Summary Report for the Technology and Innovation Research and Development Initiative

Natural Resources Canada
Ressources naturelles Canada

Canada

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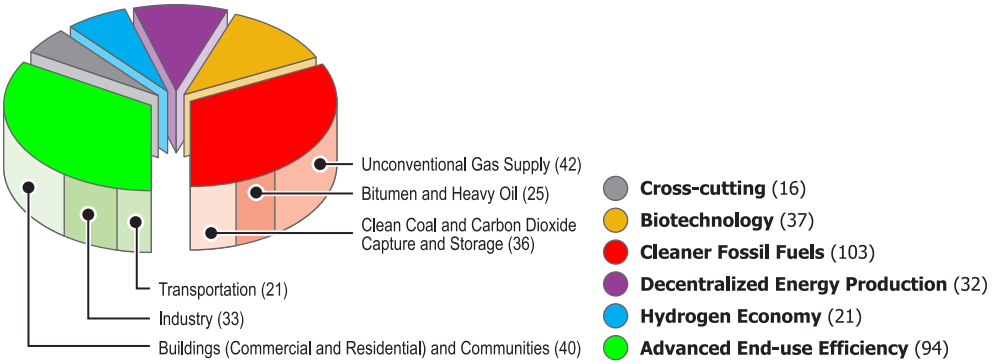
Technology and Innovation Research and Development Initiative

At a Glance

The Technology and Innovation (T&I) Research and Development (R&D) Initiative was established by the Government of Canada to advance promising technologies to achieve long-term greenhouse gas reductions and strengthen Canada's clean energy technology capacity. Natural Resources Canada's Office of Energy Research and Development coordinated and managed the T&I R&D Initiative to ensure that projects met outcomes, transferred knowledge, and paved the way for a clean energy future.

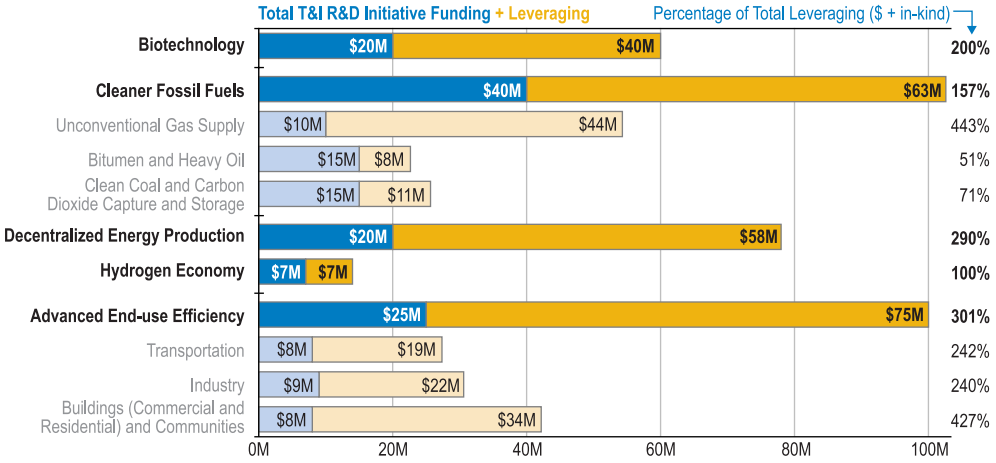
Total number of projects supported:	**303**
Funding allocation:	**$115 Million**
Average percentage of leveraging:	**229%**
Range of dollar value of investments:	**$20,000–$2,411,000**

Projects



Number of Projects by Area

Investment



Total Investment

Biotechnology
Number of Partnerships Formed: 254
Total Initiative Funding: $20M

Cleaner Fossil Fuels
Number of Partnerships Formed: 286
Total Initiative Funding: $40M

- **Unconventional Gas Supply**
  Number of Partnerships Formed: 217
  Total Initiative Funding: $10M
- **Bitumen and Heavy Oil**
  Number of Partnerships Formed: 31
  Total Initiative Funding: $15M
- **Clean Coal and Carbon Dioxide Capture and Storage**
  Number of Partnerships Formed: 38
  Total Initiative Funding: $15M

Decentralized Energy Production
Number of Partnerships Formed: 62
Total Initiative Funding: $20M

Hydrogen Economy
Number of Partnerships Formed: 25
Total Initiative Funding: $7M

Advanced End-use Efficiency
Number of Partnerships Formed: 213
Total Initiative Funding: $25M

- **Transportation**
  Number of Partnerships Formed: 41
  Total Initiative Funding: $8M
- **Industry**
  Number of Partnerships Formed: 50
  Total Initiative Funding: $9M
- **Buildings (Commercial and Residential) and Communities**
  Number of Partnerships Formed: 122
  Total Initiative Funding: $8M

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Changing the Outlook on Climate Change

Climate change is an urgent global challenge, one that Canada has a responsibility to address. A solution to this challenge involves finding ways to mitigate greenhouse gas (GHG) emissions. Because GHG emissions come from many Canadian sectors, a Canadian solution must be multi-faceted, which is a complex undertaking.

On November 21, 2002, the Government of Canada released the *Climate Change Plan for Canada*. The following year, Budget 2003 announced that $250 million of federal funding from this plan was to be used to launch the Climate Change Technology and Innovation Initiative, of which $115 million was allocated to the Technology and Innovation (T&I) Research and Development (R&D) Initiative. The objective of the T&I R&D Initiative was to focus on projects that would advance promising technologies to achieve long-term GHG reductions and strengthen Canada's clean energy technology capacity. Natural Resources Canada's Office of Energy Research and Development coordinated and managed the T&I R&D Initiative during its five-year duration, starting in October 2003 and ending in March 2008.

Through the T&I R&D Initiative, the Government of Canada identified five strategic areas as high-potential areas for significant reductions in GHG emissions: Biotechnology, Cleaner Fossil Fuels, Decentralized Energy Production, Hydrogen Economy, and Advanced End-use Efficiency. Within these five strategic areas, nine technology areas were established, under which projects would be funded.

Governing the T&I R&D Initiative

Each technology area was managed through a network of Experts Groups, made up of federal interdepartmental science and technology (S&T) and policy maker experts, and headed by a Leader of the Experts Group (LEG). External consultation was provided to the Experts Group by an External Advisory Group made up of provincial, academic, and industrial stakeholders. The LEGs then reported to an interdepartmental Directors General Steering Committee that considered and approved projects, and monitored and tracked progress to ensure that projects met the objectives of the T&I R&D Initiative.

Strategic Area	Expert Groups
1. Biotechnology	1. Biotechnology
2. Cleaner Fossil Fuels	2. Unconventional Gas Supply
	3. Bitumen and Heavy Oil
	4. Clean Coal and Carbon Dioxide Capture and Storage
3. Decentralized Energy Production	5. Decentralized Energy Production
4. Hydrogen Economy	6. Hydrogen Economy
5. Advanced End-use Efficiency	7. Transportation
	8. Industry
	9. Buildings (Commercial and Residential) and Communities

Breaking Barriers

As the T&I R&D Initiative unfolded, a cross-cutting program was introduced that covered projects in multiple technology areas. The program was comprised of two components: Technology to Market (T2M) and Integrated Applications (IA). The purpose of the T2M component was to support emerging technologies along the innovation curve to deployment through in-depth market potential assessments, standardized GHG estimation methods, dissemination strategy support, and a website hosting the necessary information. The IA component recognized that

some of the promising technologies are interdisciplinary, spanning more than one technology area in the T&I R&D Initiative. As such, the components encouraged synergies between groups—addressing a significant research gap that would otherwise be missed—and supported the overall research direction of the cross-cutting program.

Results—Now and into the Future

The T&I R&D Initiative was based on long-term strategic planning, but it also embraced possibilities to achieve GHG emission reductions in the near and medium terms. Near-term results rely on quickly developing clean technology options, which provided incremental advances, into the energy economy. In the medium to longer term, bridging technologies will help Canada transition to a low-emission energy future. Next generation technologies will eventually transform processes and lead to a clean energy future—one where society, its infrastructure, and its industries are functioning sustainably and where the maximum potential for mitigating climate change has been realized.

This Report

This report is intended to disseminate and highlight some of the successes and results of the T&I R&D Initiative over the five years. Projects highlighted span the innovation cycle from applied R&D to early stage development. Projects highlighted also supported work in regulatory and policy development. For more information on any of these projects, contact the Office of Energy Research and Development, Natural Resources Canada, 580 Booth Street, 14th Floor, Ottawa, Ontario, K1A 0E4 by mail or by e-mail: oerd.brde@nrcan.gc.ca

Project Highlights

Biotechnology

Canada has abundant sources of biomass and a large potential to develop a more sustainable and bio-based economy. The Biotechnology area was established to harness the potential for bioresources, bioenergy, bioproducts, and bioprocesses to help Canadian industries become more energy efficient and sustainable, and to diminish climate change. In particular, the projects funded under this technology area focused on researching and developing technologies that efficiently and cost-effectively convert different forms of biomass into biofuels and other useful products such as chemicals and biopolymer materials. Most of the project activities in this technology area were in the category of applied R&D, and were aimed at bridging fundamental research with demonstration projects.

Biomass Fuel Study Heats Up

Fuelled by economic concerns and high GHG emissions associated with using natural gas in the pulp and paper and cement industries, the research team set out to evaluate the replacement of natural gas with biomass-derived fuels for pulp and paper lime kilns and cement kilns. The project consisted of carrying out a life-cycle analysis of biomass supply for lime and cement kilns, including examining various logistical and technical needs associated with harvesting biomass. Project work also involved determining the physico-chemical characteristics of sourced biomass fuels and quantifying the concentration of contaminants (such as aluminium and silicon) in the stages of lime manufacture at the study mills. Fuel substitution initiatives like this project are consistent with the long-term Canadian Biomass Innovation Network (CBIN) strategy for meeting rising energy needs and GHG emissions constraints.

Project Title: Analysis of Biomass-derived Fuels for Use in Pulp and Paper Lime Kilns and Cement Kilns

Performers and Partners: Natural Resources Canada, Advanced Biorefinery Inc., Alberta Pacific, Bowater Thunder Bay, Canfor Prince George, Cariboo Quesnel, Catalyst Elk Falls, Domtar Espanola, Ensyn Technologies, FPInnovations—Paprican, Howe Sound Pulp and Paper, Irving Saint John, Druger Tois Rivières, Lafarge North America, Nexterra Energy Corporation, IEA BioEnergy Implementing Agreement—Task 33, Tembec Skookumchuck, Tolko Manitoba Kraft Papers, University of British Columbia, VTT Research (Finland)

Achievements:

- Data acquired from more than 10 mills across Canada led to an increased awareness and understanding of technologies and processes associated with biomass conversion and utilization.
- Useful knowledge generation for pulp and paper and cement industries seeking to replace fossil fuels with biomass-derived fuels.
- Anticipation that this research will lead to the installation of the first commercial biomass-fuelled lime kiln in a British Columbia mill.
- Scientific papers, technical reports, and workshops.
- Strategic partnerships among researchers, adopters, and end-users.
- Life-cycle assessment of technological-economic-environmental parameters.

Styrofoam Makes Way for Renewable, Starch-based Materials

Increasing public awareness, changing market forces, and improving cost-performance of bio-based materials have created favourable conditions for manufacturers to switch from synthetic petroleum-based materials to starch-based biopolymers for the production of short-lived products such as disposable cups and packaging. This project was launched to develop and promote starch-based biopolymers, focusing on blends and alloys of thermoplastic starch and other biopolymers such as polyhydroxyalcanoates

and polylactic acid. These materials are produced entirely from renewable sources and are biodegradable.

Project Title: Development and Production of Starch-based Biopolymers

Performers and Partners: Natural Resources Canada, National Research Council Canada—Industrial Materials Institute, Agriculture and Agri-Food Canada, École Polytechnique de Montréal

Achievements:

» Polylactic acid and thermoplastic starch were successfully compatibilized (mixed to form a homogeneous blend). This is an important finding that may translate into use of bio-based materials, especially for molded articles, packaging films, and foam materials.

» Project members carried out a collaborative project leading to pilot-scale trials with a major North American foam-packaging producer. In foamed packaging alone (e.g., plates, trays, coffee cups), the manufacturer uses 150,000 tons of polystyrene. Even a partial substitution of starch-based material could significantly benefit the environment.

» Project work involving the crop triticale, which is a hybrid of wheat and rye, resulted in the successful fabrication of triticale-based materials. This success has led to continued collaboration between the National Research Council Canada and Agriculture and Agri-Food Canada in the Canadian Triticale Bio-refinery Initiative.

» The research generated in this project led to 10 scientific articles in high-impact, peer-reviewed, international journals and over 25 presentations in national and international forums. An article published in the journal *Polymer* in January 2007, describing research carried out on compatibilization of thermoplastic starch and polylactic acid blends, was the seventh most downloaded paper of this journal in 2007. Micrographs of foams made out of these same materials were featured on the front page of *Macromolecular Bioscience* journal in July 2007. This research was also featured on the scientific TV show *Le code Chastenay*, which aired on Télé-Québec.

Information Portal Enables Analysis of Canada's Biomass

Industries throughout Canada generate biological residues or biomass. The biomass includes both woody and non-woody (herbaceous) sources, such as grain-crop residues, forest mill waste, timber-harvesting residues, and urban wood waste. These sources of biomass can be used as feedstock to generate bioenergy, biofuels, and other bioproducts.

The project team performed a national inventory of agricultural and forestry biomass with the goal of developing a comprehensive and consistent picture of the quantity, quality, cost, and opportunity provided by the available biomass. Information on the availability of woody biomass recovered from urban settings was gathered using surveys and inspections of urban waste management systems. Combining this information with geographic information systems (GIS) technology, the project team developed a web-based information portal that will be publicly accessible and will allow users to determine the feasibility of accessing the herbaceous and woody biomass for use as feedstock.

Project Title: GIS-based Inventory and Analysis of Agricultural and Forestry Biomass

Performers and Partners: Agriculture and Agri-Food Canada, Natural Resources Canada—Canadian Forest Service's Canadian Wood Fibre Centre, Above Board Inc., FPInnovations—Forest Engineering Research Institute of Canada, Manitoba Conservation, Southwestern Ontario Bioproducts Innovation Network, Sweitzer-Mauduit, University of British Columbia

Achievements:

» Created a biomass information portal, consisting of databases and an interactive web-based decision support tool using GIS technologies. The tool identifies sources of sustainable woody and herbaceous biomass feedstock spatially by type.

» The portal will provide decision makers with key information—available transportation infrastructure, significant water bodies, land cover, and location of urban areas—crucial to the exploitation of the residues and waste biomass by industry.

» The biomass information portal can also be used by investors, policy makers, and researchers to assess the presence and location of biomass feedstock inventories and, in the future, characterize the available biomass, forecast lifespan or sustainability, and evaluate the socio-economic and environmental impacts of biomass recovery and conversion.

» The project advanced knowledge and understanding of existing biomass resource potential and resulted in increased interdepartmental collaboration within the federal government, and increased involvement of provincial governments and industry stakeholders.

Growing Bioenergy

As the bioenergy industry takes off, there is a need to develop sustainable dedicated biomass production systems for bioenergy generation in Canada. The objective of this project was to provide new knowledge and technology to enable Canada to establish up to 1.3 million hectares of new short-rotation agro-forestry plantations by 2025. In this context, short-rotation agro-forestry is the culture of producing fast-growing, low-maintenance, high-yielding crops for conversion into biofuels and other bioproducts. The woody and herbaceous crops that would grow on these 1.3 million hectares were predicted to contribute 23 million tons of biomass feedstock yearly, a reduction of 30 megatons of GHG emissions, and 4.1 percent of total energy consumption in Canada. This project focused on four willows or hybrid poplar-based systems.

Project Title: Developing Short-rotation Plantation/Agroforestry Systems for Bioenergy Generation in Canada

Performers and Partners: Natural Resources Canada—Canadian Forest Service, Agriculture and Agri-Food Canada; Institut de recherche en biologie végétale—Montréal Botanical Garden; Natural Resources Canada—CanmetENERGY in collaboration with 11 academic and research institutes, including the State University of New York (SUNY-ESF); 25 companies including Enerkem, Ensyn, and Uniboard of Canada; 17 provincial and regional organizations, including the Saskatchewan Research Council and Ligniculture Quebec, 6 municipalities, and over 100 landowners

Achievements:

» Established a network of field tests across Canada to select promising native willow species for short-rotation intensive culture (SRIC). Preliminary results indicate that biomass production in native willows is comparable to that found in exotic willow clones currently being used in Canada.

» Established a network of sites across various ecozones in Canada to assess woody biomass production and carbon sequestration of short-rotation plantation systems under various land-management practices. These include the first SRIC sites in the Canadian Prairies.

» Tested new willow clones and improved cultivation practices. Carbon sequestration in the above-ground biomass produced under SRIC proved to be significantly higher than in natural systems. Created a database to store information on crop composition and to track input into expected pre-treatment issues and conversion performance. This database will help conversion facilities estimate supply costs.

» Completed scientific validation and adaptation of willow clones for agro-forestry systems. Initial biomass yield in riparian buffers and alley cropping reached 15 dt/ha/yr with minimal input. Willows were shown to be effective biofilters that can remove non-point source pollutants. Hardiness screening showed that exotic willow clones proven to be adapted to eastern Canada were at significant risk of low-temperature damage when planted in Saskatchewan.

» Developed a functional cutter-shredder-baler at a reasonable material cost. This original technology compares favourably with the only current alternative in SRIC, a self-propelled harvester-chopper that produces wood chips but requires a capital investment about seven times greater than the baling system.

» Developed or refined three bio-economic models, allowing significant progress toward assessing the economic feasibility of short-rotation woody crops in terms of bioenergy potential anywhere in Canada.

» Significant progress was made toward a better understanding of the impact of the Quebec legislative environment and of the perceptions of the system in development by potential early adopters in Quebec and the Prairies.

From Plant Waste to Ethanol Fuel: A Way Forward

Converting lignocellulose to ethanol fuel is a promising technology to help address the problem of declining fossil fuel sources. Lignocellulose, a plant component that is inedible to humans, is plentiful in Canada due to the country's abundant supply of agro-forestry wastes and municipal solid wastes. Lignocellulose can also be harvested from dedicated energy crops such as fast-growing grasses.

