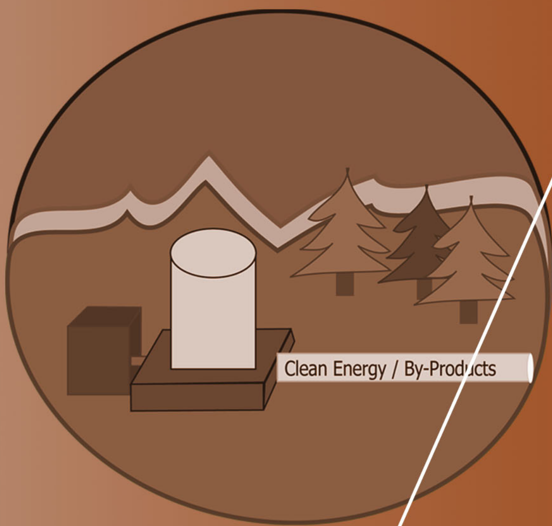
CCTRM

CANADA'S CLEAN COAL TECHNOLOGY ROADMAP

www.cleancoaltrm.gc.ca

"Developing clean coal technology options for power generation, heat and chemical production that will be energy efficient, economic and environmentally sound."



CLEAN ENERGY TECHNOLOGIES

Natural Resources Canada
Ressources naturelle Canada

Canada

Foreword

Canada is blessed with varied and abundant energy resources. This regionally diverse mix has allowed Canadians to prosper in spite of our small population spread across a vast land with all the difficulties of a northern climate. In Canada and globally there are huge proven reserves of coal which contribute enormously to our energy mix and to our nation's economic prosperity. To not continue to use coal is to deny many Canadians access to an inexpensive, secure, and readily available fuel, which is free from price volatility and completely capable of being utilized in an environmentally acceptably manner – as this *Clean Coal Technology Roadmap* illustrates.

The utilization of energy is directly linked to prosperity, which behooves us to produce energy with the smallest possible environmental effect and to consume that energy as efficiently as possible. As we look to the future, society will increasingly expect and demand that energy producers fully manage all of the emissions from their facilities including the greenhouse gases that contribute to climate change.

A critical look at all of the potential sources of energy and technologies for electricity production reveals that there are no clear winners. No one technology combines all of the most positive attributes of fuel source, waste management, reliability, cost, social acceptance, and environmental performance. Therefore, Canada will continue relying on a variety of fuel sources to meet our growing energy demand.

Future power plants enabled by clean coal technology require hardware and processes (which for the most part already exist in other industries) to be scaled–up, integrated, packaged, and optimized to meet utility performance standards. Canada is well positioned to become a world leader in the application of this technology because of the acknowledged excellence of ongoing work on both clean coal and carbon dioxide capture and storage technology. The availability of these technologies will allow utilities to move from current emissions levels to a near zero emissions profile in a single step, accelerating by years the normal incremental rate of improvement in environmental performance. Clean coal technology can form the basis for a new source of hydrogen, replacing, over time, our current dependence on natural gas reforming. Chemicals, feedstock, and other by-products add to the value proposition of future power plants enabled by clean coal technology.

Clean coal research is ongoing throughout the world, but the focus has not included the utilization of low-ranked coals such as the Canadian sub-bituminous and lignite varieties. An opportunity exists for Canada to take a leadership role (with respect to these types of coal) by accelerating the availability of clean coal technology and providing utilities with a powerful option to meet Canada's energy needs and create highly exportable technology. Internationally, emerging economies will inevitably utilize coal to meet their rapidly growing energy needs and failing access to clean coal technology will implement conventional coal technologies thereby perpetuating current emission performance and adding to the global greenhouse gas emissions burden.

The time for additional feasibility studies has past. Canada needs a clean coal demonstration project so the real learning can begin and thereby create benefits for all Canadians, as has been the result of other endeavours not so long ago, including the Great Canadian Oil Sands project.

The Canadian Electricity Association states that over the next 20 years Canada will require 20,000 MW of new capacity per decade to meet load growth and replace retiring generating units. The availability of a commercially demonstrated clean coal technology will provide utility planners with an important alternative that will provide opportunities to produce the products and by-products noted previously with the added benefit of the physical mitigation of greenhouse gas emissions, and thus the generation of emissions reduction credits for trading or for resale in international emissions markets.

On behalf of all involved in the research and writing of this Roadmap, I thank you for your interest and I urge you to provide your support in this important initiative for the nation.

Sincerely

Rick Patrick, Vice-President
Environment and Regulatory Affairs,
SaskPower

(Chairperson of the Management Steering Committee and Technical Advisory Committee for the Clean Coal Technology Roadmap)

Acknowledgements

Natural Resources Canada & SaskPower, the co-leads for this Clean Coal Technology Roadmap (CCTRM), would like to acknowledge the many contributors for their vision, energy, financial support, and in-kind assistance in creating this Roadmap.

Financial Support and In-kind Assistance

The Roadmap received its primary funding from *Industry Canada* through the *Climate Change Technology and Innovation Program*, which spawned from the Federal Government's Climate Change Action Plan 2000. The following organizations also provided in-kind and financial support (in alphabetical order):

- Alberta Energy Research Institute
- Alberta Energy and Utilities Board
- Canadian Clean Power Coalition
- Carnegie Mellon University (US)
- Electric Power Research Institute (US)
- International Energy Agency Clean Coal Centre (UK)
- Luscar Ltd.
- National Energy Technology Laboratory (NETL, US)
- Natural Resources Canada
- Nova Scotia Power
- Princeton University (US)
- SaskPower
- Science Applications International Corporation (SAIC, US)
- Tech-Wise A/S

CCTRM – Management Steering Committee

The following individuals are acknowledged for their participation in the Management Steering Committee, which developed the Terms of Reference for the Roadmap in January of 2003:

- Rick Patrick, SaskPower (Chairperson of Management Steering Committee)
- Bill Pearson, Natural Resources Canada
- Bob Stobbs, SaskPower (Industry Lead)
- Cynthia Johnston, TransAlta
- Eddy Isaacs, Alberta Energy Research Institute
- George White, Sherritt/Luscar Ltd.
- James Taylor, Nova Scotia Power
- Kelly Thambimuthu, Natural Resources Canada
- Paul Clark, TransAlta

CCTRM – Technical Advisory Committee

A special acknowledgement is directed toward the members of the Technical Advisory Committee for their dedication, commitment, and leadership throughout the Roadmap process. The committee met on numerous occasions and between the workshops, and carried out much of the background research and the technical assessments that support this Roadmap.

The Advisory Committee members are:

- Rick Patrick, SaskPower (Chairperson of Technical Advisory Committee)
- Alan Flemming, Luscar Ltd.
- Amar Amarnath, Luscar Ltd.
- Bill Pearson, Natural Resources Canada
- Bill Richards, Nova Scotia Power
- Bob Stobbs, SaskPower (Industry Lead)
- David Granatstein, Natural Resources Canada
- Duke du Plessis, Alberta Energy Research Institute
- Kelly Thambimuthu, Natural Resources Canada (Government Lead)
- Murlidhar Gupta, Natural Resources Canada

The authors of the first draft and final Roadmap documents are:

- David Reeve (Author of 1st Draft Roadmap)
- John Van Ham, Van Ham Resources Inc. (Author of Final Roadmap)

The Roadmap Management and Advisory Committees acknowledge the *Canadian Clean Power Coalition* for providing information on the Phase One Clean Coal Retrofit initiative, and for the coalition's preliminary evaluation of the technology options identified in the Roadmap. In addition, the Technical Advisory Committee members and the Roadmap authors wish to acknowledge the work done by Donna Baskin. Donna's dedication in organizing the three Roadmap Workshops, developing and maintaining the CCTRM website, and her support in the writing and publication of the draft and final versions of this Roadmap is greatly appreciated.

Appendix A is a list of the Workshop and other CCTRM participants whose involvement and advice is greatly appreciated.

Table of Contents

Executive Summary

Energy policy makers worldwide view coal as an important and strategic energy resource, one that is essential to maintaining world energy security at an economically competitive price. Over the coming years worldwide coal demand will increase and a Canadian and international commitment is required to advance clean coal technologies (CCT) to mitigate its potential impact. Canada can contribute to critical energy infrastructure through technology development and knowledge generation for domestic use, and for transfer to countries like China and India. Coal's environmental impacts are the primary challenge to overcome for this industry to continue its vital role in providing an essential service. These environmental concerns, and energy security around natural gas supply, are the key drivers behind Canada's need to develop CCT, and therefore are the primary reasons for undertaking this *Clean Coal Technology Roadmap* initiative.

The *vision* in this Roadmap is of a Canadian industry *that is a leader in adapting and integrating technology and knowledge for the effective utilization of coal and other low value carbon fuels as an energy source for the production of electricity, hydrogen, heat, and chemical feedstock with zero or minimal environmental impacts on land, air, and water.* An industry that has embraced this vision is one that has transformed in image and performance to become:

- A national leader, proactive in the research and development (R&D) of CCT
- A champion of achieving top environmental performance standards using the best available commercial technology in its operations
- A good local citizen, viewed as environmentally responsible and committed to the health and welfare of communities in Canada and globally
- A part of the solution to develop sustainable energy sources by building a fleet of clean coal plants that provide power to the nation
- Able to adapt and integrate leading technology into Canadian R&D and demonstrations

This Roadmap is a snapshot of key information for policy and decision-makers to understand regarding the strategic advantage of Canada's large endowment of coal, the challenges and expectations that clean coal will face, the various CCT options available, and projections of what clean coal might look like by 2035.

The Roadmap concludes with a set of primary objectives that must be achieved, and the strategic steps necessary to achieve these objectives. Industry and government commitment is essential for this vision of clean coal to become a reality in Canada.

Clean Coal – a Canadian Advantage

Although richly endowed with a portfolio of energy supply options, coal is an important one that provides energy security to Canada. Across many parts of the nation there is an abundance of low cost, indigenous coal. Other regions have easy access to international supply. As a result, a well-established coal-fired power sector already exists in Canada, which provides 16,985 MWe of generating capacity.

Clean coal technology will be used to continue to supply economically priced electricity, while contributing to the more stringent environmental performance objectives that are forthcoming. Canadian technology development will provide export opportunities for power generators and equipment manufacturers, and in turn will foster Canadian-based knowledge generation and innovation.

A mature CCT industry in Canada would be adept in developing or acquiring its own greenhouse gas (GHG) and air emissions mitigation technologies, building a domestic capacity for long-term technology development, and forging partnerships that help advance Canadian R&D. What stakeholders get from this Roadmap is a:

- Vision for the future of coal-fired generation, and the value proposition coal has for Canada
- Description of the critical challenges and expectations facing coal
- List of suitable performance standards for Canada's coal powered industry
- Picture of the technology pathways, highlighting the international initiatives of benefit to Canada
- Review of the relevant technology and innovations that would support developing these pathways
- List of the primary Canadian CCT objectives, and a pragmatic set of strategic steps for meeting them
- Timeframe for developing technology on schedule

In addition to providing information to decision-makers, this Roadmap provides industry champions with a starting point from which to reach the ultimate goal of commercially viable clean coal in Canada.

However, investments in R&D of this magnitude are beyond the reach of any one government or company, thus necessitating collaboration. Because of the reality of high and volatile natural gas prices developing this collaborative capacity is paramount.

Coal's Value Proposition

Coal and other fossil fuels are essential commodities to industrialization and economic growth. Fossil fuels currently supply 80% of world energy, and will continue to provide the majority of energy supply well into the 21st century. Coal is extremely important among fossil fuels, because while production is peaking for oil and natural gas, coal exists in abundance in many parts of the world (in both developed and developing nations). Canada is no different, with 66% of its fossil fuel reserves being coal.

Canada currently has 16,985 MWe of coal-fired generating capacity, which represents 18% of total domestic generating capacity. Coal already plays an important strategic role by providing power across many regions of the country.

Energy demand will increase in the coming years and some believe that natural gas can meet this demand. However, the energy picture that is unfolding is one of a natural gas supply constraint in North America and thus, high prices. As a result, North America, with its abundance of economic coal reserves, will likely move back to coal-generated electricity – provided industry can improve its environmental performance. Already, we are seeing industry make the decision to build coal-fired (instead of gas-fired) capacity in Canada based on the long-term economics.

Challenges and Expectations

Coal is facing a variety of issues and challenges that must be overcome to be a viable energy supply option in the future. At the top of the list is environmental performance, especially related to air emissions. The industry is either already or imminently facing legislation related to acid rain, smog, air toxins, and climate change. These issues and the complex legislation related to them add to the cost of coal-fired generation.

Climate change and Canada's commitment to the Kyoto Protocol are fundamental drivers behind developing CCT. Coal-fired generators are part of the Canadian government's large final emitters group, which is expected to reduce GHG emissions by 55 Mt CO_2e/year from 1990 levels by 2008 – 2012. This poses a challenge to coal fired generators, who are responsible for 17% of Canada's total GHG emissions. On top of this, there is every reason to believe that future standards will become even more stringent.

Another important challenge is competition from energy alternatives; however, each has its own set of critical challenges. Nuclear has gained support because of its zero-emissions profile, but it still faces other environmental and cost-related issues that make it comparatively risky. Natural gas facilities are the benchmark for power plants in central and western Canada today partly due to their relatively low emissions profile, short-term investment timeframe, and quick synchronization with the electricity grid. However, future supply-risk raises serious concerns about North American gas. Renewable energy, like wind and biomass, receives a lot of public attention but will only contribute small amounts to Canada's energy mix over the coming years. Hydro currently supplies the vast majority of Canada's power generation, and will likely grow in regions that have access to the resource. However, planning and building a hydro plant takes a decade to complete, is extremely capital intensive, and faces a variety of other environmental issues related to land, water, and human displacement. Therefore, the options do not provide a clear-cut alternative for new generation.

Industry has suggested that Canada replace its existing coal-fired capacity using the best available CCT on a schedule that matches the old facilities' retirement cycle. This implies replacing some 61 facilities between now and 2034. By 2010 alone, 5,000 MWe of generating capacity will be replaced. It will be difficult for Canada to deliver on this replacement schedule, let alone build new capacity to meet the increasing demand. Industry believes that the dire need for new capacity will necessitate using coal. The performance attributes of each of the energy options will determine the expected performance standards of all technologies, and so coal must also deliver on these standards to provide Canada with its needed capacity.

Clean Coal Technology Pathways

The various CCT pathways being discussed internationally (the linear progressions of technology-suite development over time) can be boiled down to two: combustion and gasification. Alongside these are the enabling equipment or processes like cogeneration, oxy-fuel systems, CO_2 capture and storage, and upstream coal cleaning, which apply to either pathway.

The combustion pathway begins with today's pulverized coal plant technology and moves in steps towards ultra-supercritical combustion, whether in fluidized bed, atmospheric or pressurized mode. This pathway consists of incremental innovations and improvements to technology that mostly already exists.

Gasification involves the development of newer technology for the generation of synthetic gas. This continuum is one of key component and technology development, along with incremental improvements to some available equipment (such as integrated gasification combined cycle technology), for use in demonstrations of new technology systems. This technology path includes the possibility of polygeneration – the generation of electricity along with multiple feedstocks including hydrogen. This technology-suite is not as far down the development pathway, however, it is being researched, developed and demonstrated by leading countries worldwide.

The international leaders in both technology pathways are the US, Japan, Australia, and EU. Each leader is gaining R&D knowledge and expertise in technology areas relevant to their own circumstances. The US has massive R&D budgets focused on gasification and they are working to develop the ultimate clean coal facility that would generate near-zero emissions and no waste. Japan is working to ensure the continuance of its current leadership role in combustion technology. As with everyone else, for Canada to capitalize on the work being done elsewhere, it must contribute to the overall R&D effort. Already many technological successes and new scientific discoveries are being made, making clean coal in Canada a possibility.

Projections for CCT deployment play out differently across Canada. The Atlantic Provinces, along with Ontario, Saskatchewan, and Alberta all provide excellent opportunities. For example, the pace of oil sands development in Alberta, which is driving up the demand for power and heat in Fort McMurray, is creating a unique opportunity for a clean coal power generation facility that would also incorporate carbon capture and storage technology.

Although the current Ontario government plans to phase-out provincial coal-fired generation, clean coal is still an option for future years. Ontario and regions of Canada not currently powered by coal may find a need for clean coal as other energy options fail to meet demand expectations.

Clean Coal in Canada

Paraphrasing from earlier, the vision is a clean coal power generation industry that is a leader in technology development and knowledge creation for the utilization of coal and low value carbon fuels as an energy source for producing electricity and a variety of feedstocks while minimizing the environmental footprint.

The critical technology and knowledge gaps holding back CCT in Canada have been identified (they include social, economic, and technical barriers), and a set of five clear objectives has been developed to address them. An essential component of these objectives is a proactive R&D Program relevant to Canadian circumstances, and therefore a separate exercise to identify the specific R&D needs has been conducted.

As a result of the Roadmap work, five components of a made-in-Canada strategy have been developed. Industry and government champions have already committed to implementing each of these components, which are:

1. Engaging in public outreach by developing a public National Clean Coal Information Program
2. Providing CCT information to stakeholders by creating a National Clean Coal Intelligence Centre
3. Developing R&D and technology programs focused on commercial demonstrations of technology
4. Developing a common national vision, business model, and risk mitigation strategy for the first CCT demonstration facility in Canada
5. Initiating the integrated and optimized design and operation of the first and subsequent demonstration plants in Canada

The roadway ahead is not unlike other endeavours previously undertaken. The success of the Canadian oil sands took years of investment in R&D and demonstrations before it became the world-class industry it is today. However, the time to invest in CCT is now, as a clear window of opportunity is opening now and over the coming 25 years. Successful demonstration projects and the subsequent roll out of technology and know-how is the prize to be won. Government and industry leadership are essential parts of a realized vision of CCT in Canada.

The anticipated impacts of implementing CCT in Canada are overwhelmingly positive: retaining energy supply security, ensuring environmental quality and integrity, and creating a technologically advanced industry sector that is open for business to the international community. Clean coal would bring benefits to regions that already rely on coal-fired power, and to others that may need clean energy in the future. Secondary impacts would be felt in other industries, including equipment manufacturing, chemical manufacturing, oil sands operations, and the public sectors.

Ultimately, the outcome of this Roadmap initiative is a resounding call to action today, to enable industry stakeholders to build the capacity for an economically competitive and environmentally sound energy future for all Canadians

List of Acronyms and Units

AB	Alberta
ACR	Alberta Camber of Resources
AG	Advisory Group
AMPCO	Association of Major Power Consumers in Ontario
ASRA	Alberta Science and Research Authority
ASU	air separation unit
þg/kJ	pico gram per kilo joule
BAU	business as usual
Bcf	billion cubic feet
Bt	billion tonnes
c	cent
C	carbon
CAC	Coal Association of Canada
CANDU	Canada Deuterium Uranium (reactor)
CBM	coal bed methane
CCPC	Canadian Clean Power Coalition
CCS	carbon dioxide capture and storage
CCSTRM	Carbon Dioxide Capture and Storage Technology Roadmap
CCT	clean coal technology
CCTIP	Climate Change Technology and Innovation Programme
CCTRM	Clean Coal Technology Roadmap
CCUJ	Centre for Coal Utilization, Japan
CDM	Clean Development Mechanism
CEA	Canadian Electricity Association
CERI	Canadian Energy Research Institute
CETC-O	CANMET Energy Technology Centre – Ottawa
CGPC	Canadian Gas Potential Committee
CH_4	methane
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COS	carbonyl sulphide
COE	cost of electricity
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSUG	Canadian Society for Unconventional Gas
CURC	Coal Utilization Research Council
^oC	degree Celsius
DIOS	direct iron ore smelting
DOE	see USDOE
DTI	Department of Trade and Industry (UK)
EC	Environment Canada
ECBM	enhanced coal bed methane
ENGR	enhanced natural gas recovery
EOR	enhanced oil recovery
EPES	emissions performance equivalency standard
EPRI	Electric Power Research Institute (US)
ESA	electric swing adsorption
EU	European Union
FBC	fluidized bed combustion
FEED	front-end engineering design
FI	Frazer Institute
g	gram
GHG	greenhouse gas
GovCan	Government of Canada
GWh	giga-watt hour
H_2	hydrogen
H_2S	hydrogen sulphide
HAT	humidified air turbine
HCN	hydrogen cyanide
Hg	mercury
HHV	high heating value
HRSG	heat recovery steam generation
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
J	Joule
JI	Joint Implementation
kg	kilogram
kg/bbl	kilograms/barrel
kt	kilo tonne
kWh	kilo-watt hour
LEBS	low emission boiler systems
LFE	large final emitters
LHV	low heating value
LNG	liquefied natural gas
mg/Nm^3	milligrams/normal cubic meter
MJ	million joules
MPa	mega Pascal
MSW	municipal solid waste
Mt	million tonnes
MW	mega-watt
MW_e	mega-watt electrical

$\mu g/m^3$	micro grams per cubic meter
µm	micro meter
N_2O	nitrous oxide
NB	New Brunswick
NCCP	National Climate Change Process (Canada)
NEB	National Energy Board (Canada)
NG	natural gas
NGCC	natural gas combined cycle
NH_3	ammonia
NO_x	nitrogen oxides
NRCan	Natural Resources Canada
NS	Nova Scotia
NSPS	new source performance standard
O_2	oxygen
OECD	Organization for Economic Co-operation and Development
ON	Ontario
OTM	oxygen transport membrane
PC	pulverized coal
PM_{10}	particulate matter < 10 µm in diameter
$PM_{2.5}$	particulate matter < 2.5 µm in diameter
ppb	parts per billion
PSA	pressure swing adsorption
R&D	research and development
RAM	reliability, availability and maintenance
RDI	RDI Consulting
SAGD	steam assisted gravity drainage
SCOPE21	super coke oven technology
SK	Saskatchewan
SMART	specific, measurable, achievable, realistic and timely (objective)
SNG	synthetic natural gas
SO_2	sulphur dioxide
SO_x	sulphur oxides
SP	supply-push
Tcf	trillion cubic feet
TV	techno-vert
TWh	tera watt hour
UCC	ultra clean coal
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
USC	ultra-supercritical
USD	US dollar
USDOE	United States Department of Energy
VOC	volatile organic compounds
VSA	vacuum swing adsorption
WCI	World Coal Institute
WCSB	Western Canadian Sedimentary Basin

1. Clean Coal – a Canadian Advantage

> ***Section Observations:***
>
> ***Clean coal is strategically important to help meet Canada's need for energy, heat, hydrogen, and chemicals.***
>
> ***Clean coal technology (CCT) will deliver economically priced power to Canadians without environmental compromise.***
>
> ***Canadian CCT and expertise will provide export opportunities throughout the world.***
>
> ***This Clean Coal Technology Roadmap lays out a set of industry-championed objectives that will lead to the successful commercialization of CCT.***

In July of 2001, the Climate Change Technology and Innovation Program (CCTIP) was announced as a crucial element of Canada's Climate Change Action Plan 2000. Under the CCTIP the importance of developing a clean coal strategy for Canada as part of a larger clean energy agenda was immediately recognized. It was decided that a technology roadmap would be developed to use for initial planning in the clean coal technology area and for publication and distribution to interested parties. An Advisory Group comprised of industry and government stakeholders was tasked with developing this Clean Coal Technology Roadmap (CCTRM). Natural Resources Canada (NRCan), through the CANMET Energy Technology Centre in Ottawa (CETC-O), provided support and facilitation for the process that has led to this Roadmap.

The Advisory Group held four working sessions, and hosted three open Workshops when gathering information for the Roadmap. Direct involvement came from the individuals and organizations noted in the Acknowledgements. Interested stakeholders provided additional input through the public Workshops.

Why Clean Coal?

Clean coal is strategically important to Canada for several reasons. First and foremost, Canada (and its closest neighbour, the US) is endowed with an abundance of economic coal deposits, around which a very strong coal-fired power generation industry has already been developed. The development of clean coal technology (CCT) will enhance the value of the existing industry and help the development of other sectors that will utilize the by-products of CCT facilities, such as heat and steam, hydrogen and other chemical by-products, and captured carbon dioxide.

As noted in subsequent sections, coal is the most abundant, commercially available fuel source today, not only in Canada but also globally. Additionally greater than 40% of global coal reserves are physically located in OECD countries; therefore access to the resource is not a typical risk consideration (which sets coal apart from other fossil-fuels). Clean coal can play an important role in supplying economically priced electricity across Canada and globally, while contributing to environmental performance objectives.

Energy experts agree that global demand for coal-fired energy will increase significantly in future years (IEA, 2004). Therefore, Canadian CCT development can contribute to greenhouse gas (GHG) emission reductions in Canada and internationally, as technology and knowledge developed at home can be transferred to places where the demand for energy is growing fastest, such as China and India (IEA, 2004). These countries stand to benefit from technology transfer by reducing their GHG emissions intensity, using their resources more efficiently, and leapfrogging the need for industrial aged infrastructure and instead developing a modern and highly developed infrastructure for the 21st century. In Canada, new CCT can replace antiquated infrastructure on a schedule that matches existing capital stock turn over.

With the projected increase in energy demand from Asia, Africa and Latin America, it is imperative that CCT be developed so that global energy demand can be met while mitigating air emissions including GHGs. The opportunity already exists for Canada and other nations to capitalize on.

Vision and Goals of Roadmap Exercise

The vision embodied in this Roadmap is one of a Canadian power generation industry: *that is a leader in adapting and integrating technologies and knowledge for the effective utilization of coal and other low value carbon fuels as an energy source for the production of electricity, hydrogen, heat, and chemical feedstock with zero or minimal environmental impacts on land, air, and water.*

Guided by this vision, the Advisory Group recommended that the ultimate goals of the Roadmap include:

- Accelerating the development of cost-effective GHG and other emissions mitigation technologies across multiple sectors
- Building the intellectual foundation required for long-term technological advances
- Forging alliances and partnerships to advance research, development, and demonstration programs

The Advisory Group noted that a practical and useful deliverable would be one that helps the industry stakeholders in achieving these goals by providing:

- A vision for the future use of coal in Canadian power generation (noted above)
- An outline of the critical challenges and expectations that confront coal's use
- A detailed description of suitable performance standards for Canada's power industry
- The identification of potential CCT pathways, and highlights of other (global) CCT initiatives that may be of benefit to Canada
- A review of the technology and innovation needed to develop these pathways in Canada
- CCT objectives for Canada, and a strategy for meeting those objectives
- A timeframe for developing the technology, with recommended implementation targets

Figure 1.1 The Past, Present, and Future Stages of Coal

Ultimately, this roadmap lays out a set of objectives and a strategy (championed by industry stakeholders), which will lead to the commercialization of CCT in Canada. This roadmap is an information source and a planning tool to help industry and government evaluate promising electricity generation technologies and to serve as a guide for Research & Development (R&D) and deployment decisions that are being made today. Achieving the objectives outlined in section 5, *Clean Coal in Canada*, would result in a significantly less carbon-intensive economy with near-zero air emissions from coal generation (see Figure 1.1).

Roadmap Overview

The information contained in this roadmap is structured as follows:

The next section, entitled *Coal's Value Proposition*, illustrates the strategic role that coal will play in Canada's electricity generation mix, and internationally.

Challenges and Expectations looks to the future and provides an overview of the 'existing versus pending' environmental, regulatory, and policy challenges facing CCT. This section also provides information on the alternative technologies for power generation in Canada, including nuclear, natural gas, hydro, and other renewables. In the final pages is a list the expected performance requirements for coal within target timeframes.

