ESTIMATING HQP DEMAND ASSOCIATED WITH INDUSTRIAL CARBON REDUCTION INVESTMENTS

REVISED FINAL REPORT

SUBMITTED TO

Naeema Bhyat
Carbon Management Canada
October 2, 2013

SUBMITTED BY

Navius Research Inc.
520-580 Hornby Street
Vancouver, BC V6C 3B6

PROJECT TEAM

Jacqueline Sharp
Noel Melton

CONTACT

Jacqueline@NaviusResearch.com
Phone: 647.893.8910
Fax: 604.683.1253

Summary of Findings

The objective of this study was to forecast the expected distribution and timing of industrial investment in carbon reduction measures under different greenhouse gas (GHG) emission constraints, and identify the implications for Highly Qualified Personnel (HQP) demand. The focus was on investment in carbon capture and storage (CCS) in the electricity, oil and gas extraction, petroleum refining and iron and steel sectors, as well as co-generation of heat and power in the oil sands. Our approach involved using an integrated energy-economy model to estimate industrial GHG reduction-related expenditures under two Canadian GHG reduction scenarios, and then using input/output factors and feedback from industry to identify the associated demand for HQP. The scenarios examined included:

1. Canada achieving its long-term target of 60 to 70% below 2006 GHG emissions levels by 2050 (including a 36% reduction by 2030); and
2. Canada achieving only half this level of abatement.

As this was a partial equilibrium analysis, and does not include wage feedbacks on labour demand or look at displacement of HQP demand elsewhere in the economy, the results should be considered an estimate of potential HQP demand.

Our analysis showed that the potential labour implications of industrial GHG mitigation are significant, particularly in the electricity generation and oil and gas extraction sectors. In 2030, an estimated 9,113 to 11,926 additional full-time equivalent HQP positions will be required in the Half Target scenario, and an estimated 21,231 to 27,537 full-time equivalent positions will be required in the Target scenario, compared to business as usual. Every $1 million of industrial investment in GHG mitigation produces between 3.0 and 4.4 person-years of HQP demand on average, while every $1 million of operations and maintenance spending produces an average of 5.9 to 6.6 person-years of HQP demand. According to industry, 90-100% of investment phase and 100% of operations spending on labour will occur in Canada.

These HQP estimates are driven by Canadian GHG constraints, and are in addition to business as usual labour demands. Forecasted increases in the production of oil and electricity are expected to result in a substantial increase in the demand for labour. The Petroleum Human Resources Council of Canada expects 16,000 new jobs to be created in the oil sands alone by 2022 – an increase of 71% from 2012 levels. If combined with additional labour demand driven by Canadian GHG constraints, the demand for HQP will be substantial, and the supply of adequate HQP may become a limiting factor for industry. Since time is required to train new HQP, it will be important for government to provide a clear policy signal and adequate notice before implementing GHG reduction policies.

Contents

1. Objectives and Approach

The objective of this study was to forecast the expected distribution and timing of industrial investment in carbon reduction measures under different greenhouse gas emission reduction target scenarios, and the implications for Highly Qualified Personnel demand.

One of Carbon Management Canada (CMC)'s objectives is the development of Highly Qualified Personnel (HQP) and Highly Qualified Skilled Personnel (HQSP)) in the carbon management and clean energy fields. HQP refers to individuals with a university degree at the bachelors' level or higher, while HQSP is defined as an individual with a diploma or certificate from a post-secondary institution other than a university, such as a college or technical institute. Throughout this report, when we refer to HQP, we are referring to both HQP and HQSP. Existing and future HQP skill shortages have already been identified by the petroleum and electricity sectors, and these may be exacerbated by additional investments aimed at reducing greenhouse gas (GHG) emissions in fossil-fuel related industries.

CMC's HQP Skills and Supply Assessment Committee (the Steering Committee) was formed to investigate both the demand for and supply of HQP in the carbon management and clean energy fields, so that CMC can work proactively toward ensuring that sufficient HQP will be trained and available to support Canada's carbon reduction efforts. The Steering Committee contracted Navius Research to conduct an analysis of the future demand for HQP in these fields.

The carbon reduction measures of particular interest to CMC include carbon capture and storage (CCS) in electricity and oil and gas operations, as well as co-generation of heat and power in the oil sands. Navius also examined the use of CCS in the petroleum refining and iron and steel sectors. The results of this research will be combined with an analysis of HQP supply being conducted by a different research group in order to identify potential HQP and skill shortages.

1.1 Our Approach

Our approach to investigating the HQP implications of industrial investment in CCS and cogeneration can be summarised as follows:

1. Select two Canadian GHG reduction scenarios;
2. Verify the project-specific investment and operating costs for CCS and cogeneration in CIMS (an integrated energy-economy model), based on interviews with industry and literature estimates;
3. Use the CIMS model to estimate industrial GHG reduction-related investment and operating expenditures under each GHG reduction scenario between 2016 and 2030;
4. Use Statistics Canada input/output factors and sector income statistics to identify the share of these industrial investment and operating expenditures that would be spent on

labour, and the additional labour demand this spending is equivalent to, compared to business as usual labour demand; and

5. Estimate the HQP portion of the additional labour demand, based on industry surveys and interviews.

What is CIMS?

CIMS is a hybrid model that forecasts the evolution of technologies in energy systems over time. We use CIMS to evaluate and compare the impact that economic conditions and policy choices have on technology adoption, energy use, and GHG emissions. CIMS simulates how policies affect the stock of technologies (such as buildings, vehicles, and energy supply infrastructure) over time, taking into account system inertia, consumer and business preferences, and stock turnover rates. **For more detail about CIMS, please see Appendix A.**

Our approach allows us to investigate pathways for reducing emissions across the Canadian economy, including a realistic picture of the types of actions that may contribute to abatement and the labour requirements of these actions. However, there are several key limitations to our analysis:

- Our analysis includes directly employed and contracted labour, but not indirect labour impacts associated with GHG reduction efforts (such as demand for legal and accounting services), or induced employment impacts (due to increased spending by employees working on GHG reduction projects).

- Our partial equilibrium modeling approach means that we estimate labour demand, but not labour supply. We do not look at where the industrial investment and labour demand associated with national GHG reduction efforts would come from, and if it displaces other investment and labour demand, either in the same sectors, or elsewhere in the economy. CMC is assessing labour supply in another analysis, which could be a key limiting factor for the adoption of GHG abatement actions. Additionally, our analysis does not include an assessment of the impact of rising demand for labour on wage rates. For sectors experiencing particularly rapid growth in demand for labour, the increase in wage rates could be substantial, which could then put downward pressure on the demand for labour.

- Any forecast of future trends in the economy is uncertain. If technological developments occur at a different pace than anticipated, it is possible that the use of CCS and cogeneration to reduce GHG emissions could become more or less significant, with implications for labour demand.

1.2 Report Structure

Our report is structured as follows:

- Section 2 provides an overview of the GHG reduction scenarios that underlie the analysis;
- Section 3 discusses the emission reduction technologies that are investigated (CCS and cogeneration);
- Section 4 presents estimated industrial GHG emissions and incremental investment and operating expenditures under each GHG reduction scenario;
- Section 5 analyses the additional labour demand resulting from these expenditures, and estimates the HQP portion of this demand;
- Section 6 provides suggestions for expanding this research; and
- Appendix A provides additional detail about the CIMS model.