Canada has laid an impressive foundation for its lignocellulose-biofuel industry, but more detailed plans were needed to fully realize the environmental and economic potential of this technology. This project focused on developing a generic environmental assessment framework to guide the responsible development of bioenergy in Canada based on experiences with first-generation biofuels feedstocks—encompassing their production, conversion, distribution, and subsequent integration into the Canadian ground transportation fuel infrastructure. The framework also identified representative environmental end points, existing regulations, licensing requirements, permits, best practices, and guidelines required for establishing ethanol and biodiesel production facility sites in Canada. The overall goal was to establish a foundation that would enable consistency in approach between municipal, provincial, and federal government involvement and, ultimately, smooth the way for future development of second-generation biofuels feedstocks. Furthermore, the framework allows for an orderly and predictable assessment of the ecological footprint from first-generation biofuel production facilities, thereby allowing the industry to optimize environmental performance over time.

Project Title: Laying the Environmental Foundation for Evaluating Impacts from Large-scale Production of Ethanol and Biodiesel as a Precursor to Lignocellulosic Biofuels Production in Canada

Performers and Partners: Environment Canada, Canadian/Indian Science and Technology Agreement (ISTPCanada), Natural Resources Canada, Canadian Renewable Fuels Association, United States Environmental Protection Agency–Cincinnati Lab, BIOTECanada, AG-West Bio Inc., Friends of the Earth, Tembec, National Research Council Canada—Institute for Chemical Process and Environmental Technology, Public Works and Government Services Canada—Green Procurement, PetroBas—Brazil, GreenCrop, Natural Sciences and Engineering Research Council—Cellulose Conversion Network

Achievements:

» Developed an environmental assessment framework.

» In Alberta, British Columbia, Manitoba, and Ontario, the ministries of the environment referenced the framework for siting of biofuels facilities.

» Integrated the framework into Agriculture and Agri-Food Canada Environmental Impact Assessment guidelines for the Biofuels Opportunities for Producers Initiative (BOPI), and Agricultural Bioproducts Innovation Program (ABIP) biorefineries.

» The framework is currently being referenced by 35 states in the United States (U.S.) under the Irrigation Training and Research Center program, by the U.K. Department for Environment, Food and Rural Affairs and the German scientific community (under Canada-Germany memorandum of understanding on S&T).

» The framework is under consideration by Natural Resources Canada for Strategic Environmental Assessment (SEA) reporting and the Renewable Fuel Facility Environmental Performance Benchmark.

» Environment Canada will use the emissions data resulting from this project to support development of the Renewable Fuel Standard (RFS) Regulations under the *Canadian Environmental Protection Act*. The data generated during this project was considered critical to developing the architecture for the S&T strategy in support of RFS and subsequent regulatory development.

» Results from this project will be used as an agenda item for the upcoming Environment Canada/U.S. Environmental Protection Agency Scientific Meeting on Biofuels scheduled for April 2009 in Ottawa, and a proposed Environment Canada/Canadian Environmental Assessment Agency meeting in spring 2009.

Cross-cutting Project:

Industry and Biotechnology

Pulp and Paper Mills Generate Electricity from Biomass

Plant-wide examination of energy use in pulp and paper mills identified energy-saving possibilities that could turn these mills into net producers of electricity from biomass, fuels such as bioethanol, and bio-based products such as specialty chemicals. To further this goal, the project team developed a set of modelling tools that identify the energy and economic impacts of the plant and the process modifications that would be needed. By incorporating innovative biorefinery concepts, these mills could make use of the existing biomass feedstock chain to produce an expanded range of commercial products.

Components of the project included identifying possible energy and GHG emissions reductions at kraft pulp and paper mills (e.g., by using the modified thermal pinch analysis currently being developed), assessing the benefits of modifications to conventional pulp and paper processes, and evaluating new biorefinery technology pathways that would transform the conventional structure of Canadian pulp and paper mills.

Project Title: Optimizing the Carbon Value Chain in the Pulp and Paper Process Biorefinery

Performers and Partners: Natural Resources Canada, École Polytechnique de Montréal, Tembec, Domtar, White Birch, Kruger, Smurfit-Stone, Hydro-Québec, Paprican, Norampac, NewPage, Abitibi Bowater, OSISoft, 3C Software, PEPITe, Aurel Systems, Metso, GAMS Development Corporation

Achievements:

» The newly developed methodology and tools are being applied at a kraft pulp and paper mill to enhance its energy efficiency and to assess biorefinery potential.

» Developed and applied life-cycle analysis methodology to two operational mills—an integrated kraft pulp mill and an integrated newsprint mill—to evaluate the current and potential environmental performance of the mills.

» Advanced energy and water methodology showed that implementing a proposed set of 15 opportunities to one of the mills would reduce its steam consumption by 10 percent (25 MW) corresponding to fuel savings of about $2.6 million per year and a reduction in GHG emissions. Process water use would also be reduced by 30 percent, equivalent to 15 percent total water usage. In addition, the mill effluent would be reduced by 15 percent and its temperature reduced by 5°C.

» Making full use of the biorefinery concept in the Canadian pulp and paper industry has the potential to yield 6.2 Mt of GHG emissions reductions per year.

» This project will be picked up for further development through alternative funding. The use of Combined Energy and Water Optimization (CEWO) modelling is being adapted to implement biorefinery technologies at an existing pulp mill in a partnered project underway at Natural Resources Canada.

Cleaner Fossil Fuels

Fossil fuels have played an enormous role in advancing development, transportation, agriculture, medicine, manufacturing, and increasing the overall quality of life for Canadians. However, fossil fuels are a finite resource. Furthermore, the production, transformation, and consumption of fossil fuels have consequences to the environment.

The Cleaner Fossil Fuels strategic area was established to address the problem of declining conventional fuel supplies and to develop technologies that enable cleaner energy production with lower emissions of GHGs and criteria air contaminants (CACs). This strategic area funded three technology areas: Unconventional Gas Supply, Bitumen and Heavy Oil, and Clean Coal and Carbon Dioxide Capture and Storage.

Unconventional Gas Supply

As natural gas reserves decline, industry is turning to alternative gas sources, such as coal bed methane (CBM), gas hydrates, and frontier gas (conventional gas that is found in remote locations). CBM is one of the first forms of unconventional gas to be commercially developed, and experts predict that by 2025 it will be the main type of unconventional gas produced. CBM consists mostly of methane with trace quantities of other gases, and it is cleaner burning than coal. Gas hydrate is a solid that forms when water combines with one or more hydrocarbon or non-hydrocarbon gases. Per unit volume, gas hydrate contains a large amount of gas, which is often methane. The amount of natural gas contained in gas hydrates greatly exceeds conventional natural gas resources and, therefore, gas hydrates hold huge potential as an energy resource. The frontier gas industry is also promising and well underway in Canada. Current gas production from the mainland territories and offshore Nova Scotia is approximately 10 billion cubic metres per year.

The objective of the Unconventional Gas Supply technology area was to reduce technological and regulatory barriers and uncertainties to the production of natural gas from unconventional and frontier reservoirs.

Mallik Gas Hydrate Project Breaks New Ground

The Mallik gas hydrate field in the Mackenzie Delta of the north-western Canadian Arctic was discovered through an exploration well drilled by Imperial Oil Ltd. in the early 1970s. In 1998, several organizations collaborated to drill a 1,150-metre deep research well at the site, resulting in the first collection of terrestrial gas hydrate core samples in the world. Studies revealed at least 10 gas hydrate layers and high gas hydrate saturation values, in some cases exceeding 80 percent of the pore volume. This established the Mallik gas hydrate field as one of the most concentrated gas hydrate reservoirs in the world. In 2002, seven international partners began full-scale field experiments as part of a research well program that included the drilling of more wells.

The T&I R&D Initiative supported a large research project spanning three phases. Collaboration with the Mallik 2002 Gas Hydrate Production Research Well program provided access to detailed well log information describing Mallik reservoir properties, results of core sample analysis, and a range of production test data. Building on this knowledge, Phase 3 was launched to appraise methodology and technology to improve the evaluation and characterization of arctic gas hydrates with industry seismic data. It was a proof-of-concept project aimed at enabling future gas hydrate explorers to better understand information from historical data sets related to the evaluation and characterization of gas hydrate. Crews, equipment, camps, and rigs were mobilized to the remote well site. The research team overcame extreme weather (-60°C), unexpected

technical difficulties in drilling, and an early break-up of an ice road in the spring. This project is the first field gas hydrate production test in the world.

Project Title: Support for Mallik Program

Performers and Partners: Natural Resources Canada—Geological Survey of Canada, Government of Japan, Government of the Northwest Territories, Aurora Research Institute

Achievements:

» Gas hydrate production using pressure-draw-down appeared to be a successful production strategy.

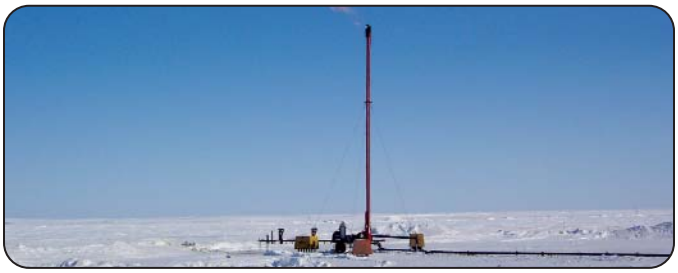
» Advances in mapping permafrost and gas hydrate occurrences using industry seismic data from Mallik and Richards Island, allowing for more accurate mapping of gas hydrate depths and dips and better seismic imaging.

» The team completed a gas hydrate quantification study to produce a refined and expanded acoustic impedance inversion data volume for all Mallik 3D seismic data, inferring the aerial extent of the 75 percent gas hydrate saturated zones within the Mallik gas hydrates pool and other occurrences tens of kilometres away.

» Evaluated field test results and identified possible improvements to instrumentation and survey design.

» During Phase 3, the team completed an extensive open-hole and cased-hole well-logging program, and ran a successful six-day production test on the production well.

» The successful progression of this project has spawned many other research projects, including research on magnetotellurics, modelling, and kinetics. This project is the first of its kind in the world, providing many countries with critical information to determine the feasibility and economics of gas hydrate production as an energy source.



Areas of Ardley Coal Zone for Coal Bed Methane Exploration and Carbon Dioxide Storage

The Alberta Geological Survey identified the Ardley coal zone in west-central Alberta as a significant repository of coal bed methane (CBM). But before CBM development can begin, several issues need to be addressed, such as concerns about potential water diversion from CBM development and uncertainty about the actual amount of CBM that could be produced.

Pumping water out of coal bed wells reduces pressure and allows for the extraction of CBM, which is found within pores and fractures of coal. Enhanced CBM extraction involves injecting carbon dioxide (CO_2) near the coal to displace the methane, because coal has a greater affinity for CO_2 than methane. The added benefit of the enhanced extraction method is that the CO_2, which is a GHG, is stored underground.

The project team characterized two specific areas in the Ardley coal zone to determine the most favourable areas for CBM exploration and CO_2 storage. The team sampled CBM wells, performed gas content and reservoir pressure evaluations, and developed detailed maps of the areas.

Project Title: Coal and Coal Bed Methane Reservoir Characterization for Production Potential, Enhanced Coal Bed Methane-Carbon dioxide Sequestration, and Groundwater Protection

Performers and Partners: Natural Resources Canada—Geological Survey of Canada, Alberta Geological Survey, Alberta Energy Research Institute, MGV Energy Inc.

Achievements:

» The project team developed a geological computer model that will be useful to industry, government, and other stakeholders for CBM exploration, development, monitoring, environmental assessment, regulation, and assessing of GHG storage capacity in geologically challenging areas.

» The team modelled gas contents from approximately 20 wells and theoretical gas contents from approximately five wells (isotherms) to create gas-in-place (total gas available) estimates for the Ardley Coal Zone.

» Geological reports on the two areas of the Ardley Coal Zone under study identified areas of reservoir continuity and risk areas for CO_2 injection.

Researchers Drill Ocean Floor to Find New Energy Source

Previous studies have identified the west coast of Vancouver Island as an area of significant gas hydrate occurrence, but more information was needed to assess the economics of marine gas hydrate production and identify possible production constraints. To learn more about the marine gas hydrate in this location, and to increase Canada's research profile on the international stage, the project researchers participated in the Integrated Ocean Drilling Program, an international marine research program that studies the Earth's history and structure by monitoring and sampling sub sea floor environments.

The project involved obtaining core samples and geophysical measurements in drill holes (called downhole geophysical measurements) through the hydrate section to determine hydrate concentrations. Researchers calibrated and verified information from over 15 years of geophysical survey systems to map and quantify marine gas hydrate. They also determined parameters to describe the magnitude and nature of *in situ* gas hydrate occurrence for reservoir modelling. Modelling could potentially be used to develop scenarios for gas production from the sub sea floor hydrate.

Project Title: Support for Canadian Research, International Ocean Drilling Program (IODP) Drilling and Measurement of Marine Gas Hydrate off Vancouver Island

Performers and Partners: International Ocean Drilling Program onboard scientific team, U.S. Navy Research Laboratory, L'Observatoire de Villefranche sur Mer, Korea Institute of Geoscience and Minerals, University of Victoria

Achievements:

» Analyzed cores and downhole measurement data from the study to provide measurements of hydrate and underlying free gas concentrations, extensive geophysical information, and hydrate parameters, such as porosity and permeability, which are required to develop methods for the production of gas from hydrate.

» Determined that Canada's distribution of marine gas hydrate is more substantial than originally anticipated in offshore British Columbia.

» The project provided training opportunities for 10 graduate students and 4 post-doctoral fellows in the group, creating trained hydrate scientists for the future.

» Verified that concentrations of hydrate a few hundred metres below the sea floor are similar to estimates from previous field data.

» Determined that there are zones containing a high concentration (60 percent) of gas hydrate. These zones are believed to represent conduits for fluids and gas migrating upward.

» Logging of the downhole geophysical data provided excellent calibration of seismic and controlled-source electromagnetic (CSEM) electrical field measurement tools, leading to improved understanding of how these tools can be used to map gas hydrates.

» The project resulted in substantial international collaboration, heightening Canada's research profile and facilitating new partnerships.

Improved Understanding and Forecasting of Ice Conditions Protects Tankers in High Arctic

Gas reserves in the High Arctic are large enough to make development viable but a challenge exists in how to transport the gas to southern markets. Large tankers are the proposed method. However, vessel operation depends on safe passage through ice-covered waters. Fifteen Arctic vessel captains were interviewed as part of a scoping study to identify research areas that would improve year-round transportation in the Arctic. Unanimously, they picked the detection of multi-year ice regionally and locally (i.e., in the immediate vicinity of the vessel) as the key research area.

This was the start of the most comprehensive ice-condition analysis of this type, covering over 30 years of shipping in the Arctic. Researchers compared actual ice conditions as recorded on Canadian Ice Service ice charts to predictions of ice conditions from satellite imagery, and from this analysis they developed

methods for identifying multi-year harder ice (old ice), which is the most dangerous to tankers. The project collaborators also developed and field-tested the Ice Hazard radar system for Canadian Coast Guard ice-breaking vessels. The system yielded huge improvements in detecting local multi-year ice, small icebergs, and other small chunks of floating ice.

Project Title: Improved Ice Information Systems for High Arctic Transportation

Performers and Partners: National Research Council Canada, Natural Resources Canada—Geological Survey of Canada, Fisheries and Oceans Canada—Canadian Coast Guard, Canadian Ice Service, Enfotec/Fednav (Canarctic Shipping), Transport Canada

Achievements:

» The project resulted in a report that presents methodology for predicting ice drift, open lanes of water, and ice pressure in the High Arctic.

» Developed a booklet that describes techniques for identifying multi-year ice from satellite imagery and from visual observations. The Canadian Ice Service, the Canadian Coast Guard, and industry will use the booklet to help train mariners.

» Transport Canada is using the information from this research to reform the *Arctic Shipping Pollution Prevention Regulations*.

» The Canadian Coast Guard is actively pursuing the radar technology for its vessels.

» The information systems resulting from this project will reduce vessel damage and improve vessel safety and operational efficiency.

Cross-cutting Project:

Clean Coal and Carbon Dioxide Capture and Storage and Unconventional Gas Supply

New Computer Model Predicts Economics of Enhanced Coal Bed Methane Extraction

According to the Alberta Geological Survey, there could be up to 14 trillion cubic metres of CBM held in Alberta coal. Enhanced CBM extraction, which involves injecting CO_2 near the coal to displace the methane, can be profitable. However, until now it was difficult to screen potential commercial projects and estimate revenue. The purpose of this project was to develop a computer model capable of modelling the economics of CO_2 capture, transport, and injection into Alberta coal seams for enhanced CBM extraction.

By linking multiple software components, the project team developed the Integrated Economics Model, which mimics the entire enhanced CBM extraction process from CO_2 source to sink. The model is specifically tailored for Alberta coal types, reservoir properties, source-to-sink distances, and prevailing local prices.

Project Title: Integrated Economic Model

Performers and Partners: Natural Resources Canada—CanmetENERGY, Alberta Energy and Utilities Board, Computer Modelling Group & Energy Navigator, Alberta Research Council, SNC-Lavalin

Achievements:

» Developed and enhanced the Integrated Economic Model by adding new features (e.g., ability to take into account effects of coal permeability changes).

» SNC-Lavalin Inc. completed and verified the accuracy of the CO_2 capture component of the model.

» The model will help with CBM prospecting by estimating the cost of CO_2 capture, transport, and injection.

» The model will increase awareness and acceptance of enhanced CBM extraction technology by industry and government.

» SNC-Lavalin is interested in continued partnership to use and further develop the tool for enhanced CBM applications and other uses, including conventional oil reservoir assessments.

» Potential for a working agreement with the Alberta Department of Energy for capture cost supply curve generation.

Bitumen and Heavy Oil

As the world demand for light transportation fuels increases and the supply of light crude oil stabilizes and then decreases, bitumen and heavy oil will become ever more important energy resources. Canada's proven petroleum reserves (second only to Saudi Arabia) are made up almost entirely of oil sands bitumen. Currently, bitumen and heavy oil are difficult to process, requiring more energy and producing more GHG emissions than light crude oil. This technology area's objective was to enable further development of technologies that reduce GHG emissions and improve the bitumen and heavy oil industry's overall environmental performance.

Better Analysis of Oil Sands Technology Provides Life-cycle Benefits

New technologies are being developed for accessing Canadian oil sands bitumen while current oil sands technologies are becoming more deeply integrated into Canada's energy system. Construction, operation, and eventual retirement of facilities in this industry will have large and complex impacts on Canada's economy and environment. Cost-effective management of GHG emissions from the oil sands sector requires accurate tools for estimating emissions from diverse oil sands extraction and upgrading technologies. In addition, accurate tools are needed to measure inputs such as capital, energy, and water required to extract oil sands bitumen. These measurements are difficult to estimate from operational data alone.

