Sustainability in Professional Engineering and Geoscience:

A Primer

Part 3f: Practice Specific Module – Industrial Processes

Developed by the Sustainability Committee of the
Association of Professional Engineers and Geoscientists of British Columbia
APEGBC

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Professional Engineers and Geoscientists of BC

Sustainability in Professional Engineering and Geoscience: A Primer

Part 3f: Practice-Specific Module – Industrial Processes

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1 Introduction

APEGBC Sustainability Guidelines

Core to APEGBC's articulation of sustainability are the Sustainability Guidelines that state that, within the scope of a Member's task and work responsibility each Member, exercising professional judgment, should:

1) Develop and maintain a level of understanding of the goals of, and issues related to, sustainability.

2) Take into account the individual and cumulative social, environmental and economic implications.

3) Take into account the short- and long-term consequences.

4) Take into account the direct and indirect consequences.

5) Assess reasonable alternative concepts, designs and/or methodologies.

6) Seek appropriate expertise in areas where the Member's knowledge is inadequate.

7) Cooperate with colleagues, clients, employers, decision-makers and the public in the pursuit of sustainability.

The Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) has developed the Sustainability Primer as part of its implementation of a Sustainability Management System. The Primer's purpose is to raise knowledge of sustainability and to function as a simple, readily accessible resource on sustainability for engineers and geoscientists. It is intended to help engineers and geoscientists implement sustainability principles in their everyday activities.

Part I: Introduction of the Sustainability Primer outlines general issues that provide context for our sustainability activities as professional engineers and geoscientists.

Part 2: Applying the Guidelines develops some suggested approaches to applying APEGBC's Sustainability Guidelines (left) across the spectrum of engineering and geoscience activities.

This document, ***Part 3f: Practice-Specific Module Industrial Processes***, provides additional resources for engineers and geoscientists working on industrial processes.

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2 Review of the APEGBC Sustainability Guidelines

The APEGBC Sustainability Guidelines presented in *Sustainability in Professional Engineering and Geoscience: A Primer Part 2 Applying the Guidelines* provide guidance for systematically incorporating sustainability into engineering and geoscience practice. They are briefly reviewed below.

2.1 Increasing Awareness of Sustainability

Guideline # 1: Develop and maintain a level of understanding of the goals of, and issues related to, sustainability.

Guideline #1 encourages ongoing education about sustainability. APEGBC has identified awareness of sustainability as one of the primary barriers to its implementation, and has identified Members as the main target group for increasing awareness. Once Members have the information they need to begin implementing sustainable solutions, the focus will shift towards clients, employers and wider audiences.

The resources found in this Primer are intended as a starting points for further research and continuing education on sustainability.

2.2 Fully Investigating the Impacts of Potential Actions

"In every deliberation, we must consider the impact on the seventh generation."

From the Great Law of the Haudenosaunee (Six Nations Iroquois Confederation)

Guideline # 2: Take into account the individual and cumulative social, environmental and economic implications.
Guideline # 3: Take into account the short and long term consequences.
Guideline # 4: Take into account the direct and indirect consequences.

These three guidelines address the short and long term, direct and indirect impacts of our designs and activities. They encourage us to transcend traditional project boundaries and to consider the greater temporal and spatial impacts of our designs and projects. As we learn more about how humans and ecosystems interact we also learn how to ensure that we enhance the wellbeing of current and future generations and ecosystems.

Tony Hodge, P.Eng, describes Guidelines #2, #3 and #4:

> These ideas veer sharply away from thinking in terms of "trade-offs", human vs. ecosystem wellbeing. There are obviously hundreds of small trade-offs in any practical application: between interests, between components of the ecosystem, across time and across space. However, in a macro sense, the idea of sustainability calls for each of human and ecosystem wellbeing to be maintained or improved over the long term. Maintaining or improving one at the expense of the other is not acceptable from a sustainability perspective because either way, the foundation for life is undermined.[1]

2.3 Weighing the Impacts of Alternative Solutions

Guideline # 5:	*Assess reasonable alternative concepts, designs and/or methodologies.*

Conventional engineering solutions often rely on historical data and a linear approach to problem solving. Many problems are 'solved' by plugging in a standard formula 'proven' throughout the years, irrespective of the uniqueness of that problem's particular setting, its timeframe, or the people and the ecosystems involved. The process of evaluating various solutions, with the contribution of other professionals as well as affected communities, can save money, increase public acceptance, and build relationships between stakeholders.

Central to the assessment of alternatives lies the consideration of whether the design contributes to human *and* ecosystem wellbeing. Tony Hode, P.Eng, expands on this idea:

> The 'positive contribution to sustainability' criterion is different from- though built upon- the 'mitigation of adverse effects' criterion that is the focus of traditional environmental and social impact assessments. The implications of the shift are two-fold. On the one hand, the 'positive' orientation opens the door to a much fuller recognition of benefits that result from engineering and geoscience activities than has traditionally been the case with impact assessment approaches. On the other hand, the same positive orientation sets the bar higher- it is harder to demonstrate a contribution than it is to mitigate a negative.[2]

[1] Tony Hodge, PEng, PhD, "APEGBC Sustainability Policy", Draft 2, April 2003.
[2] Ibid.

2.4 Fostering Consultation and Partnerships

Guideline # 6:	*Seek appropriate expertise in areas where the Member's knowledge is inadequate.*
Guideline # 7:	*Cooperate with colleagues, clients, employers, decision-makers and the public in the pursuit of sustainability.*

Partnerships with fellow professionals on areas we are unfamiliar with is only half of our responsibility to consult with others. The other half is actively soliciting local community input on what is important to them. Experts can often help answer "what could be", but it's up to the public to answer, "what should be".

3 Industrial Processes: The Context

Some Early Milestones of Industrialization

1845 - Law of thermodynamics

1850's - The first petroleum refinery is built.

1855 - Tar, naphthalene, gasoline, and various solvents are distilled from petroleum.

1869 – Celluloid, the first synthetic plastic to receive wide commercial use, starts production.

1880 - The first large steel furnace is developed.

1892 - Internal combustion engine developed by Diesel.

1889 – Canadian Pacific Railway completed coast to coast.

1900 – Mechanical refrigeration becomes widespread.

1908 – Chlorination of household water starts in New Jersey.

1912 – First oil sands boom in Fort McMurray.

1920 – The first commercial petrochemical, isopropyl alcohol, is produced.

1945 – Discovery of penicillin.

For the purposes of this module, industrial processes are defined as large scale manufacturing processes that employ a high degree of mechanization to convert feedstock to product. The products of industrial processes are common in all our lives, either knowingly, though the purchase of goods, or unknowingly, through contamination.