2. GHG Emission Reduction Scenarios

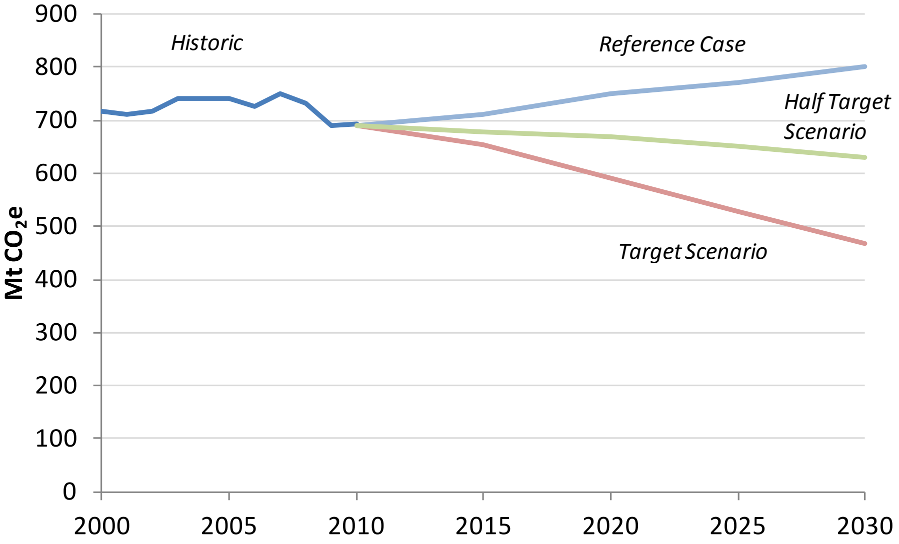
To estimate potential future investment in industrial GHG reduction efforts, we constructed two scenarios for future emission reductions in Canada. These scenarios describe pathways for reducing emissions across the economy and allow us to realistically simulate the types of actions that industry may undertake to abate GHG emissions. The required investment and associated demand for HQP can then be determined.

Figure 1 shows historic GHG emissions in Canada as well as projected emissions to 2030. The forecasts were generated using the CIMS model. If efforts are not made to control the release of GHGs, emissions are expected to rise over time as the economy expands. In the "business as usual" (Baseline) scenario, emissions reach 750 Mt CO_2e in 2020 and 800 Mt in 2050. These levels represent a 10 and 20% increase relative to 2006 levels, respectively.

Our first emission reduction scenario corresponds to a pathway that would get Canada on track toward achieving its long-term emissions target of 60 to 70% below 2006 levels by 2050. In this scenario, emissions decline to about 470 Mt in 2030, a reduction of 36% below 2006 levels.

The second emission reduction scenario assumes that about half of this level of abatement is achieved. Both scenarios are focused on GHG reduction outcomes, rather than specific policy packages, and could be achieved through the implementation of a variety of policy approaches.

Figure 1: Canadian greenhouse gas emissions, 2000-2030



3.Emission Reduction Technologies

Efforts to reduce the release of GHGs from industrial activities require capital investment for new infrastructure, and in many cases, higher variable (operating) costs. We conducted interviews with industry and reviewed estimates from the literature to identify the investment and operating costs associated with CCS projects in the electricity and oil and gas sectors, as well as cogeneration projects in the oil sands sector. This data was used to verify the cost information in the CIMS model, so that we can estimate the investment and operating costs associated with each of these activities under the different Canadian GHG reduction scenarios.

Two activities that are likely to be particularly important in reducing the emissions intensity of electricity and oil and gas operations include CCS and cogeneration of heat and power in the oil sands. Estimating future HQP demand associated with emission reduction activities requires understanding the technical characteristics of these activities (how much CO_2 could be abated by equipping coal-fired electricity plants with carbon capture technology?) and their costs (how much investment is required and what type of labour will be needed?).To determine the cost of these activities, we interviewed firms presently engaged in relevant projects and conducted a review of the cost literature.

We interviewed four firms that are engaged in a variety of CCS-related projects in electricity generation, the oil sands, petroleum refining, and CO_2 transport. Unfortunately no firms involved in co-generation in the oil sands elected to contribute to this study. The participating firms shared information about their projects' technical specifications, investment and operating costs, and anticipated labour requirements.

Since the costs of any specific GHG reduction project will vary depending on a number of factors, the CIMS model assumes heterogeneous costs, and its calculations are based on a normal distribution of costs around a point cost estimate. We compared the technical specifications and cost data from the industry interviews against the existing technology specifications in CIMS, which are derived from the literature. In most instances, the investment and operating cost data that industry shared with us fell within the bounds of literature estimates for each abatement activity. However, one area where we were able to update our cost data based on the industry interviews was in the area of CO_2 transport. The data we received from industry allowed us to refine the investment and operating costs, compared to the large observed spread in the literature.

Table 1 lists some of the cost estimates that were compiled for a previous CMC-sponsored review, and which inform the costs used in the CIMS model. Important sources for these data include the Canadian Clean Power Coalition, the U.S. Interagency Task Force, the Integrated CO_2 Network, the Alberta Electric System Operator and the Intergovernmental Panel on Climate

Change. The refinements to the CO_2 transport cost data are not shown in Table 1 for data confidentiality reasons.

Table 1: Summary of publicly available cost estimates for select industrial GHG reduction projects

Type of project	Plant Size	Avoided Emissions (Mt/year)	Investment (million $)	Annual Operating Costs (excluding energy)	$/t Avoided
Electricity Generation					
Supercritical Coal with CCS	580 MW	2.2	4,181	87	101
Natural Gas Combined Cycle with CCS	450 MW	0.5	1,268	25	132
Oil Sands					
Upgrading with CCS (steam methane reforming)					125
Upgrading with CCS (coal gasification reforming)					74
High efficiency gas cogeneration	85MWe		141[a]		
CCS for cogeneration					150-230
Natural Gas Extraction					
CCS for formation CO_2					15[b]
CCS for process heat and cogeneration					150-230
Transport					
CO_2 transport and storage					3-30[c]

Notes: All costs presented in this report are in 2005 Canadian dollars. These costs represent first-of-a-kind costs and are likely to come down in the future if more experience is gained with these technologies. Data presented here are based on a variety of sources, many of which are summarized in the following publication, which was prepared for Carbon Management Canada: Energy and Materials Research Group (EMRG), Simon Fraser University. 2012. *The effect of climate policy uncertainty on adoption of carbon capture and storage in Alberta for post-combustion electric, and post- and pre-combustion industrial applications*.

[a] Industry is already implementing cogeneration in the absence of GHG reduction policy, in order to reduce fuel costs. This cogeneration archetype is drawn from the Alberta Electric System Operator's 2012 Long-term Energy Plan. Operating costs are similar to those of a conventional combined cycle gas turbine. However, cogeneration costs will vary substantially depending on factors such as capacity, fuel, and heat to power ratio. Our technology dataset in CIMS includes over a dozen technology archetypes for cogeneration in the oil sands. We estimate that investment costs per installed kW could decrease by up to half for very large cogeneration plants (in the range of several hundred MW).

[b] Much data on the cost of formation CO_2 capture and storage is confidential. The cost presented here represents the cost of re-injection of CO_2 at the Sleipner field in Norway (MIT. 2012. *Sleipner Fact Sheet: Carbon Dioxide Capture and Storage Project*. http://sequestration.mit.edu/tools/projects/sleipner.html)

[c] Transport and storage costs vary substantially depending on distance, pipeline capacity and utilization, the market for CO_2 and other factors. This estimate was tightened for this analysis based on our interviews with industry.

4. Industrial Expenditures to Reduce GHG Emissions

We used the CIMS model to forecast the response of the electricity, oil and gas, petroleum refining and iron and steel sectors to national constraints on GHG emissions. The implementation of CCS was the primary activity undertaken by these industrial sectors to reduce their GHG emissions. We isolated each sector's incremental investment and operating expenditures on CCS, as well as the oil sands sector's incremental spending on cogeneration under each GHG emission reduction scenario. This information will then be used to estimate each sector's labour expenditures in each time period.

4.1 GHG Emissions

Table 2 summarizes GHG emissions for each sector of interest across all GHG reduction scenarios. In the Baseline scenario, emissions from the petroleum crude sector increase substantially - doubling between 2010 and 2030 - due to expansion of the oil sands. By contrast, emissions decrease in the electricity sector despite growing output because of existing electricity sector policies, particularly Ontario's coal phase out. Meanwhile, emissions stay relatively constant in the natural gas sector. Although output declines in many regions, GHG-intensive shale gas extraction increases. Note that only existing provincial and federal regulations are included in the Baseline scenario; the proposed federal regulations are not included.

