general population in other opinion surveys. What it does indicate, however, is that engineers should be considered as allies in greenhouse gas emission reduction strategies.

3. Information for incorporating the impacts of climate change into engineering is lacking.

   Almost 3 out of 4 respondents claimed they needed more information on climate change to incorporate it into their work. Transportation engineers were the strongest proponents with 81% agreement, with Water engineers next at 79%. One item of note is that Water engineers had the highest “strongly agree” response at almost 50%. These numbers provide a strong indication that when it comes to climate change issues, there is a strong need for education and knowledge transfer.

4. There are knowledge gaps on the related impacts of climate change.

   While engineers surveyed had a good general awareness of the related impacts of climate change, less than 1 in 3 felt they were very familiar when it came to specific areas. When asked about their familiarity with 9 specific climate change impacts, more than half of the respondents said they were at least somewhat familiar. The strongest knowledge area was impacts relating to weather. Engineers were less familiar with issues surrounding water shortages and flooding, permafrost and sea level changes. Despite the familiarity on all topics, there is clearly a knowledge gap that needs to be incorporated into engineering practices.

5. There are even greater knowledge gaps on proposed solutions to climate change.

   With the exception of energy efficiency and emission reductions, less than 55% of engineers surveyed indicated they were somewhat/very familiar with proposed solutions to a changing climate. The knowledge of energy efficiency and emission reductions (77%) is not surprising since many solutions have been in place for a number of years in response to escalating energy costs. As cost-saving tools, energy-efficient technologies have held additional appeal for decision-makers. In other areas, particularly those that address planning processes and design, awareness dropped considerably. Familiarity varied between infrastructure areas:

   - Transportation engineers reported the lowest strong familiarity with proposed solutions
   - Energy and Water engineers were more familiar with risk-based or contingency solutions
   - Building and Energy engineers were more strongly familiar with energy efficiency solutions

Acceptance and Practice

While engineers are aware that climate change will affect decisions in the future, few actually consider the issue in their decisions today. Education can help to bridge this gap.

1. Only 1 in 10 engineers always consider climate change impacts in their engineering decisions today.

   Even though most engineers agree that climate change will affect their decisions in the future, less than 1 in 10 consider climate change impacts in their practice today. One in four say they never consider it, while almost half say they sometimes consider it. There may be several causes for this: lack of general knowledge, constraints placed on them by decision-makers, variability in terms of need, and/or the absence of regulatory requirements.

2. Engineers' unwillingness to include the impacts of climate change into their decisions today will have significant implications on our future infrastructure.

   Even though more than 80% of the engineers surveyed agreed that a changing climate will affect their engineering decisions in the near future, less than 30% always or mostly consider it in their decisions. Of those, less than 1 in 10 say they will always consider it, while almost half say sometimes. This gap will have significant implications over the long-term given that infrastructure has a long life expectancy, often spanning many decades. Engineers need to build climate change considerations into their decisions today. Codes, standards and regulations may need to be adapted in order to provide policy incentives for Climate Change to be considered.

3. Building engineers are most likely to consider impacts of climate change.

   Of the engineers that said they would always or mostly consider climate change impacts, building engineers stood out well above the national average (36% versus 27%). This is not unexpected, since energy efficiency in buildings has been in the spotlight for many years. Transportation and Water engineers ranked the lowest versus the national average.

4. Barriers will need to be overcome before climate change can be integrated into mainstream practice.

   When asked to elaborate on what is stopping them from considering climate change in their engineering decisions, engineers identified various barriers. Some of these, such as a lack of sufficient knowledge or applicable tools, or a belief that there was no problem to address, were identified through earlier questions. However other important barriers identified were:

- Codes, standards, and regulations don’t require considerate of climate change
- Decision-makers don’t support, don’t ask for, or don’t make mandatory, additional measures to address climate change

Information and Education

Educational and information resources specific to climate change impacts must be made available and introduced into university curriculum.

1. There is a compelling need for climate change resources for engineers.

   More than half of engineers say they will seek climate change information in the next 18 months. Almost two-thirds of Water and Building engineers are likely to seek information, which may reflect the current awareness of high-profile climate change issues, such as extreme weather conditions and greenhouse gas reductions. Considerably fewer Transportation and Energy engineers (just over half) say they will seek information.

2. Engineers prefer more "passive" educational materials**.**

   When asked their preferred method for receiving climate change information, the highest-scoring methods were online resources (30%) and published information (29%). E-learning ranked the lowest at 5%. Even though many do not feel fully prepared to deal with climate change issues, it appears they prefer the more passive forms of information delivery. This could reflect a concern for the costs and time involved in other options like classroom learning. This could also imply a lack of urgency in acquiring knowledge since Climate Change considerations are not required in most specifications, standards and regulations at the present time.

3. The present-state of baseline knowledge of existing techniques and solutions is low.

   When asked the value of 9 suggested subject areas relating to climate change, more than 80% of respondents considered most to be at least very valuable or somewhat valuable additions to an engineering curriculum. These results were similar across all infrastructure areas and geographic regions. This is a very strong validation of the importance of including the previously identified, priority topics in the university curriculum. The highest priority topic was assessing and managing risk, followed closely by developing codes and standards. The two topics that ranked below 80% were the Science of Climate Change (78%) and Psychology (65%).

Discussion of Findings

This survey indicates that while most engineers accept that climate change will affect their practice in the future, very few actually consider climate change impacts in their decision-making process today. Of the infrastructure areas, the building sector appears to lead in terms of addressing climate change challenges scoring significantly above the national average. A majority of those surveyed agree that additional topics need to be introduced to the engineering curriculum to ensure that graduates have the appropriate skills to address this issue in future. They also agree that they need much more information themselves if they are to incorporate Climate Change into their practice.

6 RECOMMENDED EDUCATIONAL DELIVERY METHODS

Introduction

The purpose of this phase of the work was to analyze and identify the preferred education delivery methods. Education delivery for engineering professionals (practitioners) and undergraduate engineering students were considered separately.

Methodology

Analysis and identification methodologies used were:

- An examination of current engineering programs delivered in post secondary institutions
- Interviews with university instructors
- National on-line survey of professional engineers
- A modality assessment utilizing CSA's assessment tool to determine the optimum delivery method

Examination of current engineering programs delivered in post secondary institutions

Each engineering faculty delivers course content in different ways. For example, some faculties start with a general engineering course, and students select a specific engineering discipline later in the curriculum. In other programs, students must select the discipline before entering the engineering program.

The structure of engineering faculties varies across the country. Universities are influenced by the geography and economics of the region in which they are located, and therefore have different priorities when it comes to the disciplines they provide degree programs for. For instance, only a few universities offer Petroleum engineering, Mining engineering, Ocean and Naval engineering, or Agricultural engineering. In fact, not all universities offer an Environmental engineering specialty.

The way faculties deliver course content also varies. At many universities, there is a movement away from traditional lecture-based to a more project-based learning environment.

Interviews with university instructors

University professors from across Canada were invited to participate. Interviews were conducted with five respondents.

Each was given the list of high priority topics that had been identified by an expert panel made up of engineering professionals, climate change scientists, and sustainability experts. After initial review, each professor was asked to comment on the relevance of the information, as well as delivery methods and possibilities for integration of the identified topics into the curriculum. They also offered input on the scope of the outcomes of the identified topics.

National on-line survey of professional engineers

CSA surveyed professional engineers across Canada to determine their knowledge, awareness, acceptance, and opinions on a number of climate change topics. The survey established the extent to which expert opinions related to high priority topics were shared by a broader cross-section of practicing engineers.

Two questions within the survey pertained directly to education priorities and preferred education delivery methods. These were:

I. How would you prefer to receive information on a changing climate as it pertains to engineering practice?

II. Listed below are different education topics related to a changing climate. Please indicate how valuable you think these topics would be to improve the university engineering curriculum.

There were other questions included in the survey that were also useful in identifying practitioner knowledge gaps and educational needs.

Refer to Appendix A and Appendix B for additional details on the national on-line survey.

Modality assessment utilizing CSA's in-house assessment tool

CSA uses an electronic assessment tool to analyze learning outcomes and learner preferences as part of the preliminary planning phase of education/training product development. The CSA tool took into account the two different audiences (undergraduates and practicing engineers) and their unique attributes and related it to the available education options. Here is an overview of the possible delivery options that were investigated:

Instructor-Led Classroom Delivery
Interactive instructor-led learning sessions may include discussions and case studies, lectures or a combination. Instructor-led training is effective and is suitable for both undergraduate and continuing education audiences. However, it is not as flexible as other newer training-delivery modes in terms of cost, rigidity of start and finish times, and accessibility for students.

Distance Learning
eLearning
This Internet-based self-study learning option offers the most flexibility for students and practitioners, since the training can be easily accessed anywhere that internet with sufficient band-width and speed is available. Individuals can choose to study a complete module or specific sub-topics within a module that are applicable to their interest. A major advantage to eLearning is that individuals can learn on their own schedule.

Correspondence
This self-study and flexible delivery method can be aimed at both students and practitioners. Individuals can choose to take a full learning program or the specific topic module that applies to their interest.

Webinar
A Webinar is a presentation, lecture, or seminar that is transmitted over the Web. As such, webinars represent an effective alternative to classroom delivery for specific topic areas. Webinars work best for material that can be delivered in a lecture format with minimal interactive requirements, and would be most appropriate when the audience has some working knowledge of the subject matter.

Papers and Articles
Papers and published articles in professional publications are popular methods for reaching large segments of a population with shared interests. Many professional and ‘learned ‘societies and other organizations also distribute white papers for public consumption and sharing among communities of interest. Papers and articles represent a very cost-effective method for disseminating information and new knowledge to the engineering community. One of the limitations is that papers tend to focus on a very specific sub-topic and element and as well, consistency of approach, format and quality of content is highly variable. Individual journals often enforce consistent formats and research standards for submissions. Content for presentations could be developed using material from a module or sub-topic within a module.

Conferences
Conference presentations tend to less interactive than other methods since they usually take the form of a lecture to large audiences. This may not be the case if the presentations are designed around breakout sessions that allow for interaction between the presenter and the audience.