The project team created a life-cycle assessment (LCA) framework that provides a systematic method for analyzing the required inputs of energy and materials, and assessing outputs and environmental impacts for each stage of production, ranging from resource extraction to waste disposal. LCA is particularly appropriate for complex systems and for systems where the costs or impacts of upstream, capital construction, and retirement activities are significant compared to those that arise during operations. It was anticipated that the LCA framework would help prioritize research and development activities by identifying technologies, or optimal combinations of technologies, that would provide particularly large life-cycle benefits.

Project Title: Life-cycle Assessment of Oil Sands Technologies

Performers and Partners: University of Calgary, University of Toronto, Massachusetts Institute of Technology (MIT), Petrobank, Alberta Energy, Shell Canada, Synenco Energy Inc.

Achievements:

» Developed an LCA framework to enable systematic estimates of the life-cycle impacts of oil sands development to 2020 and beyond. In particular, the LCA framework provides new methods for assessing GHG emissions resulting from integrated oil sands operations.

» The LCA framework will guide public and private choices about major investments in oil sands technologies and research.

» LCA practitioners can use the model as a decision-support tool while consulting other companies or while working within companies in the oil sands industry.

» Results of this project will be disseminated to senior policy makers in the Alberta government through the Institute for Sustainable Energy, Environment and Economy at the University of Calgary.

Gas Injection Technique Doubles the Gains

Gas-over-bitumen reservoirs predominate certain areas of Alberta's oil sands deposits. In these reservoirs, natural gas overlays the bitumen deposit while exerting pressure on the bitumen. Gas-over-bitumen reservoirs present a unique challenge because, in many cases, rights have been issued to separate lease holders for gas extraction and bitumen extraction. The process typically used to extract natural gas conflicts with future bitumen extraction, which is accomplished by injecting steam into the reservoir. When the natural gas is extracted, the pressure required for efficient steam-injection processes is lost.

The project team set out to not only find a solution for the gas-over-bitumen dilemma, but to reduce the level of GHG emissions in the atmosphere. CO_2 is the most

prominent GHG, and is the product of any fuel combustion. Flue gas (combustion exhaust gas) is largely made up of CO_2. Using computer simulation and laboratory experimentation, researchers tested how CO_2 or flue gas can be used to displace natural gas laying over the bitumen to maintain the original or close to original pressure of these reservoirs. This would enable future bitumen extraction, while sequestering CO_2 underground.

Project Title: Carbon Dioxide/Flue Gas Injection for Methane Displacement and Pressure Maintenance in Gas-over-Bitumen Reservoirs

Performers and Partners: Alberta Research Council, Computer Modelling Group Ltd.

Achievements:

» Experimental results demonstrated the feasibility of injecting CO_2 into reservoirs to displace natural gas, maintain pressure, and enable concurrent extraction of natural gas and bitumen from gas-over-bitumen reservoirs.

» This new technique provides two major benefits: an alternative storage (disposal) option for CO_2/flue gas in geological formations and an alternative method for producing energy.

» The methods developed will enable reservoirs to be explored that would otherwise have been too difficult to explore, leading to additional oil and gas production and therefore enhancing the Canadian fossil fuels industry.

» Potential patent application by the Alberta Research Council.

Technology Road Map to Steer Heavy Oil Future

According to 2006 projections for bitumen-production growth from surface-mined ore, the supply of bitumen will run out sometime between 2020 and 2030. Through this project, a technology road map was completed to reduce the gap between what is currently recoverable and what can be recoverable through technology innovation. The technology road map builds on several road maps and reports prepared over the past 10 years. It focuses particularly on meeting the challenge of developing a pathway to recover bitumen in the 150- to 300-metre depth zone.

In addition to the main focus of the project, the technology road map was intended to motivate long-term R&D funding and activity for the development of new, more sustainable production options with reduced GHG emissions.

Project Title: Expanding Heavy Oil and Bitumen Resources: A Technology Road Map

Performers and Partners: Petroleum Technology Alliance of Canada, Alberta Energy Research Institute, Alberta Department of Energy, New Paradigm Engineering Ltd., Portfire & Associates, University of Alberta, University of Calgary, Steering Committee with members from provincial and federal governments, universities, and the oil sands industry

Achievements:

» The Alberta Energy Research Institute, Alberta Research Council, and industry are creating a joint R&D program to perform the laboratory work and fieldwork necessary to move forward the sustainable development of bitumen carbonate formations.

» Royal Dutch Shell invested $465 million for leases on 10 land parcels known to hold carbonate formations and has committed a specialized team to focus on managing carbonate reservoirs.

» One workshop (60 attendees) and six working group sessions (77 attendees) brought together experts to discuss inaccessible bitumen and heavy oil resources and brainstorm solutions.

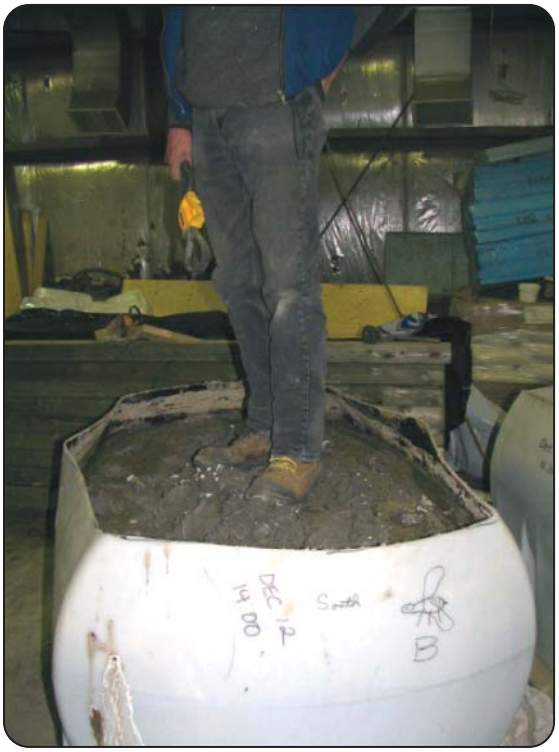
» The final report highlights over 80 potential R&D directions.

» It is anticipated that this project will stimulate interest in the potential of new deposits, including those in Alberta's Carbonate Triangle, intermediate zone oil sands, small surface-mineable deposits, and oil sands under tailings.

Green Process Developed for Fluid-fine Tailings

Fluid-fine tailings (sometimes called mature fine tailings) are created when bitumen is recovered from the oil sands. The tailings are a mix of sand, water, silt, clay, and residual hydrocarbons. The tailings are pumped into containment ponds, where the water is recycled, and the fluid-fine tailings accumulate. There is a significant amount of water in the fluid-fine tailings that could be recovered and a significant amount of energy used in the creation and maintenance of the dike structures holding the fluid tailings.

As an alternative to accumulating and storing fluid-fine tailings, this project investigated the possibility of creating dry stackable tailings by centrifugation. The addition of thickening agents (known as flocculants) to the fluid-fine tailings prepares the material for centrifugation. Once thickened, the tailings would then be spun in a centrifuge to de-water them, leaving a dry substance. The aim was to create dry tailings that could be stacked, removing the need to use a storage pond. The production of dry stackable tailings would significantly reduce both the storage volumes of water and the amount of water being taken from the Athabasca River for use in mining processes. Furthermore, the dry tailings could be used as a substrate to grow vegetation and therefore to reclaim the boreal forest at the mining site.



Project Title: Treated Tailings Process Development

Performers and Partners: Natural Resources Canada—CanmetENERGY's Advanced Separation Technologies, Syncrude Canada, Devon Energy, Suncor Energy

Achievements:

- Completed a proof-of-concept study with fluid-fine tailings being converted into dry stackable tailings.
- Developed an industry-led consortium that focused on this technology.
- Syncrude Canada committed to undertaking a large-scale pilot test to further evaluate the process and help establish the cost-per-cubic metre of tailings in partnership with CanmetENERGY, Devon Energy, and Suncor Energy.

Clean Coal and Carbon Dioxide Capture and Storage

Current combustion technologies for fossil fuels result in emissions of large amounts of carbon dioxide and other pollutants including nitrogen oxides and hydrocarbons. Clean combustion technologies are needed to reduce GHGs in general and CO_2 in particular. This technology area focused on research that would advance CO_2 capture technologies that remove CO_2 from gas mixtures, and CO_2 sequestration technologies, that dispose of CO_2 by storing it underground.

Microporous Hollow Fibre Helps Capture CO_2

Building on research started by the Alberta Research Council and the University of Waterloo, this project was launched to improve current methods of carbon capture. Carbon capture is the process of removing CO_2 from natural gas pre-combustion and from gas emissions following combustion to reduce levels of GHGs entering the atmosphere. Carbon capture is often achieved using aqueous amine-based systems, which are high-cost, high-energy, and which require SO_2 to be removed before the process can start.

The project team developed a microporous hollow fibre membrane system to increase the amount of gas-liquid contact during the carbon capture process. Initially, the technology was tested when applied to post-combustion CO_2 capture from flue gas. Following successful results, the technology was applied and tested for pre-combustion gas cleaning. One of the key findings from this project was the usefulness of straight potassium carbonate as an absorbent.

Project Title: Microporous Hollow Fibre for Greenhouse Gas Separation and Capturing

Performers and Partners: Natural Resources Canada, Alberta Research Council, Alberta Newsprint Company, Alberta Energy Research Institute

Achievements:

- In 2007 and 2008 the Alberta Research Council secured internal funding to continue working on CO_2 and SO_2 co-capture technology.
- The Alberta Research Council is in the process of partnering with Alberta Innovation and Science and the City of Edmonton to scale-up this technology and demonstrate its economic and environmental advantages over conventional systems.
- The new technology could provide a 25 to 30 percent cost reduction compared to conventional technology.
- There is potential to apply this knowledge and technology to the CO_2 and SO_2 separation associated with hydrocarbon combustion within the oil sands sector.

Next Generation Hydrogen Production Promises to Be Emissions-Free

Gasification in the presence of a lime sorbent is a process that can convert coal, petroleum, or biomass into hydrogen. Hydrogen is useful for oil sands upgrading, electrical power production, and for the transportation sector, but the gasification process for creating hydrogen results in unwanted CO_2 emissions.

Previous studies have shown that carbonation reactions performed during gasification can trap CO_2 and other impurities such as hydrogen sulphide (H_2S), resulting in pure hydrogen. The reverse reaction, calcination, regenerates the CO_2 sorbent and produces a concentrated stream of CO_2 that is ready for final sequestration. For best results, the forward and reverse reactions are run continually in a looping cycle referred to as "CO_2 looping."

This project was launched to study these reactions in more detail and to gather information on how to scale-up the process so that it can be used by industry.

Tests with synthetic gasification product gas and synthetic flue gas were conducted with the calciner (sorbent regenerator) operating with coal, biomass, petroleum coke, and blends of coal with biomass to determine whether all these fuels can be used in the process. All of these fuels were shown to be suitable for sorbent regeneration to varying degrees. Researchers

designed and installed a monitoring device inside the entrained flow slagging gasification reactor to monitor levels of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2) ,water (H_2O), and methane (CH_4).

Project Title: Zero-emissions Hydrogen Production via Gasification (ZEHP)

Performers and Partners: Natural Resources Canada, University of Ottawa, EPCOR, Sherritt International, Suncor Energy, University of British Columbia

Achievements:

» Commissioned and tested a CO_2-looping demonstration at the pilot scale, the first of its kind in the world. It featured a regenerative, calcium carbonate scrubbing technology to efficiently remove CO_2 and SO_2 from the flue stream or CO_2 and H_2S from synthetic gasification product gas.

» This process shows clear environmental benefits, with near-zero airborne emissions.

Using Oxygen to Fuel GHG-reducing Technologies

Oxy-fuel is an emerging technology for fossil fuel combustion that results in lower emissions. Traditionally, fossil fuels are burned using ambient air that has a high percentage of nitrogen present. The oxy-fuel technology involves burning fossil fuels in an environment with high levels of concentrated oxygen that does not contain nitrogen.

The resulting emissions are free of nitrogen oxide and contain CO_2 that is more concentrated and therefore easier to capture before release into the environment. Compressors can then be used to capture the CO_2. In addition, when the gas is burned at a high temperature, some of the pollutants can be converted into molten slag, which is a solid substance.

Researchers designed, built, and tested an oxy-steam burner for this project. They also investigated the use of slagging combustion and an innovative, skid-mounted CO_2 compressor train. The resulting designs include several novel concepts with significant potential for patent and technology transfer.

Project Title: Zero-emission Oxy-Fuel Combustion Technologies for Clean Fossil Fuels

Performers and Partners: Natural Resources Canada—CanmetENERGY, CanmetENERGY CO_2 R&D Consortium, Carleton University

Achievements:

» Once the intellectual property rights are secured for the slagging combustor technology, industry will be approached for technology transfer.

» The CanmetENERGY CO_2 R&D Consortium members have expressed interest in the oxy-steam burner technology. The consortium consists of industry and government organizations.

» Negotiating an agreement for the Carbon Capture Project Consortium to use the CO_2 capture technology.

» Negotiated a collaborative research agreement with the Technical University of Hamburg for the sharing of information on zero-emission systems, oxy-steam process, and advanced oxy-fuel systems.

» Signed an agreement with Foster Wheeler for collaboration on oxy-fuel combustion and with Stork of Finland.

Out with the Water, in with the Gas: Enhancing the Capacity of CO_2 Storage in Depleted Oil Reservoirs

One possible solution to reducing the amount of GHG emissions in the atmosphere is to store CO_2 in oil reservoirs once they have been depleted of oil. However, during the oil recovery process, water is injected into most oil reservoirs to help extract the oil, and the space that this water takes up limits the space for CO_2 storage.

The objective of this project was to develop techniques for injecting CO_2 into oil reservoirs that would efficiently displace the water and therefore increase the CO_2 storage capacity of these reservoirs. To accomplish this objective, the research team investigated depleted oil reservoirs with different conditions and oil-production histories. The study

comprised three tasks: laboratory CO_2 sequestration experiments, core-scale numerical simulation, and field-scale numerical simulation.

Project Title: Enhancing the Capacity of carbon dioxide Storage by Removing the Remaining Water in Depleted Oil Reservoirs

Performers and Partners: Natural Resources Canada—CanmetENERGY, University of Regina, Petroleum Research Council, Natural Sciences and Engineering Research Council

Achievements:

» The team successfully determined how CO_2 should be injected in oil reservoirs with different conditions to achieve a maximum storage capacity.

» The results obtained in this project indicated that CO_2 capacity could be greatly enhanced by the full use of gravity force and film flow mechanism.

» Experimental results showed that the effect of gravity on liquid flow can be ignored in the process of CO_2 sequestration and that different flow directions and injection rates result in different irreducible liquid saturations.

» Simulations showed that well-pattern modification is the most efficient method to enhance CO_2 capacity in depleted oil reservoirs. It was found that adding horizontal production wells in the bottom of the reservoir could improve the CO_2 storage capacity by nearly 40 percent.

» Simulations also showed that a chemical slug injection prior to CO_2 injection will provide a lower interfacial tension (lower capillary force) condition for reducing both the irreducible water saturation and residual oil saturation.

Studying CO_2 Injection in Geological Formations: Toward Integrated Monitoring and Modelling Protocols

For large-scale carbon storage systems to be successful, proper monitoring is needed to refine estimates of how much CO_2 can be contained in the reservoir, to detect CO_2 leakage, and to determine the best remedial actions if leakage occurs. Monitoring programs will need to vary the frequency and application of monitoring tools, depending upon site-specific conditions. Furthermore, what is not commonly addressed in proposed monitoring programs is the role of predictive modelling in the design of the monitoring program or the protocols for the monitoring program.

Based on the research partners' experience gained in monitoring programs at the EnCana Midale enhanced oil recovery (EOR), the Penn West Cardium EOR, and the EnerPlus Ardley enhanced coalbed methane (ECBM) sites, the team identified knowledge gaps in modelling and monitoring. Addressing these gaps, which fall under the broad headings of *capacity* and *containment*, formed the basis for the research in this project. The goal was to establish a framework of integration for CO_2 injection, storage reliability, and long-term monitoring activities. The project involved integrated experimental, numerical, and field observation approaches.

Project Title: Near- and Far-field Effects of carbon dioxide Injection in Geological Formations: Toward Integrated Monitoring and Modelling Protocols

Performers and Partners: Natural Resources Canada; Penn West Energy Trust; University of Alberta; University of Calgary; Alberta Environment; British Columbia Ministry of Energy, Mines and Petroleum Resources

Achievements:

» Addressed several knowledge gaps based on analysis of current monitoring protocols. Specifically, the knowledge gaps concerned integrity of the cements used in well systems, the integrity of cap rocks, and deformation monitoring.

» Researchers advanced the understanding of applying geochemical and geomechanical effects to the reservoir simulators; design, construction, and deployment of monitoring well systems; and use of geochemical models to assess geochemical trapping and *in situ* tracers.

» As a result of this new knowledge, the team modified some monitoring protocols and developed new protocols.

» The protocols economically and effectively integrate with oil and gas drilling and completion practices and are expected to be used by industry and governments in Canada and abroad.

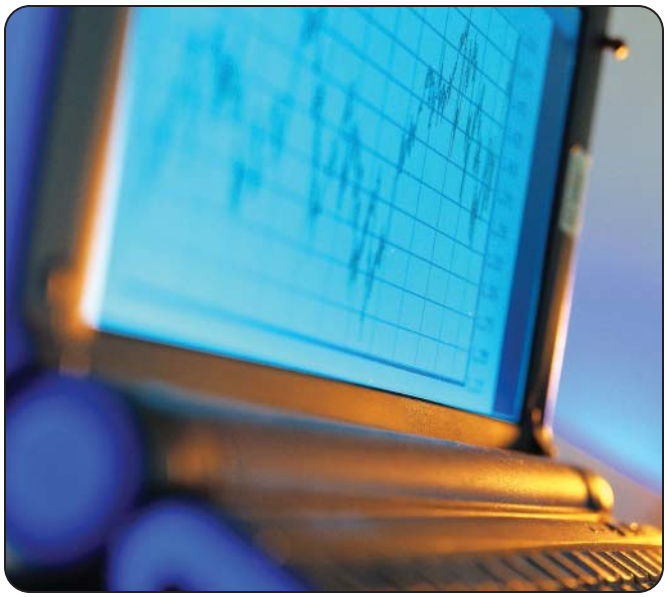
Research Team Monitors Effects of CO_2 Storage Underground

Enhanced oil recovery (EOR) refers to the techniques used for increasing the amount of oil that can be extracted from an oil reservoir. Regular oil recovery only extracts 20 to 40 percent of the oil, while EOR aims to extract 30 to 60 percent of the oil. The most common EOR technique involves injecting gas, such as CO_2, into the oil reservoir so that it pushes the remaining oil out of the reservoir. The gas also dissolves into the oil, lowering the oil's viscosity and therefore improving the oil's flow rate out of the reservoir. An added benefit is that much of the CO_2 is stored underground and away from the atmosphere.