In both the Half Target and Target scenarios, emissions are reduced substantially across all sectors. We assume that oil production stays constant at forecast levels, and does not decline in response to the Canadian GHG reduction scenarios, due to international demand for oil.

Table 2: GHG emissions by sector, 2010-2030

	2010	2015	2020	2025	2030
Baseline Scenario					
Total Canada	692	712	749	772	800
Alberta Crude Sector	63	86	107	124	138
Natural Gas Extraction	53	52	53	54	53
Utility Electricity	98	83	79	77	77
Petroleum Refining	21	21	22	22	23
Iron and Steel	10	12	13	13	13
Half Target Scenario					
Total Canada	692	677	669	650	631
Alberta Crude Sector	62	84	97	103	104
Natural Gas Extraction	53	51	43	40	37
Utility Electricity	98	82	70	61	52
Petroleum Refining	21	21	20	18	18
Iron and Steel	10	12	12	11	11
Target Scenario					
Total Canada	692	654	591	526	468
Alberta Crude Sector	62	81	73	62	54
Natural Gas Extraction	53	49	39	36	32
Utility Electricity	98	76	55	44	36
Petroleum Refining	21	20	17	13	11
Iron and Steel	10	12	10	8	6

Source: Navius analysis. Historic emissions may not align with National Inventory Report due to differences in sector categories.

4.2 Investment and Operating Expenditures

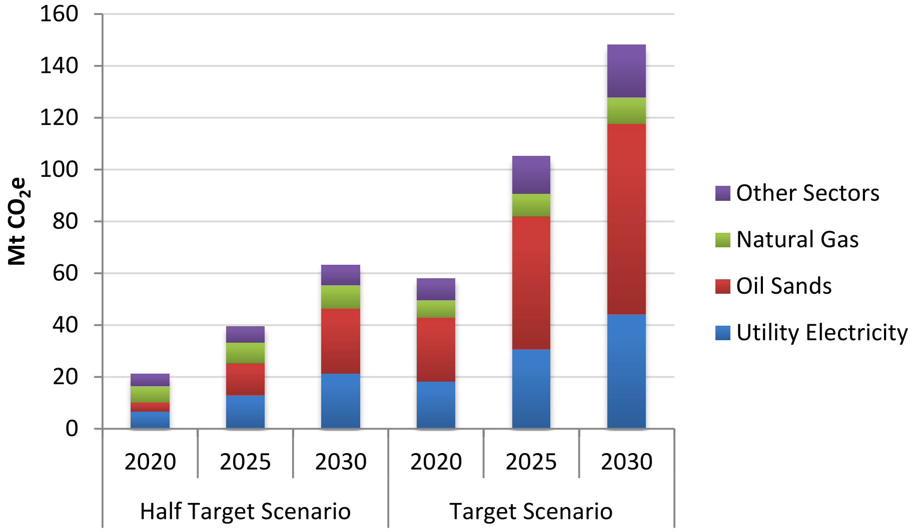
A variety of actions could contribute to emissions abatement in Canada, including switching to less emissions-intensive fuels, improving energy efficiency, and implementing CCS. This analysis focused on investment in the implementation of CCS in the electricity and oil sands sectors, as well as co-generation of heat and power in the oil sands. The petroleum refining and iron and steel sectors' approaches to reducing GHG emissions were also examined, and CCS implementation was found to be the primary GHG reduction activity.

Carbon capture and storage

Our analysis shows that CCS could contribute to substantial emissions abatement in Canada. Figure 2 shows the abatement from CCS in each scenario in electricity generation, oil sands, natural gas and other applications. This abatement totals anywhere from about one quarter to over 40% of total national emissions abatement.

The majority of CCS-related abatement occurs in the electricity and oil sands sectors, but small amounts also occur in other sectors, including petroleum refining and iron and steel. CCS represents the petroleum refining sector's greatest opportunity to reduce emissions, and capturing CO_2 emitted during the production of hydrogen represents a low cost opportunity to develop carbon capture technology. Virtually all the emissions reductions in the iron and steel sector result from the adoption of CCS.

Figure 2: Emissions abatement from carbon capture and storage (relative to the Baseline scenario)



The development of CCS requires substantial investment and operational expenditures. Table 3 reports the increase in annual expenditures on CCS over the periods 2016-2020, 2021-2025, and 2026-2030, compared to the Baseline scenario. In the Target Scenario, investment in CCS ranges between approximately \$1 and \$2 billion annually in the electricity and oil sands sectors. CCS investment in the natural gas, petroleum refining, and iron and steel sectors is lower, ranging from approximately \$100 million to \$400 million annually over the study period. This investment occurs despite demand for refined petroleum products falling by up to 25% in 2030, likely due to factors such as dramatically increased energy efficiency in the transportation sector and development of substitutes for petroleum products, such as biofuels or electric batteries.

For comparison, annual investment in the electricity and oil and gas extraction sectors averaged \$13.7 and \$42.2 billion respectively over the past decade.[1] Our investment data for the petroleum refining and iron and steel sectors are confidential, but publicly available investment figures for petroleum and coal products manufacturing and primary metal manufacturing are \$2.3 billion and \$1.7 billion respectively. As these are broader sector categories, they likely overestimate total investment in our sectors of interest.

---

[1] Statistics Canada. 2012. Table 031-0002 - Flows and stocks of fixed non-residential capital, by North American Industry Classification System (NAICS) and asset, Canada, provinces and territories, annual (dollars). CANSIM database.

Table 3: Increase in annual CCS-related expenditures, relative to Baseline scenario (2005$ million)

	Half Target Scenario			Target Scenario		
	2016-2020	**2021-2025**	**2026-2030**	**2016-2020**	**2021-2025**	**2026-2030**
Electricity Generation						
Investment	615	575	727	1,560	1,407	1,918
Operating and maintenance	78	161	267	204	373	574
Oil Sands						
Investment	292	642	852	2,051	1,804	1,450
Operating and maintenance	32	115	238	231	490	701
Natural Gas Extraction						
Investment	227	84	71	288	120	80
Operating and maintenance	107	129	149	113	142	164
Petroleum Refining						
Investment	179	40	43	328	167	117
Operating and maintenance	13	16	19	26	45	56
Iron and Steel						
Investment	179	39	42	407	114	106
Operating and maintenance	22	25	29	47	64	80

Additionally, investment in the electricity sector is likely to increase in any scenario that achieves substantial emissions reductions due to electrification of energy end uses and greater electricity sector output. This investment is not included in this analysis, but could conceivably double investment requirements in the sector over this time period (see the box on the following page).[2]

---

[2] Navius Research. 2012. *Investment and Lock-In Analysis for Canada*. Report prepared for the National Round Table on the Environment and the Economy.

Investment in electricity generation

This analysis focuses on the incremental labour requirements associated with investment in CCS in several sectors, including the electricity generation sector. However, overall electricity sector growth is likely to boost demand for jobs even further:

- Demand for electricity is expected to rise substantially over the next two decades. In 2010, total electricity generation in Canada was 579 TWh according to Natural Resources Canada. By 2030, we expect utility electricity generation to increase to 730 TWh in the Baseline scenario. Additional growth is also expected in the cogeneration of heat and power by industry. Meeting this demand for electricity will require substantial investment in Canada's electric generation capacity and transmission and distribution system, with a corresponding increase in the demand for labour.
- Electricity demand grows even more quickly in the Half Target and Target scenarios. Electrification - switching from fossil fuels to electricity generated from low emissions-intensive sources across the economy - is an important strategy for reducing Canada's emissions. By 2030, utility electricity generation reaches 820 and 930 TWh in the Half Target and Target scenarios in 2030, respectively (an increase of 12 and 27% beyond the Baseline scenario).

