NAVIGANT

Forecasting and Measuring Outcomes of Mitigation Initiatives

Presented to

Newfoundland Labrador

Office of Climate Change, Energy Efficiency and Emissions Trading

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ACRONYMS AND ABBREVIATIONS

List of acronyms does not include model names.

BAU	Business-as-Usual
CAPP	Canadian Association of Petroleum Producers
CCEEET	Climate Change Energy Efficiency and Emissions Trading
CGA	Canadian Gas Association
CGE	Computerized General Equilibrium
CHP	Combined Heat and Power
CIPEC	Canadian Industry Program for Energy Conservation
CO2e	Carbon Dioxide Equivalent
DME	DiMethyl Ester
DOE	Department of Energy
ER	Energy Rating
ERS	EnerGuide Rating System
ETSAP	Energ Technology Systems Analysis Program (at IEA)
FGT	Flue Gas Temperature
FSAT	Fan System
FTD	Fischer-Tropsch Diesel
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GO	Gross Output
GWP	Global Warming Potential
HBCS	Housing, Buildings, Communities and Simulations (group at Canmet)
HHV	Higher Heating Value
HPDE	High Density Polyehtylene
HVAC	Heating Ventilation and Air Conditioning
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IMSSA	International Motor Selection and Savings Analysis
IPCC	International Panel on Climate Change
IRR	Internal Rate of Return
LBNL	Lawrence Berkely National Laboratory

LCA	Life Cycle Analysis
LDPE	Low Density Polyehylene
LEM	Life Cycle Emmissions model
LH2	Liquid Hydrogen (H2)
LHV	Lower Heating Value
LNG	Liquid Natural Gas
mBtu	millions of British Thermal Units
MeOH	Methanol
MEPS	Minimum Energy Performance Standard
MGGRA	Midwest Greenhouse Gas Reduction Accord
MNECB	Model National Energy Code for Buildings
MNECH	Model National Energy Code for Houses
Mt	megatonne
MTCE	megatonnes carbon equivalent
MTCO2E	megatonnes carbon dioxide equivalent
MWGA	Midwest Governors Association
NG	Natural Gas
NL	Newfoundland and Labrador
NLH	Newfoundland and Labrador Hydro
NMIM	National Mobile Emissons Model
NP	Newfoundland Power
NPV	Net Present Value
NRTEE	National Round Table on the Environment and the Economy
OEE	Office of Energy Efficiency
QCT	Qualitative Choice Theory
RFP	Request for Proposal
ROI	Return on Investment
R-value	Resistance value (resistance to heat flow)
SOC	Standard Operating Conditions
UNEP	United Nations Enviroment Program
US	United States
US MECS	US Manufacturers Energy Consumption Survey
VMT	Vehicle miles travelled
w.r.t.	with respect to

EXECUTIVE SUMMARY

The Government of Newfoundland and Labrador (NL) has made a commitment to reduce greenhouse gas emissions in the province. As it sets out policies to meet this commitment, the Province wishes to ensure that it has the means necessary to model the expected and actual outcomes of energy efficiency and climate change programs. The Office of Climate Change, Energy Efficiency, and Emissions Trading (CCEEET) retained Navigant to assist in identifying methodologies to forecast and measure the outcomes of initiatives to promote energy efficiency and/or reduce greenhouse gas (GHG) emissions.

The RFP for this project separated potential tools and methods into "micro" level tools that apply to a specific building or facility and "macro" models that can be used to assess or analyse energy and climate policies at the jurisdictional level. For the purposes of this study, Navigant has interpreted "micro" level to include the range of tools and methods that can be used to identify, quantify and analyse different types and sources of emissions. This would, for example include building simulations as well as tools to review the emissions from alternative forms of transportation or municipal waste practices or emissions from a landfill facility.

There are a variety of different types of "macro" tools and models available. Some address specific applications or particular sectors. These range from GHG inventory tools (US EPA State Inventory Tool) to screening tools that estimate the emission impacts of alternate energy policies to models which evaluate energy efficiency potential for a jurisdiction. A second class of tools are available to address specific technology types or energy supply sectors. For example there are a number of models specific to the electric sector, ranging from load forecasting to optimization models. Finally, there are multi-fuel, multi-sector energy and emission models that can model policy impacts across the economy. These models can be linked to macro-economic or Computable Generalized Equilibrium (CGE) models in order to estimate the economic effects of policy changes.

Micro-level tools are often used in conjunction with macro-level models, both as an input and to provide a more refined analysis. They may also be useful in analysing specific "types" of emissions. For example, some "macro" energy and emissions models have a detailed representation of energy use, but limited detail to represent emissions from waste, wastewater, or industrial process emissions. A micro level model may be used to provide a more detailed look at these emissions and serve as an input to the macro-level model.

Developing or refining an energy or GHG inventory was not part of the scope of this project, however, understanding how and where energy is used and GHG emissions occur is essential in selecting appropriate tools to assist the Province in its efforts. Navigant has relied on the expertise of the CCEEET and NL Natural Resources staff to build a broad brush picture of energy use and emissions in the province. GHG emissions in the province are dominated by two sectors: a small group[1] of large industries which account for more than half of provincial emissions, and the transportation sector which accounts for one-third. Together these two sectors contribute just under 90% of total GHG emissions and the lion's share of energy use. The power sector accounts for about 8% of total emissions while waste and wastewater contribute a further 6%. All other sectors of the NL economy combined contribute only a further 6-7%. Figure 3ES-1 below summarizes the sources, characteristics and types of GHG emissions for the province.

Figure ES-1: Summary of NL Emission Sources

Sector	Approximate Share of GHG Emissions	Characteristics of Sector	Emission Types
Large Industry *(8 reporting facilities totalled 4.38Mt CO2e in 2009).*	46%	• <10 large facilities - 3 mines - 3 oil and gas facilities - 1 Petroleum Refinery • Includes off-road transportation (about 6.3% of total provincial GHG emission)	Energy-related Process Fugitive
Transportation	33%	• 80% due to road transportation • 10% marine • 10% domestic air travel • International air travel not included in Inventory.	Energy-related (primarily)
Power Sector	8%	• Holyrood GS owned by NL Hydro	Energy-related
Waste/Wastewater	6%	• Over 200 landfills sites of various sizes (3 large); expected to be reduced to about 40 sites by 2020. • Wastewater sites assumed to also be concentrated.	Primarily process related – minor energy-related emissions.
Residential, commercial and light industrial buildings and processes	7%	• Diffuse decision making. • Limited end use or sub-sector data	Energy-related

The pattern of energy use differs from the pattern of GHG emissions due to the significant role played by emissions-free hydro-electric power in the province. Energy use is also dominated by large industry and transportation, but the contribution of residential and commercial

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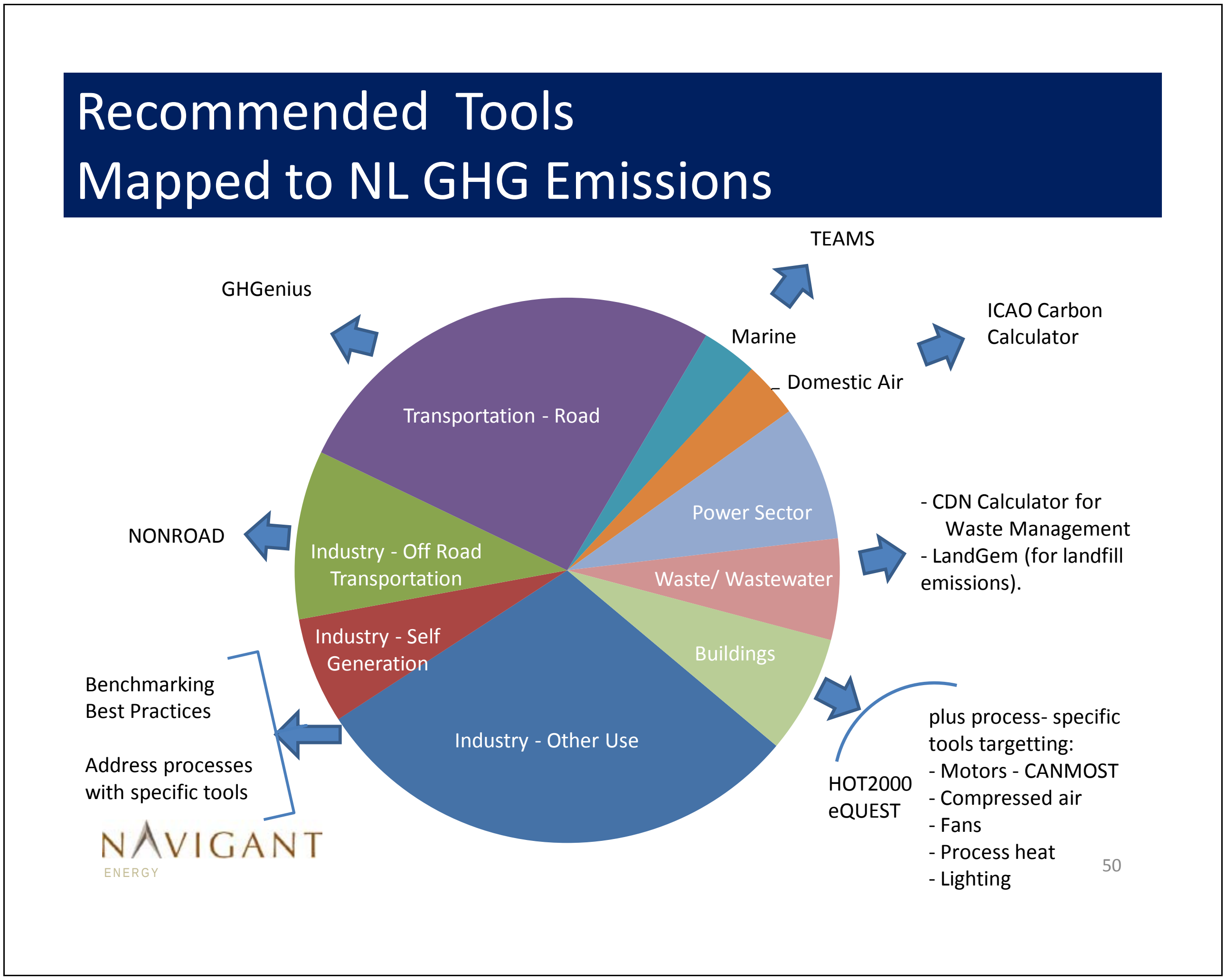
[1] Approximately 10 large mining, oil and gas, petroleum refining and pulp and paper industries.

buildings to total energy use roughly doubles compared to their contribution to GHG emissions.

Micro Level Tools and Methods

Using the criteria developed in consultation with the CCEEET and other NL stakeholders, Navigant recommends the following methods, tools and models for use by the CCEEET. The figure below shows how each of the tools relates to different sources of emissions (and energy use) in NL, while figure ES-3 describes the proposed models and the rationale for their selection.

Figure ES-2: Recommended Tools by Emission Source



Recommended Tools
Mapped to NL GHG Emissions

TEAMS

GHGenius

ICAO Carbon Calculator

NONROAD

- CDN Calculator for Waste Management
- LandGem (for landfill emissions).

Benchmarking Best Practices

Address processes with specific tools

HOT2000
eQUEST

plus process- specific tools targetting:
- Motors - CANMOST
- Compressed air
- Fans
- Process heat
- Lighting

Figure ES-3: Recommended Methods, Tools and Models

Sector	Recommended Method, Tool, or Model	Rationale for Selection
Buildings & Processes		
Residential	HOT2000	Industry standard for residential housing energy evaluation in Canada. Relative ease of use and flexibility allow adaptation to NL conditions. Model is used by other Canadian jurisdictions and subject to continued improvement and efforts to improve accuracy relative to actual energy use.
Commercial, Industrial and Other	eQUEST	Relatively easy to use, but offers flexibility for incorporating 'non-standard' design features or to apply to NL conditions. Reasonable level of support available. Provides most accurate representation of actual building use.
Processes Energy	Recommend use of all of tools presented as appropriate. Further analysis in this area not required. Tools selected could be expanded as information regarding key NL end uses is improved.	
Large Industry	Use of Benchmarking & Best Practices offers the most realistic means of evaluating the impacts of potential initiative for these customers. Accurately projecting future energy use and emissions will depend on both industry/organization specific information and the ability to project broader economic trends affecting the sectors in which the industries operate.	
Transportation		
Road – Vehicles	GHGenius	Provides ability to model full cycle emissions using a model customized to the Canadian context.
Road – Demand	Commuter	Relatively simple and easy to use model of

Sector	Recommended Method, Tool, or Model	Rationale for Selection
		transportation demand. Requires limited inputs. Builds on well established mission factors from MOBILE6. Drawback is that data used in assessing transportation choices is based on US data. Further investigation could evaluate whether this data is realistic in the Canadian and NL context.
Off Road	NONROAD	Industry standard for reviewing energy use and emissions from off-road equipment. Provides detail for different equipment types (i.e. excavators, trucks). If this capability is incorporated into the MOVES model as intended then consideration could be given to using MOVES rather than GHGenius and NONROAD.
Marine	TEAMS	Only known model to provide life cycle GHG emissions for marine transportation sector.
Air Travel	ICAO Carbon Calculator	Provides realistic and reasonably transparent methodology for assessing carbon emissions from domestic air travel. Methodology is available for review. Does not address issues of demand for domestic air travel. This could be addressed through a macro model.
Waste and Wastewater		
Waste Management Practices	Canadian GHG Calculator for Waste Management	Provides full life cycle emissions analysis based on industry standard US mode (WARM) adapted to Canadian conditions.

Sector	Recommended Method, Tool, or Model	Rationale for Selection
Landfill Gas Emissions	LandGEM	Widely used across US and Canada. Provides realistic representation of GHG generation compared to other available models. Reasonably easy to use. Default data provided for quick initial analysis, but can use site-specific data where available.

Macro Level Models

Developing a macro model to represent provincial energy use and emissions provides a number of benefits. The actual process of collecting, reviewing and analysing the data required for such a model provides an opportunity to gain a better understanding of the factors driving energy use and barriers to changing current patterns of energy use. Our experience indicates that the process of obtaining data for the modelling exercise actually accounts for the bulk of the work in most projects.

Developing a business-as-usual (BAU) or reference projection, usually the first step in any modelling exercise, can also provide a number of useful insights, which may include changing patterns of energy use, the effects of changing economic structure or demographics, and the impact of 'naturally occurring conservation' on future energy use and emissions.

Based on our analysis of available multi-sector, multi-fuel models, we have recommended three which we feel are most appropriate for consideration by CCEEET. The advantages and limitations of the three alternative models are summarized in the table below.

Figure ES – 4: Proposed Macro Models

Model	Key Advantages	Limitations
CanESS	• Modern software/architecture with interactive interface. • Transparent structure, easy to understand model relationships. • Existing representation of NL; adjustable to more detailed NL data.	• Decision making and behaviour represented through user inputs/scenarios. • Limited representation of economic impacts. • Relatively new model with limited track record.

Model	Key Advantages	Limitations
	• End use structure/flexible level of representation. • Provides database/structure for data as it is developed.	
CIMS	• Lengthy track record in Canada. • Attempts to reflect uncertainties and imperfect information in decision making. • Has been used to model carbon trading and carbon taxes. • Provides some indications of economic impacts of policies.	• Must be used through MKJA; not available in a form to run in-house. • Batch model with results comparison in Excel. • Limited transparency – appears to rely heavily on economic decision making. • Includes some built-in assumptions (i.e. w.r.t. changing urban planning/land use and impacts on energy demand).
ENERGY 2020	• Lengthy track record in US and Canada. • Some track record of predicting actual market behaviours. • Has represented NL in past models; can be adapted to improved NL data. • Provides some indications of economic impacts of policies.	• Behavioural model difficult to explain and understand. • Complex model to operate; most clients rely on SSI for model operation. • Batch model with results comparison in Excel.

Implementing any of these models will provide many of the insights just described. Each of the models offer different advantages and disadvantages in terms of model features, ease of use, transparency, and of course, cost. The choice of which model is most appropriate for CCEEET will depend to a large extent on the types of policies under consideration and how the model is expected to be used. Micro-level models can be used to both inform the macro model and to extend and refine macro-level analyses for specific sectors or applications.

Data Development

Issues relating to macro modeling and data requirements are strongly interrelated. The requirements of a given model influence the type of data required. Conversely the quality of data available can limit the value of any model.

Given the unique characteristics of NL's economy and energy use, we recommend that a priority be placed on developing improved information regarding NL's largest industries. For the balance of NL energy use, we recommend that improved information be developed regarding energy consuming assets and decision-making regarding those assets. We suggest that an initial representation of NL energy use could be developed using data available from federal and other sources[2]. In the process of compiling such a representation, we believe it would be possible to identify areas where significant differences may exist between national or regional energy use and that in NL. Using a macro model it should be relatively easy to identify which of these areas could have a significant impact on future energy use and emissions. This would then allow data development efforts to be directed to those areas where patterns of energy use in NL are significantly different from those in other areas – and where those differences are significant to the types of policies under consideration. We expect that significant differences may exist, for example, in areas such as freight transportation (less rail, more trucks and marine freight) and industry (fish processing dominates non-large industry). We do not expect that general patterns of decision-making and consumer behaviour in NL differ significantly from those in other jurisdictions, however, that could also be explored through market research.

The approach proposed above is intended to address some of the key concerns raised by the Advisory Group and CCEEET, namely:

- It recognizes the need for a different approach to the large industry sector, which has quite different characteristics from other sectors in NL,
- It minimizes costs and on-going resource requirements for developing, maintaining and updating the model and associated data by leveraging existing sources,
- It focuses data development efforts on key areas where NL-specific data differ from other regions and where those differences will make a difference in terms of energy and emissions policy.

Overall we believe the proposed approach should allow the CCEEET to build up its modelling capability at a reasonable cost and allow investments in data development to focus on areas of maximum value.

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[2] Any representation based on federal data sources would, of course, include adjustments for known discrepancies such as large facilities not included in the federal data, or differing allocations between sectors.

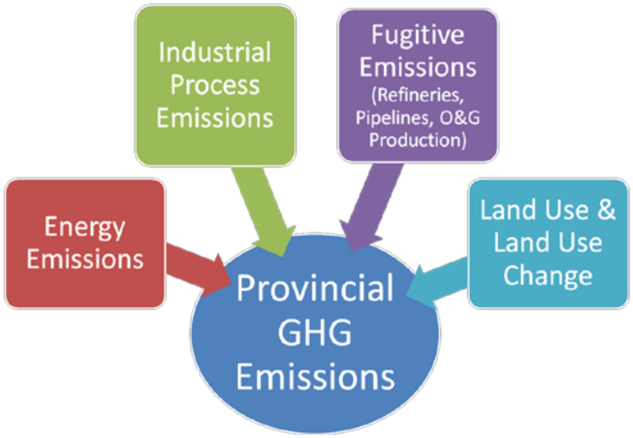
1 INTRODUCTION

The Government of Newfoundland and Labrador (NL) has made a commitment to reduce greenhouse gas emissions in the province. As it sets out policies to meet this commitment, the Province wishes to ensure that it has the means necessary to model the expected and actual outcomes of energy efficiency and climate change programs. The Office of Climate Change, Energy Efficiency, and Emissions Trading (CCEEET) retained Navigant to assist in identifying methodologies to forecast and measure the outcomes of initiatives to promote energy efficiency and/or reduce greenhouse gas (GHG) emissions.

The RFP separated potential tools and methods into "micro" level tools that apply to a specific building or facility and "macro" models that can be used to assess or analyse energy and climate policies at the jurisdictional level. For the purposes of this study, Navigant has interpreted "micro" level to include the range of tools and methods that can be used to identify, quantify and analyse different types and sources of emissions. This would, for example include building simulations as well as tools to review the emissions from alternative forms of transportation or municipal waste practices or emissions from a landfill facility.

Micro-level tools are often used in conjunction with macro-level models, both as an input and to provide a more refined analysis. They may also be useful in analysing specific "types" of emissions (see Figure 14). For example, some "macro" energy and emissions models have a detailed representation of energy use, but limited detail to represent emissions from waste, wastewater, or industrial process emissions. A micro level model may be used to provide a more detailed look at these emissions and serve as an input to the macro-level model.

Figure 1: GHG Emission Sources



In most jurisdictions the majority (in the range of 80%) of emissions are associated with energy use, while industrial processes, fugitive emissions and contributions from land use and land use changes contribute the balance.

A variety of "micro" level methods, tools and models are available, including:

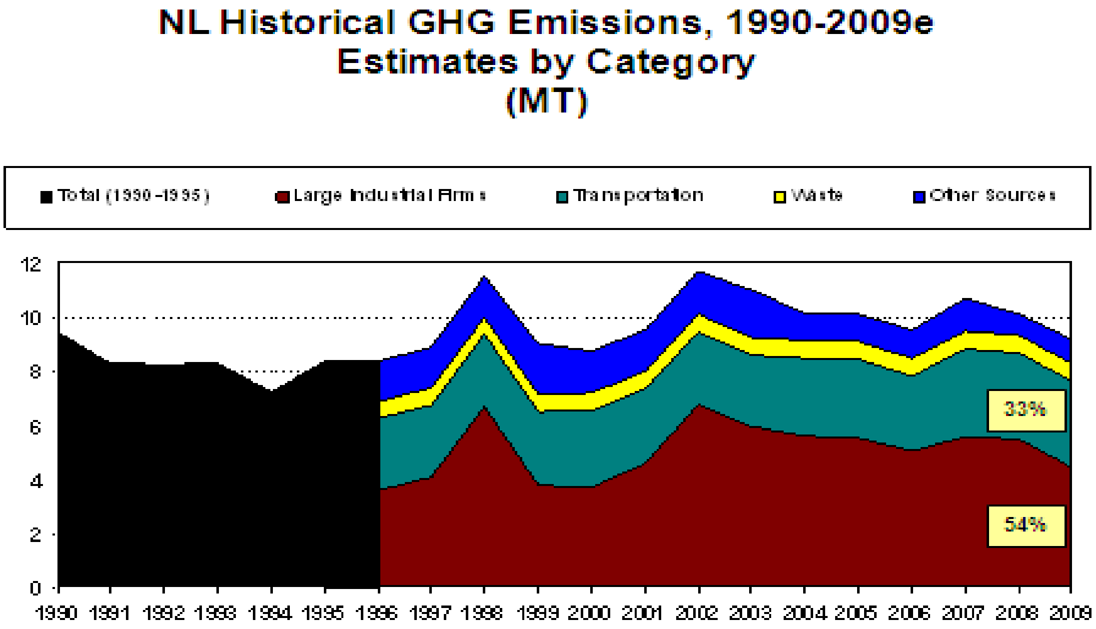
- Building simulations for the residential, commercial/institutional or industrial buildings,
- Process or end-use specific tools such as CANMOST for electric drives, AirMaster+ for compressed air, the FSAT Fan System Assessment Tool, PHAST Process Heat Assessment Tool or Daylighting123 to incorporate higher levels of daylighting into buildings.
- Sector specific models and tools are available to address emissions from transportation, ranging from life-cycle assessment tools, to tools that calculate emissions resulting from vehicle or vessel use, to logistics and transportation demand planning models. Similarly, models are available to evaluate emissions associated with different waste management processes or to quantify the emissions arising from landfills.
- A variety of carbon calculators have also been developed for different sectors (homeowners, air travel).

At the macro level, there are a variety of different types of tools and models available. Some address specific applications or particular sectors. These range from GHG inventory tools (US EPA State Inventory Tool) to screening tools that estimate the emission impacts of alternate energy policies to models which evaluate energy efficiency potential for a jurisdiction. A second class of tools are available to address specific technology types or energy supply sectors. For example there are a number of models specific to the electric sector, ranging from load forecasting to optimization models. Finally, there are multi-fuel, multi-sector energy and emission models that can model policy impacts across the economy. These models can be linked to macro-economic or Computable Generalized Equilibrium (CGE) models in order to estimate the economic effects of policy changes.

Tools developed for modelling or analysing specific sectors or supplies can be very useful in evaluating particular issues at a provincial, regional or national levels. They are often more specialized in their treatment of a particular sector (i.e. municipal waste management) or offer higher analytic granularity. The weakness of such tools is that they often do not offer the ability to capture interactive effects between measures, sectors or energy types. Experience in modelling Climate Change Plans has shown that these interactive effects can be very significant. In some cases, the GHG reductions achieved by a portfolio of policies can be 25-30% lower than what would be expected by summing the impacts of the individual measures implemented independently[3].

Developing or refining an energy or GHG inventory was not part of the scope of this project, however, understanding how and where energy is used and GHG emissions occur is essential in selecting appropriate tools to assist the Province in its efforts. Navigant has relied on the expertise of the CCEEET and NL Natural Resources staff to build a broad brush picture of energy use and emissions in the province. As Figure 2 below illustrates, GHG emissions in the province are dominated by two sectors: a small group[4] of large industries which account for more than half of provincial emissions, and the transportation sector which accounts for one-third. Together these two sectors contribute just under 90% of total GHG emissions and the lion's share of energy use. The power sector accounts for about 8% of total emissions while waste and wastewater contribute a further 6%. All other sectors of the NL economy combined contribute only a further 6-7%.

Figure 2: Historic NL GHG Emissions



Source: Estimated from National Inventory Reports and reported facility data, Environment Canada, and internal estimates. Fugitive emissions from oil refineries and net forestry emissions not included in provincial data.

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[3] For example, if a policy that improves electricity efficiency is introduced at the same time that the carbon intensity of generation is decreased, the resulting GHG reductions would be less than would be estimated for the two measures independently. Modeling can also be very helpful in identifying counter-intuitive policy interactions.

[4] Approximately 10 large mining, oil and gas, petroleum refining and pulp and paper industries.

Each of these segments can be broken down into sub-categories, though the allocations between them are more approximate. Large industries use energy to fuel off-road vehicles, self-generate power on oil and gas platforms or mine sites that are off-grid. A portion of their emissions are also attributable to process and fugitive emissions. Transportation emissions can be split between those for on-road passenger and freight vehicles, marine vessels and domestic air travel[5]. Other sources of emissions include all residential, commercial and industrial buildings and industrial processes other than those identified as "large industry". Figure 3 below summarizes the sources, characteristics and types of GHG emissions for the province.

Figure 3: Summary of NL Emission Sources

Sector	Approximate Share of GHG Emissions	Characteristics of Sector	Emission Types
Large Industry *(8 reporting facilities totalled 4.38Mt CO2e in 2009).*	46%	• <10 large facilities - 3 mines - 3 oil and gas facilities - 1 Petroleum Refinery • Includes off-road transportation (about 6.3% of total provincial GHG emission)	Energy-related Process Fugitive
Transportation	33%	• 80% due to road transportation • 10% marine • 10% domestic air travel • International air travel not included in Inventory.	Energy-related (primarily)
Power Sector	8%	• Holyrood GS owned by NL Hydro	Energy-related
Waste/Wastewater	6%	• Over 200 landfills sites of various sizes (3 large); expected to be reduced to about 40 sites by 2020. • Wastewater sites assumed to also be concentrated.	Primarily process related – minor energy-related emissions.
Residential, commercial and light industrial buildings and processes	7%	• Diffuse decision making. • Limited end use or sub-sector data	Energy-related

The pattern of energy use differs from the pattern of GHG emissions due to the significant role played by emissions-free hydro-electric power in the province. Energy use is also dominated

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[5] Emissions associated with international air travel are not included in provincial emissions inventories under international reporting rules.

by large industry and transportation, but the contribution of residential and commercial buildings to total energy use roughly doubles compared to their contribution to GHG emissions.

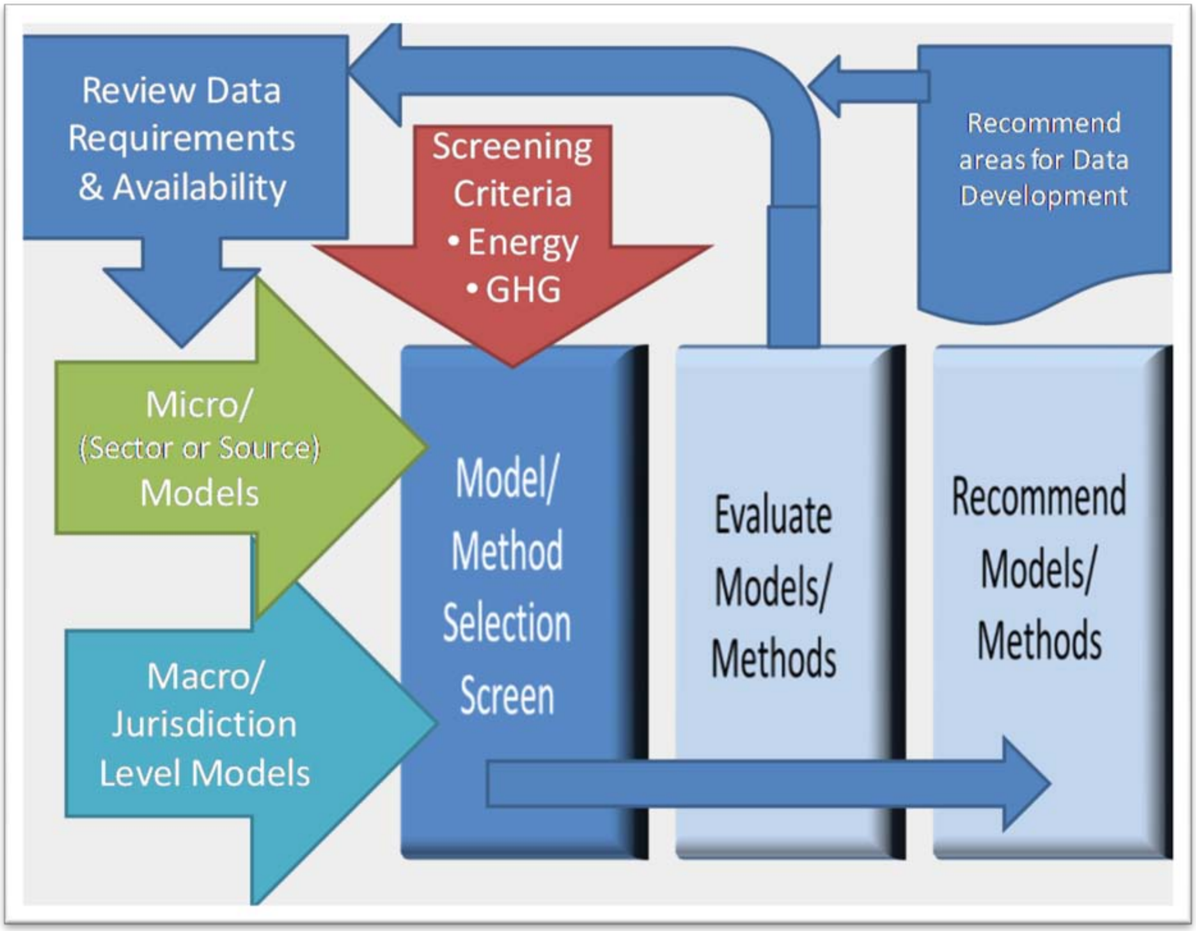
According to the OEE Comprehensive Energy Database, about 40% of transportation energy use is consumed for freight transportation and 5% is used for off-road. The limited role of rail is reflected in a slightly higher share of energy use by freight trucks compared to other provinces or Canada as a whole.

2 REVIEW PROCESS:

The review process used for this project was based on the requirements of the initial RFP and is built around a 2-step process. The first phase reviewed micro level models applicable to individual facilities or specific sectors. The second phase investigated multi-sector, multi-fuel "macro" models and data requirements associated with jurisdiction-level modeling.

As illustrated in Figure 4 below, the process began with developing screening criteria in consultation with CCEEET. Based on these criteria, appropriate methods, tools and models[6] were identified and evaluated. As noted in the figure, data requirements were also reviewed to identify any issues in applying these models in the NL context.

Figure 4: Review Process



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[6] The objective of this project is to identify methods, tools and models that may be used in NL. In the text which follows, the terms models or tools may be used as a shorthand when referring to a range of methods, tools or models.

The key screening criteria identified for the review are outlined below:

- Select models that match to the pattern of energy use and GHG emissions in NL
- Models should accurately reflect actual energy use and emissions and are applicable in the NL context
- Give preference to models that can be used with or linked to existing models and potential macro models.

For each of the models selected, Navigant reviewed:

- Methods/approaches and logic used in each model (how it works),
- Data requirements for the model,
- Where possible, the model/tool accuracy and level of precision, as well as any areas of uncertainty regarding model results,
- Ability to adjust model to make it applicable to NL and key variable that may require adjustment,
- Any strengths, weaknesses or other considerations in using the model, method or tool.

Based on this initial review, the models were screened against the CCEEET's criteria and a short list of models are recommend for further review.

Potential models that could be used in NL were identified based on past Navigant experience, research on models used by and available from the Canadian and US governments, and on models used by various utility and government programs. In addition, provincial and federal government sources were contacted to identify models used. Responses received from various provincial and federal agencies are summarized in **Figure 5** below. Some models used in other jurisdictions, including the UK and EU were reviewed but were found to be less suitable for application in NL.

The list of "micro" models reviewed in this portion of the study are shown in Figure 6. The models have been grouped by the sector or emission source to which they apply. It should be noted, that a number of "macro" models can also be used to analyse or project the impacts of energy efficiency and GHG mitigation initiatives in specific sectors. The level of analysis possible with a given macro model is dependent on model structure and granularity.

Figure 5:Models Used in Other Canadian Jurisdictions

Level of Government	Models Used
Federal	• Natural Resources Canada's Office of Energy Efficiency has developed or adapted a number of energy models that are available from their website. A number of these are referenced in the discussion of Micro models. • Environment Canada uses several macro level models to review energy and emissions impacts of policies affecting different sectors, including ENERGY2020, and Maple-C. ENERGY2020 is run as an integrated package with TIM (The Informetrica Model) referred to as E3MC.
BC	• Economic forecasting – Informetrica and DGEEM • Have used both CIMS and ENERGY2020 for energy forecasts/scenarios. CIMS has also been used to analyse transportation energy policies. DGEEM (*Dynamic Computable General Equilibrium Emissions Model*)has been used for both macro-economic and energy modelling. • Also used DGEEM for modelling effects of carbon pricing. DGEEM developed by MKJA for use with CIMS model. • Have also used HOT2000 and RETScreen.
AB	No response to-date.
SK	• Several "micro" models used, including HOT2000, RETScreen, EE4, eQUEST, GHGenius and WindPRO (*described as significantly more detailed commercial program for wind project evaluation*). • In-house macro economic model (called *Ernie*) used by SK Finance and Enterprise Saskatchewan (I/O model). • ENERGY 2020 used by SK Energy and Resources • Markal (last updated 2002) • CIMS model has been used to do some GHG policy modelling. • O&G Production forecasts from private sector forecasters and In-house models of oil and gas supply which track production by field.