To better understand the EOR process, this project monitored CO_2 that was injected into an aquifer as part of a pilot project started by a number of organizations in Alberta in the winter of 2005. The aquifer is found at the Penn West Pembina Cardium CO_2 EOR site, near Drayton Valley, Alberta. Building on the Penn West pilot, this project consisted of drilling and installing shallow groundwater monitoring wells to determine whether the CO_2 would leak into groundwater supplies.

Project Title: Environmental Monitoring for Penn West carbon dioxide-Enhanced Oil Recovery Project

Performers and Partners: Natural Resources Canada—CanmetENERGY, Alberta Research Council Inc., EnergyINet, Alberta Environment, Penn West Energy Trust



Achievements:

» Researchers developed methodology and tools to monitor the effectiveness of CO_2 storage that can be used in future projects.

» The work completed for the Penn West Pembina Cardium CO_2-EOR Pilot Monitoring Project supports development of this field for CO_2 storage for EOR operations. Both capacity and confinement have been demonstrated, and injectivity is being demonstrated by EOR operations.

» Significant advances have been made in measurement, monitoring, and verification with design and deployment of an observation well, design of a well-cement sampling system, design and deployment of an environmental monitoring system, use of vertical seismic profile (VSP) measurements, and the development of *in situ* tracers.

Decentralized Energy Production

Currently, the majority of electricity in Canada is produced in large, centralized power plants and distributed by electricity grids. Recent failures in electricity grids have raised concerns about the age and reliability of these systems. In addition, Canada's centralized power plants contribute significantly to Canada's GHGs and other air emissions. Decentralized energy production, including renewable power, is a promising solution to these issues, but institutional barriers, poor reliability, and high system costs stand in the way of installing power-generating systems on individual buildings.

The Decentralized Energy Production technology area was established to support activities that will build the foundation for increased use of decentralized energy systems by 2025. Projects in this technology area focused on researching and developing systems to increase the reliability of Canada's electric power system, to reduce GHG emissions from this system, and to accomplish these goals at an acceptable economic cost to Canadians. This work also involved updating and developing standards (e.g., codes and rules describing how to safely connect power technology), which is crucial to successfully deploying new technology.

Updated Standards Propel Wind Energy Development

At the start of this project, Canadian standards for wind energy systems were out of date and not applicable to modern wind energy technology. As a result, the previous Canadian standards were an impediment to the industry. Regulators had to use a patchwork of approaches for granting permits, which increased risks and costs for developers. The project established several technical sub-committees that not only reviewed the Canadian Standards Association (CSA) Standards for Wind Energy Conservation Systems, but harmonized them with the International Electrotechnical Commission (IEC) standards. This ensured that the standards met Canadian environmental regulations as well as other requirements such as electrical and building codes. The process engaged regulators, manufacturers, developers, and other industry stakeholders. The new standards, approved by the CSA Renewables Committee, are more aligned with international standards, which will minimize trade barriers, reduce costs and risks, and leverage international efforts to keep standards current.

Project Title: Renewable Energy Technology Development of National Standards

Performers and Partners: Natural Resources Canada, Canadian Standards Association

Achievements:

» Publication and adoption of five new Canadian wind turbine standards based on the IEC standards to better reflect modern wind energy technology. The adopted standards were as follows:

- IEC 61400-1: Wind Turbine Design Requirements (numerous Canadian deviations)
- IEC 61400-2: Small Wind Turbine Design Requirements (numerous Canadian deviations)
- IEC 61400-11 2nd Edition: Acoustic Noise Measurement Techniques
- IEC 61400-12-1: Power Performance Measurements of Electricity Producing Turbines
- IEC 61400-24: Wind Turbine Lightning Protection (Canadian deviations)

Hot Green Homes: Solar Electricity Meets Solar Thermal

Technological advances have increased the number of ways that solar energy can be used. Photovoltaic (PV) cells capture the sun's energy to produce electricity in a sustainable manner. In addition, solar thermal recuperation technology enables the sun's energy to be used to heat buildings. This project examined ways to combine solar electricity and solar thermal for use in single-family homes.

In the first phase of the project, researchers focused on the technical issues and strategies of integrating the PV and thermal (PV/T) systems into the building envelope (i.e., the rooftop, awnings, and facades). They also devised ways to recover the excess heat generated by these systems to supply the heating and cooling demands of the home. (Of note is that PV cells perform better when they are cooled.) The second phase consisted of field testing the most promising system design. This phase supported PV/T demonstrations in residential buildings (ÉcoTerra net zero energy home built by Alouette Homes as part of Canada Mortgage and Housing Corporation's EQuilibrium Initiative) and non-residential buildings (the University of Concordia's new John Molson School of Business building).

Project Title: Photovoltaic/Thermal Systems in Residential Homes

Performers and Partners: Natural Resources Canada, Saskatchewan Research Council, Canada Mortgage and Housing Corporation, Conserval Engineering, University of Concordia, Canadian Solar Buildings Research Network (University of Concordia, Queen's University, University of New Brunswick, University of Waterloo), ARISE Technologies Corporation, Maisons Alouette (Aloutte Homes), International Energy Agency—Photovoltaic Power Systems Programme Task 35

Achievements:

» Investigated four PV/T concepts for residential integration and disseminated technical reports and five papers at national and international conferences.

» Project partners took part in the 2005 U.S. Department of Energy Solar Decathlon to demonstrate integrated PV and solar thermal technologies in a residential demo house, and to model for optimized PV/T system performance and heat recovery. This house received two first-place awards from BP Solar and the U.S. National Home Builders Association for the best integrated system and the most energy-efficient house.

» Project partners participated in Annex 35 of the International Energy Agency Solar Heating and Cooling Program, focusing on energy analysis and modelling of PV/T systems. The Solar Buildings Research Network hosted an Experts Group meeting of Annex 35 in Toronto and provided an opportunity to Canadian researchers to co-operate with international experts. Technical reports and contribution to Annex outputs resulted from this activity.

» Project partners collaborated with several Canadian private-sector proponents to apply PV/T concepts in the house designs submitted to the Canada Mortgage and Housing Corporation for funding under the EQuilbrium Housing competition. These houses were approved and have been constructed.

» A continuation of this project sought to strengthen the competitive position of Canada's solar energy companies, enabling Canada to take advantage of the huge potential in the solar energy market growth. An R&D network was established to identify innovative and promising new technologies that Canada has the capacity to develop.

Mapping Canada's Winds: New Wind Atlas Promotes Renewable Energy Industry

To guide the burgeoning Canadian wind industry, project partners developed a state-of-the-art Wind Atlas that maps wind occurrences across Canada. The Wind Atlas is based on previous wind mapping work conducted by Environment Canada and a wind mapping system called the Wind Energy Simulation Toolkit (WEST) developed by the Meteorological Service of Canada Research Branch. The objective of the Wind Atlas is primarily to show Canadians and decision makers the wind energy potential of Canada and to provide free wind data to individuals who want to do a pre-feasibility assessment of their wind project. Wind information is provided at three heights

and can be interpolated or extrapolated to provide wind information at any height for the first few hundred metres above ground.

Project Title: National Wind Atlas and Related Tools

Performers and Partners: Environment Canada, Natural Resources Canada, National Research Council Canada

Achievements:

» Developed a Wind Atlas that consists of a large set of web-accessible, geo-referenced digital maps displaying long-term wind statistics, such as speed and direction frequencies, and seasonal fluctuations.

» Unlike the U.S. Wind Atlas, which features 50 small maps side-by-side, the Canadian Wind Atlas consists of a mosaic of 18 maps. To develop this mosaic, Environment Canada had to develop a new technique. This "mosaic technique" is now being used to develop wind atlases of other large countries, such as China.

» Many provinces have used the wind data developed for the Wind Atlas as the basis for the development of their own provincial wind atlases.

» Since the launch of the Wind Atlas, which can be downloaded for free by anyone, the project partners report that they have stopped hearing people argue that there is no good wind in Canada and that investing in wind energy in Canada is a waste of time and money.

» Information from the Wind Atlas and related tools will not only help in the building of new wind farms, but will guide their operation and management (e.g., forecasting of low-wind days to schedule turbine maintenance work).

Fish-friendly, Variable-speed, Low-head Turbine System Developed

This project focused on developing two new hydropower turbine systems that would be economically viable and environmentally friendly, especially to fish populations.

Hydroelectricity is the most widely used form of renewable energy, typically resulting in lower GHG emissions than fossil fuel power plants. The energy generated depends essentially on the efficiency of the power generation systems, the volume of water, and the difference in height—called the head—between the source and the water's outflow. High-head hydroelectric power systems generate more energy, but they often require the building of dams and water reservoirs, which have negative environmental and human impacts. Even low-head systems have negative environmental impacts because they kill fish that pass through the turbines. In addition, when water levels drop, available energy drops in proportion to the head and flow.

Canada has a significant low-head hydro potential, estimated to be over 4,000 MW for heads ranging from 3 to 15 metres. But to take advantage of this potential, new turbine systems were needed to overcome economic and aquatic ecosystem challenges.

Project Title: Fish-friendly, Variable-speed, Low-head Turbine System

Performers and Partners: Natural Resources Canada, Rapid-Eau Technologies Inc., University of New Brunswick, Powerbase Automation Inc., Swiderski Engineering, Norcan Hydraulic Turbine Inc., GE Hydro, Alstom Power

Achievements:

» The project team developed two low-head turbine systems that address heads from 7 to 15 metres and 3 to 7 metres, respectively. The systems include turbines, generators, power convectors, and controls.

» Operating at variable-speed, the propeller turbines can run over a wide operating range (low or high flows) with high efficiencies and high turndown ratio. Therefore, more power can be generated overall.

» The turbine systems are non-regulated, requiring a no-speed increaser (gearbox), which reduces the overall cost for run-of-river applications. Run-of-river refers to low-head operations that do not require a large dam or water storage reservoirs to be built.

» The turbines are expected to reduce fish mortality to less than 5 percent (typically, 5 to 10 percent of fish passing through the best existing turbines are killed, while 30 percent or more are killed passing through other turbines).

New Standards and Certification to Smooth Adoption of Alternative Energy

Bringing together multiple stakeholders, this project was launched to build consensus on requirements for the interconnection of distributed energy resources (DERs) to the power grid in Canada and to increase Canadian participation in the development of international interconnection standards. DERs are small power generators, often running on solar, wind, or microhydropower, which are located near the area of highest power consumption. To enable the best possible use of DERs, new standards and codes needed to be developed and old ones needed updating, especially on contentious issues such as ways of disconnecting from the grid, islanding, and power quality.

Over 50 Canadian experts participated in this project to make Canadian standards consistent with international equivalents and to ensure that Canadian requirements are recognized in international standards.

In a continuation of this project, collaborators developed standards, certification programs, and regulations for distributed generation products. These safety and performance standards will assure end-users that the products meet quality criteria without the need for additional testing.

Project Title: Distributed Generation Product Standards and Certification

Performers and Partners: Natural Resources Canada; CSA International; Electro Federation of Canada—Electrical Equipment Manufacturers Advisory Council; Xantrex Technology; City of Vancouver; members of IEC TC8; members of IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems and IEEE P1547.1 Draft Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems; Canadian Standards Association—Steering Committee on Requirements for Electrical Safety (SCORES); Canadian Standards Association—Steering Committee on Power Engineering (SCOPE); members of CE Code Section 50 Committee, members of CSA C22.2 107.1 Standard General Use Power Supplies Technical Committee; McGill University; University of Alberta; University of New Brunswick; members of IEC TC 4 (Hydro), members of IEC TC 82 (photovoltaics); members of IEC TC 88 (wind turbine); members of ISO TC97 (microturbines); members of IEC TC 105 (fuel cells); BC Hydro; NB Power; Manitoba Hydro; Nova Scotia Power Inc.; Hydro-Quebec; ENMAX Corporation; EPCOR; SaskPower; Hydro One; Toronto Hydro; Manufacturers of DG, systems integrators, power conversion equipment, motors, transformers, and electrical distribution equipment

Achievements:

» Publication of CSA C22.2 as a national standard on the interconnection of inverter-based systems to the electrical distribution system. This standard is the successful conclusion of the MicroPower Connect initiative.

» Successful development of a draft standard for heat meters (adoption of EN 1434) and the inclusion of natural gas for emergency power plants CSA C282.

» Changes were made to the *Canadian Electrical Code* in Section 14 (Protection and Control), Section 50 (Photovoltaics), and Section 84 (Interconnection).

» Completed 2nd National Standard *CSA 22.3 No.9 Interconnection of Distributed Resources with Electrical Supply Systems*.

» Adoption by provinces of *CAN/CSA-C22.22 NO.257-06 Interconnecting Inverter-based Micro-distributed Resources to Distribution Systems*.

» The work on standards completed in this project is vital to ensuring that the power technology developed in other parts of the Decentralized Energy Production technology area can be deployed. Furthermore, by ensuring that key developments are represented in the *Canadian Electrical Code*, manufacturers, installers, and electrical inspectors across Canada can deal with consistent requirements.

» A peer review meeting entitled "DER Interconnection Standards, R&D, and Project Implementation" was held March 25, 2008, in Toronto. It was organized by Natural Resources Canada in collaboration with Electro-Federation Canada. The 65 attendees learned about the latest development in interconnection R&D, technical requirements, and standards. Contributors shared their experience on lessons learned and practical issues on successful projects. The information is now publicly available at <www.powerconnect.ca/references/presentations-e.htm>.

Cross-cutting Project:

Decentralized Energy Production and Clean Coal and Carbon Dioxide Capture and Storage

Ammonia to Fuel the Future

Solid oxide fuel cells (SOFCs) have several benefits over other types of fuel cells. They can run on a variety of fuels and are particularly efficient in converting the fuels to electricity. When the heat that is generated from the reaction is harnessed (instead of escaping as waste), SOFCs become combined heat and power (CHP) systems. The project team wanted to take these benefits one step further by developing an SOFC that can run on anhydrous ammonia. Anhydrous ammonia is a clean and potentially renewable hydrogen carrier fuel. It has high energy density and is handled much like propane. Ammonia already has a widespread distribution infrastructure related to its use in agriculture, which makes it readily available and feasible to use as a fuel for SOFCs. By the nature of the industrial process, pure CO_2 is a by-product of ammonia production from natural gas (or other fossil fuels) and, as such, can be sequestered economically.

Previously, Natural Resources Canada conducted in-house R&D to develop a zero-emissions ammonia fuel cell. In partnerships with Acumentrics Canada, Natural Resources Canada tested ammonia in Acumentrics' SOFC stack, which is integral to its natural gas-based SOFC systems. The goal was to accelerate fuel cell technology development, leading to more widespread acceptance and use of ammonia as a clean and potentially renewable fuel for efficient stationary, decentralized CHP.

Project Title: Zero emission Ammonia Fuel Cells for Decentralized Power Generation

Performers and Partners: Natural Resources Canada, Terra Environmental Technologies, Agrium, Acumentrics Canada

Achievements:

» The project team successfully developed and tested novel proton-conducting ceramic fuel cell materials for direct ammonia fuel cells. Power densities achieved in the anode-supported single-cell fuel cells, rivalled commercial zirconia-type SOFCs, and operated at lower temperatures.

» This work resulted in numerous peer-reviewed journal publications and conference presentations.

» A preliminary evaluation assessed the technical and economic feasibility of exploiting ammonia as a carbon-free energy carrier, and using direct ammonia fuel cells for critical uninterruptible power and CHP.

» The project team evaluated ammonia as a fuel and measured the performance characteristics of Acumentrics Canada's proprietary SOFC, which is being developed to run on natural gas for residential CHP. Preliminary results were very encouraging.

Gas Line Expander Turbine Combined with a Molten Carbonate Fuel Cell

Opportunities exist to achieve greater energy efficiency by harnessing waste heat and using it to produce power. Experts in government and industry collaborated to seize this opportunity and build a new combined-cycle power plant using pipeline gas pressure (a waste product) and a molten carbonate fuel cell.

A hybrid power plant was built on the site of a gas pipeline let-down station in Toronto. The hybrid power station combines a 1 MW gas expansion turbine with a 1.2 MW molten carbonate fuel cell. The fuel cell operates at temperatures over 650°C and the waste heat from this operation preheats gas flow into the turbine.

Project Title: Distributed Energy Resources Fuel Cell/Expander

Performers and Partners: Natural Resources Canada, Enbridge Gas Distribution, Toronto Hydro, Government of Ontario

Achievements:

» The Fuel cell expander combined-cycle plant produces ultra-clean emissions. In comparison, the 990 MW Goreway plant located near Toronto, a state-of-the-art, gas-fired power plant with full gas cleanup, emits 13 times more criteria air contaminants (CACs) on a g/kWh basis.

» Institutional barriers were removed, including a permit issue identified with the City of Toronto, thus paving the way for future distributed generation projects.

» The expansion turbine is now operational.

» The fuel cell has also been commissioned and combined operation is expected in 2009.

» A second project to build a 7.9 MW power plant is under development in the U.S. with Enbridge Gas Distribution investment.

Hydrogen Economy

Hydrogen is the most abundant element in the universe and, although it does not occur naturally on earth as a gas, it can be separated from other elements and used as an energy carrier or fuel. Hydrogen is the cleanest burning and most efficient fuel, offering two to three times more energy per unit of mass than other common fuels. Using hydrogen as an energy carrier has a great potential to lower GHG emissions, improve air quality, promote industrial development, and generate wealth.

The Hydrogen Economy technology area was established to expand knowledge and advance technologies that mitigate climate change and air pollution through hydrogen use. This technology area facilitated hydrogen-related R&D that would contribute to creating a hydrogen energy economy. In such an economy, hydrogen would be extensively used as an energy carrier and chemical feedstock. The projects under this technology area focused on hydrogen production, storage, and use, as well as the codes, standards, safety, and outreach mechanisms necessary to guide these processes.

Biomass By-products for Hydrogen Production

This feasibility study identified Canadian sources of biomass by-products from industry that can be used for hydrogen production. The Canadian biomass sources studied included waste from the forestry and agriculture sectors, the pulp and paper industry, and glycerol, which is a by-product of biodiesel production.

The project resulted in a report that outlined the two main categories of technologies for the conversion of biomass to hydrogen: biological processes and thermal processes. Biological processes include biophotolysis, biological water-gas shift reactions, photofermentation, and dark fermentation. However, these are still in the early stages of development and, therefore, were not elaborated in the report. The three main categories of thermal processes are pyrolysis, liquefaction, and gasification. The report provides a more in-depth discussion of the two most efficient thermal processes, pyrolysis and gasification. Moreover, a brief discussion of two new gasification technologies—biomass gasification in supercritical water and catalytic thermal conversion—was presented.