Cogeneration in the oil sands

Cogeneration is the simultaneous generation of electricity and useful thermal energy, and is well suited for the oil sands sector because of the large amounts of heat and steam required for bitumen extraction and upgrading. Cogeneration is also suitable for a range of other industrial applications, and can also be used in commercial and institutional buildings.

A substantial amount of cogeneration is likely to be developed in the absence of climate policy, as firms in the oil sands attempt to minimize their energy costs. While anticipating the amount of cogeneration to be installed is uncertain, our projections are consistent with those of the Alberta Electricity System Operator. By 2030 in the Baseline scenario, we anticipate an installed capacity of over 6,100 MW in the oil sands, representing almost a doubling relative to current levels.

Our analysis reveals some interesting dynamics about the potential adoption of cogeneration to reduce emissions. Within the 2030 timeframe, efforts to reduce emissions could actually reduce investment in cogeneration because switching to more energy efficient (and less emissions intensive) processes may reduce demand for steam and power. In the Half Target scenario, we therefore see a reduction in investment in cogeneration before 2030, compared to the Baseline scenario (Table 4).

In the longer term, and especially if more dramatic efforts are made to reduce emissions, adoption of cogeneration is likely to increase beyond that of the Baseline scenario. Most of this adoption occurs after 2030 in our forecasts, but some occurs in the 2020s in the Target Scenario.

Table 4: Increase in oil sands cogeneration expenditures, relative to Baseline scenario (2005$ million)

	Half Target Scenario			Target Scenario		
	2016-2020	**2021-2025**	**2026-2030**	**2016-2020**	**2021-2025**	**2026-2030**
Investment	-163	-62	-37	-31	85	51
Operating and maintenance	-27	-23	-5	25	100	166

Why do firms choose cogeneration?

CHP (combined heat and power) is often economically attractive and reduces the environmental impact of separate heat and power generation. However, it remains difficult to accurately forecast the amount of cogeneration that industry will install. The choice to use CHP is impacted by many factors that go beyond capital and operating costs. Some of these factors relate to:

- The financial risk and longer payback periods associated with CHP rather than heat-only generation.
- The relationship between generator and host.
- Security of electricity supply.
- Expectations about energy price volatility.
- Ease of interconnection with the electricity grid
- Electricity rate structure.

5.Labour and HQP Implications

The previous section presented estimates of incremental industrial expenditures on CCS and cogeneration in response to Canadian GHG reduction scenarios. Input-output tables and income statistics were then used to identify the labour component of these expenditures, and the number of full-time equivalent (FTE) positions that this labour spending equates to. Interviews with industry were used to determine the proportion of this labour demand that would be HQP, and the types of labour that would be required.

5.1 Additional Labour Demand under GHG Reduction Scenarios

In order to identify the additional labour demand associated with industrial investment in CCS and cogeneration, labour multipliers and average annual income statistics were identified from the input-output tables in Statistics Canada's System of National Accounts. The "oil and gas engineering construction" sector was used as a proxy for investments in CCS and cogeneration, because many of the types of activities involved in constructing this infrastructure are similar to those that occur in the oil and gas sector. Likewise, "support activities for mining and oil and gas extraction" was used as a proxy for estimating operating requirements associated with CCS and cogeneration.

Table 5 shows the estimated share of expenditures on labour, as well as the average annual income for each of these sectors in our base modeling year (2005). These data show that over one quarter of investment expenditures and about half of operating expenditures on CCS and cogeneration are likely to be spent on labour. During the industry interviews, two firms provided estimated labour shares of investment expenditures and two firms provided estimates for operating expenditures. The operating expenditures labour share estimates were very similar to the Statistics Canada figures, while the investment expenditures labour share estimates were substantially higher, ranging from 30% to nearly 50%. However, these estimates were not for electricity or oil and gas extraction applications, where the vast majority of CCS investment will occur, and so are not believed to be representative.

Table 5: Direct labour requirements in 2005

Type of Expenditure	Corresponding Input-Output Sector Category	% of Inputs Spent on Labour[a]	Average Annual Income ($2005)
Investment in CCS and cogeneration	Oil and gas engineering construction	27%	$61,339
Operating costs of CCS and cogeneration	Support activities for mining and oil and gas extraction	52%	$78,898

Source: Statistics Canada, *Table 381-0019 - Historical inputs and outputs, by industry and commodity, S-level aggregation and North American Industry Classification System (NAICS), annual*; Statistics Canada, *Table 383-0010 - Labour statistics by business sector industry and non-commercial activity, consistent with the System of National Accounts, by North American Industry Classification System (NAICS), annual.*

[a] Excluding taxes and energy costs.

To estimate annual labour expenditures associated with industrial GHG mitigation efforts, the Statistics Canada labour multipliers in Table 5 were applied to each sector's average annual investment and operating expenditures on CCS and cogeneration in each five-year modeling period (as reported in Table 3). The average annual incremental labour expenditures were then divided by the average annual income statistics in Table 5 to estimate the additional person-years of labour required in each year, compared to the Baseline scenario.

How to interpret the labour and HQP demand estimates

The labour demand estimation methodology produced an estimate of the number of additional **person-years** of labour that would be required each year, compared to the Baseline scenario. However, for ease of interpretation we report our forecasted labour demand in **full-time equivalent** (FTE) positions, rather than person-years of labour demand.

The FTE labour demand identifies the total number of additional full-time employees that would be required if industry was subject to GHG constraints, relative to business-as-usual labour demand. It is measured at a single point in time, rather than over a period of time. We provide detailed FTE labour demand estimates for 2020, 2025, and 2030, as these are the final years of our five-year modeling periods.

In practice, not all of the additional labour demand associated with industrial GHG reduction activities will be for permanent full-time employees. Since some of the labour demand will be for part-time and/or temporary positions, the number of individual workers required at any point in time will exceed the FTE labour demand.

Table 6 presents the total number of additional full time equivalent (FTE) positions required in 2020, 2025, and 2030 under each GHG reduction scenario, compared to the Baseline scenario. Our analysis shows that the potential labour implications of industrial GHG mitigation are significant, particularly in the electricity generation and oil and gas extraction sectors. By 2030, we estimate that the equivalent of 11,926 additional full-time positions will be required in the Half Target scenario, and the equivalent of 27,537 additional full-time positions will be required in the Target scenario, compared to business as usual. However, we wish to emphasise that this is a partial equilibrium estimate, and our analysis did not adjust wages to balance the supply and demand for labour or identify if labour demand elsewhere in the sector or the economy is displaced by industrial GHG reduction efforts.

Table 6: Total additional full-time equivalent (FTE) positions required (relative to Baseline scenario)

	Half Target Scenario			Target Scenario		
	2020	**2025**	**2030**	**2020**	**2025**	**2030**
CCS						
Electricity Generation						
Investment	2,668	2,494	3,153	6,767	6,103	8,320
Operating and maintenance	510	1,054	1,747	1,335	2,441	3,756
Total	*3,178*	*3,548*	*4,901*	*8,102*	*8,544*	*12,076*
Oil Sands						
Investment	1,267	2,785	3,696	8,896	7,825	6,290
Operating and maintenance	209	753	1,557	1,512	3,206	4,587
Total	*1,476*	*3,537*	*5,253*	*10,408*	*11,031*	*10,877*
Natural Gas Extraction						
Investment	985	364	308	1,249	521	347
Operating and maintenance	700	844	975	739	929	1,073
Total	*1,685*	*1,208*	*1,283*	*1,989*	*1,450*	*1,420*
Petroleum Refining						
Investment	776	174	187	1,423	724	508
Operating and maintenance	85	105	124	170	294	366
Total	*861*	*278*	*311*	*1,593*	*1,019*	*874*
Iron and Steel						
Investment	776	169	182	1,765	494	460
Operating and maintenance	144	164	190	308	419	523
Total	*920*	*333*	*372*	*2,073*	*913*	*983*
Total: CCS	***8,121***	***8,904***	***12,119***	***24,164***	***22,957***	***26,229***
Cogeneration in the Oil Sands						
Investment	-707	-269	-160	-134	369	221
Operating and maintenance	-177	-151	-33	164	654	1,086
Total	*-884*	*-419*	*-193*	*29*	*1,023*	*1,307*
Total: Cogeneration in the oil sands	***-884***	***-419***	***-193***	***29***	***1,023***	***1,307***
TOTAL Additional FTE Positions	**7,237**	**8,485**	**11,926**	**24,193**	**23,980**	**27,537**