Level of Government	Models Used
	- SaskPower currently uses Excel-based models for energy forecasting, PROMOD and MARS (Multi-Area Reliability Simulator) for reliability modelling.
MB	
ON	- Economic forecasting – Ontario Multi-Sector Economic and Government Analysis Model (OMEGA) used by Ministry of Finance (in-house model). - Energy forecasting – OMEGA used by Finance and EnerPrise Market Analytics (Ventyx software) used by Ontario Finance Authority. - Known to have used ENERGY2020 for climate policy analysis for Climate Action Plan and as part of WCI. - Building Energy – HOT 2000 - Renewable Assessments – RETScreen - Transportation – MOBILE 6 (M. of Env.) and GHGenius (M. of Energy) - W & WW – CanWet (Canadian Nutrient and Water Evaluation model). - Power sector – EnerPrise Market Analytics and OPG Pricing Model (PRIMO – an in-house model). - OPA reports using C4SE, Informetrica, CIMS, HOT2000 and RETScreen. Power sector-specific models used include UPLAN and MARS. The OPA also uses a number of self-developed spreadsheet models and is developing an energy demand forecasting model.
QU	- Economic forecasting – use Informetrica and DOE projections for oil and gas prices. - Energy Forecasting – In-house model for energy demand by sector (transportation, buildings, industry, etc.) which also covers GHG emissions (covers both energy and non-energy emissions). - Power Sector – don't do supply side forecasting. Use utility forecasts submitted to *Régie de l'énergie.*
NS	No response to-date.
NB	No response to-date.
PEI	Not contacted.

The following sections (sections 3 to 8) describe the micro models and tools reviewed for each sector. Some of these models could be applied at the "micro"(facility) or "macro" (jurisdiction) level, but are presented by sector in the table below to allow ready comparison between available tools.

Figure 6: Models, Tools and Methods Reviewed

Micro (Facility or Decision Specific)				
Building Energy Simulators	**Process Energy Tools**	**Emission Intensive Industry**	**Transportation**	**Waste & Wastewater**
HOT2000 HOT 3000	CanMOST (CDN)	Benchmarking	GHGenius	WARM
DOE2	Boiler Efficiency Calculator	Best Practices	GREET	Canadian GHG Calculator for Waste Management
eQUEST	AIRMASTER+		MOVES	IWM
EE4	FSAT		MOBILE6	LandGem
	PHAST		COMMUTER	
	Daylighting 123, DesiCalc, SkyCalc		TEAMS (Marine)	
	RETScreen		ICAO Carbon Calculator (Air travel)	
			Alternative Fuel Guide	

The "macro" models reviewed in the second phase of the project are listed below. A select list of the models which have been applied in Canada are discussed in greater detail in section 9.

Figure 7: Macro Models Reviewed

Multi-Sector Energy & Emissions Models	
Models Applied in Canada:	**US & International Models** (not applied in Canada)
CIMS	IPM (IPM+)
CanESS	LEAP
ENERGY2020	NEMS (National Energy Modelling System)
MAPLE-C	
MARKAL	

3 BUILDING ENERGY SIMULATIONS:

A number of building energy simulations have been developed over the past decades. Perhaps the most well known is the DOE-2 model, developed by the US DOE. Over the years, a range of more user friendly and less input intensive models other models have been developed using the DOE2 simulation 'engine'. The most common building energy models used in the Canadian context are eQuest and EE4. There are also a number of proprietary building energy simulation models; available for a fee or from equipment suppliers such as Carrier or Trane. Some of these models are intended to simulate the performance of specific manufacturer's equipment.

Generally simpler models are used to simulate residential housing. In Canada, Natural Resources HOT2000 has become the industry standard for modelling residential housing.

Most of the building simulations for commercial and other complex buildings are built on the simulation processes used in DOE2. As a result, experience indicates that for most buildings if the same inputs are entered into different models they will yield reasonably comparable results. Some models, such as EE4 have been designed primarily to test compliance, while others have been designed to make them easier to use. These different approaches have resulted in some compromises in terms of the models ability to represent certain non-standard features. These models are usually effective in evaluating the impact of changes between alternative designs, but may not provide an accurate prediction of actual building use[7]

Actual energy use in a completed building may differ from levels projected by a building energy simulation model for several reasons. The two main areas where differences may arise are:

1. The most obvious is that actual operating conditions often differ from those assumed during the modelling. Weather, occupancy rates, and hours of operation may vary. Structural and mechanical systems may not have been installed as anticipated in the design or may not function as expected.

2. The algorithms used in the model may not accurately represent the building systems or the interactions between those systems. This may result from a lack of sophistication in the model or from a user's inability to properly apply the modelling tool.

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[7] National Renewable Energy Laboratory, Building Energy Simulation Accuracy, July 2010, reviews issues with accurately predicting energy use in low rise buildings using DOE2 and EnergyPlus.

A review of some of the most commonly used building energy simulation models in Canada follows.

HOT 2000

Model Description

Natural Resources Canada claims that HOT2000 is "Canada's leading residential energy analysis and rating software"[8]. It was developed by CanmetENERGY's Housing, Buildings, Communities and Simulation (HBCS) group and has been tested by the International Energy Agency's BESTEST to test its energy simulation capabilities. The model is widely used in Canada, having been used for some 685,000 home ratings. The current version of the model (HOT 2000-GEN-v10_51) is available at no charge from NRCan[9].

HOT2000 addresses building envelope, heating, cooling and ventilation energy use as well as water heating systems and electrical base loads. It is designed with a graphical user interface (GUI) and a visual directory tree to simplify the input process. This approach allows users to readily access screens for ceiling, wall, floor, foundation and the HVAC system. Context sensitive pop-up help screens are available to provide users with definitions and explanations for each field. Modellers can use and report in either imperial or metric units. Training in use of the model is available on a regional basis from Natural Resources Canada or the Canadian Home Builders Association.

Variations on the HOT2000 are also available.

- HOT3000 is designed to help the construction industry to "advance the design of energy efficient and net-zero energy homes.
- HOT2®XP allows users to analyse a simple home with limited inputs.
- HOT2EC can be used to model innovative building designs that fall outside of the normal scope of the Model National Energy Code for Houses (MNECH).

The model allows users to calculate:

- The seasonal efficiency, based on the characteristics of the specified house, for:

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[8] http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/software_tools/hot2000/overview.html

[9] http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/software_tools/hot2000.html)

  - space heating systems, including part load curves and on and off cycling; and hot water tanks, including hot water load, standby losses and location

- Heating and cooling loads and design heat loss rates for space heating system sizing
- Fuel consumption and costs
- Effective R-value of envelope components, including thermal bridging of the framing materials
- Effective R-values of attic ceiling structures, taking into account insulation compression at the eaves
- Effective R-value of windows, including glass type, fill type, spacer and framing
- A typical Energy Rating (ER) for each window type
- Utilized solar and internal gains and heat gain arising from insolation, including the effects of exterior roof and wall colour choices.

The program aids in the simulation and design of buildings for thermal effectiveness, passive solar heating and the operation and performance of heating and cooling systems. In order to effectively utilize the model, only basic understanding of the construction and operation of residential buildings is required. The model uses ‘drop-down’ menus to access the comprehensive library of resources in order to describe the building envelop, HVAC, base loads, solar generation, and domestic hot water.

HOT2000 is also used as the compliance software for the Canadian R-2000 Program.

The model also addresses mechanical ventilation and infiltration, allowing the user to model central ventilation systems, including fans with and without heat recovery (i.e. heat recovery ventilators). Secondary supply and exhaust fans are also modelled. Infiltration is modelled to include stack and wind effect and their interactions, as well as interactions between infiltration and mechanical ventilation systems. The user can use one of HOT2000's pre-defined air tightness levels or enter the results of an actual blower door test.

Data Inputs

The model utilizes a graphical user interface with 'drop-down' menus in order to complete a new file. The inputs required are building geometry, construction characteristics (above and below grade), HVAC, domestic hot water specifications, geographical location of the residence. Optional inputs (if applicable) include self-generation, heat-recovery ventilation, fuel costs and economic data. In addition, the model provides for many default values, if the user is not sure of certain values.

Users enter identifying information regarding the project and structure. The model can be used to describe an existing or planned house or multi-unit residential building. Initial inputs include information on structure type, thermal mass, year built, soil condition and water table level, roof and exterior wall colour, and window tightness. Individual building elements are then described in greater detail, including heating, water heating and power supply (photovoltaic) systems. Base loads are calculated based on the number of occupants (adults, children and infants) and the percentage of time the building is occupied. The user can specify hot water temperature settings and identify the number of low flush toilets. No provision is made for efficient showerheads, front loading washers, etc., but the user can specify average L/day use for both water and hot water.

House templates are available with default inputs that can be used to fill in commonly used data.

Ability to Adjust Model:

The model comes equipped with climate data from hundreds of Canadian and U.S. cities, as well as selected centres outside North America. Weather data is provided for nine locations in Newfoundland and Labrador. The monthly and annual weather and solar insolation data[10] can be edited to further customize the results

Electricity and fuel (oil, natural gas, and propane) costs are provided for some locations in Canada for different historic years, but no NL data is included. Users can edit electricity and fuel costs by adjusting both the units per block and rates per block as well as defining the type of units used.

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[10] Weather data includes average solar radiation levels, wet and dry bulb temperatures and wind speeds for each month, as well as annual design temperature, ground temperature and heating degree days for each site.

Economic inputs to the model can also be edited by users; including fuel and inflation escalation rates, mortgage rates, amortization periods and renewal terms, bank savings rates and municipal tax rates.

The EnerGuide Rating System (ERS) Technical Subcommittee has reviewed the standard operating conditions (SOC's) used in HOT2000 and identified some areas where changes could be made to the model to better reflect actual average occupant behaviour. They reported that such changes could allow the model to more accurately reflect actual energy use.

The group is also reviewing issues relating to ventilation and health and safety pertaining to the model.

Model Outputs

Outputs from the model include a technical report, with tables of projected space heating load and monthly and yearly energy requirements, taking solar and internal gains into account.

Reports can be selected for the full-house, for selective or customized house or for multiple houses. Each level of report includes site-specific data, fuel-cost data and detailed monthly tables.

The model also includes a feature which allows production of a comparison report that allows the user to compare results from up to 4 houses simultaneously.

HOT 3000

Model Description:

A variant on HOT2000, HOT3000 was designed to expand on the limits of the HOT2000 by using a more versatile calculation engine, ESP-r. HOT3000 allows for a better calculation of passive solar designs, Time-of-Use (TOU) rates, load shifting (thermal storage), houses with thermostats in each room or multiple HVAC units, electrical generation, and scheduled internal gains. By using a graphic user interface that is based on the already familiar HOT2000 platform, HOT3000 aims to minimize the amount of user input work while providing a new house wizard enhanced to deal with more geometric forms.

HOT3000 was designed for energy consultants, students, researchers, builders, engineers, and architects. The software has been developed by Natural Resources Canada in collaboration with the University of Strathclyde and other leading research centres around the world. Fully supported, HOT3000 (version 2) will be updated as new algorithms for studying emerging technologies are created. Updates will continue to be made available, at no cost, from the Natural Resources Canada website.

HOT3000 (Version 2.0 Release Candidate) features include:

- comprehensive simulation engine
- 3-D graphical view of house model
- new house wizard for simple creation of new house files
- ease of HOT2000 inputs with an advanced engine (ESP-r)
- hourly or sub-hourly analysis
- hourly scheduling of heating/cooling
- set-back thermostat simulation
- simultaneous modelling of building, airflow and HVAC
- ground heat losses by frequency-domain response factor model
- infiltration modelling
- solar domestic hot water systems
- photovoltaic systems
- thermal mass and passive-solar design
- conventional HVAC systems, including furnace, baseboards, A/C and DHW
- weather data for 42 Canadian locations
- HTML report
- detailed outputs available
- simulation run-time – approximately 1 minute for typical house

Data Inputs:

HOT3000 requires the same basic data inputs as HOT2000, since it uses basically the same graphic user interface. It is 'drop-down' menu driven with more options to allow the user to better the input. For example more flexibility is provided to detail a more complex geometric house forms. Thermal mass can be better described and defined by zone. In addition, HOT3000 allows for more detailed zone information to be included such as passive solar designs, dedicated thermostats, and solar water heating to be described.

Ability to Adjust Model:

As mentioned above, the model allows for more flexibility to adjust the input file than HOT2000. The new house wizard allows for a comprehensive description of the building envelope, HVAC, domestic hot water and solar options (generation, solar heating, etc.). Otherwise, the user has the same availability to adjust the model as in HOT2000.

Model Outputs:

The report generated by HOT3000 is extensive. In addition to providing the same output files found in HOT2000, HOT3000 provides for month-by-month energy profiles for each profile. In addition, the report can be viewed in HTML format.

Please note, during the time of this evaluation, some bugs were detected. The team at NRCAN, per the website, are currently working on addressing some on-going bugs with the program. In addition, the time required to generate a report for a completed house was noticeably more than HOT2000, approximately one minute longer to generate the report.

eQUEST

Model Description

eQUEST (the**QU**ick **E**nergy **S**imulation **T**ool) was developed by the US DOE , based on its standard DOE2 building energy simulation model, to allow users to perform a detailed analysis of “state-of-the-art” building design technologies, without requiring extensive modelling experience[11]. The model comes equipped with “building creation” and “energy efficiency” wizards built into the software and graphical outputs. The building simulation engine provides hourly building simulation for a one year period using the simulation capabilities of the well established DOE-2 model[12].

The current version of the model (version 3.64), updated in August 2010, is available for download at no charge from the DOE2.com website.

eQUEST represents a compromise between more sophisticated building energy simulation programs, such as DOE-2, which require detailed understanding of both the model and the underlying building science, and simplified but less accurate programs. A simpler, but still

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[11] http://doe2.com/equest/

[12] While the model is based on DOE-2, it also includes a number of improvements not in the DOE-2 model. (eQUEST v3 Overview - http://www.doe2.com/download/equest/eQUESTv3-Overview.pdf).

realistic model such as eQUEST was intended to facilitate more frequent (and earlier) use of the energy modelling and the collaborative design process.

The ***Schematic Design Wizard*** allows users to readily describe key architectural and mechanical features of the building, its location, weather conditions, building geometry and energy sources used.

The ***Design Development Wizard*** is used to provide more detailed design data; often later in the design process. This second step allows a much more detailed specification of building systems. Users can select among a number of system types, including more than 60 HVAC system types.

The ***Energy Efficiency Measures Wizard*** allows the user to quickly develop up to nine different alternative systems to compare with the "base" design. Energy consumption resulting from each alternative design can be viewed graphically as well as in a tabular format. Potential energy savings are presented to allow quick and easy comparison between alternative designs. The level of detail used in the model design is determined by the user. For example, the user can use default values and zoning or they can be developed for a specific project.

eQUEST is used in Canada for building energy modelling, including for LEED certifications and incentive programs such as the Ontario Power Authority's New Construction programs. Users find the model relatively easy to use while providing flexibility to evaluate different types of systems. Using the wizard features, a building simulation can be developed in about one hour[13]. The model also provides automatic HVAC sizing and support is relatively easily available for the model.

Data Inputs

Using the available "wizards", users input information on building design, geometry, orientation, building systems, including zoning and controls, and weather information. Users select the type of controls and energy management measures (such as day-lighting controls) to be used in the base and alternative designs. A wide variety of default information is available on potential building systems, including several combinations not available in DOE-2.

Ability to Adjust Model:

Users can rely on default values or enter building- and location-specific information for most inputs used in the model.

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[13] Enermodal Engineering, Introduction to Computer Assisted Energy Design, November 2005.

Model Outputs

Model outputs are presented both graphically and in table format. The model presents energy use by source/fuel type and by building system for each alternative reviewed. When reviewing multiple alternative designs, energy use and savings from the "base" design are presented for each alternative.

EE4

Model Description

The EE4 building simulation model was developed by NRCan as a compliance checking tool following the introduction of the "prescriptive" Model National Energy Code for Buildings in 1997. Under NRCan rules, building energy efficiency must be calculated using the EE4 software, though in some specific circumstances the DOE-2 program may be used to simulate features that are not readily simulated in EE4. Version 1.7 of the EE4 model automates energy use assessments and applies all of Natural Resources Canada's (NRCan's) validation of new building designs rules to verify that a design is at least 25% more energy efficient than if constructed to meet Model National Energy Code for Buildings (MNECB) 1997 requirements.

NRCan offers a service using EE4 to validate the energy performance of new buildings and certify the that building meets all of the mandatory requirements of the Model National Energy Code for Buildings (MNECB). The NRCan validation process is recognized by the Canada Green Building Council for LEED® Canada and Canada Mortgage and Housing Corporation. It is also accepted by some utilities as the basis for applying for financial incentives. It effectively allows users to ensure that energy use related to the building envelope, lighting, HVAC and service water systems in a proposed building will not exceed those for a building designed in accordance with strict prescriptive requirements under the model code.

Based on user inputs regarding the proposed design, the model automatically develops a reference building according to the MNECB addressing the following issues:

- detailed transmission, solar, internal and ventilation load calculations;
- a broad range of primary and secondary systems and components;
- flexible scheduling of occupancy, lighting and equipment loads, temperature schedules, water heating loads and fans; and
- automated generation of detailed compliance reports.

The reference building is architecturally identical to the proposed buildings, with the same wall orientations, areas, windows, level of air tightness, number of occupants, indoor set-points temperatures for space heating and cooling and hot water, fan operation, appliance and electrical usage and process equipment. But the reference building will be insulated and use defined mechanical systems which comply with the MNECB. The EE4 software simulates the energy use of the proposed building design and the reference building design.

The latest version of the model (Version 1.7, file size 6.2 Mb) released in February 2008, is available at no charge from the NRCan website[14].

Users reportedly find the model's ability to easily create a base or reference design particularly beneficial as it saves significant model development time[15]. For one provincial new construction program reviewed, about 80% of modellers reported using EE4.

One drawback reported regarding the model is that while the model is widely used for comparing alternative designs and calculating savings from proposed measures, model results may not provide a reasonable estimate of actual consumption. The Modelling Guide states that:

"EE4 was not intended to simulate all energy uses in a building (exterior lights, elevator usage, steam humidifiers, dehumidification, gas appliances, solid fuel heating, special process equipment, refrigeration), therefore energy usage as predicted by EE4 is limited only to the features modelled within the software and the inherent software assumptions. EE4 and DOE2 simulations submitted under NRCan's validation are not intended to predict the actual energy usage of the design due to underlying assumptions in the software such as occupancy patterns, schedule of equipment operation, interior temperatures, etc."[16].

Data Inputs

The model requires very detailed inputs (potentially thousands of inputs). Creating a simulation file may take several days or weeks[17]. A wide range of data is required regarding

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[14] http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/software_tools/ee4.html

[15] Personal communications with modeling firms. Developing the base or reference case can take half of the time required to develop a simulation model.

[16] Natural Resources Canada, EE4 Software Version 1.7: Modelling Guide, Feb. 2008, page 1-2.

[17] Enermodal Engineering, Introduction to Computer Assisted Energy Design, November 2005.

the proposed building design[18]; specifying building systems and associated information such as energy prices.

Building System Information Required for EE4	
Heat Recovery Ventilation	Window and Glazing Thermal Performance
Space Heating and Cooling Equipment	Panelized Wall Systems, Curtain Wall Systems
Boilers	Interior Lighting
Heat Pumps	Refrigeration Systems
Air Handling Units	Compressors
Pumps	Heat Recovery Coils
Chillers	Mechanical Sub-cooling
Cooling Towers	Floating Head Pressure
Unit Heaters, fan coils, etc.	Renewable Energy Features (if applicable)
Service Hot Water Heating Equipment	Special Energy Conserving Features (if applicable)
Envelope Construction	

NR Can provides a separate spreadsheet to complete outside air calculations exogenous to the model and a guidance document for "Building Take-Offs" to encourage greater consistency in entering building data into the model.

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[18] http://www.oee.nrcan.gc.ca/commercial/newbuildings/docs/C-submission-checklist-20071218.pdf

Ability to Adjust Model

Users are able to specify information regarding the building design and building systems to be used. Due to the design of the model and its focus on compliance, some assumptions within the model are not subject to user input.

It can also be used to simulate “non-compliant” buildings, but users are warned that even in non-compliant operation the model has a series of assumptions that are not alterable; including features such as hot water delivery temperature, piping losses, internal heat gain allocations, standby losses for equipment, boiler and chiller load/part load factors, ventilation air reheating temperatures, secondary heating and cooling loop operation, humidity control and fan performance curves.

A variant on the tool is available to simulate the performance of arenas and supermarkets (buildings with high refrigeration/chiller loads) relative a reference building designed to the requirements of the MNECB. The EE Wizard Software for Arenas [19] is also available at no charge from NRCan.

Model Outputs

The model provides a simple tabular comparison between the Proposed and Reference building; showing energy use by type, total energy use and energy costs. Sizing reports are also available on expected building loads (in kW) and air flows (L/sec) broken down by building zone.

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[19] Software can be downloaded at: http://132.156.178.35/wizard1/english/index.cfm

Summary:

A comparison of the advantages and disadvantages of the different models is presented below:

Figure 8: Comparison of Building Simulation Models

Model Name	Advantages	Disadvantages
Residential		
HOT 2000	• Widely used (685,000+ homes) Canadian software. • Tested by IEA BESTEST • Relatively easy to use/training available. • Reasonably comprehensive coverage of building systems, passive solar, etc..	• Limited ability to address non-standard designs (see HOT3000). • Limited ability to reflect changes to internal loads, hot water use, occupant behaviour, etc.. • No NL-specific data for electricity and fuel prices (must be input by user).
HOT 3000	• More versatile form of HOT2000 • Improved calculation of passive solar designs, allows TOU rates, multiple thermostats or heating systems.	• More complex than HOT2000, requiring greater operator knowledge. • Some bugs reported in initial version.
Commercial & Other		
DOE2	• US program. • Industry standard with long history of development/ refinement.	• Complex to use. • Requires extensive knowledge of building science and software program.
eQuest	• US program built on DOE2 engine; widely used in US and Canada. • Simpler but still realistic • Much greater ease of use (compared to DOE2) • Wizards included to improve ease of use. Flexible in modelling non-standard systems.	• May not be able to represent some complex or innovative building systems (may require DOE2). • Does not automatically produce reference building based on inputs.

Model Name	Advantages	Disadvantages
EE4	- Canadian (NRCan) model built on DOE2 engine. - Standard model used by NRCan to test compliance with MNECB, recognized by Green Building Council. - Automatically creates reference building based on inputs.	- Compliance design limits ability to represent "non-compliant" buildings (i.e. existing buildings or innovative designs). - Not designed to simulate all energy uses and not intended to predict actual energy use of the building design.

Each model has its own advantages and disadvantages. Each requires a different level of knowledge and has different capabilities. The time and resources required to use any of these models will depend on the type of building being analysed and the complexity of the systems involved.

4 PROCESS ENERGY TOOLS

Limited information is available on the specific allocation of energy use by end-use and technology in NL. Some national sources of data are available, such as the comprehensive energy database available from the Canadian Office of Energy Efficiency or the US Energy Information Administration's Manufacturers Energy Consumption Survey. Unfortunately, the OEE database does not provide province-specific information for NL, while the US MECS data does not cover mining or oil and gas extraction, which represent a significant portion of NL energy use.

A study of industrial energy efficiency potential for NL was conducted in 2008, but addressed only electricity use and did not include the potential savings from the self generated portion of electricity used by industry[20]. For the purposes of selecting appropriate process-related tools, we have assumed that the distribution of electricity use found in that study is reasonably representative of industry use for the province as a whole.

A significant portion of electricity used in NL is self-generated by large industries. The process tools below can be used to assess and project the potential of energy initiatives aimed at all electricity use regardless of how it is generated.

The tools presented below are intended to address the key areas of energy use in the province, including both electricity use and other forms of energy. While energy savings in some applications may not affect commercial (i.e. purchased) energy use, it will impact overall energy use and resulting GHG emissions.

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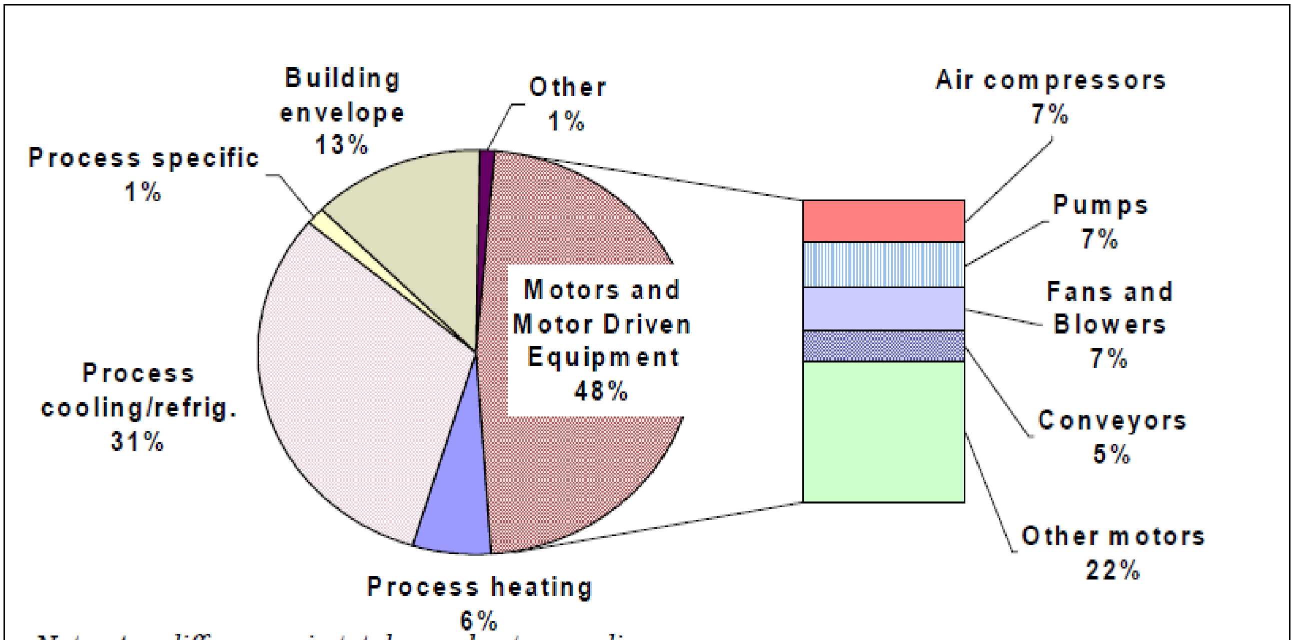
[20] The study was carried out for Newfoundland and Labrador Hydro and Newfoundland Power, and therefore was focused on electricity use by their customers.

Figure 9: Industry Sector - Base Year Modeled Annual Purchased Electricity Consumption for the Island. Labrador and Isolated Interconnected Service Region (GWh/yr.)[21]



Note: Any differences in totals are due to rounding.

CanMOST – Canadian Motor Selection Tool

Model Description

Motor driven systems consume 39% of all electricity used in Canada.[22] CanMOST – the Canadian Motor Selection Tool – was launched in June 2004, by Natural Resources Canada[23]. "CanMOST is the Canadian version of IMSSA (International Motor Selection and Savings Analysis) software, an international version of the successful MotorMaster+, developed by the U.S. motor energy-management software Washington State University Extension Energy Program. Sponsors of the IMSSA project include the International Copper Association, the United States Department of Energy, UK Action Energy (Carbon Trust), the European Commission's Joint Research Centre, the National Copper Corporation of Chile and Natural

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[21] Marbek Resource Consultants Ltd., CONSERVATION AND DEMAND MANAGEMENT (CDM) POTENTIAL NEWFOUNDLAND and LABRADOR, Industrial Sector – Final Report, *January 2008, page iv.*

[22] CanMOST Technical Fact sheet: http://oee.nrcan.gc.ca/industrial/equipment/software/FactSheet.pdf

[23] CanMOST website: http://oee.nrcan.gc.ca/industrial/equipment/software/intro.cfm?attr=24

Resources Canada"[24]. The model is available for download at no charge, though registration is required[25].

The program allows users to analyse and compare the efficiency of three-phase electric motors, using a database of over 43,000 motors. The model calculates both energy and electrical demand savings. The model has been designed to be easy to learn and intuitive to use, incorporating window-display and management features, such as buttons, tabs that separate information screens, toolbar commands and convenient menus. On-screen help features are also available.

The Motor Savings Analysis module considers three motor procurement scenarios:

- purchasing a new motor
- repairing versus purchasing
- replacing an operable motor

Based on motor specifications/requirements input by the user the model selects the top 10 motors, ranked in ascending order in terms of simple payback and in descending order of rate of return on investment. Simple paybacks are calculated as well as before- or after-tax return on investment. The software also displays cash flows, net present value, the benefit-to-cost ratio and rate of return.

CanMOST's catalogue contains a wide variety of general-purpose and definite-purpose motors. Motor classes and features include[26]:

- oil-well pumpers (NEMA Design D motors)
- high-starting torque or conveyor-drive motors (NEMA Design C motors)
- IEC or metric-frame motors (for 60-Hz operation)
- motors with explosion-proof enclosures
- C-faced motors

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[24] http://www.oee.nrcan.gc.ca/commercial/technical-info/tools/index.cfm?attr=24

[25] Registration form: http://oee.nrcan.gc.ca/industrial/equipment/software/registration.cfm?attr=24

[26] http://oee.nrcan.gc.ca/industrial/equipment/software/about.cfm?attr=24

- U-frame or automotive-duty motors
- vertical shaft motors
- close-coupled pump motors
- IEEE-841 petroleum and chemical duty motors
- Wash-down or clean-up duty motors
- severe-duty/extra-tough/corrosion-resistant motors
- inverter duty motors (variable torque, constant torque and vector drive)

The model allows users to:

- calculate energy and demand savings,
- predict energy and cost savings when replacing a failed or standard-efficiency motor,
- identify inefficient or oversized motors in your facility,
- select the best available premium-efficiency motor for a given application,
- compare operating costs of various motors,
- calculate the rate of return on a motor investment,
- calculate annual greenhouse gas emissions reductions.

NRCan has tailored the model for Canadian industry; offering a bilingual interface, including 575-volt motors only available in Canada, and reflecting Canadian utility rate structures and Canadian dollars in the model calculations.

Data Inputs

The user is required to enter the required motor specifications in the model, including specifications – size, synchronous speed, enclosure type, operating voltage, and motor load.

Ability to Adjust Model

The user can select the province in which the motor will be applied so that province-specific electricity rates are used. It is not clear how current the province-specific information on rates and power system GHG emissions are.

Model Outputs

The model provides a summary of energy and demand savings, operating costs, the rate of return on a proposed motor choice, and greenhouse gas emissions resulting from each choice.

Savings are presented in terms of amount of electricity used, cost savings and predicted annual reduction in greenhouse gas emissions.

AirMaster+

Model Description

AIRMaster+ is another energy management tool available from the US DOE. The model can be downloaded at no charge[27] with optional registration. The DOE recommends that users participate in training before applying the tool.

AIRMaster+ provides comprehensive information on assessing compressed air systems. The tool allows users to analyse existing systems and potential upgrades to estimate the cost-effectiveness and savings from potential energy efficiency measures. The model provides users with a systematic approach for collecting data and assessing compressed air systems. Using information for a specific plant or application the tool calculates the operating costs for different equipment configurations and system profiles and provides users with the estimated savings resulting from different efficiency measures. Financial evaluations are based on a simple payback.

Data can be input in either English (imperial) or metric units for pressure selections and airflows. Users can switch between units for comparison. The tool also includes a currency selection feature and regional and language settings[28] .

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[27] http://www1.eere.energy.gov/industry/bestpractices/software_airmaster.html

[2828] European Commission, Intelligent Energy eLibrary: http://www.iee-library.eu/index.php?option=com_jombib&task=showbib&id=648&return=index.php%3Foption%3Dcom_jombib%26amp%3BItemid%3D30%26amp%3Bcatid%3D48

A database of generic or industry-standard compressors is provided with the tool which creates an inventory specific to actual, in-plant air compressors. Using plant or application data supplied by the user, the tool simulates existing and modified compressed air system operations. The tool can model part-load system operations for an unlimited number of rotary screw, reciprocating, and centrifugal air compressors operating simultaneously with independent control strategies and schedules.

Data Inputs

Users must enter information the following types of information:

- Company/facility
- Utility rates
- Compressed air systems on site and end uses for each system
- Typical operating day types
- Compressor performance and operating details
- Metered hourly energy use or air flow for each day type and for each compressor.

Once the base information has been provided the user can identify potential energy efficiency system enhancements such as:

- Reduced air leaks, system air pressure, or run time
- Improved end use efficiency
- Use of unloading controls and automatic sequencer
- Adjustment of cascading set points
- Addition of primary receiver volume.

Model Outputs

Based on input, AIRMaster+ allows users to[29]:

- Manage multiple facilities and compressed air systems,
- Maintain databases of plant inventory and industry-standard air compressors,
- Simulate existing and modified compressed air system operation,
- Model part load system operation for a variety of air compressors operating simultaneously with independent control strategies and schedules,
- Calculate electrical operating costs and life cycle costs,
- Evaluate energy savings,
- Track maintenance histories of various facility, system, and compressor components.

Ability to Adjust Model:

Plant or application specific information is used in the assessment as well as user input energy rates.

FSAT (Fan System Assessment Tool)

Model Description

The Fan System Assessment Tool (FSAT) is a free online software tool, available from the US DOE[30] , that assists industries to understand how well existing fan systems are operating, determine the economic benefit of system modifications, and establish which options are most economically viable when multiple opportunities exist for system modification.

Designed for industrial plant personnel who are interested in improving fan system efficiency and measuring potential savings opportunities in both dollars and electrical energy savings, the tool requires information regarding existing fan system equipment specifications and operating conditions. The tool then calculates fan energy use and efficiency and provides estimated savings from available system improvements.

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[29] From AIRMaster+ website.