The transition to an industrial society in Canada was well under way by the 1950s and the pace has only increased since then. Engineering and geoscience has had a huge impact on the pace and direction of industrialization in all parts of the world. It was geoscientists who first drilled for oil and engineers who developed the first petroleum refinery in Pittsburg in 1850. It was engineers and geoscientist that took research and development of novel materials, such as plastics, Teflon, alloys and fertilizers, and developed large scale manufacturing facilities capable of creating global markets. These early industrial processes started a trend towards urbanization that continues today. Subsistence workers in both the agricultural and service sectors have been drawn to urban centers stimulating the rate of change. Major breakthroughs in health care, improved standards of living, and increased mobility through the development of transportation and communication have been the upside of industrialization. However, with industrialization came a population explosion, growing civil strife, cultural assimilation, species extinction and worldwide pollution.

The Nobel prize has become an indicator of industrialization. According to Alfred Nobel's will, The Nobel prize is meant to be awarded to those who have "conferred the greatest benefit on mankind". It is ironic and somehow appropriate that it was awarded to Muller in 1948 for inventing DDT, and to Fleming, Chain and Florey in 1945 for the discovery of penicillin. Industrial processes resulted from both of these discoveries: one extremely harmful, the other universally beneficial.

Engineers and geoscientists are involved in most steps of industrial processes, including feedstock selection, process design, process control and product quality assurance. They have many opportunities to increase the sustainability of industrial processes.

4 Sustainability in Industrial Processes

Sustainability has been implemented in industrial processes for decades now, and this module does not attempt to be comprehensive. Rather it provides a starting point for engineers and geoscientists to apply the APEG Sustainability Guideline #1: Develop and maintain a level of understanding of the goals of, and issues related to, sustainability.

4.1 Industrial Energy

Two issues surrounding industrial energy are efficiency and pollution. Emission regulations are becoming more stringent, energy prices are generally rising, and access is becoming less secure. According to Environment Canada, industrial processes and manufacturing equipment use about 1/3 of all energy consumed in Canada. For example, Vancouver Island has been struggling for several years over controversial proposals to meet its expanding electricity needs. Pulp and paper mills use 25% of the currently available electricity on Vancouver Island[3]. By increasing their energy efficiency they could become a major part of the solution to the expected shortfall. On a national scale, the stationary generators of energy for industrial processes contribute about 20 percent of the total air pollution and over 25% of the greenhouse gas emissions.[4]

One popular method of increasing energy efficiency is cogeneration, where a single fuel is used for both electricity generation and either heating or cooling. Savings from cogeneration are estimated to be 30-40 percent over generating heat and electricity separately. The savings arise from utilizing the spent heat from the electricity generating step. David T. Allen, in the book *Green Engineering*, describes the theoretical potential for cogeneration in the United States:

> Approximately a third of the 80-100 quadrillion BTU of energy consumed annually in the United States is used for electric power generation. Of the energy used in electricity generation, roughly 2/3 is lost as waste heat. This means that roughly a quarter of all energy demand in the united States could be met through the utilization of lost heat.[5]

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[3] Delores Broten of Reach for Unbleached, speaking at the Crofton Airshed Citizens Group Meeting January 20, 2004.
[4]Obtained from www.ec.gc.ca/energ/industry/comb_src_e.htm July 2004.
[5] D.T.Allen, "Industrial Ecology" D.T.Allen, D.R. Shonnard, *Green Engineering*, Prentice Hall pg 461-474, 2002.

Some industrial processes combine natural gas turbines with wood waste fueled steam generators. The waste heat from the natural gas turbine is captured in a recovery boiler generating steam to supplement steam generated from a wood waste boiler. In this way some facilities such as the Weyerhaeuser mill in Grande Prairie have become net energy providers to the grid[6].

Another way to harvest otherwise wasted energy is through landfill gas capture. The microbial action in landfills creates methane and other combustible gases. When released into the atmosphere the gasses contribute to climate change and disperse a valuable resource. In British Columbia there are projects in the Lower Mainland and on Vancouver Island generating electricity from landfill gas.

Many other ways of increasing energy efficiency and tapping into free or renewable energy exist. The Federal Government, through Natural Resources Canada, has a number of programs to assist and reward energy efficiency in industrial processes. They include direct funding for switching to renewable energy, workshops on how to achieve energy savings, and a national recognition program for companies that excel at energy efficiency. BC Hydro Powersmart also has a comprehensive program to help industrial facilities achieve energy savings. Visit the *Resources* section for links.

Case Study – ESCO Limited

Courtesy of BC Hydro

Like most industrial manufacturing companies, ESCO Limited, a manufacturer of engineered steel products for the global construction and mining markets, is always looking for opportunities to reduce its energy consumption and operating costs. ESCO went further than most manufacturing companies, however, in pursuing its energy efficiency goals.

After becoming a Power Smart Partner, ESCO performed a high-level energy audit at its Port Coquitlam foundry to identify efficiency opportunities. Then, with help from Power Smart, ESCO carried out a series of energy efficiency improvements to the foundry's fan systems and compressed air and related equipment, which are yielding significant energy and dollar savings.

For ESCO, energy savings are not an end in themselves, but are part of a broader corporate pledge to energy efficiency and sustainability. The company carries out that pledge through a wide range of actions

[6] T. Kryzanowski, "Alberta Co-Gen all fired up", *Logging & Sawmill Journal* page 38-41, October 2003.

that include registering as an Industrial Energy Innovator with Natural Resources Canada and committing to an environmental health policy, with a full-time Safety and Environment Manager to manage it.

ESCO found another innovative way to improve its environmental performance – by purchasing Green Power Certificates. These certificates ensure that ESCO's electricity supply is environmentally friendly and help the company meet its objective of lowering greenhouse gas emissions.

"Demonstrating leadership in energy and environmental sustainability helps us maintain a positive community presence," says Maintenance Manager, Dave Clark.

Energy Efficiency Measures Implemented by ESCO:

- upgrade of the arc furnace fan system;
- re-commissioning of the 150-horsepower air compressor;
- optimization of dust collection and compressed air systems; and
- retrofit of the dust collector baghouse.

Total electricity savings:

- 1.85 gigawatt hours; and
- approximately $93 000 annually.

Additional benefits:

- improved operational efficiency;
- better air quality; and
- improved community relations.

To learn more about the BC Hydro Power Smart Program, see the *Resources* section.