The demand for labour is expected to grow over time in the Baseline scenario as well, due to increasing production of oil and electricity. The Petroleum Human Resources Council of Canada expects 16,000 new jobs to be created in the oil sands alone by 2022 – an increase of 71% from 2012 levels[3]. The labour demand estimates in Table 6 are driven by new Canadian GHG constraints, and are in addition to these business as usual labour demands. The four firms that provided labour information for this study all reported that their CCS-related labour

---

[3] Petroleum Human Resources Council of Canada. 2013. *The Decade Ahead: Oil Sands Labour Demand Outlook to 2022.*

requirements had not previously been reported on other sector council human resources surveys, and so they are not included in existing labour demand forecasts.

5.2 HQP Portion of Additional Labour Demand

HQP are necessary for all phases of GHG reduction projects, including planning, design, construction, operation and decommissioning. Feedback from industry was used to estimate the HQP share of total GHG mitigation-related labour demand. Four firms agreed to participate in this study and provided varying amounts of information about their labour requirements during the investment and operating phases of their projects. The four participating firms were engaged in electricity production, oil sands, and petroleum refining sector CCS applications, as well as CO_2 transportation. Unfortunately, no firms involved in co-generation in the oil sands participated in the study. Due to the relatively small number of firms involved in CCS in Canada, the information provided by industry is reported in aggregate throughout this section to maintain data confidentiality.

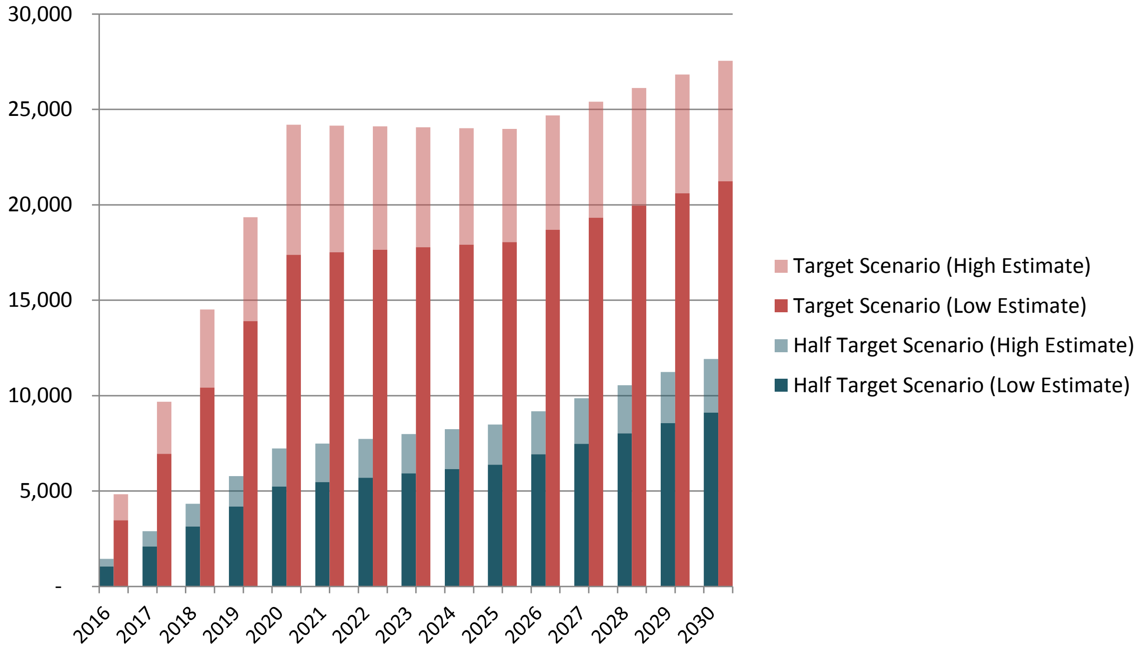
Table 7 reports the estimates provided by industry for the HQP and HQSP share of total labour demand. These share estimates are then applied to the total labour demand estimates to calculate low-end and high-end estimates of the potential demand for HQP in each sector and time period. Since no firms engaged in co-generation in the oil sands participated in the study, the ranges reported for CCS are also used for co-generation, so the results should be considered a very rough estimate of HQP demand related to industrial co-generation in the oil sands. Additional feedback from industry on the estimated HQP share of their CCS and co-generation-related labour demand would allow the range of estimated HQP demand to be tightened.

Table 7: Industry estimates of HQP share of labour demand

HQP/HQSP Share of Labour Demand	Investment Phase	Operating Phase
Firm 1	75%	n/a
Firm 2	100%	100%
Firm 3	68%	90%
Firm 4	n/a	n/a
Range	**68% - 100%**	**90% - 100%**

Figure 3 shows the forecasted additional demand for HQP under each Canadian GHG reduction scenario, relative to the Baseline scenario. In 2030, an estimated 9,113 to 11,926 additional FTE HQP positions will be required in the Half Target scenario, and an estimated 21,231 to 27,537 FTE positions will be required in the Target scenario.

Figure 3: Total additional full-time equivalent HQP positions required (relative to Baseline scenario)



Between 2016 and 2030, demand for HQP increases by an average of 795 FTE positions per year in the Half Target scenario and 1,836 FTE positions per year in the Target scenario, relative to the Baseline scenario. However, the rate of change in HQP demand actually varies substantially over this period; industry's demand for HQP rises rapidly between 2016 and 2020, as GHG constraints induce substantial investment in CCS, including the retrofit of existing facilities. Between 2021 and 2025, demand for HQP remains fairly steady as industry's remaining retrofit opportunities decline and annual GHG-mitigation expenditures level off. From 2026 to 2030, industry's demand for HQP starts to rise again as industry pursues higher-cost CCS opportunities.

Table 8 and Table 9 provide a detailed breakdown of the forecasted low-end and high-end labour demand in 2020, 2025 and 2030.

Table 8: Low-end estimate: total additional full-time equivalent HQP positions required (relative to Baseline scenario)

	Half Target Scenario			Target Scenario		
	2020	**2025**	**2030**	**2020**	**2025**	**2030**
CCS						
Electricity Generation						
Investment	1,814	1,696	2,144	4,601	4,150	5,657
Operating and maintenance	459	948	1,572	1,201	2,197	3,380
Total	*2,273*	*2,644*	*3,717*	*5,803*	*6,347*	*9,038*
Oil Sands						
Investment	861	1,894	2,513	6,050	5,321	4,277
Operating and maintenance	188	677	1,402	1,360	2,886	4,128
Total	*1,050*	*2,571*	*3,915*	*7,410*	*8,207*	*8,405*
Natural Gas Extraction						
Investment	670	248	209	849	354	236
Operating and maintenance	630	760	877	665	836	966
Total	*1,300*	*1,007*	*1,087*	*1,515*	*1,190*	*1,202*
Petroleum Refining						
Investment	528	118	127	967	493	345
Operating and maintenance	77	94	112	153	265	330
Total	*605*	*212*	*239*	*1,121*	*758*	*675*
Iron and Steel						
Investment	528	115	124	1,200	336	313
Operating and maintenance	130	147	171	277	377	471
Total	*658*	*262*	*295*	*1,477*	*713*	*784*
Total: CCS	***5,885***	***6,697***	***9,252***	***17,326***	***17,214***	***20,103***
Cogeneration in the Oil Sands						
Investment	-481	-183	-109	-91	251	150
Operating and maintenance	-159	-135	-29	147	589	978
Total	*-640*	*-318*	*-139*	*56*	*840*	*1,128*
Total: Cogeneration in the oil sands	***-640***	***-318***	***-139***	***56***	***840***	***1,128***
TOTAL Additional HQP Positions	**5,245**	**6,379**	**9,113**	**17,381**	**18,054**	**21,231**