Clean Coal Technology Pathways provides a review of the CCT pathways either under development or already commercialized in a global context. This section notes the international CCT programs from which Canada could benefit, and presents scenarios for clean coal across Canada, in the Atlantic Provinces, Ontario, Saskatchewan, and Alberta.

Clean Coal in Canada identifies the critical gaps (in terms of SMART objectives) that need bridging before CCT becomes commercial in Canada. Details of an appropriate Canadian CCT development strategy are provided along with an assessment of the likely impacts of implementation across the country.

2. Coal's Value Proposition

Coal is an essential commodity to most industrialized nations, and will continue to be for some time. Coal is also in demand for the continued industrialization of developing nations like China and India, and has a prominent role to play in primary energy supply and as an essential input in steel making and other industrial processes. Therefore, it is imperative that the environmental impacts of coal be addressed on a global scale for it to be a viable option for supplying Canadian and international energy and industrial needs.

This section provides a brief overview of the role that thermal coal plays as a primary energy source, because its use in this capacity is the primary reason for CCT development. Other benefits of CCT, including hydrogen and chemical production, are important facets of the technology development and are noted throughout this Roadmap.

Section Observations:

Fossil fuels will remain the world's primary energy source and coal will maintain its dominant position in electricity generation for the foreseeable future.

Many energy sources will contribute to the electricity supply mix, however, few are available in the abundance that coal resources are.

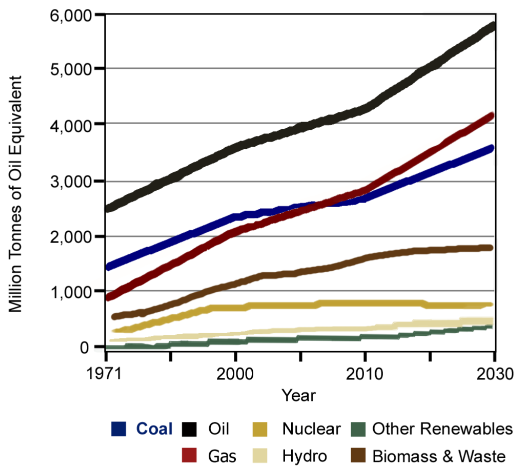
Changing natural gas markets may lead to a need for more coal-fired generation, which will only be acceptable if that generation is enabled by CCT and carbon dioxide capture and storage.

The core issues and market forces of today are driving the choices of policy and decision-makers, which is leading Canada down a pathway to our future energy industry.

International Role for Coal

Through recent history the need for affordable and secure energy has led to the situation where fossil fuels accounted for 80% of the world's commercial energy supply in 2002 (IEA, 2004). The International Energy Agency (IEA) expects this number to rise to 82% by 2030. World primary energy demand will increase at a rate of 1.7% per year between 2000 and 2030, resulting in an increase equal to two thirds of the current demand by 2030 (see Figure 2.1).

Figure 2.1 World Primary Energy Demand



(Source: IEA, 2004)

Coal is the world's most abundant conventional energy source, accounting for 60% of remaining world hydrocarbon reserves, and 91% in the US and Canada combined (not including oil sands and oil shale) (NEB, 2003). The IEA states that proven world coal reserves of 907 Billion tonnes (Bt) should last another 200 years with production at current rates (IEA, 2004). The European Union (EU), Australia, countries of the former Soviet Union (including Russia and Kazakhstan), China, and India all have extensive coal reserves. The latter two have large populations that rely heavily on coal for power generation – 75% of China's electricity is coal-fired.

Of the primary energy fuels, coal demand rose the fasted at 7% in 2003 (IEA, 2004). China led with a growth rate of 15%, as the country accounted for 31% of total world thermal coal consumption. Demand rose in Russia and Japan, by 7% and 5% respectively, as the closure of nuclear reactors required coal-fired stations to run at a higher capacity. In the US, high gas prices led power generators to switch to coal in 2003 and the country registered a 2.6% increase in demand for thermal coal.

The US, EU, Australia, and Japan all recognize the need for coal as an energy source and as such are investing heavily in domestic CCT initiatives. These countries believe that coal will continue to be the primary energy source for power generation as it is a secure and stable resource for countries that would otherwise be exposed to the uncertainty and irregularities of the oil, natural gas, and other energy markets.

Key Assumptions

Although increased demand for nuclear and renewable energy is anticipated, fossil fuels will meet more than 85% of the global increase in energy demand over the coming 25 years (IEA, 2004). The IEA has the following assumptions for each of the primary energy sources:

- Oil consumption will almost double between now and 2030, driven mainly by the transportation and power generation sectors. Oil will remain the most heavily traded fuel, and imports may account for 57% of North America's consumption (the US and Canada) by 2030. Demand will grow fastest in developing countries; however, escalating crude prices will force consumers to consider other options to meet their energy needs.
- Natural gas demand will double between now and 2030, mostly as a result of demand increases in Africa, Latin America, and Asia. New power generation will account for greater than 60% of the increase. Gas-to-liquid plants are expected to emerge as new major supply centres in Russia and the Middle East. Over half of all gas traded by 2030 will be liquefied natural gas (LNG). Recently, North American supply has exerted significant upward pressure on local gas markets, but this pressure is expected to ease if the necessary investments are made in LNG infrastructure.
- Nuclear energy has been on a decline in recent years. The retirement of existing plants led to a 2% decline in nuclear energy in 2003. In absolute terms, nuclear capacity will increase by 2030, but its overall share of the energy mix will decrease. Very recently there has been a renewed interest in nuclear because of its near-zero emissions profile and because of the role it could play in energy security. As a result of the mixed driving forces there is little certainty around the role that nuclear will play in future energy supply.
- Renewable energy covers a range of energy sources including hydro (large and small-scale), biomass, wind, and solar. Although somewhat limited by geographical capacity, some new hydroelectric sites are likely to be developed. Wind and photovoltaic energy are the fastest growing renewable sources, although biomass remains the largest commercial source worldwide. Renewable energy will continue to grow rapidly but will only play a limited role in global energy supply by 2030.
- Coal use will grow, and it will remain the primary energy source for power generation in 2030. Most of the growth will occur in developing Asian nations; China and India together will account for 68% of the total world growth. 40% of the global coal reserves reside within OECD (Organization for Economic Co-operation and Development) countries, thus coal is

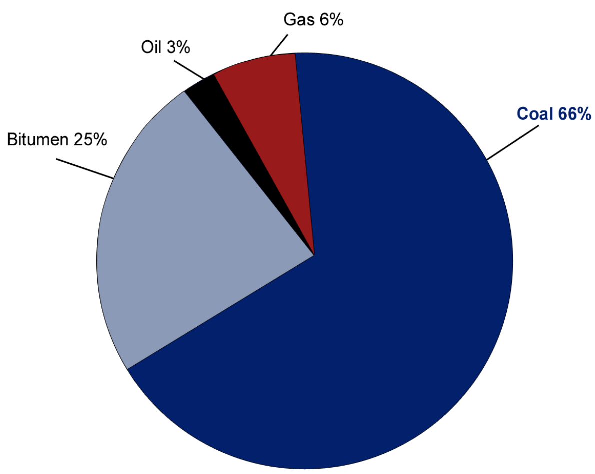
considered to be relatively accessible compared to the other fossil fuels that predominantly reside in politically unstable regions of the Middle East and Central Asia. The IEA emphasizes that the future of coal in OECD countries will rely to a great degree on climate change policy and the development and deployment of advanced CCT.

National Role for Coal

Current View

The inherent advantages of fossil fuels, such as their availability, economic competitiveness and ease of transportation, are why they account for approximately 75% of Canada's primary energy supply (96% in Alberta and 93% in Saskatchewan) (NEB, 2003; NRCan, 1999). Coal plays a significant role by contributing over $5 billion annually to the Canadian economy. The coal industries support 56,000 direct and indirect jobs in Canada, including direct employment for equipment operators, trades people, and professionals like geologists, engineers, accountants, and managers. Coal is a valuable domestic commodity for use in Canada and for export abroad. It is used both for thermal power generation, and for metallurgical and other industrial purposes.

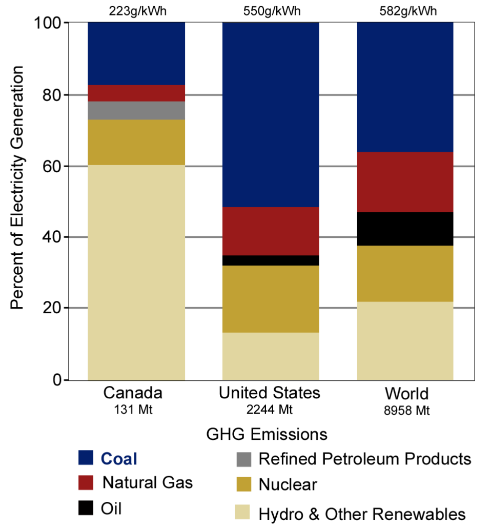
Figure 2.2 Canada's Fossil Energy Reserves



(Source: NRCan, 2001)

In 2001, Canada produced a total of 41.75 million tonnes (Mt) of thermal coal (bituminous, sub-bituminous, and lignite) for power generation (CAC, 2005). Of this total, 3 Mt were exported while the remaining amount, plus imported coals (which together total 60 Mt), were used to generate power in six provinces across Canada. A national recoverable reserves estimate was last compiled in 1987, and by deducting the volume of coal produced since that time, the remaining Canadian reserves are estimated to be 6.20 Bt, of which 4.60 Bt are thermal coals (NEB, 2003). It will take over 100 years of production at today's extraction rates to mine this reserve, compared to 8 years for Canadian oil reserves and 9 years for natural gas (NEB, 2003). The remaining measured, indicated, and inferred coal resources will last hundreds of years more. Coal is by far the most significant Canadian fossil fuel resource (as illustrated in Figure 2.2).

Figure 2.3 Fuel Mix for Electricity Generation



(Source: Pearson, 2003)

Coal's contribution to Canadian electricity production is approximately 18%, compared to 54% in the US and 36% worldwide (see Figure 2.3). Because of the relatively high contribution from hydropower, the GHG emissions intensity of generated electricity in Canada is low at 223 g/kWh.

The intensity will increase, as Canada becomes more fossil fuel dependant, unless promoting lower or zero-emissions technology prevails.

The fuel mix for Canadian power generation is different across the country, with a total of 16,985 MW of coal-fired capacity across six provinces. Table 2.1 illustrates the variability across the country, from a low of 7% of power generation coming from coal in Manitoba to a high of 67% in Alberta. Hydro-rich provinces like British Columbia, Quebec, and Newfoundland have no coal-fired generating capacity within their borders due to the abundance of available hydro resources. These regional circumstances, and market forces that prevailed during the time of plant construction are responsible for the mix that exists in Canada today.

Table 2.1 Coal Generating Capacity by Province

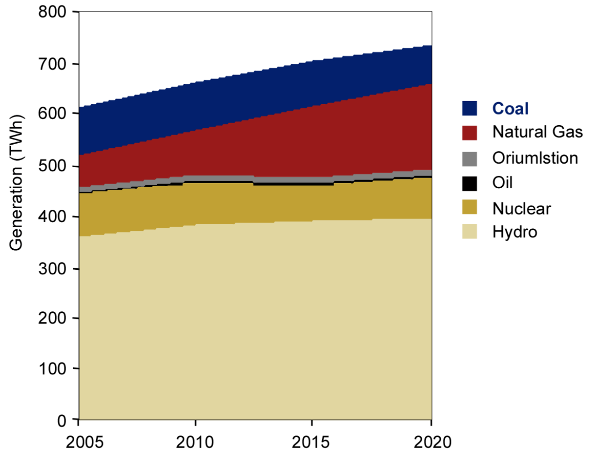
Province	MW	% of Energy Mix
Nova Scotia	1,240	60
New Brunswick	537	19
Ontario	7,561	29
Manitoba	237	7
Saskatchewan	1,624	57
Alberta	5,786	67
Canada	**16,985**	**18**

(Source: Pearson, 2003)

Future Canadian Energy Outlook

NRCan forecasts that coal's position will steadily diminish from now until 2020 (see Figure 2.4). Their forecast is based on two core assumptions. First is the supposition that current energy and environmental polices (both federal and provincial) are held constant over the period, and no new policies are implemented. The second assumption is that most new demand will be met using natural gas-fired power generation.

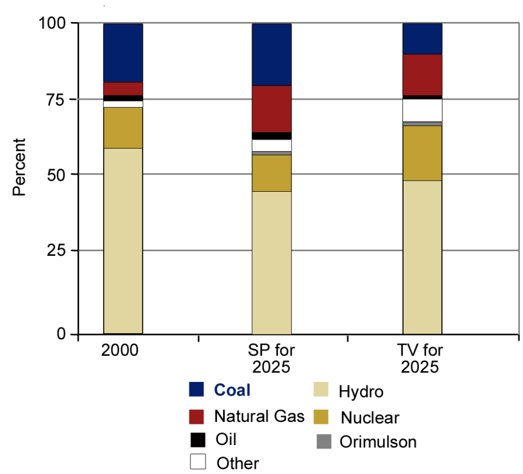
Figure 2.4 Electricity Generation by Primary Energy Source (NRCan)



Note: Renewables (other than hydro) not included in NRCan document because of anticipated small contribution.
(Source: NRCan, 1999: Pearson, 2003)

A scenarios study by the National Energy Board (NEB) suggests a slightly different outcome (see Figure 2.5), however, it still indicates a growing demand for fossil fuels. The study outlines two scenarios for the evolution of power generation capacity in Canada to 2025: a Supply Push (SP) scenario characterized by technological advances and limited environmental action; and a Techno-Vert (TV) scenario which entails rapid technology advances and societal preferences for cleaner burning fuels. Some of the predictions in this report are similar to NRCan's, such as natural gas-fired generation being the main source for new electrical capacity in Canada. The SP scenario indicates an increased demand for thermal coal (of up to 90

Figure 2.5 Predicted Energy Demand by Full Source (NEB)



(Source: NEB, 2003)

Mt/year by 2025) as new coal-fired facilities are built in Ontario[1] and the west. Under the TV scenario, coal-fired generation increases slightly but overall coal production declines. This is due to reduced thermal demand brought about by new higher-efficiency coal-fired units that employ CCT such as integrated gasification combined cycle (IGCC) and ultra-supercritical combustion (USC).

An assumption built into the SP scenario is a severe shortage of low-cost Canadian natural gas and therefore the increased reliance on coal. This is a telling point because it is consistent with the current and anticipated supply and demand picture for North American natural gas. One market study projects 280,000 MW electrical (MW_e) of new gas-fired capacity being constructed in the US between 2000 and 2015, which would result in significant upward pressure on natural gas prices and have lasting implications on North American gas markets (RDI, 2001).

Whether looking at NRCan's forecast or the NEB's scenario analyses, an important point to conclude is that the demand for fossil fuel generated electricity will only increase in Canada. At the same time, current market forces are indicating that North American natural gas resources will not be sufficient to meet demand (more on this in the following section). Although the IEA indicates that LNG will be available to meet world demand (and thus, North America's) in the future, this statement relies heavily on the assumption that significant investments are made in infrastructure in both North America and in key natural gas supply regions such as Russia and the Middle East. Therefore, it assumes that investments will be made in politically volatile regions that are prone to the type of uncertainty that makes investors nervous.

On the other side of the equation, regulatory and environmental expectations are necessitating that coal becomes cleaner, in order to become a publicly acceptable option and help make up the shortfall in energy supply that is expected. Domestic energy experts and those at the IEA do state that coal's future in the OECD lies in these countries' ability to develop and deploy clean coal and carbon dioxide capture and storage technology. Mitigating coal's environmental footprint and ensuring the continued future value of North America's vast coal reserves depends on new technology.

Section Summary

Coal and other fossil fuels are essential commodities in Canada and internationally. Coal currently supplies a significant amount of power generation across the nation, but is even more prominently positioned in the energy mix of other key nations around the world.

Other energy sources will play a significant role in the world's energy future, however, it is difficult to identify an option that can replace coal's position in the coming decades because of the cost (and in some cases, risks) associated with developing these alternatives. Coal is the most abundant fossil fuel resource available, and the most geographically dispersed around the world, and it will be used for power generation well into the future.

North American energy demand will rise in the coming years, and if natural gas demand increases as expected there will be significant upward pressure on North American gas prices. It is anticipated that this pressure will lead power generators across Canada to seek out fuels other than natural gas. Thus, there is an urgency to develop and commercialize clean coal and carbon dioxide capture and storage technology, which in turn enhances the current value of Canada's abundant and low-cost domestic resources. However, it cannot be stated enough that the future of coal relies on the ability to develop these technologies to enable a truly clean coal industry for Canada.

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[1] Ontario has since released plans for the provincial coal phase-out by 2007 (more on this in subsequent sections)

What will likely drive the success of clean coal in Canada are the regional issues (like energy cost, energy security, and environmental concerns) that guide policy-developers and decision-makers in their choices. A key constraint today is a lack of public awareness regarding clean coal and carbon dioxide capture and storage technology and its potential to address both Canada's energy and environmental concerns at a reasonable economic cost.

3. Challenges and Expectations

Coal is faced with a number of challenges that it must overcome to succeed as a viable fuel source for future power generation. These challenges include environmental, regulatory, and policy pressures, and the possibility of competition from alternative energy sources.

This section takes a forward look to provide an overview of the pending environmental regulation and environmental policy challenges that coal will face. As well, this section provides an assessment of alternative or competing technology options to coal-fired generation in Canada. The final sub-section outlines the expected economic and environmental performance requirements for coal-fired technology, and a timeframe for the key milestones and deliverable dates for the development of CCT.

Section Observations:

Expectations are driving the development of more stringent environmental standards for coal-fired generators; these will include standards for GHG emissions reductions in time.

Despite competition from other energy sources, coal will continue to play a vital role in Canada's energy mix because of its low-cost position and the security of the resource.

The profile of Canada's existing coal-fired capacity requires a high rate of replacement in the future, which provides an opportunity for advanced CCT as an economic and environmentally competitive option.

Environmental Challenges

Today's new coal-fired plants already use innovative technologies to reduce environmental impacts on the land, water, and air. Many environmental issues are already being addressed using new technology, practices and procedures, and higher industry standards. Examples of issues already being addressed include, groundwater impacts from mine effluents, surface mine land reclamation, fugitive dust from transportation, reagent disposal and tailings pond management for coal preparation plants, and the management of solid waste such as ash and solid scrubber residues.

Significant air emissions reductions have already been achieved at existing plants; however, further reductions are needed to continue to reduce environmental impacts such as acid rain, smog, particulates and air toxics build-up, and climate change. Air emissions are one of the primary drivers behind CCT development today.

Regulated Air Emissions

Regulated air emissions in the power generation industry include nitrogen oxides (NO_x), sulphur oxides (SO_x), volatile organic compounds (VOCs), and particulate matter less than 10 micrometers in diameter (PM_{10}). Mercury (Hg) and $PM_{2.5}$ will be regulated emissions for the electricity sector in the not too distant future. Small amounts of other toxic metals (such as arsenic, cadmium, chromium, and nickel) are released during coal-fired generation, and these too are a public concern. The primary environmental issues related to the regulated air emissions are indicated in Table 3.1 on the following page.

Trans-boundary emissions (across the US-Canadian border) and emissions from industry and transportation are also significant contributors to Canadian air issues, particularly east of Manitoba. Canadian acid rain research and monitoring programs indicate that 50% of annual sulphate and nitrate deposits in Canada come from US sources (Canadian Geographic, 2000). Therefore, Canada's ability to remain below pending threshold targets for acid rain deposition and smog, and particulate, ozone, and mercury concentrations, depend on the performance of US-based facilities. Further, any effective solution not only lies in improving the performance of fossil fuel-fired generators, but also of the industrial and transportation sectors, as only a portion of the total regulated emissions emitted within Canada come from power generation; 20% of SO_x emissions, 11% of NO_x, 13% of PM, and 26% of Toxics come from power generation (EC, 2005).

Table 3.1 Coal Related Emissions & Existing / Pending Regulations	
Environmental Issues and Environmental Legislation	**Emission/s causing the Environmental Impact**
Acid Rain Pending Legislation Environmental thresholds of critical loads for acid deposition. Provinces likely to be effected - Ontario, Quebec, New Brunswick, Nova Scotia	SO_2, NO_X
Smog (PM and Ozone) Pending Legislation - $PM_{2.5}$ 30 µg/m^3 (24 hour average) Canada-wide by 2010 - Ozone 654 ppb (8 hour average) Canada-wide by 2010 - Multi-pollutant reduction strategy Canada-wide by 2010 - Transboundary NO_2 (39 kt cap Ontario, 5 kt cap Quebec) by 2007	NO_X, PM
Toxins Pending Legislation - 69 to 90% reduction under negotiation	PM, Hg
Climate Change Pending Legislation GHG emissions reduction under negotiation	CO_2, N_2O
** through the formation of secondary particulates, SO_2 and NO_X indirectly contribute to Smog and Air Toxins.*	

Intricate and complex relationships exist among the regulated emissions as well as GHGs, which add to the complexity of dealing with these emissions. For example, sulphur dioxide (SO_2) emissions contribute directly to acid rain and through the formation of secondary particulates they contribute to smog and air toxics. NO_x contributes directly to acid rain, and indirectly to smog. Because of these intricate relationships, legislation that is meant to manage the impacts of the emissions is also complex. Table 3.1 depicts the air emissions that are directly responsible for causing each impact. Amid all the complexity, the simple truth remains that fossil fuel-based power generation is one of the key contributors to air emissions, and industry must address this problem in order to sustain its future.

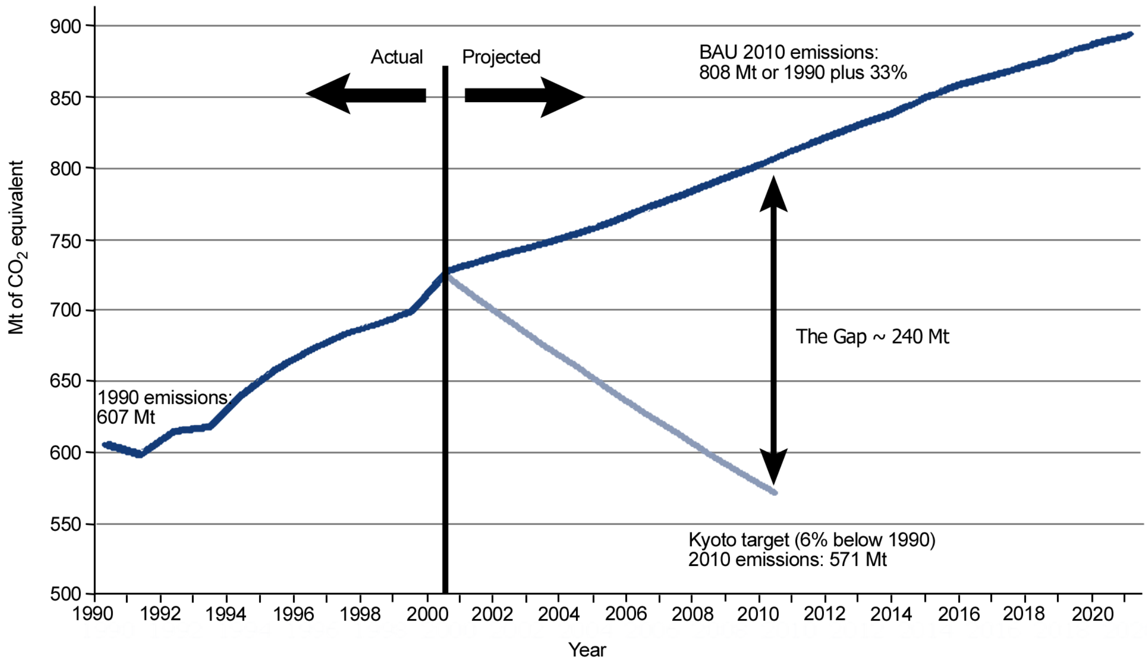
Carbon Dioxide and GHGs

Carbon dioxide (CO_2) is the primary GHG produced during coal combustion or gasification. However, methane (CH_4) is another GHG, and one that escapes during coal mining operations. Nitrous oxide (N_2O) is a GHG that is produced while generating power under certain combustion conditions.

GHGs are a concern because of their contribution to global climate change. As GHG concentrations increase in the atmosphere, so does their greenhouse (or overall warming) effect on the planet. GHGs are not currently regulated air pollutants in Canada, although this situation is changing. Canada has ratified the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), and thus has agreed to a commitment to lowering its GHG emissions to 6% below 1990 levels during the period from 2008 – 2012. However, the gap between Canada's Kyoto target and the business as usual (BAU) scenario (Figure 3.1 on next page) has increased in recent years. It is estimated that for the 2008 – 2012 period, the gap will reach 240 Mt or more of CO_2 equivalent (CO_2e) emissions, if the appropriate reductions programs and initiatives are not in place. The challenge that Canada faces is how to reduce these emissions while minimizing the negative economic impacts of those reductions. In an ideal situation, the negative impacts would be mitigated and in fact positive benefits would accrue through the development of technology and knowledge that would result in a more innovative and competitive Canadian market.

The coal-fired generators are part of NRCan's large final emitter's (LFE) group, and projections show that LFEs could be responsible for up to half of Canada's GHG emissions by 2010. As a result, companies under the LFE system are being asked to collectively reduce their emissions by 55 Mt CO_2e/year by 2008 – 2012 (GovCan, 2002). This number has been the subject of debate since 2002, and there is indication that the number may be reduced to 37 Mt. Regardless, industry will be expected to reduce emissions during the Kyoto period and any subsequent commitment periods.

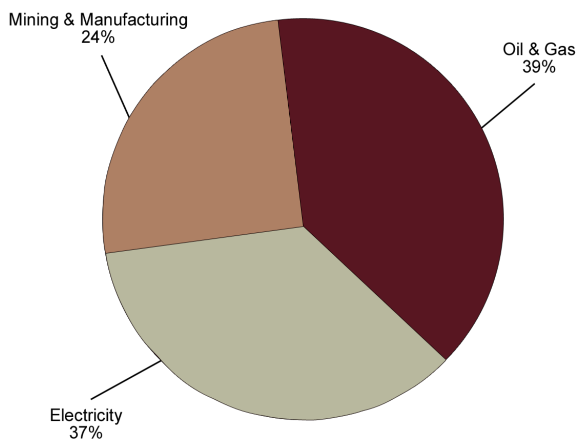
Figure 3.1 Canada's GHG Emissions Gap



(Source: NCCP, 1999; Gov Can 2002)

Within the LFE group the emissions are split as indicated in Figure 3.2. Electricity generation, which emits 17% of total Canadian GHGs, accounts for 37% of LFE emissions (EC, 2002). Thermal power generation is the largest single industry sector source of GHGs under the LFE, and coal-fired facilities generate the majority of those emissions.

Figure 3.2 Emissions from Large Industrial Emitters 2000 (Total 342 Mt)



(Source: EC, 2002; NRCan, 2002)

Emissions reduction targets for all of the sectors under LFE are being established through voluntary covenant agreements between government and industry, which are based on regulatory compliance and financial penalties for non-compliance. The government will have sector specific backstop targets in place in case covenant agreements are not reached. Only the steel industry has agreed to a covenant agreement on emission intensity thus far. A series of options have been discussed for power generation, including a national thermal intensity target, provincial/territorial thermal intensity targets, and intensity targets for new and/or near end-of-life thermal plants (Buckley, 2004).