4.2 Industrial Ecology

Industrial ecology is the design of industrial process to reduce material flows through networking between processes. The re-use of waste or byproducts is a defining principle of industrial ecology. Just as in the natural ecosystem, where one creature's waste is another's food, in industrial ecology one process's waste is another's feedstock. Industrial ecology takes a systems view of design and manufacturing. Industrial ecology makes it possible for the industrial system to imitate a natural system, with all waste and byproducts utilized within the system, resulting in reduced requirement for virgin material.

Simplified examples of industrial ecology include the recycling of aluminum and co-generation. Recycling of aluminum is one of the best examples of retaining and re-using resource flows, since only 5% of the energy required to produce aluminum from its raw state is required to recycle it. Recycled aluminum also retains its quality. Co-generation, discussed in the *Industrial Energy* section, represents the productive use of an industrial by-product. The by-product is waste heat from electricity generation, and the productive use is heating. These examples demonstrate how industrial ecology can be applied at a global level, such as aluminum flow, and a micro level, such as cogeneration within an industrial processing facility.

One engineering application of industrial ecology is the design and implementation of eco-industrial parks. Eco-industrial parks apply industrial ecology concepts to a cluster of industrial processes thereby integrating energy and material flows. This concept is best described by an example. Many examples exist, since eco-industrial parks are not new. There has been considerable work done in Canada to promote the development of eco-industrial parks, both by government and industry. The case study below, Kalundborg Eco-Industrial Park, was chosen because it is widely regarded as a classic example. Also, since it is over 30 years old, it demonstrates that eco-industrial networking can be a long-term, profitable way of doing business.

Case Study – Kalundborg Eco-Industrial Park

The Kalundborg Eco-Industrial Park in Denmark is the oldest and possibly most comprehensive example of eco-industrial networking. The network includes six processing companies, one waste handling company and the municipality of Kalundborg. The savings resulting from the network are worth $12-15 million dollars a year[7].

The eco-industrial network is built around six major processing companies, the municipality of Kalundborg, and a waste company. Other, smaller tenants also participate. The six major networked processing companies are:

1. a coal burning power plant;
2. a pharmaceutical manufacturer
3. an oil refinery;
4. an enzyme producer;
5. a gypsum board manufacturer; and
6. a soil remediation company.

[7] C. Fussler, P. James, *Driving Eco Innovation* Pitman Publishing, London 1996.

The coal burning power plant, Denmark's largest, uses cogeneration to produce both heat and power, resulting in a 30% efficiency gain compared to separate production of heat and power. The power is provided to the municipality of Kalundborg. The heat is used to provide process steam for the oil refinery and pharmaceutical manufacturer, and heating for the municipality of Kalundborg. A portion of the power plant's cooling water is diverted to a fish farm, where elevated water temperatures increase productivity.

The power plant makes money by complying with pollution control regulations. Like power plants in Canada, it is required to remove sulphur dioxide from its flue gas. The desulphurization produces gypsum as a byproduct, which is then sold to the gypsum board manufacturer. Fly ash is recovered from the power plant's smoke stacks and sold to the cement industry. Nickel and vanadium recovered from the fly ash also find a market.

The oil refinery is the other anchor in the eco-industrial network, providing gas, cooling and waste water to the power plant. One of the oil refinery byproducts, ammoniumthiosulphate from desulphurization of refinery gas, is sold as fertilizer. The refinery's liquid sulphur waste is sold to a sulphuric acid producer.

A fertilizer and livestock feed industry has grown out of the industrial network. The enzyme producer generates solid and liquid biomass as a byproduct which is used as a fertilizer after inactivation and hygienisation. The pharmaceuticals manufacturer has found a market for its byproduct as livestock feed.

Other networks include the use of sludge from the Kalundborg municipal wastewater treatment plant by the soil remediation company, and the collection of waste from all the networked processes for the generation of landfill gas electricity.

In addition to spin off economic benefits of commercializing byproduct streams, the networked companies at Kalundborg have achieved the following savings: 25% reduction in water consumption and 20,000 tonnes reduction in oil use[8].

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[8] Obtained from http://www.symbiosis.dk/ August 2004.

Kalundborg Eco-Industrial Park Schematic Legend

Energy E2 Asnaes Power Station	*Coal Burning Power Plant*
Novo Nordisk A/S	*Pharmaceuticals Manufacturer*
Statoil A/S	*Oil Refinery*
Novozyme A/S	*Enzyme Plant*
Novoren I/S	*Waste Handling*
BPB Gyproc A/S	*Gypsum Board Manufacturer*
Bioteknisk Jordrens Soilrem A/S	*Soil Remediation Company*

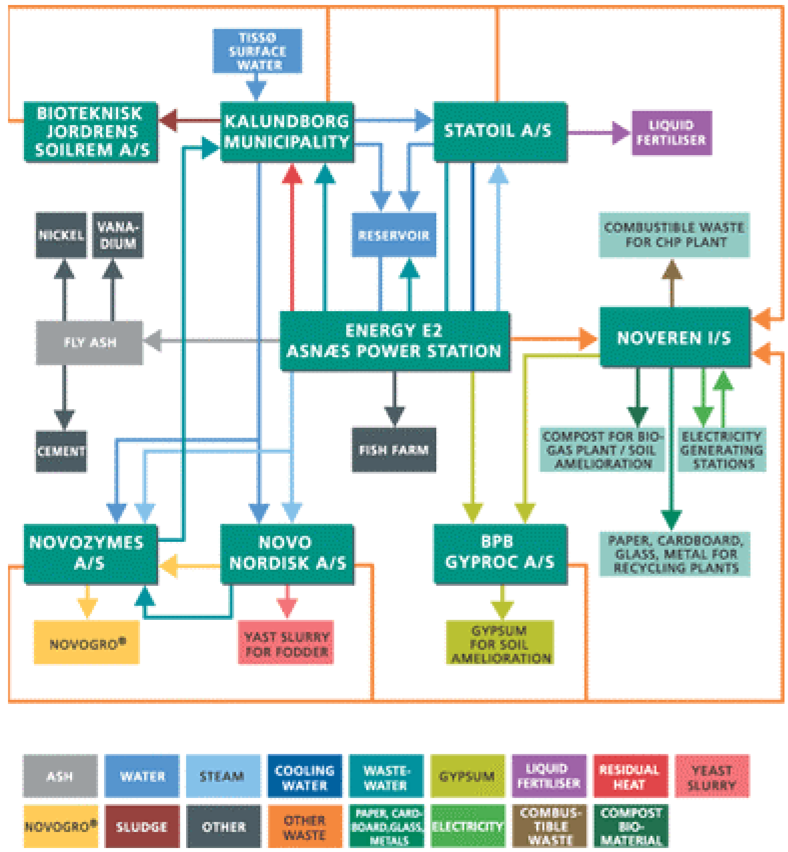

Figure 1. Schematic of Kalundborg Eco-Industrial Park. Source: http://www.symbiosis.dk/, July 2004.