[30] http://www1.eere.energy.gov/industry/bestpractices/softwaretoolregistration.asp?product=4

Data Inputs

FSAT users will need to input the following information[31]:

- Fan and motor specifications
- Operating fraction and electric rate
- System required flow and pressure
- System power kW (or amps and volts).

Model Outputs

Based on input, FSAT will:

- Calculate how much energy the fan system is using
- Determine how efficiently the system is operating
- Quantify savings from potential system upgrades.

PHAST (Process Heat Assessment Tool)

Model Description

The Process Heating Assessment and Survey Tool (PHAST) is one of a number of energy management tools available from the US DOE[32]. It allows industries to survey process heating equipment that use fuel, steam, or electricity, and identifies the most energy-intensive equipment. A heat balance can be developed using the tool; identifying major areas of energy use under various operating conditions and test "what-if" scenarios for various options to improve thermal efficiency and reduce energy use.

The most current version of the model (PHAST 3.0) is available for download, at no charge from the US DOE website.[33]

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[31] http://www1.eere.energy.gov/industry/bestpractices/software_fsat.html

[32] http://www1.eere.energy.gov/industry/bestpractices/software_phast.html#factsheet

[33] http://www1.eere.energy.gov/industry/bestpractices/softwaretoolregistration.asp?product=9

Four different user manuals are available for PHAST 3.0 for applications covering fuel-fired or electro-technologies to provide the process heat, with each able to be run for metric or US units.

Data Inputs

Users provide inputs to define their process heat needs:

- General manufacturing plant information,
- Available energy sources for the plant and the fuel heating value and cost,
- Energy use data for furnaces, and heaters,
- Energy used by auxiliary equipment associated with the furnace,
- Energy used in various parts of the furnace under given operating conditions,
- Commonly used materials for charge material, fixtures and process atmosphere in process heating applications.

Model Outputs

Using the inputs provided the model:

- Provides a comparison of the energy performance of individual pieces of equipment under various operating conditions
- Reports annual energy use for each piece of equipment
- Builds a detailed heat balance for selected pieces of equipment
- Suggests methods to save energy in each area where energy is used or wasted.

The outputs include a Sankey Diagram showing energy flows.

Boiler Efficiency Calculator (OEE)

Model Description

The Boiler Efficiency Calculator was developed by Natural Resources Canada to provide a tool to quickly analyze the efficiency of boiler operations associated with heating and steam plants fired by natural gas and fuel oil. The tool is available on-line at no charge from the NRCan website[34].

In addition to estimating the efficiencies of steam boilers and high temperature water generators, such as those used in central heating and industrial steam generation systems, the tool is designed to help users make informed decisions and investments to optimize performance, including:

- upgrading control systems
- installing additional heat exchangers, economizers and air heaters
- replacing existing systems with new, more efficient equipment.

The tool focuses on the main two or three losses that typically represent 10 to 20 % of fuel input[35].

The tool follows a six-step process to calculate boiler stack losses. The calculations differ depending on fuel composition, firing conditions and flue gas temperatures. The fuels covered by the model include natural gas, light (#2) fuel oil, light (low sulphur) diesel oil, and heavy (#6) fuel oil (regular and low sulphur). The tool uses standard formulas from the American Society of Mechanical Engineers (ASME) in its calculations.

Once losses from an existing system have been calculated, the tool allows users to evaluate the application of a Boiler Economizer, or heat exchanger, that capture some of the flue gas heat into another medium. In most instances the recovered heat is used to pre-heat the boiler feed-water. Two types of economizers are available: non-condensing and condensing.

- Non-condensing economizers are most common and typically can raise boiler efficiencies by 2-4%. Designed to operate to maintain the flue gas temperature above the flue gas condensing temperature these systems prevent corrosion of the flue gas ducting; particularly important for fuels containing sulphur.
- Condensing economizers are designed to accommodate the corrosive fluids generated when condensing the moisture out of the flue gas. By capturing the latent heat in the flue gases, they can raise the overall boiler efficiency by 10% to 15%. These types of

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[34] http://www.oee.nrcan.gc.ca/industrial/technical-info/tools/boilers/index.cfm?attr=24

[35] A number of factors may result in energy losses from a boiler, but most are relatively insignificant.

economizers are not addressed by the BEC due to the greater complexity of the calculations required[36].

Data Inputs

In order to apply the model, users must obtain and input basic information on the operation of the existing boiler system, including:

- Flue gas temperature (FGT), °F or °C.
- combustion air temperature (CAT), °F or °C.
- O^2 in flue gas, % by volume.
- actual unit output, lb/h or millions of Btu/h

Ability to Adjust Model:

The user inputs site or application-specific data that is used as the basis for the modelling results.

The model makes a number of assumptions in order to simplify the required calculations. CO in the flue gases is assumed to be zero, for example, because the maximum amount allowable under emissions regulations has a very small impact on efficiency calculations. For the same reason, the tool assumes that all the carbon in the fuel is burned.

Model Outputs

NRCan includes a disclaimer with the tool indicating that the results from the Boiler Efficiency Calculator (BEC) are based on simplifying assumptions, and are only intended for general information purposes and should not be used as a guide for investment or other commercial activities.

The tool allows calculation for up to five tests at one time. Output tables provide information on the efficiency of the system and a breakdown of losses that contribute to total energy loss:

- % CO2 in flue gas,
- Output rate of dry flue gas (lbs/lb of fuel),

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[36] http://oee.nrcan.gc.ca/industrial/technical-info/tools/boilers/economizers.cfm?attr=24

- % excess air,
- Losses to dry flue gas,
- Flue gas loss due to moisture,
- Radiation and convection losses,
- Unaccounted losses,
- Total losses.

Results are provided for the base boiler with and without the benefit of an economizer. The results can also be plotted to graphically show the boiler system's efficiency versus the unit load[37].

Daylighting 123

Model Description

Developed by National Research Council and Natural Resources Canada, Daylight 1-2-3[38] (former Lightswitch Wizard) is a design analysis tool to support the incorporation of daylighting features into commercial building design. The tool is designed for use by non-experts. It can predict the contribution of daylighting to energy performance for both top-lit and side-lit spaces. The model is based in part on the DAYSIM tool[39].

The main objective in providing the tool is to help design professionals interested in developing climate-responsive daylighting design concepts; to optimize façade/ roof layout and orientation with respect to daylight and energy use; and to quantify energy savings from occupancy sensors and/or photocell controlled dimming; without requiring expert knowledge of daylighting design.

The tool can be downloaded at no charge[40] after registering at the Daylight 123 site. It provides a graphical user interface (GUI) and extensive help files. The model can be used to produce:

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[37] http://oee.nrcan.gc.ca/industrial/technical-info/tools/boilers/index.cfm?attr=24

[38] Version 1.3 - http://lightswitch.irc.nrc.ca/website/Software.html

[39] Information on DAYSIM is available at: http://www.daysim.com/

[40] Download form: http://lightswitch.irc.nrc.ca/website/Download.html

- annual daylight simulations using a validated, RADIANCE-based daylight coefficient approach,
- integrated thermal/lighting simulations based on a customized version of ESP-r models of space use based on the latest generation of occupant behaviour models,
- model skylights and windows with shading devices are modeled using SKYVISON use pre-calculated daylight coefficient sets keep simulation times under a minute (depending on server traffic),
- apply advanced daylight performance metrics including daylight autonomy and useful daylight index.

NRCan claims that the software uses a state-of-the-art simulation engine that provides relevant, reliable, and fast results.

Data Inputs

The user specifies the characteristics of the space being reviewed, developing a 3-D representation of the space (room or building). Inputs describe the geometry, size, location and construction of the space, as well as surface reflectance, fenestration and skylights, occupancy, and lighting systems.

Ability to Adjust Model:

The user defines the space and lighting conditions.

Model Outputs

The user can also view an interactive 3-D representation of the space being reviewed and view daylight performance metrics. The tool also presents a report which 1) summarizes the user-input description of the space being reviewed, 2) shows a representation of the space with various lighting metrics, 3) provides graphs of monthly energy loads (total and per unit of floor area) and finally 4) a table of monthly lighting, heating and cooling requirements for the designed space.

Summary:

Given the variety of processes, only one tool or model has been presented above for each area.

5 ENERGY INTENSIVE INDUSTRY

As discussed in the introduction, a small number of industrial sites consume the bulk of energy use and generate the majority of GHG emissions in NL. A study of electricity efficiency potential for the province, published in 2008[41], points out that:

- "Almost 70% of all electricity use by industry is self-generated, while the remaining 30% (1,359 GWh/yr.) is supplied by NLH and NP. All the self-generated electricity is produced by the Large Industrial sub sector.
- Large industrial facilities use approximately 94% of all the electricity used by industry in Newfoundland and Labrador but consume about 1,067 GWh/yr. (79%) if only purchased electricity is considered.
- Of the Small and Medium Industrial sub sector,[42] the Fishing and Fish Processing sub sector accounts for about 53% of electricity use"[43].

Projecting energy use and emissions for this group of large industries, or the impact of initiatives to improve energy efficiency and reduce GHG emissions, is particularly challenging. Unlike the broader business sector, decisions in this sector are highly concentrated; so a single corporate decision can result in a facility expanding, opening, or closing. Each of these industries is subject to economic conditions as well as decisions within their corporate structure.

Energy and emissions models are not well suited to predicting the impacts of broad energy and climate policies on such industries. Developing a reasonable projection of future energy use and emissions will depend on both industry/organization specific information as well as the ability to project broader economic trends affecting the industries. Regardless of how such projections are developed, they will be subject to significant uncertainty given that one corporate decision can have a very significantly impact overall provincial energy use and emissions. Scenario analysis is suggested as the best means of dealing with this uncertainty when considering future levels of energy use and emission.

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[41] The distribution of electricity use will change over time as industries grow or downsize. Since 2008 NL's pulp and paper industry has downsized and new mining facilities are under development.

[42] Small and medium sub-sector as defined in Marbek study would coincide with distribution customers. Large industrial customers would include transmission connected customers and some off-grid facilities.

[43] Marbek Resource Consultants Ltd., CONSERVATION AND DEMAND MANAGEMENT (CDM) POTENTIAL NEWFOUNDLAND and LABRADOR, Industrial Sector – Final Report, *January 2008.*

In terms of projecting the response of these customers to energy and GHG mitigation initiatives, the use of "benchmarking" and consideration of best practices is recommended. In some instances, the processes which drive energy use in these industries may be industry-specific or even specific to a particular process within that industry (i.e. mechanical pulping). On the other hand, many of the energy applications used may be common across many industries (i.e. motor drives, compressed air, fans and blowers).

When considering benchmarking it will be important to understand the specific processes used by the industries located in NL to ensure that levels of energy use are compared to comparable industries. In benchmarking GHG emissions, it will also be important to identify the specific processes used, as a significant share of GHG emissions may be related to industrial processes rather than as a result of energy conversions (i.e. fugitive emissions from oil and gas and refineries).

Again, some portion of the energy consumption in each of these industries is due to conventional end-uses such as motor drives, process heat, compressed air and lighting. The process energy models and tools discussed in the prior section can be applied to those end uses.

A number of Canadian benchmarking studies are available from Natural Resources Canada, including reports for:

- Open Pit Mines
- Bulk Underground Mines
- Pulp and Paper (3 reports)
- Petroleum Refining (conventional petroleum)

In addition, information is available on industry best practices that could be applied to industries operating in NL. For example, CAPP[44] has published guidance on best practices with respect to control of fugitive emissions in the oil and gas sector.

Comparing the energy and emissions performance of large industries in NL with those of industries using comparable processes in other jurisdictions and consideration of best practices in those industries should provide CCEEET with an insights into the potential to improve energy and emissions performance in this sector.

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[44] Canadian Association of Petroleum Producers, Best Management Practice, Management of Fugitive Emissions at Upstream Oil and Gas Facilities, January 2007 (reviewed January 2009).

6 TRANSPORTATION SECTOR

Several different types of tools are available for analyzing energy and emissions associated with transportation, including:

- Inventory tools designed to assist in developing an inventory of GHG or criteria air emissions resulting from transportation[45]
- Tools and models which calculate direct emissions, focussing solely on emissions which occur during vehicle or equipment use. These tools are usually designed to develop emission factors or emission estimates for gases emitted during vehicle use (examples include MOBILE 6, NONROAD).
- Life-cycle GHG Emission Calculation Tools , which estimate emissions from the full fuel cycle or full fuel and vehicle cycle. Examples include GREET, the Life Cycle Emissions Model (LEM), MOVES and GHGenius. Within the sphere of life cycle analysis, some models address only the fuel cycle while others include all energy and emissions associated with the materials used in the vehicle.
- Transportation and emissions strategy analysis tools such as the COMMUTER model.
- Energy and Economic Models which have been designed to forecast energy consumption based on economic activity, fuel prices, etc.. Most of these models address multiple sectors including transportation.
- Economic comparison or purchase evaluation tools, such as Canada's Alternative Fuel Guide help consumers evaluate purchase decisions regarding more efficient or alternative fuel vehicles.

Most of the tools available address one specific mode or type of travel and compare the impacts of alternative choices of vehicles, programs, etc.. Macro models add an extra dimension by allowing the user to evaluate changes in transportation demand and changes between transportation modes (i.e. driving vs. walking or bicycling, personal vs. public transit, or trucks vs. rail).

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[45] It should be noted that GHG emissions from transportation arise not only from energy conversion (the amount of fuel consumed) but are also dependent on the conversion and emission control technologies used.

There are also a wide range of models used by logistics firms, transportation and urban planners that can be used to analyse transportation demand which are not addressed in this project.

A selection of models felt to be most appropriate for NL's consideration are presented below. Models that represent "on road" energy use are presented separately from "off road", marine and air transportation.

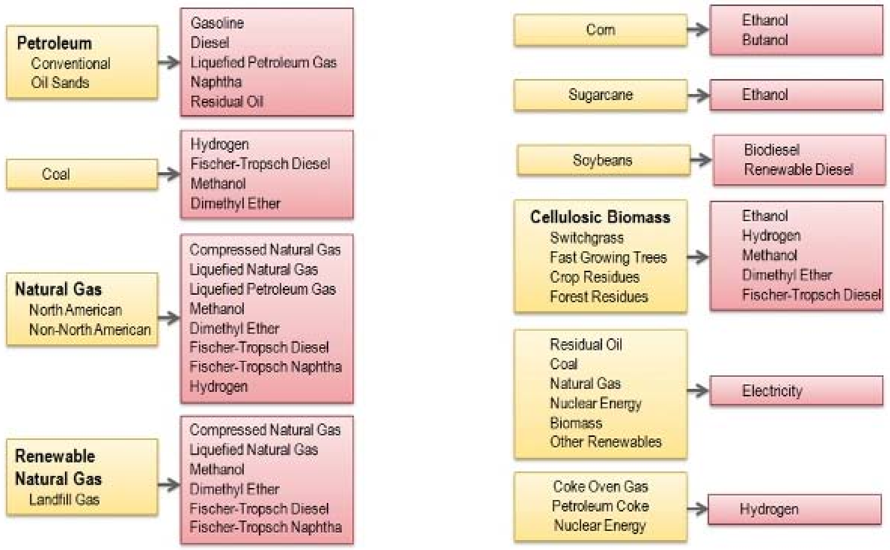
6.1 On Road:

GREET: Greenhouse Gas Emission from Transportation

Model Description

GREET can be used to calculate air emissions resulting from passenger on-road transportation. The model calculates life-cycle energy use, air pollutant emissions and greenhouse gas emissions for various vehicle/fuel systems. Energy and emission impacts are tracked from "well-to-wheels" for each fuel cycle and vehicles are tracked from material extraction to vehicle disposal and material recovery.

Figure 10: Fuel Cycles Available



The latest version of the GREET model (GREET 1.8b) was released in March 2008 and consists of 27 Microsoft® Excel sheets, modeling more than 100 fuel production pathways and 80 vehicle/fuel systems (see figures below). The model does not currently include heavy vehicles used for freight transportation, other transportation modes (rail, marine, air) or off-road transportation. Work is currently underway on a new version of GREET (GREET3.7)[46] that will provide full cycle modeling for heavy duty vehicles[47].

The modelling approach starts by calculating energy use and emissions for vehicle operations for a given vehicle/fuel option for the fuel economy and emissions of baseline vehicles (gasoline and diesel vehicles) and compares this baseline to changes in fuel economy and emissions for the given vehicle/fuel option

Figure 11: Vehicle Options in GREET

Gasoline vehicle technology options	Diesel vehicle technology options
• Spark-ignition (SI) engine	• Compression-ignition (CI) DI engine,
• SI direct-injection (DI) engine	• GI HEV with CIDI engine
• Grid-independent (GI) hybrid electric vehicle (HEV) with SI engine	• GHEV with CIDI engine
• Grid-connected (GC) HEV with SI engine	• FCV with on-board reforming of diesel to H2 — FCV is only available for low-sulphur
• Fuel cell vehicle (FCV) with on-board reforming of gasoline to H2	

For a given vehicle and fuel system, GREET separately calculates the following:

- ***Total energy consumption*** (including both non-renewable and renewable sources,
- ***Greenhouse gas emissions***, in CO_2-equivalent terms, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and,
- ***Criteria air pollutant emissions*** for six pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NOx), particulate matter with size smaller than 10

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[46] Tools to Estimate the Energy Use, Criteria Air Pollutant Emissions and Greenhouse Gas Emissions from Your Fleet, Andrew Burnham, Center for Transportation Research Argonne National Laboratory, Clean Cities Webcast, April 17, 2008.

[47] As of March 10, 2011, the new version had not been released.

micrometre (PM10]), particulate matter with size smaller than 2.5 micrometre (PM2.5),and sulphur oxides (SOx).

Results are presented in terms of:

1) Well-to-Pump (WTP) Energy Use and Emissions
2) Well-to-Wheels (WTW) Energy Use and Emissions
3) Well-to-Wheels Energy and Emission Changes.

The model is used by more than 14,000 users world-wide[48] and is available through the Argonne Laboratory website at: ***http://www.transportation.anl.gov/software/GREET/***

Data Inputs

The model estimates resulting GHG emissions and petroleum displacement. Emission coefficients are based on those in the GREET model. Users of the model are able to input or adjust a range of inputs and assumptions included in the model. Information is entered into fourteen input sheets allowing the user to:

- Select key options for simulation.
- Select vehicle types for simulation.
- Enter key input parameters for simulating petroleum-based fuels.
- Input key parameters for simulating natural gas-based fuels. (Key input parameters for feedstock sources [e.g., biomass and coal] other than natural gas (NG) for simulating Fischer-Tropsch Diesel [FTD], dimethyl ether [DME], and methanol [MeOH] are also included in this section.)
- Input key parameters for simulating hydrogen.
- Set assumptions regarding boil-off effects of liquefied natural gas (LNG) and liquid H2 (LH2).
- Adjust transportation distance from feedstock production sites to final destinations.
- Input key input parameters for simulating fuel ethanol.

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[48] GREET Brochure, Argonne National Laboratory.

- Enter input parameters for simulating soybean-based biodiesel.
- Input key parameters for simulating electricity generation.
- Establish input parameters for simulating vehicle operations.
- Adjust default assumptions for WTP activities.
- Input fuel economy and emission rates of baseline vehicles.
- Set fuel economy and emission changes for alternative-fuelled vehicles (AFVs) and advanced vehicle technologies (AVTs).

Ability to Adjust Model:

Key assumptions used in the model are displayed for each 5-year intervals. In addition to the ability to adjust inputs and assumptions discussed above, users can alter key assumptions for any range of years from 1990 to 2020.

The GREET model calculates emissions associated with electricity generation for a wide variety of power plant types, including both plant emissions and those associated with production and delivery of the fuels to power plants. The model uses two different sets of electricity generation mix: the first being the generation mix used for transportation use (i.e. for electric vehicles, or H2 production via electrolysis at refuelling stations) and second the average generation mix, which is used in all WTP activities.

The user can select an electricity generation mix from one of four options:

- U.S. average electricity mix
- North-Eastern U.S. average electricity mix
- California electricity mix
- user-defined mix

Model Outputs

The model provides three levels of output:

"1) The **Well-to-Pump Energy Use and Emissions** section presents energy and emission results from wells to refuelling station pumps (WTP, in Btu or grams per mmBtu of fuel available at fuel pumps) for each transportation fuel included in GREET.

2) The **Well-to-Wheels Energy Use and Emissions** section calculates fuel-cycle (well-to-wheels, WTW) energy use and emission rates for all vehicle/fuel options included in GREET. For each vehicle/fuel option, energy use and emission rates are separated into three stages: feedstock (including feedstock recovery, transportation, and storage), fuel (including fuel production, transportation, storage, and distribution), and vehicle operation. Shares of energy use and emission rates by each of the three stages are also presented in this section. This section also calculates both urban emissions (emissions occurring in urban areas) and total emissions (emissions occurring everywhere) for the five criteria pollutants.

3) The **Well-to-Wheels Energy and Emission Changes** section calculates changes in fuel-cycle energy use and emission rates for each alternative-fuelled vehicle or advanced vehicle technology. These changes are calculated against gasoline vehicles fuelled with gasoline (CG and/or RFG)."[49]

Outputs provided on per mile basis and include emissions of greenhouse gases (CO2, CH4, and N2O) and six criteria pollutants (VOC, CO, NOx, SOx,PM10, and PM2.5). Results can be broken down for urban areas and in total.

Stochastic simulations can be run to provide stochastic results for WTP results, WTW results, and WTW relative changes rather than a point estimate of energy use and emissions.

MOVES – MOtor **VE**hicle Emissions Simulator

Model Description

Developed by the U.S. EPA, the Motor Vehicle Emissions Simulator (MOVES) model[50] was intended to replace MOBILE6, NONROAD, and NMIM (National Mobile Emissions Model) by combining the results of those models into a single model. The most recent version of the model only addresses on-road emissions. The model can be run for different geographic regions (US), and for different time periods; ranging from specific hours or aggregated for months or years.

The current version of the model (MOVES2010) estimates transportation energy consumption from on-road vehicles. Future revisions are intended to incorporate off-road and other transportation options. MOVES2010a "*incorporates new car and light truck greenhouse gas*

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[49] Operating Manual for GREET: Version 1.7, prepared by Center for Transportation Research, Argonne National Laboratory, November 2005, Revised February 2007.

[50] http://www.epa.gov/otaq/ngm.htm

emissions standards affecting model years 2012-and-later (published May 7, 2010[1]*) and updates effects of corporate average fuel economy standards affecting model years 2008-2011.*[2] *MOVES2010a includes reductions in greenhouse gases associated with those standards in future calendar years, and small reductions in refuelling and sulphur-related emissions associated with the reductions in vehicle fuel consumption"*[51].

The model accounts for the impacts of vehicle speeds, age, and stock on emissions. It also includes estimates of direct and upstream emissions, based on the GREET model. MOVES can be used to develop GHG emissions estimates or to generate emissions factors for project-level analyses, though current versions are more oriented toward inventory development rather than evaluating individual project emissions.

According to the 2010 Users Guide: "MOVES is distributed free of charge by EPA …. It is written in Java and uses the MySQL relational database management system. . . . The principal user inputs and outputs, and the internal working storage locations for MOVES are MySQL databases. The MOVES model includes a "default" input database, which uses national data and allocation factors to approximate results for the 3,222 counties in the United States, District of Columbia, Puerto Rico, and the U.S. Virgin Islands. MOVES is capable of modeling emissions for the calendar years 1990 and 1999-2050"[52].

A 2006 study of available tools to model GHG emissions from transportation, prepared for the American Association of State Highway and Transportation Officials, concluded that "*Of all the tools examined, EPA's MOVES provides the most functionality and applicability for conducting different types of transportation GHG analyses. EPA's MOVES model was designed for transportation emissions analysis and overcomes most of the limitations of these other tools when it comes to GHG analysis"* [53]. The intent of the model developers is to provide a model that can be used for a range of purposes including:

- Inventory development (for US);
- Policy evaluation (e.g., technologies, fuels, travel incentives);
- Hot spot and project level analysis; and
- Model validation and uncertainty analysis.

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[51] US EPA, MOVES User Guide, August 2010, page iii.

[52] US EPA, **Motor Vehicle Emission Simulator (MOVES):** User Guide for MOVES2010a, August 2010.

[53] **Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects.** American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Environment , *Prepared by* ICF Consulting, May 2006

The model includes several advances over MOBILE6 to make it easier to use. For instance, it includes a graphical user interface (GUI), and defines vehicle use types on the basis of HPMS[54] vehicle classifications (as opposed to EPA's weight-based emission classifications used in MOBILE6); eliminating the need for transportation planners to map their HPMS data to EPA categories.

Data Inputs

Model inputs are similar to those for MOBILE6, which means that agencies which have used that model or other travel demand models may have many of the inputs required for MOVES. MOVES includes a default database of meteorology, vehicle fleet, vehicle activity, fuel, and emission control program data for the entire United States[55]. Users of the MOVES model input information such as VMT and vehicle fleet mix, usually obtained from other transportation planning processes. The tool also accounts for the effects of transportation investments and policies, including changes in levels of vehicle travel, mix of vehicles (classification and fuel type), activity patterns (e.g., VMT mix by road type and time of day), and operating speeds.

Inputs to the model include the following data types: meteorological, population, age, vehicle types, VMT and VMT fractions, average speed distributions, road types, fuel formulations, and driving schedules, among others. Use of the model is simplified by the provision of a great deal of default data, including values for vehicle age distributions, technology types, and other operating characteristics. Unfortunately the default data is all based on US jurisdictions and may not be readily applicable to the Canadian or Newfoundland and Labrador context.

The model is sensitive to factors such as VMT and vehicle operating conditions. If the user is able to provide inputs on VMT, vehicle operating conditions and fleet characteristics, then the model can be used to conduct policy analyses and examine the implications of alternative initiatives.

Ability to Adjust Model:

Users can provide an input database, to replace some or all of the default data used in the model. Each user database added can replace one or more MOVES input database tables[56].

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[54] Highway Performance Monitoring System.

[55] US EPA, Technical Guidance on the Use of MOVES2010 for Emission Inventory Preparation in State Implementation Plans and Transportation Conformity, April 2010, page 5.

[56] US EPA, Motor Vehicle Emission Simulator (MOVES) 2010User Guide, December 2009.

Model Outputs

The model produces detailed outputs in an outputs database. Results from multiple runs can be stored in a single output database to facilitate comparisons. The EPA recommends that separate output databases be created for runs that use considerably different units or aggregation. MOVES allows the user to select multiple activity output options, including distance travelled, population, starts, source hours, source hours idling, source hours operating, and source hours parked. Activity outputs are not required for Inventory calculations, but can provide a reality check on results.

The model provides resulting emissions, by emission type, by time period (down to one hour intervals), for specific or typical days, or for longer time periods (month/year).

The user can choose the units to use in their outputs (metric or imperial, etc.).

MOBILE 6

Model Description

MOBILE was initially developed in the late 1970's and has gone through a number of significant updates over time. The most current version of the model (MOBILE6.2) is available for download, at no charge, from the US EPA[57]. The model identifies 28 vehicle classes, based on fuel type, vehicle type, and weight.

MOBILE6 is the model approved by the US EPA to estimate on-road motor vehicle emission factors for use in transportation analysis at the state, region, or project level. It has become the effective industry standard for estimating transportation air emission in the U.S., however, the EPA has recently indicated that the MOVES model now effectively replaces MOBILE 6.2[58]

The model calculates CO2 emission factors as well as for three criteria pollutants (CO, hydrocarbons, and NOx). The CO_2 emission factors can be combined with VMT data to estimate resulting CO_2 emissions for a jurisdiction. The tool provides estimates of gram per mile emissions of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), carbon

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[57] http://www.epa.gov/oms/m6.htm

[58] Technical Guidance on the Use of MOVES2010 for Emission Inventory Preparation in State Implementation Plans and Transportation Conformity, April 2010, page 4. http://www.epa.gov/otaq/models/moves/420b10023.pdf

dioxide (CO2), particulate matter (PM) and air toxics from cars, light- and heavy-duty trucks, and motorcycles under various conditions[59]

MOBILE is based on emissions testing of tens of thousands of vehicles. The model accounts for the emission impacts of factors such as changes in vehicle emission standards, changes in vehicle populations and activity, and variation in local conditions such as temperature, humidity and fuel quality[60]

MOBILE6 is based on emissions testing data and models the effects of vehicle emission standards, vehicle type, vehicle operating characteristics, and local conditions such as temperature, humidity and fuel quality on criteria pollutant emission factors. The model uses average fuel economy for the US fleet for each vehicle category and model year. The model provides outputs in terms of grams of pollutant per vehicle mile. This information can be combined with vehicle miles travelled (VMT) data outside of the model to produce emissions estimates. One reported limitation of the model relates to fuel economy data for developing projections. A 2006 review indicated that much of the fuel economy data stopped in 1996 and that the model assumed that heavy-duty truck, passenger car and light truck fuel economy would stay constant for future model years and that fuel economy data ends around 2001[61].

MOBILE can be used at any geographic level within the US, from the county level to the national level.

Data Inputs

MOBILE6 provides default input values for most of the data required by the model. The default values are intended to represent US "national average" input data values[62]. Inputs include:

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[59] http://www.epa.gov/otaq/mobile.htm

[60] . http://www.epa.gov/otaq/models/mob_hist.txt

[61] Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects. American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Environment , Prepared by ICF Consulting, May 2006.

[61] Highway Performance Monitoring System.

[62] US EPA, User's Guide to MOBILE 6.1 and MOBILE 6.2, Mobile Source Emission Factor Model: User's Handbook, August 2003, http://www.epa.gov/oms/m6.htm

- Calendar year
- Month (January, July)
- Hourly Temperature
- Altitude (high, low)
- Weekend/weekday
- Fuel characteristics (Reid vapour pressure, sulphur content, oxygenate content, etc.)
- Humidity and solar load
- Registration (age) distribution by vehicle class
- Annual mileage accumulation by vehicle class
- Diesel sales fractions by vehicle class and model year
- Average speed distribution by hour and roadway
- Distribution of vehicle miles travelled by roadway type
- Particle size cut off
- Engine starts per day by vehicle class and distribution by hour
- Engine start soak time distribution by hour
- Trip end distribution by hour
- Average trip length distribution
- Hot soak duration
- Distribution of vehicle miles travelled by vehicle class
- Full, partial, and multiple diurnal distribution by hour
- Inspection and maintenance (I/M) program description
- Anti-tampering inspection program description
- Stage II refuelling emissions inspection program description
- Natural gas vehicle fractions
- Emission factors for PM and HAPs
- Output format specifications and selections

Ability to Adjust Model

The type of inputs and assumptions required by the model are generally available to government departments involved in transportation planning. Users can tailor MOBILE6 using input files; overriding default inputs and entering different data to model local conditions. A wide range of fields listed in the User's Manual can be replaced as required.

Model Outputs

Five types of outputs are provided by the model.

1. Database Output Report.
2. Descriptive Output Reports.
3. Spreadsheet Output.
4. Warning and Error Messages.
5. User Screen Dialog.

The "Descriptive Output Reports" provide summary level emission results in a printable format, but can also be output in form suitable for use by a spreadsheet or database program. the default form in an hourly format, which reports all emission factors for each hour of the 24-hour day

The database output has three forms. The default form is an hourly format, which reports all emission factors for each hour of the 24-hour day. This results in a large volume of output and is suitable only for use with database management software.

1. A daily format is also available which summarizes the hourly information into emission factors pertaining to the entire 24-hour day; significantly reducing output volume allowing analysis with spreadsheet software.
2. The third option provides an aggregated format, which aggregates the daily results into values similar to those reported in the descriptive output report(s).
3. The user cannot specify both the DAILY OUTPUT and the AGGREGATED OUTPUT commands in the same MOBILE6 input file.

COMMUTER

Model Description

The COMMUTER Model was also developed by the U.S. EPA with the objective of helping worksite transportation coordinators and local planners to estimate the impacts of commuter programs and analyze the impacts of transportation control measures (TCMs). The model is focussed on estimating changes in VMT due to initiatives such as employer-based transportation demand management programs or transit improvements. Impacts on VMT, criteria pollutant emissions, and CO_2 are modelled using default emission factors from MOBILE6. Vehicle trip, VMT, and emissions reductions associated with TDM programs are calculated automatically by the model based on inputs provided by the user. The spreadsheet based model is available for download, at no cost, from the US EPA[63]. The most recent release is from October 2005 (Commuter v2.0).

COMMUTER offers a substantial savings in time and effort compared to traditional transportation modelling approaches; employing shortcuts to reduce both data and calculation

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[63] http://www.epa.gov/oms/stateresources/policy/pag_transp.htm

requirements. The result is a trade-off of some accuracy for a significant increase in ease of use and flexibility for the user[64].

The model doesn't take the mix of vehicles affected or operating characteristics of vehicle trips reduced into account in calculating CO2 impacts. Nor does it take future changes in vehicle fuel economy into account. Emissions are only calculated for CO2, excluding the GHG effects of N_2O or CH4. The study of GHG Analysis Techniques completed for the Association of State Highway Officials concluded, however, that while the CO2 calculation procedures are fairly simplistic, the resulting uncertainty in the CO2 factors are relatively small in comparison with uncertainties in travel activity estimates[65].

The model is built around two elements: 1) an analysis of travel impacts and 2) analysis of emissions. Travel impacts are calculated using a logit mode-choice model ("pivot point" approach), which starts with current mode shares and calculates mode share changes resulting from a potential program. Multiple strategies can be analysed in combination. The changes in mode shares are then translated into changes in trips and VMT. The second part of the model then applies emission factors based on EPA's MOBILE5b model to calculate emission impacts. Two levels of analysis are possible using the model : 1) regional analyses can be done on programs covering an urban area, a central business district or a highly-travelled corridor; 2) site-specific analyses can be made for programs at individual worksites. CO_2 estimates from the model rely on a simple average emissions factor per vehicle mile.

The advantage of this approach is that the model is relatively easy to use; relying on a limited set of inputs. The drawback is that the CO2 emission factors used do not account for differences in vehicle mix, age or travel speeds. There is some ability to link to emission factors developed from another program such as MOBILE. Further uncertainty can be created by the estimates of travel impacts used.

Model can be used to test a range of strategies including:

- Transit fare decreases or other incentives that reduce the cost of using transit;

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[64] EPA420-B-05-018 October 2005, **Procedures Manual for the COMMUTER Model v2.0,** Transportation and Regional Programs Division Office of Transportation and Air Quality U.S. Environmental Protection Agency, Prepared for EPA by J. Richard Kuzmyak, Thomas R. CarlsonRobert G. DullaSierra Research, Inc., Stephen D. DeckerChristopher D. PorterErin E. VacaCambridge Systematics, Inc..