Fossil-fuel generators are important to these discussions because they are the sources from which meaningful CO_2 emissions reductions can be made, and coal is the most emissions-intensive of all fossil fuels. Also, large stationary point sources (such as a thermal plant) are generally thought to be the best opportunities for retrofits, in terms of cost-effectiveness due to the scale of the facilities. As a result, the development and deployment of CCT is essential for reducing GHG emissions from coal. Carbon capture and storage (CCS) is an important component of CCT, as it will enable the possibility of truly near-zero emissions from fossil fuel power generation. As such, CCS is an important component to this Roadmap, and efforts have been made to link to a concurrent roadmap exercise being carried out for CCS (more on the CCS technology roadmap in subsequent sections).

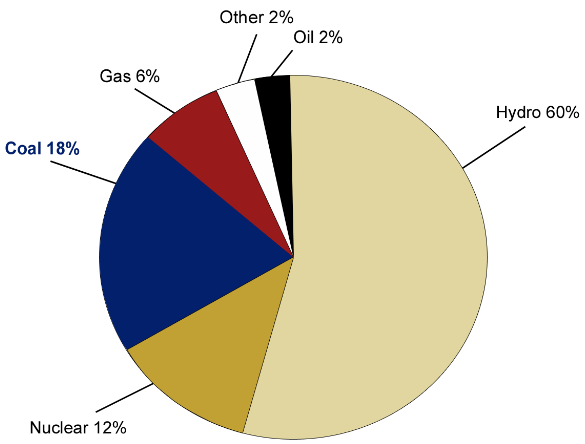
LFE companies will likely be able to use a number of flexible mechanisms to meet their GHG reduction goals, including domestic emissions trading and offsets, and the international mechanisms under the Kyoto Protocol (including international carbon markets, Clean Development Mechanism, and Joint Implementation).

To meet the challenge, Canada's electricity industry has suggested an emissions performance equivalency standard (EPES) as a starting point for the discussions on new and near end-of-life plants, proposing that coal-fired plants achieve an equivalent rate of emissions intensity to that of a natural gas combined cycle (NGCC) plant. Elements of the proposed EPES include: new facilities meeting or exceeding the standard, facilities 40 or more years old meeting or exceeding the standard, and facilities less than 40 years old being exempt. Industry believes that applying this standard would lead to more than 50% reductions in net CO_2 emissions intensity from coal-fired plants.

Competing Alternatives to Coal

Many alternatives compete as a fuel source for electricity generation and it is very clear that several will have a significant place in the future energy mix. Currently Canada's mix is characterized by hydro as the dominant source, with coal and nuclear making up most of the balance (see Figure 3.3). The most important primary energy sources in terms of Canada's future are discussed in the following pages.

Figure 3.3 Electricity Generation by Fuel Source (2000)



(Source: NEB, 2003)

Natural Gas

Natural gas has been the preferred fuel source for new power plants in central and western Canada, despite the fact that it is fuelled by the most expensive of fuel options. Gas-fired capacity has been growing the fastest of all power generation technologies in Canada, and the NEB (2003) expects it to rise from 5% of the fuel mix in 2000 to 12 – 18% in 2025 (depending on the scenario).

Among the fossil fuels, natural gas is the cleanest fuel with very low SO_x, NO_x, PM, and toxic emissions, and relatively low GHG emissions. In fact, GHGs from a gas-fired facility are half that of an equivalent conventional coal fired plant (see Table 3.2). Gas-fired plants are relatively easy to build, and take less time to commission than other large-scale facilities (especially nuclear or hydro).

Gas-fired plants have other advantages over coal; they require less capital to build and involve short construction lead-times. Delivery of the gas is simple, as it comes by pipeline and is relatively risk free. On-site fuel preparation, storage, and solid waste disposal are not required with natural gas, as the necessary processing has already occurred prior to the gas' delivery. Coal processing and preparation occurs on site at the power generation facility, which accounts for part of the emissions imbalance between the two fuels. For coal, more than 97% of CO_2 emissions occur at the power plant, while for natural gas almost 25% occur upstream. A full lifecycle analysis is therefore the best measure for comparing fossil fuel based technologies (see Table 3.2). However, even with the lifecycle analysis taken into account, gas is less GHG intensive than coal. A reason for gas' low emissions profile is its fuel to electricity conversion efficiency. For natural gas the number is 48 – 52%, compared to 35 – 43% for coal.

Table 3.2 Life-Cycle Analysis of CO_2 Emissions

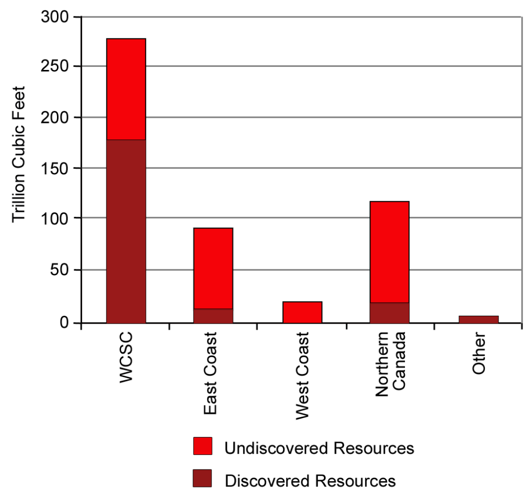
System	g-CO_2e/kWh	Emissions source (as % of total emissions)		
		Surface mine	Fuel transportation	Power plant subsystems
Coal New Source Performance Standard	941	0.9	1.7	97.4
Coal Low Emission Boiler Systems	741	1.0	1.8	97.2

System	g-CO_2e/kWh	Pipeline construction	Production & distribution	Ammonia production	Power plant subsystems
Natural Gas Combined Cycle	499	0.4	24.9	0.1	74.6

(Source: Spath and Mann, 2000; Spath, Mann and Kerr, 1999)

Most Canadian gas production comes from the western reaches of the Western Canadian Sedimentary Basin (WCSB). Alberta accounts for 83% of gas production, British Columbia for 13%, and Saskatchewan for 4%. Large deposits of natural gas have also been discovered offshore in Nova Scotia and Newfoundland. Frontier basins, with no immediate plans for production include the Beaufort Sea, the Mackenzie Delta, the Arctic Islands, and the Labrador and Grand Banks basins. Figure 3.4 illustrates the total discovered and undiscovered gas resources across Canada.

Figure 3.4 Canadian Natural Gas Resources



(Source: NEB, 2004a)

In addition to these resources, the potential for unconventional gas such as coal bed methane (CBM) is significant. The Canadian Society for Unconventional Gas estimates that total Canadian CBM resources are estimated between 182 and 553 trillion cubic feet (Tcf), 96% of which resides in the WCSB in Alberta and BC (CSUG, 2004). If this resource were actually produced it would represent an increase in total Canadian gas reserves of 36 – 110%. Conventional natural gas production has already peaked in Canada, and although the introduction of CBM is significant it will likely only delay the peak in total gas production to the end of this decade. The rate of decline in production after the peak will depend upon whether new technology can extend or enhance natural gas recovery (ENGR) in the same way as enhanced oil recovery (EOR). The bottom line is that Canada is becoming constrained by its natural gas supply.

Liquefied natural gas (LNG) from overseas may offset some of the decline and help in re-powering the old oil-fired facilities in Atlantic Canada. As noted previously, the IEA places a lot of emphasis on LNG exports from Russia and the Middle East to meet North American demand. However, the reality that is emerging is upward pressure on North American natural gas prices, and looming uncertainty over whether North America wishes to rely on deliveries from Russia and the Middle East.

Gas prices are a big concern to oil sands operators, as they currently use 0.6 billion cubic feet (Bcf)/day and by 2015 are expected to use 1.6 Bcf/day (NEB, 2004). Since more than half of the cost to produce synthetic crude is tied to the use of natural gas, oil sands developers are exploring the options such advanced clean coal, to supply their energy, hydrogen, and heating requirements.

Nuclear

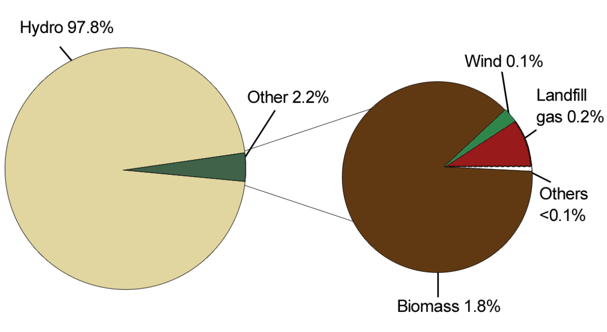
The centrepiece of Canada's nuclear industry is the Canada Deuterium Uranium (CANDU) pressurized heavy water reactor, which uses a once-through natural uranium fuel cycle, which avoids the need for enriched uranium. There are 22 CANDU reactors in Canada (17 were operational in December 2004), 20 in Ontario, 1 in Quebec, and 1 in New Brunswick. The Ontario plants were built for decommissioning by 2010, but will likely be refurbished to extend their lifetimes.

Today, it is uncertain what the appetite is for new advanced reactor construction in Canada. However, it is clear that nuclear is receiving more attention largely due to its near-zero GHG emissions profile. Increased nuclear capacity could be used to avoid or offset GHGs and other air emissions that would otherwise be emitted from fossil fuel power generation. However, the industry still needs to improve the economics of nuclear power and prove that plant safety and the handling of radioactive waste can be managed successfully. As well, to plan and commission a new nuclear facility takes on the order of a decade to complete. In addition, the public's acceptance of new nuclear facilities will likely pose an issue. For these reasons, nuclear does not appear to be a clear-cut option for future power supply and so another choice must be available.

Renewable Energy

The term 'renewable energy' refers to several energy sources that have little in common technically, but each can be used to produce electricity without a noticeable depletion of the energy source. Renewable energy technologies include: hydroelectricity turbines, biomass combustion and gasification plants, wind turbines, photovoltaic and solar cells, and ocean or tidal power turbines. Renewable energy plays a significant role in Canada's electricity sector, but primarily because of large-scale hydroelectricity. The contribution that hydro and other renewables make to Canada's total electricity production mix is 62% (taken from Figure 3.3). A further break out of the various renewable subcategories is illustrated in Figure 3.5.

Figure 3.5 Renewable Electricity Production 1999/2000
(total of 336,030 GWh)



(Source: NRCan, 2001)

Hydro

60% of Canada's electricity generation is hydro based, with 62,500 of the 64,000 MW being large hydro (NRCan, 2000). Hydro is the least expensive source of base-load electricity because of its low associated fuel and operating costs. Hydro is also considered to be near-zero emissions and therefore is attractive. Large hydro capacity is expected to increase by 20% by 2025 (NEB, 2003). The increased generation will come primarily from British Columbia, Manitoba, Quebec, and Newfoundland and Labrador. Some projects being discussed include 2,264 MW at Gull Island on the lower Churchill River, 824 MW at Muskrat Falls, and a new 1,000 MW facility at the existing Churchill River site (NCCP, 1999).

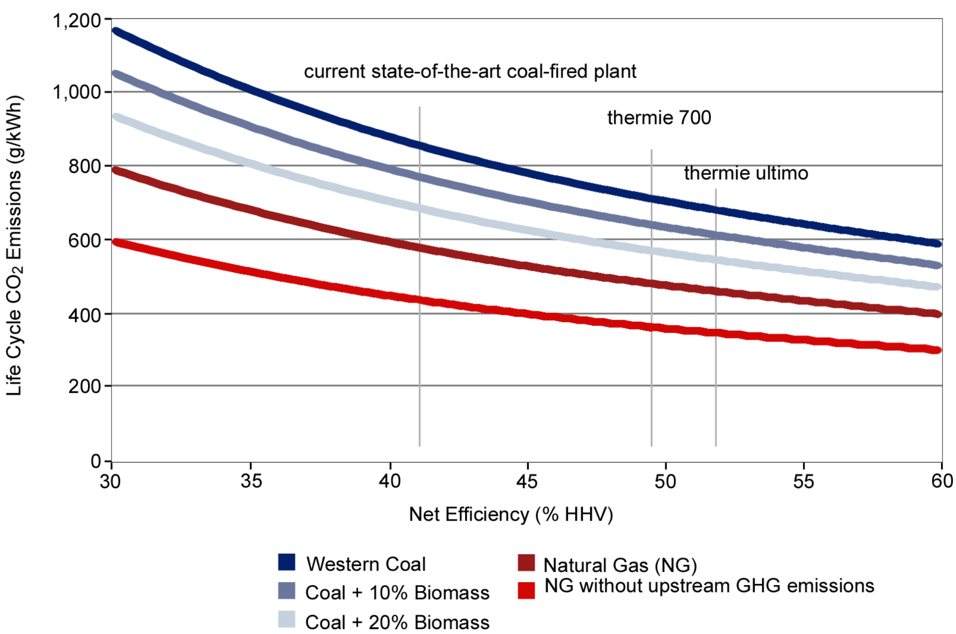
This capacity is not enough to meet the growth in demand in the required timeframe, let alone to make up for the replacement of existing generation capacity that has served its plant life. New large-scale hydro projects are expensive and difficult to build. Hydroelectric dams are long-term projects and are extremely capital intensive. Building them submerges large areas of land, changes river ecology, affects fish habitat, and may displace rural populations. Hydroelectricity has significant impacts on the land and water resources. As a result, it is no longer considered to be 'the' green option in power generation, despite its renewable stature. As with nuclear, hydro is not a clear-cut option for providing all the future electricity capacity that Canada needs, and therefore an alternative must be made available.

Biomass

After hydro, biomass is the second most abundant source of renewable electricity capacity in Canada. Two major industrial sources of biomass are sawmill residues and black liquor from pulp and paper mills. The pulp and paper industry has more than 1,200 MW of installed bio-energy capacity (often co-fired with fossil fuels). These are typically cogeneration units that also provide on-site heat for industrial processes. Independent power producers use sawmill wood waste for an additional 200 MW at 10 other plants across Canada. Most of these biomass sources, however, have low energy densities, which lead to high transportation and handling costs. Small amounts of electricity are generated from landfill methane, by incinerating municipal solid waste (MSW) or using the biogas by-product from the anaerobic digestion of sewage and industrial effluents.

Biomass on its own is not a feasible option in many cases, but it can be co-fed into advanced fossil fuel-fired facilities to generate significant emissions reductions over a regular plant. The figure below shows the effect of efficiency improvements at advanced coal and gas facilities, and the

Figure 3.6 Impacts of Energy Efficiency and Biomass Co-Feed



effect that biomass can have when co-fired. The uppermost line demonstrates western coal's profile compared to co-firing with 10% and 20% biomass (the next two blue lines). At 20% co-firing, the CO_2 emissions from a current state-of-the-art coal-fired plant operating at 42% efficiency is only 180 g CO_2/kWh more than at an equivalent gas-fired plant operating at 50% efficiency (red lines below). This indicates a significant reduction in the GHG emissions imbalance noted previously. In a future scenario, with higher efficiencies for both coal and gas plants, the difference narrows to 131g CO_2/kWh.

Wind

The cost of wind power has decreased dramatically due to technology improvements and economies of scale in turbine production over the past two decades. Canada has a large wind resource, but its development is limited because of competition from other low-cost electricity supplies. In addition, wind power is intermittent and therefore can only supply a portion of the total installed generation capacity.

The largest wind farm in Canada is Le Nordais, a 100 MW facility with 133 turbines on the south shore of the St. Lawrence River on the Gaspé Peninsula, Québec. Large-scale wind farms also exist in Pincher Creek, Alberta. Although the wind industry is growing the fastest in Canada and the world in terms of rate of installed new capacity, its overall presence in the energy mix will continue to be small in the near future.

The public's acceptance of the aesthetics of wind farms is undetermined as of yet and may play a role in the technology's future success.

The Impact of Competing Alternatives on Coal

As noted previously, new nuclear units take a minimum of 10 years from planning to commissioning and their construction may not necessarily be in tune with the public's interests. Similarly, building new hydroelectricity facilities is on the order of a 10 year cycle. The time required to build a clean coal plant is four – five years, and the first ones may be available by 2012. Therefore, coal has a strategic advantage over hydro and nuclear. However, natural gas-fired plants require even shorter construction times. The biggest question around natural gas will be the availability of gas supply as demand for it increases over the coming years.

Despite the promise of the other renewable energy sources, they will not be mature enough to replace other base-load generating facilities over the coming decades. However, the alternative energy sources, with their higher environmental performance standards will set the criteria for new fossil fuel-fired generating plants, especially when it comes to air emissions. Thus, CCT is essential for coal to maintain its competitive position in Canada's fuel mix, let alone to build from this position. The choice of which CCT suits a particular application depends upon factors like the availability of local or imported coals (and other low-value carbon fuels for co-firing), markets for by-products of the clean coal process (such as hydrogen), and whether or not CO_2 can be captured and either used or stored effectively.

Establishing Performance Standards

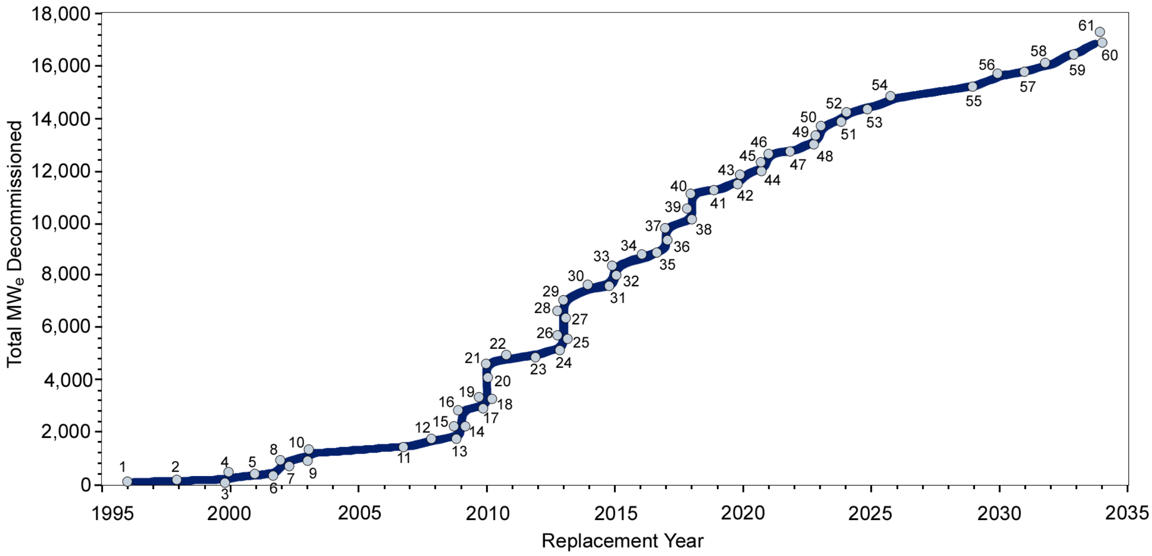
Consistent with the discussion of an EPES proposal noted previously (page 23), special consideration needs to be paid to the three types of coal plants that were discussed: new plants, existing ones, and near end-of-life plants. Performance standards for the new and near end-of life plants were both covered during the development of this Roadmap. The Canadian Clean Power

Coalition (CCPC)[2] is handling the development of standards for existing plants, and recently conducted an extensive study to evaluate the expected performance of near term technologies to eliminate SO_x, NO_x, PM, and air toxics at existing facilities (CCPC, 2004a). The study concluded that the goal to eliminate these emissions could be achieved by retrofitting existing facilities at an incremental cost of 1.5 – 2.7 ¢/kWh. The variance in the cost of electricity (COE) is dependant on the formula used for amortizing capital cost.

The CCPC study does not include the cost of CO_2 capture, and in fact the study concluded that it would not be cost effective to retrofit existing facilities for CO_2 capture because of the large energy penalty involved and the cost of retrofits. Therefore, the industry is requesting that existing facilities be left in operation and be exempt from CO_2 emissions reductions until they reach their 40 year economic life. Thus, it is proposed that GHG emissions from power generation be dealt with solely through new coal-fired facilities and brown-field installations on existing sites.

Figure 3.7 is a cumulative plot of Canada's coal-fired facilities that will require replacement (expressed in MWe decommissioned) as they reach their 40 year life. Appendix B provides a cross reference to the specific units in Figure 3.7. About half of the current installed capacity is over 25 years old, 33 units will have reached economic maturity by 2015, and 61 will need to be replaced by 2034. If Canada opted for the proposed EPES standard, all of Canada's coal-fired facilities would be performing to the standard of an equivalent NGCC plant by 2035. The rate of change to the higher performance standard is approximately 725 MW_e/year, assuming a start date of 2005 and continuing for the next 25 years. This replacement schedule (with the critical milestone dates for replacing existing facilities) is taken into account in the strategy section of this Roadmap. The Canadian Electricity Association has stated that Canada will need to invest upwards of $150 billion (Canadian) over a 20 year period to develop 20,000 MW of new generating capacity per decade between 2001 and 2020, which includes the development of both replacement capacity and capacity specifically for meeting new power demand (CEA, 2001). An important consideration is

Figure 3.7 Replacement Schedule for Canadian Coal-Fired Units



Note: based on a 40 year plant life
(Source: Pearson and Pomalis, 2004)

[2] The CCPC is a national public-private association of leading coal-fired electricity producers, representing 90% of Canada's coal generating capacity. As noted in the Acknowledgements section the CCPC was intimately involved in the development of this Roadmap.

that the next fleet of generating capacity will have an equally long lifespan, thus investments made in the near term will affect Canada's emissions profile for decades to come.

Table 3.3 summarizes the anticipated performance standards for advanced CCT, both for pulverized coal (PC) and integrated gasification combined cycle (IGCC), based on the expectation of competing with NGCC. These standards and timeframes have been adopted as CCT performance targets under this Roadmap. As noted earlier, the performance of the best available commercial technologies drive the expectations for others. As the 2020 – 2025 timeframe approaches, where CO_2 capture and storage technologies are proven suitable, clean coal will be able to deliver near-zero emissions electricity. In regions where CO_2 storage proves impractical, the focus will be on improving output efficiency to reduce CO_2 emissions intensities by 25 – 50% from 1990 levels.

Also included in the table are cost estimates to meet the specific standards. For example, based on today's best available technology, the average capital cost to replace existing facilities with CCT is $1,250 US dollars (USD)/kW of installed capacity. If CO_2 capture technology were included, the average cost would be just over $1,900 USD/kW. Using these figures, the annual investment required to replace all existing coal-fired facilities is on the order of $900 million – $1.4 billion USD/year for the next 25 years.

Table 3.3 Anticipated CCT Performance Standards

Performance	Past	Present		Future			
		Best Available Technology		2010 - 2015		2015 - 2025	
	Typical Conditions	PC	IGCC	PC	IGCC	PC	IGCC
Capital Cost (US$/kW)[a]		1,000 - 1,200	1,200 - 1,500	900 - 1,100	1,000 - 1,200	900 - 1,000	800 - 1,000
Efficiency (% HHV)[b]	33 - 35	40 - 43	40 - 44	45 - 50	45 - 50	50 - 53	50 - 60
SO_2 - coal specific (ng/J)[c]	234 - 1,300	198 - 1,462	43	4.5 - 5	4.5 - 5	<1 Matching to NGCC	
NO_x (ng/J)[d]	200 - 230	219 - 258	64	4 - 5		<4	
Mercury Removal (%)[e]		n/a	50	70 - 90		>90	
PM_{10} and $PM_{2.5}$ (ng/J)[f]	11 - 59	15 - 30	5	2 - 3		<2	
VOCs (mg/Nm^3 flue gas)[g]			1/150 of permitted	1		<1	
Efficiency De-rating for 90% CO_2 Removal (%HHV)[h]		7 - 12	6 - 8	4 - 7	4 - 5	2 - 4	2 - 3
Capital Cost for CO_2 Removal (US$/kW)[i]		700 - 900	300 - 800	500 - 600	200 - 500	300 - 400	100 - 300
COE without Capture (US cents/kWh)[j]		3.5 - 4.4	4.4 - 4.9	3.0 - 4.1	3.0 - 4.1	<3.0	<3.0
COE with CO_2 Capture (US c/kWh)[k]		6.3 - 7.9	5.7 - 6.4	3.6 - 4.9	3.3 - 4.5		

([a] CURC/EPRI/DOE, 2003; [b, h & i] Gupta and Thambimuthu, 2003; [c, d, f & g] CCPC, 2004; [e] EnvCan, 2004; [j & k] Scott et al, 2003)

Section Summary

Coal is facing a variety of challenges that it must overcome to continue its position as an important energy supply in future years. The two primary challenges include its comparative environmental performance and competition from alternative power generation technologies.

Coal-fired electricity producers already use a variety of technologies to reduce SO_x, NO_x, PM and other toxic air emissions. However, the challenge will be to meet the anticipated North American air standards for future years, which will include limitations on GHG emissions. Increased awareness of the environmental impacts of fossil fuel power generation in the US and Canada is pressing coal-fired generators to meet stringent new standards and CCT is essential to meeting those standards.

Canada's fuel mix for electricity generation will continue to be dominated by hydroelectricity, with coal, nuclear, and natural gas making up the majority of the balance. Many predict that fossil fuels, and in particular natural gas, will increase its share of this mix by the largest amount. However, declining production of conventional and unconventional gas in the WCSB before the end of the decade will put upward pressure on natural gas prices. LNG from abroad may not be available in the volume that is necessary. Some electricity generators have already made the decision to build new coal-fired capacity instead of gas, because of these emerging market forces.

Regardless of the type of capacity built, the environmental and economic performance standards of the alternatives affect the expectations of any technology. CCT will need to meet strict performance standards in order to succeed. To keep coal economically and environmentally competitive, R&D and the commercial demonstration of CCT is required, and thus the importance of the strategic and concerted effort spent during the development of this Roadmap. It will take a significant investment to make clean coal competitive with other energy technologies, but the investment is essential for Canada to meet its future energy requirements at an economically acceptable price, and with minimal environmental impacts.

4. Clean Coal Technology Pathways

Two primary CCT pathways are being developed worldwide, along with various other enabling technologies or components that are more broadly applicable to energy technology in general. This section provides a brief description of the two major pathways, combustion and gasification-based, along with a review of the international initiatives underway in support of either of them. World leaders in the development of R&D capabilities and expertise related to clean coal technology are the US, Australia, Japan, and EU. Much can be learned from the initiatives and programs being led by these nations.

Future scenarios of how the provincial CCT pathways may develop in Canada over time are also provided. The benefits of CCT will be felt across the country (in the Atlantic Provinces, Ontario, Saskatchewan, and Alberta) and by many industry sectors (such as technology developers, industrial manufacturers, refiners, and chemical producers).

Section Observations:

Combustion, the predominant means of coal-fired generation today, continues to technologically develop as environmental constraints increase.

Gasification will unleash the full value of coal by enabling the generation of electricity, heat, H_2, and other feedstock all in one facility.

Upstream coal cleaning, CHP, oxy-fuel, materials development, and CCS are all important to the development of near-zero emissions technology.

Canada can benefit from international CCT programs already underway by using the most advanced technology when conducting its own domestic R&D and deployment.

Opportunities exist across Canada; an immediate need for advanced CCT is already felt in Atlantic Canada, Ontario, Saskatchewan and Alberta.