Project Title: Biomass By-products to Produce Hydrogen

Performers and Partners: Natural Resources Canada, Université du Québec à Trois-Rivières

Achievements:

- The resulting report evaluates the economic and technical feasibility of using biomass sources and conversion technologies for efficient hydrogen production.
- The project identified pulp waste as a potential source of 145,000 tonnes per year of hydrogen, and glycerol as a potential source of 70,000 tonnes per year of hydrogen.
- It was determined that production of hydrogen from biomass via gasification is economically comparable to steam methane reforming if GHG impacts are considered.

New Materials Improve Hydrogen Fuel Cells

Solid oxide (ceramic) fuel cells produce energy by adding oxygen to a fuel. The ceramic conducts electricity while keeping the oxygen and hydrogen separate. The most commonly used ceramic, zirconia, requires a high operating temperature (600°C to 1,000°C) to be efficient. The high temperature necessitates the use of high-cost materials in the fuel cell's construction and affects the life and reliability of the fuel cells.

This project investigated the use of alternative ceramics, such as lanthanum gallate, for use in solid oxide fuel cells to allow the operating temperature to be reduced to the 500°C to 800°C temperature range. Enabling fuel cell operation at this temperature range would mean a wider range of materials could be used in their construction, including metallic components, reducing the cost as well as extending the life and reliability of the fuel cells.

Project Title: Materials for Hydrogen Fuel Cells

Performers and Partners: Natural Resources Canada, National Research Council Canada

Achievements:

» The publications produced as a result of the research are widely cited in the scientific literature related to solid oxide fuel cells.

» Published seven papers in international peer-reviewed journals.

» Developed novel electrolyte materials for solid oxide fuel cells in the 500°C to 800°C temperature range.

Converting Sour Gas into Hydrogen

Natural gas contains various levels of hydrogen sulphide (H_2S). When the concentration of H_2S in natural gas is particularly high, it is commonly referred to as "sour gas." Because H_2S bonds require less energy to split than other compounds that contain hydrogen, such as water or methane, H_2S is a promising source for low-cost hydrogen.

In this project, Kingston Process Metallurgy adapted an innovative H_2S splitting technology to develop a hydrogen production method. This method would allow hydrogen to be produced from sour gas at a low cost and with limited CO_2 generation.

The method isolates the H_2S gas using existing technology, then bubbles the gas through molten copper. Pure hydrogen gas is released and captured, while the sulfur reacts with the copper and turns it into copper sulfide. The reactions between the H_2S and copper and the copper sulfide and air release energy that helps to heat the system, thus increasing efficiency.

Project Title: Hydrogen Production from Hydrogen Sulphide and Methane

Performers and Partners: Natural Resources Canada, Kingston Process Metallurgy Inc., U.S. Department of Energy—Argonne National Laboratory

Achievements:

» The research team defined optimum experimental conditions including cycle rate, extent of reaction, control of end-of-cycles, carbon removal from hydrocarbons, H_2S to hydrocarbon ratio, and impact of impurities.

» The research team developed a lab-scale reactor capable of handling H_2S with a flow rate of 20 L/min.

» Performed calculations that optimized the process and system for industrial-scale hydrogen production. This included determining the optimum rate of hydrocarbon injection for application on the industrial scale.

» In addition to producing hydrogen from sour gas, this process also produces concentrated sulphuric acid, a valuable product in the chemical industry and agriculture.

» This project was highlighted on the Argonne website.

Nanomaterials Advance Hydrogen Storage

Existing hydrogen storage systems for use in vehicles are heavy and expensive since they are based on compression or liquefaction of hydrogen. Making hydrogen a viable alternative to carbon-based fuels will depend on developing compact and lightweight hydrogen storage systems for vehicles using low-cost materials and components. Research worldwide in this area is focused on creating hydrides, which are compounds of hydrogen and other materials. Various approaches and materials, mostly involving lightweight metals, are being investigated.

This project examined the use of novel nanomaterials and emerging nanotechnologies for hydrogen storage. One area investigated was the use of magnesium to store hydrogen through the creation of magnesium hydride or magnesium chemical hydride complexes. Research was also conducted into the use of metal-water slurries. The project also investigated hydrogen storage and delivery using water-soluble borohydrides.

Project Title: Nanomaterials for Hydrogen Storage

Performers and Partners: Natural Resources Canada, University of Waterloo, INCO (now Vale INCO), University of Wollongong (Australia), Russian Academy of Sciences, and Hy-Energy (U.S.)

Achievements:

» In partnership with the University of Waterloo, developed new process for charging hydrides in mechanical ball mills fed with hydrogen under ambient temperature and pressure.

» Through an international collaborative project, jointly developed new nanostructural materials Mg_2FeH_6 and (nano) Ni-catalyzed MgH_2.

» In partnership with INCO, developed new nanonickel catalyst for hydrogen storage in magnesium metal.

» Published more than 40 technical papers in international R&D journals.

Towards a Successful Wind-Hydrogen-Diesel Demonstration

Ramea Island, located off the coast of Newfoundland, was chosen in 2004 to be the site of Canada's first wind-diesel demonstration project. The wind turbines are so productive that the energy generated often exceeds the community's needs. Since the wind energy cannot be easily stored, the excess energy that is generated is lost. Meanwhile, during periods when the wind turbines are not able to produce enough energy, the community must rely on diesel generators to produce electricity.

This project involved conducting a feasibility study to determine whether hydrogen technology could be used to capture and store the wind energy being lost. If possible, the small island would be able to reduce the use of diesel generators when demand is low.

Simulations were developed to analyze the impact of adding hydrogen generation, storage, and utilization technologies to the current wind-diesel demonstration project. Specifically, the study's objective was to look at using the electricity created by the wind turbines to create hydrogen through electrolysis and then storing the hydrogen for future use.

Project Title: Ramea Island Wind Demonstration Project

Performers and Partners: Newfoundland and Labrador Hydro, Atlantic Canada Opportunities Agency, Government of Newfoundland and Labrador, Natural Resources Canada, Memorial University, University of New Brunswick, Frontier Power Systems

Achievements:

» The model designed by this study will have the potential to evaluate the feasibility of future wind-diesel-hydrogen demonstrations.

» This tool will be useful for decision-making processes by power utility companies.

Advanced End-use Efficiency

End-use energy is the final energy used by residential, commercial, and industrial communities and the transportation systems that connect them. It differs from supply-side energy, which is the energy used to extract, convert, and transport energy resources to users. Improving end-use energy efficiency plays a major role in reducing GHG emissions and curbing climate change. In addition, it is significantly less expensive to reduce the amount of energy used than to produce more energy.

The Advanced End-use Efficiency strategic area researched and developed energy-efficient technologies that would help in building, renewing, and powering communities and infrastructures while reducing emissions of GHGs and other pollutants. The Advanced End-use Efficiency strategic area funded three technology areas: Transportation, Industry, and Buildings (Commercial and Residential) and Communities.

Transportation

Transportation is the single largest source of GHG emissions in Canada, accounting for 25 percent (179 million tonnes) of the country's total emissions in 2000. The objectives of the Transportation technology area were to gain a better understanding of the transportation sector's role in climate change, including the magnitude of its role and the mechanisms involved. Furthermore, the technology area aimed to develop and implement new technologies to mitigate the transportation sector's contribution to climate change, thereby strengthening Canada's technology capacity for a more efficient transportation system.

Black Carbon Demystified

Black carbon is created through the incomplete combustion of fuels, including fossil fuels, biofuels, and biomass. Research indicates that it is the second most important contributor to global warming after CO_2. Black carbon contributes to climate change by absorbing sunlight and heating the surrounding air. When deposited on ice and snow, black carbon decreases the reflection of sunlight, thereby increasing the rate of ice and snow melt.

Black carbon from different sources has very different physical and chemical characteristics. These characteristics are altered when the particles are emitted into the atmosphere. Black carbon is emitted in one locale (i.e., an urban area), mixes with air from other polluted areas, and then mixes with relatively clean air from remote locations.

The exact role and extent of black carbon's impact on climate change is unknown due to significant knowledge gaps related to the amount of black carbon in the atmosphere and its chemical and physical properties. These knowledge gaps make it difficult to develop accurate models of climate change that take into account black carbon's effects.

This project examined the contribution that North American emissions make to black carbon atmospheric levels in the northern hemisphere using black carbon measurements from the Canadian Arctic. Researchers also investigated the relative contribution of black carbon from transportation sources versus other sources, such as forest fires. Finally, the researchers sought to couple regional air quality models with hemispheric black carbon models. Analysis of this data included isolating Canadian transportation sources of black carbon and determining their influence on variations of black carbon concentrations over North America and the Arctic at different points in time and space.

Project Title: Black Carbon Emissions and Atmospheric Levels in Canada

Performers and Partners: Natural Resources Canada, National Research Council Canada—Institute for Chemical Process and Environmental Technology, Environment Canada—Emissions Research and Measurement Division, Environment Canada—

Meteorological Service of Canada, Ontario Ministry of the Environment, York University, University of Toronto, University of Windsor, University of Western Ontario, University of British Columbia, United States Environmental Protection Agency, United States National Oceanic and Atmospheric Administration, United States Department of Agriculture—Desert Research Institute, Tsinghua University (China), Graduate University of Chinese Academy of Sciences (China), International Steering Committee for Black Carbon Reference Materials, Artium Technologies Inc., Sandia National Laboratories (United States Department of Energy), Cranfield University (United Kingdom)

Achievements:

» Developed capability to reliably assess the impact of black carbon (and organic carbon) emissions both globally and within Canada on air quality and climate.

» Developed new modules for the enhancement of the Canadian Global Climate Model that will improve its effectiveness and increase its usefulness in policy development.

» Field trials have shown that it is possible to unambiguously measure black carbon levels in the atmosphere.

» Analysis of black carbon measurements from Arctic databases narrowed down the source areas to be predominantly in continental Asia.

» Helped to demonstrate that particulate contribution to global warming is the greatest uncertainty in climate change models.

» Multi-year measurements have improved the current knowledge of aerosols and will allow better estimates of their impact on Canadian and global climate.

» Three peer-reviewed publications, one Ph.D. thesis, and content contribution to a book.

Curbing Off-road Emissions

Off-road transportation equipment, which includes everything from lawn tractors to snowmobiles to excavators, is a significant contributor to GHG emissions and other air pollutants. However, there are considerable knowledge gaps in the area of off-road machine contributions to GHG emissions in Canada. This is exemplified by the fact that the current GHG emissions estimates for these machines, based on emission factors and activity information, are not reflected in estimates based on actual fuel consumption during real-world use.

This project involved collecting activity information for a variety of off-road equipment operated outdoors under real-world conditions. A data acquisition system was developed and used to take measurements from governed spark ignition engines. This system was then modified for use in recreational vehicles and deployed to gather real-world activity data on a snowmobile and all-terrain vehicle. Another data acquisition system was designed for diesel engines and installed on City of Ottawa equipment. The measurements were then used to quantify GHG emissions and fuel consumption.

Project Title: Greenhouse Gas Emissions from Off-road Transportation Sources

Performers and Partners: Natural Resources Canada, Carleton University, City of Ottawa, United States Environmental Protection Agency

Achievements:

» Measurements taken using data acquisition systems showed that there was a marked difference between established testing protocols and the real activity levels observed under actual operations.

» Developed a knowledge base of GHG emissions and activity. As a result, recommendations can now be made to change the way the equipment is used to reduce fuel consumption and GHG emission that encompass both new and in-service off-road machines.

» Collaborations spanning provincial and municipal governments.

» Linked with Environment Canada Off-road CO_2 Initiative.

» Two students and research fellows developed new skills in measuring vehicle activity, in interpreting that data into useful laboratory testing procedures, and in quantifying CO_2 emissions from this sector.

» Published an internal technical report.

Advanced Fuels for Homogenous Charge Compression Ignition Engines

The upcoming 2010 diesel emission standards for North America mandate drastically reduced particulate matter (PM) and nitrogen oxides (NO_x) emissions. To comply with these standards, automotive manufacturers may look to homogenous charge compression ignition (HCCI), which offers the potential of diesel-like fuel conversion efficiency (25 to 30 percent higher) with low emissions of PM and NO_x. This project studied the effects of fuel properties on HCCI combustion under various conditions to develop a practical method for rating the combustion quality of HCCI fuels.

The National Research Council Canada (NRC) commissioned a state-of-the-art facility to clarify the relationship between fuel chemistry and the performance and emissions from an HCCI engine. HCCI combustion and emissions data were collected using commercial gasoline and diesel fuels. A novel diesel fuel vaporizer was then developed to improve fuel-air mixing using middle distillates. The vaporizer will enable NRC researchers to become leaders in quantifying the auto-ignition behaviour of HCCI fuels under realistic in-cylinder conditions.

NRC plans to continue studying this area to support the development of a future American Society for Testing and Material method for rating HCCI fuels, as well as to ensure that the Canadian oil sands and renewable fuels industries are able to profit from this emerging opportunity.

Project Title: Advanced Fuels for Homogenous Charge Compression Ignition (HCCI) Engines

Performers and Partners: National Research Council Canada, Natural Resources Canada, United States Department of Energy–National Renewable Energy Laboratory, Environment Canada

Achievements:

- NRC researchers were the first to report increased NO_x emissions when combustion phasing (the timing of auto-ignition) is slowed.
- Disseminated HCCI combustion knowledge to the scientific community, the oil industry, and fuel policy-makers.
- Developed new skills in the measurement of vehicle activity, in the interpretation of that data into useful laboratory testing procedures, and in the quantification of GHG emissions from this sector.
- The project generated two conference publications in fiscal year 2007 to 2008, as well as six other publications with the related Program of Energy Research and Development (PERD) Advanced Fuels and Transportation Emissions Reduction (AFTER) Program.

Multinational Venture for Safe and Fuel-efficient Lightweight Vehicles

This project set out to substantially decrease the weight of vehicles—to reduce GHG and other emissions—while at the same time improving vehicle safety. To achieve this dual task, ultra-high-strength steels (UHSS) were used in a redesigned safety cage of vehicles and combined with light magnesium alloys for their front-end structure.

In the first part of the project, steelmakers and automotive producers in Canada and the U.S. collaborated to determine the process window for hot forming and die quenching of UHSS. They also assessed performance coating during hot forming and tested the mechanical properties of the steel under the process conditions.

Under the second part of the project, Canada collaborated with the U.S. and China to develop initial designs for two automotive sub-assemblies (front end) using magnesium in place of current steel parts. Partners are moving on to design, manufacture, and assemble magnesium components and test them for their performance. Some of these components are already in production vehicles today, with others still in their final design stage.

The knowledge and technologies developed through this project could contribute to the development of hybrid (diesel) and fuel cell vehicle technology, which calls for low vehicle weight without compromising passenger safety.

Project Title: Lightweight Vehicle-body Architecture (LiVBA) Project: Part I – Advanced ultra-high-strength Steel (UHSS) Processing, Manufacturing, and User Properties; Part II – Magnesium Front-end Development (MFED)

Performers and Partners: Natural Resources Canada, United States Department of Energy, Chinese Ministry of Science and Technology, Cosma International, G-Mag International, Husky Energy, Trimag, Auto Steel Partnership, Magna International, Martinrea, Centreline, USCAR

Achievements:

» The project generated technology transfer to industry partners on hot forming, phase transformation during hot forming, and microstructure control in hardened parts.

» The work has confirmed that galvanized steel is suitable for indirect forming, leading to significant cost reductions.

» Husky Energy and G-MAG (member of Magna International) jointly developed thixomolding technology to cast a magnesium component for the front end.

» Cosma Engineering (member of Magna International) designed the first magnesium front end, which was 40 kg lighter than conventional steel front ends.

» Project partners worked with the Canadian company Centreline to demonstrate that cold spraying technology can protect magnesium alloys from corrosion.

Safety Key to Powering Next Generation of Hybrid Vehicles

Hybrid electric vehicles are effective for reducing GHGs as well as particulate, toxic, and smog-forming emissions. However, these vehicles currently use nickel metal hydride (NiMH) batteries, which take up significant cargo space and lose power quickly. This project aimed to address these issues by developing a lithium ion battery—with three times the energy storage density of NiMH—that would be safe enough for use in hybrid vehicles.

The approach in this project was to replace the flammable liquid organic electrolyte of conventional lithium ion batteries with a solid electrolyte of similar ionic conductivity. Plastic crystal electrolytes and ceramic oxide electrolytes were investigated, as well as the cycling stability of metal alloy anodes in combination with plastic crystal electrolytes and lithium iron phosphate cathodes.

New electrode and electrolyte materials developed in the first two years of this project have shown excellent performance characteristics in early-stage testing in laboratory-scale batteries. However, their compatibility with other cell components and their longer term durability must be verified.

Project Title: High Energy Density Electrical Storage for Hybrid, Fuel Cell, and Electric Vehicles

Performers and Partners: Natural Resources Canada, Electrovaya, Defence Research and Development Canada

Achievements:

» New electrolyte formulations significantly improve the safety of lithium ion batteries while retaining the required performance characteristics for use in hybrid, fuel cell, and electric vehicles.

» Filed a provisional patent application based on the early results of the project.

» Developed a novel method of synthesis of low-cost, high-voltage cathodes that results in concurrent improvements in battery safety and storage capacity retention.

» Project partners demonstrated safe, higher energy and power density lithium ion batteries suitable for a range of transportation applications.

» Project partners assisted in the planning and organization of the first international conference on plug-in hybrid electric vehicles, held in Winnipeg in November 2007.

» Initiated discussions with potential industrial partners regarding commercialization of new electrolyte formulations developed under this project.

Industry

Canada's industry sector accounts for approximately one third of energy use and one fifth of emissions. The Industry technology area's objective was to conduct R&D and facilitate innovation that would lead to clean, efficient, and economic energy use by industry. The Industry technology area focused on the approximately 30 largest heavy industries in Canada that are responsible for 80 percent of Canadian industry's GHG emissions. Heavy industries include pulp and paper, mining and smelt, chemical refining, petroleum refining, and others.

Efficient Mixing in Chemical Reactors to Reduce Energy and GHGs

Many chemical reactors and combustion systems (burners) require the dispersal and mixing of liquid feedstocks as droplets in an airborne stream to create the conditions necessary for reaction. The behaviour of these particles in the airborne stream is referred to as multiphase flow. The size distribution, the distribution within the aerosol stream, and the mixing of the various components is crucial to the efficiency of the reaction processes.

Chemical reactors encourage this mixing by forcing the aerosol stream past baffles and through channels. With a better understanding of the fundamentals of phenomena such as fluid turbulence, shear, and phase-changes, it is possible to achieve mixing without the need for these energy-wasting barriers. The key lies in the design of the reactor configuration and the nozzles that generate the aerosols. This project built on previous research at the NRC in the application of complex computer modelling tools to the design of energy-saving nozzles for application in bitumen processing in the heavy oil industry. The design is being commercialized by a Calgary company.