[65] Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects. American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Environment , Prepared by ICF Consulting, May 2006.

- Transit service improvements (faster or more frequent service);
- Ridesharing programs, in which employers support carpooling and/or vanpooling through on-site programs, financial incentives, or preferential parking;
- Other actions, such as increased parking charges or cash-out programs, that change the time and/or cost of travelling by any particular mode;
- Non-motorized (e.g., bicycle and pedestrian) commuting programs;
- Alternative work schedules, including flex-time, compressed work weeks, and staggered work hours; and
- Telecommuting

Data Inputs

The user establishes a baseline by supplying essential information on local conditions, The type of information required by the model includes locally-specific travel data and emissions factors based on a MOBILE6.2 run representing the area[66]. To analyse potential programs, information such as the number of employees covered and the types of benefits offered under the initiative must be entered. MOBILE6.2 look-up tables can be used to provide default emission factors in the model, though the EPA requires locally-generated MOBILE6.2 emission factors and local travel activity data where the model is used for regulatory purposes.

User specified inputs to the model include[67]:

- Metropolitan Area Size
- Application Setting Characteristics
- Affected Employment
- Mode Choice Model Coefficients
- Starting Mode Shares
- Average Trip Lengths

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[66] http://www.epa.gov/oms/stateresources/transconf/newguide_bwc.htm

[67] Ibid., page 20.

- Vehicle Occupancy
- Peak and Off-Peak Travel Characteristics

While most of the input data items that are requested by the COMMUTER model should be relatively easy to obtain, default values are provided for many of the inputs for user convenience The defaults may also be of value in checking the reasonableness of any user-supplied data.

Ability to Adjust Model

The default data supplied by the model is based on US travel patterns. The information used, including that around mode choices, is heavily based on the Federal Highway Administration's Travel Demand Management Evaluation Model (FWHA TDM Model[68]).   The TDM model was originally developed in 1993 to facilitate analysis of TDM programs and strategies for congestion management and air quality programs and was widely used across the US.

The COMMUTER mode does allow users to enter data reflecting local conditions into the model, however, it should be borne in mind that the logic and model responses are based on US experience.

Model Outputs

The key outputs for the model include:

- Baseline and final mode shares for each mode, including percent of trips eliminated;
- The percentage of trips shifted from the peak to off-peak period;
- Baseline and final peak, off-peak and daily Vehicle Miles Travelled (VMT;
- Baseline and final peak, off-peak and daily vehicle trips; and
- Changes in total daily emissions for each pollutant.

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[68] Information on the US Federal Highway Administration's Transportation Demand Model is available at: http://www.fhwa.dot.gov/environment/air_quality/conformity/research/transportation_control_measures/emissions_analysis_techniques/descriptions_tdm_evaluation_model.cfm The model is available at a cost of $250US.

GHGenius

Model Description

GHGenius is a spreadsheet sheet model, available from the OEE, that allows users to calculate full cycle GHG emissions for a wide variety of vehicle technology and fuel combinations[69]. The model was derived from the ***Lifecycle Emission Model*** (LEM) developed by Dr. Mark Delucchi of University of California at Davis[70] .

The model calculates full cycle GHG and other air contaminant emissions[71], including all emissions arising from the extraction or growth of the fuel source to its combustion in an internal combustion engine or transformation in a fuel cell. GHGenius calculates the GHG emissions from a wide variety of fuels and technologies, the amount of energy used and provided, and the cost effectiveness of the entire life cycle.

The scope of the model includes the full life cycle from raw material acquisition to end-use. Including[72]:

- Feedstock Production and Recovery
- Fertilizer Manufacture (if used in the fuel pathway)
- Land Use Changes and cultivation associated with biomass derived fuels
- Leaks and Flaring associated with production of oil and gas
- Feedstock Transport
- Fuel Storage and Distribution at all Stages
- Fuel Dispensing at the Retail Level
- Vehicle Operation
- Carbon in Fuel from Air

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[69] http://www.oee.nrcan.gc.ca/transportation/tools/greenhouse-gas-info.cfm?attr=24

[70] Model Development at Argonne, Michael Wang, Center for Transportation Research Argonne National Laboratory, GREET User Workshop, Argonne, IL, June 25-26, 2007.

[71] The model estimates emission for five GHG's (CO2, CH4, N2O, Chlorofluorocarbons, and Hydrofluorocarbons, as well as CO, SO2, NOx, non-methane organic compounds and total particulate matter.

[72] http://www.ghgenius.ca/about.php

- Vehicle Assembly and Transport
- Materials used in the vehicles

The model addresses both light and heavy duty vehicles. For light duty internal combustion vehicles the model is capable of analyzing a range of fuels including:

- Conventional gasoline (including hybrids),
- Low sulphur or reformulated gasoline (light duty or hybrid vehicles),
- Diesel fuel (regular or low sulphur) including hybrids,
- Natural gas (compressed or liquefied),
- Methanol from natural gas, coal, wood, or landfill gas in 0 - 100 % blends in conventional or reformulated gasoline,
- Mixed Alcohols from natural gas, refuse derived fuel or wood,
- Liquefied petroleum gases (LPG) from refineries and natural gas plants (propane and butane mixture),
- Hythane® (a mixture of natural gas and hydrogen),
- Hydrogen from electrolysis or reforming natural gas (compressed or liquefied),
- Ethanol from corn, sugar beets, sugar cane, wheat, barley, peas or a mix of 0-100 % wood or agricultural cellulosic material (four different agricultural feedstocks) in 0 - 100 % blends in conventional or reformulated gasoline,
- Synthetic natural gas from coal or wood,
- Butanol from corn,
- Fischer Tropsch Distillate from natural gas, wood, RDF, or coal (including hybrids),
- Biodiesel blends with biodiesel produced from canola, soybeans, tallow, yellow grease, palm, or fish oil (including hybrids),
- Biomethane from landfill gas or anaerobic digestion of manure and/or agricultural residues.

In addition seven fuel cell types can be modelled for light duty vehicles.

A range of fuels for heavy duty can also be analysed:

- Diesel fuel,
- Low sulphur diesel fuel,
- Gasoline,
- Hybrid vehicles,
- Natural gas (compressed or liquefied),
- DME (dimethyl ether),
- Liquefied petroleum gases (LPG) from refineries and natural gas plants (propane and butane mixture),
- Hythane® (a mixture of natural gas and hydrogen from reforming natural gas),
- Diesel fuel from Fischer-Tropsch (FTD) synthesis of natural gas, coal, wood or RDF and mixes of diesel and FTD,
- Ethanol from corn, sugar cane, sugar beets, wheat, barley, peas, or a mix of 0-100 % wood or four agricultural cellulosic materials in 0 - 100 % blends in diesel fuel,
- Biodiesel from soybeans, canola, palm, tallow, yellow grease, or marine oils in 0-100% blends in diesel fuel in heavy duty applications,
- Methanol made from natural gas, coal, wood or landfill gas,
- Mixed alcohols from wood, RDF or natural gas,
- Super Cetane from tallow or canola oil,
- Synthetic natural gas from coal or wood,
- Biomethane from manure or agricultural residues

Data Inputs

The quality of data is critical in any life-cycle assessment. GHGenius has data for Canada, the US, and other countries for many of the steps in the fuel processes.   Users can provide data for some steps if it is felt that better data is available.   Much of the US data has been sourced from the US DOE Energy Information Administration, including historic and projected data for electric power, crude oil, refined petroleum products, natural gas and coal production.

For Canada, data on the production of power, crude oil, refined petroleum products, natural gas and coal production has been obtained from Statistics Canada, Natural Resources Canada, Environment Canada and the National Energy Board reports. Industry associations such as the Canadian Association of Petroleum Producers (CAPP) and the Canadian Gas Association (CGA) have also been used as sources of data[73].

Full cycle emissions arise from both energy combustion and non-energy related process emissions. The model calculates these emissions based primarily on US EPA AP-42 emission factors. Vehicle emissions for conventional fuels are derived from the Environment Canada model Mobile6.2C. Alternative fuel emissions are calculated based on relative emission factors, some of which are based on analysis performed by the US EPA or other available literature.

Ability to Adjust Model:

GHGenius is populated with data for all of the processes included in the model. Flexibility is provided by:

- Allowing the user to make changes to many of the steps in the lifecycle, customizing the LCA to local needs, and,
- Enabling the user to change many of the specific steps in the life cycle.

This ability also allows the user to test the sensitivity of the processes to changes in different inputs.

Model Outputs

A range of outputs are available from the model to meet different user needs. Output data includes:

- GHG emissions in CO_2-equivalent terms (as either g/km or g/unit fuel) by stage of fuel cycle and for vehicle manufacture, for selected feedstock/fuel/vehicle combinations,
- A summary of changes in lifecycle emissions from alternative-fuel vehicles, relative to conventional gasoline LDV's or diesel HDV's,
- Emissions (in g/km) by individual pollutant for each stage of the fuel cycle for each feedstock/fuel,
- Emissions from Electric Vehicle's, by region,

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[73] http://www.ghgenius.ca/about.php

- CO_2-equivalent emissions (in g/unit of fuel) by fuel cycle stage and for vehicle manufacture, for the feedstock/fuel/vehicle combinations selected,
- CO_2-equivalent emissions (in g/GJ) (HHV or LHV) for each stage of the upstream fuel cycle for each feedstock/fuel,
- Emissions (in g/GJ) (HHV or LHV) by individual pollutant for each stage of the upstream fuel cycle for each feedstock/fuel,
- Process and end-use energy per kilometre of travel by stage of lifecycle, for different feedstock/fuel/vehicle combinations (in kJ),
- Fossil fuel use for process and end-use energy per kilometre of travel by stage of lifecycle, for different feedstock/fuel/vehicle combinations,
- Breakdown of energy use by type of energy (e.g., diesel fuel, natural gas, propane), stage of lifecycle, and feedstock/fuel combination,
- Emissions from electricity use: CO_2-equivalent emissions (in g/GJ and g/kWh delivered) for different sources of electricity generation,
- Emissions from use of heating fuels: CO_2-equivalent emissions (in g/GJ-heat-delivered) for natural gas, LPG, electricity, biodiesel and fuel oil;
- The cost effectiveness of GHG's reduced for each of the vehicle/fuel combinations in the model[74]

The model can be run for specific regions within a country, regionally or for the continent and produce all of the above results for specific regions.

A "Sensitivity Solver" and Monte Carlo simulation tool are also built into the model. Results can be presented in either a tabular or graphic format.

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[74] Descriptions all from GHGenius website: http://www.oee.nrcan.gc.ca/transportation/tools/greenhouse-gas-info.cfm?attr=24

Alternative Fuel Guide

Model Description

This relatively simple tool available from Natural Resources Canada allows users to calculate the cost-effectiveness of different vehicle types when buying alternative fuel vehicles from the original manufacturer. It is not designed to evaluate retrofits. The tool can be used to evaluate purchase of vehicles capable of operating on alternative fuels such as natural gas, propane and E-85[75].

Data Inputs

The user of the tool makes a number of selections to indicate the province in which they operate, the type of vehicle, fuel type, etc..

Ability to Adjust Model

Default values are provided for some of the values in the calculator (i.e. cost to acquire or gasoline price), but the user has the option of changing the values provided.

Model Outputs

Based on user inputs, the tool calculates savings per year and kilometre as well as a simple payback in kilometres and in years.

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[75] http://www.oee.nrcan.gc.ca/transportation/tools/afvguide/index.cfm?attr=16

6.2 Off Road:

The majority of energy use and GHG emissions associated with transportation in most jurisdictions is associated with highway (on-road) passenger and freight transportation. As a result, most available energy and emissions models focus on passenger vehicles and trucks. The most commonly used model for calculating and projecting off-road vehicle and equipment use is the "NONROAD" model available from the US EPA.

NONROAD

Model Description

The US EPA's NONROAD model[76] produces estimates of criteria pollutant emissions and CO2 from all non-road sources, similar to those provided for on-road vehicles by the MOBILE6 model[77]. NONROAD does not address commercial marine vessels, locomotives, and aircraft. "The model includes more than 80 basic and 260 specific types of non-road equipment, and further stratifies equipment types by horsepower rating. Fuel types include gasoline, diesel, compressed natural gas (CNG), and liquefied petroleum gas (LPG)"[78]. The model provides estimated air emissions for estimates emissions for CO2 as well as several criteria air pollutants, including hydrocarbons, NO_X,CO, SO_X, and particulate matter (PM 10, PM2.5 and PMT. Emissions are reported in short tons (i.e., 2000 lbs).

The current version of the model (NONROAD 2008a) is available for download from the EPA's website at no charge (http://www.epa.gov/OMSWWW/nonrdmdl.htm) .

As with MOBILE6, the EPA offers this model for use by state and local governments to estimate criteria pollutant and CO_2 emissions for compliance plans. The model covers non-road sources, such as recreational vehicles, agricultural equipment, construction equipment, lawn and garden equipment, recreational boats, airport ground support equipment, railroad maintenance equipment and others.

The model uses information on equipment populations, average load factors (expressed as an average fraction of available power), available power in horsepower, hours of use per year, and

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[76] See website: http://www.epa.gov/oms/nonrdmdl.htm#docs

[77] Like MOBILE, NONROAD reflects only emissions due to vehicle operation. It is not a full life cycle model.

[78] US EPA, User's Guide for the Final NONROAD2005 Model, December 2005, page 1-2.

emission factor with deterioration and/or new standards to estimate air emissions. Emissions are then temporally and geographically allocated using appropriate allocation factors[79].

Past, present and projected future emissions can be calculated 80 base and 260 specific non-transportation equipment categories. The "model can estimate current year emissions for the specified geographic area as well as project future year emissions and backcast past year emissions for calendar years 1970 through 2050. In estimating future year projections and in backcasting, the model includes growth and scrappage rates for equipment in addition to a variety of control program options. The model can calculate emissions for a variety of time periods — an entire year, one of four seasons, or any particular month. Emissions for the period selected are estimated either for the total period or for a typical day (weekday or weekend) in that period"[80] The model is designed to estimate emissions within the US from county to the national level, from 1970 to 2050.

Data Inputs

Inputs required by the model include[81]:

- Equipment population for base year (or base year population grown to a future year), distributed by age, power, fuel type, and application;
- Average load factor expressed as average fraction of available power ;
- Available power in horsepower;
- Activity in hours of use per year; and
- Emission factor with deterioration and/or new standards.

Ability to Adjust Model

Several input files are used to provide the required information to the model. Default values are provided for all input files, however, the user can replace the default values as required (or where better data exists).; making it relatively easy to adapt the model to local conditions.

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[79] **Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects.** American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Environment , *Prepared by* ICF Consulting, May 2006..

[80] US EPA, User's Guide for the Final NONROAD2005 Model, December 2005, page 1-3.

[81] Users Guide, page 1-6.

A review of the NONROAD model found that background calculations used in the model are not particularly transparent and noted that activity data for some of the areas addressed by the model may not be readily available and that default values used in model are not always specific to transportation-related activities[82]

Model Outputs

NONROAD produces CO_2 estimates for many non-road sources with the results broken out for specific types of equipment. The model outputs from the core model are provided as an ASCII file, that can be imported to the model's reporting utility or to a spreadsheet or database program. The reporting facility also has the ability to export to Excel.

A number of standard reports are provided, including[83]:

- Emissions Totals by County.
- Emission Totals by County and Fuel Type
- Emission Totals by Equipment Type
- Emissions Totals by Horsepower
- Emissions Totals by HP and Source Classification
- Emission Totals by HP and Equipment Type.
- Emissions Totals by SCC
- Emissions Totals by Source Classification
- Population and Fuel Consumption by HP and Source Classification
- Population and Fuel Consumption by SCC

Full descriptions of the reports are available in the User documentation.

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[82] **Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects.** American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Environment , *Prepared by* ICF Consulting, May 2006.

[83] Users Guide, Section 5.

6.3 Marine

As with other forms of transportation marine emissions are driven by 1) vessel characteristics, including vessel size, weight and hull design, engine technology and fuel type, and 2) operating characteristics such as distance travelled, speed, etc.. A wide variety of logistics and transportation demand models are available to analyse shipping routes and the impact of changes to vessel speed and travel distances or alternative shipping choices[84].

Only one model was found that provided full-cycle energy and emissions analysis modelling for marine vessels.

TEAMS: Total Energy & Emissions Analysis for Marine Systems model

Model Description

The TEAMS Model calculates fuel life-cycle energy use and emissions for different marine vehicles. The model includes all up and down stream stages of the total fuel cycle for all forms of energy consumed and presents results on a per trip basis. TEAMS calculates total energy use from all energy sources, as well as specifically from fossil fuels (petroleum, natural gas and coal) and petroleum. Air emissions are calculated for criteria pollutants(Sox, VOC, CO, NOx, PM2.5 and PM10) and various GHGs (CO2, CH4, and N2O). Total GHG emissions are calculated on a CO2e basis using a 100-yr global warming potential factor for each individual GHG type[85].

This model, available for download from the ***Center for Energy Analysis and Policy***[86], purports to be "the first-ever model able to calculate total fuel-cycle emissions and energy use for marine vessels. Development of the model was sponsored by the US Department of Transportation Center for Climate Change Research. "*TEAMS captures "well-to-hull" energy use and emissions - that is, energy and emissions along the entire fuel pathway (extraction -> processing -> distribution -> use in vessels). TEAMS conducts analyses for six fuel pathways: (1) petroleum to residual oil; (2) petroleum to conventional diesel; (3) petroleum to low-sulfur diesel; (4) natural gas to compressed natural*

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[84] For example, the US DOT has developed a tool that can be used to evaluate alternative shipping routes. See: Emissions Analysis of Freight Transport Comparing Land-Side and Water-Side Short-Sea Routes: a Freight Routing and Emissions Analysis Tool (FREAT), (undated), **http://climate.dot.gov/documents/emissions_analysis_of_freight.pdf**

[85] James J. Winebrake & James J. Corbett & Patrick E. Meyer TEAMS: Total Energy & Emissions Analysis for Marine Systems model, TECHNICAL PAPER)(Report), Journal of the Air & Waste Management Association , Jan, 2007

[86] http://www.rit.edu/cla/teams/downloads.html

gas; (5) natural gas to Fischer-Tropsch diesel; and, (6) soybeans to Biodiesel."[87] The model includes a variety of user-defined vessels, including cargo ships, passenger ferries, and container ships.

The model is described as a multi-dimensional Excel spreadsheet model. The methodology for calculating full cycle emissions from biofuels follows the same method used in the GREET model. The most recent version of the model (2007) was updated to reflect feedback from the California Air Resources Board. Three case studies and user documentation are available from the TEAMS web page.

The model can be used to complete several different types of analyses:

- Assessing full-cycle energy and environmental impacts of marine transportation, including passenger ferry and marine freight transport;
- Evaluating tradeoffs between different pollutants and marine transportation modes;
- Evaluating and comparing emissions impacts between alternative fuel marine technologies (i.e. comparing use of residual fuel, diesel, biodiesel or natural gas);
- Supporting GHG emission inventories;

Allocating marine transportation emissions to various parts of the total fuel-cycle, and;

Assisting with national or provincial assessments of criteria pollutant, GHG emission, and petroleum use.

The developers hoped the model would contribute to international discussions about GHG emissions from marine transportation fleets and help decision-makers understand the complete GHG emissions picture from marine transport.

Data Inputs

Users can only modify or enter information into certain cells in the model because the spreadsheet is "protected" to prevent users from accidentally altering cells containing formulas. As with other fuel life cycle models, the bulk of the inputs relate to the specification of different fuel-cycles.

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[87] From TEAM website (http://www.rit.edu/cla/teams/overview.htm).

Ability to Adjust Model

The model uses the global warming potential value from the IPCC's second assessment report for methane (21). The GWP values can be changed by the user.

For the electric sector, and its related emissions, the user can choose to use a default generation mix or provide a "user input" generation mix. Transmission and distribution losses can also be adjusted based on user input.

Model Outputs

Model outputs are presented on a "well-to-pump" and "well-to-hull" basis. An combination of fuels can be used for the main and auxiliary engines and separate results are presented for the main and auxiliary engines. For each of the fuel alternatives modelled, energy use and emissions are presented separately for three stages: *feedstock* (including recovery, transportation, and storage), *fuel* (including production, transportation, storage, and distribution), and *vessel operation.* The percentage shares of total energy use and emissions attributed to each stage are also presented. The model produces results in terms of both energy (mmBtu) and air emissions and calculates differences between the scenario being modelled and based case conditions. Both tabular and graphic results are presented.

6.4 Air Travel

ICAO Carbon Emissions Calculator

Model Description

The model allows passengers to estimate the emissions attributable to their travel – available from *International Civil Aviation Organization.*[88]

The methodology used in the Calculator[89] builds on a distance-based approach to estimate the GHG emissions resulting from an individual trip. The model uses current data for a range of aircraft types. The ICAO indicates that it has used the best publicly available data regarding fuel consumption and will continue to update the tool as improved information becomes available.

The tool is designed for consumer use and is therefore designed to minimize the amount of user input information regarding the flight. Industry averages are used for the various factors used in calculating the emissions associated with the individual passenger's air travel. Since actual emissions will be affected by continuously changing variables specific to each flight, average factors are used to account for the effect of these flight parameters. "While these factors cannot be captured on a flight-specific basis, this methodology considers them for the purpose of developing a more robust estimation of flight emissions and educating the public and the industry as to how these factors affect an individual passengers' emission intensity"[90].

Users enter their starting and destination airport into the model. This information is used to obtain the aircraft types used to serve the two airports concerned and the number of departures per aircraft. Aircraft are mapped to one of fifty aircraft types that have "equivalent" emissions and fuel consumption is calculated based on the distance between airports. The model takes into account passenger load factors, cargo ratios, etc. to calculate average fuel consumption that should be attributed to passengers. Average fuel consumption for the journey is weighted by departure frequency and split over "economy class equivalent" passengers to give an average fuel use per economy customer and converted to CO2equivalent emissions to derive the CO2 footprint attributable to each passenger travelling between the selected airports.

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[88] http://www2.icao.int/en/carbonoffset/Pages/default.aspx

[89] International Civil Aviation Organization (ICAO) Carbon Emissions Calculator, Version 3, August 2010. http://www2.icao.int/en/carbonoffset/Documents/ICAO%20MethodologyV3.pdf

[90] Ibid.

Data Inputs

To use the calculator, the only input required from the user is the origin and destination airport for a direct through flight (i.e. a flight which does not have a change of the flight number).

Ability to Adjust Model

There is no capacity for users to adjust the mode beyond changing their inputs, however, the structure and design of the model would result in appropriate values being used for flights arising or ending in NL.

The model represents a "best approximation" of the carbon footprint associated with air travel and strikes a balance between simplicity of use and a more accurate estimation that would require more user input. One of the key assumptions in the model relates to how energy consumption and emissions are allocated between passengers and freight payloads.

Model Outputs

The user is provided with an estimate of the CO2e emissions resulting from their flight.

Summary

A comparison of the advantages and disadvantages of the different models is presented below:

Figure 12: Comparison of Transportation Models

Model Name	Advantages	Disadvantages
On-Road		
GHGenius	• Canadian program with CDN data, electricity mix, etc.. • Life cycle emissions for fuel cycle and vehicle assembly. • Covers range of fuels and vehicle types. • Emission factors based on well-established AP-42 and Mobile factors. • Can be run for specific regions.	• Covers only passenger vehicles, does not address freight vehicles or non-road transportation.
GREET	• Industry standard program in US .	• US program designed for compliance requirements.

Model Name	Advantages	Disadvantages
	• Wells-to-wheels or wells-to-pump assessment of air emissions; including vehicle materials. • Includes both energy use and GHG/CAC air emissions. • User can change default inputs.	• Model based on US data, electricity mix, etc.. • Does not address freight vehicles or non-road transportation.
MOVES	• Intended to address on-road, off-road transportation. • Includes recently approved changes in vehicle efficiency out to 2017.	• US model – can be run for different US regions but not for Canada. • Current version addresses only on-road energy and emissions.
MOBILE 6	• Well established model; industry standard in US • Calculates CO2 and 3 CAC air emissions for on-road energy use.	• US model based on US data • Adjustable for different US regions but not for Canada. • Very detailed outputs (hourly) provide more detail than required for CCEEET purposes.
COMMUTER	• Designed for worksite coordinators to estimate impact of commuter programs • Simplified travel demand improves ease-of-use. • Allows analysis of multiple simultaneous strategies. • Most of required data relatively easy to obtain.	• US program based on US travel patterns; may need to be adjusted for NL context. • Simplified analysis doesn't take changing vehicle efficiency, changing vehicle age or travel speed (compromise to improve ease-of-use).
Off Road		
NONROAD	• Models CO2 and CAC emissions for wide variety of off road equipment. • Detailed database of off-road equipment types. • User can adjust inputs.	• US EPA program based on US data. • Designed for compliance purposes to allocated emissions in US, not Canadian, regions. • Does not cover rail, marine, or aviation emissions.

Model Name	Advantages	Disadvantages
Marine		
TEAMS	• Calculates fuel life-cycle emission for marine transportation. • First-ever life cycle model for marine emissions. • Covers variety of vessel types and fuels; allows modelling of multiple fuels per vessel.	• Limited experience with model.
Air		
ICAO Carbon Calculator	• Allows calculation of GHG emissions for point-to-point travel. • Realistic representation of split between passenger/freight and equipment used for a particular route. • Simple to use.	• Limited capabilities (specific flight between specific points). • No ability to modify assumptions or inputs used in model.

7 WASTE AND WASTEWATER

Two distinct types of models are presented in this section. The first type is designed to allow users to evaluate the energy and emission impacts of alternative waste management practices. The second is designed to allow users to estimate potential GHG emissions from a landfill facility. In addition to the tools listed below, Navigant reviewed some tools used outside of North America, such as GasSim2[91]; a landfill gas calculator used in the U.K. The tools listed below were selected as being the most appropriate match for the CCEEET's needs and most readily adaptable to the NL context.

The models for evaluating alternative waste management approaches generally take a life cycle assessment approach. As in the transportation sector, however, the boundaries of the life cycle assessment differ between models, with some including the full product life cycle (WARM and the Canadian GHG Calculator for Waste Management), while others draw the life cycle boundary at the point where the material is disposed (IWM).

A description of the selected models follows.

WARM

Model Description

EPA's **WA**ste **R**eduction **M**odel (WARM) was developed by the US EPA to provide a tool for assessing the GHG emissions from alternate waste management practices. The model can be used to develop a baseline and an alternative waste management method for handling any of 26 materials and 8 mixed materials categories[92]. It can be used by communities both to project and to measure the effects of waste management related initiatives. Being widely used, results can be readily compared to other analyses carried out in other jurisdictions. WARM is the most commonly used tool for waste management analysis in the US.

"WARM calculates and totals GHG emissions of baseline and alternative waste management practices—source reduction, recycling, combustion, composting, and landfilling. The model calculates emissions in metric tons of carbon equivalent (MTCE), metric tons of carbon dioxide equivalent (MTCO2E), and energy units (million BTU) across 34 material types commonly

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[91] GasSim2 was developed by the Environmental Agency of England and Wales and is available for a fee: http://www.gassim.co.uk/.

[92] - **http://captoolkit.wikispaces.com/WARM**

found in municipal solid waste (MSW). The emission factors represent the GHG emissions associated with managing 1 short ton of MSW in a specified manner".

To estimate GHG savings, the user first calculates a baseline scenario and then compares those emissions to alternative scenarios. Emissions are calculated on a life-cycle basis, incorporating all emissions associated with each material from the point of raw materials acquisition, through processing, manufacturing, transportation, to end-of-life management. Emissions resulting from the use of materials is *not* considered in the model's calculations (i.e. emissions resulting from energy used by an appliance). The model also assumes a closed loop for most recycled materials (i.e. a plastic bottle is recycled to become a plastic bottle). Details on exceptions are found in an FAQ for the model[93]

The model addresses a wide range of materials (see Figure 13 below), however, there are some limitations on its coverage. For example, it does not include some construction materials such as sheetrock, or household items such as furniture, toys, sporting goods, or home electronics other than PCs. A full list of materials covered is available on the WARM homepage[94]

Figure 13: Materials Recognized in WARM

Material Types Recognized by WARM

- Aluminum Cans
- Branches
- Carpet
- Clay Bricks
- Concrete
- Copper Wire
- Corrugated Cardboard
- Dimensional Lumber
- Fly Ash
- Food Scraps
- Glass
- Grass
- HPDE
- LDPE
- Leaves
- Magazines/ 3rd -Class Mail
- Medium-Density Fiberboard
- Mixed Metals
- Mixed MSW
- Mixed Organics
- Mixed Paper (general)
- Mixed Paper (primarily from offices)
- Mixed Paper (primarily residential)
- Mixed Plastics

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[93] Frequently Asked Questions - http://www.epa.gov/climatechange/wycd/waste/calculators/WARM_faq.html

[94] Material list is found on the WARM homepage: http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html.

Material Types Recognized by WARM

- Mixed Recyclables
- Newspaper
- Office Paper
- Personal Computers
- PET
- Phonebooks
- Steel Cans
- Textbooks
- Tires
- Yard Trimmings

WARM is not intended as a materials management inventory tool or to provide a GHG inventory, but rather "to help solid waste planners and organizations track and voluntarily report greenhouse gas emissions reductions from several different waste management practices.[95]" WARM is available both as a Web-based calculator and as a Microsoft Excel spreadsheet (as a 355K WinZip archive).

Data Inputs

To use WARM effectively the user must provide baseline information on waste management practices and an alternative scenario. Inputs include how many tons of waste were managed (or will be managed) for a given time period, split out by material type between different waste management practices. The "mixed" material types are defined as shown in the table below [96].

Figure 14: WARM Default Materials Types

Mixed Material Types

Material Type	Assumed Mix
Mixed Metals	Steel 71%, Aluminum 29%
Mixed Plastics	HDPE 46% LDPE 15% PET 40%.
Mixed Recyclables	Aluminum Cans 1.4%

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[95] WARM website.

[96] US EPA, User's Guide for WARM, Calculating Greenhouse Gas Emissions with the Waste Reduction Model. http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_UsersGuide.html

Mixed Material Types	
	Steel 3.4%, Glass 5.2%, HDPE 1.0%, LDPE 0.3%, PET 0.9%, Corrugated Cardboard 46.8%, Magazines/Third-class Mail 5.5%, Newspaper 23%, Office Paper 8.8%, Phonebooks 0.2%, Textbooks 0.4%, Dimensional Lumber 2.8%
Mixed Organics	Food Scraps 48%, Yard Trimmings 52%.
Mixed MSW	Represents the entire municipal solid waste stream as disposed

This may require translating existing information on the waste stream into the categories used in the model, and the composition assumed in the model (i.e. for "mixed plastics") may differ from that of the study area.

The user can customize model results based on project-specific landfill gas recovery practices and transportation distances. Default values can be used if \landfill gas recovery practices and/or transportation distances are not known.

Different can be constructed by entering data on the amount of waste handled by material type and by management practice. WARM automatically applies material-specific emission factors for each management practice to calculate the GHG emissions and energy use for each scenario.

The US EPA developed the GHG emission factors used in the model using a life-cycle assessment methodology and using the same estimation techniques developed for national inventories of GHG emissions[97].

Ability to Adjust Model

The model relies on user input to reflect the actual mix and volume of waste materials flowing to various waste streams or waste management practices. The user can view the emission factors used to estimate emissions for various materials and management practices. These emission factors reflect national average default values for landfill gas recovery and transportation distances. Several key inputs, such as landfill gas recovery practices and transportation distances to MSW facilities, can be modified by the user.

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[97] The methodology used is described in the US EPA's guide Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks (EPA530-R-06-004) available at: http://www.epa.gov/climatechange/wycd/waste/SWMGHGreport.html

As with most models there are a number of limitations to the coverage and accuracy of the model. Some key issues are listed below:

The Global Warming Potential (GWP) used for methane is based on the 100 year GWP listed in the IPCC's Second Assessment Report (SAR) from 1996 (GWP of 21) rather than the higher level (25) used in the more recent IPCC Assessment 4 (2007).

The treatment of long-term carbon sequestration in landfills in WARM differs from that in ICLEI's GHG Emissions Analysis Protocol and the California Air Resources Board Local Government Operations Protocol (WARM includes sequestration; the other protocols do not).

Each run of WARM compares against a single disposal option, requiring multiple runs for communities with more than one disposal facility (for example, a landfill with gas recovery, a landfill without gas recovery, and an incinerator).

Some materials management efforts are better evaluated using other methods and tools. WARM is not easily adapted to comprehensive comparisons of materials management strategies such as product stewardship, EPP or reuse programs. The lack of "upstream" (or production-related) emissions for food limits WARM's utility for evaluating food waste prevention projects.

WARM has been in development for over 10 years and relies on information from leading scientists and technical experts. The methodology and data has been peer reviewed at several stages[98] and the model has been widely used across the US and Canada.

Model Outputs

WARM calculates GHG emissions for baseline and alternative waste management practices and provides a choice of outputs in either metric tons of carbon equivalent (MTCE) and metric tons of carbon dioxide equivalent (MTCO$_2$E) [99]as well as energy units (million Btu).

Emissions and emissions reductions are presented in a single number and are not broken out by the year in which the emissions occur. This limits WARM's usefulness as an input to GHG inventories. Organic materials (e.g. cardboard, paper, lumber) have avoided emissions associated with source reduction and recycling that are time-sensitive.

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[98] Peer review is described in: http://www.epa.gov/climatechange/wycd/waste/downloads/BackgroundDocumentC.pdf

[99] MTCE and MTCO2E are units of measurement that express the heat-trapping effects of various greenhouse gas emissions in carbon and carbon dioxide equivalent, respectively. An international protocol has established carbon dioxide (CO2) as the reference gas.

Reductions due to an alternative waste management strategy are calculated as the difference between model runs.

Environment Canada – GHG Calculator for Waste Management

Model Description

This GHG calculator was developed by Environment Canada[100] to help municipalities and other users estimate GHG emission reductions from different waste management practices. The model is based on the United States Environment Protection Agency's WAste Reduction Model (WARM). It allows the user to estimate GHG reductions resulting from alternative waste management practices including recycling, composting, anaerobic digestion, combustion, and landfilling.