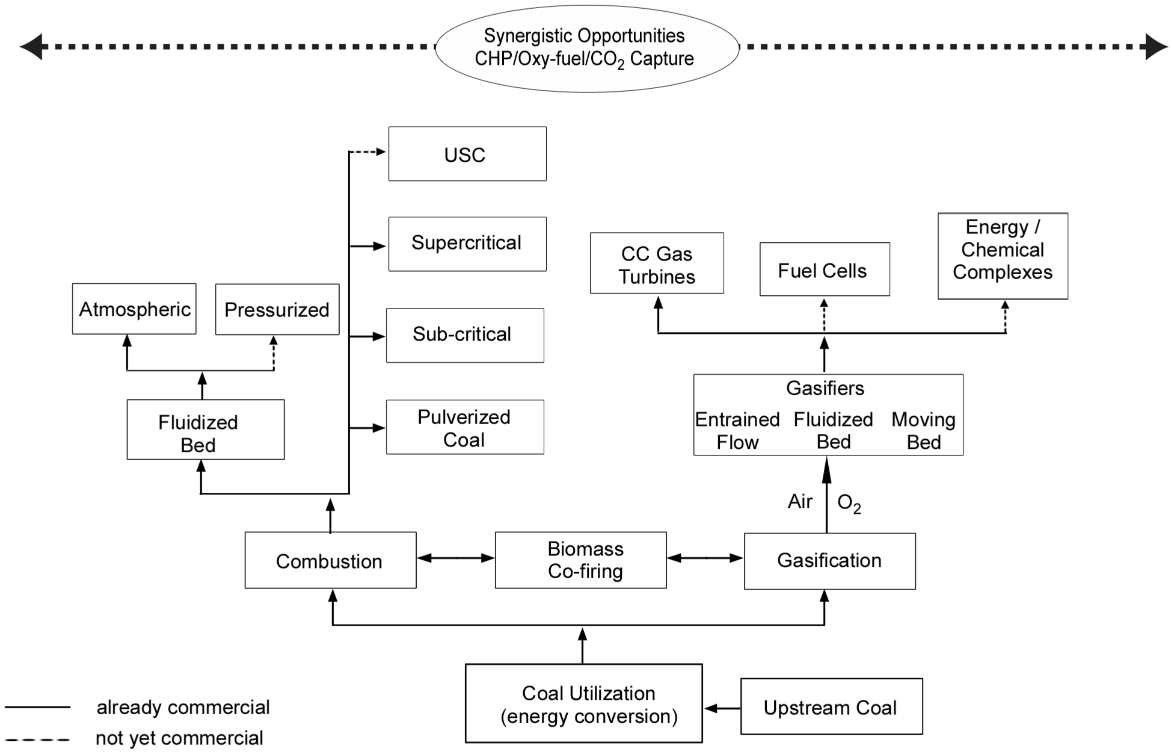
Pathways Options

CCT pathways are essentially the technology routes for coal preparation and utilization for electricity generation. A pathway is a linear progression, or a continuum, of a technology-suite's development over time. Examples include the Microsoft Windows technology pathway versus UNIX, or a rail versus road transportation pathway. The two primary utilization pathways under CCT (combustion and gasification) can be further subdivided into categories like pulverized coal (PC), fluidized bed combustion (FBC) and others (see Table 4.1 and Figure 4.1). The gasification pathway (which is a relatively new route) will be the precursor to hybrid electricity generation cycles that involve energy efficient fuel cells, and multi-product energy/chemical plexes. Both pathways offer the potential for combined heat and power (CHP). These pathways also include the emerging concept of oxy-fuel combustion, which would result in a concentrated CO_2 flue gas stream that would be ready for capture, transportation, and geological storage. Biomass co-firing is simply a co-feed option under either of the two primary pathways. A breakdown of the specific technologies under each pathway and those common to either is provided in Table 4.1.

Table 4.1 CCTs by Pathway

Combustion	Gasification
Pulverized Coal . Sub-critical steam cycles . Supercritical steam cycles . Ultra-supercritical steam cycles	Integrated Gasification Combined Cycle . Entrained Flow Gasifier . Fluidized Bed Gasifier . Moving Bed Gasifier
Fluidized Bed Combustion . Atmospheric Combustion . Pressurized Combustion	Pre-combustion Capture Fuel Cells Integrated Energy/Chemical Plexes
Ultra Clean Coal Oxy-fuel Combustion Cogeneration and Combined Heat and Power Post Combustion Carbon Capture CO_2 Transportation and Storage	

Figure 4.1 Potential CCT Pathways



Combustion Pathway

Combustion is the predominant pathway for current coal-fired generation. So far, technical improvements have focused on the cycle efficiency and on reducing pollutant emissions (other than CO_2) to below acceptable limits. Growing concerns over GHG emissions are driving a revisit of this pathway to explore how capturing and storing the emissions geologically can be used to mitigate CO_2 emissions.

Pulverized Coal (PC) combustion utilizes steam as a working fluid in a Rankine cycle to transform the thermal energy from coal combustion to generated power. PC combustion is used in over 90% of coal-fired plants worldwide. Since both the highest and lowest temperatures of the working fluid govern the efficiency of a Rankine cycle, the temperature and pressure limits used are a reflection of the state of the technology's development. The higher the range of temperature and pressures, the more advanced the technology. Most of the world's PC plants use *sub-critical steam cycles* with pressures < 22.1 MPa. These plants are very reliable, and comprehensive information databases on these facilities exist for a wide range of fuel sources and operating conditions. However, these systems are relatively inefficient at ~36% (higher heating value (HHV)), which makes achieving emissions reductions difficult.

By taking advantage of materials improvements and of associated fabrication technologies *supercritical steam cycles* utilize steam at a pressure of 24 MPa, and temperature ranges between 540 – 560°C, and achieve efficiencies up to 40% (HHV). Supercritical PC plants are already commercially viable and are the preferred choice of coal-fired technology in Asia and Europe. Over 40 supercritical plants operate worldwide. EPCOR constructed the first one in Canada (Genesee III near Edmonton, Alberta), which was commissioned in March 2005. The plant uses western Canadian sub-bituminous coal and operates under steam conditions at 24.1MPa/540°C/540°C.

The development of new materials such as high-strength ferritic steels, coupled with improved steam turbine design has allowed steam conditions to increase to *ultra-supercritical cycle* levels, > 25 MPa and 565°C. Ultra-supercritical cycles will achieve efficiencies of up to 47%. This technology is being used for new plants in Japan, the most recent being a 1050 MW_e unit that operates at 35.1 MPa and 600 – 610°C (Henderson, 2003).

Fluidized bed combustion (FBC) is a well-established method of burning low-grade coals, biomass, and other waste fuels. It produces less NO_x and SO_x than a conventional PC plant. In this technology, fuel particles and other inert solids and/or calcium-based sorbents are kept in suspension at temperatures between 800 – 900°C. Units that operate at atmospheric pressure are classified as bubbling-bed or circulating fluidized bed, depending on the method for solids circulation. Bubbling-bed units operate at elevated pressures. Circulating fluidized beds have had success in relatively small units (less than 300 MW) and in niche markets where low-value coal, variable-quality solid waste, or 'opportunity' fuels exist. A number of these plants are already in commercial operation (Nova Scotia Power already operates a 165 MW unit at Point Aconi).

Combustion is the dominant means of coal-fired generation today. However, emerging regulations are dictating the following major issues be addressed:

- ***the development of advanced materials***
- ***the reduction of pollutant emissions***
- ***cost-effective CO_2 capture and storage***

Gasification Pathway

In the gasification process, coal, steam, and either air or pure oxygen (O_2) react at an elevated temperature and pressure to produce a raw synthesis gas (syngas), which consists mostly of carbon monoxide (CO), hydrogen (H_2), and some impurities. When a gasifier is incorporated into a combined cycle unit (a gas turbine/generator and a steam turbine/generator) the plant is referred to as an *integrated gasification combined cycle* (IGCC) plant. The inner workings of an IGCC plant are illustrated in Figure 4.2, where pulverized coal and O_2 are fed into a gasifier, which transforms the inputs into syngas. The hot syngas then passes through a heat exchanger to cool the gas and recover the heat. The cooled gas passes through a gas-cleaning unit prior to it being expanded in the gas turbine to produce electrical power. The turbine exhaust then passes through a heat recovery steam generator (HRSG) to recover the waste heat and use it to produce additional electricity. Typically, the gas turbine produces 65% of the power and the steam turbine 35%.

Two commercial-sized coal-based IGCC plants operate in the US and two in Europe. The general details of these plants are summarized in Table 4.2. An alternative to an IGCC power plant, would be to de-carbonize syngas from a gasifier to produce H_2 either for turbine or fuel cell applications, or for the synthesis of chemicals.

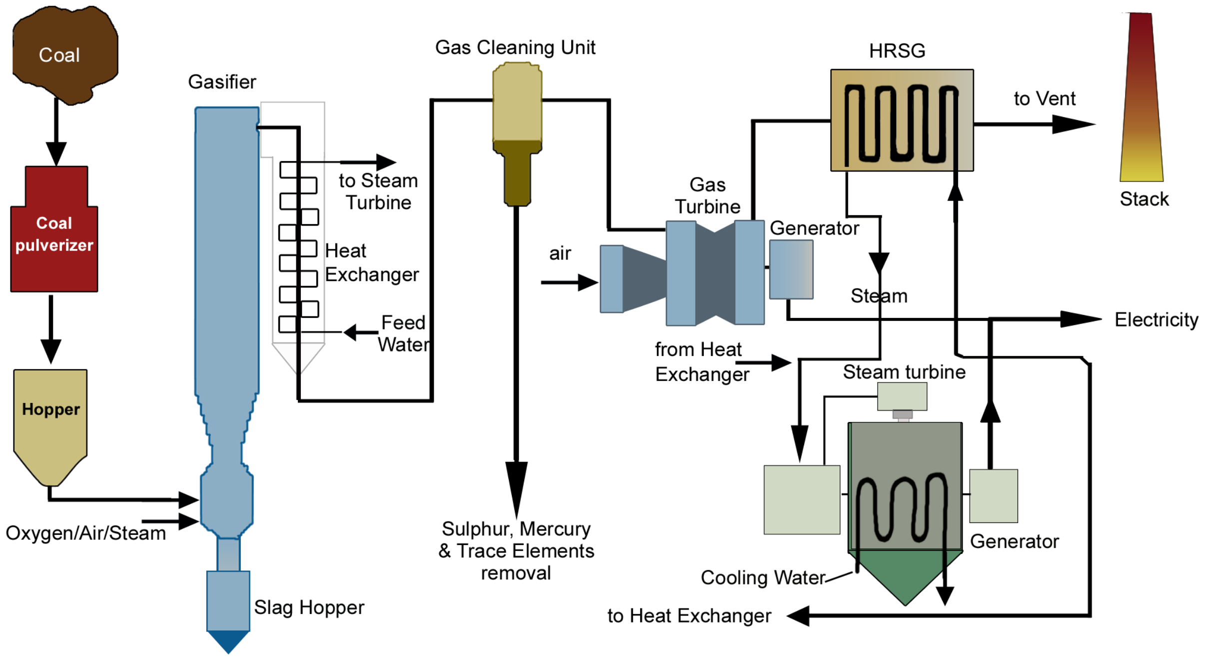
Table 4.2 Commercial IGCC Plants

Location	Technology Supplier	Plant Size (MWe)	Startup Date
Indiana, USA	Destec	262	October 1995
Florida, USA	Texaco	250	September 1996
Buggenum, Netherlands	Shell	253	Early 1994
Puertollano, Spain	Prenflo	310	December 1997

Note: The prenflo technology is 50:50 fed by coal and pet-coke
(Source: Courtright and Armor, 2003)

Syngas can also be catalytically reformed to create chemical feedstock like fertilizer or methanol. This type of chemical synthesis from coal is well established in many countries. Examples of operating plants include the SASOL Fischer-Tropsch Synfuels complex in South Africa, the Great

Figure 4.2 Flow Diagram of Typical IGCC Plant



Plains Synfuels plant in North Dakota, the Eastman Chemicals plant in Kingsport Tennessee, a fertilizer plant in Farmland Kansas, and a Sinopec fertilizer plant in China.

> ***IGCC has been successfully demonstrated at full commercial scale, but a number of issues remain:***
> - ***reliability, availability and fuel flexibility***
> - ***capital and operating cost***
> - ***demonstration of the CO/H_2 'shift' reaction***
> - ***development of large-scale H_2-fired turbines and fuel cell technology***

The approach of generating chemical feedstock and H_2 along with the generation of electricity and steam can take place in *integrated energy/chemical plexes*, or 'polygeneration' facilities. These polygeneration plants of the future could be designed with dual downstream options, to generate energy and chemical products all within the same complex (see Figure 4.3). Grid power would be generated during times of peak power demand, but during low demand times hydrogen and other fuels/chemicals would be produced. CO_2 emissions from a polygeneration facility would be in a relatively pure stream and would be ideal for capture and use in enhanced coal bed methane (ECBM), enhanced oil recovery (EOR), or for permanent storage in geological formations.

Other Enabling Technology

A variety of other 'enabling' technology or components would have serious implications on the success of either technology pathway.

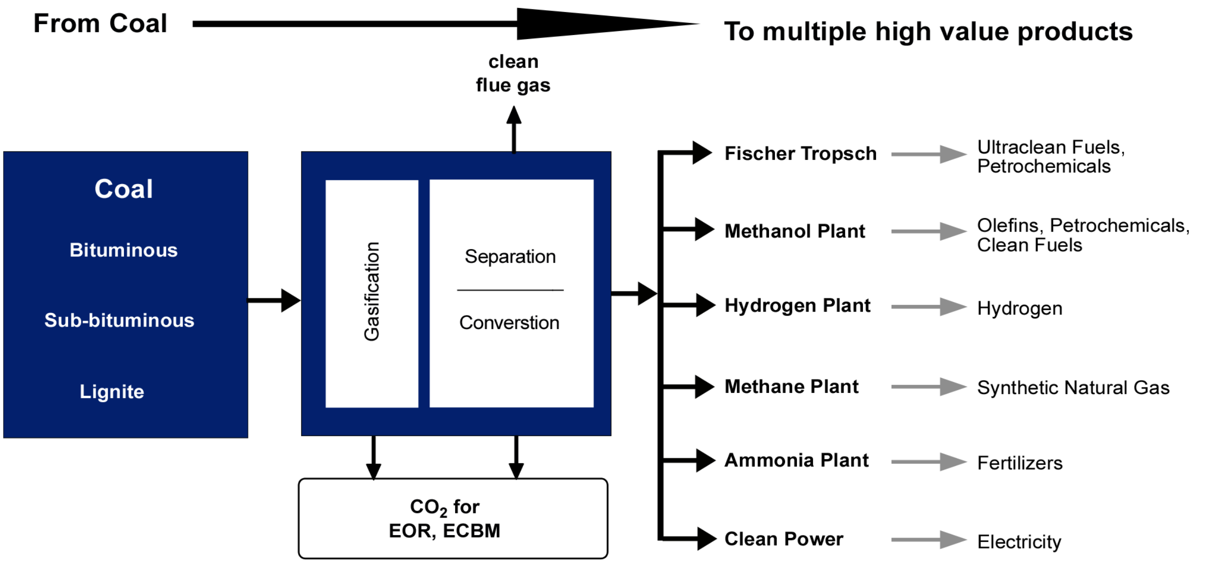
CO_2 Capture and Storage

The type of GHG reductions that will be expected over the long-term from power generation will likely only be achievable through the development of CO_2 capture and storage (CCS) technology. Therefore, a major technical challenge for coal-fired generators is the CO_2 capture side of CCS so that future plants can be built to be CO_2 capture-ready for when CCS becomes available. The integration of CO_2 capture technology at coal plants and other LFE facilities is being covered under a sister roadmap to the CCTRM, known as the *Carbon Capture and Storage Technology Roadmap* (CCSTRM, forthcoming). The objectives of the CCSTRM are to identify:

- The future technology needs and pathways, and process integration needs for capturing CO_2 from LFE facilities
- The CO_2 storage opportunities in Canada's depleted oil and gas reservoirs, saline aquifers, and deep coal seams, and the technologies needed to capitalize on these opportunities
- The synergistic opportunities to both store CO_2 and use it for other purposes, such as EOR, ENGR, and ECBM

There are many places where the CCTRM and CCSTRM initiatives overlap. As illustrated in Figure 4.4 the coal and oil and gas industries depend on CCS to enable truly emissions free energy from fossil fuels. Either industry can and will achieve significant emissions reductions on their own, however, near-zero emissions depends on CCS. Ultimately, how CCS will unfold is still being developed, but power generation offers the potential of relatively pure and large-scale GHG sources. Oil and gas can play host to geological storage, and in some cases, the use of captured CO_2 for ECBM, EOR, or ENGR.

Figure 4.3 Polygeneration from Coal

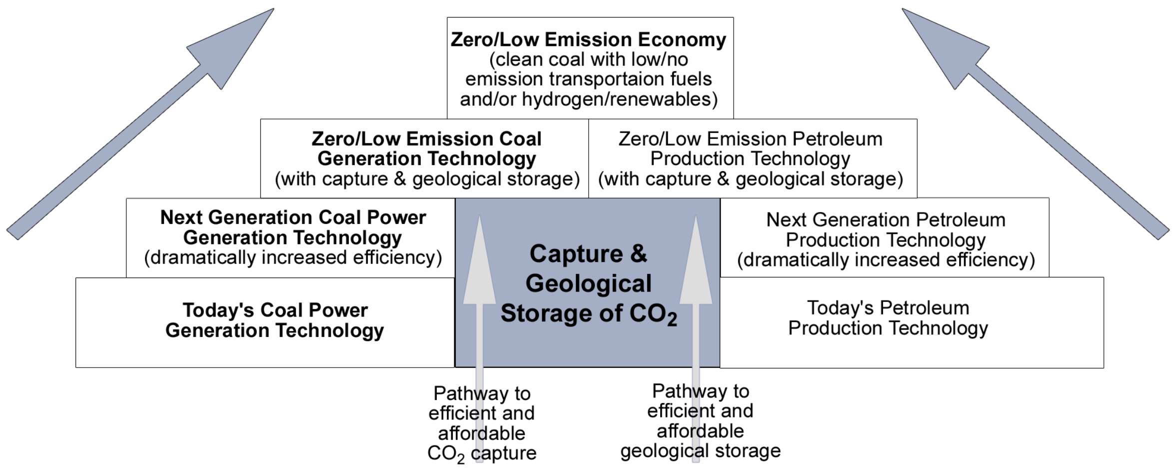


(Source: ASRA, 2001)

CCS is being developed for use in either combustion or gasification pathways. For the combustion pathway, *post-combustion capture* seems most appropriate. The CO_2 would be removed by scrubbing with solvents such as an amine solution. For the gasification pathway, the CO_2 would be more effectively removed using *pre-combustion capture*. In effect, syngas can be de-carbonized through a water-gas shift conversion, leaving H_2 as the fuel for downstream applications and captured CO_2 for either storage or other purposes.

Oxy-fuel combustion is an alternative approach for CO_2 capture, whereby combustion takes place in a pure oxygen environment, producing a CO_2 rich (greater than 80%) flue gas stream that can easily be compressed and transported. A variant of oxy-fuel combustion, called O_2-CO_2 recycle, can be retrofit into existing PC combustion. Also, new concepts such as chemical looping and hydro-gasification may emerge as CO_2 capture options.

Figure 4.4 CCT and CCS Roadmapping Overlap



(Source: CCSTRM, Forthcoming)

Combined Heat and Power

Both combustion and gasification facilities can be adapted to recover low-grade heat for use in process steam applications (such as pulp and paper making or district heating) by using commercially available technology, and by doing so will achieve efficiencies above 80%. Overall efficiencies may be greater than 90% by utilizing a condensing heat exchanger to recover the latent heat caused by evaporation from the flue gas, and using it for a low-temperature need.

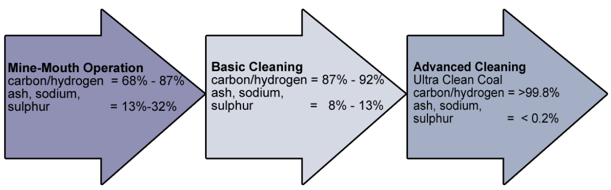
Combined heat and power (CHP) becomes economically feasible when a suitable heat sink is close to the generation facility. The Canadian Electricity Association (CEA) and NRCan have evaluated a number of potential CHP sites in Canada (in Toronto, Edmonton, Halifax, and Winnipeg), but the development of these sites faces a number of financial, regulatory, and institutional barriers. CHP is widely used in Asia and Europe in industrial complexes or adjacent to housing developments.

Upstream Coal Cleaning

The upstream cleaning of coal by removing the intermittent mineral matter from mined coal would help the combustion process by reducing ash. Industry has typically looked at emissions reductions as an end-of-pipe issue, instead of looking at coal cleaning as a front-end option that would result in emissions reductions by enhancing the combustion process. Power plant operators have typically paid little attention to coal cleaning despite the fact that coal quality impacts power plant operations significantly.

Upstream cleaning can be explained as a series of stepwise improvements that would result in an ultra-clean coal (UCC) that is 99.8% pure (see Figure 4.5). This stepwise approach is designed to first reduce the ash content (the deleterious elements) to 8 – 13%. Second stage treatment involves two approaches to eliminate all organic

Figure 4.5 Result of Advanced Cleaning

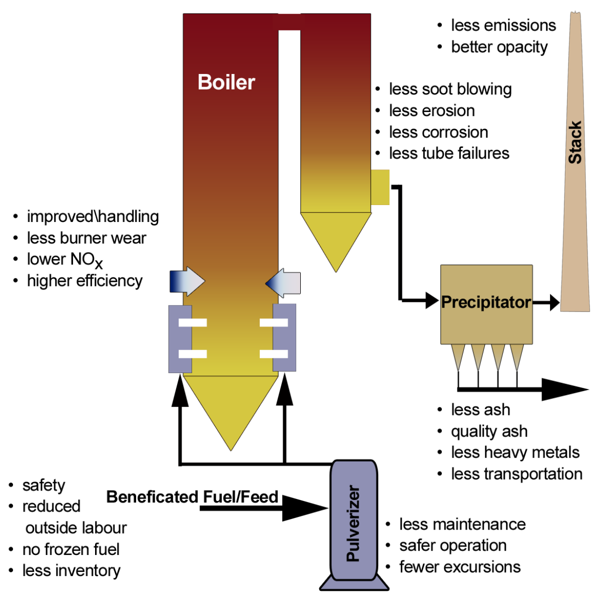


(Source: Amarnath, 2004)

and inorganic minerals and produce a 99.8% pure carbon product. The first approach is acid or caustic treatment, which leaches out all of the inorganic material (including metals) and moisture, leaving behind a hydrocarbon-enriched fuel (carbon and hydrogen > 99%). The second approach uses organic solvents to leach out organics from the coal leaving behind an inorganic ash rich residue.

The positive impacts that coal-fired facilities would experience from upstream coal cleaning are illustrated schematically in Figure 4.6. Operators of these facilities would realize the following business-related benefits: increased operating profit by reducing operating costs, higher capacity factors and increased life expectancy of assets, improved environmental performance, and reduced capital expenditures on future plants. If successful, upstream cleaning will bring about a revolutionary change to coal use in the electricity sector, as the use of a UCC gasifier would eliminate the need for expensive gas cleaning and extend the gasifier's economic operating life.

Figure 4.6 Process Benefits of Upstream Coal Cleaning



(Source: Amarnath, 2003)

Upstream coal cleaning techniques are being developed through the collaboration of White Mining and the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia, and Mitsubishi, Idemitsu Kosan and the Kyushu Electric Power Company in Japan. This international consortium has been successful in producing UCC with 99.8% purity at a pilot plant in Australia (Clark *et al*, 2002). Carbonxt Inc. in the US also has a chemical coal refining process that removes 99% of the impurities from coal (Grouch, 2002).

International Technology Development

Canada is not alone in its pursuit of CCT; several other countries have embarked on similar programs to promote new technology, thereby ensuring the future value of their own coal resources. Some programs are resulting in the development of technology roadmaps, thereby laying out the strategic direction and necessary steps to overcome the technological, economic, and social hurdles that restrict CCT. Programs in the US, Japan, Australia, and EU are briefly detailed below. More information on these programs is available through the IEA Clean Coal Centre.

United States

Because it is home to the largest coal reserves in the world, and because of the energy supply issues it faces in other fossil fuel markets, the US is investing heavily in CCT through a variety of programs and policy directions. The US Department of Energy's (USDOE) *Clean Coal Technology Demonstration Program* was the first of many CCT initiatives and has been running for over 15 years thus far. The total cost of the initiative has been $4.8 billion USD.

The *Clean Coal Power Initiative* is specifically guided by two policy priorities released by the Bush Administration in May 2001. First is the Clear Skies legislation which is focused on developing effective and lower cost ways to remove SO_x, NO_x, and Hg over the next 15 years. The second is the Global Climate Change Initiative, which focuses on increased power efficiency and CCS technology development.

Vision 21 embodies the goal of developing the 'ultimate energy facility' with near-zero SO_x, NO_x, and CO_2 emissions, and no net wastewater or solid waste discharges (USDOE, 2001). The program calls for the first commercial plant designs by 2015, with major benefits already accruing in 2005. Vision 21 plants are expected to be cost and environmental-performance competitive with other energy options (see Table 4.3). Vision 21 includes the integration of modular concepts to build power plants that can use multiple feedstocks, such as fossil fuel, biomass, and waste material (Figure 4.7), and enable the concept of polygeneration.

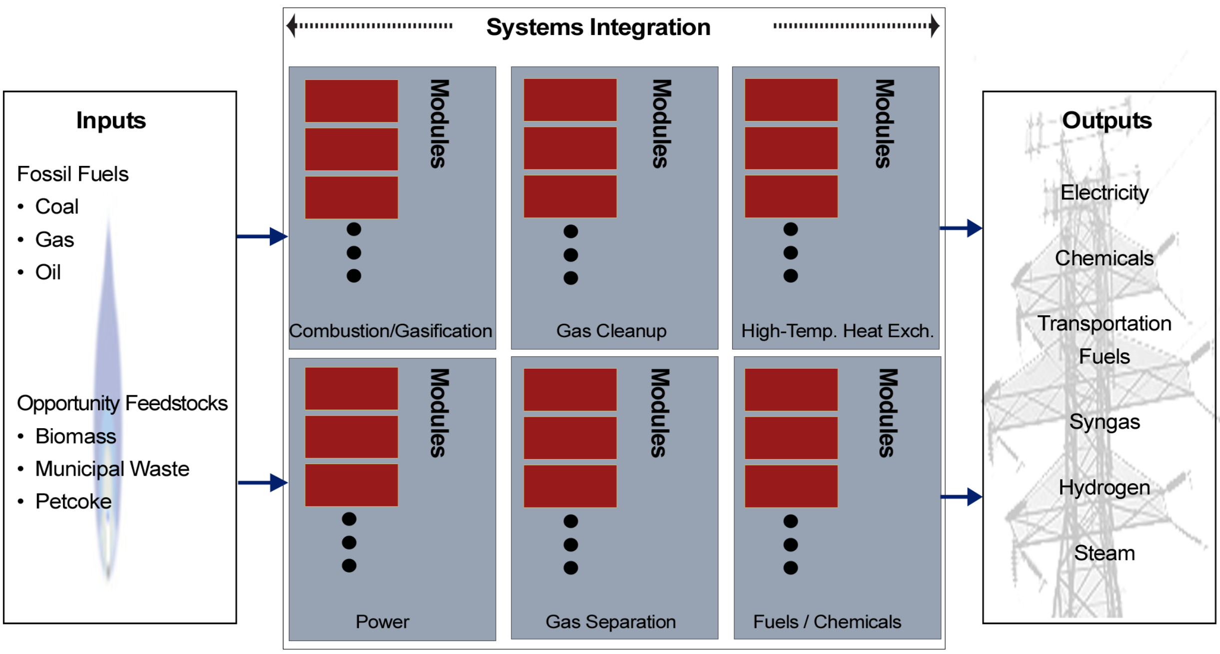
Table 4.3 Performance Targets for Vision 21 Program

Electrical Efficiency	60% (LHV)
Cost competitiveness	Cost competitive with other energy systems
Timing	Major benefits by 2005; subsystems and modules by 2012; commercial plant design by 2015
NO_x/SO_x emissions	<4.3 µg/kJ
PM emissions	<2.5 µg/kJ
Hg emissions	<430 pg/kJ
CO_2 emissions	40 - 50% reduction with efficiency improvement; 100% reduction with CCS

(Source: IEA, 2003)

FutureGen is a $1 billion government-industry project announced in early 2003, set aside to achieve the performance goals under Vision 21. The ultimate goal is demonstrating a near-zero emissions 275 MW_e coal-fired IGCC power generation plant, with CO_2 separation and storage and H_2 production. The produced H_2 will be shipped by pipeline to other end users such as the refining industry. The CO_2 will also be transported by pipeline for geological storage or for EOR. International collaboration is encouraged but the US will fund the majority of the cost, with industry managing the project and contributing 20% of the cost.