4.3 Eco Efficiency

1992 Declaration of the Business Council for Sustainable Development

" Corporations that achieve ever more efficiency while preventing pollution through good housekeeping, materials substitution, cleaner technologies, and cleaner products and that strive for more efficient use and recovery of resources can be called eco-efficient."

Eco-efficiency, cleaner production, and pollution prevention are all basically synonymous, and work to implement APEG Sustainability Guideline #2: Take into account cumulative social, environmental and economic implications. They all reduce the raw material, energy and pollution required to maintain a viable economy. The term eco-efficient was defined by the World Business Council for Sustainable Development (WBCSD) in 1992. The WBCSD is an international coalition of mostly large corporations with a shared interest in social progress, economic growth and ecological balance. Member corporations come from all business sectors and achieve various levels of sustainability in their own operations. Eco-efficiency fits in well with the business community, as higher efficiency and lower pollution are directly related to profit. The WBCSD publishes extensively on sustainability and business. For more information on the WBCSD, see the *Resources* Section.

The WBCSD defines eco-efficiency as "being achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the Earth's estimated carrying capacity".

The WBCSD definition assumes that there is a level of impact that biological systems on the earth can assimilate, and that the level can be determined. This is not always the case. Many industrial feedstocks, byproducts and wastes have no known safe exposure level in mammals. Some are highly persistent in the environment. Many industrial releases have complex, poorly characterized composition. It can be difficult or impossible to know what the impact of pollution will be once it is the natural environment where it inevitably migrates and interacts with countless other factors.

Reducing waste and reliance on raw materials and energy makes business and environmental sense. Eco-efficiency can be achieved by considering sustainability at the earliest stages in design. The design considerations below all enhance eco-efficiency.

- Prefer materials with high recycled content, low embodied energy, and low lifecycle impact
- Reduce waste through reducing the mass of the product or packaging
- Eliminate undesirable substances from the product and manufacturing process
- Reduce the energy required over the lifecycle of a product and its packaging
- Extend the life of a product and its components

- Design for disassembly
- Design for recycling
- Design for safe disposal
- Design for reuse
- Design for remanufacture
- Design for energy recovery[9]

A lot of work has been published on eco-efficiency. See the *Resources* section for references to more information.

[9] Adapted from: D. Fiskel "Achieving Eco-efficiency through Design for the Environment" R.C.Dorf *Technology, Humans, and Society*. Academic Press 2001.

4.4 Green Chemistry

Principles of Green Chemistry
from P.T. Anastas,; J.C. Warner, Green Chemistry: Theory and Practice*, Oxford University Press: New York, pg.30 1998.*

Prevention
It is better to prevent waste than to treat or clean up waste after it has been created.

Atom Economy
Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

Less Hazardous Chemical Syntheses
Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

Designing Safer Chemicals
Chemical products should be designed to effect their desired function while minimizing their toxicity.

Safer Solvents and Auxiliaries
The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

Design for Energy Efficiency
Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.

Health and environmental problems resulting from chemical processes have led to the development of Green Chemistry. Green Chemistry aims to design chemical processes with the following characteristics:

- simplicity
- safety
- high yield and selectivity
- energy efficiency
- renewable and recyclable reagents and raw materials[10]

Green chemistry demonstrates APEG Sustainability Guideline # 5: Assess reasonable alternative concepts, designs and/or methodologies. The application of this guideline to the selection of feedstock, solvents, and synthetic pathways leads to safer chemical products and processes. For example, the following criteria can be used to compare chemical feedstocks: availability, price, environmental persistence, bioaccumulation potential, toxicity, and abundance. Whether or not the feedstock is renewable may also be considered. Using the criteria mentioned, it may be possible to identify a feedstock that is innocuous, selective, and efficient.

Solvents have emerged as one of the most toxic and environmentally damaging artifacts of industrialization. According to Material Safety Data Sheets, the common industrial solvents such as toluene, dicholoromethane, and methanol, are implicated in cancer, toxicity, and / or birth defects. Solvents also account for a significant portion of ozone depleting chemicals, and in some cases are strong greenhouse gases. Moving either towards safer solvents or away from solvents altogether is an important part of green chemistry.

Optimization of synthetic pathways and products can reduce bio-availability and persistence of released chemicals. For example, most organic chlorine compounds studied to date are persistent, bio-accumulate up the food chain and cause cancer and reproductive disorders in mammals. Avoiding the use of the chlorine in the synthetic pathway may significantly reduce the impact of the process on human and ecosystem health.

For more information on Green Chemistry, see the *Resources* section.

[10] P.T. Anastas, D. Allen "Green Chemistry". Editors: D.T. Allen, D.R. Shonnard, D.R: *Green Engineering*, pg. 177-199 Prentice-Hall 2002.

Principles of Green Chemistry Continued

Use of Renewable Feedstocks
A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

Reduce Derivatives
Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

Catalysis
Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

Design for Degradation
Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

Real-time analysis for Pollution Prevention
Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

Inherently Safer Chemistry for Accident Prevention
Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Case Study: US Presidential Green Chemistry Awards

The US Presidential Green Chemistry Awards are meant to stimulate and reward innovations in cleaner, cheaper, smarter chemistry.[11] The awards recognize winners in academia, small business, alternative synthetic pathways, alternative reaction conditions, and safer chemicals.

In 2002 the winner in the Alternative Solvents/Reaction Conditions category was Cargill Dow Nature Works polylactic acid polymer. This "bio-polymer" is completely biodegradable, produced without the use of organic solvents, and uses genetically engineered corn as a feedstock. These polymers can compete with and replace traditional synthetics for use in fabric, carpets and packaging.

Synthetic polymers for fabric, carpets, packaging and other applications have been traditionally made with petroleum feedstock. The disposal of these persistent synthetics presents an increasing burden to society. Another problem with traditional synthetics is that the production process typically calls for dangerous organic solvents and heavy metal catalysts.

To address the environmental and social concerns associated with synthetics, the chemical industry has been revisiting processes developed in the 1920s for the synthesis of bio-degradable polymers from organic feedstock.

Recently a number of companies have made breakthroughs in processing and feedstock technology and are now producing compostable bio-polymers at commercial levels. The Cargill Dow facility in Nebraska has a capacity of 300 million pounds/year of bio-polymers. In addition to Cargill Dow, Toyota Motors, NEC, Dupont and Mitsubishi are also working on bio-polymers, indicating that the growth potential is expected to be huge.