The calculator uses the same approach as WARM (described above); building baseline and alternative scenarios for managing the same quantity and composition of municipal solid waste. GHG emission reductions and energy savings are automatically calculated for the difference between the base and alternative scenario. For example, GHG emission reductions expected from a municipal program to compost organic waste instead of sending it to landfill, or an expansion of curb-side recycling could be estimated using the calculator.

Data Inputs

The data input process is the same as that for WARM.

Ability to Adjust Model

The Canadian calculator has been expanded and customized to the Canadian context by:

- Using Canadian GHG emission factors for common materials in the Canadian waste stream,
- Estimating GHG emissions from provincial fuel generation[101],
- Adding anaerobic digestion among the waste management options, and,
- Adding several new material types such as electronics and large appliances (ie. white goods).

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[100] http://www.ec.gc.ca/gdd-mw/default.asp?lang=En&n=D6A8B05A-1

[101] Note that these provincial emission factors are used to represent emissions where the products are manufactured.

The same capability exists as in WARM to change information relating to landfill gas recovery practices, and transportation distances.

Model Outputs

Model outputs are similar to those described for WARM.

Integrated Waste Model (IWM)

Model Description

Integrated Waste Model developed by Environment Canada in partnership with the Environmental and Plastics Industry Council (EPIC) and Corporations Supporting Recycling (CSR)

CSR and EPIC commissioned the development of this model to assist municipalities and others to evaluate the environmental impacts of alternative waste management initiatives. The model provides a life cycle assessment of environmental and energy effects of waste management processes, which can guide municipal waste managers in the evaluation of waste management systems and initiatives. The model was intended to enable Canadian municipalities to evaluate the environmental performance of current or proposed waste management systems.

The City of London, Ontario, as a co-participant in the project, provided an initial test case for the model and contributed to the development of the model. Environment Canada later joined the project and became a major contributor to upgrading and extending the range of waste management processes addressed by the model[102].

The IWM was subject to an independent peer review by a panel of five reviewers with expertise in life cycle analysis and waste management. It is available free of charge by registering on the IWM website[103].

A life cycle assessment (LCA) approach is used to estimate the environmental and energy impact, but it should be noted that the boundaries used to establish the life cycle differ between

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[102] http://environment.uwaterloo.ca/research/iwm-start/

[103] Link to website is given in footnote 60 or through Natural Resources Canada (http://www.nrcan.gc.ca/smm-mms/busi-indu/rad-rad/rad-gge-eng.htm#c). At the time of this review the website was being revised and links were not working, but should be available in future. Due to the limited access to the website, full documentation was not available.

models. Unlike the WARM model, the IWM defines the life cycle as starting from the point when materials are discarded.

"The life cycle of a waste on the other hand, starts when a material is discarded into the waste stream and ends when the waste material has either been converted into a resource (such as recycled material or recovered energy) or, when it has been finally disposed"[104].

The model is available free of charge to any interested party simply by registering. Registration is required to ensure that applicants receive announcements of changes and additions made to the model.

The site claims that the IWM Model is the only tool available in Canada at this time that can identify the environmental impacts of waste management decisions for a broad range of environmental indicators.

Data Inputs

At the time of this review there was limited access to the IWM website. As a result it was not possible to fully review the documentation. A further review may be carried out during the second phase of the project.

Ability to Adjust Model:

Users of the model can enter data specific to their region or municipality to ensure that results are applicable and accurate. Default values are provided, wherever possible. Multiple scenarios may be viewed at the same time, in order to allow users to make a quick initial review.

Model Outputs

Unable to review due to limited access to IWM website.

LandGem

Model Description

LandGEM is a tool developed for the US EPA, that is designed to estimate emission rates for total landfill gas, methane, carbon dioxide, non-methane organic compounds (NMOCs), and

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[104] IWM website at University of Waterloo (url provided in footnote 60).

individual air pollutants from municipal solid waste in landfills. The model is considered by the EPA as a screening tool to identify whether a given MSW landfill is subject to different regulations. It uses a relatively simple approach, based on a first-order decomposition rate equation for estimating landfill gas emissions. Default data used in the model are based on empirical data from U.S. landfills[105].

The model is comprised of nine worksheets within an Excel spreadsheet. The most current version of the model (LanGEM version 3.02) is available for download from the EPA's website[106]. The model is capable of modelling CO2, CH4, and up to 46 other air pollutants. Up to four types of emissions (gases) can be modelled at one time.

Data Inputs

Users input information to identify and describe the characteristics of the landfill being analyzed, including the years of operation and waste capacity. The model calculates emissions based on empirical data from US landfills, and assumes a waste composition that includes municipal solid waste, inert material and other non-hazardous waste. If a portion of the landfill contains primarily non-biodegradable materials (i.e. inert materials such as ash from waste combustion) then that portion may be deducted from the "waste design capacity"; though that is not generally recommended.

Waste acceptance rates can be entered for each year of landfill operation. The model is limited to 80 years of landfill operation.

A function is available to print all of the inputs entered into the model, both as a form of documentation and to allow input review.

A study of 35 Canadian landfill sites which compared landfill gas recovery to levels projected by different models found that the "Belgium, Scholl Canyon, and LandGEM version 2.01 models produced the best results of the existing models with respective mean absolute errors compared to methane generation rates"[107]. The study found that the LandGEM model

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[105] US EPA, Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide, May 2005, page 3.

[106] Down load from: http://www.epa.gov/ttn/catc/products.html#software

[107] Waste Manag. 2009 Jul;29(7):2085-91. Epub 2009 Mar 27, **Building a better methane generation model: Validating models with methane recovery rates from 35 Canadian landfills,** Thompson S, Sawyer J, Bonam R, Valdivia JE., Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2. thompso4@cc.umanitoba.ca available at: http://home.cc.umanitoba.ca/~thompso4/Buildling%20a%20better%20methane%20model.pdf

consistently underestimate methane production, while the other models included in the comparison substantially over-estimate the amount of methane produced.

Ability to Adjust Model:

LandGEM comes populated with two sets of default parameters for landfill conditions and emission factors:

1) Based on the requirements for MSW landfills under the US Clean Air Act (CAA), and
2) Inventory Defaults based on emission factors in the U.S. Environmental Protection

Alternatively, site-specific data can be used to replace the default parameters and reflect local conditions. The user can also adjust some model parameters (i.e. the methane generation rate or methane content) if required. These values vary depending on landfill location and climate.

Model Outputs

Results from the model are provided in tabular form, but may also be viewed graphically. The results display the amount of waste accepted, waste in-place, and landfill gas emissions for each year of landfill operation and include:

- Landfill closure year (provided on USER INPUTS worksheet or calculated),
- Methane content from USER INPUTS worksheet,
- Years of waste acceptance from open year to closure year of the landfill,
- Annual waste acceptance rates used by the model in megagrams per year and short tons per year,
- Annual waste-in-place amounts based on acceptance rates used by the model, in megagrams and short tons,
- Annual emission estimates for the four gases/pollutants selected, in megagrams per year, cubic meters per year, and a third user-selected measurement unit (options include average cubic feet per minute, cubic feet per year, and short tons per year. LandGEM uses average cubic feet per minute as the default third unit.

When comparing the results to measurements of gas extracted from the facility, the results must be adjusted for air infiltration.

The User documentation notes that the *Methane Content* is assumed to be 50 percent by volume (default), and carbon dioxide is also assumed to be 50 percent by volume. However, methane and carbon dioxide emission rates will differ from one another on a mass basis as methane and carbon dioxide have different molecular weights.

Summary:

A comparison of the advantages and disadvantages of the different models is presented below:

Figure 15: Comparison of Waste and Wastewater Models

Model Name	Advantages	Disadvantages
Canadian GHG Calculator for Waste Management	• Canadian model based on established WARM model. • Covers full material life cycle (extraction to end result). • List of materials covered has been expanded and adjusted for Canada. • Calculates energy and emissions for each strategy. • Automatically calculates difference from base scenario.	• Includes assumptions in WARM model (i.e. carbon sequestration), which user may not want to use.
WARM	• Industry standard model in US. • Models GHG emissions for 26 materials and 8 mixed waste categories. • Covers full material life cycle (extraction to end result). • Enables comparisons between waste management strategies	• US EPA model based on US data (waste stream mix and other factors may differ US to Canada). • Some materials not covered (construction materials, white goods). • Not intended for inventory purposes. • Multiple runs required for multiple scenarios.
IWM	• Covers material life cycle from point of disposal. • Calculates energy and emissions for each strategy.	• Does not address emissions associated with material production. • More limited support

Model Name	Advantages	Disadvantages
		available relative to Environment Canada model.
LandGem	- Estimates air emission rates for a specific landfill facility based on user inputs. - Relatively easy to use. - Found to produce best results in a study of 35 Canadian landfills. Tends to underestimate methane emissions vs. actual, while others overestimated.	- US EPA program. - Data based on US landfill data. Waste mix may differ regionally (user can adjust).

8 SUPPORT TOOLS

RETScreen – Clean Energy Project Analysis Software

Model Description

RETScreen is a decision support tool developed by Natural Resources Canada with contributions from experts from government, industry, and academia. The free software[108] provides project evaluation supports which can be used to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). The software is actually comprised of a number of models with a common look and feel and includes "product, cost and weather data, as well as a detailed online user manual"[109] as well as a case study based college/university-level training course, including an engineering e-textbook. The model can be used in multiple languages and can be switched between languages at any time to facilitate sharing of the project analysis.

The model was developed in cooperation with the United Nations Environment Program (UNEP), the UNEP Collaborating Center on Energy and Environment at the RISO National Laboratory, and the World Bank's Prototype Carbon Fund and subjected to review by a team of experts from government and industry.[110]

The software includes a number of technology-specific project models that can be used to evaluate different renewable technologies and energy efficiency projects, including:

- Wind energy,
- Small Hydro,
- Photovoltaic ,
- Biomass heating,
- Solar air heating,

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[108] Download at: http://www.retscreen.net/ang/identification.php

[109] http://www.oee.nrcan.gc.ca/commercial/technical-info/tools/software-new.cfm?attr=24

[110] The list of experts who participated in the review is included in Appendix A of the RETScreen Engineering & Cases Textbook, previously cited.

- Solar water heating,
- Passive solar heating,
- Ground-source heat pumps,
- Combined heat and power[111].

The tool was developed with the contribution of numerous experts from government, industry, and academia. It is made available worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of RETs[112]. The most recent version of the model includes a suite of models to evaluate energy efficiency measures for residential, commercial and institutional buildings; communities; and industrial facilities and processes. Climate data is available from some 6,500 ground-station locations around the globe and incorporates information from the NASA Surface Meteorology and Solar Energy Dataset for populated areas. The range of renewable projects that can be analysed has been expanded to include emerging technologies, such as ocean current and wave power.

The core of the software tool is a standardized integrated project analysis software, which can be used to evaluate energy production, life cycle costs and GHG emissions from energy efficiency and renewable energy technology projects. The user provides base information about the project and is then led through a 5-step process, performing:

1. Energy modelling
2. Cost analysis
3. Emissions analysis
4. Financial analysis, and
5. Sensitivity and risk analysis,

for the proposed project. The model compares the proposed project with a 'base case' established by the user in order to compare and contrast the costs and GHG emissions between cases. The sensitivity and risk analysis uses a Monte Carlo simulation approach.

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[111] Clean Energy Project Analysis: RETScreen Engineering & Cases Textbook, Introduction to Clean Energy Project Analysis Chapter, 2005, page Intro41. The methodology for each technology model is described in the text.

[112] http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/software_tools/retscreen.html

Data Inputs

The model is populated with climate and renewable resource data as well as product performance and specifications data for more than 6,000 clean energy systems. The user inputs data for each step in the analysis relating to the specific project under review:

- For the Energy Model the user specifies the parameters describing project location, the type of system used in the base case and for the proposed case, the loads (as applicable) and the renewable energy resource.
- For the Cost Analysis, the user enters the initial, annual and periodic costs for the proposed system, as well as any credits for the base case that are avoided in the proposed case. Alternatively, incremental costs can be entered. The user can choose between a less detailed "pre-feasibility" study or a full "feasibility" study.
- Calculation of GHG emissions is optional. If the user chooses to use the calculation, either a simplified, standard analysis or a custom analysis can be performed. The user can also choose to evaluate the project as a potential CDM (Clean Development Mechanism) project.
- For the Financial Summary, the user specifies the financial parameters to use in the analysis, including the avoided cost of energy, production credits, GHG emission reduction credits, incentives, inflation, discount rate, debt and taxes.
- For the Sensitivity & Risk Analysis (also optional) the user can elect to perform either a sensitivity analysis, a risk analysis, or both.

Ability to Adjust Model

The user can enter and change most of the key inputs to the model, including factors such as the global warming potential used for different greenhouse gases. The default value used for methane is based on the IPCC's Second Assessment Report (SAR) from 1996.

Model Outputs

The model produces a report summarizing the project and the key assumptions, inputs and system characteristics for the base and alternative case. Depending on the type of project analysed the report summarizes:

- Annual energy production and system efficiency

- GHG emissions of CO2, CH4, N2O and in total, including the emission intensity for energy and electricity used, for the base and alternative case.
- Financial evaluation of the project, including:
  - After-tax internal rate of return (IRR) and return on investment (ROI)
  - After-tax IRR – equity
  - After-tax IRR – assets
  - Year-to-positive cash flow (equity payback)
  - Net present values (NPV)

Results of the financial analysis are also displayed graphically.

9 MACRO MODELS

9.1 Overview

Macro models, for the purposes of this analysis, are defined as jurisdiction level models that simulate energy use across the economy. A number of "micro" models were addressed in the previous sector which address specific facilities or sectors. Some of these micro models, such as those dealing with transportation or waste management practices, could be applied at the provincial level but do not allow modelling of policy interactions between sectors. Macro models, which can be used to model policies across multiple fuels and economic sectors (multi-sector, multi-fuel energy and emissions models) can provide valuable insights into policy impacts that cross multiple sectors, or how portfolios of policies may interact.

Micro and macro models may both be used for some analyses. Micro models are often used to provide more detailed analysis of a sector (i.e. anticipated emissions from landfill facilities) or of specific types of facilities (i.e. building simulations), either as an input to a macro model or to carry out a more granular analysis than is possible with a macro model (i.e. more detailed modelling of changes in the power sector). The interaction between micro and macro models will depend on the type of analysis required and the level of representation in each model.

There are a number of macro models that have been used across the US. Some of these, however, have not been applied in Canada or do not have "Canadian" versions. In 2009, the NL Department of Finance recently completed a review of a number of potential macro models which could be used for evaluating climate change and energy policies[113]. The study reviewed several of the most commonly used energy and emissions models in Canada.

All models provide a simplified representation of reality. Energy use permeates all aspects of our society, so any attempt to represent energy use necessarily covers multiple sectors and a broad range of activities. Energy and emissions models attempt to represent key elements of energy use and GHG emissions in such a way as to allow modellers to study how alternative policies or initiatives may affect energy use or emissions. It is useful to think about how energy and emissions arise before considering how to most effectively model them. Figure 16 illustrates the basic relationship between assets, energy use and emissions in very broad terms:

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[113] *Models for Evaluating Climate Change and Energy Policies: A Newfoundland and Labrador Perspective,* Prepared by Economic Research & Analysis Division, Department of Finance for Senior Policy Advisor on Climate Change, Energy Efficiency and Emissions Trading, June 2009.

- The bulk of GHG emissions in most jurisdictions arise from burning fuels to provide energy services and the level of emissions tends to be directly derivable from the level of fuel use.
- Energy use is often classified in terms of categories of "end uses".

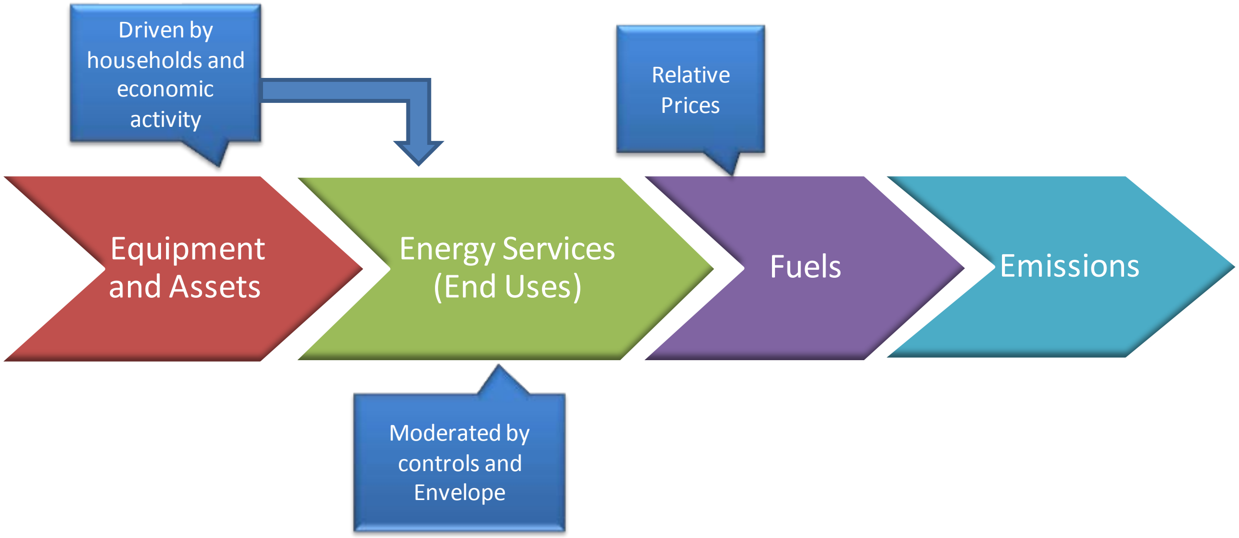


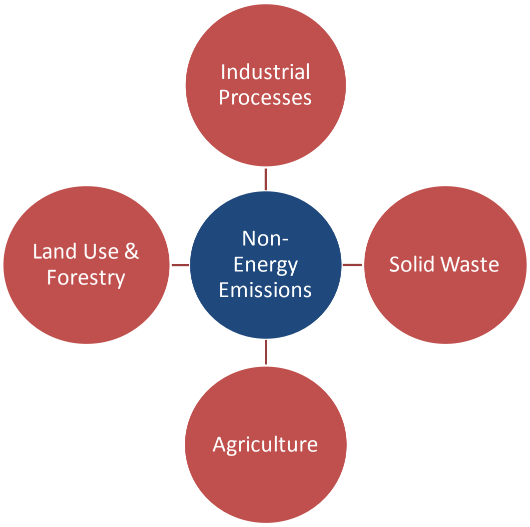
Figure 16: Simplified Representation of Energy Use

- Energy services (heat, light, mobility) are provided by devices and equipment, influenced by physical assets (building design or vehicle size) and controls (off switches to thermostats). It should be noted that the policy impacts of many potential energy/emissions policies, may be constrained by turn-over of physical, energy-consuming stocks, unless it is assumed that capital will be retired prematurely.
- The level of demand for energy services is influenced by economic and demographic activity, while choices between fuel types are driven by relative energy prices as well as equipment requirements (i.e. electricity-specific end uses).
- Devices tend to be fuel-specific and have a relatively fixed level of efficiency, so that once a choice is made to install a given piece of equipment, that efficiency level and fuel type generally remain fixed during the life of that asset.

Decisions which determine energy consumption and emissions occur at each stage or level of this process. The ability to project the impact of changing these decisions through policies and initiatives depends on the level of detail represented in the model.

GHG Emissions also arise from processes and unintentional emissions in industry as well as from agricultural, land use, forestry and waste management practices.

Figure 17: Non-Energy GHG Emission Sources

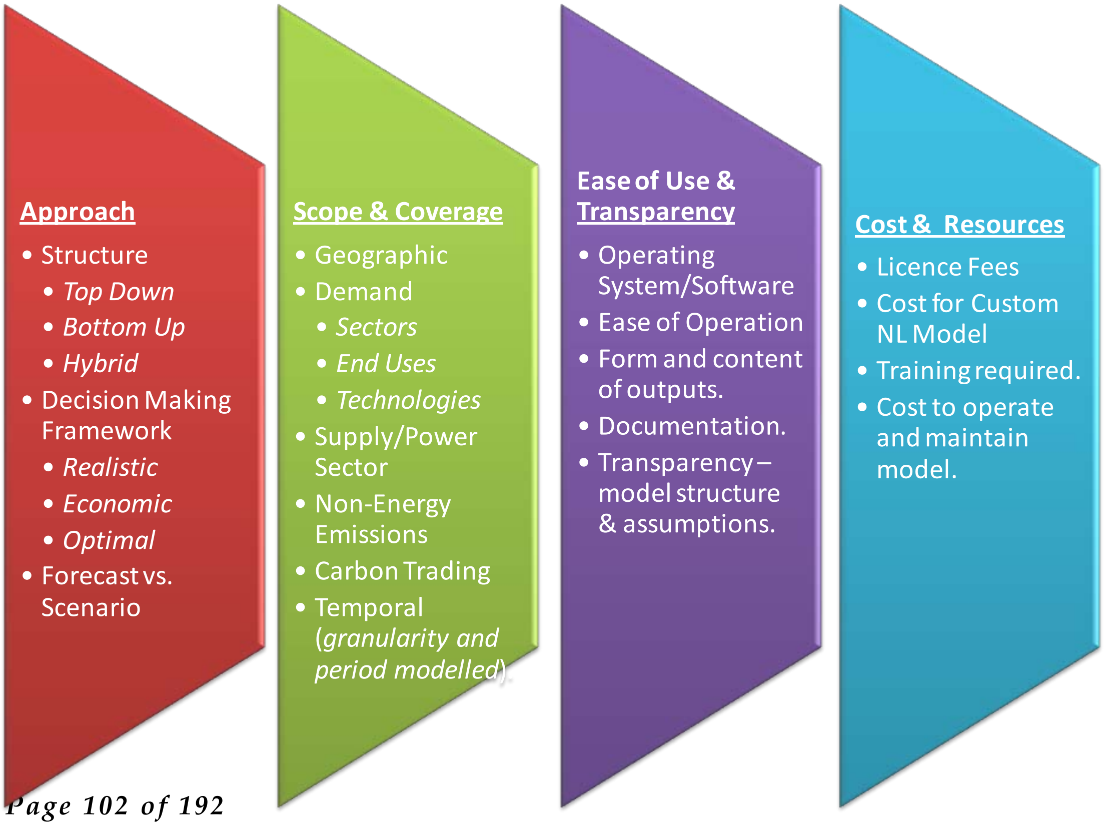


9.2 Modelling Approach

Macro models attempting to model the energy/emission processes described in Figure 16 differ on a number of dimensions. Some of the key dimensions are presented in

Figure 18 below.

Figure 18: Dimensions of Macro Models



Approach

- Structure
  - *Top Down*
  - *Bottom Up*
  - *Hybrid*
- Decision Making Framework
  - *Realistic*
  - *Economic*
  - *Optimal*
- Forecast vs. Scenario

Scope & Coverage

- Geographic
- Demand
  - *Sectors*
  - *End Uses*
  - *Technologies*
- Supply/Power Sector
- Non-Energy Emissions
- Carbon Trading
- Temporal *(granularity and period modelled).*

Ease of Use & Transparency

- Operating System/Software
- Ease of Operation
- Form and content of outputs.
- Documentation.
- Transparency – model structure & assumptions.

Cost & Resources

- Licence Fees
- Cost for Custom NL Model
- Training required.
- Cost to operate and maintain model.

Macro models are often described in terms of whether they are "top down" or "bottom up"[114]. Top down models tend to use econometric approaches to project future energy use with little or no consideration of end uses or the underlying stock of energy consuming equipment. Bottom up models on the other hand base energy use on building up a representation of energy end uses or the underlying physical assets that drive energy use. Both approaches have their relative weaknesses; top down models tend to understate constraints imposed by changing physical stocks and miss trends in end-use efficiency, while bottom up models may miss broader economic trends that can overshadow changes at the end use level. A review of energy and emissions models carried out by the National Roundtable on the Environment and the Economy concluded that:

> *"From a methodological perspective Hybrid energy-economy models are more effective in producing accurate GHG emissions forecasts as they integrate the strengths of both the traditional bottom-up and top-down approaches to modelling emissions forecasts"*[115]

Macro models also differ in terms of the decision-making frameworks assumed or applied. The general approaches can be characterized as follows:

- **Optimizing** – Some models, such as MARKAL and most models used for power sector simulations, apply some form of optimization to develop a "best" or "least cost" solution within some specified set of constraints.

- **Economic -** To varying degrees, models assume that consumers and other decision makers make choices based on an economic rationale; for example, selecting the choice with the lowest life cycle cost.

- **Consumer Choice –** Some models, such as CIMS and ENERGY2020, attempt to provide a realistic representation of behaviour and choices - models based on consumer choice/consumer behaviour – should provide a realistic indication of how decision-

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[114] A discussion of "top down" versus "bottom up" energy models is provided in Appendix C of the NRTEE's report on Greenhouse Gas Forecasting: Learning from International Best Practices available from NRTEE website: http://www.nrtee-trnee.com/eng/publications/greenhouse-gases-forecasting/section1-ghg-forecasting.php.
The report offers the following illustration: In a bottom-up model of soft drink consumption in a group of teenagers, we would look at the soft drink consumption of each teenager, and then add them up to get the group's consumption. By contrast, a top down model begins with a model of the aggregate; an attempt may be made to deduce properties of subunits from the aggregate. In a top-down model of the group of teenagers, total soft drink consumption by the group is modelled, and then we try to allocate it among individuals.

[115] NRTEE, page 6.

makers will respond to a policy – does not represent an optimal or least cost solution – usually based on past patterns of decision-making – caution required if policy or environment expected to significantly change factors around decision making (i.e. would social change that has made smoking less acceptable be captured based on analysis of past experience). ENERGY 2020 approach using QCT – CIMS claims to use this approach to some extent).

Each of these approaches may be appropriate, depending on the user's objectives. A utility choosing which type of plant to build or operate wants to know the lowest cost option and choose an optimization approach. A government may wish to know which policy option has the lowest societal cost and apply an economic framework. If, however, the intent is to understand how decision-makers will respond to a proposed policy, then a model with some representation of actual consumer behaviour will be required.

Finally, models may also differ in terms of how they are applied. Models may be designed for use in projecting or forecasting future energy use or for exploring scenarios. The differences between these approaches may be slight or quite pronounced depending on the model design. Some of the models which incorporate a representation of consumer choice may be used to simulate alternative scenarios. In other scenario models, the modeller specifies how changes in end uses or technologies are introduced. This approach eliminates assumptions about decision-making and consumer behaviour by allowing modeller to simulate a variety of different responses. The drawback of this approach is that it may not capture rich interactions between alternate choices. The advantage is that it can make those assumptions more explicit and transparent. To use one example, if the intent were to model a policy which would increase vehicle efficiency but which raises vehicle prices, a behavioural model may indicate whether consumers will choose to drive more (due to lower cost per mile), or elect to buy smaller vehicles (due to increased cost associated with increased efficiency), or delay purchase of a new vehicle (extending use of older, less efficient vehicles due to higher cost of new vehicle). By contrast, in a scenario model, the modeller could explore all of these scenarios, but would have to make a judgement as to which scenario, or combination of scenarios, would be used to project the policy impact. Models incorporating decision-making behaviours may capture these effects and their interactions to varying degrees, but the extent to which underlying assumptions in the model may determine relative effects may not be evident to the modeller.

This last point speaks to the issue of transparency. The ability to readily understand model structure and key assumptions is critical in allowing users to properly apply a model. If the model is applied in the context of a public or stakeholder process this becomes even more critical in achieving acceptance and buy-in into the overall process.

Models may be configured to represent different demand and supply segments or geography, be run for different time periods and have different capabilities in terms of representing market behaviours or market mechanisms. It is obviously critical to ensure that the macro model selected addresses the key areas of concern to the modeller. Some of the questions that should be addressed in order to match the model to organizational objectives are outlined below.

Scope and Coverage

- Geographic coverage and granularity - *Does the model cover NL only, Canada only or all of North America. Alternatively is there a need to model separate areas within NL?*
- Sectoral, End Use and Technology detail – *There is a trade-off to be made between a more detailed representation that can evaluate a wider array of options and the level of data collection required to support such an effort. Are all potential supply sectors represented (i.e. renewable fuels, new generation technologies such as wave or tidal)? For the power sector, does the model represent types of generation technology en-masse or model individual stations or generating units?*
- Temporal representation – *Some macro models only estimate selected future milestone years (i.e. every 5 years), while others provide year-by-year projections. For power sector modelling resolution of less than one-year may be required. How far can the model project into the future?*
- Market representation - *How does the model represent market mechanisms such as a cap-and-trade system, carbon tax or other such schemes?*
- Boundary issues – *How does the model represent material, energy and population flows into and out of the Province?*

Ease of Use and Transparency

- *Is the structure of the model easily understood and explained?*
- *Are assumptions included in model structure identifiable and explicit? Are assumptions incorporated in the data used in the model? Are they made explicit (i.e. costs of new technologies and how they change over time, how equipment efficiencies change over time, how do emerging technology costs change as they achieve wider adoption, etc.).*
- *Do available outputs provide the key information of interest to modellers?*
- *How long does it take to produce results (i.e. to run model, extract useful results in order to to review each scenario)?*

- *Do results provide sufficient detail to understand what is happening and why? (i.e. transportation energy use declines by less than anticipated – were reduced savings due to consumers not buying efficient new cars or driving more because cost of driving was reduced).*

Cost and Resource Considerations

- *What will the full cost be to customize the model for application in NL?*
- *What will be the costs to operate, maintain and update the model?*
- *How much time will be required to train staff and learn to use the model?*
- *Software fees involved?*

9.3 Multi-Sector Multi-Fuel Models

As discussed earlier, a number of federal and provincial agencies within Canada were contacted to identify which models and tools are being used to review energy and emissions policy issues. The results of that survey are presented in Figure 5. The publicly available multi-fuel, multi-sector macro models reported in this survey include: CIMS, ENERGY 2020, MAPLE-C, and Markal. For power sector modelling, EnerPrise Market Analytics, PROMOD and IPM were reported, as well as some in-house models.

A number of models have been used in the US by states modelling policies for *State Climate Action Plans (CAPs)* and by regional groups reviewing cap-and-trade schemes. A survey of carried out in 2008[116] found that the of 30 states which had developed CAP's at that time, 7 had used an econometric, CGE or their own in-house models, 2 had used the NEMS model, 3 had used ENERGY 2020 and 4 had used REMI (some in conjunction with ENERGY2020). A few states also reported using sector or application specific (micro) models, including GREET, WARM and the US EPA landfill gas model.

Illinois and Wisconsin, which were not included in the survey are also known to have used ENERGY2020 with REMI in developing their Climate Action Plans. A number of states are also known to have relied on spreadsheet models to analyse alternative policies included in their CAP's. An expanded version of the proprietary power sector model IPM model, referred to as IPM+, was used by the Mid-West Governor's Association (MWGA) to model carbon

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[116] The survey was completed by Hawaiian Department of Business Economic Development and Tourism (DBEDT) on behalf of the Hawaiian Greenhouse Gas Reduction Task Force.
http://hawaii.gov/dbedt/info/energy/greenhouse/Material/Encl_1I_Models_Used_by_States.pdf

trading systems. ENERGY 2020 was used to model potential cap-and-trade options for the Western Climate Initiative.

The National Round Table on the Environment and the Economy (NRTEE) carried out a review of international best practices for forecasting greenhouse gas emissions[117]. The review examined both governance and methodological issues involved in GHG forecasting and reviewed models used for energy/GHG modelling in different countries. From a methodological perspective the review concluded:

- *"Hybrid energy-economy models are more effective in producing accurate GHG emissions forecasts as they integrate the strengths of both the traditional bottom-up and top-down approaches to modelling emissions forecasts;*
- *The use of a consistent baseline from year-to-year (including baseline data), assumptions, and conditions across the board is fundamental to ensure emissions forecasts can be accurately compared from year to year;*
- *The use of consistent and agreed definitions of terms and concepts, such as for free ridership and additionality, across government departments involved in forecasting would ensure greater transparency of emission forecasts and facilitate assessment of the forecasts' accuracy.*
- *There is need for an international perspective in the model so that it can respond appropriately to world events (since in most cases, Canada is a price taker for both commodities and energy, and a primary trader of goods and energy). Canada is acting in concert with other countries on climate policy and its forecasting approaches need to reflect this reality."*[118]

From a governance perspective, the NRTEE concluded that:

- *"Use of an independent forecasting agency is preferable to provide more accurate and transparent emission forecasts .. . . .*
- *Multi-source emissions forecasting from a group of individual government departments can be accurate, but works best both when centrally coordinated and with independent authority by the central coordinating department or agency to question other departmental forecasts.*
- *Regular independent reviews, audits and evaluations of government forecasts and forecasting methods by a third-party agency or process helps ensure accuracy of forecasts and that forecasting methodologies are up-to-date and robust.*

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[117] National Round Table on the Environment and the Economy, Greenhouse Gas Emissions Forecasting: Learning from International Best Practices, available from website: http://www.nrtee-trnee.com/eng/publications/greenhouse-gases-forecasting/section1-ghg-forecasting.php

[118] NRTEE, page 19.

- *Forecasting must be sufficiently resourced and financed by governments to ensure data is up to date and most recent improvements in forecasting methodologies are incorporated for the benefit of policy makers taking decisions based on these forecasts.*
- *Regular, ongoing evaluation of past forecasts for accuracy and effectiveness is necessary to ensure continuous improvement of government forecasting methodologies and approaches.*
- *Ensure transparency and clarity with respect to key assumptions and methods"*[119].

The review also proposed criteria for assessing potential forecasting models:

- *"past accuracy, which may or may not bode well for future forecasts;*
- *sound representation of current and emerging system dynamics, which should increase the probability of a better forecast;*
- *greater transparency, which increases the ability for outsiders to examine and critique all key assumptions, and perhaps test alternatives; and*
- *the ability to conduct and record sensitivity analyses, which should improve the understanding of the critical forecast model assumptions and related key uncertainties"*[120]

A common theme arising from the review was the importance of transparency, both in terms of the model and in terms of model inputs. The ability to have independent parties review the model and forecasting process and assumptions was noted as a key best practice. The report also focussed on the value of being able to explore multiple scenarios and sensitivity forecasts to aid understanding of both model assumptions and the impacts of model changes in areas of uncertainty.