Key Findings

Key findings from the research and modality assessment include:

1. Flexibility is a key component of delivery for both students and practitioners:

    - Since content must be updated frequently due to the dynamic nature of climate change and a continually changing knowledge base, education programs or delivery methods must be easy to modify
    - To implement climate change education effectively across all engineering disciplines, delivery methods must adapt to different curriculum structures and priorities
    - Flexibility is consistent with the philosophy of the Canadian Engineering Accreditation Board, and the preferences of practising engineers

2. A modular approach will facilitate flexible delivery and provide the most effective knowledge transfer:

    - For undergraduate programs, each climate change theme/topic would be a discrete learning module
    - For practising engineers, modules would be differentiated based on the specialized needs of each discipline, as well a by major infrastructure category
    - Depending on the size of the underlying knowledge base, a module may include any number of related subtopics
    - A modular approach allows for the customization of educational material based on the needs of the user

3. Each module and related subtopic should accommodate different delivery methods in a format that best meets the needs of each individual education provider. Many institutions will use a variety of approaches.

    Delivery methods were described in more detail earlier and they include:

    a) Instructor-led classroom lectures (both undergraduates and practitioners)
    b) Case study and project-based learning (both undergraduates and practitioners)
    c) Distance learning (both undergraduates and practitioners)
        I. eLearning
        II. Correspondence
        III. Webinars
    d) Labs or workshops (undergraduate students)
    e) Papers and articles (practitioners)
    f) Conferences or workshops (practitioners)

CSA's analysis identified the recommended delivery methods aimed at practising engineers would be instructor-led courses and eLearning. However, each module and related subtopic should also accommodate alternative delivery methods to best meet the needs of engineers. This finding is somewhat contradictory to the preferences expressed by practising engineers, and as identified in the national on-line survey. This will have implications for continuing education providers and for the viability of commercial courses in the absence of adequate incentives or other public policy drivers.

When asked, engineers expressed a preference for learning from "reference" materials, whether online or via published documents. This may reflect a concern for the cost and lost time associated with higher commitment options like instructor-led courses. However, instructor-led courses and eLearning would be more effective in achieving the knowledge transfer objectives.

Course materials should be developed by climate change/subject matter experts. Material content should be reviewed and updated as knowledge on climate change and infrastructure changes.

For student knowledge transfer, each university in Canada should address all six identified modules, and determine the level of coverage of each module based on the needs of the students and the priorities of the university:

- Program designers should provide options on how to incorporate the material into programs. This can include:
    - Stand-alone courses using an entire module, or a combination of modules, such as:
        - A full course could be offered on risk management that uses climate change issues to demonstrate the material
        - A full introduction to a climate change course for engineers that incorporates climate change science, general impacts, mitigation, and adaptation strategies
        - A project-based course looking at a particular municipal infrastructure category could be offered that would integrate climate change impacts and adaptations with the application of the principles of total lifecycle asset management, revenue planning, condition assessment, etc.
    - Creating "blocks" within existing courses using an entire module or module subtopic, such as:
        - A series of lectures and associated problems or projects on the principles of social and environmental costs could be included in an engineering economics course
        - A series of lectures on specific impacts and the latest adaptation strategies related to an infrastructure specialty could be added to an existing engineering design course

- o Picking and choosing different elements from a module (e.g. sample problems, projects or case studies) to augment existing courses, for example:
  - – A project could be offered as part of a sustainability course that prioritized energy efficiency methods for a particular infrastructure asset

4. For student knowledge transfer, specific implementation of the modules should recognize each university's different structure and organization:

   - A module implementation plan should be developed or reviewed by faculty leadership teams to ensure consistent coverage throughout the engineering faculty
   - Each institution should decide on the appropriate time and place to introduce the various topics and learning modules

5. It is necessary for students and practicing engineers to understand the role and importance of cross-functional teams in resolving Climate Change challenges. It is also necessary for them to have the knowledge and awareness to recognize the different vocabulary, viewpoints, objectives and backgrounds that members of such teams bring to the table. While this is difficult to teach in a formal curriculum, every effort should be made to create opportunities for students to interact with professionals from outside of the engineering field

6. For practising engineers, continuing education providers should provide a range of options in a format that would allow engineers to customize their own learning experience:

   - Engineers should have a suite of options so that they can receive instruction on the subtopics that are relevant to their practice or interest. Options include:
     - o Pre-packaged courses combining a series of related infrastructure subtopics and relevant non-technical topics
     - o Receiving instruction on only those individual subtopics they require – individual subtopics could be combined to create a customized module
     - o Access to examples and case studies that apply to their field of interest

   As previously mentioned, a key challenge for continuing education providers is that it is difficult to build compelling business-cases for Climate Change courseware. Investment risk is high. This may be due to the lack of significant incentives, and/or lack of other strong public policy drivers.

<u>Undergraduate Student Modules</u>

The six undergraduate modules are identified in Table 2. Included is a summary of the recommendations for priorities, preferred delivery methods, implementation timing, pre-requisites and rationale for undergraduate student knowledge transfer:

TABLE #2 - PROPOSED FRAMEWORK FOR UNIVERSITY UNDERGRADUATE CURRICULUM

2.1 Undergraduate Module: Climate change science

LEVEL OF IMPORTANCE*	AFFECTED DISCIPLINES	IMPLEMENTATION ALTERNATIVES	PRE-REQUISITE	DELIVERY METHOD	RATIONALE
High	Mandatory for all disciplines.	Suggested – That the module be included early in the program preferably in Year 1. It could be combined with a sustainability course or included as an introduction to the impacts of climate change module.	None	Instructor-led sessions. Alternatively e-Learning	The content of this module provides students with the fundamental science behind climate change which will be necessary to put any further climate change content into context.

2.2 Undergraduate Module: Climate change impacts and adaptations

LEVEL OF IMPORTANCE*	AFFECTED DISCIPLINES	IMPLEMENTATION ALTERNATIVES	PRE-REQUISITE	DELIVERY METHOD	RATIONALE
Very High	*Impacts & adaptations general* - Mandatory for all disciplines. *Impacts & adaptations specific* – Mandatory for specialties affected.	Suggested – That the general impacts and adaptations sub-topics be introduced in Year 1 with sustainability material. The specific impacts and adaptations should be introduced in Year 3 or Year 4 in existing courses dealing with infrastructure design. Optional – The impacts module and the adaptations module combined into a stand alone course.	Climate change science	Instructor-led sessions supported by examples and projects. Alternatively e-Learning	Engineers have a profound effect on the sustainability of infrastructure and will be expected to provide recommendations and solutions relating to climate change. Solutions may include mitigating carbon emissions as well as looking at some of the emerging tools for adapting infrastructure for the impacts of climate change.

Note: * Level of importance was determined through interviews with a cross-section of engineering educators

2.3 Undergraduate Module: Risk

LEVEL OF IMPORTANCE*	AFFECTED DISCIPLINES	IMPLEMENTATION ALTERNATIVES	PRE-REQUISITE	DELIVERY METHOD	RATIONALE
Very High	Mandatory for all disciplines.	Suggested – That the module subsections be combined into a stand alone course offered in Year 3 or 4 of the program. Optional – Augment existing design courses by using relevant module subsections.	Probability and statistics	Instructor-led sessions supported by case studies and examples	Climate change involves assessing and planning for uncertain future states. Engineers require the knowledge to deal with this. Risk topics apply to all disciplines.

2.4 Undergraduate Module: Decision-making processes: Economic, Environmental and Social cost-benefit analysis

LEVEL OF IMPORTANCE*	AFFECTED DISCIPLINES	IMPLEMENTATION ALTERNATIVES	PRE-REQUISITE	DELIVERY METHOD	RATIONALE
Very High	Mandatory for all disciplines.	Suggested – That the module be included as part of an engineering economics course in Year 3 or Year 4. Optional – Module could be included in a course on assessing and managing risk, or a course on sustainability	None	Instructor-led sessions supported by examples. Alternatively e-Learning	Decision-making processes include the study of how economic, environmental and social factors are inter-linked. It combines quantitative and qualitative evaluation tools and techniques to determine optimal solutions for capital asset decisions. Sub-topics in this area come from the fields of finance and accounting, environmental studies and social science.

Note: * Level of importance was determined through interviews with a cross-section of engineering educators

2.5 Undergraduate Module: Public policy and related regulatory frameworks: Role of codes and standards

LEVEL OF IMPORTANCE*	AFFECTED DISCIPLINES	IMPLEMENTATION ALTERNATIVES	PRE-REQUISITE	DELIVERY METHOD	RATIONALE
High	Mandatory for all specialties that use codes and standards. Recommended for all others.	Suggested – That the module be introduced when codes and standards are introduced, usually Year 3 or Year 4 during design courses. Optional – Module could be introduced with a sustainability course or with the adaptations for climate change module.	Assessing and managing risk. Impacts of climate change.	Instructor-led sessions supported by case studies, and examples. Alternatively e-Learning	Many codes and standards are reliant on climatic data. Where up-to-date or sufficiently detailed guidance is not available, engineers need the knowledge and skills to develop alternative solutions. Engineers need to recognize that codes and standards are not intended to be substitutes for professional judgement. An understanding of the role of codes and standards and processes for accepting innovation into mainstream practice is essential.

2.6 Undergraduate Module: Psychology - decisions, perceptions, and behaviour

LEVEL OF IMPORTANCE*	AFFECTED DISCIPLINES	IMPLEMENTATION ALTERNATIVES	PRE-REQUISITE	DELIVERY METHOD	RATIONALE
Low	Elective for all disciplines.	Suggested – That the module be included as a non-technical elective coordinated through another faculty. This elective should be offered in Year 1 and/or whenever non-technical electives are available.	None	Instructor-led sessions supported by case studies and group discussions. Alternatively lab or workshop Alternatively e-Learning	Engineers are key decision-makers and should be aware of how people evaluate evidence, how they determine risks, and how biases, past experiences, peer pressure, and need can affect their decisions and behaviour.

Note: * Level of importance was determined through interviews with a cross-section of engineering educators

Practicing Engineer Modules

The eight continuing education modules are identified in Table 3. Included is a summary of recommendations on subtopics, importance, prerequisites, and affected disciplines.