Table 9: High-end estimate: total additional full-time equivalent HQP positions required (relative to Baseline scenario)

	Half Target Scenario			**Target Scenario**		
	2020	**2025**	**2030**	**2020**	**2025**	**2030**
CCS						
Electricity Generation						
Investment	2,668	2,494	3,153	6,767	6,103	8,320
Operating and maintenance	510	1,054	1,747	1,335	2,441	3,756
Total	*3,178*	*3,548*	*4,901*	*8,102*	*8,544*	*12,076*
Oil Sands						
Investment	1,267	2,785	3,696	8,896	7,825	6,290
Operating and maintenance	209	753	1,557	1,512	3,206	4,587
Total	*1,476*	*3,537*	*5,253*	*10,408*	*11,031*	*10,877*
Natural Gas Extraction						
Investment	985	364	308	1,249	521	347
Operating and maintenance	700	844	975	739	929	1,073
Total	*1,685*	*1,208*	*1,283*	*1,989*	*1,450*	*1,420*
Petroleum Refining						
Investment	776	174	187	1,423	724	508
Operating and maintenance	85	105	124	170	294	366
Total	*861*	*278*	*311*	*1,593*	*1,019*	*874*
Iron and Steel						
Investment	776	169	182	1,765	494	460
Operating and maintenance	144	164	190	308	419	523
Total	*920*	*333*	*372*	*2,073*	*913*	*983*
Total: CCS	***8,121***	***8,904***	***12,119***	***24,164***	***22,957***	***26,229***
Cogeneration in the Oil Sands						
Investment	-707	-269	-160	-134	369	221
Operating and maintenance	-177	-151	-33	164	654	1,086
Total	*-884*	*-419*	*-193*	*29*	*1,023*	*1,307*
Total: Cogeneration in the oil sands	***-884***	***-419***	***-193***	***29***	***1,023***	***1,307***
TOTAL Additional HQP Positions	**7,237**	**8,485**	**11,926**	**24,193**	**23,980**	**27,537**

As shown in Table 10, every $1 million of industrial investment in CCS and co-generation produces between 3.0 and 4.4 person-years of HQP demand on average, and every $1 million of operations and maintenance spending produces an average of 5.9 to 6.6 person-years of HQP demand. According to the firms interviewed, 90-100% of investment phase and 100% of operations spending on labour will occur in Canada.

Table 10 Average person-years of HQP demand per million dollars of expenditures

Type of Expenditure	**Person-years of HQP demand per million dollars of expenditures**
Investment	3.0 – 4.4
Operations and Maintenance	5.9 – 6.6

Excluding energy expenditures and taxes.

5.3 HQP Characteristics

The firms interviewed for this project also provided additional detail and perspectives about their anticipated HQP needs, which provide insight into the type of HQP that will be required if Canada makes a concerted effort to reduce GHG emissions.

HQP VERSUS HQSP

Industry was asked about their need for HQP versus HQSP within their reported labour demand estimates. There was substantial variation in the responses (as seen in Table 11), but the need for HQSP was clearly greater than that for HQP, particularly during the investment (construction) phase of a project.

Table 11: Industry estimates of HQP versus HQSP share of skilled labour demand

Type of Expenditure	Investment Phase		Operating Phase	
	HQP	HQSP	HQP	HQSP
Firm 1	38%	62%	n/a	n/a
Firm 2	~8%	~92%	6%	94%
Firm 3	26%	74%	45%	55%
Firm 4	n/a	n/a	n/a	n/a
Range	**8% - 38%**	**74% - 92%**	**6% - 45%**	**55% - 94%**

SOURCE OF LABOUR

When industry was asked how they expected to meet their HQP needs, firms generally responded that for the investment phase (construction), they would hire experienced trades and engineering personnel from the oil and gas and construction sectors. Both union and non-union labour would be used, with needs met from in-province personnel to the extent possible, but resources brought in from other areas of Canada when required. Operating phase labour requirements will be met predominantly by redeploying existing staff.

REQUIRED SKILL SETS

The firms interviewed were in agreement that there was not really a need for specialized CCS-related skill sets. They emphasised that oil and gas and other processing businesses have dealt with capturing and transporting CO_2 for many years, and workers in those areas generally have the required experience and skills. There will be significant demand for engineering, trades, and construction skill sets, but CCS-specific skills are not required. The only area that was identified as requiring specialised skills was storage: assessing the suitability of potential storage sites and monitoring storage performance. This will require geologists, geophysicists and hydrogeologists who have an understanding of CO_2 subsurface characteristics. However, industry considered this to be well within the abilities of their existing subsurface teams.

While not CCS-specific, the following general skill sets were identified as important to CCS development:

- Construction trades
- Project managers
- Engineers and laboratory technicians
- Process operators
- Maintenance trades (Electricians, Instrument and Electronic Technicians, Mechanics)

The types of HQP and HQSP that are in the shortest supply and are the most difficult to find include:

- Engineering and construction management
- Welding and instrumentation
- Construction trades
- Process operators, especially with 2nd class or higher Power Engineering certificates

Most industries in Alberta and Saskatchewan are facing challenges finding sufficient skilled labour in these areas.

As more experience is gained with CCS technology, the type and quantity of labour needed is not expected to change significantly. The number of process operators required may eventually fall as CO_2 capture plants become better integrated into existing industrial facilities. Additionally, HQSP skills will have to evolve to address the continually expanding use of instrumentation.

6. Suggestions for Future Research

The objective of this study was to prepare a "quick but critical in-depth summary" of future HQP demand associated with industrial GHG emission reduction activities. The results provide an initial estimate of the range of HQP demand, and can be combined with CMC's analysis of HQP supply to identify potential future HQP and skill shortages.

In the future, CMC may choose to expand and refine this analysis. If so, the following suggestions for further research may be of interest:

- Analyse the indirect and induced labour demand associated with industrial GHG reduction investments.
- Analyse the sector-level impacts of national GHG reduction efforts and the implications for HQP demand (such as increasing demand for electricity due to electrification of other sectors, and decreasing demand for refined petroleum products due to efficiency improvements in transportation and other sectors).
- Conduct a regional analysis of the investment and HQP implications of industrial GHG reduction efforts.
- Conduct a full equilibrium analysis that includes wage feedbacks and balances the demand and supply for labour.
- Conduct a more detailed investigation of the impact of learning curves and economies of scale on labour requirements.
- Conduct another survey of industrial HQP requirements, but in partnership with an industry organisation or other group that can compel broader and deeper participation.

Appendix A: The CIMS Modelling Methodology

This analysis uses the CIMS energy-economy model to estimate the impacts of climate change policies in Canada. The CIMS model is a technologically explicit energy-economy model that captures equilibrium feedbacks for the supply and demand of energy and energy intensive goods and services. CIMS requires external inputs – forecasted demand for products, services and energy prices. These drivers determine the processes, technologies and energy required to meet demand, enabling CIMS to produce regional and sector emissions forecasts.

The CIMS model is well suited for this analysis because of its disaggregated sector structure and technologically explicit framework, which allow it to simulate both price policies (e.g. British Columbia's Carbon Tax) and technology regulation (e.g. the federal transport emissions intensity regulations). CIMS models all the major energy supply and demand sectors in the economy as well as the main processes within those sectors (where demand for each process is satisfied by current and emerging technologies). The model captures most emissions, energy consumption and energy production in the economy; thus, it is well positioned to provide a realistic forecast of abatement opportunities in Canada.[4]

CIMS has a detailed representation of technologies that produce goods and services throughout the economy and attempts to simulate capital stock turnover and choice between these technologies realistically. It also includes a representation of equilibrium feedbacks, such that supply and demand for energy intensive goods and services adjusts to reflect policy.