Figure 4.7 Vision 21 Development Strategy



(Source: USDOE, 2001)

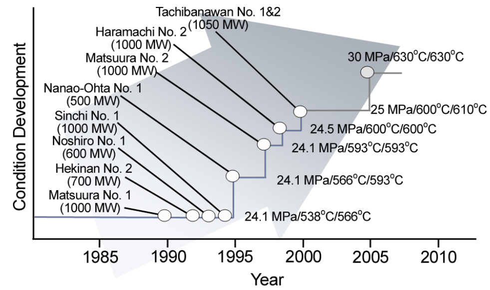
The USDOE has also initiated a *Materials Development Program* along with a consortium of funding agencies and contractors, including EPRI, the Ohio Coal Development Office, Energy Industries of Ohio, and several US boiler manufacturers (Courtright and Armor, 2003). This program focuses on ultra-supercritical PC combustion that would potentially take steam operating temperatures over 750°C.

Japan

Japan is another world leader in clean coal R&D and deployment. Program goals under the New Energy Development Organization and Centre for Coal Utilization, Japan (CCUJ) are to reduce Japan's CO_2 emissions intensity by > 30% by 2030. As well, the plan is to decrease the overall environmental load by utilizing by-products from existing generating systems. Finally, the programs are intended to ensure international competitiveness by promoting CCT in Asia and overseas.

Of the 40 supercritical PC combustion plants worldwide, 30 are in Japan. All of these were designed, engineered and manufactured domestically and by doing so have created an extensive knowledge base and an endowment of experience with new plant designs in Japan. Figure 4.8 depicts the development path of steam conditions in Japanese supercritical PC plants, all of which operate with excellent reliability (Gupta and Thambimuthu, 2003).

Figure 4.8 Steam Condition Development in Japan



(Source: Gupta and Thambimuthu, 2003)

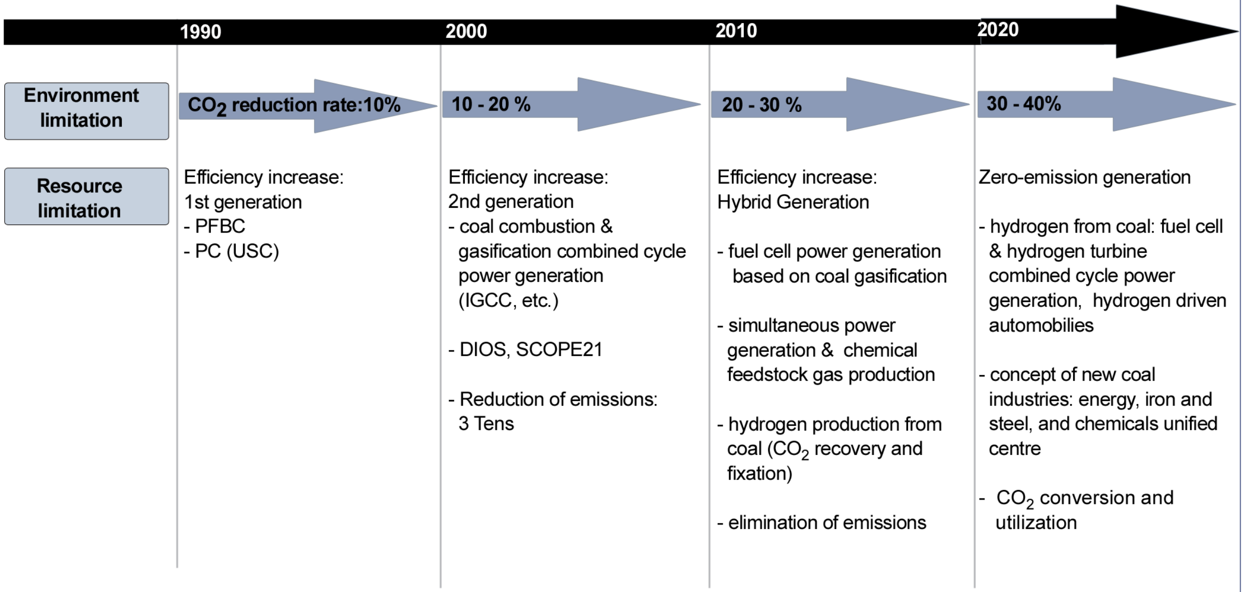
CCUJ created a clean coal development strategy for the 21st century based on some critical assumptions around the environmental standards and the resource limitations that Japan faces (see Figure 4.9). The strategy assumes that fossil fuels, and principally coal, account for the majority of Japan's energy supply until 2050. The plan calls for IGCC efficiencies of 43 – 48% and the deployment of IGCC with 50 MW_e fuel cells by 2010. The programs under this strategy are rolling out through four phases.

The first phase (1990 – 2000) involved efficiency improvements in pressurized FBC and PC ultra-supercritical steam boilers. The goal in this timeframe was to reduce Japan's CO_2 emissions intensity by 10% from 1990 levels. The second phase, from 2000 – 2010, involves the development and introduction of second-generation combustion and gasification technologies to reduce CO_2 emissions intensity by 20%. Japan has established a '3 Tens' approach for this period, to reduce SO_x and NO_x to < 10 ppm, and PM to < 10 mg/Nm^3. Part of this integrated approach is the implementation of direct iron ore smelting (DIOS) and super coke oven technology (SCOPE 21) to improve productivity and environmental stewardship. The third phase (2010 – 2020) includes hybrid power generation using fuel cells and the development of polygeneration facilities, with the objective of reducing CO_2 emissions intensity by 20 - 30% through both efficiency gains and CO_2 recovery and use in other products. During the fourth phase (2020 – 2030), Japan anticipates an oil shortage and therefore plans to generate hybrid power and value added chemicals from coal with near zero emissions technologies, and by doing so reducing Japan's emissions intensity by 30 – 40%.

Australia

The Australian Coal Association launched *COAL21*, which has wide stakeholder involvement including representation from the Commonwealth and State governments, and coal consumers and producers. The objectives of this program are to develop a national clean coal strategy for reducing or eliminating GHG emissions from coal-fired electricity. As well, the program will help promote and facilitate the

Figure 4.9 Coal Technology Development for 21st Century, Japan



Note: Reduction rates are on an intensity basis
(Source: Michiaki, 2002)

demonstration, commercialization, and early uptake of CCT in Australia, primarily focusing on Australian R&D. Finally, Coal21 will foster the public's awareness of the role of coal in Australia, and the potential for the production of this vast domestic resource.

In terms of research effort, ongoing support exists for the Cooperative Research Centre for Coal in Sustainable Development with a seven year funding commitment of $65 million per year (Australian dollars). Targeted programs specifically relate to combustion efficiency and gasification. One program focuses on advanced combustion and gasification using high-moisture lignite.

European Union

The EU is supporting an ambitious materials development project similar to the US', called the European Advanced Pulverized Fuel Power Plant Project. This project is part of the larger *THERMIE* program framework that includes 40 organizations from 11 countries. The project aims to develop super alloys and to attain ultra-supercritical steam conditions in PC boilers at temperatures > 700°C, pressures > 37.5 Mpa, and efficiencies that exceed 50%.

Two ultra-supercritical units with steam conditions at 29 MPa/580°C and an efficiency of 43% (HHV) were recently commissioned in Denmark. The German government has a new R&D initiative (*CO_2 Reduction Technologies*) aimed at enhancing the efficiency of coal-fired power plants to 53 – 55% by 2020.

UK government policy, under the Department of Trade and Industry (DTI), is encouraging CCT use abroad through a program that covers R&D, technology transfer, and export promotion (Henderson, 2003a). The policy will enable the UK to play a significant role in CCT transfer to developing countries by:

- Helping industry meet technology targets for advanced power generation
- Encouraging fundamental coal science research in collaboration with the UK Engineering and Physical Sciences Research Council

- Supporting the development of an internationally competitive clean coal equipment industry and promoting UK expertise in export markets
- Examining the potential for developing the UK's CBM resources using coal gasification technology

A UK company already has the design plans for a 460 MW carbon-capture ready IGCC power plant.

It is important to note the distinction between the CCT needs of Canada versus the R&D that is being undertaken elsewhere. Canadian CCT will need to be suited for low-rank sub-bituminous and lignite coals. Thus, the R&D and technology development will be different from that in the US, Japan, Australia, and EU, which are primarily focusing on higher-rank sub-bituminous and bituminous coal. This means there is a unique opportunity for the export of Canadian CCT to countries that also rely on low-rank coal. In 2001, 903 Mt of lignite was produced worldwide for power generation, of which Canada produced 36 Mt; over 48% of all coal produced worldwide was of the lignite or sub-bituminous varieties in that year (WCI, 2005). It is easy to see that the market for low-rank CCT could reach far beyond Canada's borders and that the opportunity for technology export or transfer may be very large.

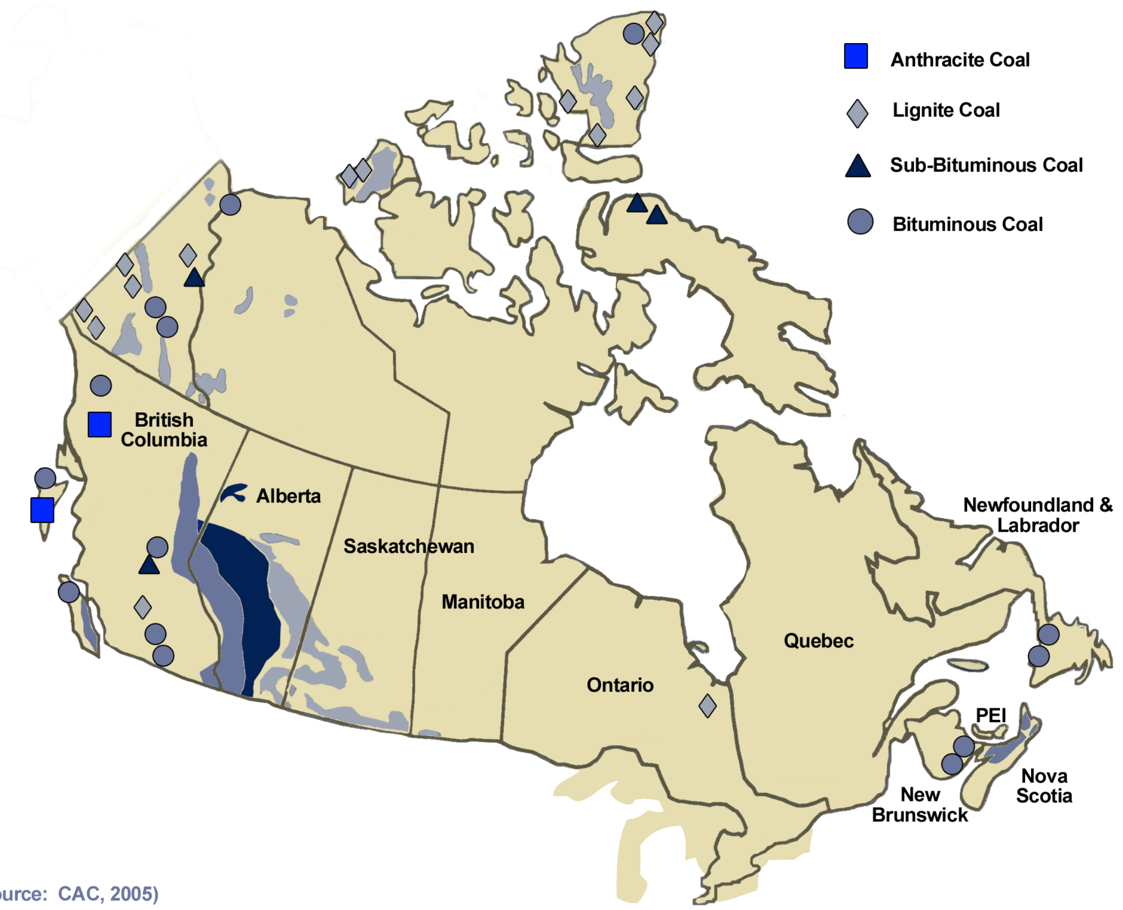
Projections for Clean Coal in Canada

Before describing the technology opportunities and their projected potentials across the regions of Canada, it is important to highlight the regional geological characteristics that exist for Canadian coal. Figure 4.10 illustrates the distribution of coal resources in Canada. Sub-bituminous and lignite coal is used for electricity generation in the prairie provinces of Alberta and Saskatchewan. Bituminous coal was produced in the past for electricity generation on the east coast, and is produced today in the mountain regions of Alberta and British Columbia for export as coking coal. At present, US and South American coal is imported to eastern Canada. Western US sub-bituminous coal from Montana and Wyoming makes its way to Ontario with lesser amounts going to Manitoba (Downing, 2002).

Many Canadians have good access to domestic coal deposits, which are of strategic value to some parts of the country. The western provinces of Saskatchewan and Alberta rely heavily on coal to generate power; coal supplies 57% and 67% respectively of the electricity mix in these provinces. All of the coal used in Saskatchewan and Alberta comes from provincial reserves. Another point of geographic importance is that Alberta and Saskatchewan based industry is well located for the implementation of CCS technology, as large CO_2 storage sites exist across the WCSB. Once again, this highlights the importance of the linkages between the information in this Roadmap and that of the sister initiative, the CCSTRM. Clean coal needs CCS technology to truly enable a zero-emissions power generation future.

Any new coal generation will likely be built in regions that have traditionally relied on coal, and so it is in the context of these regions that the following projections for clean coal technology may emerge. The Atlantic Provinces and Ontario have used coal extensively in the past for power generation, and continue to do so today. Despite Ontario's policy on coal phase-out, the region is included in this section because of questions related to the appropriateness of this policy in light of the new possibilities enabled by CCT.

Figure 4.10 Coal Deposits in Canada



(Source: CAC, 2005)

Atlantic Provinces

By 2010, thermal generators in the Atlantic Provinces will be required to add multi-pollutant (SO_x, NO_x, and Hg) emissions control systems to existing PC facilities, and over the long-term will be expected to meet near-zero emissions standards.

As a result, a 250 MW_e FBC cogeneration power plant could be considered for Nova Scotia and/or New Brunswick by 2010. The plant would use pet-coke blended with bituminous coal from international sources and be co-fired with local biomass material. The plant would be built to be retrofit at a later date (~2020) with an amine scrubber to remove CO_2 for ECBM recovery from Nova Scotian coal seams.

Atlantic thermal generators have access to imported fuels, such as coal, pet-coke, natural gas, and LNG.

In 2001, Nova Scotia consumed 3.5 Mt and New Brunswick an additional 1.4 Mt of coal from the US and South America, nearly all of which was used for power generation (CAC, 2005).

Because of the regional demand for small to medium sized generating units, nuclear is not attractive.

The main interest for Nova Scotia and New Brunswick is fossil fuel powered generation including coal; options also exist for CCS into deep coal seams for ECBM recovery or for permanent storage.

A new 250 MW_e supercritical or ultra-supercritical PC cogeneration plant may be built to be co-fired using imported pet-coke and indigenous bituminous or sub-bituminous coal by 2020, providing the impetus to reopen the Cape Breton coalmines. Atlantic Canada may also consider a supercritical or ultra-supercritical oxy-fuel plant (~300 MW_e) from which the flue gas (with enriched CO_2) would allow for easy capture and use in ECBM production.

A possible 200 – 400 MW_e IGCC plant at Port Hawkesbury Nova Scotia would use both imported and Nova Scotian bituminous coals, and take advantage of the deep-water port access available at this site. Pet-coke and biomass may also be co-fed in the gasifier. The plant would be cost-competitive with a NGCC plant that uses Scotian Shelf gas, and would replace one of the current PC plants. Captured CO_2 would be used for ECBM recovery. Steam and hydrogen from the IGCC unit would be used by local industry and for commercial heating.

Imported bituminous coal may also be used in an IGCC plant in Saint John, New Brunswick. A market for the by-product H_2 would exist at a local oil refinery, thus reducing the refinery's emissions from natural gas reforming. Again, the cost would be competitive with a NGCC plant using offshore gas. The cost of CCS at the New Brunswick plant may be prohibitively high because of the distance to a potential storage site.

Ontario

Recent studies indicate that the phase-out of coal is not achievable in the timeframe noted in Ontario's policy, because of the lack of access to other electrical capacity (CERI, 2005; FI, 2005). If the anticipated electricity supply shortfall occurs during coal's phase out in Ontario, consideration may be given to coal combustion (with enhanced pollution controls) to meet demand.

Ontario consumed 14.3 Mt of thermal coal in 2001 (down from a high of 20 Mt in 1988) and used an additional 4.8 Mt of other coal for steel production and general industrial purposes (CAC, 2005).

Current provincial policy calls for the phase-out of coal-fired plants in Ontario by 2007. However, it will be difficult to fill the supply gap created by this policy and many believe that coal will be needed.

Any new coal capacity will need to meet stringent emissions standards.

Even if coal phase out does take place, it is very easy to envisage a scenario that plays out over the longer term (beyond 2020) in which coal returns to Ontario's energy mix in either supercritical or ultra-supercritical PC plants. These plants may include 250 MW_e cogeneration facilities that are fuelled by pet-coke and imported bituminous coal. It is possible that an efficient IGCC power plant could be built in Ontario to replace retiring thermal units and to complement any new or refurbished nuclear plants. A 200 – 400 MW_e IGCC plant in Nanticoke could use US bituminous coal in combination with MSW. The by-product H_2 could be sold to oil refineries or used for direct reduction of iron ores in the steel making process.

Saskatchewan

Saskatchewan produced 11.4 Mt of lignite coal in 2001, 9.4 Mt of which was used for local power generation (CAC, 2005).

Saskatchewan will continue to rely on its cheap and plentiful supply of lignite for most of it future electricity needs; the preferred technology path is advanced combustion and CCS.

By 2020, a new 450 MW_e oxy-fuel supercritical or ultra-supercritical power plant could be operating in Saskatchewan. The plant would be fuelled by indigenous lignite and CO_2 would be removed from the flue gas and used either in fertilizer plants or for EOR – as is already being done at Weyburn. Today, the Weyburn project is piping CO_2

from a gasification plant in North Dakota, but locally sourced CO_2 would certainly be attractive in many respects.

Saskatchewan's lignite feedstock poses more of a technical challenge for IGCC gasification than do Alberta's sub-bituminous coals. However, a demonstration-scale advanced second-generation plant (200 – 400 MW_e) is envisaged at Belle Plaine by 2010 – 2020 followed by another in either Lloydminster or Regina. If the technology becomes commercial, a third plant would be built in Estevan post-2020.

Markets for H_2 already exist at the heavy oil upgraders, which could then displace the H_2 currently being generated by reforming natural gas. Markets for H_2 would also exist with ammonia and fertilizer producers. As already noted, CO_2 would be used in fertilizer plants and for EOR.

Alberta

Alberta is Canada's largest coal producer at 30.9 Mt in 2001; the province consumed 25.4 Mt in 2001, all of which was used for power generation (CAC, 2005).

Alberta will continue to use its sub-bituminous coal for electricity generation and to replace the natural gas it currently uses at the oil sands.

The preferred technology is gasification for combined-cycle power generation or for the polygeneration of chemicals and other fuels; in either case followed by CCS.

Alberta's primary interest is in gasification. However, the province will also consider oxy-fuel combustion plants similar to Saskatchewan's for post-2020. Such a combustion plant would use sub-bituminous coal, and captured CO_2 would be used for ECBM, EOR, or ENGR.

The increase in Alberta's electricity demand will primarily be met using IGCC technology. A major driver behind this focus is the need for an alternative fuel source to natural gas in the oil sand regions. Natural gas is currently used for on-site electricity generation, H_2 generation for upgrading, and steam generation for bitumen extraction. However, growing concerns about the future of natural gas supply is causing oil sands operators to look to alternative fuel sources, because of the operators' sensitivity to natural gas prices.

It is widely expected that the pace of development in Alberta (and especially, of the oil sands) will set the pace of IGCC development in Canada. Existing market forces, specifically rising natural gas prices, will likely lead to the construction of the first Canadian IGCC demonstration plant (400 – 600 MW_e) in Canada in the Fort McMurray region possibly by 2012. The first plant would use high-sulphur pet-coke blended with oil-sands bitumen and sub-bituminous coal. This option would best meet local needs, beating out all other competition including nuclear.

An even higher proportion of Alberta coal will fuel second-generation commercial plants at Fort Saskatchewan and Fort McMurray. In these plants, CO_2 will be captured and used for ECBM, EOR, and ENGR in the WCSB. A polygeneration IGCC plant in Fort Saskatchewan would provide steam, H_2, and syngas for petrochemical plants, refineries, and heavy oil upgraders, as well as H_2 for local fertilizer plants. In the long term (beyond 2020), a third generation plant may be built at Genesee, if all the necessary technological components become commercial by then. Many opportunities exist for combustion or gasification plants across Canada. A summary of those noted previously is provided in Tables 4.4 and 4.5.

Table 4.4 Future Combustion Opportunities

Feed	Combustion & Capture Technologies	Products for Industry		Timeframe & Where			Size of Facility
		Power, Steam, H_2 for:	CO_2 for:	To 2010	2010 - 2020	Beyond 2020	
Indigenous Bituminous & Sub-Bituminous, Imported Pet-Coke	New Supercritical and Ultra-supercritical with Amine Scrubbing, Combined Heat and Power	Electric Utilities, Industry, and Commercial Heating	Enhanced Coal Bed Methane		AB, SK	AB, SK, NS, NB, ON	250 MW
Biomass, Indigenous Bituminous, Imported Pet-Coke	Fluidized Bed, Combined Heat and Power	Electric Utilities, Industry, and Commercial Heating		NS, NB			250 MW
Biomass, Indigenous Bituminous, Imported Pet-Coke	Retrofit Amine Scrubber	Electric Utilities, Industry, and Commercial Heating	Enhanced Coal Bed Methane			NS, NB	250 MW
Bituminous, Imported Pet-Coke	New Oxy/Fuel Supercritical with CO_2 Capture, New Oxy/Fuel Ultra-supercritical with CO_2 Capture	Electric Utilities	Enhanced Coal Bed Methane, Enhanced Oil Recovery			NS, NB	300 MW
Indigenous Sub-Bituminous & LIgnite	New Oxy/Fuel Supercritical with CO_2 Capture, New Oxy/Fuel Ultra-supercritical with CO_2 Capture	Electric Utilities	Enhanced Coal Bed Methane, Enhanced Oil Recovery		AB, SK	AB, SK	450 MW

(Source: AG, 2004)

Table 4.5 Future Gasification Opportunities

Feed	Gasification Technology	Products for Industry		Timeframe & Where			Location of Facility
		Power, Steam, H_2, and Syngas for:	Secondary N_2 & CO_2 for:	2010	2010 - 2020	Beyond 2020	
Imported Bituminous	3rd Generation	Electric Utilities, Industry, & Commercial Heating	Enhanced Coal Bed Methane			NS	Port Hawkesbury
Imported Bituminous	2nd Generation	Upgrading, Refining			ON		Nanticoke
Indigenous, Imported Bituminous	3rd Generation	Refining				NB	Saint John
Indigenous Sub-Bituminous, Pet-Coke	Demonstration, 2nd Generation, 3rd Generation	SAGD, & Upgrading	Enhanced Coal Bed Methane, Enhanced Oil Recovery		AB	AB	Ft. McMurray
Indigenous Sub-Bituminous, Pet-Coke	2nd Generation, 3rd Generation	Refining, & Petrochemicals	Enhanced Coal Bed Methane, Enhanced Oil Recovery, Enhanced Gas Reovery		AB	AB	Ft. Saskatchewan
Indigenous Sub-Bituminous	2nd Generation	Refining, & Petrochemicals	Enhanced Coal Bed Methane, Enhanced Oil Recovery, Enhanced Gas Reovery		AB	AB	Genesee
Indigenous Lignite, Pet-Coke	Demonstration, 2rd Generation, 3rd Generation	Refining, & Fertilizer	Enhanced Coal Bed Methane, Enhanced Oil Recovery, Enhanced Gas Reovery, Fertilizer		SK	SK	Belle Plaine
Indigenous Lignite, Pet-Coke	2nd Generation	Upgrading, Refining, & Fertilizer	Enhanced Oil Recovery, Fertilizer		SK	SK	Lloydminster
Indigenous Lignite, Pet-Coke	2nd Generation	Upgrading, Refining, & Fertilizer	Enhanced Oil Recovery, Fertilizer		SK	SK	Regina
Indigenous Lignite	3rd Generation	Electric Utilities	Enhanced Oil Recovery			SK	Estevan

(Source: AG; 2004)

Section Summary

CCT opportunities exist along both the combustion and gasification pathways. The combustion pathway is largely one of incremental improvements to existing technology along with the development of some new components along the way. Gasification technology is currently in the much earlier stages of the R&D to commercialization continuum, and therefore will rely much more on the development of entirely new technology. Under the gasification pathway, a significant opportunity exists for integrated energy/chemical plexes (polygeneration), where one facility can be used to generate chemical feedstock, H_2, electricity, heat, and steam.

Upstream coal cleaning will help remove contaminants prior to coal's use in either type of plant, in much the same way that natural gas is user-ready upon delivery today. Combined heat and power is attractive to either the combustion or gasification pathways. Further fundamental R&D in materials development will benefit all thermal facilities. CO_2 capture and storage is essential for either pathway, as it will only be through the use of this technology that the coal industry can achieve its ultimate objective – zero-emissions power generation.

The US, Japan, Australia, and EU have embarked on ambitious programs to develop and commercialize CCT. Canada could benefit from the information and technology being developed under these international programs. However, for Canada to capitalize on the work being done elsewhere, it must cooperate and contribute to the overall R&D effort being made.

Opportunities for combustion and gasification exist throughout Canada, with some immediate ones in the current coal-dependent provinces of Nova Scotia, New Brunswick, Ontario, Saskatchewan, and Alberta. The deployment of CCT will play heavily in coal maintaining its current position in Canada's primary energy mix, and is the only way for coal to play a more dominant role across the nation in the future.