TABLE #3 - PROPOSED FRAMEWORK FOR CONTINUING EDUCATION

3.1 Continuing Education Module: Multi-discipline Engineering

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
The science behind climate change and the broad impacts of climate change on the physical environment.	High	Introductory	- None	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Concepts, options, and technology for climate change mitigation	High	Advanced	- Climate change science	Civil, Mechanical, Electrical, Chemical, Industrial, Mining, Petroleum, Aerospace, Other
The application of design codes and standards, and the adaptation of codes and standards, in the face of climate change impacts.	High	Advanced	- Climate change impacts - Assessing and managing risk	Civil, Mechanical, Electrical, Chemical, Mining, Geological, Petroleum, Other
Importance and sourcing of accurate environmental data	Moderate	Introductory	- Climate change impacts - Assessing and managing risk	Civil, Electrical, Chemical, Mining, Petroleum, Other
Land use planning for vulnerable areas and monitoring of vulnerable areas	Moderate	Intermediate	- Climate change impacts - Climate change adaptations - Assessing and managing risk	Civil, Electrical, Mining, Geological, Other
Using climate change models and climate change model experts to integrate modeling into design at the local project level.	Moderate	Advanced	- Climate change science - Climate change impacts - Assessing and managing risk - Capital budgeting incorporating climate change	Civil, Electrical, Chemical, Mining

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
Potential opportunities for adaptive infrastructure that can be modified as conditions change.	Moderate	Intermediate	- Climate change impacts - Assessing and managing risk - Adapting codes and standards - Capital budgeting incorporating climate change	Civil, Electrical, Chemical, Mining, Petroleum, Other
Asset management systems including infrastructure inventories and condition ratings	Moderate	Intermediate	- Capital budgeting incorporating climate change - Climate change impacts	Civil, Electrical, Mining

3.2 Continuing Education Module: Water Infrastructure

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
Impacts on storm water management due to precipitation from extreme weather events, and the potential adaptations that are available.	Highest	Intermediate	- Assessing and managing risk - Capital budgeting incorporating climate change - Adapting codes and standards - Climate change models	Civil, Chemical, Mining, Other
Impact of climate change on the availability and sources of potable water, and potential adaptations to ensure its availability.	High	Advanced	- Assessing and managing risk - Capital budgeting incorporating climate change - Adapting codes and standards - Climate change models	Civil, Chemical, Geological

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
Available adaptations for coastal infrastructure for dealing with climate change induced long term sea level rise and/or short term storm surge from extreme weather events.	Moderate	Intermediate	- Climate change impacts - Assessing and managing risk - Adapting codes and standards - Capital budgeting incorporating climate change	Civil, Geological, Petroleum, Other
Impacts on infrastructure from river flooding due to extreme weather events, and the implications for municipal planning.	Moderate	Intermediate	- Capital budgeting incorporating climate change - Assessing and managing risk - Climate change models	Civil, Electrical, Geological, Other
Impacts of climate change on waste water infrastructure, and the implications for human health.	Moderate	Intermediate	- Capital budgeting incorporating climate change - Assessing and managing risk - Climate change science	Civil, Chemical
Decision support recommendations on how to properly prioritize water asset adaptations in an environment of limited funding.	Moderate	Advanced	- Climate change impacts - Assessing and managing risk - Capital budgeting incorporating climate change	Civil, Electrical, Chemical, Mining, Other

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

3.3 Continuing Education Module: Buildings Infrastructure

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
Knowledge of energy efficiency options in building systems and/or building envelope technology, to mitigate carbon emissions through reduced usage of energy.	Highest	Advanced	- Climate change impacts - Climate change mitigation - Science of climate change - Capital budgeting incorporating climate change	Civil, Mechanical, Industrial
Tools and techniques for evaluating and comparing 'green', 'climate-friendly,' or 'sustainable' building technologies and materials.	High	Advanced	- Climate change science - Climate change mitigation	Civil, Chemical
Impacts of climate change on the durability of buildings and building components, and the potential adaptations that can be made to improve durability.	Moderate	Intermediate	- Climate change impacts - Assessing and managing risk - Capital budgeting incorporating climate change	Civil, Mechanical, Chemical, Metallurgical, Geological
Methods for designing buildings for climatic loads when historical records are no longer predictive of future conditions.	Moderate	Advanced	- Climate change impacts - Assessing and managing risk. - Climate change models - Adapting codes and standards - Capital budgeting incorporating climate change	Civil, Geological

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

3.4 Continuing Education Module: Transportation Infrastructure

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
Impacts of extreme weather events on the drainage systems of roads, and available adaptations for existing drainage systems that may now be inadequate.	Highest	Advanced	- Climate change impacts - Assessing and managing risk. - Climate change models - Adapting codes and standards - Capital budgeting incorporating climate change	Civil, Geological
Available knowledge on asphalt design adaptations to improve durability due to variations in temperature caused by climate change.	High	Advanced	- Climate change impacts - Capital budgeting incorporating climate change	Civil, Chemical, Metallurgical, Geological
Methods for designing drainage structures, like culverts and ditches, when historical water parameters are no longer predictive of future conditions.	High	Advanced	- Climate change impacts - Assessing and managing risk. - Climate change models - Adapting codes and standards - Capital budgeting incorporating climate change	Civil, Geological
Potential impacts of climate change induced storm surge and river flooding on road embankments, and potential adaptations to limit or eliminate damage.	High	Advanced	- Climate change impacts - Assessing and managing risk. - Adapting codes and standards - Capital budgeting incorporating climate change - Climate change models	Civil, Geological

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
Impacts of rising or more variable temperatures on pavement performance.	Moderate	Introductory	- Climate change impacts - Climate change science	Civil, Chemical, Metallurgical, Geological
Impacts of climate change on long term variation to water or moisture conditions affecting existing roads and possible implications on seasonal load restrictions or winter weight premiums	Moderate	Introductory	- Climate change impacts - Capital budgeting incorporating climate change	Civil, Geological
Impacts of warming temperatures on pavement rutting, and adaptations to limit the effect.	Moderate	Intermediate	- Climate change impacts - Adapting codes of standards	Civil, Chemical, Metallurgical, Geological
Impacts of melting permafrost on new and existing roads, and related adaptations to address the problems.	Moderate	Advanced	- Climate change impacts - Assessing and managing risk - Adapting codes and standards - Capital budgeting incorporating climate change	Civil, Geological
Pervious/permeable/porous pavement technologies that can be incorporated into urban areas	Moderate	Introductory	- Impacts of climate change - Climate change science	Civil, Chemical, Metallurgical, Geological

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

3.5 Continuing Education Module: Energy Infrastructure - Electricity Generation

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
The expected local impact of climate change on long term water supply, and variability of supply, as it relates to hydroelectric dams.	Highest	Intermediate	- Climate change impacts - Climate change models - Assessing and managing risk - Climate change science	Civil, Electrical
The effect of climate change on demand patterns and the magnitude of peak energy demands.	High	Intermediate	- Climate change science - Climate change impacts - Assessing and managing risk - Climate change models	Civil, Mechanical, Electrical
Approaches for the prediction of floods from extreme precipitation as it relates to hydroelectric dam safety.	Moderate	Advanced	- Climate change impacts - Assessing and managing risk. - Climate change models - Climate change science	Civil, Electrical
The implications of a change in the energy supply mix if hydroelectric capacity is reduced because of changes to dam water supply.	Moderate	Advanced	- Capital budgeting incorporating climate change - Climate change mitigation - Assessing and managing risk - Climate change models	Mechanical, Electrical, Industrial
The effects of increased air temperature and humidity on the output of gas turbine plants	Moderate	Advanced	- Climate change science - Climate change impacts - Assessing and managing risk	Mechanical, Electrical, Industrial
The effects of changes in wind strengths and patterns on the output of Wind Farms	Moderate	Introductory	- Climate change impacts - Climate change models - Assessing and managing risk	Civil, Electrical

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
The risks to overall supply reliability and security due to changes in power plant capabilities and outputs.	Moderate	Advanced	- Climate change impacts - Assessing and managing risk - Capital budgeting incorporating climate change - Climate change models	Civil, Mechanical, Electrical, Chemical, Industrial, Mining

3.6 Continuing Education Module: Energy Infrastructure - Transmission and Distribution

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
The impact of climate change on localized climatic loads, particularly ice and wind, as it relates to transmission and distribution wires and structures.	Highest	Intermediate	- Climate change impacts - Assessing and managing risk - Capital budgeting incorporating climate change - Climate change models	Civil, Electrical
Measures to ensure more reliability and robustness in transmission and distribution systems to contend with extreme storms or disasters	High	Advanced	- Climate change impacts - Climate change mitigation - Assessing and managing risk - Capital budgeting incorporating climate change - Adapting codes and standards	Civil, Electrical
Impacts of higher temperature on transmission and distribution systems	High	Introductory	- Climate change impacts	Civil, Electrical

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
Adaptations for transmission system components that is sensitive to higher temperatures.	Moderate	Intermediate	- Climate change impacts - Assessing and managing risk - Adapting codes and standards - Capital budgeting incorporating climate change	Electrical
Expectations for changes in system demands, particularly due to increasing summer heat, and its effect on transmission and distribution system design.	Moderate	Advanced	- Impacts of climate change - Assessing and managing risk - Climate change mitigation	Civil, Electrical

3.7 Continuing Education Module: Northern Infrastructure

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
Dealing with the effect of melting permafrost on new and existing buildings and transportation structures.	Highest	Advanced	- Climate change impacts - Assessing and managing risk - Adapting codes and standards - Climate change mitigation - Capital budgeting incorporating climate change - Climate change models	Civil, Mining, Geological
Anticipated impacts unique to Northern communities of climate change on various municipal infrastructure	High	Intermediate	- Climate change science - Climate change impacts - Assessing and managing risk - Capital budgeting incorporating climate change - Climate change models	Civil, Electrical

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING DISCIPLINES***
Winter roads impacts and adaptations because of rising temperatures and a shorter season.	High	Intermediate	- Climate change impacts - Assessing and managing risk - Adapting codes and standards - Capital budgeting incorporating climate change - Climate change models	Civil, Mining, Geological
The implications of later freeze and earlier thaw in water transportation routes because of climate change.	Moderate	Intermediate	- Climate change science - Climate change impacts - Assessing and managing risk - Capital budgeting incorporating climate change - Climate change models	Civil, Mining, Petroleum
The effect on the lives of Northern populations, and the way they use infrastructure, because of changes to traditional snow and ice conditions.	Moderate	Introductory	- Climate change impacts - Climate change adaptations	Civil, Petroleum
Potential impacts on Northern roads from additional volumes of water from mountain streams and melting glaciers.	Moderate	Introductory	- Climate change science - Assessing and managing risk - Climate change models	Civil, Geological