This project focused on designing simpler, more energy-efficient chemical reactors and on developing the thermodynamics and the computer tools needed to model the impacts of nozzle and reactor design on the mixing that takes place inside the reactor.

Project Title: Development of Multiphase Flow Fundamentals for Next-generation technology to Mitigate Greenhouse Gas Emissions

Performers and Partners: National Research Council Canada—Institute for Chemical Process and Environmental Technology, University of Ottawa, Nagoya University (Japan), Dynatec Corporation, Shell Canada, ETX Systems Inc.

Achievements:

» Conducted pilot-scale experiments at NRC's multiphase flow laboratories to examine the complex nature of energy-intensive industrial multiphase flow.

» Conducted detailed experiments on the laboratory multiphase contactors to examine the multiphase flow behaviour in the phase-mixing arrangements of commercial-scale nozzles.

» Purchased and used a new laser diagnostic system, Particle Image Velocimetry (PIV), to profile flow in conjunction with dynamic pressure signal analysis to obtain more detailed information on the overall multiphase flow behaviour and patterns found in industrial chemical reactors.

» Developed a generalized Droplet Population Balance Model (DPBM) that simulates multiphase and spray behaviour for energy-saving reactors.

» Identified a new approach for passive mixing of multiple phases (without the use of baffles, other obstructions, or mixing devices) that depends on the geometrical design of a flow channel path. This pattern of mixing and phase redistribution may have significant effects on increasing heat and mass transfer and energy efficiency of multiphase flow reactors.

» A two-phased internally mixed feed nozzle for energy-efficient processing of heavy oil in EXT Systems Inc. reactors as developed and tested in this Alberta-based company's pilot plant facility.

Cross-cutting Project:

Industry and Biotechnology

Biofuels for Canadian Steelmakers

Iron and steel production involves consumption of various fossil fuels in large blast furnaces—a process that produces significant amounts of GHGs annually. Solid fuel in the form of coke provides most of the energy for generating the high temperatures required. It also serves as a reagent in converting raw ore to molten iron. Smaller amounts of liquid, gaseous, and powder fuels are injected to supplement and control the combustion processes. If these fossil fuels could be to some extent substituted by renewable biofuels, GHGs could be reduced and steel production in Canada would become greener and more sustainable. The project team set out to determine what type of biomass would be most effective for the substitution and how much could be added to steelmaking processes to reduce GHGs without sacrificing production. The biofuels studied were switchgrass, willow, charcoal, and pyrolysis oil.

The first part of the project examined the effect of using biomass in the gas/liquid/powder streams that are injected into the blast furnace. The project partners developed a software model to simulate the impacts of biomass substitution on the heat and mass balances in the blast furnace. The new model analyzed actual Canadian industrial blast furnace operating data from Dofasco, Stelco, and Algoma.

The second part of the project examined the substitution of charcoal for coke. Coke is made by feeding bituminous coal into a coke oven heated to high temperatures for 14 to 36 hours. In addition, the project team studied the feasibility of using coke made from biomass. In a preliminary coking study, varying amounts of commercial-grade charcoal (biomass) were added to an industrial coke oven blend and carbonized. The researchers then evaluated the coke quality.

The third part of the project examined the use of charcoal (biomass) for slag forming in the electric arc furnace (EAF) process and the potential for GHG reduction.

Project Title: Canadian Steel Breakthrough Program—Biofuels for Canadian Steelmakers

Performers and Partners: Natural Resources Canada, Canadian Carbonization Research Association, Canadian Steel Producers Association, McGill University, BioCAP, Dofasco, International Iron and Steel Institute (IISI)

Achievements:

» Developed a new software model replicating blast furnace behaviour. It features a graphical user interface, reduced calculation time, and more flexibility in accepting industrial data.

» It was estimated that 50 percent biofuel substitution of injected fuels could reduce GHG emissions substantially while maintaining proper operation of the blast furnace in the steelmaking process.

» The reduction in GHG emission is strongly affected by the chemical composition of the biofuel as well as the type of fossil fuel being replaced. Evaluations indicate that biomass high in carbon content (e.g., wood chars) is the best biomass substitute for coal and coke.

» Results showed that adding biomass in the form of charcoal during coke production decreases coke quality, but that two percent addition produces a grade of coke acceptable to industry. This finding is an important first step, and strategies to increase the acceptable level of charcoal addition are being assessed.

» Results indicated that substituting fossil fuel injection by charcoal injection in EAF steelmaking could reduce GHG emissions of the slag foaming process by 25 percent.

» The project team inventoried Canada's biomass and found that the demand for biomass in Canada to support industrial-scale application can easily be met.

» An economic overview of biomass use was conducted and the results show that presently, only gaseous biofuels can be economically competitive with fossil fuels for use in the Canadian iron and steel industry.

Mining Process Optimization Yields Explosive Energy Savings

Hard rock mining typically involves a blasting operation that produces large rock fragments. Blasting is followed by a series of crushing and grinding operations that yield an aggregate within a size range suitable for further processing. The crushing and grinding operations are referred to as comminution. It is well documented that crushing requires about 10 times more energy than blasting, and grinding about 100 times more. Current mining industry operations show 3 to 5 percent energy distribution for blasting, 5 to 7 percent for crushing, and 90 percent for grinding. Therefore, blasting techniques that result in an aggregate that requires less crushing and grinding could reduce energy requirements.

Improved blasting design and the use of electronic detonators are known to enhance rock fragmentation and reduce material strength. Because blasting pre-weakens the rock material and produces finer and more homogenized fragments, it enables easier crushing and grinding later on. This project developed a technique that uses electronic blasting detonators to improve material excavation, transportation, crushing, and grinding. The project also developed a methodology for assessing the efficiency of comminution processes. This methodology integrates the most advanced tools for comminution process analysis, and could facilitate further testing and adoption of the electronic detonator technology in Canadian mine operations.

Project Title: Integration of Advanced Blasting and Information Technology for Comminution Process Optimization and Greenhouse Gas Reduction in the Canadian Mining Industry

Performers and Partners: Natural Resources Canada, Québec Cartier Mining Company, COREM, Dyno Nobel, Rocky Lake Quarry

Achievements:

» Electronic-blasting detonators reduced the run-of-mine ore and rock size by 15 percent in the quarry under study. The effect is a 5 percent production increase in the open pit and a 10 percent energy and operating cost saving in primary crushing.

» The electronic detonator technology was adopted at Rocky Lake Quarry in April 2006.

» Model-based process optimization studies indicate a 5 percent GHG reduction potential at Mont-Wright Mine of Québec Cartier Mining Company in Fermont, Quebec.

» Experimental work started in October 2006 at the Québec Cartier Mining Company with preliminary blasting tests.

» Technology tools tested and developed at Rocky Lake Quarry are being transferred to the Québec Cartier Mining Company.

» Technology improvements were needed due to the complexity of the ore geology at the Québec Cartier Mining Company. Potential solutions were identified and the R&D work is progressing.

Green Concrete Makes Use of Industrial By-products

Portland cement is the most common type of cement in general use worldwide, and it is an essential constituent of concrete. Manufacturing Portland cement uses about 4 GJ of energy and emits about 1 ton of CO_2 per ton manufactured. There are a number of materials that can be substituted for cement in the production of concrete that do not involve this expenditure of energy or production of CO_2. They are referred to as supplementary cementitious materials (SCMs). Using SCMs such as fly ash, ground-granulated blast-furnace slag, and silica fume (which are all industry by-products) is a cost-effective and efficient way to reduce GHG emissions, minimize waste disposal, and lessen the pressure on natural resources. Such substitutions must be carefully regulated to maintain the quality of the concrete produced and the structural integrity of buildings.

Although the use of SCMs is generally well accepted by the construction industry, local availability issues, transportation costs, and building codes limit its use. Furthermore, new environmental regulations to reduce NO_x and SO_x emissions from thermal power plants have lowered the quality of coal fly ash for use in concrete.

This project focused on non-conventional, or alternative SCMs. Considerable R&D is needed to better understand the chemical and physical effects of different types of industrial by-products on the performance of concrete. The by-products examined were from various metallurgical processes (steel, lead, zinc slags), combustion industrial processes (incinerator ashes, ashes from co-combustion of biomass), and thermal power stations (bottom and other ashes). Waste glass materials and reclaimed materials from previous landfilling operations were also studied.

Project Title: Performance Standards for Industrial By-products in Cementitious Systems for "Green Concrete" Construction

Performers and Partners: National Research Council Canada—Institute for Research in Construction, University of New Brunswick, University of Toronto, Louisiana-Pacific Canada, Alcan Inc., Whitemud Resources Inc.

Achievements:

» Increased knowledge of the chemical processes involved during cement combination with alternative SCMs along with a better understanding of the engineering properties of the final products.

» The final results demonstrate that new supplementary materials can replace 15 percent of cement, but it is imperative to assess the cement's long-term durability for acceptance.

» Generated interest from industry with the publication of an article and a fact sheet in the Institute for Research in Construction's *Construction Innovation* and *Construction Technology Updates* newsletters.

» Several research groups and cement manufacturers worldwide are examining this new way of making concrete more sustainable and durable.

» The CSA and the American Concrete Institute are considering developing new or modified methods and testing procedures to implement the use of these types of products.

Iron Production on Track to 30 Percent Energy and Emissions Savings

The iron-making process begins with iron ore mining, concentration, and aggregation into pellets in the size range of 9 to 16 mm. The pellets are then fed into blast furnaces where they are converted into iron. Canadian iron ore companies produce pellets and concentrate for domestic and international markets. Induration furnaces used in pellet production create approximately 3 Mt per year of GHG equivalent emissions. Many companies have expressed interest in improving the efficiency of their induration furnaces, especially since the pelletizing operation accounts for some 60 percent of total plant energy consumption.

This project consisted of three parts. The goal of Part 1 was to confirm, through modelling, the potential to enhance the overall efficiency for an actual induration furnace operation. The results were applied in Part 2 to identify how burner and furnace efficiencies could be improved. Part 3 involved preparing a comprehensive report and presenting the findings and results to the plant operator.

Project Title: Induration Furnace Optimization

Performers and Partners: Natural Resources Canada, Quebec Cartier Mining Company, COREM

Achievements:

» Refined a model of an optimal flue-gas recirculation scheme to maximize thermal efficiency of an induration furnace for the pelletization of iron ore, and delivered the refined model to client-partners.

» Heat and mass balance scenarios from the model showed the potential efficiency gains for plants, including reductions as high as 30 percent in energy and emissions.

» The plant operator is now using the results of this project in the redesign of plant equipment.

» There are considerable opportunities for adapting this proprietary technology to iron ore pelletization plants worldwide. Worldwide adoption would significantly reduce GHGs and improve energy efficiency.

» Through alternative funding, this project is being further developed to include a detailed retrofit plan for the induration furnace, incorporating flue gas recycling and heat recovery, with Québec Cartier Mining Company and COREM as industrial partners.

Chemical Processes Go Green

Distillation processes to separate reaction mixtures in the chemical and petroleum refining industries account for approximately half of the energy consumed by these industries and a corresponding part of the GHG emissions. This project identified ways to reduce the energy and emissions footprint through better design of hybrid separation systems that incorporate new technologies with traditional distillation. In particular, researchers developed a thermodynamically guided modelling (TGM) methodology for designing energy-efficient separation processes that improve productivity and reduce GHG emissions.

Researchers developed the TGM model for azeotropic distillation and completed a survey of membrane technologies and material characteristics suitable for hybridization of water/ethanol columns. In collaboration with the NOVA Chemical Corporation and the University of Ottawa, these tools were also applied to the retrofit hybridization of the C2 splitter distillation tower at the NOVA Joffre, Alberta facility. This work involved energy and technology targeting studies and generated a set of scenarios to identify ways to increase productivity and decrease energy intensity.

Project Title: Energy-efficiency Improvement and Greenhouse Gas Emission Reduction in Distillation Processes

Performers and Partners: Natural Resources Canada, NOVA Chemicals, University of Ottawa, University of Chemnitz (Germany), San Diego State University (U.S.), Iogen Corporation

Achievements:

» The TGM approach provides an inexpensive way to assess many opportunities for improving separation processes and for selecting economically viable retrofits.

» A preliminary design for the Joffre C2 splitter identified the possibility for a 14 percent increase in productivity along with an 11 percent decrease in energy use and GHGs.

» Developed and validated a complete set of numerical tools, including a superstructure, separator models, and an optimization algorithm for the energy-efficiency optimization of hybrid binary separation systems.

» Completed a review of the potential application of the TGM method in the petrochemical sector and identified opportunities.

» The University of Ottawa, Iogen Corporation, and Natural Resources Canada launched a joint project entitled "Enhancement of Bioethanol Production through Process Synthesis, Integration, and Optimization." The project was awarded a three-year, 120K$ per year Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Project Grant.

Using Microwaves to Reduce Industrial GHG Emissions

Microwaves, such as those generated by microwave ovens, produce localized heating and thereby provide more efficient energy transfer to reaction processes. When used in the kitchen, the outcome is an energy-efficient way of cooking food—but the potential for microwaves does not stop there. This project investigated how microwaves could be applied to three different industrial processes to save energy and reduce GHGs.

Extracting oil from oleaginous seeds is an important agri-food activity in Canada. However, the process contributes significantly to GHG emissions. Microwaves can be used to extract the oil in combination with a non-absorbing solvent at atmospheric pressure. Ethylene production is another important Canadian industry that is energy- and GHG-intensive. A considerable part of the energy expended in the production of ethylene goes into battling the unwanted production of side-products that coat the reactors and limit efficiency. The project team investigated the potential to avoid this problem by employing microwave radiation. The team also investigated the potential to apply microwave radiation in the catalytic conversion of petroleum products.

Project Title: Microwaves as Greenhouse Gas-reducing Process Tools

Performers and Partners: Environment Canada, Natural Resources Canada, NOVA Chemicals, Bunge, Sairem, McGill University, Saint-Gobain NorPro (U.S.)

Achievements:

» International scientific experts and Canadian petrochemical, refining, and oil sands industry representatives have shown a willingness to explore a fundamental scientific approach to examine potential applications of microwave energy.

» Conducted an expanded literature review and identified materials suitable as reactors or catalysts.

» Designed and commissioned a pilot plant for ethane-to-ethylene conversion, incorporating conventional and microwave reactors. Incorporating microwaves into the process should reduce the need for steam co-feed, improve the catalyst performance, and reduce energy use.

Buildings (Commercial and Residential) and Communities

Canada's communities (buildings and transportation combined) currently account for 50 percent of the nation's total energy use. Residential, commercial, and institutional buildings alone use 30 percent of the country's energy. The objective of the Buildings (Commercial and Residential) and Communities technology area was to achieve marketable innovations and industry capacity for buildings and entire communities to be energy positive and to have net-zero GHG emissions by 2025. The research and development funded under this technology area included designing, constructing, operating, and renovating buildings, neighbourhoods, and communities, as well as advancing the energy systems they used.

Moving Neighbourhood Development toward a Sustainable Energy Future

Conventional neighbourhood development misses many market-viable opportunities for improved sustainability. Through the pilot of an integrated and expanded development process—including multiple developers, design teams, sustainability consultants, and key municipal staff—the planning and design of the Emerald Hills Urban Village in Strathcona County, Alberta, demonstrated the value of this approach in achieving on-the-ground results. Originally developed under the PERD initiative, "SuN LIVING" guides the development of sustainable neighbourhoods using a step-by-step approach that transforms broad concepts of sustainability into practical actions. Its application at the Emerald Hills Urban Village facilitated a comprehensive evaluation of planning, design, and technology alternatives to reduce energy use and supply renewable heat; collaboration between developers and the municipality; and increased in-house capacity of the partners.

Project Title: Sustainable Urban Neighbourhood (SUN)—Moving Sustainability Mainstream

Performers and Partners: Natural Resources Canada, Strathcona County, Christenson Developments, Howell-Mayhew Engineering, University of British Columbia—Design Centre for Sustainability

Achievements:

» All developers have committed to building energy performance levels they had initially thought to be too costly.

» Analyzed alternative energy supply options, including a waste heat-based community energy system and solar domestic hot water heaters, with support from all stakeholders.

» Amended municipal by-laws to enable the sustainable urban neighbourhood features.

» Strathcona County has integrated the sustainability principles and evaluation themes into its Municipal Development Plan and is now requiring all urban neighbourhood developments to follow a process that addresses the sustainability principles and themes outlined in SuN LIVING.

» Christenson Developments is introducing the integrated design process to its design, marketing, and construction teams, and personnel are being trained to move projects in a more sustainable direction. SuN LIVING will be the process they apply to all future urban village projects.

» BEST Communities, the townhouse developer, has hired engineers trained specifically in sustainable development to lead its company as far as possible along the sustainable development path. One goal is to achieve all net-zero homes within 10 years.

» ISL Engineering, the coordinating landscape engineer, is applying SuN LIVING to another major development in Strathcona County.

» The pilot project resulted in the book *SuN LIVING—Developing Neighbourhoods with a One Planet Footprint*, a full-colour, illustrated guide describing how to plan and design sustainable neighbourhoods.

» SuN LIVING is being used as the basis for a proposed credit under the new green building rating system Leadership in Energy and Environmental Design (LEED) for Neighbourhood Development. LEED is a highly recognized, private-sector rating system.

Zoned Comfort Technology Saves Energy during Utility Peaks and Improves Homeowner Comfort

Residential air conditioning demands the vast majority of home energy during summer heat waves. This can be a contributing factor to electricity grid overcapacity issues such as the one that caused a blackout in Ontario and areas of the U.S. in the summer of 2003. Home cooling systems often have twice the capacity that homes theoretically need. Typically, air-conditioned air is distributed through the furnace ductwork and treats the whole house as a single zone. This often leads to an upper floor that cannot be cooled enough while the basement is overcooled to the point of being uncomfortable. As occupants spend most of their time on upper floors, complaints lead to retrofitting larger condensers and higher powered blower motors to try to cool the upper floor.

Zone Comfort technology takes a new approach to zoning, building automated dampers into the central air-handling device. This can keep installation costs down and enable the system, in both cooling and heating mode, to use controls to optimize performance. It enables occupants to get the comfort they want in the zone they are in, while setting back heating or cooling demands in unoccupied zones. Natural Resources Canada facilitated a review of technical challenges, researched related market potential, and assisted with a field trial involving six homes in a Hamilton row-house development. The project fast-tracked from the concept board through R&D to initial commercialization in less than two years, and is now in the demonstration phase with support from Technology Early Action Measures (TEAM).