5. Clean Coal in Canada

Vision

The vision that emerges from this CCTRM is one of a Canadian power industry that is *a leader in adapting and integrating technology and knowledge for the effective utilization of coal and other low value carbon fuels as an energy source for the production of electricity, hydrogen, heat, and chemical feedstock with zero or minimal environmental impacts on land, air, and water.*

The intent behind this vision is to reduce all the environmental impacts of energy produced from coal to a level that is consistent with the public's acceptance. To accomplish this will require the development and implementation of near-zero emissions CCT.

A power industry that has embraced this vision would be one that will have transformed in image and performance to become:

- A national leader, proactive in the research and development of CCT
- A champion of achieving top environmental performance standards using the best available commercial technology in its operations
- A good local citizen, viewed as environmentally responsible and committed to the health and welfare of communities in Canada and globally
- A part of the solution to develop sustainable energy sources by building a fleet of clean coal plants that provide power to the nation
- Able to adapt and integrate leading technology into Canadian R&D and demonstrations

Section Observations:

The critical gaps holding back CCT in Canada have been identified and they include social, economic, and technical barriers.

The strategic components outlined here will address the critical gaps by laying out the steps to achieve five SMART objectives.

Industry stakeholders are taking the lead in carrying out the five strategic components; partnerships with relevant national and international organizations are required.

The impacts of implementing this strategy will be felt across Canada and by many industry sectors.

The opportunity to capitalize on advance clean coal technology is now, and doing so will be of benefit to all Canadians for generations to come.

This section provides a review of the CCT gaps that exist in Canada, and a clear set of objectives for bridging them. Also included are five components of an overall implementation strategy to achieve the objectives, and the impacts this strategy will have on the various regions of Canada.

Critical Gaps and Objectives

Using inputs received during the CCTRM Workshops, the Roadmap Advisory Group carried out a critical gap analysis which consisted of first defining the current state of affairs, followed by identifying six key factors that are primarily responsible for holding back CCT commercialization in

Canada. These factors are listed in column one of Table 5.1. The second column is a description of the desired future state (or vision) for each of the factors. The third column describes the high-level goals that must be achieved to fill

the gap between the current and desired states. The Advisory Group also identified specific, measurable, agreed-upon, realistic, and timely (SMART) objectives, which will be pursued in order to fulfill the high-level goals and thus promote CCT in Canada.

Table 5.1 SMART Objectives for Canadian CCT

Current State	Desired Future State (Vision)	Critical Gaps (High-Level Goals)	SMART Objectives
Public perception of coal as a 'dirty' fuel; little understanding of strategic advantages of coal.	Coal viewed as a bridge to a clean, carbon free, near-zero emissions energy economy.	A national organization responsible for public information.	**1. Public Outreach** Establish a National Clean Coal Information Program to develop and disseminate public information on websites, and through publications and speakers forums.
Large and dispersed international body of knowledge on coal processing, combustion, gasification, chemical production, and power generation.	Access to this knowledge, to apply and adapt relevant information and technology to Canadian needs.	A national website with access to up-to-date information on CCT. The continuation of the current CCTRM website managed by CETC-O can be expanded to effectively fill this role.	**2. Technology Watch & Collaboration** Establish a National Intelligence Centre on international technology advances, with web-based information available on a subscription basis.
While offering higher environmental performance standards, CCTs are not commercially available or cost competitive with commercially available conventional coal, natural gas, or other fossil fuel technologies.	CCTs are cost competitive with best available commercial technologies, using an equivalent lifecycle comparison and including environmental impacts.	Improved technologies for coal types, coal cleaning/conditioning, feeding, combustion, gasification, gas cleaning/conditioning, power generation, chemical production, and synthetic fuel production.	**3. R&D Programs** Canadian technology development programs are in place to address critical gaps, having a maximum impact on demonstration and commercial plants.
Absence of vision and business models that identify critically needed demonstrations of CCTs that offer the best commercial potential and impact for Canada.	A common national commitment to 'learning by doing' enabled by a government/industry consortium that invests in, builds, and operates demonstration plants with commercial potential.	A common vision among government and industry partners. Business models that identify demonstration sites with the best commercial potential.	**4. Pre-Demonstration Business Development** **a.** Common national vision and business model to be developed by government/industry consortia. Selection of demonstration site and arrangements for financing.
As independent entities, industry and governments are exposed to the high risk of developing and commercializing CCTs in Canada.	Coordinated agreed upon risk mitigation strategies amongst all stakeholders to ensure timely development and commercialization of CCTs.	Effective government and industry risk mitigation strategies.	**b.** Risk mitigation strategy in place by 2006 to support the first demonstration plant. Development programs in place to address risk mitigation strategies for other demonstration needs.
Absence of demonstration plants and a lack of supporting Canadian R&D to develop technologies that meet Canadian needs.	One or more demonstration facilities in Canada, with R&D focused on critical technology gaps (as happened with oil sands development in the past).	Balanced technology and commercial development portfolio, focused on technology, integration, adaptation, and international collaboration and coordination.	**5. Technology Demonstrations** Integrated optimized design and operation of first and subsequent clean coal demonstration plants. Initial strategy in place by 2006 and continually updated.
Note: the first Canadian CCT demonstration plant is currently planned for commissioning by 2012			

The R&D Programs component (SMART Objective 3) is extremely important and the Advisory Group engaged in a separate exercise to develop another set of SMART objectives related specifically to R&D (see Appendix C for details of this work). As well, a two-part objective (4a and 4b) was developed for pre technology-demonstration because of the relatedness of the two tasks.

Five Strategies for SMART Objectives

The immediate need for the Canadian CCT community is a timely and strategic approach to carry forward from the current to the desired future state of a clean coal industry sector. This requires vision, commitment, and the continuous championing of strategic activities aimed at achieving the five SMART objectives. Ultimately, by fulfilling these objectives the performance targets noted earlier (Table 3.2) will be achievable. Thus, each of the following five components of the overarching implementation strategy relates directly to a SMART objective. The specifics of each component are described in terms of planned activities, reach, outputs, desired outcomes, and implementation champions.

1 Public Outreach

Gaining the public's acceptance that advanced technologies can allow for the use of coal while meeting more stringent environmental objectives is paramount to the success of CCT in Canada. Public outreach is the purpose of a National Clean Coal Information Program, which will be used to disseminate information on CCT through websites, publications, and public speaking forums.

Activities:

- Identify recognizable experts in the scientific and engineering communities and encourage their participation on task forces or advisory panels to whom the media will turn for information
- Develop a strategy to target regulatory officials (both elected and staff) for briefings on Canadian energy options and ensure that coal remains among those options
- Identify fossil fuel related policy-makers, and urge them to keep coal as a viable option in the interest of maintaining a vigorous economy and national energy security
- Inform education leaders and educational institutions of the importance of science in maintaining an informed public
- Develop a public outreach program to act as a forum for discussion on energy and the energy sources available to Canada

Reach:

The Information Program will target governments, policy-makers, the scientific community, and the general public.

Outputs:

A public website, brochures, reports, and presentations at public forums will be the outputs.

Desired Outcomes:

The desired affect will be the public's acceptance of coal as a strategically important and environmentally acceptable energy source in Canada's overall energy mix.

Implementation Champion:

The Coal Association of Canada (CAC) is the lead agency to establish and manage the National Clean Coal Information Program. CAC was selected because of its role as an Association that represents a broad range of industry stakeholders, from the major coal producers and coal-fired utilities, to the railroads and ports that ship coal, and the industry suppliers of goods and services. The CAC represents companies engaged in the exploration, development, use, and transportation of coal.

The CAC advocates the use of clean coal through engaging in technology development and communicating with its members, government, and public-sector stakeholders. Association members have a strong belief that coal will play an important role in meeting Canada's future energy needs.

2 Technology Watch & Collaboration

Managing an international technology watch by establishing a virtual web-based National Clean Coal Intelligence Centre, focused on exchanging information on technology advancements, will provide a forum for collaborative technology watch activities. This centre will enable CCT stakeholders to respond effectively to shifting energy market demands and environmental requirements.

Activities:

- Identify national and international CCT development and business opportunities
- Establish a network of expertise among R&D organizations, technology suppliers, and other stakeholders
- Establish a network of information related to technology demonstrations and environmental controls
- Promote partnerships and collaboration among industry, academia, and government, to form the best alliances for developing and commercializing technology
- Promote network members' commercial products and services
- Foster public and private sharing of specialized combustion R&D facilities
- Prepare quarterly newsletters
- Promote membership growth, participation, and interaction
- Provide recommendations for website improvements based on client surveys

Reach:

The network of collaboration is targeting audiences that include:

- Operators of boilers, gasification furnaces, turbines, and kilns
- Manufacturers of combustion and control equipment
- Designers and producers of environmental control technology
- Manufacturers of emissions monitoring equipment
- Producers and distributors of coal
- Consultants on combustion, gasification, and environmental controls
- Associations of companies that promote clean coal
- Regulatory agencies, whether federal, provincial, or municipal
- Universities that study or teach coal related energy conversion processes
- Research organizations, whether national or international, private or public

Outputs:

The outputs will be a comprehensive web-based Intelligence Centre with information on R&D organizations, advanced CCT, technology suppliers/manufacturers, and demonstration initiatives.

Desired Outcomes:

The result will be to enhance the communication linkages to improve the quality of the activities undertaken among individuals, institutes, industry, and government partners, and to accelerate the development and commercialization of CCT in Canada.

Implementation Champion:

CANMET Energy Technology Centre – Ottawa (CETC-O) is the lead for establishing the National Clean Coal Intelligence Centre. CETC-O was selected because of existing linkages to the national and international clean coal R&D communities through the IEA and cooperative governments.

As the government lead for developing this Roadmap, CETC-O has already created a website for communicating with Roadmap stakeholders. The website will be maintained in the future and used as the portal to the National Clean Coal Intelligence Centre for Canada.

3 Research & Development

The importance of identifying technology pathways that are relevant to Canadian circumstances is noted throughout the Roadmap. This implies pathways that address the primary challenges that coal faces in Canada, including environmental regulations and competition from alternative energy options. As well, this implies pathways that are of interest to Canada and to the international community. Embarking on new R&D pathways is costly and risky, which necessitates finding synergistic opportunities with others through international consortia. Following both the combustion and gasification pathways will help meet the variety of Canadian needs that exist, and either pathway is receiving considerable support through other programs around the world. Upstream coal cleaning occurs further up the coal supply chain and is of interest to either technology pathway.

As noted previously, the Advisory Group delved into this strategic component to identify the primary technology and knowledge gaps that exist in Canada today. The group developed SMART objectives to address each of these gaps. These objectives are displayed in the impact versus achievability diagrams in the following subsections (see Figures 5.1, 5.2 and 5.3). These figures illustrate the relative affect that bridging each technology gap would have on CCT (the impact) versus an assessment of the ability to bridge each gap (the achievability). The information in the impact versus achievability diagrams can assist in the design of research programs or help in prioritizing funding allocation. Technologies in the bottom right-hand quadrant should be the easiest to develop, but have a relatively low impact on CCT deployment. Technologies in the upper left-hand quadrant will have major impacts, but are risky to develop. The sweet spots are the technologies that have the highest impact and probability of success. More on the rationale behind the information in these figures is available in Appendix C.

Activities:

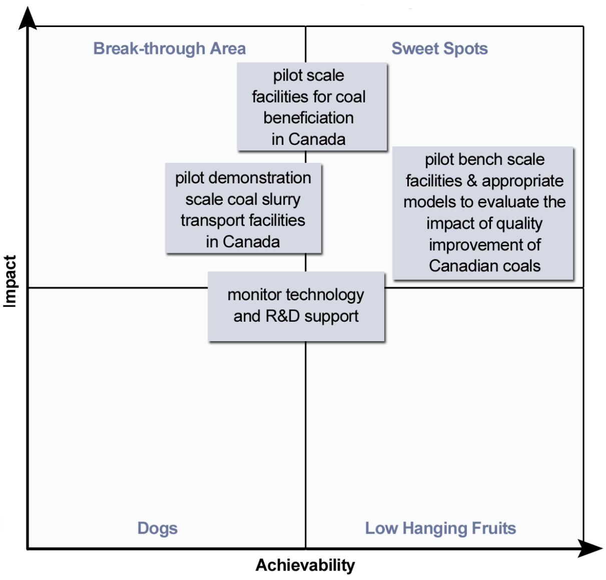
The following subsections provide sequential steps or activities laid out to achieve the successful commercial application of upstream clean coal, combustion, and gasification technology. In the case of combustion and gasification, the steps were formulated in full consideration of the performance standards in Table 3.2, because achieving these standards is what will ultimately determine the overall success of CCT in Canada. Implementation targets for core demonstration facilities or programs are indicated in the sidebars.

Upstream Coal Cleaning

The dominant producer of thermal coal in Canada (Luscar Ltd.) has already developed a long-term strategy to address the technical issues with upstream coal cleaning. The strategy is designed to deliver clean or ultra-clean coal to operators of combustion or gasification plants by removing deleterious components early in the supply chain. Over the next three to five years, the following steps will be carried out:

- Discuss with primary coal customers (coal-fired generators in Western Canada) to develop a coal feed specification that minimizes maintenance costs and reduces the environmental impact of existing power plants
- Develop appropriate coal beneficiation processes (both conventional and non-conventional) to produce clean coal of a quality that is desirable to customers
- Create a win-win partnership model with customers to jointly develop and implement beneficiation processes
- Install Alberta and Saskatchewan coal beneficiation plants for existing generators
- Develop technologies to transport high-density clean coal slurries, both sub-bituminous and lignite
- Investigate the possibility of commercializing a CHP plant in Canada
- Explore and develop new mining methods to maximize resource extraction

Figure 5.1 Upstream Coal Cleaning - Impact vs. Achievability



Over the next five to ten years, the steps for developing technology that delivers 99.8% purity are:

- Investigate and identify upstream coal cleaning technologies being developed elsewhere
- Develop upstream coal cleaning technology – lab and pilot-scale facilities
- Develop economic models to delineate the impact of UCC on combustion and gasification technology

- Upstream Coal Cleaning Implementation Target -

By 2008 – develop UCC production and transportation research centre

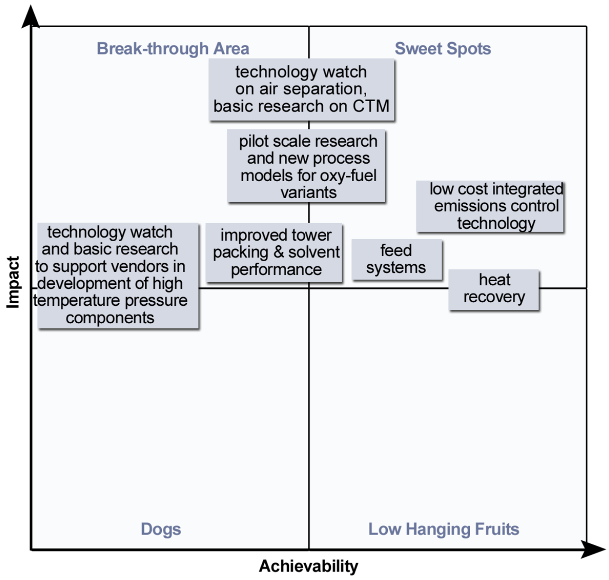
Combustion Strategy

For air-fired combustion R&D, the steps include:

- Develop improved coal feeding systems
- Identify and optimize system integration to address site-specific CHP opportunities
- Integrate and optimize use of beneficiated coal and captured CO_2 in overall cycle
- Develop low-cost integrated emissions control technologies (including CO_2) and waste management control technologies

- Develop low-cost scrubbing solvents with better stability, improved corrosion, and degradation resistance
- Develop improved contactors and mass transfer systems for CO_2 scrubbing solvents
- Develop low-temperature, low-pressure cryogenic/hybrid technologies for CO_2 separation
- Develop membrane or membrane/solvent technologies for CO_2 capture
- Develop improved solid sorbent technologies for CO_2 capture

Figure 5.2 Combustion - Impact vs. Achievability



For oxy-fuel combustion, the steps include:

- Develop integrated systems for O_2/CO_2 recycle, pure O_2, and hydroxy-fuel combustion in direct, combined, or hybrid cycles
- Improve understanding of the combustion, heat transfer, and pollution forming behaviour of conventional and beneficiated coal for O_2/CO_2 recycle, pure O_2, and hydroxy-fuel combustion
- Improve understanding of optimization of recycle flows in combustors, process heaters, and boilers
- Develop oxygen chemical looping combustion systems
- Design and develop high temperature tolerant combustors, process heaters, boilers, compressors, and turbo-machinery for O_2/CO_2 recycle, pure O_2, and hydroxy-fuel combustion
- Develop improved cycles and methods for CO_2 compression, cooling, and separation in the presence of trace gaseous impurities
- Develop novel integrated multi-pollutant control technology for NO_x, SO_x, Hg, and fine PM, with heat recovery from oxy-fuel combustion flue gas streams
- Maintain technology watch on less energy intensive air separation processes such as oxygen transport membranes (OTMs). Integrate the outcomes with advanced oxy-fuel cycles and support technology vendors with basic research

- Combustion Pathway Implementation Targets -

By 2010 – construct cost-competitive coal-fired plant to demonstrate near-zero emissions power generation and CO_2 capture for EOR55

By 2014 – integrate coal-fired power facility with a municipal district energy system

By 2016 – demonstrate CO_2 captured from coal-fired facility can be used for ECBM production

By 2017 – demonstrate commercial use of fuel cells in coal-based electricity generation facilitv

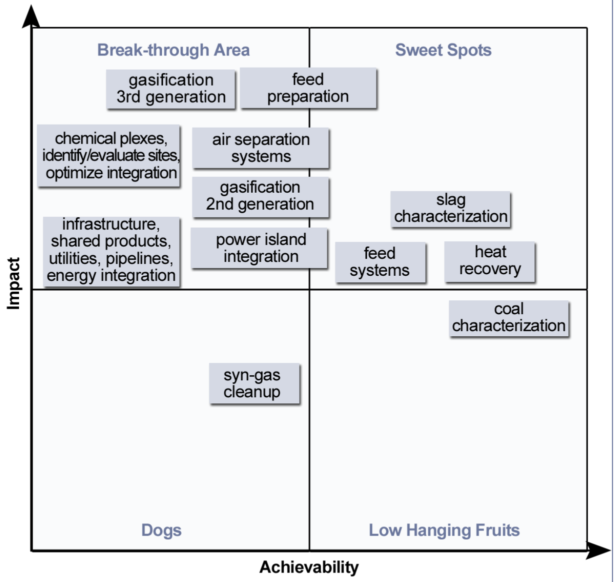
- Improve low-temperature cryogenic/distillation processes for CO_2 purification

Gasification and Chemical Plexes Strategy

The steps for the IGCC gasification and energy/chemical plexes pathways are:

- Develop advanced feed preparation and feeding systems
- Improve coal and slag characterization
- Provide modular gasification / carbonator / calciner / hydrogen separation tests
- Build pilot scale facilities so that advanced concepts for 2nd and 3rd generation gasifiers can be evaluated economically
- Develop plant optimization and integration tools involving the impact of coal beneficiation, impact of fuel cell developments, and CO_2 capture systems
- Develop solid sorbent enhanced reaction systems for CO_2 separation and steam reforming, or water gas shift
- Identify and evaluate polygeneration opportunities
- Keep technology watch and provide basic research to technology vendors on cryogenic / hybrid systems for CO_2 separation from hydrogen
- Maintain technology watch on less energy intensive air separation processes, such as OTMs; integrate outcomes with advanced gasifier cycles
- Develop integrated hot gas clean-up systems for H_2S, COS, HCN, NH_3, CO_2, fine PM, and alkali removal

Figure 5.3 Gasification - Impact vs. Achievability



- Gasification Pathway Implementation Targets -

By 2015 - construct coal-based polygeneration facility to produce H_2, electricity, and heat for Canadian oil sands and heavy oil upgrading operations

By 2016 – demonstrate CO_2 captured from coal-fired facility can be used for ECBM production

By 2017 – demonstrate commercial use of fuel cells in a coal-based electricity generation facility

Reach:

The results under all three technology areas are intended to reach Canada's federal, provincial, and municipal regulators, the industry and academic R&D communities, coal-fired electric utilities, and other stakeholders such as chemical manufacturers and oil sands operators.

Outputs:

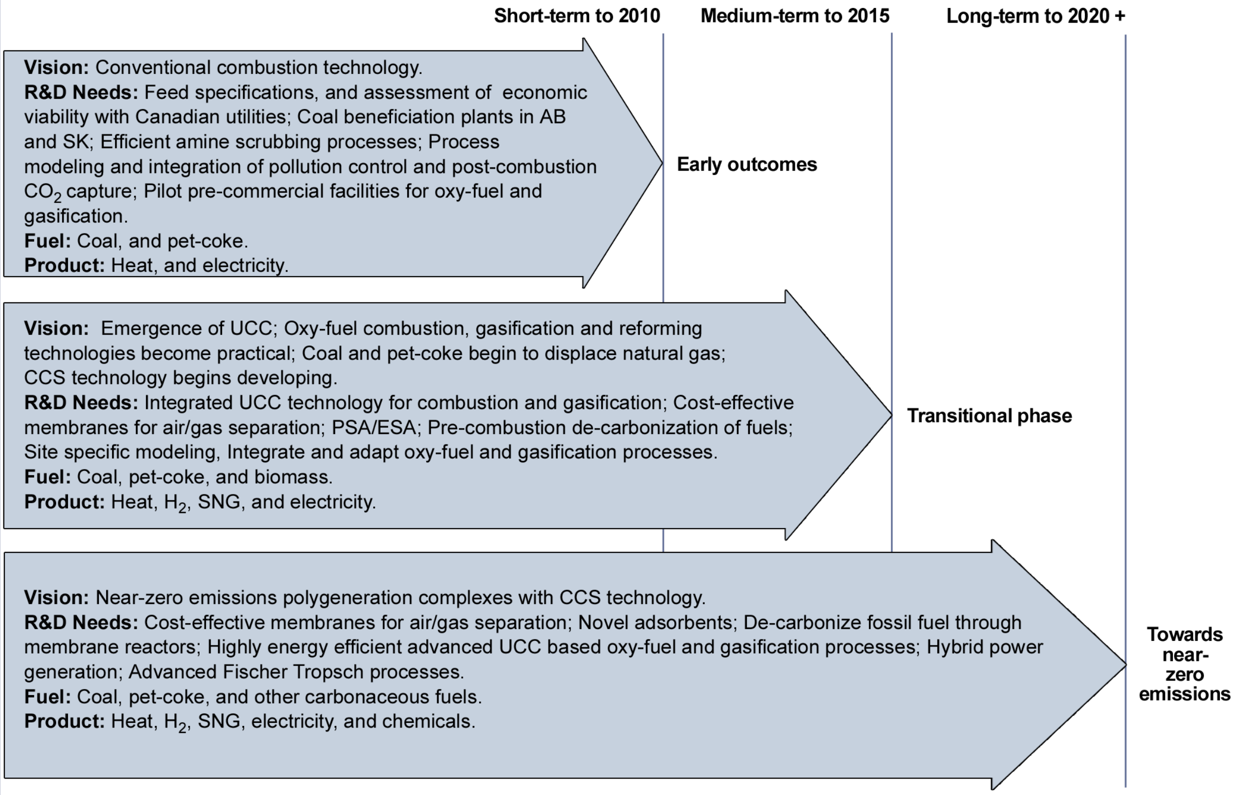
Advanced technology will be the result in each of the three priority technology areas. In addition, fundamental and applied R&D know-how and expertise will accumulate in the Canadian research community, thus enabling the provision of local technical support to improve the overall performance of commercial operations.

Desired Outcomes

Overcoming technology constraints and enhancing the prospect of commercial technology demonstrations are the desired outcomes, which will be a result of technology development and the creation of Canadian expertise in the technology areas.

The R&D needs required to meet the envisioned targets described in the previous subsections are summarized in the Innovation Timeline below. Also included are the likely fuel sources and the by-products of the various CCT technologies over time.

Figure 5.4 CCT Innovation Timeline



Implementation Champion:

Nationally coordinated R&D programs, such as NRCan's Program for Energy Research and Development and the Climate Change Technology and Innovation initiative, will focus on bridging the critical technology gaps to help achieve the goal of fully competitive commercial facilities in operation by 2020. CETC-O, the University of Regina (through its International Test Centre), the Alberta and Saskatchewan Research Councils, Luscar (through its Coal Beneficiation Program), the electrical utilities, and universities across Canada, will all play a significant role in developing a CCT R&D capacity in Canada.

The Clean Coal and Clean Carbon Innovation Programs under the Canadian Energy Innovation Network (EnergyINet) will play a key role in coordinating the specific research initiatives among interested stakeholders. EnergyINet is an evolving vehicle for collaboration amongst industry, governments, research providers, and not-for-profit groups with the vision of an abundant supply of environmentally responsible energy that creates economic prosperity and social well-being for Canadians.

4a & 4b Pre Technology-Demonstration

Strong championing by government/industry consortia is needed, to establish a common national vision and business model aimed at selecting viable demonstration technologies, appropriate sites for development, and at making the arrangements for demonstration project financing. By 2006, a risk mitigation strategy is needed to support the development of the first clean coal demonstration plant, but also to serve as a starting point for developing the risk mitigation strategies for future demonstration sites.

Activities:

- Develop business cases for one or more demonstration sites
- Select technology suite, equipment and sub-components for demonstration project, and identify an appropriate site for the type of demonstration
- Develop risk mitigation strategies in conjunction with all stakeholders to manage the identified technological, commercial, and other risks of a demonstration project

Reach:

Targeted audiences include Canada's federal and provincial governments and regulators, electric utilities, financial institutions, equipment manufacturers, and other stakeholders. Organizations that have a financial stake in clean coal demonstration projects are the target audience for the pre technology-demonstration activities.

Outputs:

Desired outputs would be strategies, plans, and business models that can serve as starting points for the decision-making, planning, and the development of demonstration projects. The information and data, and the processes and procedures used in the business model and risk strategy (for the first demonstration project) can be used as a basis of information in subsequent projects.

Desired Outcomes:

Expected outcomes are the establishment of policies and programs within government and industry that would allow for a simplified and transparent approach to implementing risk management strategies for new CCT demonstration projects. The strategy will address the management of constructing and operating such a facility without exposing the involved stakeholders to excessive risk.

Implementation Champion:

The Clean Coal & Clean Carbon Innovation Programs of EnergyINet will play a key role in developing the business model for the first demonstration plant and in collaborating with other stakeholders to develop a risk mitigation strategy.

5. Technology Demonstration

Companies participating in the Canadian Clean Power Coalition (CCPC) recognize that developing electricity generation facilities is not a typical government responsibility. However, an opportunity exists to advance the technology used in the next suite of power plants beyond what industry would normally do in a business as usual (BAU) situation. Because of the long lifetimes of these capital-intensive facilities (40 years or more), decisions made today have long-term implications. CCPC members are interested in going beyond the current emissions standards as long as a mechanism to share the risk of doing so can be agreed to by government.

In particular, a demonstration plant can be designed to be CO_2 capture ready to help reduce GHG emissions in support of Canada's Kyoto commitments. However, building a plant of this nature would entail going beyond BAU and companies involved would need a government contribution to offset the additional risk of the project. The contribution could be financing the incremental capital cost between a current compliant power plant and one that meets the near-zero emissions standard. Another alternative would be an operating subsidy similar to the current Wind Power Production Incentive.