CIMS simulations reflect the energy, economic and physical output, GHG emissions, and CAC emissions from its sub-models as shown in Table 12. CIMS does not include adipic and nitric acid, solvents or hydrofluorocarbon (HFC) emissions. CIMS covers nearly all local air pollutant emissions except those from open sources (e.g., forest fires, soils, and road dust).

---

[4] This excludes non-vehicle energy consumption and emissions in the construction, forestry and aspects of the agriculture sector as well as energy commodities used as refinery or chemical feedstock.

Table 12: Sector Sub-models in CIMS

Sector	BC	Alberta	Sask.	Manitoba	Ontario	Québec	Atlantic
Residential	▨	▨	▨	▨	▨	▨	▨
Commercial/Institutional	▨	▨	▨	▨	▨	▨	▨
Personal Transportation	▨	▨	▨	▨	▨	▨	▨
Freight Transportation	▨	▨	▨	▨	▨	▨	▨
Industry							
Chemical Products	▨	▨			▨	▨	
Industrial Minerals	▨	▨			▨	▨	▨
Iron and Steel					▨	▨	
Non-Ferrous Metal Smelting*	▨			▨	▨	▨	▨
Metals and Mineral Mining	▨		▨	▨	▨	▨	▨
Other Manufacturing	▨	▨	▨	▨	▨	▨	▨
Pulp and Paper	▨	▨			▨	▨	▨
Energy Supply							
Coal Mining	▨	▨	▨				▨
Electricity Generation	▨	▨	▨	▨	▨	▨	▨
Natural Gas Extraction	▨	▨	▨	▨	▨	▨	▨
Petroleum Crude Extraction	▨	▨	▨		▨		▨
Petroleum Refining	▨	▨	▨		▨	▨	▨
Agriculture & Waste	▨	▨	▨	▨	▨	▨	▨

* Metal smelting includes Aluminium.

Model structure and simulation of capital stock turnover

As a technology vintage model, CIMS tracks the evolution of capital stocks over time through retirements, retrofits, and new purchases, in which consumers and businesses make sequential acquisitions with limited foresight about the future. This is particularly important for understanding the implications of alternative time paths for emissions reductions. The model calculates energy costs (and emissions) for each energy service in the economy, such as heated commercial floor space or person kilometres travelled. In each time period, capital stocks are retired according to an age-dependent function (although retrofit of un-retired stocks is possible if warranted by changing economic conditions), and demand for new stocks grows or declines depending on the initial exogenous forecast of economic output, and then the subsequent interplay of energy supply-demand with the macroeconomic module. A model simulation iterates between energy supply-demand and the macroeconomic module until energy price changes fall below a threshold value, and repeats this convergence procedure in each subsequent five-year period of a complete run.

CIMS simulates the competition of technologies at each energy service node in the economy based on a comparison of their life cycle cost (LCC) and some technology-specific controls, such as a maximum market share limit in the cases where a technology is constrained by physical, technical or regulatory means from capturing all of a market. Instead of basing its simulation of technology choices only on financial costs and social discount rates, CIMS applies a definition of

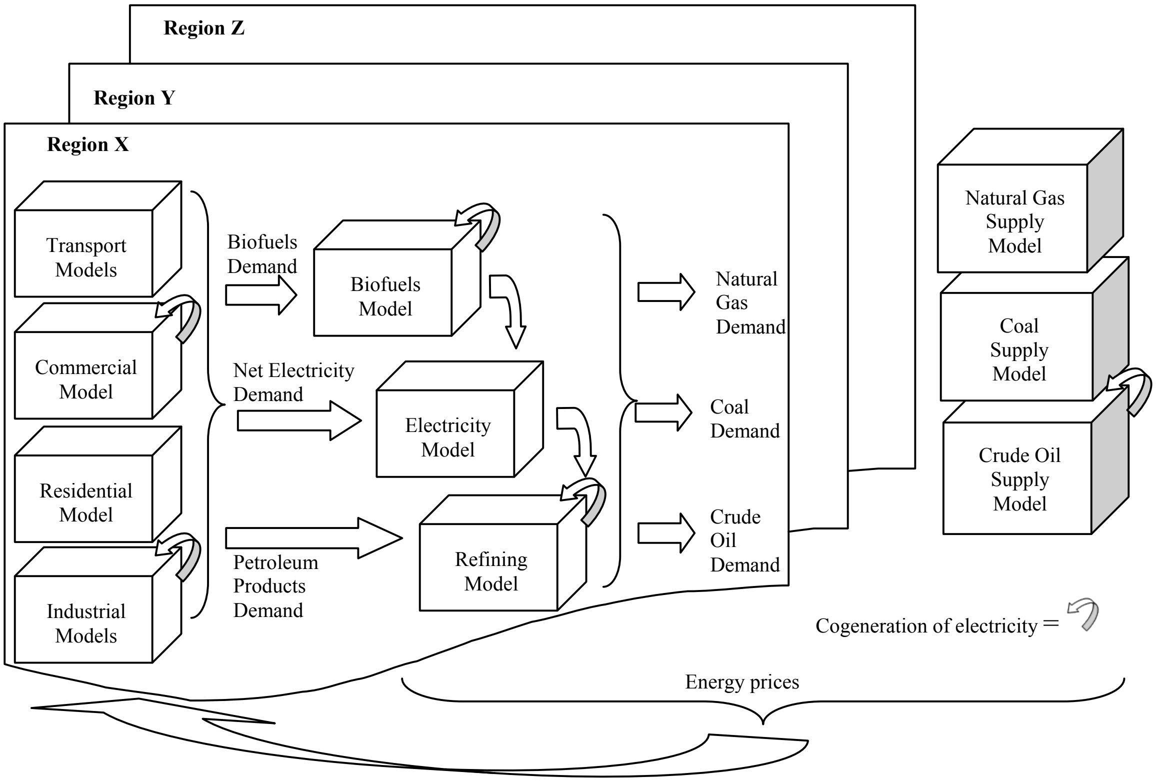
LCC that differs from that of bottom-up analysis by including intangible costs that reflect consumer and business preferences and the implicit discount rates revealed by real-world technology acquisition behaviour.

Equilibrium feedbacks in CIMS

CIMS is an integrated, energy-economy equilibrium model that simulates the interaction of energy supply-demand and the macroeconomic performance of key sectors of the economy, including trade effects. Unlike most computable general equilibrium models, however, the current version of CIMS does not equilibrate government budgets and the markets for employment and investment. Also, its representation of the economy's inputs and outputs is skewed toward energy supply, energy intensive industries, and key energy end-uses in the residential, commercial/institutional and transportation sectors.

CIMS estimates the effect of a policy by comparing a business-as-usual forecast to one where the policy is added to the simulation. The model solves for the policy effect in two phases in each run period. In the first phase, an energy policy (e.g., ranging from a national emissions price to a technology specific constraint or subsidy, or some combination thereof) is first applied to the final goods and services production side of the economy, where goods and services producers and consumers choose capital stocks based on CIMS' technological choice functions. Based on this initial run, the model then calculates the demand for electricity, refined petroleum products and primary energy commodities, and calculates their cost of production. If the price of any of these commodities has changed by a threshold amount from the business-as-usual case, then supply and demand are considered to be out of equilibrium, and the model is re-run based on prices calculated from the new costs of production. The model will re-run until a new equilibrium set of energy prices and demands is reached. Figure 4 provides a schematic of this process. For this project, while the quantities produced of all energy commodities were set endogenously using demand and supply balancing, endogenous pricing was used only for electricity and refined petroleum products; natural gas, crude oil and coal prices remained at exogenously forecast levels, since Canada is assumed to be a price-taker for these fuels.