Project Title: Optimized Zoning Approach for Peak Air Conditioning Load Shaving

Performers and Partners: Ecologix Heating Technologies Inc., Natural Resources Canada, Ontario Ministry of Energy and Infrastructure, University of Ottawa, McMaster University, Canada Mortgage and Housing Corporation

Achievements:

» Ecologix has commercialized a zoned air handler and associated distribution system.

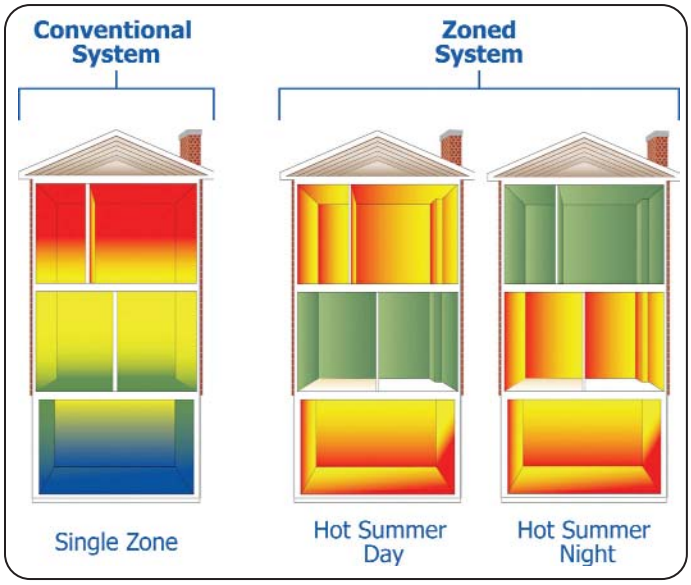
» Achieved energy performance and demand management improvements in the marketplace. Preliminary results from a few homes indicate that zoning can reduce cooling energy demand by approximately 12 to 24 percent during peak periods of peak days. The current TEAM project will determine statistically valid results and consider various factors of energy use (i.e., summer cooling, summer peak draws, winter heating).

» Sold 77 units valued at approximately $200,000. In addition to the environmental and comfort benefits, there will likely be a return on investment for homeowners.

» Demonstrated the technology at an Open House at the field trial site in Hamilton.

» *Holmes on Homes*, the HGTV show, showcased the Zoned Comfort technology in episode 7083, "Re-Inventing," of Season VII, where the system was used to solve a heating problem for the owners of a new townhouse.

» Successful collaboration among partners.



Solar Power Opportunities Increasing for Canadian Cities

This project was launched to facilitate the wide-scale uptake of PV technology in urban areas as part of an integrated approach that maximizes building energy efficiency and solar thermal and PV usage. The technology uses PV arrays, commonly called solar panels, to convert the sun's energy into usable electricity.

The project approach involved participating in Task 10 of the International Energy Agency's Photovoltaic Power Systems (IEA PVPS) Implementing Agreement. A forum of international experts addressed building, regulatory, marketing, and policy issues concerning the integration of clean, solar energy technologies into the built environment to facilitate their urban-scale market penetration. In Canada, it made connections between the building design and development industry and transferred IEA PVPS knowledge and products to Canadian applications. The project involved producing recommendations on how to remove barriers to mass-market uptake of solar energy, using expanded tools (e.g., models, road maps, guides), and conducting analysis relevant to the needs of emerging global markets. The project team also designed and developed system components and applications with the largest global market penetration potential, taking into consideration aesthetic values along with mechanical and energy-related value. Throughout the project, knowledge dissemination was a priority to encourage adoption of PV technology.

Project Title: Facilitating the Uptake of Solar Energy Applications in Canadian Communities

Performers and Partners: Natural Resources Canada, IEA Photovoltaic Power Systems, IEA Solar Heating and Cooling Annex

Achievements:

- Adoption of integrated design concepts and whole system approach by Net Zero Energy EQuilibrium Housing projects—the Les Maison Alouette *EcoTerra™* housing model in Eastman, Quebec and the Sevag Pogharian Design Associates Alstonvale NZEH houseSPD Architects in Hudson, Quebec.
- Adoption of integrated design concepts and whole-system approach by Canadian design teams in the U.S. Solar Decathlon competition in 2005, 2007, and 2009.
- Development of a professional development course in collaboration with the School of Architecture at the University of British Columbia and the Royal Architectural Institute of Canada (RAIC) entitled "Mainstreaming Building-integrated Photovoltaics in Canada."
- Provided training in the professional development course to over 100 architects in five Canadian cities organized by the RAIC.
- Information dissemination (e.g., through peer-review publications, national and international presentations, targeted stakeholders reports, and conferences and workshops) to meet the needs of specific stakeholder groups and to promote solar energy.

Homes Born Ready for Alternative Energy

Over 200,000 new homes are built in Canada every year, but few of them are designed to accommodate alternative-energy systems. Although many homebuyers may not be ready to install alternative energy systems immediately, foreseeable changes in the energy supply may lead them to retrofit their homes later on.

To facilitate the adoption of alternative energy systems for residential buildings, the project team analyzed and built homes designed in such a way that they could easily be retrofitted to allow solar hot water heating or electricity (PVs) in the future, or both. Certain design features—easy to install when the house is first built but more complicated and expensive to install later—are needed to allow homes to use alternative energy systems.

The goals of this project included learning from current installations (companion initiatives already under way with partners), documenting the installation practices, issues, and retrofit requirements, and finding common elements that could be implemented at the construction phase to facilitate future retrofitting for alternative energy systems.

Project Title: Alternative Energy-ready Homes

Performers and Partners: Natural Resources Canada, Doug Tarry Homes, EnerWorks Inc.

Achievements:

» The alternative energy-ready concept has been commercialized and branded as Solar Ready in a successful pilot with Doug Tarry Homes, which built over 80 Solar Ready homes.

» Feedback from this pilot has been positive, including significant media coverage and interest from other builders who want to offer their clients Solar Ready homes.

» Tartan Homes (not part of this project) now offers Solar Ready for its single-family models. Nearly 50 percent of their clients purchase the Solar Ready upgrade.

» The project team developed the *Solar Ready Guideline*, describing how to make homes alternative energy-ready. The guideline covers issues such as plumbing and electrical requirements, as well as design issues such as space considerations for thermal storage, controls, and panels on the roof.

» The *Solar Ready Guideline* is currently being incorporated into the ecoENERGY for New Houses Program for release in its next program update. Natural Resources Canada is recommending the guideline for all best-in-class programs such as the R-2000 standard and ENERGY STAR for New Homes, including regional programs such as Novoclimat, Built Green, Power Smart, and GreenHome.

The Future Looks Bright for Energy Efficiency in the Workplace

Lighting is responsible for a major fraction of the energy used by commercial buildings, and represents the largest single energy-saving opportunity. Daylight-linked dimming technology, which uses automatic controls that dim electrical lights in response to daylight levels, has been proposed as a way to seize this opportunity.

Current daylight-linked dimming technology is designed to maintain a constant illuminance (incident light falling on a surface) on desktops. This is difficult to achieve because it is impractical to place a sensor on the desktop. Moreover, evidence shows that constant illuminance is not what people prefer. In fact, the eye detects luminance (reflected light coming from a surface), and people's preference likely varies in response to changing tasks, sky conditions, and times of day.

The goal of this project was to develop a luminance-based control system with control algorithms based on building occupant preference. To keep costs low, this system uses a cheap digital camera device to provide spatial luminance information, allowing control based not just on total light level, but also on ratios between important surfaces.

Project Title: Development of a Luminance-based Lighting Control System to Enhance Energy Savings

Performers and Partners: Natural Resources Canada, Lawrence Berkeley National Lab, Aalborg University—Danish Building Research Institute, Somfy Canada, Sun Project Toro

Achievements:

» The project team successfully demonstrated that a cell-phone camera can be used for reliable daylight-linked dimming control, occupancy sensor control, and window blind control.

» There is potential for further applications because such a sensor can also be used to detect smoke and monitor the progress of an occupant evacuation. Therefore, the prototype camera-based system can replace multiple sensors with a single sensor, reducing costs and eliminating the need for complex wiring.

» A human factors study was completed. Results showed that, while perfect automatic daylight-linked dimming saved 38 percent lighting energy, simple manual dimming control (that allows occupants to choose less electric light when daylight is present) saved 25 percent. Manual dimming controls also improve occupant satisfaction.

On the Horizon

The T&I R&D Initiative explored innovative ideas and solutions to reduce GHG emissions. The results and impacts of the projects supported by the T&I R&D Initiative will contribute to significant long-term benefits for the environment and the Canadian economy.

Having met its objectives of advancing promising technologies to achieve long-term GHG reductions and strengthening Canada's clean energy technology capacity, the T&I R&D Initiative ended as planned in March 2008. R&D that resulted from the T&I R&D Initiative is being picked up by industry, government, and academia. New policies, regulations, standards, and technologies developed through the T&I R&D Initiative will continue to be used and optimized.

Moving Forward with Partnerships

Program delivery was built on federal technical expertise in partnership with the private sector, provinces, and academia. Partners were identified through targeted consultations conducted by the Experts Groups with the External Advisory Boards. The participation of non-federal performers and funding partners in R&D projects was an essential component of the success of the T&I R&D Initiative. This participation leveraged costs, added technical know-how, and mitigated risks to effectively encourage the deployment of the T&I R&D Initiative's results. Over 840 partnerships were formed during the T&I R&D Initiative's five-year duration.

Project partners continued to develop many of the technologies forward to the next stage of the innovation spectrum, demonstration, or out into the market. These activities were aided by the T2M program, which assessed the next steps for selected technologies to identify gaps and opportunities. Assessments reviewed progress made through the T&I R&D Initiative, market conditions, and the capacity of the private sector to pick up the technologies and take them to market. The T2M program component was intended to help establish a knowledge framework that could be applied to all T&I activities.

Capacity for Continued Success

An important and persistent contribution of the T&I R&D Initiative was the training opportunities afforded for new scientists. The T&I R&D Initiative has contributed to building Canada's scientific capacity and ensuring that there will be highly qualified people available to carry out future work. Another essential component of the T&I R&D Initiative's activities was a dissemination strategy carried out through various means, including publications, reports, case studies, conferences, and workshops to broadcast and support uptake of the R&D resulting from the projects. These dissemination activities have expanded the knowledge base of Canada's governmental, academic, and industrial sectors, and will facilitate new discoveries and developments. Techno-economic studies, market analyses, and road maps were also developed to identify gaps and research opportunities and to smooth the path for commercialization and widespread adoption.

Partners

During the five years of the T&I R&D Initiative, over 840 partnerships were formed across Canada and abroad. The following list provides examples of the governmental, industrial, academic, and other partners involved in the T&I R&D Initiative. It is not an all-inclusive list.

Government (municipal, provincial, and federal)	
Agriculture and Agri-Food Canada	Government of British Columbia
Alberta Energy and Utilities Board	Health Canada
Alberta Research Council	Indian and Northern Affairs Canada
Atlantic Canada Opportunities Agency	Industry Canada
British Columbia Ministry of Energy, Mines and Petroleum Resources	Manitoba Hydro
Canada Mortgage and Housing Corporation	National Energy Board
Canada-Newfoundland and Labrador Offshore Petroleum Board	National Research Council Canada
Canadian International Development Agency	Natural Resources Canada
Department of National Defence	Newfoundland and Labrador Hydro
Environment Canada	Public Works and Government Services Canada
Fisheries and Oceans Canada	Transport Canada
Government of Alberta	

Industry	
A.V. Tchouvelev	Kingston Process Metallurgy
AES Shady Point	Materials and Manufacturing Ontario
Alstom Power	New Paradigm Engineering Ltd.
Arvin Meritor (U.S.)	Nova Scotia Power Inc.
Atlantic Combustion	Ontario Power Generation Inc.
Babcock & Wilcox Power Generation Group	Penn West Energy Trust
CEA Technologies Inc.	Petro-Canada
Cefertech	Purolator Courier
Devon	SaskPower
Encana	Shell Canada
EPCOR Inc.	Sithe Energies Inc.
Gas Technology Institute	Sonic Environmental
GM Allison Inc.	Syncrude Canada
Hatch Ltd.	Thompson Machine Shop
Hyteon Inc.	TransAlta Corp
Kinectrics	Unicell Inc.

Academia and Affiliated Associations	
Alberta Energy Research Institute	Petroleum Technology Alliance Canada (PTAC)
Canadian Crude Quality Association (CCQA)	Research Triangle Institute
Canadian Oil Sands Network for Research and Development (CONRAD)	Technical University of Hamburg (Germany)
Canadian Renewable Fuels Association	University of Alberta
Carleton University	University of British Columbia
École Polytechnique de Montréal	University of Calgary
Friends of the Earth	University of Ottawa
Hydrogen Research Institute: Université du Quebec à Trois Rivières	University of Regina
Laval University	University of Toronto
Massachusetts Institute of Technology (MIT)	University of Victoria
McGill University	University of Waterloo

International	
Government of Japan	NATO Science
IEA Clean Coal Centre	United States Department of Energy–Sandia National Laboratories
IEA Greenhouse Gas Research and Development Program	VTT Research (Finland)

Summary Data

Biotechnology Projects	Total T&I Funding ($ k)
Agricultural Crop Residues for Bioenergy and Bioproducts	311
Analysis of Biomass-derived Fuels for Use in Lime and Cement Kilns	300
Biodiesel for Heat and Power	100
Bio-oil in Lumber Kiln Application	65
Biotechnology Intellectual Property Survey	30
City of Toronto Waste to Energy	261
Conversion of Chicken Litter and Straw to Energy	200
Developing Short-rotation Plantation/Agroforestry Systems for Bioenergy Generation in Canada	2,331
Development and Production of Starch-based Biopolymers	1,259
Development and Validation of an Environmental Framework for Minimizing Impacts from Large-scale Production of Ethanol from Lignocellulosic Biomass Sources in Canada	200
Extraction, Separation, and Purification Processes for Value-added Products	660
Federation of Canadian Municipalities Waste Guide (Dissemination)	38
Forest Products Biorefinery/Pre-hydrolysis of Cellulose in Wood Chips	115
From Manures to Novel Bioproducts Using Micro- and Nanotechnologies	698
GIS-based Inventory and Analysis of Forestry and Agricultural Biomass	1,296
Hemmicellulose Project	30
Identification and Evaluation of the Issues Associated with the Development of the Large-scale Infrastructure Necessary for the Future Blending, Transportation, Storage, and Distribution of Bioethanol in Canada	30
Inventory Development and Analysis of Potential Environmental Impacts of Selected Greenhouse Gas-reducing Crops Prior to Introduction and Commercial Development in Canada	30
Laying the Environmental Foundation for Evaluating Impacts from Large-scale Production of Ethanol and Biodiesel as a Precursor to Lignocellulosic Biofuels Production in Canada	145
Manure Digestion	172.4
Natural Fibres Initiative for Biochemicals and Biomaterials	1,476
New and Improved Fatty Acid Biomass Feedstocks	968
Novel Fractionation Process and Co-products Related to Ethanol Production	283.2
Oilseed Integrated (Biodiesel) Biorefinery	448
Planning for a Technology Road Map on Biorefining	45
Portable Oilseed Extraction and Biodiesel Processing	221
Pulp and Paper Sludge Upgrading for Energy Production	50
Pyrolysis Network	50
Renewable Energy for Greenhouses: Biomass Residues and Advanced Conversion Technologies	1,182
Renewable High-cetane Diesel Blending Stocks for Northern Climate	75
Residual Organic Wastes to Bioenergy	1,404.4
Superior Pectinase for Processing Industrial Hemp and Other Agro-fibres	375
Survey of Energy Conversion Processes and Life Cycle	20
Survey of Manure Source Potential	23
Survey of Non-traditional Biomass Source Potential	20
Validation of Environmental Criteria for Reducing the Ecological Footprint from Large-scale Conversion of Oil Seeds/Animal Products into Biodiesel in Canada	200
Wheat Ethanol Research and Development	150

Unconventional Gas Supply Projects	Total T&I Funding ($ k)
Assessment of the Coal Bed Methane Potential and carbon dioxide Storage	85
Assessment of the Coal Bed Methane Potential of the Rocky Mountain Foothills and Front Ranges of Western Canada	120
Carbon and Hydrogen Isotope Systematics of Biogenic Coal Bed Methane Production	150
Coal Bed Methane and Methanogenic Bacteria	71
Coal Bed Methane Geomechanical Response of Reservoirs	70
Coal Bed Methane Potential in Saskatchewan	75
Characterization of Jean Marie Tight Gas Reservoirs	73.3
Coal and Coal Bed Methane Reservoir Characterization for Production Potential, Enhanced Coal and Coal Bed Carbon Dioxide Sequestration, and Groundwater Protection	80
Development of Models for Gas Production from Hydrates by Depressurization and Interpretation Techniques for Analyzing Tests Conducted on Hydrate Wells	125
Development of Pipe-in-Pipe System for Arctic Pipelines	275
Emergency Evacuation and Rescue From Beaufort Sea Production Structures	232.9
Environmental Aspects of Coal Bed Methane Exploration and Extraction	177
Establishing a Protocol for the Laboratory-based Analysis of Natural Gas Hydrate	460
Gas Hydrate Identification, Characterization, and Quantification Experiments Using Industry Seismic Data Near Strategic Mackenzie Delta Conventional Gas Fields	155
Geochemical and Isotopic Characterization of Produced Waters from Coal Bed Methane Operations in Alberta	45
Harpoon: Corer Free-Fall Cone Penetrometer (FFCPT) Data Acquisition for Frontier Geohazard Assessment	110
Ice Rubble Generators for Offshore Production Structures	406.6
Identification and Geophysical Characterization (Offshore GH)	172
Improved Ice Information Systems for High Arctic Transportation	598
Magnetic Surveys for Gas Hydrate Assessment	142.2
Marine Compressed Natural Gas Loading and Unloading	300
Methane Hydrate Kinetics	160
Methane Hydrate Reservoir Simulation	45
Methane Hydrates – Offshore East Coast	44
Methane Hydrates Mallik Production	115
Nano-composite Membranes	50
New Methods of Detecting and Mapping the Marine Gas Hydrate Resource; Electromagnetic Surveying System	279.5
Permeability Changes in Coals during Production and Injection	195
Removing Seabed Barriers to the Production and Transport of Proven Gas Reserves, Offshore Newfoundland and Labrador	460
Removing the Geoscientific, Environmental, and Regulatory Barriers to Exploration, Production, and Transportation of Onshore and Offshore Arctic Islands Gas	448
Reservoir Characterization of Gas Shales and Environmental Impact of Produced Fluids	261
Scoping Study: Ice Information Requirements for Marine Transportation of Natural Gas from the High Arctic	39.7
Shore and Shallow Water Morphology Identified by Helicopter-borne Electromagnetic Sensor	135
Study of Natural Gas Handling Operations in Marine Transportation of Compressed Natural Gas	500