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

3.8a Continuing Education Module: General Topic– Risk

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING SPECIALTIES***
Probabilistic and quantitative methods for the analysis of Climate Change issues and risks.	Highest	Introductory	- None	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Qualitative methods for the analysis of Climate Change risks and responses	Highest	Introductory	- None	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Political and public policy considerations in Climate Change risk management	High	Intermediate	- Adapting codes and standards	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Areas related to risk and Climate change: safety, economics, serviceability, levels of service, social and cultural impacts	High	Introductory	- Climate change impacts	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Vulnerability assessments/ and vulnerability-based approaches and techniques	Moderate	Advanced	- Climate change impacts - Risk topics	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

3.8b Continuing Education Module: General Topic – Integrated decision-making processes

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING SPECIALTIES***
The financial elements of infrastructure decision-making	Highest	Introductory	- None	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Tools and techniques for the consideration of social and environmental costs	Highest	Introductory	- None	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Principles of life-cycle costing, lifecycle assessment and life-cycle analysis.	Highest	Intermediate	- Quantitative and qualitative risk analysis	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Social implications and related considerations, and implications for the public and industry	High	Introductory	- None	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Addressing systemic barriers (public and private sector) to the acceptance of innovative solutions	High	Advanced	- Financial elements of decision making - Life-cycle analysis - Social and environmental costing	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
The effect on public health as a result of climate change and the effects of engineering infrastructure decisions on public health issues	High	Advanced	- Climate change impacts - Climate change adaptations	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
The relationship between Climate Change issues and Sustainability issues	Moderate	Introductory	- Climate change science - Sustainability	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING SPECIALTIES***
Value analysis - techniques for integrating financial cost-benefits, as well as the social and environmental cost-benefits into decision-making	Moderate	Advanced	- Financial elements of decision making - Life-cycle analysis - Social and environmental costing	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other

3.8c Continuing Education Module: General Topic – Emergency preparedness and response

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING SPECIALTIES***
Critical infrastructure vulnerabilities due to climate change	Moderate	Advanced	- Impacts and adaptations for climate change - Assessing and managing risk	Civil, Mechanical, Electrical, Chemical, Industrial, Mining, Petroleum,
Addressing infrastructure failures and preventative measures	Moderate	Advanced	- Impacts of climate change - Assessing and managing risk	Civil, Mechanical, Electrical, Chemical, Industrial, Mining, Petroleum,
Contingency planning processes and practices	Moderate	Advanced	- Impacts and adaptations for climate change - Assessing and managing risk - Disaster management	Civil, Electrical, Chemical, Industrial, Mining, Petroleum, Other

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

3.8d Continuing Education Module: General Topic – Planning processes

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING SPECIALTIES***
The role of multi-discipline, multifunctional cooperation in infrastructure planning	High	Introductory	- None	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Frameworks for looking at climate change and other infrastructure issues	Moderate	Advanced	- None	Civil, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
Integrating climate change responses into planning processes	Moderate	Advanced	- Climate change impacts - Climate change adaptations - Risk topics	Civil, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other
The principles of scenario planning and analysis	Moderate	Advanced	- Risk topics - Climate change models	Civil, Electrical, Chemical, Mining, Geological, Petroleum, Other

3.8e Continuing Education Module: General Topic – Legal and regulatory issues

SUBTOPIC	LEVEL OF IMPORTANCE* (within module)	COMPLEXITY**	PREREQUISITE (climate change related subjects)	AFFECTED ENGINEERING SPECIALTIES***
Understanding the legal and ethical responsibilities for infrastructure engineers (duty of care) as it applies to Climate Change issues	Moderate	Introductory	- None	Civil, Mechanical, Electrical, Chemical, Industrial, Metallurgical, Mining, Geological, Petroleum, Aerospace, Other

Notes: * Importance relates to education priority and was determined by consensus of the expert panel and a cross-section of engineering practitioners
** Complexity refers to the requisite experience level of the practitioner concerned with the subtopic, or the complexity of the issue
*** Disciplines are based on the National Occupational Classification. Details can be found in Appendix D.

7 KEY FINDINGS AND NEXT STEPS

This project yielded a number of significant findings in terms of the resources needed to improve education and awareness of Climate Change issues and solutions. It is evident that:

- There is an already available body of knowledge on climate change responses for built infrastructure and it is expected that this knowledge-base will continue to evolve and improve over time. The framework proposed in this report will help to accelerate this existing knowledge into mainstream practice. In many specific areas of built infrastructure however, the research on climate change has not yet reached a point where it can be applied with confidence by the mainstream of practicing engineers. Further evidence that proposed solutions are practical, along with additional advances in the 'state-of-the-art', will be required in some areas.

- For many respondents, there seems to be a significant gap between what engineers know and what they would need to know to deal with Climate Change issues more effectively. This has implications for undergraduate curriculum, as well as professional development courses aimed at practicing engineers. While most infrastructure engineers already accept that Climate Change will affect their practice in the future, very few are currently factoring Climate Change into their infrastructure decisions now. This has significant implications for built infrastructure, recognizing that the useful design life often exceeds 50 years for many categories of built infrastructure.

- Climate Change should be considered as one of many stressors or factors that infrastructure engineers will need to consider in the future, and should not be considered in isolation. Here is a list of typical factors that affect infrastructure:
  - More uncertain, or more frequent extremes in climatic conditions
  - Service delivery – changes to level of service required, or loads and capacity
  - Inadequate maintenance
  - Public health and safety issues
  - Environmental issues
  - Changes in demographics and other population characteristics
  - Institutions and how they are organized
  - Security
  - Availability of funding - access to capital
  - Local social factors
  - Stability of local and regional political situations.

- Infrastructure engineers acknowledge that they need much more knowledge if they are to incorporate Climate Change into their practice. Practicing engineers do not feel the current university curriculum sufficiently prepares students to deal with Climate Change, and recommend additions to the curriculum to better prepare them. Additionally, they recognize they are also not sufficiently prepared and believe they should seek more knowledge.

- Climate Change represents a relatively new challenge for most engineering disciplines. Therefore, the emphasis on preparing engineers to deal with the effects of a changing climate should be concerned with giving them the tools and foundation to apply their engineering knowledge in a new way. Risk assessment and risk management are examples of important topics that will play a greater role in future engineering decision-making.

- Engineering faculties should be given the flexibility to customize the delivery of Climate Change content to university students in a way the best suits their department structures, course offerings, and priorities, as long as a minimum level of coverage is assured. This implies a modular approach that allows for the unique teaching, research and organizational philosophy of each institution to be preserved. Each institution would therefore determine and adapt their curriculum with the optimal combination of new courses, course components, projects and problems.

- While much of the education required needs to be developed and instilled at the university curriculum level, efforts must be made to also build awareness with practising engineers through alternative sources such as distance learning, workshops, papers and continuing education courses. Because of the broad range of engineering disciplines, and the high degree of specialty within disciplines, every effort must also be made to create a flexible modular approach that can be tailored to meet specific Climate Change educational needs.

- Removal of systemic barriers will also help to accelerate the integration of climate change considerations into mainstream engineering practice. For example, codes and standards have a profound influence on engineering decision-making. Codes and standards developers and stakeholders have further work to do, so as to ensure that Canada's complex network of codes and standards enable rather than inhibit climate change responses and solutions. Furthermore, there was evidence that at least some decision-makers don't yet support or require climate change issues to be considered as part of technical decision-making. This also has implications for how effectively engineers can address climate change issues in their day-to-day work.

While implementation of the education recommendations lies outside of the scope of this project, following are recommended action items that should be considered as next steps:

1. A formal consultation with the Canadian Engineering Accreditation Board and the provincial/territorial associations/orders regarding implementation of these recommendations for universities. This consultation will focus on the need for

Climate Change to be mentioned specifically in their accreditation criteria.

2. Further consultation with the Deans of engineering and science faculties to discuss how the findings could be implemented.

3. Discussions on how Engineering faculties can partner with Science or Business faculties and others to deliver Climate Change courses/materials.

4. Development of course and teaching materials for implementation with universities and continuing education providers. This project provides a basic framework for addressing engineering topics from a Climate Change perspective. More detail work is necessary, such as estimating the number of instruction hours per module, assessing how to balance this additional coursework with existing demands on students and instructors, as well as to determine where courses need to be sub-divided into smaller components.

5. Conduct pilot projects with selected education providers, using a limited number of modules to further test and evolve the proposed educational framework.

6. Consider a certificate/diploma program and/or incorporate the Climate Change topics into existing specialized certificates and diplomas in the various areas of infrastructure engineering. This would further facilitate a higher level of Climate Change knowledge amongst practicing infrastructure engineers.

8 APPENDICES

APPENDIX A - SURVEY QUESTIONS

Question 1
In which province or territory do you practice professional engineering most often?

- Alberta
- British Columbia
- Manitoba
- New Brunswick
- Newfoundland and Labrador
- Northwest Territories / Nunavut
- Nova Scotia
- Ontario
- Prince Edward Island
- Quebec
- Saskatchewan
- Yukon Territory
- I don't practice professional engineering

Question 2
In which industry or sector are you employed?

- Consulting
- Resources (mining, oil and gas, forestry)
- Manufacturing
- Government or public agency
- Utility
- Service
- Other

Question 3
In your day-to-day job, in which area do you most often make engineering decisions affecting, design, operations, maintenance, planning or tendering?

- Water infrastructure (including storm-water, shoreline protection, drinking water, wastewater)
- Transportation infrastructure (including roads, highways, associated drainage structures, seaports)
- Energy infrastructure (including transmission and distribution systems, pipelines, electricity generation)

- Buildings infrastructure (including structures, HVAC systems, building envelope, foundations)
- Other

Question 4

For each of the following statements, please indicate your level of agreement. If you are not sure, please select the response that is closest to your level of agreement;

Strongly agree
Somewhat agree
Somewhat disagree
Strongly disagree

- I believe that a changing climate will affect my engineering decisions in the near future.
- I believe that reducing greenhouse gas emissions would lessen the magnitude of future climate change.
- I need much more information to enable me to incorporate the impacts of a changing climate into my engineering practice.