Canada must develop its own demonstration projects and cannot adopt a 'wait and see' approach. The United States is developing several gasification projects, none of which will advance the gasification technologies suitable for Canada's low-rank sub-bituminous and lignite coal reserves. US projects focus on high-rank fuels and will not begin to look at low-rank coal until well after the Kyoto period. In addition, the US projects do not include plans for CCS, or for amine scrubbing or oxy-fuel – the types of technologies that Canada will need. By waiting too long, any capacity additions that take place between now and when CCT becomes feasible will affect the nation's emissions profile for decades to come, and so 'wait and see' is insufficient.

Activities:

- Select the technology suite and a site for the first demonstration plant
  - Form a consortium of interested parties to take ownership of the project
- Conduct a project definition study to
  - Develop a sufficient cost estimate to obtain project approval from consortium members
  - Develop the basis of commercial terms, with equity and commodities parties executing letters of intent prior to the work
- Develop front-end engineering design (FEED) package including
  - Completion of commercial documents between consortium members
  - Finalized engineering procurement and construction agreements
  - Completion of permitting and approvals
  - Consortium commitment to the FEED package
- Design, construct, and commission demonstration plant

Reach:

All of the electrical utilities and the various levels of governments, as well as policy makers, the scientific community, and the public at large are the targeted audiences. Eventually, the results will be felt by all industrial users of fossil fuels, through the development of entirely new energy and chemical plexes (polygeneration).

Outputs:

A commercial scale demonstration plant operating in Canada is the desired result. In addition, useful information and data from the project will be generated and disseminated through the public Information Program and Intelligence Centre.

Desired Outcomes:

The installation of other clean coal facilities with minimized commercial and technological risk is the expected outcome. R&D and pre-demonstration investments will be justified by the positive results of successfully implementing CCT in commercial applications.

Implementation Champion:

The CCPC will facilitate the process of developing the demonstration project, as members of this group will already have capabilities in managing and implementing large projects. The CCPC is already working on developing the first near-zero emissions coal-fired demonstration plant in Canada, which will be commissioned by 2012. As part of this work, a business model for the project and a vision for the larger strategy behind it are already being developed.

The CCPC is also considering how the commercial application of CCT fits into Canada's larger energy and environmental strategies. To avoid duplication and maximize returns, the CCPC builds on the latest technology developments and encourages international collaboration and investment when appropriate. As such, the CCPC suggests incorporating some of the lessons learned from the USDOE's past experience with its demonstration program (Energy Resources International, 2001), which are included in Appendix D.

CCT Roadway Ahead

Table 5.2 provides a summary of the commitments already made to the five SMART objectives. The CAC, CETC-O, NRCan, EnergyINet, and the CCPC are already leading the work being done and the process for making possible the first commercial application of CCT in Canada.

To realize the vision and achieve the strategic objectives in this Roadmap the journey ahead is not unlike previous undertakings in Canada. Technology development and innovation are part of the Canadian psyche and our competitive advantage. The development of the oil sands, one of the greatest technological achievements in Canadian history, started with a vision to make a vast Canadian resource economically viable. The sector still faces challenges today; however, since the beginning of the Great Canadian Oil Sands project in 1967 oil sands developers have had great success in addressing their two main challenges. The cost of producing a barrel of synthetic crude is down to $20 Canadian, from a cost of over $40 in the early 1980s (ACR, 2004). As well, GHG emissions intensity is down 27% since 1990, from just under 140 kg/bbl to just over 100 kg/bbl in 2003 (ACR, 2004). By building the first oil sands facilities and using them for learning-by-doing, the real potential of these deposits have been released. Without the opportunity for knowledge acquisition and the incremental innovation that took place, the oil sands would not be the success they are today.

Table 5.2 Stakeholder Commitments to the Objectives

SMART Objectives	Stakeholder Commitments
1. Public Outreach Establish a National Clean Coal Information Program to develop and disseminate public information on websites, and through publications and speakers forums.	CAC is championing development of National Clean Coal Information Program and will lead the initiative until 2010.
2. Technology Watch & Collaboration Establish a National Intelligence Centre on international technology advances, with web-based information available on a subscription basis.	CETC-O developing Intelligence Centre; information is already available on CCTRM website.
3. R&D Programs Canadian technology development programs are in place to address critical gaps, having a maximum impact on demonstration and commercial plants.	NRCan's Program for Energy Research and Development, and Technology and Innovation initiative, will support R&D in: upstream coal cleaning, combustion, gasification, and CCS. EnergyINet to coordinate specific research initiatives for interested stakeholders.
4. Pre-Demonstration Business Development **a.** Common national vision and business model to be developed by government/industry consortia. Selection of demonstration site and arrangements for financing.	EnergyINet to lead in collaborating with other stakeholders to develop business model for first demonstration plant.
b. Risk mitigation strategy in place by 2006 to support the first demonstration plant. Development programs in place to develop risk mitigation strategies for other demonstration needs.	EnergyINet to lead in collaborating with other stakeholders to develop a risk mitigation strategy for first demonstration plant.
5. Technology Demonstrations Integrated optimized design and operation of first and subsequent clean coal demonstration plants. Initial strategy in place by 2006 and continually updated.	CCPC to lead work being done to design first CCT demonstration plant in Canada.

The time to invest in CCT is now, as a clear window of opportunity exists over the next 25 years. As noted earlier, 725 MWe/year of coal facilities need replacing on top of the projected growth rate for new electricity capacity. The real opportunity years are indicated in Figure 3.7. Between 2009 and 2014 approximately 5,200 MWe of coal-fired capacity will need replacing, with an additional 2,400 MWe needed in 2017 and 2018. It takes five years from initial planning to build a coal plant, and so the first big opportunities for CCT lie within the first window of 2009 – 2014. The first demonstration plants could be built within that timeframe, but action is required now.

Stakeholder relations, intelligence gathering, R&D and technology deployment, and commercial-scale applications, are all necessary components of an advanced and innovative clean coal industry in Canada. Successful demonstrations, and the subsequent role out of technological components, expertise, and know-how is the prize to be won over the coming years. However, each of the SMART objectives needs a strong champion with a clear vision of the future. The organizations tied to each of the SMART objectives will take on their obligations, but Canada's private and public sectors need to make investments to mobilize this strategically important initiative for the nation. Government is part of the solution, but an approach that encourages the self-sufficiency of demonstration facilities, by placing the responsibility for achieving long-term operating performance targets on the utilities and equipment manufacturers, is the most sustainable approach.

Anticipated Impacts of CCT Strategy

The expected impacts of CCT development across Canada are detailed below by region. The impacts include retaining energy supply security by keeping such a large and domestic resource a vital part of the energy mix. Success with CCT commercialization will maximize the value of Canadian coal resources, as well as other abundant low-grade resources like pet-coke and biomass. Another impact will be that using coal in the future will come without compromising Canadian environmental quality. Spin-off benefits include the use of CO_2 as a valuable by-product, and the co-production of chemicals, fuel, and industrial heat while generating near-zero emissions electricity. An innovative and advanced clean coal industry sector will have the potential to tap into export markets abroad. Implementing the strategic components of this Roadmap will result in coal becoming increasingly important to Canada's energy mix.

Atlantic Provinces

- A revitalized coal industry in Cape Breton
- An alternative fuel source to Scotian Shelf natural gas for electricity generation
- A phased approach to implementing CCT in Atlantic provinces, with supercritical PC combustion eventually giving way to IGCC
- At a later date, captured CO_2 used for ECBM recovery

Ontario

- The Association of Major Power Consumers in Ontario (AMPCO)[3] reports that using NGCC plants to replace coal-fired capacity in Ontario would cost $5.3 billion, compared to $3 billion to simply reduce air emissions at existing coal plants (AMPCO, 2004). Additional costs for new NGCC plants could add up to another $1.9 billion/year. Thus, CCT offers an economically competitive option to Ontario policy-makers
- A route to environmentally clean power in Ontario, while retaining access to a stable fuel price

Saskatchewan

- A logical framework for replacing existing lignite-fired units and adding new capacity that uses Saskatchewan's low-cost fuel
- The adaptation of CCT being developed elsewhere to Saskatchewan's low-grade fuel source, whether using combustion or gasification technology
- An opportunity to build the first high-tech supercritical clean coal plants in Canada
- A chance to illustrate the value-added of using amine scrubbing to capture carbon for EOR and fertilizer manufacture

Alberta

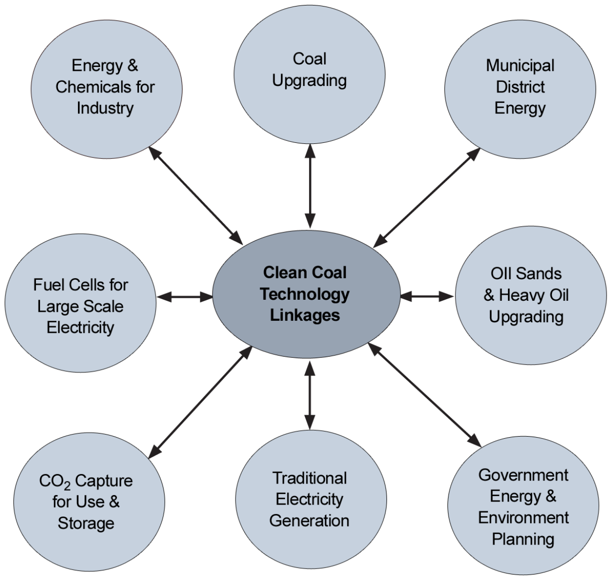
- A framework to move Alberta away from natural gas dependence for fuel and H_2 generation in the oil sands and other industrial applications
- The adaptation of CCT being developed elsewhere to Alberta's sub-bituminous coal, whether using combustion or gasification technology
- An opportunity to demonstrate the value-add of UCC to clean coal power plants
- The chance to build an IGCC plant with polygeneration capacity, to provide valuable feedstock to the chemical industry, as well as CO_2 for ECBM, EOR, and ENGR

[3] AMPCO is an association of Ontario power consumers that promotes Ontario industry through an efficient, competitive electricity market and a reliable and economic transmission and distribution network.

Other CCT Opportunities

Canadian manufacturing sectors can respond to this Roadmap by developing technology that leads to commercial applications in Canada and abroad. The benefits of manufacturing in Canada include meeting domestic technology needs and standards, immediate employment in the manufacturing sectors, and better performance and reliability – as products are designed for site specific conditions and serviced locally. Technology manufacturers can be involved in operating the demonstration facilities and share the responsibility for achieving baseline performance targets.

Figure 5.5 CCT Linkages to Other Industry Sectors



Coal's traditional use has been as a primary energy source for electricity generation and a manufacturing input into steel making. However, the emergence of CCT will broaden this traditional role to a spectrum of commercial applications (see Figure 5.5). Besides the impact on manufacturing, the following are some anticipated impacts of CCT over the next 20 years:

- High efficiency (42 – 48%) ultra-supercritical PC power plants, some with CCS; further efficiency gains of 37% when integrated into municipal district energy systems, thereby making use of low-grade waste heat
- High efficiency coal gasification facilities that capture CO_2 and produce electricity, steam, and H_2 for oil sands and heavy oil
- Coal gasification facilities that produce syngas as either a chemical feedstock or fuel source to a host of other industries
- Coal gasification facilities that provide fuel for fuel cells, with 65% fuel-to-electricity conversion efficiency
- Coal upgrading facilities that remove ash, trace metals, water, and contaminants, thereby lowering transportation costs and improving the environmental performance of downstream customers
- Pipeline networks that transport captured CO_2 from coal-fired boilers and gasifiers, to be used in ECBM, EOR, or ENGR

The champions of the five components of this Roadmap will continuously work to develop these linkages with other industry sectors. One way to do so is by continuing to work with other agencies that are implementing relevant and overlapping roadmap exercises, such as those for Fuel Cells and the Hydrogen Economy, Oil Sands and Heavy Oil Upgrading, and CO_2 Capture and Storage. A forum for this type of cooperation may best be served under EnergyINet.

Developing CCT is a means of ensuring that the value of Canada's vast coal resources remains high. Meeting the environmental and regulatory challenges that face coal will enable forging a permanent place for coal as a future energy alternative. A strategic plan with a made-in-Canada approach to technology and innovation will help meet our national objectives and those of other nations around the world.

Ultimately, the outcome of this Roadmap initiative is a resounding call to action today, to enable industry stakeholders to build the capacity for an economically competitive and environmentally sound energy future for all Canadians.

Section Summary

To bring life to the vision outlined early in this section, the CCTRM Advisory Group conducted a critical gap analysis that resulted in the identification of six key factors holding back the successful commercial application of CCT in Canada. Based on these gaps, the group developed five SMART objectives:

- Engaging in public outreach by developing a publicly accessible National Clean Coal Information Program
- Acquiring CCT information for a network of interested stakeholders by creating a National Intelligence Centre
- Developing R&D and technology programs that focus on demonstrating technology in commercial applications
- Developing a common national vision, business model and risk mitigation strategy for implementing the first CCT demonstration facility in Canada
- Initiating the integrated and optimized design and operation of the first and subsequent demonstration plants in Canada

Through industry/government consortia, formed under the leadership of the CAC, CETC-O, NRCan, EnergyINet, and the CCPC, stakeholders will take the lead in addressing the strategic issues facing coal by working towards achieving the SMART objectives.

The impact of CCT development will be felt across the country and in various industry sectors, by enhancing the current value of a vast domestic resource and ensuring its vital role in Canada's future energy mix. The time is right to make the strategic investment and begin down the pathway of replacing Canada's aging thermal capacity with CCT, which will ensure both a clean and affordable energy future for generations to come.

Canadians have the opportunity to demonstrate emerging CCT and gain market advantage through early experience and commercialization. Having proven its capacity to advance technology through to commercialization will encourage partnerships among research groups, and make Canada a sought-after base for further development and demonstrations. The ability to roll out the results of these efforts, both across Canada and to other parts of the world, is the reward of making a strategic investment today.

Appendix A

Table A.1 List of CCTRM Participants

Name	Organization	Name	Organization
Abu-Shaqra, Baha	Albarrie Canada Limited	Gupta, Murlidhar	NRCan, CETC-Ottawa
Allard, René-Pierre	NRCan, CETC-Ottawa	Hayes, Jason	The Coal Association of Canada
Amarnath, Amar	Luscar Ltd.	Hearn, Bill	Neill and Gunter Limited
Anthony, Ben	NRCan, CETC-Ottawa	Hicke, Kel	BC Ministry of Water, Land & Air
Aroonwilas, Adisorn	University of Regina	Holt, Neville	EPRI
Avison, Norm	Premium Pellet Ltd.	Hughes, Dave	Geological Survey of Canada
Bachu, Stefan	Alberta Energy and Utilities Board	Isaacs, Eddy	AERI
Ball, Max	SaskPower	Johnson, Alan	ZECA Corporation
Barrie, John	Fluor Canada Ltd.	Jung, Tony	ATCO (Alberta Power Ltd.)
Barton, Carolyn	Resources, Coal Industry, AUS.	Kennedy, Bill	Albarrie Canada Limited
Bateson, Dwayne	TransAlta Corporation	Kjaer, Sven	Tech-wise A/S
Bauwens, Luc	University of Calgary	Kostler, Joe	ATCO Power
Boyd, Malcolm	ATCO Power	Krusche, Jack	Morrow Engineering
Bulut, Dubravka	NRCan, OERD	Kuhn, Robyn	Alberta Environment
Burke, Michael	NRCan, CETC-Ottawa	Lakeman, Brent	Alberta Research Council
Caldwell, Richard	ATCO Gas	Leslie, John	SNC-Lavalin Inc.
Campbell, Doug	Nova Scotia Power Inc.	Lew, Richard	Teck Cominco Research
Campbell, Frank	NRCan, CETC-Ottawa	Lonsberry, Duane	Albarrie Canada Limited
Carlson, Sid	University of Alberta	Lord, Elisabeth	Levelton Engineering Ltd.
Castillo, Francisco	Alberta Research Council	Loseth, Howard	SK Industry & Resources
Chambers, Allan	Alberta Research Council	Luhning, Richard	Enbridge Inc.
Chiwetelu, Chris	Canadian Customs & Revenu	Macdonald, Derek	Alstom Canada
Choi, Gerald N.	Nexant Inc.	Macdonald, Don	Alberta Environment
Chow, Dann	Alberta Research Council	Macdonald, Doug	SNC-Lavalin Inc.
Church, Ken	NRCan, CETC-Ottawa	MacRae, Morgan	CERI
Clark, Paul	TransAlta Utilities Corp.	Mahinpey, Nader	University of Regina
Clements, Bruce	NRCan, CETC-Ottawa	Marrone, John	NRCan, CETC-Ottawa
Cousens, Des	Nova Scotia Power	McCann, Tom	T.J. McCann & Associates Ltd.
Daming, Liang	Beijing Research Institute of Coal	McDonald, Malcolm	TransAlta Corp.
deFayer, Paul	Alberta Energy	McKenny, Colin	Elk Valley Coal Corporation
Dell, Leah	NRCan, CETC-Ottawa	McLaughlin, Roger	BC Ministry of Energy & Mines
Denman, Keith	Alberta Environment	Mehta, Raj	University of Calgary
Dinning, Jim	TransAlta Utilities Corp.	Mercier, Gilles	NRCan, CETC-Ottawa
Douglas, Peter	University of Waterloo	Mertikas, Bill	NRCan
Doyle, Jim	Alberta Department of Energy	Mikalson, Daryl	TransAlta
du Bruyn, Theo	NRCan, CETC-Devon	Mitchell, Bob	Inspired Value Inc.
du Plessis, Duke	Alberta Energy Research Institute	Mitchell, Garner	SaskPower
Dunbar, Bob	CERI	Mohamad, Majeed	University of Calgary
Faltinson, John	Alberta Research Council	Moore, Robert	University of Calgary
Finzel, Christeen	Alberta Environment	Mourits, Frank	NRCan, OERD
Flaman, Leo	Bantrel Co.	Napior, Chris	Eco Power Solutions
Flemming, Allan	Luscar Ltd.	Nguyen, Yen	Kinectrics
Flint, Len	Lenef Consulting	Ojanpera, Ron	Babcock & Wilcox Canada
Fraser, Bob	NRCan, CETC-Ottawa	Patrick, Rick	SaskPower
Gatens, Michael	MGV Energy Inc.	Pearson, Bill	NRCan, CETC-Ottawa
Gunter, Bill	Alberta Research Council	Podgurny, Dave	Air Liquide Canada Inc.

Table A.1 List of CCTRM Participants (cont'd)			
Name	Organization	Name	Organization
Potter, Ian	Alberta Research Council	Singh, Surindar	AERI
Preston, Carolyn	NRCan, CETC-Devon	Sit, Song P.	EnCana Corporation
Pugsley, Todd	University of SK	Spinner, Ken	Spinergy Services Inc.
Ranganathan, Range	SK Research Council	Stobbs, Bob	SaskPower
Redden, Dwight	ATCO Power	Sundermann, Rudy	EnCana Corporation
Rhodes, Alan	Jacobs Canada Inc.	Tan, Z Chao	University of Calgary
Richards, Bill	Nova Scotia Power	Taylor, Alison	Suncor Energy
Richter, Tim	TransAlta Corp.	Thambimuthu, Kelly	NRCan, CETC-Ottawa
Rigg, Andy	CO2CRC Program, Australia	Tibble, Dave	ATCO Power
Rivers, Keith B.	Babcock & Wilcox Canada	Topper, John	IEA Clean Coal Centre
Rose, Don	Environment Canada	Twa, Bob	EPCOR Power Dev. Corp.
Rothschild, Dave	Alstom Power Inc.	Van Ham, John	Van Ham Resources Inc.
Rubin, Ed	Carnegie Mellon University	van Nierop, Pieter	Alberta Research Council
Runstedtler, Allan	NRCan, CETC-Ottawa	Villavicencio, Hector	EnCana Corporation
Ruth, Larry	NETL, U.S. Department of Energy	Wenhua, Li	Beijing Research Institute of Coal
Sahay, Hari	Alberta Energy	Williams, Robert	Princeton University
Savoy, Mark	Nova Scotia Power	Wong, Joseph	NRCan, CETC-Ottawa
Seckington, Blair	Ontario Power Generation	Wong, Sam	Alberta Research Council
Seifried, Anke	Alberta Environment	Wright, Allen	The Coal Association of Canada
Simandl, George J	BC Ministry of Energy and Mines	Yuhua, Liu	Beijing Research Institute of Coa
Simonson, Bryan	Alstom Power Inc.	Zhou, John	Alberta Research Council

Appendix B

The following table provides the details of Canadian coal-fired power plants that are scheduled for replacement or refurbishment by 2034. These plants, numbered 1 through 61, represent the nodal points in Figure 3.7 of section 3.

Table B1 Canadian Coal-fired Electricity Generating Units

Plant #	Plant Name	Province	Facility Size (MWe)	Plant #	Plant Name	Province	Facility size (MWe)	Plant #	Plant Name	Province	Facility Size (MWe)
1	Wabamun 2*	Alberta	64	21	Lambton 4	Ontario	494	41	Lingan 1	Nova Scotia	155
2	Wabamun 1*	Alberta	64	22	Boundary Dam 3	Sask.	150	42	Sundance 6	Alberta	366
3	Boundary Dam 1	Sask.	66	23	H.R. Milner	Alberta	150	43	Lingan 2	Nova Scotia	155
4	Selkirk 1	Manitoba	66	24	Sundance 2	Alberta	280	44	Battle River 5	Alberta	375
5	Selkirk 2	Manitoba	66	25	Boundary Dam 4	Sask.	150	45	Poplar River 2	Sask.	300
6	Wabamun 3	Alberta	140	26	Nanticoke 1	Ontario	490	46	Thunder Bay 2	Ontario	155
7	Boundary Dam 2	Sask.	66	27	Nanticoke 2	Ontario	490	47	Thunder Bay 3	Ontario	155
8	Lakeview 1	Ontario	285	28	Nanticoke 3	Ontario	490	48	Keephills 1	Alberta	403
9	Lakeview 2	Ontario	285	29	Point Tupper 2	Nova Scotia	150	49	Poplar River 1	Sask	300
10	Grand Lake	New Brunswick	57	30	Nanticoke 4	Ontario	490	50	Lingan 3	Nova Scotia	155
11	Lakeview 5	Ontario	285	31	Battle River 4	Alberta	150	51	Keephills 2	Alberta	403
12	Wabumun 4	Alberta	280	32	Boundary Dam 5	Sask.	150	52	Lingan 4	Nova Scotia	155
13	Battle River 3	Alberta	150	33	Nanticoke 5	Ontario	490	53	Atikokan	Ontario	215
14	Lakeview 6	Ontario	285	34	Sundance 3	Alberta	355	54	Sheerness 1	Alberta	398
15	Lampton 2	Ontario	494	35	Sundance 4	Alberta	355	55	Genesee 1	Alberta	410
16	Trenton 5	Nova Scotia	150	36	Boundary Dam 6	Sask.	292	56	Sheerness 2	Alberta	398
17	Sundance 1	Alberta	280	37	Nanticoke 6	Ontario	490	57	Trenton 6	Nova Scotia	155
18	Brandon	Manitoba	105	38	Sundance 5	Alberta	355	58	Shand	Sask.	300
19	Lambton 1	Ontario	494	39	Nanticoke 7	Ontario	490	59	Belledune	New Brunswick	480
20	Lambton 3	Ontario	494	40	Nanticoke 8	Ontario	490	60	Genesee 2	Alberta	410
								61	Point Aconi	Nova Scotia	165

Appendix C

Critical Gap Analysis and SMART Objectives

During the course of first two CCT workshops, which included many of the stakeholders noted in Appendix A, interactive subgroups were formed to discuss the four technology areas (upstream coal cleaning, combustion, gasification, and chemical and energy plexes) in terms of the critical gaps that exist in each of them. The later two groups were subsequently joined under the heading of gasification.

Based on the feedback from these workshops, the CCTRM Advisory Group compiled critical information to help formulate a CCT development and deployment strategy for Canada. When developing the strategy the Advisory Group conducted two SMART[4] objective analyses. The first resulted in the five SMART objectives that are illustrated in Table 5.1. During the second analysis, the Advisory Group delved deeper and developed more specific SMART objectives under the R&D Programs component (SMART Objective 3 in Figure 5.1). During this process the Advisory Group:

- Defined the current state of affairs of CCT in Canada
- Formulated a vision for CCT in Canada, for the 2020 – 2025 timeframe
- Defined the desired future state that embodied this vision
- Identified the specific technology gaps between the current and desired future states
- Developed SMART objectives for bridging each of these technology gaps

The results of the second analysis are tabulated in the first four columns of Tables C.1, C.2 and C.3. Based on the R&D efforts being pursued by the international community as well the ongoing efforts and facilities available in Canada, the advisory group qualitatively ranked the SMART objectives in terms of the relative impact and achievability of each specific objective (see columns five and six of Tables C.1, C.2 and C.3). Figures 5.1, 5.2 and 5.3 in the main text of the Roadmap illustrate the relative ranking of these SMART objectives using impact versus achievability diagrams. Technologies in the bottom right-hand quadrant should be the easiest to develop, but have a relatively low impact on CCT deployment. Technologies in the upper left-hand quadrant will have major impacts, but are risky to develop. The sweet spots are the technologies that have both the highest impact and probability of success.

[4] A SMART objective means a Specific, Measurable, Achievable, Realistic and Timely objective.