A number of energy and emissions models were identified based on this review of models used in other jurisdictions and Navigant experience. The table below lists both energy and emissions macro models as well as economic models. Given the focus of this report and the identified needs of the CCEEET, only the multi-sector energy and emissions models are discussed below.

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[119] NRTEE, page 19.

[120] NRTEE, page 8 of 24.

Figure 19: Jurisdiction Level Macro Models

Multi-Sector Energy & Emissions Models	
Models Applied in Canada:	**US & InternationalModels** (not applied in Canada)
CIMS	IPM (IPM+)
CanESS	LEAP
ENERGY2020	NEMS (National Energy Modelling System)
MAPLE-C	
MARKAL	

Summary descriptions of all of the models listed in

Figure 19 are provided below.

CanESS

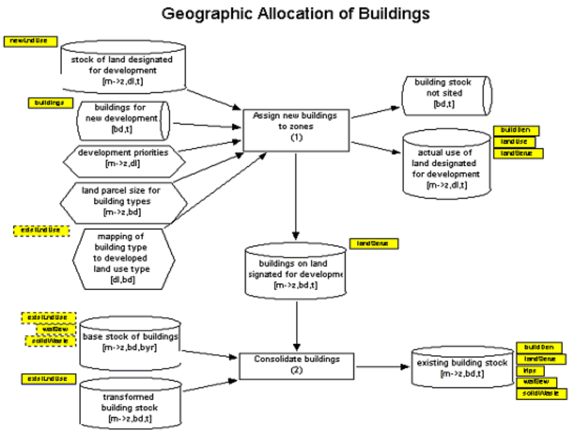
The Canadian Energy Systems Simulator (CanESS) is an interactive scenario model designed specifically for the Canadian market using software specifically designed for model building. The model is based on a bottom-up stock and flow representation of the physical assets underlying energy use and emissions.

CanESS is an integrated model of the physical economy, energy use and demand that represents Canadian energy supply and demand systems from the bottom up and can be used to explore the long-term impacts of ongoing transitions in the energy system or examine alternative future scenarios.

Energy use in the transportation, residential, commercial and industrial end use sectors is represented at a detailed sector and end-use level. On the supply side, production of electricity and hydrocarbon fuels from a wide range of energy sources is also modeled in detail. The model is calibrated for each year from 1978 to the base year to create a complete historical database of all of the variables.

The model differs from other available models in that it does not incorporate assumptions about behaviour and decision making frameworks. In designing the model a conscious choice was made to separate the representation of the underlying, physical basis of energy use from the decison-making and behavioural framework affecting future energy use. As a scenario model, CanESS allows the modeller to choose between relying on past patterns of market shares, equipmnt efficiency levels, etc. or to specify how those shares will change in future. Alternative decision-making frameworks (i.e. cost minimizing behaviour) can be layered onto the model depending on modeller needs.

Figure 20: Illustrative Relationship Diagram



The model structure is built around hierarchical and relationship diagrams, allowing users or other to view model structure and the relationships between variables. The model developer "whatIf? Technologies" claim that the model development process is essentially self-documenting,.

The interactive nature of the model allows users to explore a range of possible scenarios or outcomes.

CanESS is relatively new compared to other energy and emissions models. It has been used by a number of federal and provincial agencies since 2004.

A more complete description of the CanESS model is provided in Appendix A.

CIMS

Originally known as ***Canadian Integrated Modeling System***, and introduced to the US as Consolidated Impacts Modeling System, the model is now just referred to as CIMS. A recent study using CIMS provides the following summary description of the model:

"CIMS is a hybrid energy-economy model that simulates the technological evolution of the energy-using capital stock in the Canadian economy (such as buildings, vehicles, and equipment). CIMS has a detailed representation of technologies that produce goods and services throughout the economy and 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. CIMS simulates the competition of different technologies 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. It also includes a representation of equilibrium feedbacks, such that the supply and demand for energy intensive goods and services adjusts to reflect policy"[121].

A comparison with the MARKAL optimization model describes the behavioural framework used in CIMS as an attempt to reflect "bounded rationality of decision making". The algorithms used to estimate consumer decisions attempt to achieve the lowest life cycle cost, but include a variable to reflect "intangible costs", such as perceived convenience, status issues, imperfect information, etc.[122].

The high level of technological detail included in CIMS comes from a "myriad" of sources and imply a need for continuous updating and maintenance of these databases.

CIMS uses a detailed spreadsheet model of electricity supply for each province which finds a cost-minimizing solution to electricity production, but is not a full linear optimization solution[123].

In order to model economic feedbacks between the energy sector and broader economy, CIMS is run in multiple stages for each 5-year period. The first phase estimates the impact of a policy on final goods and services. The second phase then calculates energy demand and prices. If prices vary by more than a threshold amount then the model iterates until an equilibrium set of prices and demands are achieved.

A more complete description of the CIMS model is provided in Appendix B.

ENERGY2020

ENERGY 2020 is a detailed multi-sector, multi-fuel model that has been used for a wide variety of energy and climate policy analyses for almost three decades. It includes a detailed representation of energy end uses for a range of economic sectors and housing types. Primarily a scenario model, ENERGY 2020 is differentiated by its use of Qualitative Choice Theory (QCT) to represent consumer behaviour and decision making. Both energy demand and energy supply are represented in the model. The model projects energy demand, electricity sales, prices, electric generation mix, fuel-switching, capacity expansion, and air emissions, and can be used to model the financial health of the electric and natural gas

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[121] Final Technical Report - The capacity for integrated community energy solutions policies to reduce urban greenhouse gas emissions, Prepared for: Quality Urban Energy Systems of Tomorrow (QUEST) , August 26, 2010, Submitted by: M. K. Jaccard and Associates.

[122] Combining Top-Down and Bottom-Up Approaches To Energy-Economy Modeling Using Discrete Choice Methods, Nic Rivers & Mark Jaccard, The Energy Journal, Vol. 26, No. 1, 2005, page 87.

[123] Simon Fraser University, Policy Modelling website: http://www.emrg.sfu.ca/Our-Research/Policy-Modelling

industries. The model also estimates economic effects of policies (i.e. changes to electricity prices, levels of investment, etc.) which can be used to determine the benefits or costs of new facilities or changing energy prices to the economy. Energy 2020 can also be linked to run iteratively with a more sophisticated macroeconomic models in order to calculate impacts on GDP, personal income and employment.

The representation of decision making used in ENERGY2020 may be both the model's greatest strength and greatest weakness. The QCT approach essentially separates price and non-price elements of decision making, providing a more realistic representation of how consumers make decisions about new energy-consuming equipment. The disadvantage of this approach is that it can lead to the perception that the model is a 'black box' and make it difficult to understand how the model arrived at certain results. The model developers (Amlin and Backus) claim that the model has successfully predicted system behaviours in a variety of situations, including electricity market deregulation and DSM program performance[124].

A more complete description of ENERGY2020 is provided in Appendix C.

MAPLE-C

MAPLE-C is a version of the US Energy Information Administration's NEMS model, modified to reflect the Canadian economy. The model is built around modules that represent 11 different regions of Canada (10 provinces plus the territories). The earlier review by the NL Finance Department concluded that MAPLE=-C was not recommended for use by the CCEEET. MAPLE-C would be one of most expensive models reviewed by that study, to implement and maintaining the model would require maintenance of data for 11 regions. ***We concur that MAPLE-C is not an appropriate match to the CCEEET's objectives.***

MARKAL

Developed over two decades by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency[125], MARKAL (the MARKet Allocation Model) has been used to model US energy systems at the national, regional, state, or community level. The model uses an "optimization framework"[126] to select technologies that minimize total system cost.

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[124] George Backus and Jeff Amlin, "A History of Making Energy Policy - 27th International Conference of the System Dynamics Society, July 2009. Paper lists several pages of examples of past projects where the model simulations predicted subsequent market behaviour.

[125] See website: http://www.etsap.org/Tools/MARKAL.htm#back

[126] *Projections of Industrial Energy Use: Does the Modeling Framework Make a Difference?* Joseph M. Roop, Pacific Northwest National Laboratory PNNL-SA-46673 Lorna Greening, Consultant, Los Alamos, New Mexic,

Emission impacts (both GHGs and criteria pollutants such as SO_X and NO_X) of alternative policy and technology options can be compared between scenarios. Technologies in the model are represented by a set of performance and cost standards. The US model has a database containing a menu of current and predicted future technologies, emission standards, and emission coefficients. Past Canadian users have included the Alberta Research Council, Saskatchewan Energy and Mines, University of Regina and Hydro Quebec. The previous NL review of models recommended that MARKAL not be adopted, in part due to lack of Canadian experience and in part due to a lack of potential support for model development. In addition to those reasons, we suggest that the optimization approach used in MARKAL-TIMES is not well suited tot he CCEEET's objectives.

Models Used in US and Internationally:

A number of other models have been widely used in the US and elsewhere for energy and climate policy analysis. Brief descriptions of these models, which have not been applied in Canada, are presented for information.

IPM+

The Integrated Planning Model (IPM®) is a linear optimization model, used by the US EPA, Environment Canada and others, in modelling power system issues. A multi-sector, multi-fuel version of the model, owned by ICF International, has been developed for the US and was used to model a potential cap-and-trade system for the Mid-West Greenhouse Gas Reduction Accord (MGGRA). A Canadian version is not available at this time.

LEAP (Long-range Energy Alternatives Planning System)

The LEAP model is a scenario-based modeling tool used internationally for energy and climate policy analysis developed by the Stockholm Environmental Institute. It can be used to track and project energy supply and demand in all sectors of the economy as well as non-energy sector GHG emissions.

"LEAP is not a model of a particular energy system, but rather a tool that can be used to create models of different energy systems, where each requires its own unique data structures. LEAP supports a wide range of different modeling methodologies: on the demand side these range from bottom-up, end-use accounting techniques to top-down macroeconomic modeling. LEAP also includes a range of optional specialized methodologies including stock-turnover modeling for areas such as transport planning. On the supply side, LEAP provides a range of accounting and simulation methodologies that are powerful enough for modeling electric sector generation and capacity expansion planning, but which are also

sufficiently flexible and transparent to allow LEAP to easily incorporate data and results from other more specialized models[127]."

The model can generate optimum or market-equilibrium scenarios or be used to identify least-cost scenarios. Intended for use in modelling medium to long-term scenarios most of its calculations occur on an annual time-step. One of the key benefits claimed for the model is its ability to start with limited data, depending on the options chosen. "*Modelling tools that rely on optimization tend to have high initial data requirements because they require that all technologies are fully defined both in terms of both their operating characteristics and their costs. They also require that the market penetration rates of those technologies have been reasonably constrained to prevent implausible knife-edge solutions. Developing the data for such models is a time-consuming task, requiring relatively high levels of expertise.*[128]

The model includes a number of built-in tools to simplify the model creation and projections. Non-consulting licence is available for cost of $1,000 to $3,000 for one or more users at a single site. Support and training are also available.

The National Energy Modelling System (NEMS):

NEMS is a hybrid general equilibrium model of U.S. energy use and economy designed and implemented by the U.S. Energy Information Administration (EIA) of the Department of Energy (DOE). The model projects the production, import, conversion, consumption, and prices of energy, subject to assumptions on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioural and technological choice criteria, cost and performance characteristics of energy technologies, and demographics[129]. NEMS provides a very comprehensive treatment of supply-side technologies (particularly in the electricity sector), and a detailed treatment of energy demand at the end-use level. Projections are made on a year-to-year basis, including changes resulting from new energy programs and policies. The model has been used to project the impact of carbon dioxide fees and emissions caps, trading, and banking of emission credits for carbon dioxide, sulfur dioxide, nitrogen oxides, and mercury in the electricity generation sector. NEMS is used to produce the EIA's *Annual Energy Outlook* for the U.S.

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[127] LEAP website: http://www.energycommunity.org/default.asp?action=47

[128] LEAP website.

[129] See "The National Energy Modeling System: An Overview": http://www.eia.doe.gov/oiaf/aeo/overview/

9.4 Model comparisons

Based on our assessment of the available models and the identified needs of the CCEEET, Navigant has identified three models as being most appropriate to NL's needs:

- CanESS
- CIMS
- ENERGY2020

More detailed descriptions of these three models are provided in Appendices A to C.

The final determination of which model to select will depend on the CCEEET's assessment of its key objectives in using such a model, the types of policies it wishes to examine, whether it wishes to use the model in-house, and of course, cost considerations, including the cost of developing and maintaining data required

A comparison of model features is presented in Figure 21. For consistency and ease of comparison, the table incorporates some information included in the prior analysis entitled "*Models for Evaluating Climate Change and Energy Policies: A Newfoundland and Labrador Perspective*" carried out by the Economic Research & Analysis Division of the Department of Finance for the CCEEET in 2009. Content from the prior NL analysis is indicated in italics. Additional elements have been added to the analysis to reflect some key considerations and the screening criteria established for this project.

Figure 21: Comparison of Macro ***Model Features***

Note - *Text shown in italics based on NL Review of models*(1). Balance of table based on review by Navigant.

Model	**CanESS**	**CIMS**	**ENERGY2020**
Background & Approach			
Developer	***whatIf? Technologies (WIT)*** Ottawa, Ontario Founded in 1989 (as Robbert Associates). Contact: Michael Hoffman, Principal	Energy and Materials Research Group (EMRG) at Simon Fraser University *and* ***M.K. Jaccard and Associates(MKJA)*** Contact: Mark Jaccard, President, MKJA.	***Systematic Solutions, Inc.*** *(SSI), Fairborn, Ohio* *Founded 1985* *Contact: Jeff Amlin, President* Now located in Xenia, Ohio
Model Description	A **scenario** model with rich representation of physical assets which drive energy consumption. Based on software platform designed for model development and scenario analysis.	*A technology-vintage model that* ***forecasts*** *emissions via the turnover of energy-using and energy-supplying technology stocks. CIMS models consumers' choices of new technologies.*	*A technology-vintage model that* ***forecasts*** *emissions via the turnover of energy-using and energy-supplying technology stocks. ENERGY2020 models consumers' choices of new technologies.*
Modelling Approach	**Bottom up scenario model** of energy demand and supply. CanESS keeps track of the physical stocks and flows of energy feedstocks and fuels, the stocks of capacity for producing energy and the stocks of artefacts such	**Hybrid** – top down equilibrium economic model with macro-economic demand feedback and demand-dependent supply and energy trade. Assumptions built into model w.r.t. changing urban	**Hybrid** – bottom up representation of demand and supply sectors with QCT-based behavioural/decision making framework and optimized power system dispatch. Economic feedback provided by linking to

Model	CanESS	CIMS	ENERGY2020
	as vehicles, hot water heaters, HVAC systems, and appliances that use energy in the production of services. The model is calibrated with historic data from 1976 to 2006 to ensure model is aligned with historic stocks and flows and runs in 1 year steps to 2100.	planning/land use and impacts on energy demand.	macro-economic model.
Decision-making Representation	Representation of physical energy using assets and equipment intentionally modelled separate from behaviour and decision-making. Modeller can exogenously determine future market choices under different scenarios or apply alternative behavioural/decision-making frameworks to marginal changes in physical assets.	Models technology choice based on approach used in predecessor ISTUM[130] models; simulating purchase decisions based on "observable" and intangible costs and risks[131].	Qualitative Choice Theory (QCT) used to provide realistic representation of consumer and business decision making.
Past Canadian Clients	• Alberta Department of Energy • Alberta Energy Research Institute	• BC Climate Action Secretariat • Greater Vancouver Regional	• Environment Canada • National Energy Board

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[130] ISTUM – Intra-Sector Technology Use Model

[131] See Appendix B. From SFU EMRG CIMS website: http://www.emrg.sfu.ca/Our-Research/Policy-Modelling.

Model	CanESS	CIMS	ENERGY2020
	• Natural Resources Canada • Energy Futures Network • National Research Council • Pembina Institute • Transport Canada (CanTEEM model; predecessor of CanESS)	District • BC Hydro • Translink • Alberta Energy • Alberta Environment • Alberta Innovates • NWT Government • National Round Table on the Environment and the Economy • Natural Resources Canada • Environment Canada • Canadian Gas Association • NL CCEEET • SK Ministry of the Environment • The Pembina Institute • The David Suzuki Foundation • Ontario Power Authority • Ontario Power Generation • Atlantic Canada Opportunities Agency.	• Ontario Ministry of Environment • National Round Table on the Environment and the Economy • Province of Alberta • SK Energy and Resources

Model	**CanESS**	**CIMS**	**ENERGY2020**
Scope & Coverage			
Geographic Coverage	Model broken out into 10 regions (provinces) with territories aggregated with BC.	*Seven regions: BC, AB, SK, MB, ON, QC, aggregation of Atlantic Provinces.*	Covers all 10 Canadian provinces, and 3 territories (aggregated with BC), and 50 US States as well as Mexico. Can be configured to model a single province or region.
Adaptable to NL	CanESS has a representation of NL based on a combination of national and available provincial level data. Much of information for NL is confidential in national sources, so data currently in model represents a best estimate. A stand-alone NL-specific model could be created and the model re-calibrated using NL specific data if better data is available.	Yes. *NL-specific model does not exist but is possible.*	*Yes.* *No NL-specific model exists but company claims it can produce a custom-tailored NL.* ENERGY2020 models are often built for specific jurisdictions or regions as required.
Demand Sectoral Representation	Detailed representation of demographic and economic drivers, and physical stocks of energy consuming equipment. • Residential – 3 dwelling types and 100 thermal archetypes. • Commercial – 10 building types. • Industrial - 9 sub-sectors (2-digit	Four demand modules: • Residential – 4 housing types • Commercial – 10 sub-sectors • Industrial – 7 sub-sectors; plus 4 energy producing sectors. • Transportation- split between passenger and freight. Five modes represented with sub-sets	• Residential – 3 classes • Commercial – 16 sub-sectors • Industrial – 10 sub-sectors (23 in US) • Transportation – 7 modes (on/off road, rail, marine, air, bus, etc.). • Split between passenger and freight.

Model	CanESS	CIMS	ENERGY2020
	NAICS) plus separately modelled energy producing sectors (8-10). • Transportation – split by passenger and freight, 6 modes.	for some modes (i.e. light duty and transit passenger vehicles).	
Detailed End-Use	Yes	*Yes*	*Yes*
End Use Representation	• Residential – 16 heating systems, 46 water heaters, 6 air conditioners, 15 major and 8 minor appliances and 7 types of lighting (all vintaged). • Commercial – 6 end uses • Industrial – no end use representation for non-energy producing sectors. Energy production sectors are modelled from extraction to production of energy 'currencies'. • Transportation – 5 road vehicle sizes, 22 engine types, 20 fuels.	• Residential – 7 end uses • Commercial – 7 end uses. • Industrial – 4 end use categories. • Transportation - Small and large cars and light trucks, buses light/medium freight trucks, heavy freight trucks. • 7 fuels for on-road; 3 fuels for off-road and specific choices for rail, marine and air transportation.	• Residential – 8 end uses • Commercial -6 end uses. • Industrial – 4 end use categories. • Transportation – 3 classes of vehicles modelled for passenger and freight on-road vehicles. • Up to 6 fuels modelled for each end use.
Supply Sector Representation	All forms of energy production are represented in the model; including power sector, oil and natural gas production, oil sands and petroleum refining. Bio-ethanol and bio-diesel	• Power sector based on spreadsheet model of supply • Electricity and petroleum refining modules can be replaced by MARKAL.	• Power sector • Oil and gas – including oil sands (3 segments - in-situ, mining and upgraders). • Refineries represented as

Model	CanESS	CIMS	ENERGY2020
	sectors have been modelled for the National Research Council. Each sector is modelled from resource extraction to production of energy products (i.e. electricity, gasoline or ethanol fuels for consumption).		industrial sector. • Bio-fuels – limited representation.
Power Sector Representation	Archetype generation technology types are dispatched to 8760 hour load shapes. Dispatch logic uses dispatch order to represent realistic generation dispatch.	Model uses spreadsheet model of electricity supply to find least cost solution (not linear programming).	Model can be run with unit-level representation or archetype plants. Uses LINDO linear optimization process to optimize dispatch.
Non-Energy GHG Modelling	Non-energy related GHG emissions from industrial processes, land use, solid waste and agriculture are all modelled.	Non-energy GHG emissions from solid waste, agriculture, ammonia and hydrogen production, natural gas formation CO2, venting and flaring in oil and gas, methane leaks in coal, oil and gas are represented as process emissions related to a physical amount of some process represented in the model (e.g. per tonne of ammonia or tonne of cement clinker produced). Non-energy	Represents industrial process emissions at sub-sector level, LULUCF, waste and wastewater non-energy emissions. Less detailed structure than for energy. Projected emissions related to relevant drivers for each sector.

Model	CanESS	CIMS	ENERGY2020
		emissions release during the synthesis of adipic acid and nitrous acid are not included.	
Macro-economic Feedback	Macro-economic inputs are used as drivers in the model, but there is currently no feedback based on energy use or investments.	*Simplified; MKJA continues to develop Dynamic General Equilibrium Emissions Model (DGEEM) that is linked to CIMS.* Model is run in 2 phases; first phase models final demand for goods and services; 2nd phase then calculates energy demands. If prices change by more than a threshold amount, model runs iteratively to solve.	Has been linked to various macro-economic models. Environment Canada runs model with TIM (the Informetrica Model). Economic impacts are estimated by iteratively feeding changes in prices, investments, etc. from ENERGY 2020 back to macro model until convergence achieved. Should be able to run with NALEM.
Emissions Trading Capability	Not included in current version of model.	Model has been used to simulate Canadian carbon trading systems and carbon taxes, and alternate allocations of carbon revenues.	Yes. Model has been used by Environment Canada, Ontario MOE, Western Climate Initiative and several US states to model potential cap-and-trade systems.
Ease of Use & Transparency			
How is Model normally applied	*what If?* recommends development process start a design workshop in which WIT staff meet with client to review and customize model. Model	MJK reports that some clients possess the model used for their analysis as a data/assumption store, but none operate it in-house.	For most clients, SSI develops and operates the model and delivers results to client.

Model	CanESS	CIMS	ENERGY2020
	may be operated by client or hosted by whatIf? Technologies. Client may operate the model to run scenarios, make changes to the model, or use WIT to do either. Model may be hosted by client or WIT.	They indicate that they are working to put elements of CIMS into user-friendly community energy and emissions model in a project funded by the Pacific Institute for Climate Solutions. The resulting product is to be publicly available and will be operated by local/municipal governments.	
Clients currently operating software	The CanESS model has been applied to a number of projects, but is not currently hosted by any existing clients. A number of clients operate comparable models built on whatIf? platform. • **Transport Canada, Sustainable Development Division** (Transport Canada Transportation Energy and Emissions Model) - operate the model. • **National Energy Board,** EDM (Energy Demand Model) and CanPlan – NEB staff operate but do not make changes to the model.	None. Model is operated by MKJA, not currently available in a form that can be operated by clients.	• **Environment Canada** – Operates model linked to Informetrica model and make changes to model. • **California Air Resources Board (CA ARB)** – Operate model to run scenarios but do not make model changes. • **NEB** – Run and modify the model with SSI support. • **Bonneville Power Administration (BPA)** – Run and modify BPA version of model. • **Northwest Power &**

Model	CanESS	CIMS	ENERGY2020
	• **Natural Resources Canada, Office of Energy Efficiency, Energy Demand and Policy** (Energy end use and Technology data base) – OEB staff operate the model. • **Commonwealth Scientific and Industrial Research Organization (CSIRO)**, Australia. CSIRO staff have used WIT software system to build a stock and flows energy model for Australia similar to CanESS. • **Regional Municipality of Waterloo** - RMOW staff operate a WIT land use model and build own scenarios.		**Conservation Council (NWPC)** – runs model and does some manipulation with SSI support.
Data Inputs & Requirements (Note: Data requirements reflect level of detail and breadth of coverage	• StatsCan CanSIM (Demographics, GDP, Agriculture, Land Use) • OEE RESD • OEE DPAD • National GHG Inventory • EPA Mobile 6 Model & Database • Electric Power Statistics • CanPlan National Energy Board	*Uses data from: Statistics Canada, NRCan, the Canadian Industrial Energy End-Use Data and Analysis Centre and the National Energy Board.* Reportedly requires detailed information on technologies that	*Initial energy demand, supply and prices, as well as unit-by-unit generator data (if unit-level representation used). GDP, gross output per sector and income from a linked macroeconomic model or other forecast source. Projected fuel prices and technology*

Model	CanESS	CIMS	ENERGY2020
in each model).	(NEB) • LCA models (GREET/ GHGenius) • Scientific Reports (Sandia Labs, Battelle, USDA, …) • Anecdotal Data WIT recommends starting with a needs analysis and discussion of what data is available in order to most effectively focus data collection efforts.	comprise existing building and equipment stocks and information on how the equipment stocks change over time.	*costs and performance. Availability and costs of offsets.* Inputs and assumptions used in several past modelling exercises for various US states and the WCI are available on-line[132].
Documentation	Approach to model development uses linked structural diagrams to represent model relationships. Computer Aided Software Engineering (CASE) used for model development provides self documentation. Reference manual produced for model includes hierarchy diagram showing model		Model documentation updated in past few years. Documentation for the model has been posted on California Air Resources Board site as part of it's Scoping Plan[133]. The assumptions and data inputs used in several ENERGY 2020 modelling exercises are also

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[132] For example the Inputs and Assumptions used in modeling for the WCI (which included several Canadian Provinces, can be found at: http://www.westernclimateinitiative.org/component/remository/Economic-Modeling-Team-Documents/Updated-ENERGY-2020-Inputs-and-Assumptions

[133] Energy 2020 Documentation available at: http://www.arb.ca.gov/cc/scopingplan/economics-sp/models/models.htm

Model	CanESS	CIMS	ENERGY2020
	components and structure with descriptions of each variables, units of measure, dimensions and data sources. User can view structure and drill down to specific variables and data.		available on-line. For example, the "*2009 Assumptions Book*" for the CA ARB modelling is available from the same link noted above for the documentation.
Model Outputs	Interactive. User can interactively run model and produce graphic or tabular scenario results to compare several scenarios. Allows user to 'drill down' into model to review factors behind changes, investigate relationships and review data.	Batch operation. Model results for multiple scenarios are organized and compared in an excel spreadsheet.	Batch operation. Model outputs are produced in Excel compatible form. Standard reports are available or they may be customized to user needs. Differences between scenario runs are normally compared in Excel spreadsheets. Model run times vary depending on model complexity.

(1) Models for Evaluating Climate Change and Energy Policies: A Newfoundland and Labrador Perspective, Prepared by Economic Research & Analysis Division, Department of Finance for Senior Policy Advisor on Climate Change, Energy Efficiency and Emissions Trading, June 2009, Appendix 1: Summary of Models.

All three of the models proposed for consideration provide a relatively detailed representation of energy demand by sector and end use. The key advantages and limitations of the three models selected (*not in order of preference*) are summarized in the Figure 22.

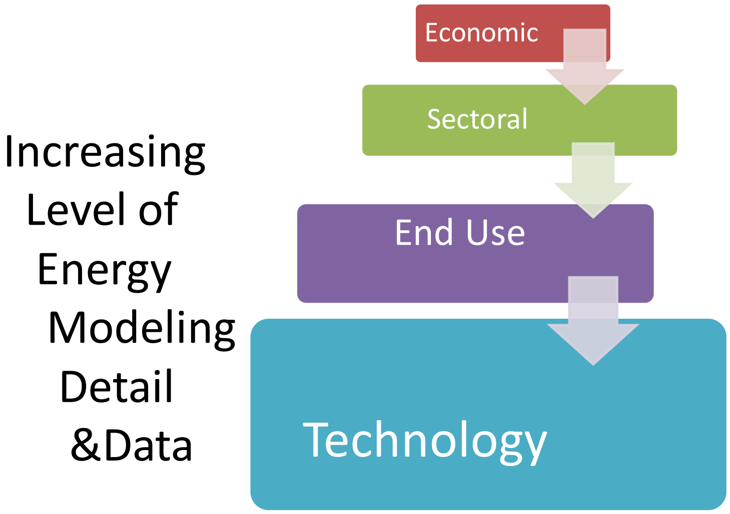
Figure 22: Proposed Macro Models for NL CCEEET

Model	Key Advantages	Limitations
CanESS	• Modern software/architecture with interactive interface. • Transparent structure, easy to understand model relationships. • Existing representation of NL; adjustable to more detailed NL data. • End use structure/flexible level of representation. • Provides database/structure for data as it is developed.	• Decision making and behaviour represented through user inputs/scenarios. • Limited representation of economic impacts. • Relatively new model with limited track record.
CIMS	• Lengthy track record in Canada. • Attempts to reflect uncertainties and imperfect information in decision making. • Has been used to model carbon trading and carbon taxes. • Provides some indications of economic impacts of policies.	• Must be used through MKJA; not available in a form to run in-house. • Batch model with results comparison in Excel. • Limited transparency – appears to rely heavily on economic decision making. • Includes some built-in assumptions (i.e. w.r.t. changing urban planning/land use and impacts on energy demand).
ENERGY 2020	• Lengthy track record in US and Canada. • Some track record of predicting actual market behaviours. • Has represented NL in past models; can be adapted to improved NL data. • Provides some indications of economic impacts of policies.	• Behavioural model difficult to explain and understand. • Complex model to operate; most clients rely on SSI for model operation. • Batch model with results comparison in Excel.

10 Data issues & Sources

10.1 Data Requirements

The variety and volume of data required for modelling is determined by the scope and granularity of the model selected. As the figure below illustrates, data requirements increase dramatically as modelling is extended to include sectoral detail, end uses and technologies. Each additional level of structure incorporated into the model increases the level of detail that must be developed and incorporated into the model. The type and volume of data required is also determined by the granularity both in terms of the energy-consuming stock represented (i.e. number of sectors, sub-sectors and end uses represented), but also in terms of geographic and temporal representations (i.e. multi-jurisdiction or sub-jurisdiction, annual or hourly modelling).



The following table provides a high-level outline of the type of data typically required for a multi-sector, multi-fuel energy model. Each of the following categories can be viewed as "nested" in the sense that the data will ideally be available at each level within each sector. For example, in a model representing technologies, residential energy use data would be required for each energy source used by each technology within each end use within each housing type. Ideally time series data would be available at each level for the historic period used. Information for the drivers of energy use would be required for the entire historic period and projected for the period to be modelled.

Figure 23: ***Data Requirements for Macro Modeling (Columns independent – do not read across)***

Energy Use	**Physical Assets/ Technology**	**Typical Drivers/Influences**
Residential		
By fuel/source	Housing stock & characteristics	Households
By housing type	Equipment / Appliance stock & characteristics	Economic (real personal disposable income, etc.)
By end-use	Building/ device average and marginal efficiency.	Codes/standards
By technology	Technologies used to meet end use need (i.e. different light bulbs/fixtures/reflectors).	Energy prices
Commercial		
By fuel/source	Building stock & characteristics (i.e. age, intensity – energy use/unit floor area/employee or $GDP)	Floor area
By business type (sub-sector)	Equipment / Appliance stock & characteristics	Economic (GDP, employment, etc.)
By end-use	Building/ device efficiency. *(i.e. boilers, combination units, chillers, T12 or T8 lighting, incandescent or CFL general lighting, etc.)*	Energy prices
By technology		Codes/standards Consumer choice Incentives
Industrial		
By fuel/source	Building & Process types and characteristics	Production – GDP, GO or physical units.
By type of industry	Equipment stock & characteristics	Equipment standards
By end use	Process/equipment efficiency	Energy Prices
By technology	Technology	
Transportation		
By mode	Vehicle stock & characteristics – size, vintage, efficiency, etc..	Households & personal income
By vehicle/ vessel type	Vehicle (vessel) efficiency	Economic activity (*GO or GDP*) & type of activity (*bulk vs. non bulk transportation demand)*

Energy Use	Physical Assets/ Technology	Typical Drivers/Influences
By vehicle size	Engine type	VMT, tonne-miles
By vehicle size/ vintage	Fuel(s) used	Codes & standard
	Emission technology	Energy prices

If non-energy process and fugitive emissions from industrial processes, waste management, agriculture and land use are also to be modelled then information must be also be gathered on historic emissions (usually for each specific greenhouse gas) and the factors which drive those emissions (i.e. tonnes of clinker production, production of specific chemicals, volumes of petroleum refined, or levels of oil and gas production).

In most cases, potential models will have some level of default data available and standard sources of obtaining data for the specific jurisdiction being modelled. The table below lists some potential data sources.

A number of agencies in the province, including the Departments of Natural Resources and Finance and the electric utilities, have existing models and databases in place that could provide some of the data described below.

Figure 24: ***Potential Data Sources***

Data	Potential Data Sources	Caveats/Limitations/Questions
Historic Energy Production and Consumption by Fuel	Statistics Canada , Report on Energy Supply-Demand in Canada (RES-D), Catalogue No. 57-003-X	• Discussions with NL Natural Resources indicate some inadequacies in 57-003 report.
Energy use by sector and end use	OEE Comprehensive Energy Use Database (1990 to 2008) • **Residential** -information presented for NL , includes end use breakdown, including major appliances, by fuel type, and by housing type. • **Commercial** – information available for Atlantic region. Could be estimated for NL using intensity for Atlantic and activity information for NL, adjusted for fuel mix differences. Other sources include: - Marbek potential analysis includes estimated breakdown of electricity use by sub-sector by end use. - NRCan *Commercial and Institutional Consumption of Energy Survey* (CICES) and *Commercial and Institutional Energy Use Survey* (CIBEUS); though both are limited to Atlantic Region. • **Industrial** - information available for Atlantic region. Could be estimated for NL using intensity for Atlantic and activity information for NL, adjusted for fuel mix differences. • **Transportation** - breakdown by transportation mode available for NL (including drivers, breakdown by transportation mode, etc.). Information could be confirmed by NL-specific sources such as vehicle registrations from Department of Transportation and Works and Government Services. • **Agriculture** - information available for Atlantic. Could be estimated for NL using intensity for Atlantic and activity information for NL, adjusted for fuel mix differences.	• Some assumptions required to project Regional info to NL (i.e. mix of energy sources , % of space and water heating supplied by electricity) • Energy intensities may differ due to differences in building codes and practices. • Intensities (and underlying technology shares) may also differ from those in other jurisdictions depending on the state of efficiency/CDM/ DSM programs. • The form of energy used will differ between provinces due to different access to natural gas. • Space conditioning energy use can be adjusted for climatic differences. • Large industry energy use

Data	Potential Data Sources	Caveats/Limitations/Questions
	- **CIEEDAC** – Information on energy use emissions and activity data by industrial sub-sector at the national level is available through on-line search. CIEEDAC makes reference to an industrial load databases held by NL Hydro and a database of electricity use, fuel use, CO2 emissions, other greenhouse gas emissions and other emissions (NOx), held by Darren Hicks at NL Natural Resources.	would need to be further refined based on local knowledge. - Discussion with CCEEET advisory group indicates some federal data sources do not include some key industry sites.
Device efficiencies - energy usage per device (Unit energy consumption (UEC) per year by device by vintage).	- OEE Database provides historic energy intensity by end use (broadly defined to include some classes of appliances - refrigerators). - **Average and range of efficiencies of major appliances** – National level data available from Natural Resources Canada, *Energy Consumption of Major Household Appliances Shipped in Canada* and *Survey of Household Energy Use*. - **Minimum efficiency levels** – prescribed in codes and standards effective in different historic or future periods (i.e. minimum energy performance standards (MEPS) contained in the *Energy Efficiency Regulations* under Canada's Energy Efficiency Act applicable in different years).	- Most data available only at national or at best regional level. - Is there any reason to expect that appliance/equipment choices would differ in NL vs. national/regional patterns?
Device capital costs & retrofit costs	- RETScreen database - Market studies - Various sector-specific reports and tools (see report on Micro models). - Some models include a database of efficiency or mitigation costs or marginal abatement cost (MAC) curves.	- Unclear if costs need to be adjusted to reflect NL-conditions.
Physical life of capital equipment	Varies by end use/device or vehicle type/mode for each sector. - Residential - Commercial - US DOE, Building Energy Data Book – for both residential and	- Asset lives for large industries expected to be industry/ process specific.