Although bio-polymers, such as polylactic acid, appear to be a solution to environmental concerns, the use of genetically engineered organisms as feedstock has generated some opposition from environmental groups. Perhaps the next step in creating a truly sustainable synthetic fibre is production from non-genetically engineered low value bio-mass such as corn husks or sawdust.

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[11] _Presidential Green Chemistry Challenge Award Recipients_, United States Environmental Protection Agency, June 2002. www.epa.gov/greenchemistry

5 Measurement and Assessment

Engineers and geoscientists are familiar with the need to assess and measure initiatives in order to determine whether the intended benefit is being derived. Several tools to assess and measure progress towards sustainability in industrial processes are presented below.

5.1 Sustainability Indicators

Sustainability indicators measure the performance of important success factors. There are currently no universal standards for industrial sustainability indicators. Regulations have prompted measurement and assessment of specific species in a waste stream, but this may not reflect overall progress towards sustainability. For example, regulations may call for measuring and controlling the toxicity of a liquid effluent; a related sustainability indicator would be the overall quantity of water used by the process. Likewise, regulations may require monitoring and control of carbon dioxide emissions; a related sustainability indicator would be the energy input to the process.

Sustainability indicators are discussed in more detail in *Module 3e: Consulting Engineering and Geoscience*. An example is also provided there. The reference for that work is in the *Resources* section.

5.2 Risk Assessment

When performing risk assessment using sustainability, it is helpful to consider a range of issues. Joe Thornton, Postdoctoral Research Scientist at Columbia University's Earth Institute and Department of Biological Sciences poses some essential questions regarding risk:

- How much risk is acceptable?
- Who benefits and who suffers the risks of the practice?
- Is the product really necessary?
- Are there less hazardous ways to satisfy human needs?
- Who should bear the burden of proof in decisions about technologies?
- Why does society assume that firms have a right to produce, use, and discharge toxic chemicals at all?[12]

A number of regulatory agencies and most civil society groups prefer to use the Precautionary Principle when considering risk. The Precautionary Principle states that where there is a risk of serious,

[12] J. Thornton *Pandora's Poison* MIT Press, Cambridge, 2000.

irreversible harm, a lack of complete scientific certainly does not justify inaction. This principle is behind emerging regulations such as the proposed REACH legislation for the EU, which is examined in more detail below.

Several of the APEGBC Sustainability Guidelines can provide useful guidance when considering risk. For example, Guidelines 3 and 4 support taking into consideration short and long term, direct and indirect consequences. The importance of considering long-term and indirect consequences in risk assessment is outlined for the case of endocrine disruptors by Arnold et al:

> There is evidence that domestic animals and wildlife have suffered adverse consequences from exposure to environmental chemicals that interact with the endocrine system….Whether similar effects are occurring in the general human or wildlife populations from exposures to ambient environmental concentrations is unknown….Because the endocrine system plays a critical role in normal growth, development, and reproduction, even small disturbances in endocrine function may have profound and lasting effects. This is especially true during highly sensitive prenatal periods, such that small changes in endocrine status may have delayed consequences that are evident much later in adult life or in a subsequent generation. Furthermore, the potential for synergistic effects from multiple contaminants exists.[13]

Depending on the level of risk, risk assessment may involve engineers, toxicologists, ecologists, chemists, industrial hygienists, medical and legal staff, and civil society groups. Civil society groups such as environmental and social non-governmental organizations are important partners in risk assessment. When consulted early in the process, they can contribute as a gauge of social acceptance levels to particular risks, and can lend credibility and knowledge to a project. Broadening the scope of consultation on risk assessment is an example of APEG Sustainability Guideline # 7: Cooperate with colleagues, clients, employers, decision-makers and the public in the pursuit of sustainability.

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[13] F. Arnold, G. Froiman, J. Blouin, “Risk Concepts”, ”. Editors: D.T. Allen, D.R. Shonnard, D.R: *Green Engineering*, pg. 45 Prentice-Hall 2002.

Case Study – REACH

Below is an excerpt from The REACH Proposal Process Description prepared by the REACH Implementation Project, June 2004.

> To adequately control the risks arising from the manufacture, import, placing on the market and use of substances, the REACH proposal reverses the burden of proof from the authorities to industry for gathering information on chemical substances and using this information to assess the safety of chemicals and select appropriate risk management measures. To reflect this new approach, the Regulation states in Art. 1 (3) that it is based on the principle that it is up to manufacturers, importers and downstream users of substances to ensure that they manufacture, place on the market or import or use such substances in a way that does not adversely affect human health or the environment.[14]

The need for regulations, such as REACH, based on the Precautionary Principle was demonstrated by a European study of human contamination levels of industrial chemicals. The study, organized by the Co-operative Bank and the World Wildlife Fund, tested for five types of chemicals: brominated fire retardants, phthalates, perfluorinated chemicals, PCBs, and organo-chlorine pesticides. Thirty nine members of the European Parliament, four observers, and 4 members of the public underwent blood tests for the five chemical types. Chemicals from each of the five groups were found in every individual tested, including those with no occupational exposure. The median number of individual chemicals detected in participants was 41. Some of the chemicals found have been banned in Europe for over 20 years. The phthalate DEHP was found to have the highest median concentration in whole blood, with a value of 55,000 pg/g blood. DEHP is associated with reproductive disorders. The highest median concentration in blood serum was p,p'-DDE, a DDT metabolite, at 1265 pg/g serum.

To learn more about the REACH Proposal and the European study, check the *Resources* section.[15]

[14] The REACH Proposal Process Description, REACH Implementation Project 1, obtained from www.europa.eu.int/ July 2004
[15] *Chemical Check Up*, World Wildlife Fund, The Cooperative Bank, 2004

5.3 International Agreements

International agreements can be powerful agents of change and can have wide ranging implications for measuring and assessing industrial processes. International agreements have the advantage of providing a universal standard for measurement and assessment of some aspects of industrial processes.

A number of international agreements affect industrial processes, but only three are presented here. The Montreal Protocol on ozone depleting substances is considered to be one of the most successful international agreements. Two of the current international agreements with implications for industrial processes are the Stockholm Treaty and the Kyoto Protocol. These three agreements demonstrate Sustainability Guideline #2, by taking into account cumulative social, environmental and economic implications of both the targeted substances and the changes required for compliance.