Unconventional Gas Supply Projects	Total T&I Funding ($ k)
Subsurface Current Statistics from Deep-Water Drifters and Other Measurements in Atlantic Slope Frontier Gas Areas	136
Support for Canadian Research, International Ocean Drilling Program (IODP) Drilling and Measurement of Marine Gas Hydrate off Vancouver Island	170
Support for International Gas Hydrates Conference to Canada	25
Support for Mallik Program	1240
Support for Unconventional Gas Supply Road Map	25
Testing Magnetotellurics to Identify, Characterize, and Quantify Experiments Using Industry Seismic Data near Strategic Mackenzie Delta Conventional Gas Fields	70
Upscaling Gas Hydrate Decomposition Kinetic Constants from the Laboratory to Reservoir Models	312
Western Canada Tight Gas Resource Characterization	125

Bitumen and Heavy Oil Projects	Total T&I Funding ($ k)
Bioremediation of Tailings	270
Bio-upgrading and Corrosion Mitigation	342
Bitumen Recovery and Upgrading from Intermediate Zone: Scoping Study	216
Bitumen Recovery Scoping Study	90
Carbonate Triangle – Exploration Study	270
Clay and Bitumen Characterization	300
Cold-water Injection Enhanced Oil Recovery	220
Conventional Heavy Oil Technology Scoping Study	50
Cryogenic Scanning Electron Microscope	800
Efficient Pipelining of CT	200
Energy Efficiency of Emulsions Stability	800
Fouling Reduction/Elimination	1,470
Gas over Bitumen	360
Heavy Oil Treatment: Natural Surfactants	70
Impact of Water Chemistry	300
Life Cycle Assessment of Oil Sands Technologies	206
Mass Flow Characterization	168
Methane Production from Carbon Dioxide-consolidated Tailings	150
Oil Sands and Heavy Oil Scoping Study	90
Physical Separation Process	870
Selective Ring Opening	1,511
Selective Separations in Upgrading	943
Slurry Hydrocracking and Gasification	381
Technical Support and Scoping Studies for Expert Group	120
Techniques for Process Foulants	50

Clean Coal and Carbon Dioxide Capture and Storage Projects	Total T&I Funding ($ k)
Advanced Brayton-Cycle-based Zero-emission Power Plants Burning Fossil Fuels	200
Analysis of Acid Gas Injection Sites in Alberta That Have Experienced Unforeseen Reservoir Performance Problems	270
Automated Soil Gas Grid-Sampling System	183
Canadian Carbon Dioxide Capture and Storage Program	25
Coal Bed Methane/Enhanced Coal Bed Methane Reservoir Characterization Methodology	130
Clean Coal and Carbon Dioxide Capture and Storage Technology Road Maps	39
Creation of a National Intelligence Centre on Near-zero Emissions Clean Coal Technologies	159
Degree of Coal Swelling and Loss of Permeability Associated with Sequestration of Carbon Dioxide, Hydrogen Sulphide and Flue Gas—Selecting Optimum Coals for Sequestration	361
Development and Demonstration of Cost-effective Amine-based Solvent Scrubbing Technologies for Carbon Dioxide Capture from Combustion Flue Gases	300
Development of a Generalized Systems Scheduling Framework for the Operation of Generating Stations with Carbon Dioxide Constraints in Canada	62
Development of Carbon Dioxide Inorganic Membrane	30
Direct Carbon Fuel Cells	190
Electrical Power Production from Circulating Fluidized Bed Combustor (CFBC) Boilers with Carbon Dioxide Capture	893
Enhancing the Capacity of Carbon Dioxide Storage by Removing the Remaining Water in Depleted Oil Reservoirs	80
Environmental Monitoring for Penn West Carbon Dioxide-enhanced Oil Recovery Project	216
Experimental Investigation of Carbon Dioxide/Coal Interaction	62
Feasibility of Integration of Membrane Reactor with Gasification for Clean Coal Application	200
Hydrate Technology for Gas Separation and Carbon Dioxide Capture	182
IEA Weyburn Carbon Dioxide Monitoring	80
Increasing Gasifier Availability via Improved Refractory and Injector Designs	601
Integrated High-efficiency Oxy-fuel Combustion Process for Carbon Dioxide Capture Comprising Slagging Combustor, Air Separation, and Gas Turbine Technologies	199
Microporous Hollow Fibre for Greenhouse Gas Separation	50
Microporous Hollow Fibre for Greenhouse Gas Separation and Capturing	465
Near- and Far- field Effects of Carbon Dioxide Injection in Geological Formations: Toward Integrated Monitoring and Modelling Protocols	945
Non-thermal Plasma Multi-pollutant Control Technology for Flue Gas Pre-cleaning before Amine-CO_2 Scrubbing Operation	526.4
Novel Oxy-fuel Burner with *in situ* Emissions Control of Multi-pollutant and Carbon Dioxide	300
Optimization of Integrated Carbon Dioxide Capture, Transportation, and Storage in Canada	105
Optimizing Carbon Dioxide Storage in Oil Reservoirs	295
Oxy-fuel Combustion Technology: A Marketing Study	35
Performance Assessment and Siting of Carbon Dioxide Storage in Coal Beds, Combining Probabilistic and Deterministic Methods	145
Physical Model Studies of Wellbore Stability for Underground Carbon Dioxide Storage	150
Pressurized Gasifier	500

Clean Coal and Carbon Dioxide Capture and Storage Projects	Total T&I Funding ($ k)
Time Lapse Seismic Monitoring of Carbon Dioxide Injection into Ardley Coals (CSEMP project)	120
VC Refurbishment	300
Zero-emission Oxy-Fuel Combustion Technologies for Clean Fossil Fuels	2,071.1
Zero-emissions Hydrogen Production via Gasification (ZEHP)	1,160

Decentralized Energy Production Projects	Total T&I Funding ($ k)
An Exit-stay Apparatus to Improve Francis Turbine	340
Canadian Centre for Housing Technology (CCHT) Testing of Residential Combined Heat and Power Systems	869.8
Codes and Standards for Wind Energy	1072
Communications Systems for Distributed Energy Resources	130
Distributed Energy Resources Grid Interconnection Standards	1,037
Distributed Generation Product Standards and Certification	466
Distributed Power using Gas Network Pressure and Combined Heat and Power	1,051
Energy from Waste/Gas Turbine Hybrid Combined Cycles for Combined Heat and Power	176
Enhanced Deployment of Residential Combined Heat and Power Systems	297
Extracting Energy from Water-current	205
Fish-friendly, Variable-speed, Low-head Turbine System	1,220
High-efficiency Cascading ThermoPhotoVoltaic and ThermoElectric Systems for Residential Micro Combined Heat and Power	289
Impact of Large-scale Distributed Generation Integration into the Grid	1,718
Inlet Air Supercharger	120
Lab-scale Solid Electrolyte Fuel Cell Development	75
Lithium Ion Batteries for Decentralized Energy Production Applications	290
Mid Merit Power Using On-site Combined Heat and Power and Biofuels	492.2
National Wind Atlas and Related Tools	1,495
Ocean and River Current Energy Generation	171
Planning Studies	207
Planning Studies	40
Power from Non-traditional Gaseous Fuels	640
Photovoltaic Electricity and Solar Resources Assessments	482
Photovoltaic/Thermal Systems in Residential Homes	400
Redox Flow Battery Development	170
Regulatory Assistance Project	997
Residential Distributed Energy Resources Model Development Verification	670
Small-wind Turbines	452.7
Solar Cell Research and Development Network Development	129
System Testing and Modelling	414
The Prototype Universal Small-wind Turbine	483
Very Low-head Turbine to Reduce Civil Works	342

Hydrogen Projects	Total T&I Funding ($ k)
A Hydrogen Road Map for Canada	50
Advanced Stationary Fuel Cell Algorithms and Prototype Interface	25
Biomass By-products to Produce Hydrogen	42
Fuel Cell Test Station	100
Fundamental Properties of Carbon Nanotubes	88
High-capacity Reversible Hydrogen Storage	250
Hydrogen Production from Hydrogen Sulphide and Methane	600
Hydrogen Production Research and Development: Development of IMET Electrode Catalysts	640
Hydrogen Sensors	210
Hydrogen Utilization Research and Development	566.6
Materials for Hydrogen Fuel Cells	534
Membrane Reactor Technology	250
Microstructured Fuel Cell	500
Nanomaterials for Hydrogen Storage	856
Nanotechnology for Hydrogen Storage	150
National Codes and Standards Development	97
Proton-transition Catalyst Development	210
Ramea Island Wind Demonstration Project	100
Residential Fuel Cell Cogeneration	410
Technology Gap Analysis: Ceramic Materials for Fuel Cells	30
Tools for Evaluating the Performance of Metal Hydride Reservoirs	200

Transportation Projects	Total T&I Funding ($ k)
Advanced Fuels for Homogenous Charge Compression Ignition (HCCI) Engines	690
Black Carbon Emissions and Atmospheric Levels in Canada	1,095
Compacted Graphite Iron and Austempered Graphite Iron – Potential Materials to Produce Lightweight Automotive Parts	408
Development of Lightweight and High-performance Lightweight Aluminum Composite Brake Rotors for Automobile Applications	286
Greenhouse Gas Emissions from Engines and Vehicles with Advanced Emissions Control Technologies	201.3
Greenhouse Gas Emissions from Off-Road Transportation Sources	166
High Energy Density Electrical Storage for Hybrid, Fuel Cell, and Electric Vehicles	340
High-strength Dual-phase Steels for Automotive Applications	50
Immediate Reduction of Fuel Consumption Throughout the Commercial Transportation Fleet via Reduction of Aerodynamic Drag	413
Improved Durability and Lightweighting of Hydrogen Fuel Processors	30
Inhibiting Additives for Casting of Magnesium in Sand Moulds	40
Investigation of On-road Vehicle Performance for Fuel Consumption, Greenhouse Gas, and Criteria Emissions	120
Lightweight Foamed Nanocomposites from Renewable Resources	640
Lightweight Refrigeration Trailer	70

Transportation Projects	Total T&I Funding ($ k)
Lightweight Ultrafine Grained Magnesium and Aluminum Alloys	80
Lightweight Vehicle Body Architecture (LiVBA) Project: Part I – Advanced Ultra-high-strength steel (UHSS) processing, manufacturing, and user properties; Part II – Magnesium Front-end Development (MFED)	915
Low-pressure Casting Magnesium Alloys Automotive Applications	60
Measurement of Black Carbon from Transportation Sources	55
Microstructural Application – Magnesium Alloys for Automotive	40
Regulated and Greenhouse Gas Carbon Dioxide and Nitrous oxide Emissions from Diesel Engines	55
Welding of Lightweight Materials for Automobile Weight Reduction	44

Industry Projects	Total T&I Funding ($ k)
A Novel Approach to Energy and Greenhouse Gas Reduction in Comminution	300
Advanced Burner Technologies for Metals, Refining, Chemical Industries	470
Carbon Dioxide Sequestration Using Alkaline By-products and Residues	167
Combined Catalytic Non-thermal Plasma Decomposition of Greenhouse Gas SF6	200
Condensing Heat Recovery for Papermaking Applications	300
Design, Construction, and Verification a Multi-purpose Energy-efficient Demonstration-scale Plant Using Microwave and HF	76
Development and Evaluation of Advanced Combustion Technologies for Efficient, Clean Industrial Combustion	200
Development of a Technology for Capture and Mitigation of Natural Gas Leaks from Compression Stations	225
Development of Multiphase Flow Fundamentals for Next-generation Technology to Mitigate Greenhouse Gas Emissions	346
Direct Carbon Dioxide Reduction of Industrial Emissions Using Membranes	300
Efficient Wood Kiln Drying	60
Energy-efficiency Improvement and Greenhouse Gas Emission Reduction in Distillation Processes	655
Energy-efficiency Improvement of Distillation Processes	77
Enhancing the Innovative “Eco-efficient” Platform Technology	40
Ethane to Ethylene in a Membrane Reactor	123
Gas Separation by Mixed-matrix Polymer – Zeolite Membranes	46
High-performance Computing Cluster for Industrial Research and Development	110
High-temperature Cascading Air Heater	100
Hydrodynamics of Gas-Liquid Multiphase Flow Systems	72
Induration Furnace Optimization	252
Integration of Advanced Blasting and Information Technology for Comminution Process Optimization and Greenhouse Gas Emissions Reduction in the Canadian Mining Industry	225
Measuring Granular Multiphase Flow Velocities	52.1
Microwave-enhanced Methane Gas – Organic Wastes	40
Microwaves as Greenhouse Gas Reducing Process Tools	700
Modelling of Natural Gas-injection Blast Furnace	50
Nanocomposites from Renewable Polymers – Supercritical Carbon Dioxide	60
Opportunity and Technology Assessment for Soft Sensors Application and Benefits for Process and Energy Performance in the Pulp and Paper and Cement Sectors	64

Industry Projects	Total T&I Funding ($ k)
Oxygen-blast Furnace Utilizing Combined-cycle Technology for Iron Production and Power Generation	190
Performance Standards for Industrial By-products in Cementitious Systems for “Green Concrete” Construction	240
Reduction of Greenhouse Gas Emissions Emissions in the Steel Industry via Transformation of Off-gases to Valuable Products	220
Stochastic Modelling of Black Liquor Gasification	210
Test Bench for the Development of Advanced Ejector Systems for Refrigeration and Heat Pumping	75
Virtual Prototyping of Advanced Greenhouse Gas Emission Reduction Technologies for Industries	235

Buildings and Communities Projects	Total T&I Funding ($ k)
3SI Building (Three Strategic Initiatives)	35
Alternative Energy-Ready Homes	136
An Innovative Tool for the Next Generation of Buildings, Energy-efficiency Programs and Policies	440.8
Assessment of Community Priorities	55
Benchmarking Communities through Archetypes	322
Benchmarking for Communities Growth Related Integrated Development Strategies (GRIDS)	70.4
Canada/U.S. Emerging Building Energy Technologies Scan and Greenhouse Gas Impacts Methodology for Strategic Planning	45
Clean Energy Generation for Innovative, High-performance Autonomous Floor	210
Cost-effective Commissioning for Low-energy Buildings, an IEA Annex in Preparation	302
Creating a Consolidated Network and Platform for the Simulation of Solar-building Technologies	98
Daylighting Design Guide for Energy-efficient and Sustainable Commercial Buildings in Canada	150
Development of a High-efficiency, High-capacity Ground Source Heat Pump for Community Applications	240
Development of a Luminance-based Lighting Control System to Enhance Energy Savings	226
Development of ECM Furnace Retrofit Packages	63
Electrical Network Models for Demand Management and Decentralized Energy Systems Integration in Housing	45
Enhancing the Lightswitch Wizard to include Classrooms and LEED Daylighting Credits	29
Exploring Possible Greenhouse Gas Reductions in Canadian Cities through Low-energy Housing Retrofit Options and Electric Vehicles	27
Facilitating the Uptake of Solar Energy Applications in Canadian Communities	120
Feasibility of Reducing Energy Use by Reducing Ventilation Requirements through Selection of Low-emission Materials	54
Field/CCHT Characterization and Benchmarking of Instantaneous Water Heaters	175
Ground-source Heat Pumps in District Energy, Economic Assessment	134
High-performance Multi-unit Residential Building (MURB) In-Suite Ventilation	339
High-performance Thermal Insulation Systems in Building Applications	148.9
Integration and Evaluation of Residential Fuel Cell/Combined Heat and Power System at the Canadian Centre for Housing Technology (CCHT)	75
Large-impact Reductions in Greenhouse Gas Emissions from Greenhouse Operation by Applying the “Closed Greenhouse” Concept and Integrated Solar Thermal Seasonal Energy Storage Technologies	75
Large-scale Community Field Trial of Major Home Retrofits	224
London Tract-Home Energy Innovation Initiative	125

Buildings and Communities Projects	Total T&I Funding ($ k)
No-incremental-cost Advanced Energy-efficient Houses and Support Network for Federal and Provincial Agencies	212.2
Optimize Supermarket Operation through Ongoing Commissioning	158.6
Optimized Zoning Approach for Peak Air Conditioning Load Shaving	346
Prototype Development and Field Trial for Desiccant Evaporative Cooling for Residential Buildings	248
Research and Development for the Optimization of Low-energy Solar Homes in Canada	160
Renewable Energy Integration for Small Rural Town and Farm Communities	194.6
Stratégies et outils pour l'utilisation du stockage d'énergie thermique dans les arénas, curlings et supermarchés	35
Sustainable Office Lighting Energy Savings by Using Task Lighting	20
Sustainable Urban Neighbourhood (SUN) – Moving Sustainability Mainstream	421
Telework Centres – Exemplars for the Environment	20
Testing and Assessment of an Emerging Residential Distributed Generation/Combined Heat and Power System	35
Use of Advanced Technology to Convert Electrically Heated Buildings to Hydronic Heating	190
Utilization of Renewable-derived Ethanol as a Domestic Furnace Fuel for Residential/Commercial Applications	90

Cross-cutting (Integrated Applications) Projects	Cross-cut	Total T&I Funding ($ k)
Bio Breakthrough Initiative	Industry (lead) and Biotechnology	83
Canadian Steel Breakthrough Program – Biofuels for Canadian Steelmakers	Industry (lead) and Biotechnology	476
Integrated Design Process for Renewable Energy Systems in Rural Canada	Buildings and Communities (lead) and Decentralized Energy Production	1,171
Integrated Economic Model	Clean Coal and Carbon Dioxide Capture and Storage (lead) and Unconventional Gas Supply	240
Optimizing the Carbon Value Chain in the Pulp and Paper Process Biorefinery	Biotechnology (lead) and Industry	1,200
Petroleum Bio-upgrading and Corrosion Mitigation	Bitumen and Heavy Oil (lead) and Biotechnology	1,030
Zero-emission Ammonia Fuel Cells for Decentralized Power Generation	Decentralized Energy Production (lead) and Clean Coal and Carbon Dioxide Capture and Storage	738

Cross-cutting (Technology to Market) Projects	Total T&I Funding ($ k)
Assessment of Select Community Energy System Technology Applications to Displace Natural Gas in Mixed-use Residential Developments	100
Energy Pathways Study	25.5
Greenhouse Gas Evaluation Study – Oil Sands	25
Greenhouse Gas Evaluation Study – Tool Development	136
Low-head Hydro Market Assessment	60
Ocean Energy Market Transformation	85
Opportunity/Gap Market Assessment of Anaerobic Digestion in Canada	95
Scoping Tables	24
Selective Reinforcement Metal Matrix Composites (SR-MMC) for Automotive Brake Rotors	36