Data	Potential Data Sources	Caveats/Limitations/Questions

	commercial.
	- Industrial
	  - Varies significantly by industry. Review of past analysis, such as energy efficiency potential assessments would provide default assumptions.
	- Transportation
	  - US DOE Transportation Energy Data Book.
		- Asset lives may change in response to economic conditions or changing costs of replacement equipment.

Load shapes	- Some representation of load shapes required if modelling generation dispatch for power system. Some models use representative days. - NL Power & NL Hydro may have NL-specific load shape data. - Some complimentary load shape data is available from commercial services such as Itron – http://capabilities.itron.com/eShapes/ – or may be acquired for a fee.	- Care would be required in applying load shapes from other jurisdictions to NL.
Historic energy Prices	Statistics Canada, Energy Statistics Handbook, Catalogue No. 57-601-X, section 9.	
Forecast Energy Prices	- US Annual Energy Outlook – world oil prices, Henry Hub natural gas prices, coal prices - National Energy Board - NL Natural Resources - NL Board of Commissioners of Public Utilities (PUB) - Economic forecasts – Conference Board of Canada, etc..	- In projecting oil prices need to be aware of developing differences between West Texas and Brent Crude price. - Sensitivity runs may be used to determine impact of differing forecasts.
Co-generation energy use	- Energy inputs and power generated – volumes, fuel types, etc.. - CIEEDAC "*Review of Existing Cogeneration Facilities in Canada*"; updated bi-annually. 2010 report shows 17,500kW in cogeneration capacity at CornerBrook Pulp and Paper Ltd.	

Data	Potential Data Sources	Caveats/Limitations/Questions
Co-generation efficiency	Heat rates of co-generation units available from same sources as for other generation (see earlier notes).	Heat rates for CHP may change seasonally. Generally not significant in terms of jurisdiction-wide modelling.
Feedstocks	Feedstocks may be included in the model or may need to be understood in adjusting information on fuel use and production.	
Economic and demographic-historic and projected.	• Residential - Dwelling characteristics, structure type, age, etc. also available from Census data. • Commercial - Marbek study completed for NL Hydro and NL Power contains historic and projected floor area estimates by sub-sector. • Industrial - Driver information available from OEE Comprehensive Database for NL. - CIEEDAC database provides information on energy use, emissions and activity data (GO, GDP, physical units) by NAICS category for 1990 to 2009. Data is at national level but provides intensity information that could be applied to NL. • Census data – Information is available on housing by type and age, employment by sector, and GDP by economic sector over time. Historic data may be used to approximate age of stock, distribution by type of business, etc.. • Transportation – historic data regarding modal splits, intensities, VMT and tonne-miles by mode available from OEE. • Gross Output, GDP, Population, Households, employment , Real Disposable Income, etc. also available from StatsCan and Dept. Of Finance	• Accuracy of driver information may be subject to question for NL. • Recommend confirming information such as number of housing and business units where possible with NL Hydro/NL Power and others which have NL-specific data. • Projections of commercial floor area may need review. • Small number of large industries pose particular problem (discussed below).

Data	Potential Data Sources	Caveats/Limitations/Questions
	• Projections for modelled period from macro-economic model.	
Weather – historic & projected.	• Environment Canada – detailed meteorological data. • Heating and cooling degree day information provided in OEE Comprehensive Energy Database. • Data also available from RETScreen database.	• Heating and cooling degree days, solar insolation, etc. available from Meteorological Services, Environment Canada.
Tax Rates	• NL Department of Finance, Revenue Canada	
Return on investment required	• Differs by sector. • Behavioural studies from other jurisdictions are available.	Decision criteria in NL likely similar to those in other jurisdictions.
Inflation and exchange rates	• Historic levels available from Statistics Canada and NL Finance. • Projected levels from macro-economic model.	
Mitigation costs	• Technology costs for energy efficiency improvements, renewable energy projects, etc.. • Landfill gas reduction costs, Marginal Abatement Cost (MAC) curves, etc.	• Unclear if general adjustment required to reflect price conditions in NL.
Transportation	• Modal splits, passenger/freight splits, fuels used, vehicle efficiencies, size, etc. available for NL in the OEE Comprehensive Energy Database. • Alternative sources, such as US Energy Data Handbook available but would need to be applied with care.	• NL may wish to review reasonableness of OEE methods for developing NL-specific data. • Freight modal splits likely to be different in NL; reflecting increased role of marine and limited rail (Labrador only).

Data	Potential Data Sources	Caveats/Limitations/Questions
Power Sector	• Information requirements differ depending on level of granularity represented in model. Typically includes the following for archetype plants or specific stations or units. - Historic Peak Capacity (MW), - Historic generation levels (GWh), - Historic capacity factor, - Type of fuel used, - Heat rate, - Historic annual fuel use (PJ), - O&M costs, - Capacity factors, - Outage rates or availability, - Plant type (Hydraulic, Coal, Combined Cycle Turbine, etc.) • If the model is to include consideration of new plants, then information on the expected cost and performance of new generating units will also be required (i.e. overnight construction cost, fixed and variable operating costs, heat rates, fuel type by technology choice) • Default values may be based on information in US AEO or EPA Base Case (i.e. costs and characteristics of new generation). • Transmission and distribution losses • Transmission limitations and interconnections • Historic information available from Statistics Canada (see for example, Energy Statistics Handbook, Catalogue No. 57-601-X • Information on the cost and performance of new generation and transmission is available from past studies, may be obtained for recent projects, or based on estimates of planned projects from NL Hydro, NL Power or others.	• Number of new projects expected to be limited and costs/performance characteristics may be relatively unique. NL Hydro and NL Power may have project-specific information. • Not clear if Statistics Canada information includes all off-grid generation, including that on off-shore platforms.

Data	Potential Data Sources	Caveats/Limitations/Questions
Heat rates	If only modelling NL, then information could be obtained for specific plants (i.e. Holyrood). Alternatively, technology specific information is available from past analyses that have been subject to stakeholder review, AEO, US EPA Base Case, etc..	
Transmission nodes and capacities	Information required depends on area modelled. Information on interties available from EPA base case, or from North American Electricity Reliability Council (NERC) assessment reports. If only NL is modelled then not an issue, unless jurisdictions within NL represented separately.	
Construction times	Information used in past analyses which have been subject to stakeholder review is available or specific estimates could be obtained from NL Hydro.	
Capital and operating costs	Information used in past analyses is available or specific estimates could be obtained from NL Hydro.	May be very NL-specific.
Capacity factors	Historic capacity factors may be available from NL Hydro.	Confidentiality issues.
Pollution control costs	Information used in past analyses is available, or project specific estimates could be developed for NL facilities.	Confidentiality issues.
Unscheduled outage rate	Historic values may be available from NL Hydro. Alternately technology specific information may be obtained from other jurisdictions (i.e. Ontario IESO).	Confidentiality issues.

A number of proprietary models have developed databases with standard or default information covering many of the types of data listed above (i.e. acceptable payback periods, technology costs, and the cost/performance of new generation).

10.2 Large Industries

A small number of large industrial facilities have a disproportionate impact on NL energy use and GHG emissions. As discussed in section 1, less than 10 industrial facilities account for about 45% of GHG emissions in the province and a similar proportion of total energy use. The key large industries include:

- 3 open pit mines
- 3 oil and gas facilities
- 1 Petroleum Refinery

An additional challenge in obtaining energy use data for the industrial sector is that 70% of industrial energy use in the province is reported to be self-generated[134]. Large industrial facilities also account for a disproportionate share of industrial electricity use; using 94% of all electricity used by industry in the province. The balance of industrial use is dominated by fish processing facilities, which account for just over half of the remaining electricity use (or about 3% of total industrial electricity use).

As discussed in section 5, projecting or modeling energy use and emissions for a small number of specific industries is particularly challenging. Energy and emissions models are not well suited to predicting the impacts of broad energy and climate policies on such industries. Models may be able to predict industry trends and expected policy responses, but will be substantially more uncertain when applied to a particular facility. Individual facilities may expand, reduce production or close based on specific corporate decisions and facility conditions. At the same time, new facilities may be developed which are large enough to have a material impact on provincial targets.

The challenge in modelling specific industries lies not only in predicting decision-making relating to a specific facility, but also in obtaining information on energy use and emission from a specific facility. Many of the publicly available information sources on energy use and emissions in NL are also limited by confidentiality requirements.

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[134] Marbek Resource Consultants Ltd., CONSERVATION AND DEMAND MANAGEMENT (CDM) POTENTIAL NEWFOUNDLAND and LABRADOR, Industrial Sector – Final Report, *January 2008*, page 11.

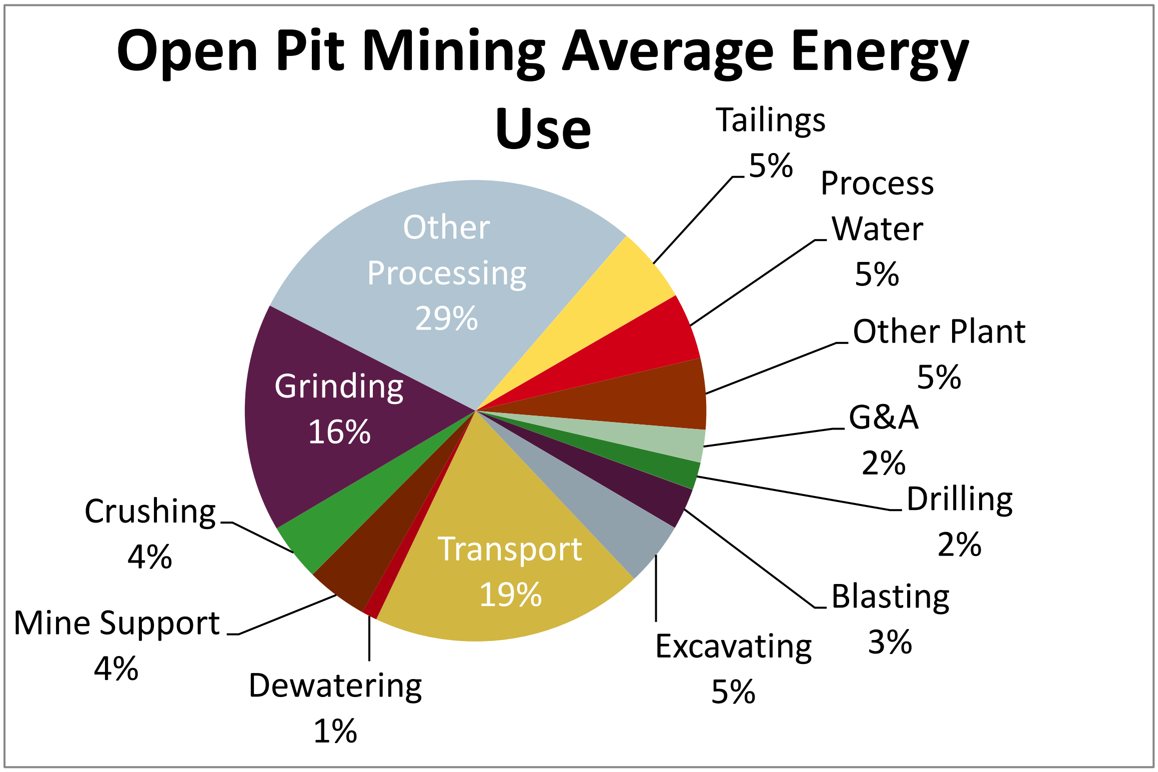
Section 5 recommended the use of "benchmarking" and consideration of best practices as the most appropriate means of anticipating the potential of these industries to respond to energy and emission mitigation policies. Benchmarking is most effective when it addresses differences in processes and conditions in each industry. This can be challenging, as detailed energy use is often not publicly available in a form that allows such comparisons. A number of existing benchmarking reports for the key industries listed above, plus pulp and paper, were discussed in section 5.

A review of information available for the key industry sectors in NL is presented below.

Open Pit Mining:

CIPEC completed a benchmarking analysis of open pit mining in 2005. Energy use was compared for nine open pit mining facilities in the oil sands, iron ore and gold mining sectors. Approximately 25 categories of energy cost and usage information were examined. Figure 25 shows an average breakdown of energy use by function. As discussed below, there are wide variations in energy use between mines depending on mine characteristics and mine type.

Figure 25: Open Pit Mining Energy Use

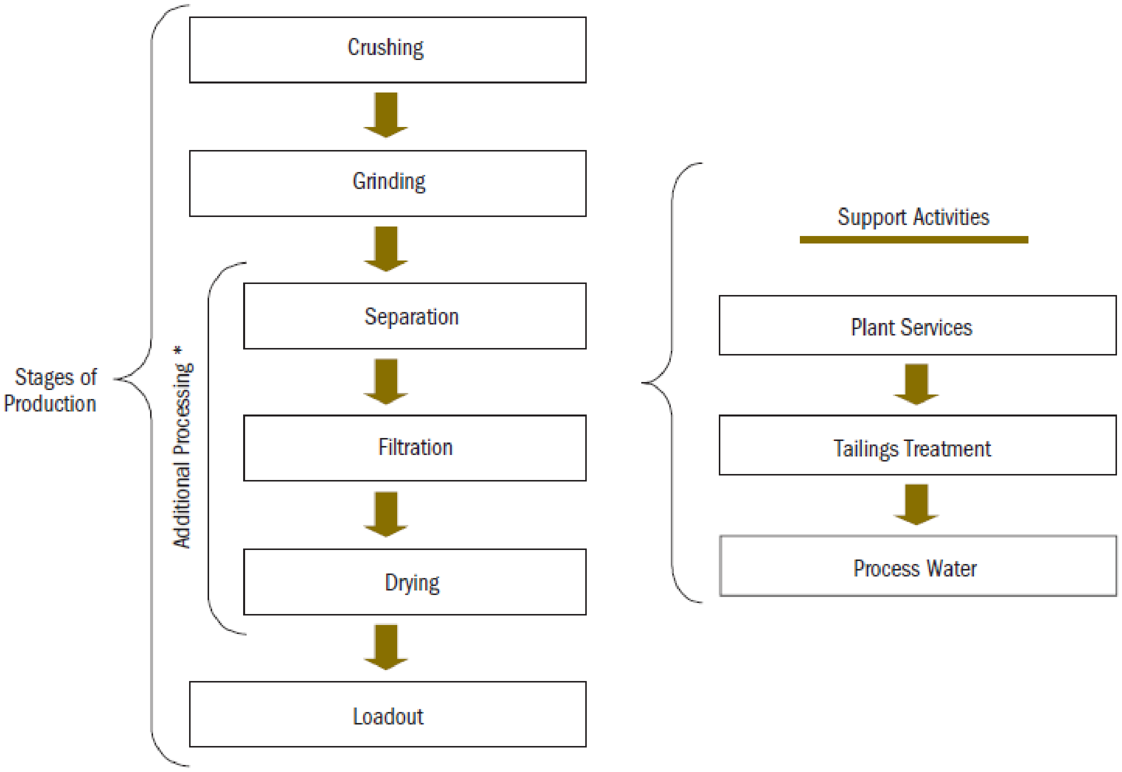


The analysis compared energy use on the basis of both the amount of material removed and the amount of ore mined or processed as shown in Figure 27. The figure shows the average energy use (in kWh equivalent terms) for each stage of production, as well as the highest and lowest reported level of energy use. As the table shows, the amount of energy used for ore extraction varied widely depending on the amount of overburden that had to be removed in order to extract the ore. The range of energy use was much smaller when viewed on the basis of total kt of material removed. Differences in the amount of overburden or waste material that must be removed to access the ore must be considered in any effort to benchmark energy use.

Only one of the participating mines required energy for 'dewatering'.

Concentration and milling operations were also compared in the report. Figure 26 shows the stages of production reviewed for iron ore facilities.

Figure 26: Stages of Production in Iron Ore Concentration Facilities[135]*:*



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[135] CIPEC, Benchmarking the Energy Consumption of Canadian Open-Pit Mines, 2005, page 12.

The processes involved in processing and concentrating the ore differ significantly between different types of mines included in the study (iron vs. gold). Crushing and grinding processes are common across all mining processes, but energy use varies with ore concentration.

Figure 27: Benchmarking Data - Open Pit Mines

Energy Use in Open Pit Mines

Based on 9 participating open pit mines (oil sands, iron ore, and gold mines)

Activity	**Basis**	**Average**	**High**	**Low**	**Multiple**
Waste Rock Drilling	$/kt of ore mined	*366*	3,618	35	103.4
Waste Rock Blasting	$/kt of ore mined	*504*	1,845	203	9.1
Waste Rock Excavation	$/kt of ore mined	*693*	6,209	332	18.7
Waste Rock Transport	$/kt of ore mined	*3492*	22,307	442	50.5
Waste Rock Handling	$/kt of ore mined	*636*	1,743	298	5.8
Ore Drilling	$/kt of ore mined	*271*	641	54	11.9
Ore Blasting	$/kt of ore mined	*453*	520	284	1.8
Ore Excavating	$/kt of ore mined	*784*	2,201	407	5.4
Ore Transport	$/kt of ore mined	*2793*	4,432	2,020	2.2
Mine Dewatering	$/kt of ore mined	*355*	4,920	-	*n.a.*
Mine Support & Services	$/kt of ore mined	*1419*	6,463	549	11.8
Total Mining Operations -	***$/kt of ore mined***		***42,474***	***7,006***	***6.1***
Drilling	$/kt of total material		641	55	11.7
Blasting	$/kt of total material		662	284	2.3
Excavating	$/kt of total material		2,202	389	5.7
Transport	$/kt of total material		4,591	2,359	1.9
Dewatering	$/kt of total material		928	-	*n.a.*
Mine Support	$/kt of total material		2,078	301	6.9
Total Mining -	***$/kt of total material***		***3,231***	***8,035***	***0.4***
Crushing	$/kt of ore processed	*1320*	2,804	253	11.1
Grinding	$/kt of ore processed	*5269*	16,320	2,639	6.2
Crushing/Grinding Total -	$/kt of ore processed		16,874	3,704	4.6
All Other Mill/Concentrator	$/kt of ore processed	*9473*	26,105	2,744	9.5
Tailings Treatment	$/kt of ore processed	*1754*	2,261	245	9.2
Process Water	$/kt of ore processed	*1527*	2,249	79	28.5
Other Plant	$/kt of ore processed	*1647*	3,326	552	6.0
General/Administrative	$/kt of ore processed	*752*	4,818	83	58.0
Mill/Concentrator Total -	***$/kt of ore mined***		***35,701***	***13,144***	***2.7***

Source: CIPEC, Benchmarking the Energy Consumption of Canadian Open-Pit Mines, 2005.

Offshore Oil Platforms

Very little information was found relating to how energy is consumed on offshore oil drilling platforms. Information on the disposition of natural gas produced on these platforms indicates that about 6% is used as fuel while 91% is re-injected into the reservoir (see figure below). The portion used as fuel in 2009-2010, roughly 5.4 billion cubic feet (0.159 cu.m.).

Figure 28: Natural Gas Disposition (2009-2010)[136]

Disposition	% of Total Production
Flared	2.4%
Used as Fuel	6.2%
Injected	91.4%

The natural gas consumed as fuel is used to generate power and provide heating and other energy services on the production platform. Natural gas and the electricity produced from it would typically be used for desalination and to run all of the equipment necessary for oil production. Some diesel fuel is also used for power production, however, limited information on how much diesel is consumed. Many of the resulting end uses (space heating, motor drives, etc.) could be addressed using the "micro" level tools described earlier in the report.

Petroleum Refineries

The 115,000 barrel-per-day North Atlantic Refining Ltd. Come-by-Chance oil refinery is described as a "sour crude" refinery. The refinery, built in the 1970's[137], is one of 16 'cracking' refineries in Canada[138].

As discussed in section 5, CIPEC published a Benchmarking Guide for conventional petroleum refining energy consumption in Canada in 2002. The Guide provides information on the breakdown of energy use by type, how energy use has changed over time, and compares energy use in 16 refineries based on the Solomon Energy Intensity Index. The Solomon index is an industry standard which compares energy consumption in a given refinery against a computer model of a plant using the same type of technology and crude feedstock. Unfortunately the CIPEC guide does not discuss differences in the technologies used or the implications of feedstock differences.

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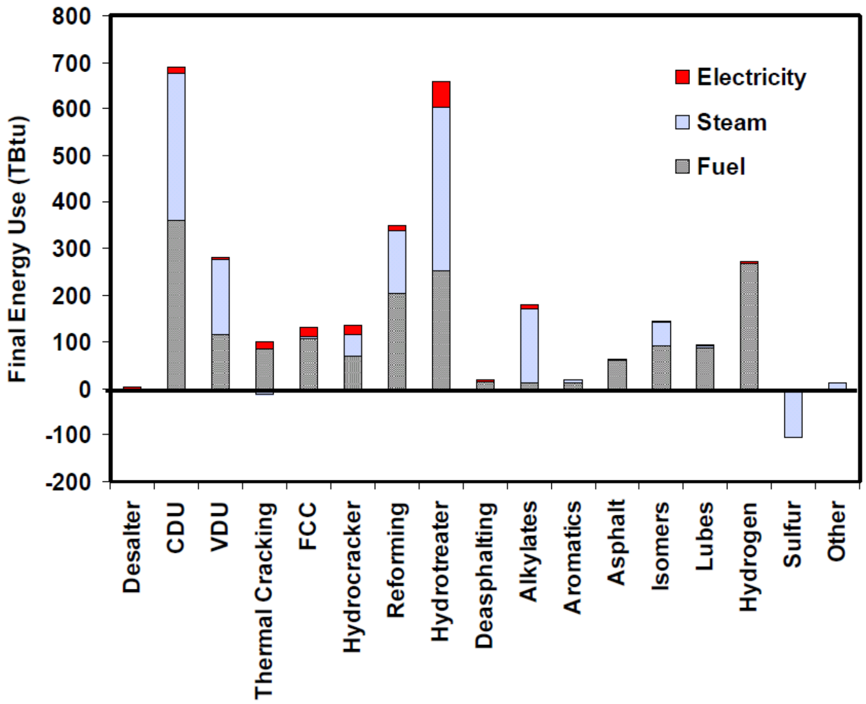
[136] Canada-Newfoundland and Labrador Offshore Petroleum Board, Annual Report 2009-2010, Page 33, Table 6.

[137] North Atlantic website: http://www.northatlantic.ca/about.asp

[138] NEB website - http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/prcng/crdlndptrlmprdcts/cndnndstr-eng.html. The remaining three refineries are 'coking' refineries.

There were 137 operating refineries in the U.S. according to the US EIA[139]. While these refineries process a variety of crudes, the trend has been towards heavier and higher sulphur content[140] or more 'sour' crude. Energy consumption in refineries is primarily driven by a small number of key processes - including the crude (or atmospheric) distillation unit, hydrotreaters, reformer, vacuum distillation unit, alkylate production, catalytic crackers, and hydrocrackers[141]. Figure 29 shows the estimated relative fuel and electricity use by process based on a review of the US refinery industry in 2005[142].

Figure 29: Estimated Energy Use by Process



Source: *Energy Efficiency Improvement and Cost Saving Opportunities For Petroleum Refineries- An ENERGY STAR® Guide for Energy and Plant Managers", Ernst Worrell and Christina Galitsky , Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, February 2005, Sponsored by the U.S. Environmental Protection Agency. (CDU = Crude Distillation Unit; VDU= Vacuum Distillation Unit; FCC=Fluid Catalytic Cracking).*

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[139] http://www.eia.gov/dnav/pet/pet_pnp_cap1_dcu_nus_a.htm

[140] "*Energy Efficiency Improvement and Cost Saving Opportunities For Petroleum Refineries- An ENERGY STAR® Guide for Energy and Plant Managers*", Ernst Worrell and Christina Galitsky , Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, February 2005, Sponsored by the U.S. Environmental Protection Agency.s, page 6. (*LBNL Opportunities report)*

[141] LBNL Opportunities, page 9.

[142] LBNL Opportunities report.

The Lawrence Berkeley National Laboratory (LBNL) review focussed on the energy requirements for five key processes that account for 70% of refinery energy use. The report notes some caveats regarding their analysis, which was based on publicly available data and assumed capacity utilization levels across some processes. The report also provides a useful discussion of the processes and technologies used in the industry, key differences affecting energy consumption and opportunities for improved energy efficiency.

From a benchmarking perspective, some differences between refinery energy intensities would be expected based on refinery and feedstock characteristics. Two key areas relevant to NL are noted below:

"The processing of many heavy crude oils . . . increases the likelihood of localized coke deposits in the heating furnaces, thereby reducing furnace efficiency and creating potential equipment failure. An estimate by the Office of Industrial Technology at the U.S. Department of Energy noted that the cost penalty for fouling could be as much as $2 billion annually in material and energy costs. The problem of fouling is expected to increase with the trend towards processing heavier crudes".

Higher sulphur content may increase the energy used in the hydrotreating process. Increased demand for low-sulphur automotive fuels may also contribute to this issue. "This will result in an increase of hydrotreating capacity at the petroleum refinery, as well as alternative desulfurization processes in the future".

Information on best practices and energy efficiency opportunities in refineries is available from a number of sources, including the US DOE Energy Efficiency and Renewable Energy (EERE) office. Both the US DOE and California Energy Commission have developed technology roadmaps for the industry. ExxonMobil has developed a program which describes over 200 best practices and performance measures for key process units, major equipment and utility systems which it estimates can reduce energy consumption by 15% at ExxonMobil refineries and chemical plants worldwide on top of a 35% reduction between 1975 and 1999.

Figure 30 shows the calculated energy intensity for those key refinery processes based on information provided in the report. The report notes some caveats regarding their analysis, which was based on publicly available data and assumed capacity utilization levels across some processes. The report also provides a useful discussion of the processes and technologies used in the industry, key differences affecting energy consumption and opportunities for improved energy efficiency.

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[143] LBNL Opportunities Report, Page 43.

[144] LBNL Opportunities Report, page 7.

[145] See for example the Petroleum Refining site for the Industrial Technologies Program: http://www1.eere.energy.gov/industry/petroleum_refining/tools.html

[146] LBNL Opportunities Report, page 25.

[147] IPCC Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Section 7, Industry, page 466.

Figure 30: Energy Intensity of Key Refinery Processes

Estimated Energy Intensity of US Petroleum Refineries*

Process	Units (millions)	Fuel	Steam	Electricity	Final
		mBtu	mBtu	GWh	mBtu[2]
Desalter	*million bbl/year*	38	-	0.1	207
CDU	*million bbl/year*	67,604	45,828	0.7	129,449
VDU	*million bbl/year*	47,792	52,179	0.3	116,729
Thermal Cracking	*million bbl/year*	116,257	(14,515)	6.2	118,607
FCC	*million bbl/year*	57,388	265	3.7	70,436
Hydrocracker	*million bbl/year*	135,055	72,752	11.2	267,942
Reforming	*million bbl/year*	176,758	86,878	2.9	299,657
Hydrotreater	*million bbl/year*	68,808	73,401	4.2	178,434
Deasphalting	*million bbl/year*	143,111	2,667	1.9	152,889
Alkylates	*million bbl/year*	35,714	330,153	7.2	488,822
Aromatics	*million bbl/year*	120,370	42,181	3.0	185,185
Asphalt	*million bbl/year*	209,196	-	2.6	217,971
Isomers	*million bbl/year*	441,997	195,301	1.9	702,398
Lubes	*million bbl/year*	1,290,560	36,873	18.4	1,401,180
Hydrogen	*lbs/year*	45,008	-	0.2	45,511
Sulfur	*short tons/year*	-	(9,022,222)	12.1	(11,677,778)
Other					

Notes:

1. Unit is million barrels/year, except for hydrogen (million lbs/year) and sulfur (million short tons/year).

2. Final fuel use is calculated by estimating the boiler fuel to generate steam used. Electricity is accounted as site electricity at 3,412 Btu/kWh.

3. Primary fuel use includes the boiler fuel use and primary fuels used to generate electricity. Including transmission and distribution losses the electric efficiency of the public grid is equal to 32%, accounting electricity as 10,660 Btu/kWh. Some refineries operate combined cycles with higher efficiencies. For comparison, Solomon accounts electricity at 9,090 Btu/kWh.

4. Cogeneration is assumed to be in large singe-cycle gas turbines with an electric efficiency of 32%.

5. Boiler efficiency is estimated at 77%.

** Calculated based on data in Table 3 of "Energy Efficiency Improvement and Cost Saving Opportunities For Petroleum Refineries- An ENERGY STAR® Guide for Energy and Plant Managers", Ernst Worrell and Christina Galitsky , Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, February 2005, Sponsored by the U.S. Environmental Protection Agency.*

Negative values indicate processes which contribute heat to the process.

The US DOE has also reviewed the technical potential for reducing energy use in refineries[148]. An analysis of the five key processes which account for the majority of refinery energy use estimated the Theoretical Minimum Energy (TME), Practical Minimum Energy (PME) for each process and compared those estimates to the Current Average Energy (CAE). As

Figure 31 shows, the potential efficiency gains estimated ranged from 23 – 54%. The report points out that the *"bandwidth is the difference between PME and CAE and provides a snapshot of energy losses that may be recovered by improving current processing technologies, the overall process design, current operating practices, and other related factors"[149].*

Figure 31: Energy Bandwidth for Key Refinery Processes

The TME, PME, and CAE and Energy Bandwidth Values for the Five Principal Petroleum Refining Processes

Process	**TME**	**PME[a]**	**CAE**	**Energy Bandwidth (CAE-PME)**	**Potential Energy Bandwidth Savings (%)[d]**	**Total Annual CAE by Process (10^{12} Btu/yr)**		**Potential Energy Bandwidth Savings (10^{12} Btu/yr)**	
	10^3 Btu/bbl feed[b,c]								
1. Crude Distillation:									
Atmospheric	22	50	109	59	54%	658		356	
Vacuum	46	54	89	35	39%	242		95	
2. Fluid Catalytic Cracking	40	132	183	51	28%	377		105	
3. Catalytic Hydrotreating	30	55	81	26	32%	382		123	e
4. Catalytic Reforming	79	203	264	61	23%	339		78	
5. Alkylation:									
H2SO4 (f)	-58	156	250	94	38%	102	g	38	
HF	-58	152	245	93	38%				
Total						2101	h		

a This represents the minimum PME; in practice, the PME value may be greater due to overlap of the energy saving measures identified for each unit operation.
b A positive energy represents energy consumed by the process (endothermic). A negative energy represents energy produced by the process (exothermic).
c Energy values exclude losses incurred during the generation and transmission of electricity.
d This represents the maximum bandwidth savings; in practice, the savings may be less due to overlap of the energy saving measures identified for each unit operation.
e Energy value is based on the U.S. hydrotreating/desulfurization capacity.
f Energy values are based on the autorefrigeration-based sulfuric acid process.
g Energy value is based on the average CAE for the sulfuric and hydrofluoric acid processes.
h Total Annual CAE value is off by one due to rounding of the individual values. Sources: DOE 2005b; See Appendix A for TME, CAE, PME sources.

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[148] *Energy Bandwidth for Petroleum Refining Processes,* Prepared by Energetics Incorporated for the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Industrial Technologies Program, October 2006

[149] Energy Bandwidth Report, page 1.

Benchmarking comparisons may also be made using commercial services such as the "Solomon Index" for refineries; available through Solomon Associates (*http://solomononline.com*).

GHG emissions from refineries arise both from energy conversion and from other releases[150]. Information on mitigation opportunities and best practices are available from sources such as:

- US EPA, Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Petroleum Refining Industry, October 2010 (*http://www.epa.gov/nsr/ghgdocs/refineries.pdf*)
- US EPA, Energy Trends in Selected Manufacturing Sectors, Section 3.11 Petroleum Refining, March 2007. (*http://www.epa.gov/sectors/pdf/energy/ch3-11.pdf*).

Refineries could be benchmarked on GHG emissions as well as on the basis of energy consumption.

Pulp and Paper Mills

While pulp and paper mills were not included in the list of large industries discussed in the Introduction and listed in Figure 1, the sector is a significant energy user in the province. Energy costs are also particularly important to the competitiveness of the sector, representing up to one-quarter of operating costs for some plants. Of the three plants located in the province, two have closed since 2005. The remaining plant, Corner Brook Pulp and Paper, uses thermal mechanical pulping and produces approximately 700 tonnes of newsprint per day. The plant consumes a mix of bunker C, waste oil and hog fuel according to the NL Department of Environment and Conservation website[151]. Thermal mechanical pulping is more efficient than alternative processes, but more electricity intensive. In the NL context, this implies lower GHG emissions associated with the sector.

The benchmarking studies discussed in Section 5 provide a basis for comparing energy use at NL facilities with those of comparable Canadian plants. The report on "Benchmarking Energy Use in Canadian Pulp and Paper Mills"[152], published in 2008, provides comparisons of energy use by process and product type. At the time the report was prepared, there were 28 plants using mechanical pulping and 20 that produced newsprint.