Question 5

For all of the following impacts that have been suggested for a changing climate, please indicate your current level of familiarity;

Not at all Familiar
Not very Familiar
Somewhat Familiar
Very Familiar
Not Applicable to my Practice

- More frequent and intense storms
- Changes in seasonality and type of precipitation
- Increases or decreases in freeze/thaw cycles depending on region
- Melting permafrost in Northern climates
- More frequent and severe water shortages
- Changes to historical climatic loads such as wind, snow, and ice
- Increased coastal and river flooding
- Changes to peak energy demand magnitudes and seasonality (Resulting from additional hot days/heat waves and fewer extreme cold days)
- Sea level rise

Question 6

For all of the following tools and techniques that have been suggested for responding to the impacts of a changing climate, please indicate your current level of familiarity;

Not at all Familiar
Not very Familiar
Somewhat Familiar
Very Familiar
Not Applicable to my Practice

- Increase the magnitude of design parameters or safety factors
- Perform a formal risk assessment and risk management process
- Review existing practices and use entirely new solutions
- Encourage energy efficiency and low emission solutions
- Develop contingency plans for infrastructure failure
- Identify infrastructure that is at risk because of a changing climate, and retrofit priority assets
- Consider increased deterioration rates in design and maintenance plans
- Consider different climate change scenarios or models for design, maintenance or planning
- Identify locations that may be vulnerable to climate change impacts and avoid them altogether or modify designs accordingly
- Design infrastructure that can be modified over time as the impacts of a changing climate occur

Question 7

To what degree do you consider the impacts of a changing climate in your current engineering decisions?

Always consider
Mostly consider
Sometimes consider
Never consider

Question 8

How likely are you to seek specific information on a changing climate that pertains to engineering practice in the next 18 months?

Very likely
Somewhat likely
Somewhat unlikely
Not very likely

<u>Question 9</u>
How would you prefer to receive information on a changing climate as it pertains to engineering practice?

- Classroom continuing education (CEUs)
- Scholarly articles in engineering publications or journals
- Online resources
- E-learning (CEUs)
- Conferences and peer interaction
- Published guidelines, best practices, information pamphlets

<u>Question 10</u>
Listed below are different education topics related to a changing climate. Please indicate how valuable you think these topics would be to improve the university engineering curriculum;

Not at all Valuable
Not very Valuable
Somewhat Valuable
Very Valuable

- Assessing and managing risk when design parameters are uncertain
- The science of climate change
- Developing solutions when codes and standards are not definitive
- Impacts of climate change
- Working effectively, in a multi-discipline, cross-functional, team-based situation
- Psychology as it relates to human decisions, perceptions, and behaviour
- Financial elements behind capital asset decisions including life-cycle costing
- General adaptations for climate change
- New technical methods that address Climate Change

<u>Question 11</u>
If you are not considering the risk of a changing climate in your engineering decisions, please elaborate on what is stopping you.

APPENDIX B – Survey results

1) In which province or territory do you practice professional engineering most often?

PROVINCE	NUMBER OF RESPONDENTS	PERCENTAGE OF TOTAL
Quebec	582	28%
Ontario	517	25%
Alberta	259	13%
BC	226	11%
Manitoba	220	11%
New Brunswick	123	6%
Nova Scotia	63	3%
Newfoundland	39	2%
NWT	19	1%
PEI	5	0%
Saskatchewan	5	0%
Yukon	2	0%

2) In which industry or sector are you employed?

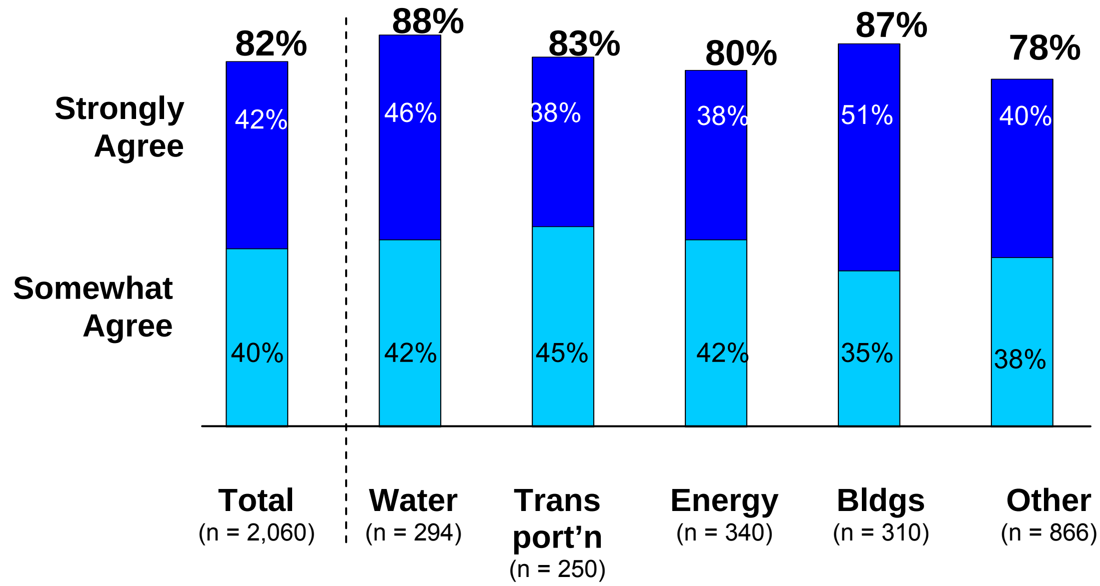
INDUSTRY OR SECTOR	NUMBER OF RESPONDENTS	PERCENTAGE OF TOTAL
Consulting	757	37%
Resources	116	6%
Manufacturing	358	17%
Government or public agency	330	16%
Utility	187	9%
Service	86	4%
Other	226	11%

3) In your day to day job, in which area do you most often make engineering decisions affecting, design, operations, maintenance, planning or tendering?

INFRASTRUCTURE CATEGORY	NUMBER OF RESPONDENTS	PERCENTAGE OF TOTAL
Water infrastructure	294	14%
Transportation infrastructure	250	12%
Energy infrastructure	340	17%
Buildings infrastructure	310	15%
Other	866	42%

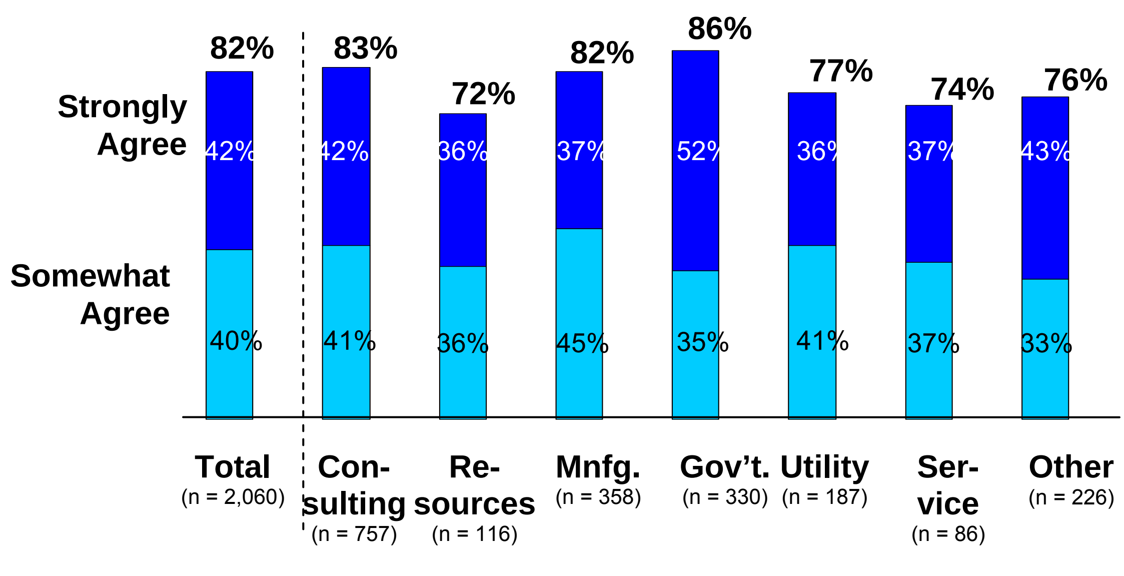
4a) I believe that a changing climate will affect my engineering decisions in the near future

By Infrastructure Category:



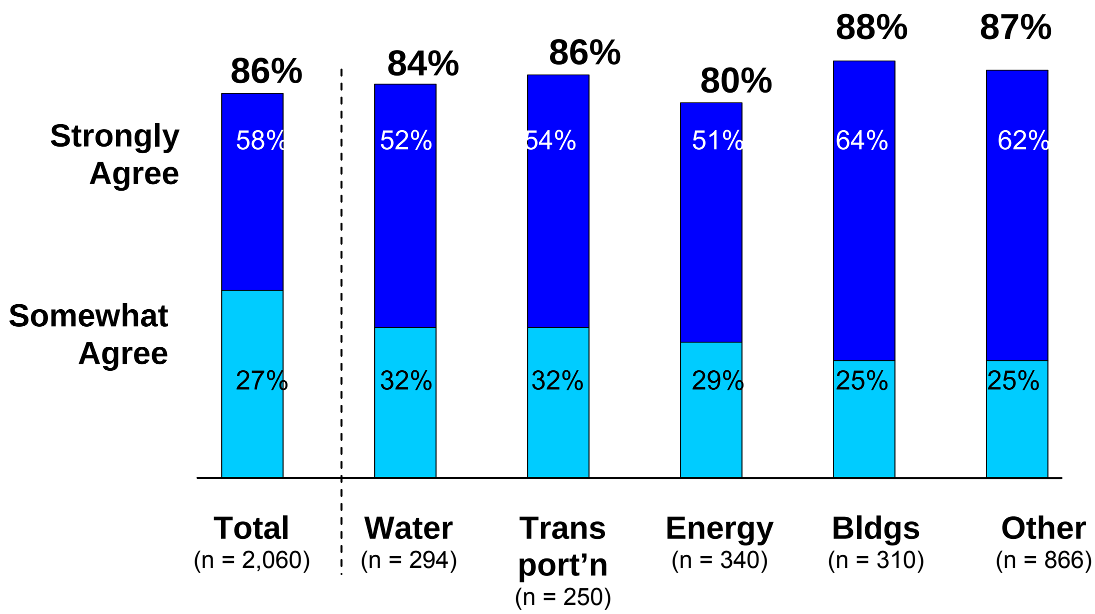
4a cont'd) I believe that a changing climate will affect my engineering decisions in the near future

By Target Sector:



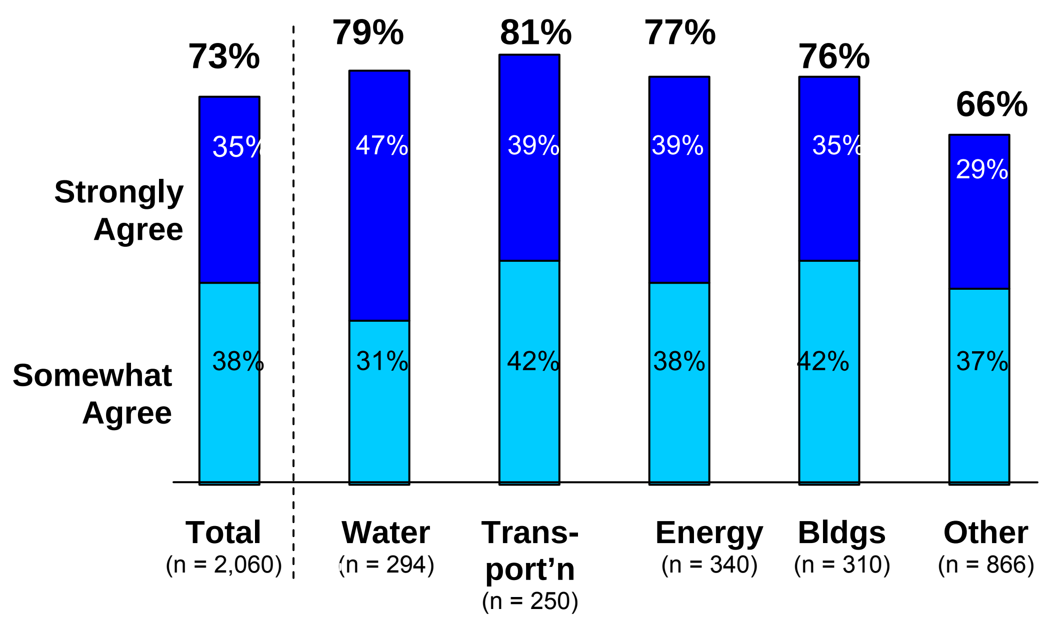
4b) I believe that reducing greenhouse gas emissions would lessen the magnitude of future climate change

By Infrastructure Category:

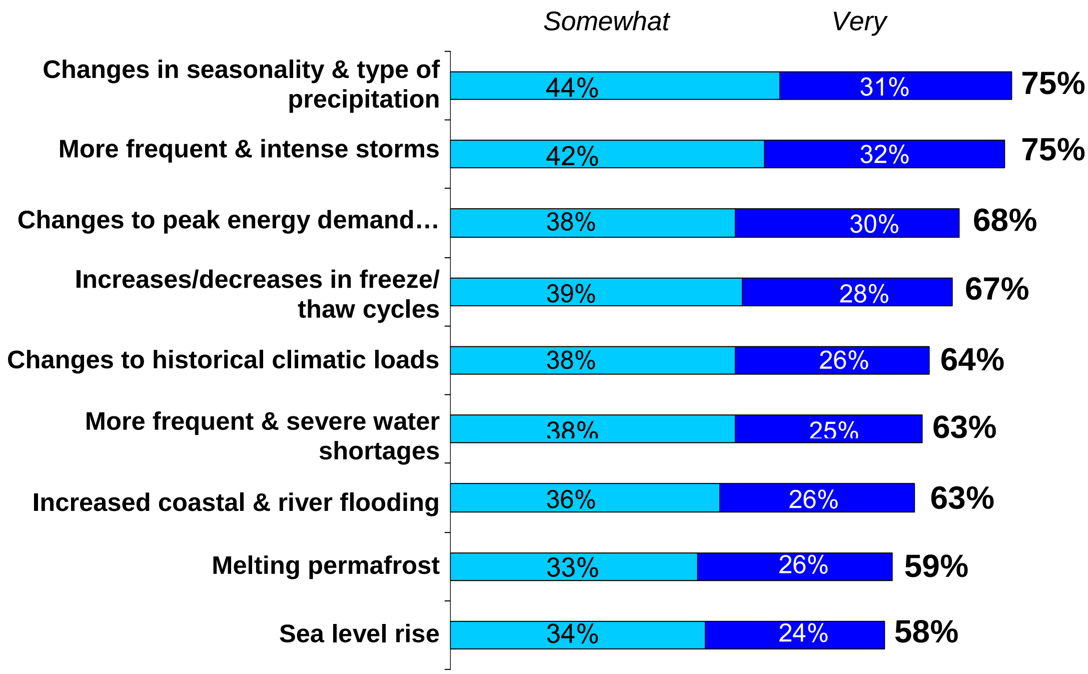


4c) I need much more information to enable me to incorporate the impacts of a changing climate into my engineering practice

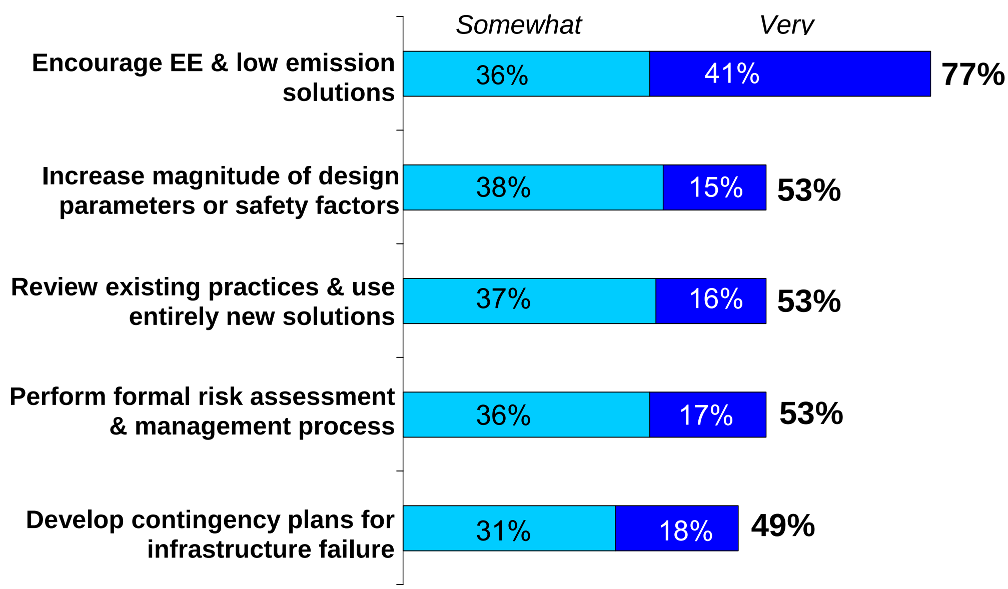
By Infrastructure Category:



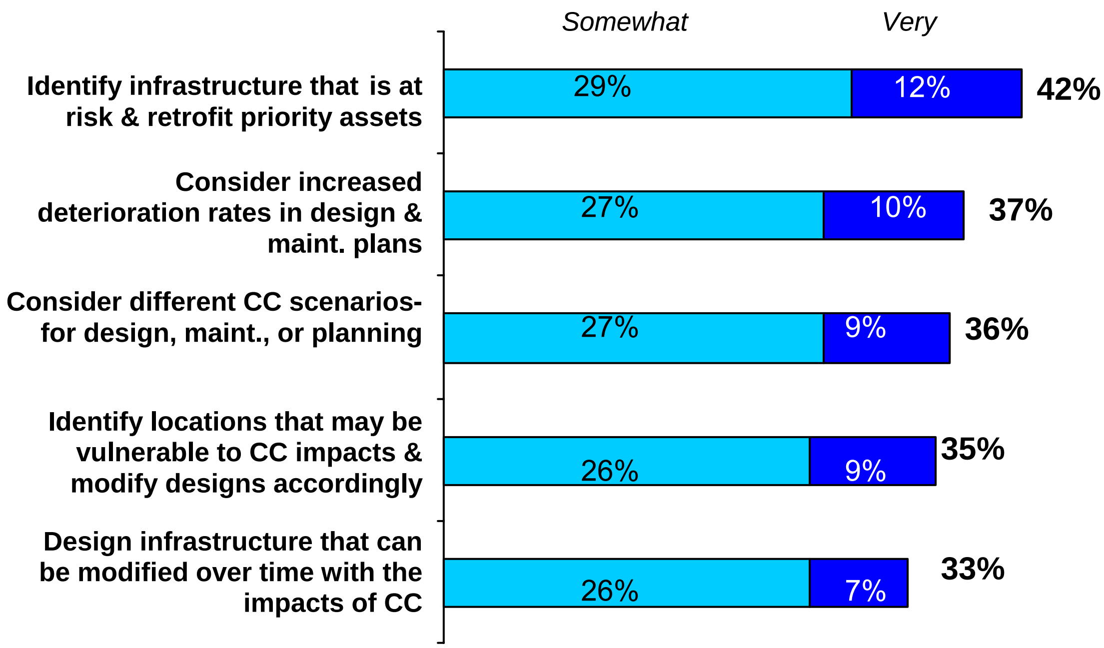
5) For all of the following impacts that have been suggested for a changing climate, please indicate your current level of familiarity



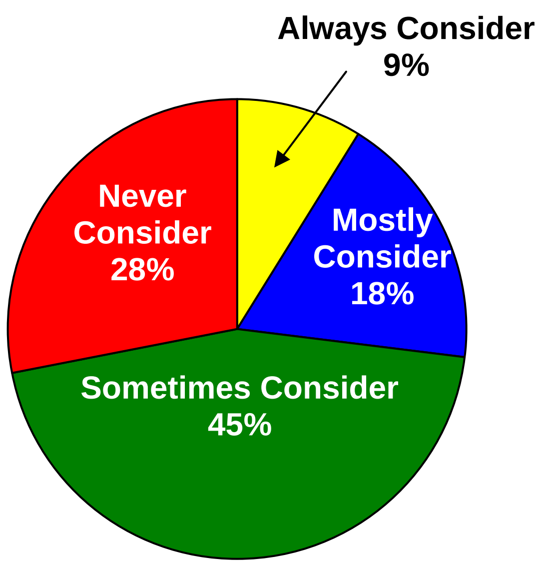
6) For all of the following tools and techniques that have been suggested for responding to the impacts of a changing climate, please indicate your current level of familiarity



6 cont'd) For all of the following tools and techniques that have been suggested for responding to the impacts of a changing climate, please indicate your current level of familiarity