Montreal Protocol on Ozone Depleting Substances

In the 1980s, it was recognized that global environmental damage was being caused by ozone depleting substances. Ozone depleting substances are synthetic halogenated organic chemicals, such as chlorofluorocarbons (CFCs), introduced in the 1930s as refrigerants, pesticides, and solvents. Destruction of the stratospheric ozone layer by ozone depleting substances damages fisheries, agriculture, forestry and human health.

Atmospheric science still cannot completely account for the loss of stratospheric ozone over the last 30 years. In 1987, when the international community came together to sign the Montreal Protocol on Ozone Depleting Substances, the science behind ozone depletion was even less complete. In signing the Montreal Protocol, the international community was adopting the Precautionary Principle, deciding that lack of complete scientific certainly would not stop action on issues creating potentially widespread and irreversible environmental damage.

In 1997, Canada's Environment Minister Christine Stewart stated "The bottom line …. is that the Montreal Protocol was the right choice …. for Canada and the global environment. Each nation is sharing in the benefits arising from the protocol. It's a model for countries to follow on other environmental challenges, such as climate change." She was commenting on a study showing that the economic and human health benefits of implementing the Montreal Protocol far exceeded its significant costs. The study, "The Right Choice at the Right Time" also notes that costs to implement the Montreal Protocol were lower than originally predicted because of technological innovation borne out of necessity.

It is now predicted by the United Nations Development Program Montreal Protocol Unit that the recovery of the ozone layer is expected to occur around 2050 if all parties comply. Canada is in full compliance with the phase-out schedules prescribed by the Protocol.

Stockholm Treaty on Persistent Organic Pollutants

On May 23, 2001 Canada became the first nation to ratify the Stockholm Treaty on Persistent Organic Pollutants (POPs). On May 17, 2004, the agreement came into effect following ratification by 50 nations. Implementation of the agreement will dramatically reduce or eliminate the production and transportation of the following 12 toxic chlorinated organic chemicals: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, PCBs, toxaphene, dioxins, and furans.

As a northern country, Canada is particularly impacted by pollution from chlorinated organic chemicals. These pollutants are volatile at moderate temperatures and condense at high latitudes. Hydrophobicity causes them to bio-accumulate up the food chain reaching much higher concentrations in the fatty tissue of mammals than in the environment. According to findings published in the *Consultations on Canada's National Implementation Plan under the Stockholm Convention on Persistent Organic Pollutants* by the Hazardous Air Pollutants and Transboundary Air Issues Branch of Environment Canada in 2004, "Levels of POPs in Canadian Inuit populations are among the highest observed in the world…in the Kitikmeot, Kivalliq and Baffin Regions of Nunavut, 40 to 65 per cent of the women participants had levels of PCBs up to five times above values used by Health Canada and the Governments of the Northwest Territories and Nunavut to identify a level of concern." Many studies indicate that the environmental persistence and biological activity of these pollutants lead to cancer and reproductive disorders.

A number of the listed POPs are pesticides not registered for use in Canada. Dioxins and furans are unintentional by-products of several industries, including the pulp and paper industry. They are released into soil, water, and air. Canada has slated dioxins and furans for virtual elimination under the *Canadian Environmental Protection Act* and should be in compliance with the Stockholm Convention.

Most British Columbia pulp and paper mills have been working for years to reduce releases of dioxins and furans. They have generally been successful reducing effluent concentrations, but still struggle with atmospheric emissions. The case study below takes a look at their progress and challenges.

Case Study – BC Coastal Pulp Mills

Dioxins and furans are two of the persistent families of organic pollutants targeted by the Stockholm Convention. BC pulp and paper mills have been working for over 10 years to reduce releases of dioxins and furans. They have had both successes and failures, and continue to be faced with major challenges to meet the goal of virtual elimination of dioxins and furans.

In 1992, the British Columbia provincial government legislated a phase out over ten years of releases of absorbable organic halogens or AOX, including dioxins and furans. Of major concern at the time was contaminated liquid effluent, which had led to widespread fisheries closures. At that time, most coastal mills used elemental chlorine in their pulp bleaching processes. In response to the legislation, BC mills switched from elemental chlorine bleaching to chlorine dioxide bleaching. As a result of this switch, the measured concentrations of dioxins and furans in mill effluents were greatly reduced, but not eliminated. Figure 2 shows the measured dioxin emissions in pulp mill effluents from all Canadian mills between 1988 and 1999. Studies in other countries show similar results. A Finnish study, conducted in 1994, at a pulp mill that had completely replaced chlorine gas bleaching with chlorine dioxide, found dioxin concentrations in mill effluent between 0.002 and 0.2 pg TEQ per cubic metre. A US EPA study estimated that if all American pulp and paper mills switched to chlorine dioxide bleaching, 11.1 grams per year of dioxins and furans would still remain in mill effluent[16].

Levels of dioxins and furans from coastal pulp mill air emissions are illustrated in Figure 3. Emissions to air from just 8 BC mills are still about 3 times those in the effluent from some 50 Canadian bleached kraft mills. Coastal mills use wood waste for fuel, an apparently sustainable fuel choice. Logs are transported to the pulp mill or sawmill by log boom and arrive saturated in salt water. The combustion of salt-laden wood waste produces organic chlorine compounds, including dioxins and furans. Stack dioxin emissions from coastal power boilers burning salt-laden hog fuel have decreased by over 68% since 1995, from 10.5 grams of TEQ per year in 1995 to 3.3 – 3.4 grams of TEQ in both 2001 and 2002. These reductions have been realized through a series of capital expenditures (totaling over $160 million) and boiler shutdowns and through ongoing efforts to improve power boiler combustion efficiency and decrease particulate emissions. Nevertheless, stack dioxin emissions test results for the coastal power boilers are still highly variable. The results from single

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[16] J. Thornton *Pandora's Poison* MIT Press, Cambridge, 2000.

tests on any of the coastal power boilers vary by a factor between 5 and 45 and four of the 8 mills have measured emissions in the last three years that exceed the Canada Wide Standard for existing facilities (0.5 ng TEQ/m^3 @11% O_2). Despite the general improvement in dioxin emissions, and the fact that the average stack emissions over the last three years for seven of the eight affected coastal mills are now below the CWS limit for existing facilities, the large variations of individual test results present difficulties for many of the mills in ensuring compliance with the current CWS limit.