Table C.1 Upstream Coal Cleaning: SMART Objectives Relative to Impact and Achievability

Objective	Desired Future State (Vision)	Critical Gaps	SMART Objectives	Achievability	Impact
Coal characterization	Impact assessment of coal quality for combustion and gasification.	Lack of coal-quality specifications required by end users.	Survey and understand bolier and gasifier performance by improving coal quality.	High	High
		Gasification and combustion reactivity of low rank coals. Trace element partitioning behaviour. Desired specifications for ash/slagging/ fouling behaviour.	Develop pilot-scale and bench-scale facility to evaluate performance of low-grade Canadian coals. Develop appropriate models to simulate commercial performance.		
Coal beneficiation	Solvent extraction and de-ashing technology to improve coal quality.	Need for Canadian capability.	Develop pilot scale facility for coal beneficiation in Canada.	Medium	High
	Low-cost techniques for making briquettes and pellets, and low-cost binders, especially for fine coal. Optimized feed preparation for slurry feed systems.	Need for feed preparation research capability.	Create centre of excellence on coal feed preparation.	Medium	High
Coal transportation	Coal transportation through slurry pipelines.	Lack of optimization studies on coal-slurry transport systems.	Develop pilot and demonstration scale coal slurry transport projects in Canada.	Low	High

Table C.2 Combustion: SMART Objectives Relative to Impact and Achievability

Objective	Desired Future State (Vision)	Critical Gaps	SMART Objectives	Achievability	Impact
Coal characterization	Characterization of Canadian and imported coals for supercritical cycles in air or oxy-fuel combustion, and for chemical looping cycles. Models to predict coal performance in the above cycles.	Reactivity of coals. Trace element partitioning behaviour. Desired ash and slagging behaviour or specifications for combustion.	Through pilot scale research, characterize coals of interest to Canada and develop appropriate models to simulate commercial performance.	High	High
Feedstock preparation	New and improved approaches to remove moisture and ash to enhance the energy density. Solvent extraction/de-ashing technology to improve coal quality.	Canada does not have a coal research beneficiation capability.	Create a centre of excellence on coal beneficiation.	Medium	High
	Low-cost techniques for making briquettes and pellets, and low-cost binders, especially for fine coal. Optimized feed preparation for slurry feed systems.	Canada does not have a feed preparation research capability.	Create a centre of excellence on coal feed preparation.	Medium	High
	Characterization of coal and alternative solid fuel blends, e.g., pet-coke, MSW, biomass and sewage sludge.	Lack of information on performance of the fuel blends in existing and new furnace designs.	Conduct pilot scale testing and develop a database on fuel-blend performance.	High	High
Feed systems	Flexible feed systems to handle fuel variations.	Material development for dry/wet (slurry) feed systems. Develop systems for co-feed of alternative fuel blends.	Provide basic research to support commercial vendors and interested users.	Medium	Medium
Air separation	Cost-effective oxygen separation membranes.	OTMs are not commercially available.	Technology watch and basic research to support vendors.	Medium	High
	Intermediate temperature ASUs involving PSA/VSA processes .	Technology not commercially available.		Low	High
Boiler	RAM demonstration of new boiler process cycles.	Unknown RAM at electric utility scale.	Demonstrate new technology boiler processes at electric utility scale.	Medium	Medium

Table C.2 Combustion: SMART Objectives Relative to Impact and Achievability (cont'd)					
Objective	**Desired Future State (Vision)**	**Critical Gaps**	**SMART Objectives**	**Achievability**	**Impact**
Materials development	Materials development and reliability evaluation of advanced ultra-supercritical steam cycle boilers, steam tubes, headers and steam valves.	Lack of proven alloys for high temperature/ pressure components.	Technology watch and basic research to support vendors.	High	High
	Advance boilers based on oxy-fuel combustion and O_2/CO_2 recycle.	Overall cycle and components not optimized; further materials and components development required.	Basic research to support vendors in co-operation with technology users.	Medium	High
	Commercially available oxy-fuel coal burners.	No availability of oxy-fuel coal burners.	Develop coal fired oxy-fuel burners including slagging combustors.	Medium	High
	Advanced boilers/ reactors for chemical looping combustion.	Technology at pilot scale research stage.	Identify commercial viability through pilot scale research.	Medium	High
Pollution abatement technologies	Low-cost integrated emissions control technologies.	Lack of low-cost emissions control technologies that conform to future regulatory requirements.	Develop low-cost integrated emissions control technologies in co-operation with technology vendors and users.	High	High
	Hot gas clean-up technologies.	Materials and technology not commercially available.	Technology watch and basic research to support vendor interests.	Medium	Medium
Slaggging combustor	Commercially viable oxy-fuel slagging combustor, furnace, and pollution abatement processes.	Burners and furnaces not commercially available. Pollution abatement processes not optimized.	Evaluate effectiveness of using slagging combustors to reduce overall furnace and pollution abatement costs and optimize process design, along with technology vendors and users.	Medium	High
Heat transfer	Materials and design configuration for high temperature heat transfer.	Technology at development stage.	Develop materials and design configurations for efficient high temperature heat transfer, in co-operation with technology vendors and users.	Medium	High
Steam turbine	Materials to mitigate turbine blade erosion.	Need for advanced materials.	Technology watch on EU and Japanese program developments.	Medium	High
In-situ & post-combustion capture	Advance solvents with higher CO_2 capture capacity, lower solvent losses, and lower energy penalty	High capital and operating costs.	Improve tower packing and solvent performance.	Medium	High
	Development of gas separation and gas absorption membranes	Technology at developmental stage.	Bench scale research in co-operation with technology vendors.	Medium	High
	Scale-up of post-combustion CO_2 capture capacity	RAM not proven at electric utility scale.	Demonstrate performance at electric utility scale.	High	High
Component modelling & system integration	Develop models to predict cycle and component performance.	Lack of operational data and process models .	Obtain operational data through pilot scale research and develop process models.	High	High

Table C.3 Gasification: SMART Objectives Relative to Impact and Achievability					
Objective	**Desired Future State (Vision)**	**Critical Gaps**	**SMART Objectives**	**Achievability**	**Impact**
Coal characterization	Characterization of Canadian coals and models of their performance in gasifiers.	Data on gasification reactivity of low rank coals. Knowledge on partition behaviour of trace elements. Desired specifications for ash/slagging/fouling behaviour.	Develop pilot-scale and bench scale facilities to evaluate performance. Develop appropriate models to simulate commercial performance.	High	High
Feedstock preparation	New and improved approaches to remove moisture and ash to enhance energy density Solvent extraction/de-ashing technology to improve coal quality.	Canada does not have a coal research beneficiation capability.	Create a centre of excellence on coal beneficiation.	Medium	High
	Low-cost briquetting, pelletizing techniques and low-cost binders, especially for fine coal. Optimized feed preparation for slurry feed systems.	Canada does not have a feed preparation research capability.	Create a centre of excellence on coal feed preparation.	Medium	High
	Characterization of coal and alternative solid fuel blends, e.g., pet-coke, MSW, biomass and sewage sludge.	Lack of information on performance of the fuel blends in existing and new gasifier designs.	Conduct pilot scale testing and develop a database on fuel-blend performance.	High	High
Feed systems	Behaviour of feedstock quality on the life of feed-injectors and plant availability.	Material development for dry/wet (slurry) feed systems. Systems for co-feed of opportunity feedstocks such as pet-coke, biomass, and MSW .	Consult and provide basic research to support commercial gasifier vendors.	Medium	Medium
Air separation	Oxygen separation membranes.	Commercial availability of cost effective OTM membranes.	Basic research and support to vendors.	Medium	High
	Intermediate temperature ASUs involving PSA/VSA process.	Lack of commercial availability.			
Gasification	Increased RAM.	Satisfactory RAM not demonstrated yet.	Demonstrate technology at utility scale.	Medium	High
	New materials for lining, enhancing refractory performance at reduced cost; R&D on water-cooled refractories.	Material development and new water-cooled refractories.	Consult and provide basic research to support commercial gasifier vendors.	Low	Medium
	Kinetic models of gasification reactions.	Lack of understanding of coal decomposition and its impact.	Improvement of coal gasification at low temperature.	Medium	Medium
	CFD models for burners.	Lack of reliable models for Canadian coals.	Develop CFD models for burners in gasification environments.	Medium	Medium

Table C.3 Gasification: SMART Objectives Relative to Impact and Achievability (cont'd)					
Objective	**Desired Future State (Vision)**	**Critical Gaps**	**SMART Objectives**	**Achievability**	**Impact**
Gasification	Reduced ash fusion temperatures to below 1200°C for increasing heating value of syngas and reducing oxygen consumption.	Lack of suitable fluxing agents.	Develop fluxing agents for Canadian coals.	High	Low
	3rd generation gasifiers involving hydrogasification, CO_2-gasification, and steam gasification using low-rank coals.	Lack of suitable models to analyse and identify benefits of 3rd generation gasifiers.	Develop CFD and process models.	Medium	High
Syn-gas cleanup	High-pressure H_2/CO_2 separation.	Commercial technology for high pressure H_2/CO_2 separation.	Identify promising technologies and develop those with the best potential.	Medium	High
	Hot gas clean-up.	Advanced materials and technology development.	Technology watch and evaluation.	Low	Medium
Ash slag characterization	Reduction of residual carbon and moisture. Database on viscosity and flow properties. Market disposal issues.	Ash slag characterization of Canadian coals.	Pilot scale research on ash/slag characterization of Canadian coals.	High	Medium
Heat recovery	Efficient heat transfer systems.	No commercial alternative to water quench cooling.	Investigation of use of other efficient cooling systems.	Low	Medium
Power island	Development of hydrogen rich syngas compatible turbines.	Commercial availability of hydrogen-rich syngas turbines.	Basic research and support to vendors.	Medium	Medium
	Oxy-fuel turbines.	Commercial availability of oxygen/CO_2-rich turbine.	Basic research and support to vendors.	Medium	High
	HAT-type cycles with lower cost quench gasification.	Technology is commercially not available.	Assess the commercial viability of HAT- type cycles.	Medium	Mediium
	Syngas-compatible fuel cells.	Lack of appropriate commercial technology.	Develop fuel cell technologies under Canadian fuel cell R&D and commercialization programme.	Medium	High
Chemical plexes	Process development and market identification.	Limited opportunity due to economic competitiveness of alternatives.	Provide commercial vendors with R&D support to improve economics of processes of interest to Canada.	Low	Medium
Process integration & optimization	Optimization for co-production of hydrogen, synthesis gas, steam, CO_2 and electricity.	Lack of site-specific market data and operating parameters to feed into process optimization packages.	Conduct market studies and identify operational parameters through pilot scale research and develop appropriate process optimization models.	High	High
Supplementary infrastructure	A full-scale Canadian lignite/sub-bituminous coal-fed demonstration plant having multiple slipstreams specifically designed to test new technology in plug and play mode.	No demonstration facility	Construct a full scale demonstration facility	Low	High

Appendix D

The CCPC suggests incorporating some of the lessons learned from the USDOE's past experience with its demonstration program:

- Have advanced appropriations – for full multi-year funding at the beginning of the program adds certainty that government is committed for the life of the program.
- Multiple solicitations spread over several years – which affords the time needed for the lessons learned from one solicitation to be factored into the next.
- Allow industry to determine the technical agenda – based on goals established by government. With input from industry and with policy guidance, define performance-based objectives and requirements against which proposals can be judged.
- Define roles for government and industry - allows the implementation of the program to progress smoothly without conflict.
- Involve the public in defining the focus and criteria for solicitations – by using public meetings to get comments and suggestions that will help government define the goals and objectives.
- Define clear, succinct criteria – against which proposals are evaluated.
- Use split financing – where a first phase is for the period of resolving detailed project development issues and a second phase for detailed design, construction, and operation.
- Set time limits on contract negotiations.
- Offer debriefing sessions for all proponents whose proposals were not selected.
- Scale the demonstration appropriately – as the objective of the demonstration program is to prove that promising advanced CCT can operate effectively at full commercial scale. Experience has shown that this objective can only be met if the demonstration takes place at full commercial scale, and if fully integrated with other unit operations.
- Cost-share throughout all phases of each project – as it is important to have commitment from industry participants and require them to provide significant cash (or acceptable in-kind) cost-sharing (>50%) in every phase of the project.
- Impose stringent environmental standards – to prove that the technology can meet and exceed all anticipated environmental requirements.
- Impose reasonable indemnification requirements – as industry participants must have the financial assets or insurance to indemnify the government against project completion.
- Submit only the technical and financial information for proposal evaluations – to reduce the cost of preparing proposals and avoid receiving information that is not needed to select a proposal.
- Provide property rights to the industry participants – with the understanding that demonstrated technology must be made available on a non-discriminatory basis to all Canadian companies.
- Repay the government's investment – in commercially successful projects to make the subsidies provided by the government more reasonable.
- Relinquish government rights to prematurely withdraw from the project – if the industry participant is performing as agreed.
- Divide cooperative agreements into clear decision points – consistent with project decision points.

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Glossary

2nd Generation Gasification: This refers to current state of high-tech gasifier technology today.

3rd Generation Gasification: This refers to state of the art gasifiers available in the 2010 timeframe, which will offer higher efficiency, high flexibility to low-rank coals, and will be adaptable to CO_2 capture.

Acid Rain: Also referred to as 'acid precipitation' or 'acid deposition', acid rain is any form of precipitation containing harmful amounts of nitric and sulphuric acids, formed primarily by nitrogen oxides and sulphur oxides released into the atmosphere upon combusting fossil fuels.

Ash: The inorganic, non-flammable substances (impurities such as silica, iron, aluminium) left over after coal, pet-coke, or other solid fuels are burned off. Ash increases the weight of the fuel, which increases the cost of handling and can affect the burning. Ash content is measured as a percentage of the total weight of the dry fuel source.

Biomass: Plant material and animal waste that is available as a form of feedstock, and in the case of the electricity industry as a fuel source. Biomass is considered a renewable resource (and greenhouse gas emissions free) as long as the fuel source is replenished over time.

Bitumen: A naturally occurring viscous mixture, made up primarily of hydrocarbons; it may also contain high levels of sulphur compounds. In its natural occurring viscous state, bitumen is not commercially recoverable through a conventional oil well. Bitumen typically makes up 10% of the weight of oil sands, but saturation levels vary.

Carbonaceous Fuel: A fuel that contains carbon as the major constituent for the oxidation process and therefore release of potential energy for useful purposes.

Carbon Dioxide (CO_2): A colourless, odourless, non-poisonous gas that is a normal constituent of the earth's many systems including the atmosphere, biosphere and oceans. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing plants and by the oceans. Carbon dioxide is also produced during the combustion of any carbonaceous fuel source including fossil fuels. Carbon dioxide is a greenhouse gas, and is the primary one of concern related to climate change because of its pervasiveness and increasing concentration in the earth's atmosphere as a result of human-related activities.

Carbon Dioxide Capture and Storage (CCS): Capturing carbon dioxide from the flue gases from combustion or gasification of carbonaceous fuels, or from other industrial processes, and concentrating it for transportation to a permanent geological site for storage. Examples of storage sites include ocean beds, aquifers, abandoned oil and gas reservoirs, or coal beds. This is a new and unproven concept for controlling human induced carbon dioxide emissions into the atmosphere and mitigating climate change.

Clean Coal Technology (CCT): A number of innovative new technologies designed to extract and utilize coal in a more efficient and cost-effective manner while reducing the environmental impact of these activities. Examples of clean coal technology include oxy-fuel combustion and coal gasification.

Clean Development Mechanism (CDM): One of three market mechanisms under the Kyoto Protocol, the Clean Development Mechanism is designed to promote sustainable development in developing countries and assist Annex I Parties in meeting their greenhouse gas emissions reduction commitments. The Clean Development Mechanism enables Annex I countries to invest in emission reduction projects in developing countries and receive certified emission reductions in return.

Climate Change: The term 'climate change' may refer to all forms of climatic variation or deviation; however, the term is more commonly used today to describe the recent phenomenon of global warming as a result of increasing anthropogenic greenhouse gas emissions into the earth's atmosphere (also see **Global Warming**).

Coal: A black or brownish-black solid combustible substance formed from prehistoric organic material such as vegetable matter. Coal is mined and combusted to produce heat and energy. The rank of a coal is based on the amount of volatile matter, fixed carbon content, and its heating value. The different ranks include anthracite, which contains approximately 23 – 33 MJ of energy per kilogram; bituminous coal is at 20 – 32 MJ/kg, sub-bituminous coal at 17 – 25 MJ/kg, and lignite at 9 – 18 MJ/kg.

Coal Beneficiation: The process of removing impurities, such as ash, sulphur and moisture, from raw coal, in order to increase the energy density of the product. Beneficiation increases the value of coal as a fuel source by reducing the moisture, sulphur, and inorganic content prior to transportation to a coal-fired facility. As well, beneficiation improves the combustion process once at the facility.

Coal Slurry: Pulverized coal that is suspended in water for transportation or injection into a boiler and gasifier.

Combined Heat and Power (CHP): The simultaneous production of useful electricity and heat from a thermal power generation process. Low-grade heat is extracted from flue gases for use in the thermal power plant or for district heating purposes, thus increasing the overall fuel to energy conversion efficiency. Combined heat and power is also commonly referred to as 'co-generation'.

Combustion: The oxidation of carbonaceous fuels with the release of energy in the forms of heat and light. Combusting fuels such as coal, oil, gas, and wood releases pollutants and other air emissions as a by-product (including sulphur dioxide, nitrogen oxide, particulate matter, and carbon dioxide).

Energy/Chemical Plexes: A concept of advanced, ultra-clean, and highly efficient power plant/chemical complexes that are capable of producing several energy products (such as electricity, liquid fuel, steam, and heat) and premium chemicals and other feedstock. Also frequently referred to as 'polygeneration plexes'.

Flue Gas: Gas that is left over after a fuel is burned. Flue gas is typically disposed of through a pipe or a stack to the atmosphere. In some cases flue gas is captured, and its constituent gases are used for additional purposes.

Fluidized Bed Combustion (FBC): A process whereby a facility burns powdered solid fuel particles, which are suspended in the air or a gas, and therefore behave like a liquid stream.

Fossil Fuel: Any naturally occurring organic fuel, such as crude oil, natural gas, coal, peat, or their by-products. Fossil fuels are all formed by a series of earthly processes whereby the remains of formerly living organisms from prehistoric times have been geologically buried (or sealed off). It is essential that the organic matter experiences the appropriate amount of underground heat and pressure, and for the right amount of time, to form the fossil fuel or hydrocarbon product.

Fuel Cell: An electrochemical device with no moving parts, which converts the chemical energy from fuel sources (such as hydrogen and oxygen) into electricity, heat and other by-products. The principal components of a fuel cell are two catalytically activated electrodes (the positive anode and negative cathode) and an electrolyte, which transmit the ions between the two electrodes and allow for the flow of electrical current.

Gasification (using a gasifier): Partial (or controlled) oxidation of carbonaceous fuels, which produces a mixture of gases (including hydrogen, carbon monoxide, and water) and solids such as ash or slag. Gasification is a process that can be used to generate a multitude of fuels and chemical feedstock.

Global Warming: The progressive but gradual rise in the earth's surface temperature thought to be caused by the greenhouse effect. Global warming is responsible for the global climate changes being observed by the Intergovernmental Panel on Climate Change. Global warming has occurred in the past as the result of natural influences, but the term today is used to refer to the earth's warming that is either already occurring, or predicted to occur, as a result of increased anthropogenic activities and the generation of greenhouse gas emissions.

Greenhouse Gases (GHGs): The atmospheric gases that allow solar radiation to penetrate the earths atmosphere and therefore reach the earths surface, yet which absorb the infrared radiation that would otherwise return back to space. The process of trapping the long-wave infrared radiation is known as the greenhouse effect, and it is what prevents the earth's atmosphere from being as cold as it otherwise would be. However, human induced activities may be increasing the concentration of atmospheric GHGs to dangerously high levels. The primary greenhouse gases are carbon dioxide, methane, nitrous oxide, ozone, water, and chlorofluorocarbons.

High Heating Value (HHV): The maximum potential energy released from the complete oxidation of a unit of fuel, which includes the thermal energy recaptured by condensing and cooling all by-products of the combustion process.

Hydro Electricity: Electricity that is produced by capturing the kinetic energy of falling water, by using the water to mechanically rotate a turbine generator. Commonly referred to as 'hydro'.

Integrated Gasification Combined Cycle (IGCC): The same process as for natural gas combined cycle, with the exception of the fuel source. In an integrated gasification combined cycle, the fuel is produced from a solid source such as coal, which is then gasified to produce syngas. The syngas is then combusted and expanded in a gas turbine (Brayton cycle) followed by a second cycle of heat recovery from the flue gases to run a steam turbine (Rankine cycle), all for the purpose of electricity generation.

Joint Implementation (JI): One of three market mechanisms under the Kyoto Protocol, Joint Implementation is a contractual agreement where an Annex 1 country invests in an emissions reductions or a sink enhancement project in another Annex 1 country in order to earn emissions reduction units.

Kyoto Protocol: An international agreement adopted in December 1997 in Kyoto, Japan. The Protocol has binding greenhouse gas emission targets for developed countries, whereby they will be expected to jointly reduce their emissions from 1990 levels by 5.2% (on average). The Kyoto Protocol officially came into force as a binding agreement on February 16, 2005.

Lifecycle Emission Analysis (LCA): A system of analyzing the complete emissions from a specific fuel source or energy technology, by accounting for the complete lifecycle of the fuel source. In other words, the analysis includes emissions from the fuel's extraction, production, transportation, and its final consumption.

Liquefied Natural Gas (LNG): Natural gas that has been condensed to its liquid form, which is typically done by cryogenically cooling the gas to -200 C^o.

Lower Heating Value (LHV): The net energy released during the oxidation of a unit of fuel, excluding the heat required to vaporize the water in the fuel or the water produced by combusting the hydrogen.

Natural Gas: A naturally occurring mixture of hydrocarbon and non-hydrocarbon gases found in porous geological formations beneath the earth's surface. Natural gas is often associated with crude oil (or petroleum). The principal constituent of natural gas is methane, but it also includes ethane, butane, propane and other gases. Impurities in natural gas often include nitrogen, carbon dioxide, and hydrogen sulphide.

Natural Gas Combined Cycle (NGCC): An integrated power generating plant that, first extracts energy from the combustion of natural gas by using expansion turbines to convert mechanical energy into electrical energy (a Brayton cycle), followed by heat recovery from the outgoing flue gas to produce additional electricity through a steam expansion turbine (a Rankine cycle).

Nitrogen Oxides (NO_x): These are criteria air pollutants that are often formed from the nitrogen in air when any carbonaceous fuel is burned at a high temperature. Nitrogen oxides are a primary contributor to the formation of smog. Nitrogen oxides are also a chief contributor the creation of acid rain.

Nuclear Power: Electricity that is generated by either splitting heavy atoms (fission) or joining light atoms (fusion). Currently, only nuclear fission is technologically feasible for power generation. A nuclear power plant uses controlled atomic chain reactions to produce heat, which is then used to make steam, for driving a conventional turbine generator. Nuclear power was the top choice for new power generation facilities in the 1970's and early 1980's, but since then its contribution to global energy supply has fallen.

Oil (Crude): A liquid mixture of hydrocarbons that is found in suitable rock formations, which can be discovered, extracted, and refined to produce a variety of oil products, such as gasoline, diesel, paraffin, and chemical feedstock.

Oil Sands: Bitumen-soaked sand, located in four geographic regions of Alberta (Athabasca, Wabasca, Cold Lake and Peace River) and in other parts of the world. The Athabasca Oil Sands is the largest oil sands deposit in the world, encompassing more than 42,340 km^2. Total bitumen resources in Alberta are estimated at 1.7 – 2.5 trillion barrels.

Orimulsion: An emulsion of bitumen and water. It is a trademark product of Bitumenas, Orinoco, SA of Venezuela.

Oxy-fuel Combustion: The combustion of a carbonaceous fuel in a pure oxygen (or nitrogen deficient) environment to produce a flue gas stream that consists mainly of water and carbon dioxide. The purpose of this process is to avoid inert nitrogen in the burning process, thereby controlling the flue gas streams by reducing the volume of flue gas and making it easier to concentrate carbon dioxide for capture, transportation, and storage.

Ozone: Molecules that are made up of three oxygen atoms. Ozone occurs naturally, and large concentrations are found in the stratosphere high above the earth. Stratospheric ozone shields the earth from harmful ultraviolet rays from the sun. The primary component of smog is ozone in its ground-level form. Ozone is a product of chemical reactions and the combustion of fossil fuel.

Particulate Matter (PM): Dust and unburned fuel particles that form smoke or soot, and other particles of solid material, that is released into the atmosphere as an air emission. Particulate matter, or particulates, is produced from many sources, including diesel engines in trucks and buses, garbage incineration, fertilizer and pesticide mixing and application, road construction, industrial processes, and the operation of fireplaces and woodstoves. Particulates can stick to lung tissue when inhaled causing respiratory problems, and can cause eye, nose or throat irritation.

Pathway: A pathway is a linear progression, or a continuum, of a technology-suite's development over time. Examples include the Microsoft Windows technology pathway versus UNIX, or a rail versus road transportation pathway. In the case of clean coal technology, these are essentially the two different technology routes for the preparation and utilization of coal for electricity generation, which are combustion and gasification.

Pet-coke: A residue that is high in carbon and low in hydrogen content, which is a by-product of the thermal decomposition of oil sands or heavy oil from the condensation process in upgrading. Pet-coke is typically >90% carbon and low in ash. However, it contains heavy metals such as vanadium.

Polygeneration: (see **Energy/Chemical Plexes**)

Pulverized Coal (PC) Combustion: A process in which very finely ground (pulverized) coal is combusted and the heat is used to produce steam for power generation (in a Rankine cycle). Normally this process is referred to as a sub-critical steam cycle, supercritical steam cycle or ultra-supercritical steam cycle depending on the steam pressure/temperature conditions (which today range between 22 – 35 MPa and 500 – 700 C^o). The higher the steam temperature in the Rankine cycle the higher the fuel to electricity conversion efficiency.

Renewable Energy: Sources of energy, where the resource can be managed so that they are not subject to significant depletion over time. Renewable energy sources include solar, wind, hydro, biomass, and geothermal. Renewable energy does not include the sources that are bound by their earthly limits, such as fossil fuels and nuclear. No matter how extensive an energy source may be, if by using the source it is being depleted, it is not renewable.

Reserve: The volumetric portion of a mineral or fossil fuel resource that is extractable under current technological and economic conditions, and that is also anticipated to be legally extractable.

Resource: The volume of a mineral or fossil fuel deposit that is suitable enough for its continued exploration and development by virtue of a favourable combination of the deposits thickness, depth, quality, and location.

Shift Conversion: A catalytic process that is used to convert one molecule into another, such as using steam to shift carbon monoxide into hydrogen and carbon dioxide.

Slag: The molten form of inorganic ash residue left over after the oxidation of a carbonaceous fuel at a high temperature. The material that would normally form ash, converts to its liquid state when at high enough temperatures, which then solidifies into a glassy (slag) material when cooled.

Smog: A mixture of pollutants (but principally ground-level ozone) produced by chemical reactions that occur in air that includes smog-forming constituents like nitrogen oxides and water. Fossil fuel combustion is a major contributor to the formation of smog. However, smog is often worse away from the source, since the chemical reactions that result in smog occur in the air while the reacting chemicals are being blown away. Smog is a health hazard, it damages the environment, and it causes poor visibility.

Sulphur Oxides (SOx): These are criteria air pollutants. Sulphur dioxide and Sulphur trioxide are produced during the combustion of coal and other fossil fuels, mostly from power plants. Some industrial processes, such as paper production and metal smelting, also produce sulphur oxides. Sulphur oxides are closely related to sulphuric acids, which are strong acids that play a significant role in the formation of acid rain.

Syngas: Synthetic gas is a product of the gasification of coal, and consists mainly of a mixture of carbon monoxide and hydrogen.

Synthetic Natural Gas (SNG): A fuel gas produced from syngas that mostly contains methane, and is therefore similar to natural gas.

Steam Assisted Gravity Drainage (SAGD): An in-situ oil production process that uses closely spaced horizontal wells for the production of heavy oil/bitumen without the need for excavating the land or other significant surface land disturbances. In a typical steam assisted gravity drainage process, one well will be used for steam injection, and the proximate well will be used to extract the bitumen/water emulsion from oil sands or heavy oil deposits.

Toxics (Air Toxics): Substances that are present in the air (either solid, liquid or gas form) in low concentrations, but their toxicity is such that they represent a risk to human health and the environment. The effects of air toxics cover a wide range of conditions from lung irritation to birth defects to cancer. Examples of air toxics include particulate matter, formaldehyde, benzene, carbon tetrachloride and metals.

Ultra Clean Coal (UCC): An extremely pure coal product (> 99% carbon and hydrogen) that is the result of an ore beneficiation process, whereby the coal has been stripped to near zero sulphur content and < 1% inorganic content.

Volatile Organic Compounds (VOCs): Organic compounds that are extremely volatile when at room temperature and under normal atmospheric pressures. Vapours escape very easily from these compounds, which include fuels like gasoline, industrial chemicals like benzene, and solvents like toluene, xylene, and tetrachloroethylene. Many volatile organic compounds are hazardous pollutants; for example, benzene is a carcinogen.

Western Canadian Sedimentary Basin (WCSB): The primary and most prominent continental sedimentary basin in Canada, which extends from British Columbia in the west to Manitoba in the east, and from the Northwest and Yukon Territories south into the US. The WCBS covers approximately 1,484,800 km^2 and it is the primary source of fossil fuel deposits in Canada whether oil, natural gas, bitumen, or coal.

Wind Power: A renewable form of electricity that uses the energy from wind to mechanically drive wind turbines. Inside each wind turbine is an electricity generator that converts the mechanical power into electrical power.