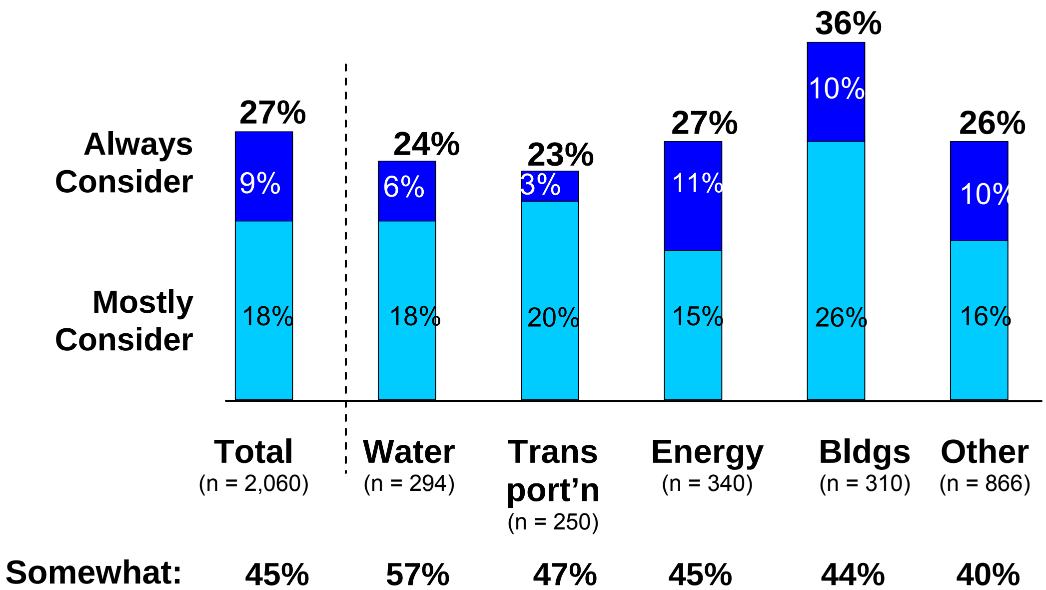


7) To what degree do you consider the impacts of a changing climate in your current engineering decisions?



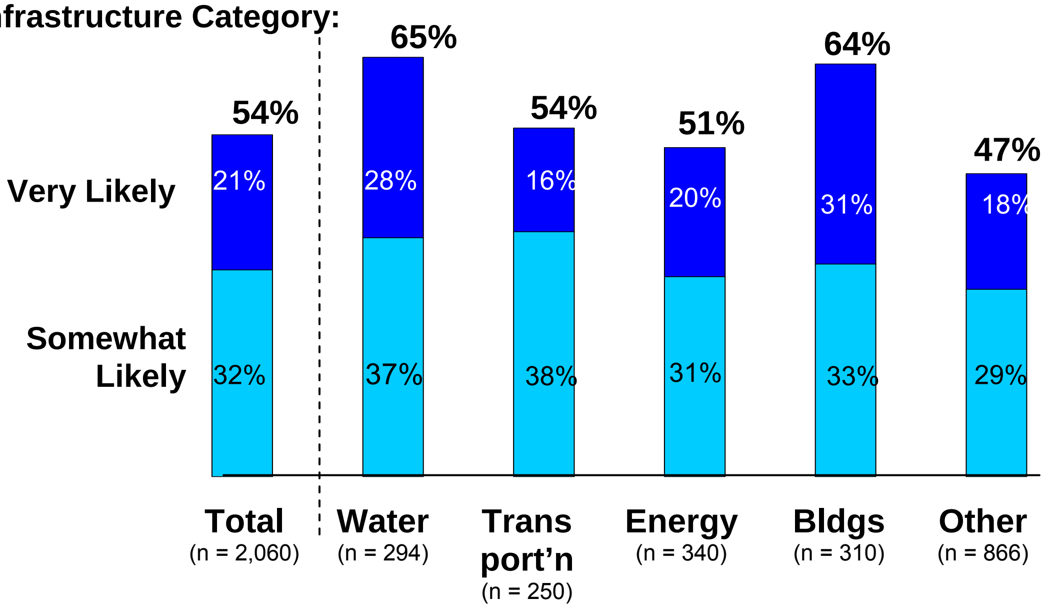
7 cont'd) Profile of "Always/Mostly" Consider Climate Change Impacts in Engineering

By Infrastructure Category:

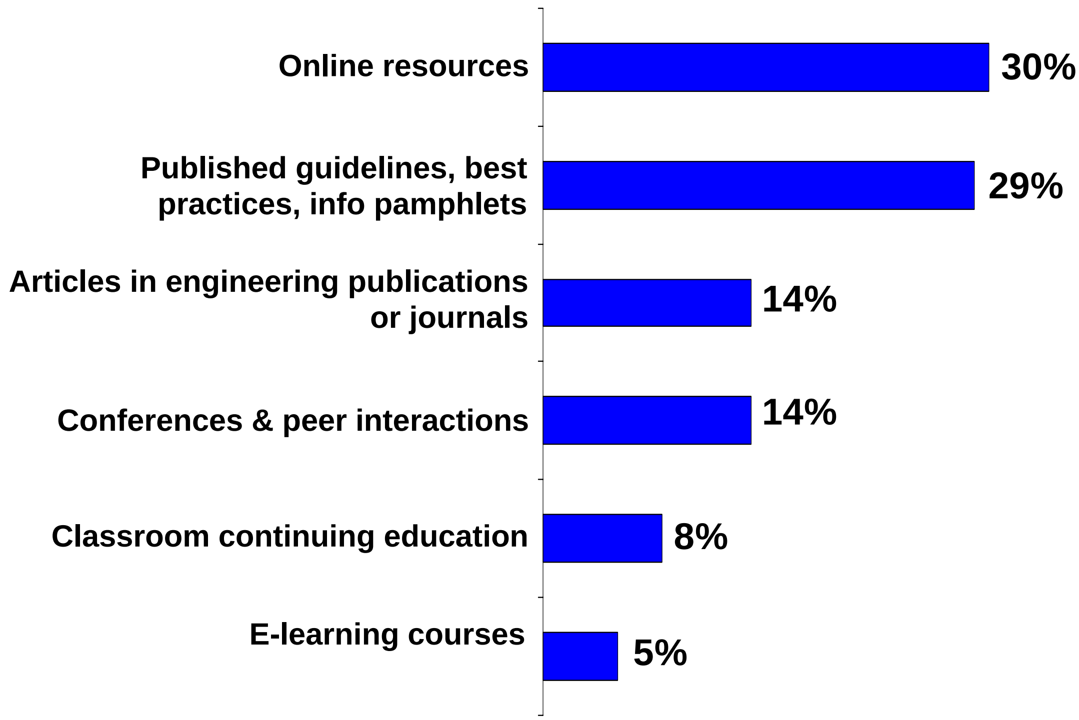


8) How likely are you to seek specific information on a changing climate that pertains to engineering practice in the next 18 months?

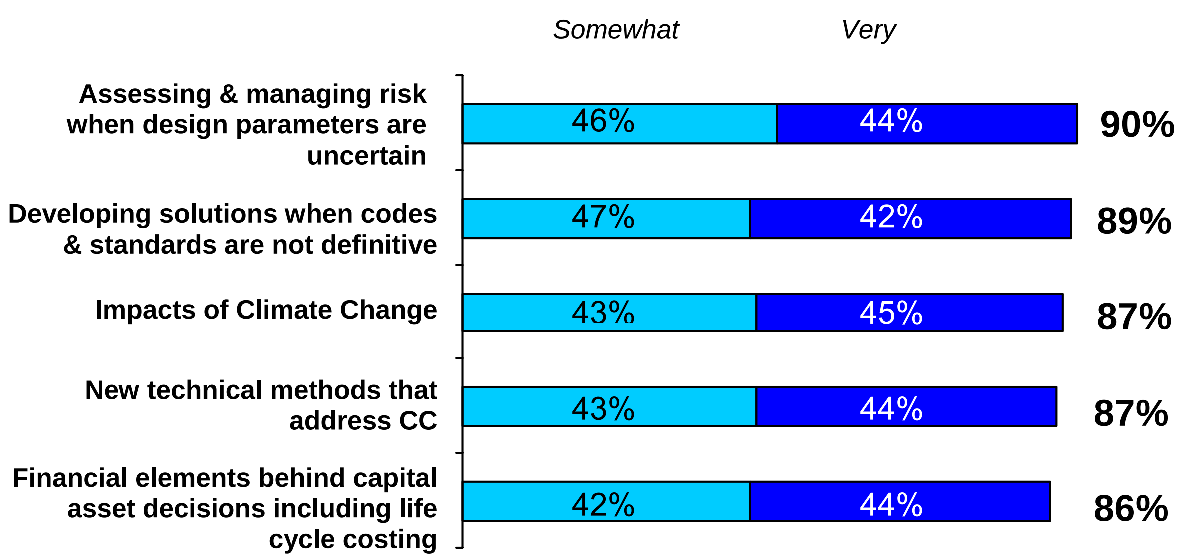
By Infrastructure Category:



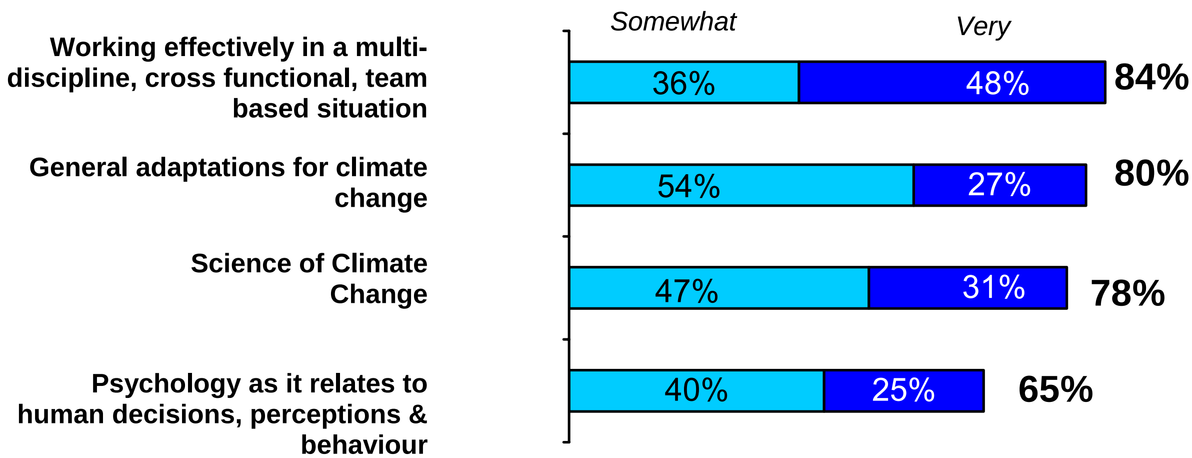
9) How would you prefer to receive information on a changing climate as it pertains to engineering practice?