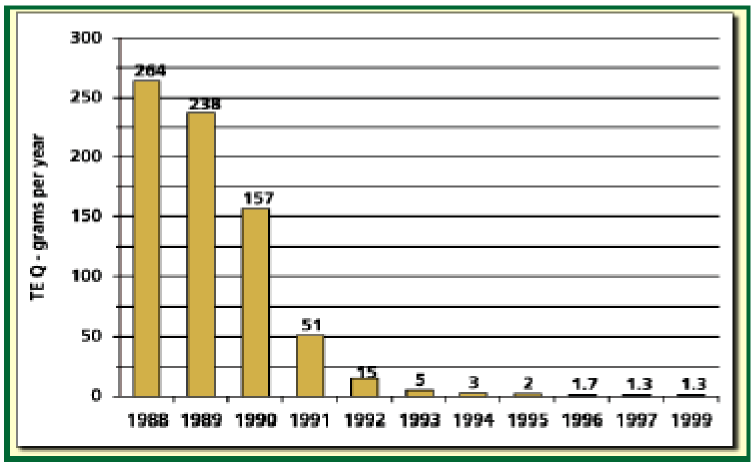

Figure 2. Dioxin Emissions in Canadian Pulp Mill Effluents. Source: Paprican, 2003.

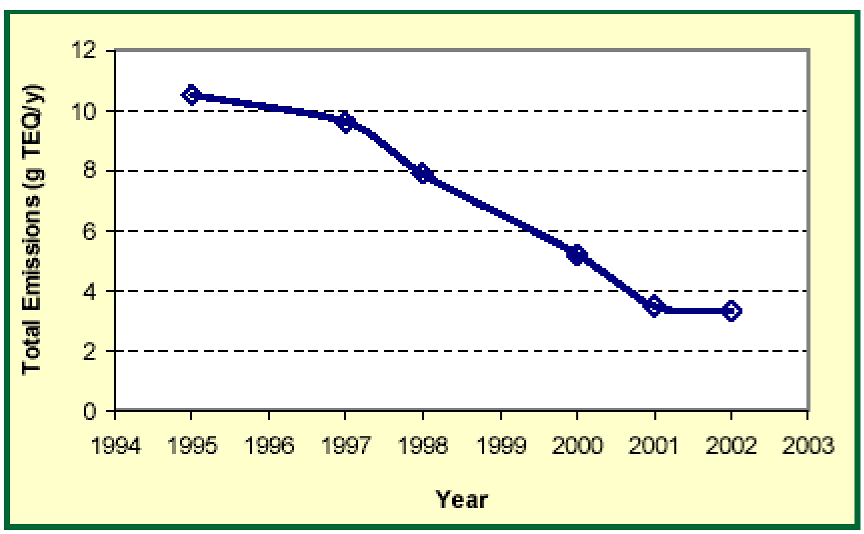

Figure 3. Total Dioxin Emissions from BC Coastal Power Boilers. Source: Paprican 2003.

Kyoto Protocol on Climate Change

The Kyoto protocol was adopted by the Government of Canada as an attempt to mitigate climate change. As a northern country we are already impacted by climate change. For example, since the 1960s the Canadian Arctic has seen a 25% decrease in the area permanently covered by sea ice. Similarly, the ice free period on the Hudson Bay has increased by a week over the last 30 years. The Helm Glacier in Garibaldi Provincial Park near Vancouver shrunk by more than a kilometer between 1895 and 1995. Economic, social and environmental impacts of climate change can be severe. In British Columbia there is evidence that climate change has contributed to increases in the population of mountain pine spruce beetles, pests that have infested most of the interior and northern forests. The impact and rate of climate change is expected to increase over this century. Climate change has been accepted by the international scientific community and most governments as being attributable to increased levels of greenhouse gas emissions (GHGs) resulting from industrialization. The Kyoto protocol is expected to be the first in a series of measures to quantify and control the release of GHGs.

The Kyoto protocol requires measurement and reporting of greenhouse gas emissions where feasible. Industrial firms account for about half of Canada's GHG emissions. The federal government is offering assistance to industry to apply the Kyoto guidelines on measurement and reporting.

One of the Government of Canada's first initiatives regarding industrial sources of GHGs was the Voluntary Challenge and Registry (VCR). The VCR started in 1995 with the goal of encouraging large industrial emitters to report on GHG emissions and enact reduction strategies. In March 2004 Canada moved to mandatory reporting of GHG emissions, and the by the end of 2004 the VCR will be closed completely. Industrial emitters are now required to report emissions in excess of 100 kilotonnes of CO_2 equivalent by June, 2005. Amoung other reasons, the VCR may have been abandoned because of problems with inconsistent methodology for calculating emissions, including the use of non-standard and poorly documented methodologies, unreferenced methodologies for quantifying offsets, the exclusion of subsidiaries or wholly-owned subsidiaries or joint ventures, and the exclusion of non carbon dioxide greenhouse gases by some reporters.[17]

The Kyoto Protocol clearly outlines the methodology and standards for measuring GHG emissions. It stipulates that progress achieving

[17] M. Bramley, *The Case for Kyoto: The Failure of Voluntary Corporate Action*, The Pembina Institute and The David Suzuki Foundation, 2002.

reduction of emissions "will be measured through the use of a set of internationally agreed to emissions and removals inventory methodologies and reporting guidelines."[18] For example, unlike the VCR, the Kyoto Guidelines require measurement and reporting on six GHGs: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfloruocarbons, and sulphur hexafluoride. It endorses the following methodologies for the measurement of greenhouse gases:

- Direct Measurement: At present, a very limited number of sources have measured and reported GHG emissions.

- Mass Balance: Mass balances are most appropriately applied to fuel-carbon contributions and mineral-processing activities, where sufficient data are available to derive average carbon contents of process streams. Generally, CO_2 emissions resulting from fuel combustion are readily estimated by the carbon balance method.

- Technology-Specific Emission Factor Calculations: Company-specific emission factors can be used to estimate the rate at which a pollutant is released into the atmosphere (or captured) as a result of some process activity or unit throughput. Although emissions or removals may not be measured, individual facilities may have measured rate data for various parameters for their plant. These can be combined with other plant-specific information, such as throughput, activity data, and the number of such sources, to derive plant-specific emissions or removals for a point source or "bottom-up" inventory.

- *Average or General Emission Factor Calculations:* Where plant-specific data are not available, average or general-use emission factors can be used for a given source or sector. These can be combined with company-specific, sector-specific, process-specific, or general activity and population data to calculate emissions for a top-down inventory. Average or general emission factors for most of the sectors in the inventory have been developed by Environment Canada, in consultation with other government departments, industry associations, and other agencies and organizations. These values reflect the most accurate methodologies based on currently available data and include information currently being

[18] D. Blain, *Canada's Greenhouse Gas Inventory 1990-2002*, Greenhouse Gas Division, Environment Canada, 2004.

developed by the Intergovernmental Panel on Climate Change (IPCC) for the UNFCCC[19].