Figure 4: CIMS energy supply and demand flow model



In the second phase, once a new set of energy prices and demands under policy has been found, the model measures how the cost of producing traded goods and services has changed given the new energy prices and other effects of the policy. For internationally traded goods, such as lumber and passenger vehicles, CIMS adjusts demand using price elasticities that provide a long-run demand response that blends domestic and international demand for these goods (the "Armington" specification).[5] Freight transportation is driven by changes in the combined value added of the industrial sectors, while personal transportation is adjusted using a personal kilometres-travelled elasticity (-0.02). Residential and commercial floor space is adjusted by a sequential substitution of home energy consumption vs. other goods (0.5), consumption vs. savings (1.29) and goods vs. leisure (0.82). If demand for any good or service has shifted more than a threshold amount, supply and demand are considered to be out of balance and the model re-runs using these new demands. The model continues re-running until both energy and goods and services supply and demand come into balance, and repeats this balancing procedure in each subsequent five-year period of a complete run.

---

[5] CIMS' Armington elasticities are econometrically estimated from 1960-1990 data. If price changes fall outside of these historic ranges, the elasticities offer less certainty.

Empirical basis of parameter values

Technical and market literature provide the conventional bottom-up data on the costs and energy efficiency of new technologies. Because there are few detailed surveys of the annual energy consumption of the individual capital stocks tracked by the model (especially smaller units), these must be estimated from surveys at different levels of technological detail and by calibrating the model's simulated energy consumption to real-world aggregate data for a base year.

Fuel-based GHGs emissions are calculated directly from CIMS' estimates of fuel consumption and the GHG coefficient of the fuel type. Process-based GHGs emissions are estimated based on technological performance or chemical stoichiometric proportions. CIMS tracks the emissions of all types of GHGs, and reports these emissions in terms of carbon dioxide equivalents.[6]

Both process-based and fuel-based CAC emissions are estimated in CIMS. Emissions factors come from the US Environmental Protection Agency's FIRE 6.23 and AP-42 databases, the MOBIL 6 database, calculations based on Canada's National Pollutant Release Inventory, emissions data from Transport Canada, and the California Air Resources Board.

Estimation of behavioural parameters is through a combination of literature review and judgment, supplemented with the use of discrete choice surveys for estimating models whose parameters can be transposed into CIMS behavioural parameters.

Simulating endogenous technological change with CIMS

CIMS includes two functions for simulating endogenous change in individual technologies' characteristics in response to policy: a declining capital cost function and a declining intangible cost function. The declining capital cost function links a technology's financial cost in future periods to its cumulative production, reflecting economies-of-learning and scale (e.g., the observed decline in the cost of wind turbines as their global cumulative production has risen). The declining capital cost function is composed of two additive components: one that captures Canadian cumulative production and one that captures global cumulative production. The declining intangible cost function links the intangible costs of a technology in a given period with its market share in the previous period, reflecting improved availability of information and decreased perceptions of risk as new technologies become increasingly integrated into the wider economy (e.g., the "champion effect" in markets for new technologies); if a popular and well respected community member adopts a new technology, the rest of the community becomes more likely to adopt the technology.

---

[6] CIMS uses the 2001 100-year global warming potential estimates from Intergovernmental Panel on Climate Change, 2001, "Climate Change 2001: The Scientific Basis", Cambridge, UK, Cambridge University Press.

To sum up, the main advantages of CIMS are:

- **CIMS accounts for non-linearities in emissions abatement.** Many models simulate abatement using elasticities of substitution or linear functions that represent how firms can change their inputs while maintaining a given level of production. For example, computable general equilibrium models use elasticities to show how firms may switch from refined petroleum products to electricity, or how they can increase capital consumption to reduce energy consumption. The result is that the abatement from these models is relatively linear as a function of an emissions price. Rather than using elasticities or linear functions to represent abatement, CIMS simulates a competition between technologies (e.g., an oil furnace vs. a ground source heat pump) that provide the same service (i.e., space heating). The result is that some abatement technologies may be uncompetitive until an emissions price reaches a specific threshold (e.g., plug-in electric vehicles), at which point the sector undertakes a significant amount of abatement.
- **CIMS is technologically detailed.** Every sector requires several services and processes to function. For example, natural gas extraction requires a combination of drilling, extraction, and processing services to produce natural gas. For each service and process required, CIMS allows a suite of technologies to compete to fulfil the particular service or process needs of the sector. For example, low efficiency diesel, high efficiency diesel and biodiesel trucks may compete to provide freight trucking services to the freight transportation sector. CIMS represents each of the major processes/services and associated technologies, whereas the other modelling approaches represent the sector as a single production unit.
- **CIMS produces detailed policy impacts.** Because of the level of detail in the CIMS model it is possible to separate the impacts of policies on each sector. For example, CIMS describes the changes in energy intensity of space heating in the commercial sector (GJ / m2 floor space), or the changes in average vehicle fuel price (2005¢ / L gasoline eq.) that are produced when policies are implemented.

The limitations of CIMS are:

- **CIMS does not account for economic activity unrelated to energy consumption or greenhouse gas emissions.** The CIMS model accounts for the energy and emissions intensive portion of the economy, but does not account for other economic activity. For example, the CIMS model accounts for a household's costs related to energy consumption (e.g., light bulbs), but does not account for other household expenses. Therefore, CIMS does not estimate how a change in expenditures on energy or capital related to energy consumption might affect other household expenditures. However, supplemental analysis with our in-house general equilibrium model, GEEM, provides an estimate of policy impacts on these broader economic structures.
- **CIMS is not a general equilibrium model, and does not account for some markets likely to be affected by the implementation of climate policy.** The CIMS model also does not

> account for key markets such as capital or labour, and cannot simulate how increased capital expenditures to abate emissions might affect interest or wage rates. Additionally, while CIMS does balance supply and demand of key energy commodities, such as electricity and refined petroleum products, it does not ensure this balance for commodities such as iron or newsprint. The result of these omissions is that CIMS cannot be used to estimate a policy's impact on gross domestic product.

The CIMS model used in the study is also a Canada only model, and therefore not integrated with the United States. The CIMS model does not account for the integrated impacts of shifts in energy supply and demand between Canada and the United States. Moreover CIMS does not account for policy-induced market interactions (e.g., changing commodity prices) between the United States and Canada. For example, if the United States and Canada both adopted an equivalent carbon charge there would likely be market interaction affecting abatement costs and energy prices. However, the trade impacts of Canada's climate change policies in operation in 2010 are likely to be small.

CIMS References

Please see the Energy and Materials Research Group website at www.emrg.sfu.ca.

Jaccard, M. 2009 "Combining top down and bottom up in energy economy models." In *International Handbook on the Economics of Energy*. In. J. Evans & L.C. Hunt (Eds.). pp.311-331. Northampton, MA: Edward Elgar.

Bataille, C, Wolinetz, M, Peters, J, Bennett, M, Rivers, R. October 2009. "Exploration of two Canadian greenhouse gas emissions targets: 25% below 1990 and 20% below 2006 levels by 2020." Prepared for the David Suzuki Foundation and the Pembina Institute by MK Jaccard and Associates, Inc. Accessible at http://www.davidsuzuki.org/publications/reports/2009/exploration-of-two-canadian-greenhouse-gas-emissions-targets-25-below-1990-and-2/

Bataille, C., M. Jaccard, J. Nyboer, and N. Rivers. 2006. "Towards general equilibrium in a technology-rich model with empirically estimated behavioral parameters." *Energy Journal*, 27, Special Issue on Hybrid Modeling of Energy-Environment Policies: Reconciling Bottom-up and Top-Down: 93-112.

Jaccard, M., N. Nyboer, C. Bataille, and B. Sadownik. 2003. Modelling the cost of climate policy: Distinguishing between alternative cost definitions and long-run cost dynamics. The Energy Journal 21 (1): 49-73.