10) Listed below are different education topics related to a changing climate. Please indicate how valuable you think these topics would be to improve the university engineering curriculum



10 cont'd) Listed below are different education topics related to a changing climate. Please indicate how valuable you think these topics would be to improve the university engineering curriculum



11) If you are not considering the risk of a changing climate in your engineering decisions, please elaborate on what is stopping you.

APPENDIX C Catalogue of References (Body of Knowledge)

The following list of works cited is organized into 10 different categories. A bullet point (•) next to a reference indicates that the reference is also applicable in another category, and also appears in duplicate in the list of another category.

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APPENDIX D – National Occupational Classification Details

Civil Engineers

airport engineer
appraisal engineer
Architectural engineer
asphalt engineer
bridge engineer
building envelope engineer
buildings and bridge engineer
Cartographic engineer
chief civil engineer
civil engineer
civil inspection engineer
coastal engineer
concrete engineer
construction engineer
construction project engineer
consulting civil engineer
county engineer
dams engineer
district engineer
drainage design engineer
engineer, solid waste management
engineer, surveying
environmental engineer
environmental engineer, civil
erecting engineer
foundation engineer
geodetic engineer
geomatics engineer
highway engineer
hydraulics engineer
hydrographic engineer
hydrological engineer
irrigation and drainage engineer
irrigation engineer
land drainage engineer
mapping engineer
materials and testing engineer, civil
military engineer - civil
military engineering officer - civil

Mechanical Engineers

acoustical engineer
acoustics and vibration engineer
acoustics engineer
automotive engineer
building systems engineer
chief mechanical engineer
consulting mechanical engineer
cryogenics engineer
design engineer - mechanical
design engineer, oil well equipment
diesel engineer - design and research
energy conservation engineer
engineer, mechanical design
engineer, nuclear operations
engineer, power generation
fluid mechanics engineer
gas utilization mechanical engineer
heating specialist engineer
heating, ventilation and air conditioning (HVAC) engineer
HVAC (heating, ventilation and air conditioning) engineer
internal combustion engineer
land ordnance engineer - military
lubrication engineer
marine mechanical engineer
mechanical design engineer
mechanical engineer
mechanical engineer, gas utilization
mechanical engineer, marine
mechanical engineer, projects
mechanical hydraulic engineer
mechanical maintenance engineer
mechanical power engineer
mould design engineer
nuclear design engineer
nuclear engineer
nuclear operations engineer
oil well equipment design engineer
pattern engineer
piping engineer

municipal engineer
navigation and positioning engineer
noise abatement engineer
ocean engineer
photogrammetric engineer
pipeline engineer, civil
pollution control engineer
precision survey engineer
project engineer, construction
public health engineer
public works engineer
rail transportation traffic engineer
reclamation engineer
remote sensing engineer
river and canal works engineer
sanitary engineer
sanitation engineer
sewage control engineer
soil engineer
solid waste management engineer
spatial information systems engineer
structural design engineer
structural engineer
structural engineer, civil
survey engineer
surveying engineer
traffic engineer
traffic engineer, rail transportation
traffic operations engineer
transportation engineer
tunnel engineer
urban road system engineer
water and sewer engineer
water management engineer
water resources engineer
water systems engineer
water treatment engineer
power generation engineer
power plant engineer
project mechanical engineer
refrigeration engineer
robotics engineer
thermal design engineer
thermal power engineer
tool engineer
Tribologist

Electrical Engineers

analogue amplifier design engineer
antenna engineer
audio engineer - electricity and electronics
avionics engineer
broadcasting professional engineer
chief electrical engineer
chief electronics engineer
chief engineer - electric power
chief engineer - radio and television broadcasting
circuit design engineer
communications and electronics engineer - military
control systems engineer
design and development engineer, electrical and electronic systems
design engineer, electrical
design engineer, electrical power systems
design engineer, radio and television broadcasting systems
digital circuit design engineer
displays and controls design engineer
distribution planning engineer, electrical
electrical and electronics research engineer
electrical design engineer
electrical distribution engineer
electrical energy transmission engineer
electrical energy transmission planning engineer
electrical engineer
electrical engineer, process control
electrical equipment engineer
electrical network engineer
electrical power scheduling engineer
electrical power systems design engineer
electrical research engineer
electrical systems planning engineer
electronics engineer
electronics research engineer
electronics test engineer
engineer, avionics
engineer, electrical distribution planning
engineer, electrical energy transmission

Chemical Engineers

adhesives engineer
biochemical and biotechnical engineer
biochemical engineer
biotechnical engineer
biotechnology engineer
chemical engineer
chemical engineer, design and development
chemical engineer, environmental
chemical engineer, production
chemical engineer, research
chemical process engineer
chief chemical engineer
chief process engineer
coatings engineer, chemical
electrochemical engineer
engineer, adhesives
engineer, biotechnology
engineer, chemical processes
engineer, coatings
engineer, industrial hygiene
engineer, pulp and paper
engineer, refinery
engineer, waste treatment
environmental chemical engineer
environmental engineer, chemical
explosives engineer
fuels engineer
industrial hygiene engineer
industrial waste treatment engineer
liquid fuels engineer
petrochemical engineer
petroleum refinery process engineer
pipeline transport engineer
plastics engineer
polymer engineer
process control engineer, chemical
process engineer, petroleum refinery
project engineer, chemical

engineer, electrical energy transmission planning
engineer, electronics
engineer, instrumentation
engineer, instrumentation and control
instrumentation and control engineer
instrumentation engineer
land electrical and mechanical engineering officer - military
line construction engineer
low voltage equipment engineer
meter engineer
metrology engineer
microelectronics engineer
overhead electrical distribution engineer
planning engineer, electrical energy transmission
planning engineer, electrical systems
process control engineer, electrical
process instrumentation engineer
professional engineer, broadcasting
protection engineer, electrical systems
protective relay engineer
radar engineer
radio and television broadcasting design engineer
radio and television broadcasting systems design engineer
radio research engineer
roadway lighting design engineer
rural electrification engineer
satellite instrumentation engineer
service engineer, electrical power systems
signal engineer
spacecraft electronics engineer
technical services electrical engineer
television systems engineer
test engineer, electronics
pulp and paper engineer
pulp and paper engineer, chemical
refinery engineer
underground electrical distribution engineer
waste treatment engineer

Metallurgical & Materials Engineers

ceramics engineer
coal preparation consulting engineer
corrosion engineer
electrometallurgical engineer
engineer, ceramics
engineer, materials
extractive engineer
extractive metallurgy engineer
foundry engineer
hydrometallurgical engineer
materials engineer
metallurgical engineer
physical metallurgical engineer
pyrometallurgical engineer
refining and metalworking engineer
smelter engineer, minerals
smelting plant engineer
welding engineer

Mining Engineers

consulting mining engineer
engineer, mineral
engineer, mining
exploration engineer, mines
mine design engineer
mine development engineer
mine layout engineer
mine planning engineer
mine production engineer
mine safety engineer
mine ventilation engineer
mineral dressing engineer
mineral engineer
mines exploration engineer
mining engineer

Geological Engineers

engineer, geological
engineer, geophysical
engineer, geotechnical
geological engineer
geophysical engineer
geotechnical engineer
hydrogeological engineer
hydrogeological engineer - engineering
hydrogeology engineer - engineering
supervising engineer - petrography
supervising engineer - rock sciences

Petroleum Engineers

chief engineer, drilling and recovery
chief petroleum engineer
drilling and recovery chief engineer
drilling and recovery petroleum engineer
drilling engineer, oil and gas
engineer, natural gas
engineer, oil and gas drilling
engineer, petroleum
engineer, petroleum production
engineer, petroleum well completion
exploitation engineer - oil and gas
exploitation engineer - petroleum
logging engineer, oil wells
mud engineer
mud engineer - petroleum drilling
natural gas engineer
offshore drilling engineer
offshore drilling rig subsea equipment engineer
oil and gas drilling engineer
oil and gas production engineer
oil well logging engineer
petroleum engineer
petroleum engineer, completion
petroleum engineer, drilling and recovery
petroleum engineer, production
petroleum production engineer
petroleum reservoir engineer
petroleum well completion engineer
production engineer, oil and gas
reservoir engineer, petroleum
subsea engineer
subsea equipment engineer, offshore drilling rig
well logging engineer

Aerospace Engineers

aerodynamics engineer
aeronautical engineer
aerospace engineer
aerospace engineer - design and development
aerospace engineer - flight operations
aerospace engineer - flight support
aerospace engineer - flight test
aerospace engineer - mass properties
aerospace engineer - material stress
aerospace engineer - materials and processes
aerospace engineer - military
aerospace engineer - propulsion systems
aerospace engineer - systems
aerospace engineer - systems analysis
aerospace engineer - weight and balance
aerospace engineer, structures
aerospace reliability specialist
aerospace structural engineer
aerospace systems engineer
aerospace test engineer
aircraft design engineer
design engineer, aircraft
projects engineer, aeronautical
propulsion engineer - aerospace vehicles
space reliability specialist
stress engineer - aerospace
structural engineer, aerospace
structures aerospace engineer
systems engineer, aerospace
test engineer, aerospace
weight analyst, aircraft design - engineer
weight and balance engineer - aerospace

Other Engineers

agricultural engineer
agronomy engineer
agro-processing engineer
architect, naval
bio-resource engineer
bioelectrical engineer
biomechanical engineer
biomedical engineer
biomedical engineer - research and development
clinical biomedical engineer
dairy plant engineer
engineer in agronomy
engineer, agro-processing
engineer, bioelectrical
engineer, biomechanical
engineer, biomedical
engineer, food processing
engineer, food technology
engineer, textile
engineering physicist
engineering scientist
food processing engineer
food technology engineer
marine engineer
marine systems engineer
naval architect
naval engineer
ship construction engineer
shipbuilding engineer
textile engineer