The Government of Canada defines Large Final Emitters as processes emissions intensity of at least 20 kg CO_2e/$1000 output and average annual emissions of at least 8 kt per facility. They are required to have an overall reduction of 55 Mt of CO_2 between 2008 and 2012. For more information on the Large Final Emitters regulation, see the *Resources* section.

[19]D. Blain et al, Canada's Greenhouse Gas Inventory 1990-2002, Greenhouse Gas Division, Environment Canada, 2004

6 Summary

Measuring and assessing the effectiveness of sustainability initiatives is essential to their success. Engineers and geoscientists measure progress on broad issues such as water or energy efficiency using Sustainability Indicators. Risk assessment can be performed to include sustainability. A number of new regulations provide guidance on measuring and assessing specific environmental or health impacts.

Industrial processes are increasingly incorporating sustainability principles. Engineers and geoscientists have many opportunities to increase the sustainability of industrial processes. Some of the major initiatives, such as energy efficiency, industrial ecology, eco efficiency, and green chemistry are essential tools for APEG members to be familiar with and apply where possible.

7 Resources

APEGBC Sustainability Guidelines

To learn more about the APEGBC Sustainability Guidelines see the Primer Part 2 available through APEGBC, or by download from www.sustainability.ca.

L. Failing, G. Long, *Sustainability in Professional Engineering and Geoscience: A Primer Part 2: Applying the Guidelines*, APEGBC, 2002.

Association of Professional Engineers and Geoscientists
200-4010 Regent Street, Burnaby BC, Canada, V5C 6N2
Phone: 604-430-8035, Fax: 604-430-8085
Email: info@sustainability.ca Webpage: www.sustainability.ca

Industrial Energy

The summer 2003 issue of *Sustainability Now*, the APEG sustainability newsletter explores innovative energy technology. It can be ordered from APEG or downloaded from www.sustainability.ca.

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BC Hydro has resources for increasing the energy efficiency of industrial processes. Check out : http://www.bchydro.com/business/, or contact them directly for more information on Power Smart and green energy certificates.

BC Hydro
6911 Southpoint Drive, Burnaby, BC, V3N 4X8
Phone: 604-224-9376, 1-800-224-9376

The Natural Resources Canada Office of Energy Efficiency has a number of programs to promote and reward energy efficiency. Contact them directly or visit http://oee.nrcan.gc.ca/english/index.cfm.

Office of Energy Efficiency Natural Resources Canada
580 Booth St. 18th floor Ottawa ON K1A 0E4
Phone: 1-800-387-2000

Industrial Ecology

The Journal of Industrial Ecology published by MIT press is a good source for case studies and applications of industrial ecology. Find it at http://mitpress.mit.edu/catalog/item/default.asp?sid=91279A65-93F4-4D0F-B014-510659C1D4F3&ttype=4&tid=32

Information of the Kalundborg Eco-Industrial Park can be found at http://www.symbiosis.dk/

Environment Canada maintains a website on Industrial Ecology at http://www.ec.gc.ca/energ/industry/indus_ecol_e.htm

Eco-Efficiency

The World Business Council for Sustainable Development maintains a comprehensive website on sustainable business, eco-efficiency and current events at www.wbcsd.org

The United Nations Environmental Program maintain a website on cleaner production, eco-efficiency, and pollution prevention at http://www.uneptie.org/pc/cp/

Environment Canada maintains a website on pollution prevention at http://www.on.ec.gc.ca/pollution/fpd/prevention/6001-e.html

Green Chemistry

The US Environmental Protection Agency maintains a good website on green chemistry that includes information on the US Presidential Green Chemistry Award. http://www.epa.gov/greenchemistry/

A very interesting and provocative book that presents a case for Green Chemistry is:

J. Thornton, *Pandora's Poison*, MIT Press, 2000.

A book on green chemistry with a chemical engineering focus is:

D.T. Allen, D.R. Shonnard, *Green Engineering*, Prentice Hall, 2002.

Climate Change

For a brief overview of climate change and how it affects Professional Engineering and Geoscience read the APEGBC climate change primer. It can be downloaded from www.sustainability.ca or ordered by phone.

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Email: info@sustainability.ca

For an in depth look at the science and policy issues surrounding climate change the best source is the *Third Assessment Report* by the United Nations Intergovernmental Panel on Climate Change.

IPCC Secretariat, C/O World Meteorological Organization,
7bis Avenue de la Paix, C.P. 2300, CH- 1211 Geneva 2, Switzerland
Phone: +41-22-730-8208 Fax: +41-22-730-8025
E-mail: IPCC-Sec@wmo.int Webpage : http://www.ipcc.ch/

Sustainability Indicators

Sustainability in Professional Engineering and Geoscience: A Primer Part 3e: Consulting Engineering and Geoscience contains a section on sustainability reporting that looks at the development of sustainability indicators. It can be ordered through the association of Professional Engineers and Geoscientists of BC or downloaded from www.sustainability.ca

Association of Professional Engineers and Geoscientists
200-4010 Regent Street, Burnaby BC, Canada, V5C 6N2
Phone: 604-430-8035, Fax: 604-430-8085
Email: info@sustainability.ca

The Global Reporting Initiative (GRI) is a multi-stakeholder process and independent institution whose mission is to develop and disseminate globally applicable Sustainability Reporting Guidelines. They have useful guidelines for developing sustainability indicators.

Global Reporting Initiative Secretariat
Keizersgracht 209,P.O. Box 10039
1001 EA Amsterdam, The Netherlands
Phone: 31 (0) 20 531 00 00 , Fax: 31 (0) 20 531 00 31
Webpage: http://www.globalreporting.org/

REACH

More information on the REACH proposal can be found at http://europa.eu.int/comm/enterprise/reach/docs/reach/reach_process_description-2004_06_15.pdf

The full report on a European study of human contamination levels of industrial chemicals can be viewed at http://www.panda.org/downloads/europe/checkupmain.pdf

Kyoto Protocol

Canada's Greenhouse Gas Inventory 1990-2002 describes the tools for measuring and assessing greenhouse gas emissions. It also describes greenhouse gas emissions by sector and source. It can be accessed on line through the United Nations Framework Convention on Climate Change at http://unfccc.int/program/mis/ghg/submis2004.html

Information on regulations regarding measuring and reducing greenhouse gas emissions for the large final emitters can be found at the Natural Resources Canada web link http://www.nrcan-rncan.gc.ca/lfeg-ggef/English/lfeg_en.htm. Large final emitters have emissions intensity of at least 20 kg CO_2e/$1000 output and average annual emissions of at least 8 kt per facility.