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[150] See for example: CIIEDAC, The Development of Improved CO2, CH4 and N2O Emission Factors for Producer-Consumed Fuels in Oil Refineries Prepared for: Environment Canada..http://www.cieedac.sfu.ca/media/publications/Petroleum_Refining_GHG_Coeff_Final.pdf, and Environment Canada site on Petroleum Refining - http://www.ec.gc.ca/energie-energy/default.asp?lang=En&n=1467336C-1

[151] http://www.env.gov.nl.ca/env/env_protection/ics/pulp.html

[152] http://oee.nrcan.gc.ca/industrial/technical-info/benchmarking/pulp-paper/pdf/benchmark-pulp-paper-e.pdf

Information on energy efficiency opportunities and best practices are available from a number of sources. A "Guide to Energy Saving Opportunities in the Kraft Pulp Industry" is also available from the Office of Energy Efficiency[153]. Similar studies for the US are available from LBNL[154], the Wisconsin Focus on Energy[155] (*Pulp and Paper Best Practices Guidebook*) and the *Energy Star Focus on Energy Efficiency in Pulp and Paper Manufacturing*[156]. In Ontario, the P&P industry has reduced its electrical intensity by 13% between 1990 and 2008

Greenhouse gas emissions from the P&P sector are almost all related to fuel use.

10.3 Data gaps & Data Development Strategies

Data gaps:

A review of the available data sources, and discussions with staff at NL agencies, indicates a number of existing data gaps or issues:

- Commercial, industrial and agricultural end use energy consumption data available from the OEE Comprehensive Energy Database is only available at the Atlantic Region level. NL has also indicated that data on biomass use from OEE may not be complete.
- Some data available from federal sources does not include all NL industrial facilities, such as new off-shore oil platforms.
- Most data sources regarding electricity use do not include consumption in facilities not connected to the grid (i.e. remote facilities or off-shore oil platforms).
- A number of federal data sources, including energy use for household appliances, commercial building energy use, etc., are only available at the national or regional level or are not statistically valid for NL.
- Natural Resources reports some uncertainties in the available data regarding:
    - Tracking the source of coal and coke imports.
    - The distribution of Refined Petroleum Products use in the commercial sector.

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[153] *http://oee.nrcan.gc.ca/industrial/technical-info/benchmarking/benchmarking_guides.cfm?attr=24*

[154] LBNL, Opportunities to Improve Energy Efficiency in the US Pulp and Paper Industry, 2001 - http://ies.lbl.gov/iespubs/48353.pdf

[155] http://www.focusonenergy.com/Business/Industrial-Business/PulpPaper.aspx

[156] http://www.energystar.gov/index.cfm?c=in_focus.bus_pulppaper_focus

  - The reporting of fuel use for off-road transportation by large industries.

- Limited information is available on floor area and energy use by sub-sectors within the commercial/institutional sector and how that might differ by building vintage.

It is not unusual to face a number of challenges in obtaining realistic data on energy use and emissions when developing modelling capability. The CCEEET, however, faces two challenges that are particularly unique to NL:

- Much of the information available from federal sources is aggregated for the Atlantic Provinces as a region, and,
- Roughly half of provincial energy use and emissions are concentrated in less than ten large facilities; some of which are not connected to the provincial grid.

The following section suggests a general approach to developing data to overcome these issues and discusses some specific recommendations for data development.

Data Development Strategies

From past experience and based on our analysis and understanding of the challenges facing the CCEEET, we offer the following general comments regarding data development:

1. Data Sources:

- Where possible, we recommend that the CCEEET utilize existing federal, NL agency and industry data sources. The objective should be to leverage existing data sources both to minimize costs and increase the likelihood that consistent data will be available for longitudinal analyses. Some data sources may serve as an input for modelling while others can serve as a check on data developed through NL-specific primary data collection. A number of data sources are available which can assist in this regard, from Statistics Canada to the NRCan/OEE to commercial services such as Reed Construction Data or industry–specific sources .
- We also recommend that studies from other jurisdictions be reviewed and used where appropriate. For example, several US jurisdictions (California, Massachusetts, etc.) have conducted sectoral baseline studies. Some of the information from these studies may be applicable to NL.
- Finally, we suggest that the CCEEET leverage data already collected by the NL government or its agencies, such as vehicle information collected through licensing processes, or which is collected through future programs; such as energy audits conducted by NL Hydro and NL Power.

- As a modelling framework is developed it can also be used to refine data development priorities. By running scenarios with alternative values (or sensitivity runs) for data that is either missing or uncertain, it is possible to see how significant potential variations in the data would be. If the model results indicate that differences in input data would have only a marginal impact on model results, then it would not be necessary to invest in developing improved data.

2. Asset Based Approach and Decision Making

- The physical stock of buildings and equipment which use energy have substantial inertia, and projections of future energy use are to varying degrees bounded by that inertia. Understanding the physical assets underpinning electricity use, on its own, enables analysis of stock turnover, analysis of the impacts of codes and standards, and evaluation of programs designed to encourage retrofits and replacements. We therefore recommend that the CCEEET develop data representing the physical assets which drive energy use and emissions .
- An understanding of the physical energy-using base of equipment should be complemented with information relating to how decisions are made in each market segment. Market surveys of selected segments can explore decision-making processes around transactions relating to energy use. Survey instruments can be designed to explore issues such as the extent to which energy use is considered in equipment purchases, awareness of energy costs, expectations of future prices, the relative importance of price vs. non-price factors and capital versus operating budget considerations. This type of research can also be useful in identifying differences between segments and by organization size within segments.
- Market research could also identify decision drivers for key players in different markets (i.e. for industrial plant managers or purchasing agents buying motors, or commercial building operators considering renovations). In many instances, energy prices play a very minor role in these decision making processes. Understanding the driving forces in each market can make modelling and policy design more effective. Many of these factors are not expected to be unique to NL.

3. Scope, Granularity and Cost:

- In any market research, there tends to be a trade off between the level of detail obtained and the associated confidence in the data and the cost of obtaining that data. We anticipate that these trade-offs will arise as the CCEEET explore the number of segments, the number of dimensions associated with those segments, and the sampling approach taken in characterizing each data element. Some general comments on the design of market research efforts are included in Appendix D.

- In general, we recommend that market research efforts be focussed on obtaining high confidence data on those segments which have the greatest impact on energy use and the greatest potential for energy efficiency initiatives. Using known data for Ontario as an example::
    - In 2005, there were about 168,000 commercial and institutional establishments in Ontario with a total floor area in excess of 259 million square meters. The largest 2% of commercial establishments account for more than half the floor area and 54% of energy use[157].
    - Similarly, there were over 15,000 industrial facilities in the province, yet 200-250 of these facilities account for half of Ontario's industrial electricity demand[158]. This concentration is even more extreme in NL.
    - Ownership is similarly concentrated. For example, in Ontario almost 45% of large office and retail space in the province is owned by just 25 companies[159].

  It is expected that a similar pattern may be found in NL. Clearly focussing research efforts on key market segments can reduce data development costs while providing a higher level of confidence in the representation of the bulk of the market.

As discussed in the section on Data Gaps, there are a number of areas where NL specific data is not available from other sources. In those instances, we suggest that consideration be given to whether the differences from available data are likely to be significant (i.e. the data may not be exactly representative but may be reasonable) and secondly, whether the area under consideration is significant (i.e. is it important to have exact data if the area represents only a few percent of total energy use).

The data collection approach taken to collect energy use data will depend on decisions relating to the level of segmentation desired and the time and resources available. Energy data can be collected for facilities based on self-reporting or utility data, or for specific processes or technologies based on on-site metering. The range of studies that could be carried out is illustrated by two studies carried out for the commercial sector:

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[157] Natural Resources Canada, Commercial and Institutional Consumption of Energy Survey, June 2007.

[158] "RFP for 2010-2012 Transmission Connected and Distribution Connected Industrial Energy Efficiency Program Evaluation - Appendix C

[159] Ontario Power Authority Conservation Bureau, Large Office and Retail Market Opportunity Assessment, December 22, 2005, prepared by Marbek Resource Consultants Ltd..

- In 2005 Natural Resources Canada (NRCan) carried out a Commercial and Institutional Consumption of Energy Survey (CICES). The study reviewed the level of energy consumption by end use within commercial building types but did not cover the technologies, systems or efficiency related behaviour.

- By contrast, California's Energy Commission carried out a "Commercial End-Use Study"[160] which captured *"detailed building systems data, building geometry, electricity and gas usage, thermal shell characteristics, equipment inventories, operating schedules, and other commercial building characteristics."... "For each utility service area, floor stocks, fuel shares, electric and natural gas consumption, energy-use indices (EUIs), energy intensities, and 16-day hourly end-use load profiles were estimated for twelve common commercial building type categories."*

NRCan took ***four months*** to collect the data presented in the 2005 Commercial and Institutional Consumption of Energy Survey (CICES) and a year to complete the final report. By contrast, the California study took ***four years*** to complete. The NRCan study involved collection of energy use for buildings by type, while the California study involved the development of much more detailed information, including technologies used, hourly load shape data. The NRCan study was based on phone contacts and questionnaires while the California study involved a number of site visits, installation of on-site metering and a physical audit of the buildings. The time required for data development will therefore depend on the level of detail that the CCEEET ultimately decides is appropriate given its needs and available resources. Careful consideration of the level of detail required can make such efforts much more effective.

Returning to the data gaps listed above:

- Regional end use data – It should be possible to develop a reasonable estimate of commercial, industrial (excluding large) and agricultural energy use by end use by extrapolating information from the OEE database with known NL characteristics and other data sources (such as the CDM Potential analyses completed by Marbek). Bearing in mind that building energy use represents less than 10% of provincial GHG emissions and perhaps 15% of energy use this approach should be sufficiently accurate. As programs are addressed to this sector, additional data may be collected.

  Market research could also be carried out to identify current levels of appliance or equipment saturations, decision making criteria and awareness of government or utility initiatives in the residential, commercial and small industry segments. Where possible,

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[160] http://www.energy.ca.gov/ceus/

such market research should be designed to allow decision makers to determine whether attitudes and behaviours in NL differ significantly from those found in research in other jurisdictions[161]. It is recommended that such "baseline studies" be completed before developing energy efficiency initiatives that attempt to influence decision making. If the two utilities already engage in such surveys, it is recommended that the CCEEET work with the utilities to incorporate questions into these existing initiatives.

- Large Industry – The key characteristic that differentiates energy use in NL is the dominant role that a small number of industrial facilities play in energy use and the provincial economy. As discussed earlier, the ability of any macro model to project future energy use and emissions for such specific facilities will be limited.

  Energy use at large industrial sites may initially be modelled using benchmarking data, with some calibration based on available information regarding specific facility energy use and emission and overall energy use. Developing improved data for these sites is recommended as a priority. Provision of industrial energy audits for these sites could benefit the industries while improving understanding of how energy is used. If NL Hydro or NL Power offer such a service, it is recommended that the offering be expanded to include all forms of energy used. Meetings with key decision-makers at each facility are also recommended in order to explore decision-making frameworks and key considerations in decisions regarding energy consuming equipment. In undertaking such an initiative it will be important to assure the affected industries that data collected as part of the initiative will not later be used for regulatory purposes.

Maintaining a Database

One of the key benefits of developing a macro model of energy use and emissions is that it can provide a structure for developing and maintaining data on all of the interrelated elements which drive energy use. As data is developed in such a structure, and begins to be applied, inconsistencies are almost certain to arise and additional data gaps will be identified. If the model is calibrated over a historic period, unexplained variances will almost surely arise. Resolving these issues presents an opportunity to improve understanding of actual energy use and emissions.

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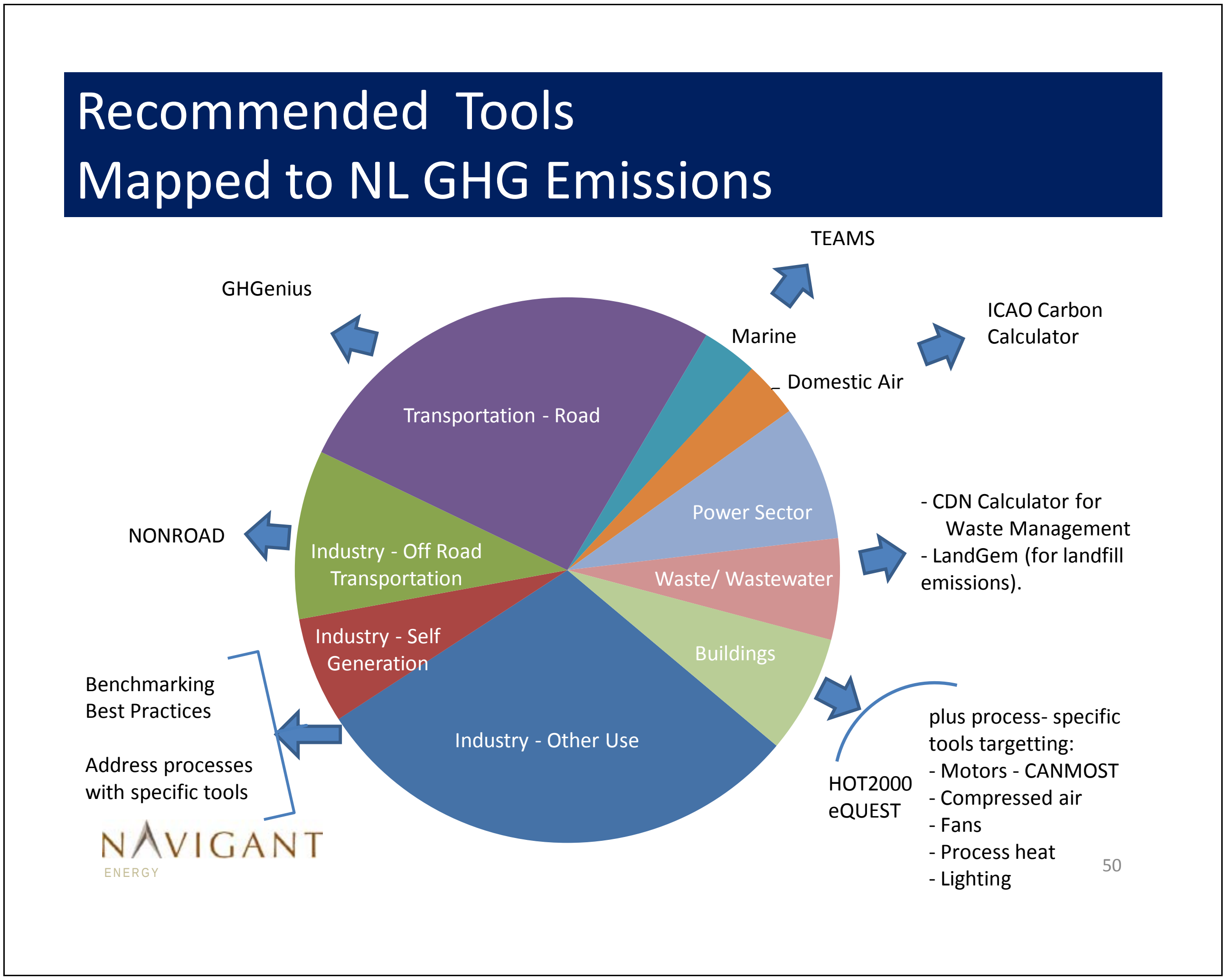
[161] A number of baseline studies are available from other jurisdictions. If market research indicates that technology saturations in NL are consistent with those in other areas this would support use of available research in modeling NL energy use and emissions.

10.4 Micro Level Tools and Methods

Using the criteria developed in consultation with the CCEEET and other NL stakeholders, Navigant recommends the following methods, tools and models be selected for more detailed evaluation.

Figure 32: Recommended Tools by Emission Source



Recommended Tools
Mapped to NL GHG Emissions

GHGenius

TEAMS

ICAO Carbon Calculator

NONROAD

- CDN Calculator for Waste Management
- LandGem (for landfill emissions).

Benchmarking
Best Practices

Address processes
with specific tools

HOT2000
eQUEST

plus process- specific tools targetting:
- Motors - CANMOST
- Compressed air
- Fans
- Process heat
- Lighting

Figure 33: Recommended Methods, Tools and Models

Sector	Recommended Method, Tool, or Model	Rationale for Selection
Buildings & Processes		
Residential	HOT2000	Industry standard for residential housing energy evaluation in Canada. Relative ease of use and flexibility allow adaptation to NL conditions. Model is used by other Canadian jurisdictions and subject to continued improvement and efforts to improve accuracy relative to actual energy use.
Commercial, Industrial and Other	eQUEST	Relatively easy to use, but offers flexibility for incorporating 'non-standard' design features or to apply to NL conditions. Reasonable level of support available. Provides most accurate representation of actual building use.
Processes Energy	Recommend use of all of tools presented as appropriate. Further analysis in this area not required. Tools selected could be expanded as information regarding key NL end uses is improved.	
Large Industry	Use of Benchmarking & Best Practices offers the most realistic means of evaluating the impacts of potential initiative for these customers. Accurately projecting future energy use and emissions will depend on both industry/organization specific information as well as the ability to project broader economic trends affecting the industries.	
Transportation		
Road – Vehicles	GHGenius	Provides ability to model full cycle emissions using a model customized to the Canadian context.
Road – Demand	Commuter	Relatively simple and easy to use model of

Sector	Recommended Method, Tool, or Model	Rationale for Selection
		transportation demand. Requires limited inputs. Builds on well established mission factors from MOBILE6. Drawback is that data used in assessing transportation choices is based on US data. Further investigation could evaluate whether this data is realistic in the Canadian and NL context.
Off Road	NONROAD	Industry standard for reviewing energy use and emissions from off-road equipment. Provides detail for different equipment types (i.e. excavators, trucks). If this capability is incorporated into the MOVES model as intended then consideration could be given to using MOVES rather than GHGenius and NONROAD.
Marine	TEAMS	Only known model to address marine transportation sector.
Air Travel	ICAO Carbon Calculator	Provides realistic and reasonably transparent methodology for assessing carbon emissions from domestic air travel. Methodology is available for review. Does not address issues of demand for domestic air travel. This could be addressed through a macro model.
Waste and Wastewater		
Waste Management Practices	Canadian GHG Calculator for Waste Management	Provides full life cycle emissions analysis based on industry standard US mode (WARM) adapted to Canadian conditions.
Landfill Gas Emissions	LandGEM	Widely used across US and Canada.

Sector	Recommended Method, Tool, or Model	Rationale for Selection
		Provides realistic representation of GHG generation compared to other available models. Reasonably easy to use. Default data provided for quick initial analysis, but can use site-specific data where available.

10.5 Macro Level Models

Developing a macro model to represent provincial energy use and emissions provides a number of benefits. The actual process of collecting, reviewing and analysing the data required for such a model provides an opportunity to gain a better understanding of the factors driving energy use and barriers to changing current patterns of energy use. Our experience indicates that the process of obtaining data for the modelling exercise actually accounts for the bulk of the work in most projects.

Developing a business-as-usual (BAU) or reference projection, usually the first step in any modelling exercise, can also provide a number of useful insights, which may include changing patterns of energy use, the effects of changing economic structure or demographics, and the impact of 'naturally occurring conservation' on future energy use and emissions.

Based on our analysis of available multi-sector, multi-fuel models, we have recommended three which we feel are most appropriate for consideration by CCEEET. Implementing any of these models will provide many of the insights just described. Each of the models offer different advantages and disadvantages in terms of model features, ease of use, transparency, and of course, cost. The choice of which model is most appropriate for CCEEET will depend to a large extent on the types of policies under consideration and how the model is expected to be used. Micro-level models can be used to both inform the macro model and to extend and refine macro-level analyses for specific sectors or applications.

10.6 Data Development

Issues relating to macro modeling and data requirements are strongly interrelated. The requirements of a given model influence the type of data required. Conversely the quality of data available can limit the value of any model.

Given the unique characteristics of NL's economy and energy use, we recommend that a priority be placed on developing improved information regarding NL's largest industries. For the balance of NL energy use, we recommend that improved information be developed regarding energy consuming assets and decision-making regarding those assets. We suggest that an initial representation of NL energy use could be developed using data available from federal and other sources[162]. In the process of compiling such a representation, we believe it would be possible to identify areas where significant differences may exist between national or regional energy use and that in NL. Using a macro model it should be relatively easy to identify which of these areas could have a significant impact on future energy use and emissions. This would then allow data development efforts to be directed to those areas where patterns of energy use in NL are significantly different from those in other areas – and where those differences are significant to the types of policies under consideration. We expect that significant differences may exist, for example, in areas such as freight transportation (less rail, more trucks and marine freight) and industry (fish processing dominates non-large industry). We do not expect that general patterns of decision-making and consumer behaviour in NL differ significantly from those in other jurisdictions, however, that could also be explored through market research.

The approach proposed above is intended to address some of the key concerns raised by the Advisory Group and CCEEET, namely:

- It recognizes the need for a different approach to the large industry sector, which has quite different characteristics from other sectors in NL,
- Costs and on-going resources for developing, maintaining and updating the model and associated data could be minimized,
- Data development efforts could be focussed on key areas where NL-specific data differ from other regions and where those differences will make a difference in terms of energy and emissions policy.

Overall we believe the proposed approach should allow the CCEEET to build up its modelling capability at a reasonable cost and allow investments in data development to focus on areas of maximum value.

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[162] Any representation based on federal data sources would, of course, include adjustments for known discrepancies such as large facilities not included in the federal data, or differing allocations between sectors.

APPENDIX A: CANESS

The following description of the CanESS model was provided by
Michael Hoffman at whatIf? Technologies.

The Canadian Energy Systems Simulator (CanESS) is a new and powerful tool for rapidly exploring a wide range of energy systems scenarios over the long term – allowing for iterative exploration of possible future outcomes whether in a workshop setting or individual use. CanESS is unique in its physical economy approach, providing coherent scenarios to explore the long term impacts of ongoing transitions in the energy economy. This approach complements more conventional econometric energy models that focus on near-term international energy prices and the behavioural response to incentive programs and energy policies.

Background

Canada is home to vast sources of energy that span coast to coast. With our mix of conventional sources such as oil, gas, coal and hydro, unconventional sources such as oil sands, and alternative and emerging sources such as wind and biofuels, Canadians have a wide variety of energy options to meet our rapid population and economic growth. At the same time Canada is committed to reducing the greenhouse gas emissions that contribute to global climate change and the emission of criteria air contaminants that affect human health – both of which are, in part, a by-product of the production and use of hydro-carbon fuels.

Looking at the range and magnitude of Canada's resources and our growing contribution to the global energy picture, Prime Minister Harper has declared Canada to be an 'emerging energy superpower'. Claiming that role – especially a 'green' energy superpower – brings long term obligations along with significant opportunity.

If Canada, its governments, industries and citizens are to make the energy superpower vision a reality, an assessment of our energy options must be undertaken – undertaken in a way that looks at the energy system as an integrated whole and considers the implications of different choices on our energy future. We need to look at the 'green energy superpower' vision not as a 'given', but an opportunity that can be either seized or squandered.

Current growth in the energy sectors is an exciting contributor to Canada's economy. The energy sector underpins much of the Canadian economy – through investment, jobs and taxes, through reliable and affordable energy inputs to our homes and businesses, and through the generation of foreign exchange with which Canadians can acquire goods and services produced abroad. Investment and policy decisions that will have profound long term implications should be made with broad input, with an appropriate long term time horizon and with a fact based analysis of the possibilities, limitations and implications of those decisions.

Each source of energy that we rely on comes with recognized set of challenges relating to unequal regional distribution of different resource types, to the cost of converting resource into consumer energy and to the emission of CO2 and other by-products associated with both energy production and consumption. We are entering an era where traditional energy sectors can no longer live in silos, but are becoming significantly integrated as increasing volumes of non-traditional energy enter the mix and as we look for innovative solutions.

Shifts in the energy economy can only be observed over relatively long time periods due to the long lead times for major projects, the slow rate of capital stock turnover, and the time for new technologies to penetrate the marketplace. Thus, decision makers need long-term insights to balance the short-term demands of both investors and electorate in making decisions whose outcome will span decades.

CanESS is unique in its detailed representation of the technologies that transform energy sources into the energy currencies, hydro-carbon fuels, electricity and hydrogen, and that transform energy currencies into services such as transportation, space conditioning and the mechanical energy and process heat required for the production of goods. CanESS keeps track of the physical stocks and flows of energy feedstocks and fuels, the stocks of capacity for producing energy and energy currencies, and the stocks of artefacts such as vehicles, hot water heaters, HVAC systems, appliances, and electronic devices that use energy in the production of services. This physical economy approach is appropriate for examining coherent scenarios that explore the economic, social and environmental consequences as Canada transitions from an energy economy based primarily on conventional oil and gas to one based on a variety of renewable and non-conventional energy sources and on electricity and hydrogen as energy currencies. CanESS simulations reveal trade-offs among options and tensions, challenges or gaps that may be resolved by new technology, policy alternatives, or changes in the behaviour of energy producers and consumers.

This approach complements the more conventional econometric energy models that focus on the behavioural responses of energy producers and consumers to international energy prices and economic incentives, and that are appropriate for short term policy analysis.

The nature of Canada's diverse geography, geology and market forces suggest there will be regional variations for these energy options. As such, the assessment needs to be built on a good understanding of these regional differences and the opportunities (and infrastructure required) for cross-region and cross-sectoral integration. Because CanESS is being built upon regional building blocks, disaggregation of simulator outputs can be provided for regional analysis.

Approach

CanESS uses a Dynamic Systems Modelling Approach. It simulates alternate energy system scenarios in the context of the Canadian economy and the demand and supply of fuels for Canada. This contrasts with the life cycle analysis approach which is intended to compare products/technologies over the life cycle of the product/technologies.

CanESS scenarios run from the present (2006) to 2100 in one year steps. This long a time horizon is needed to explore the transition of one energy system to another as it is necessary to simulate one if not two turnovers of stocks.

CanESS is calibrated over historical time from 1976 to 2006 in one year steps. The result of the calibration is a complete historical data base of all of the variables in CanESS adjusted to be coherent with the stock-flow and supply disposition accounting identities of CanESS. This data base is a synthesis of data from a wide variety of data sources including Statistics Canada censuses and surveys, the energy end-use data bases compiled by the Demand Policy Analysis Division, Natural Resources Canada, and technical data from engineering studies and the GHGenius life cycle model for Canada.

The common starting point for the scenario analysis are the existing stocks in 2006 including population, households, buildings, vehicles, appliances, productive capacity, resources and reserves fuel that are produced in the model calibration.

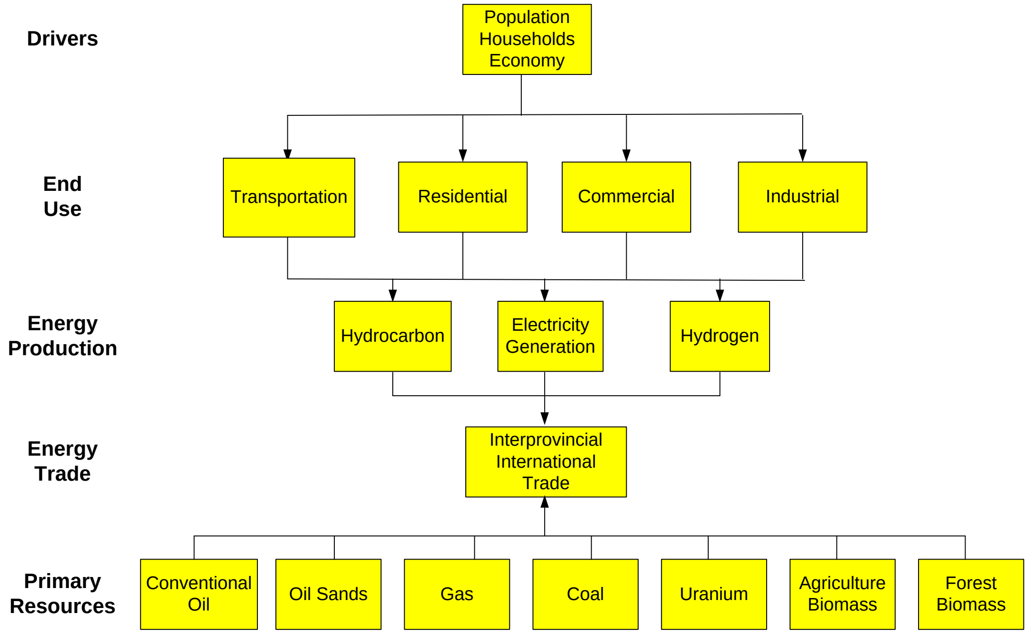
New technologies for producing feedstocks, transforming them into energy currencies, and for transforming energy currencies into useful energy for the production of services can only be introduced as new capacity is required for expansion and/or replacement of the stock.

The emissions of greenhouse gases and criteria air contaminant are calculated at point of source within the boundaries of Canada and the year in which they are released. This is unlike life cycle analysis which attributes all emissions to the products/technologies selected for analysis including those that occur in other countries and accumulates them over the life time of the product/technology.

CanESS focuses on coherency – on creating scenarios assuring consistency between the population, level of economic activity, the services required by the population, the energy system, and the emission of greenhouse gases and criteria air contaminants. It assures coherency both over time and within time periods through the use of stock-flow accounting rules, vintaged stocks and life tables, supply/disposition balances for fuels and feedstocks, and the explicit representation of energy transformations.

An overview of the computational structure of the CanESS is shown in the diagram below.

Simplified Schematic of the Canadian Energy System Simulator (CANESS)



First, the context for the energy system is set in terms of population, households and gross domestic product to the time horizon of the simulation – the user can set values for migration flows, fertility and mortality parameters, and per capita GDP. Then the transportation, residential, commercial buildings and industrial models calculate the energy currencies – hydrocarbon fuels, electricity, and hydrogen required to deliver services at a level commensurate with the economic context. Essentially these models keeps track of the stocks – vehicles, houses , buildings, etc – and associate conversion efficiencies with the vintages of the stocks. The model user can set the efficiencies of future vintages and the rates at which new or alternative technologies penetrate into the stocks. Then these requirements for energy currencies along with those required to produce energy sources are fed to process models that calculate energy feedstocks required to produce the energy currencies. The feedstock production models – for conventional, oil sands, natural gas, coal, uranium, and biomass – represent the resources and the rate at which the resources can be produced. Differences between feedstocks required and feedstocks produced are made up by international trade.

All of the component models are provincially disaggregated and account for the supply, demand, and trade (both international and interprovincial) for all fuels and feedstocks.

The models are rich in compositional detail. For example, population is disaggregated by age and sex; passenger trips are disaggregated by type (commuting, intercity etc.) length of trip, and mode; road vehicles by size of vehicle, age, engine type. It is also rich in the representation of pathways for producing fuels and feedstocks.

The richness of the structure of CanESS makes it possible to explore many alternative configurations of the energy system that are coherent with alternative evolutions of the demographic and economic context.

Model Origins

The need for a model appropriate for the development of an energy strategy for Canada became urgent as the issues of 'peak oil', greenhouse gas emissions, and urban air quality came onto the public agenda. It was clear that such a model should be transparent and accessible to all stakeholders: federal and provincial government agencies, utilities and energy producers and distributors, and non-government organizations. Existing models fail to meet this need for one or more of the following reasons: lack of transparency, too short a time horizon for strategic analysis, housed in institutions without a mandate to support access by other parties, based on methodology developed for issues that are decades old.

Several years ago, we proposed the establishment of a not-for-profit that would house such a model. The proposed model would use the Canadian Transportation Energy and Emissions Model (CanTEEM) as its starting point. Further development, including development of the residential, commercial and industrial energy end-use components, would be funded by contributions from key stakeholders. The proposal met widespread approval from key stakeholders; however, government agencies found it difficult from an administrative point of view to fund such a project with the result that financial support for was not forthcoming.

Since that time, we have been engaged in a number of energy related projects that have enabled us, as by-products of those projects, to proceed with the development of CanESS by means of a significant investment of staff time and effort. We have been particularly fortunate to be engaged by the Demand Policy Analysis Division of the Office of Energy Efficiency to support the design and implementation of energy end-use data bases and simulation models for the transportation, residential, commercial and industrial sectors for the last decade. The experience and knowledge gained from these projects has been adapted for the purposes of CanESS.

Services Available

CanESS has been designed as a platform upon which a wide range of scenarios and sensitivity analyses can be built and, if desired, shared within the user community. To serve this purpose, CanESS is fully transparent with respect to the structure of the model, the data base underlying it, and the assumptions made to arrive at particular results. Further, CanESS has been designed with flexibility to incorporate new structure, alternative data sets, and new assumptions as required for particular analyses.

Services based on the use of CanESS (including direct access to CanESS itself) are available to all interested parties such as government agencies, businesses, industry associations and non-government organizations on a fee-for-service basis in one of three ways:

1. Commissioned Studies. Some clients may wish to commission the development of customized scenarios for their particular organization. These studies may require the development of additional CanESS modules or the refinement of existing modules with sufficient structure for exploring themes of particular interest to the client. Service offerings range from the provision of basic assistance in developing and running scenarios for analysis by the client organization through to scenario development in response to client questions, running selected scenarios, analyzing results and providing a comprehensive report to the client. Costs will be on a fee-for-service basis.
2. Thematic Workshops. Periodic workshops and forums will be organized to explore various themes, where scenarios will be developed and options explored. Each workshop or forum will focus on a particular theme, for example: renewable energy, hydrogen economy, clean coal, oil sands, conservation practices, fuel switching, electricity generation, or greenhouse gas emissions. Workshop participants will use CanESS to design, build and evaluate a series of scenarios in "real-time", with learnings published in a post-workshop report.
3. Direct Access. Clients can choose to have direct access to CanESS from their desktops in order to develop an "in-house" scenario analysis capability. whatIf? will provide training and support services to such members on a fee-for service basis.

Development of the Canadian Energy Systems Simulator (CanESS) fills the need for an integrated energy framework. Making CanESS accessible to all stakeholders with an interest in examining energy futures for Canada – federal and provincial governments, industries, non-government organizations, and citizens – will make it a truly Canadian tool. Our goal is to foster the shared understanding of the opportunities to be realized and the challenges to be overcome in realizing the potential of Canada's energy future.

Applications

The separation of physical accounting from the representation of behaviour provides support for strategic analysis, as well as policy analysis. Strategic analysis involves the delineation of possible or physically coherent pathways some of which may lead to a desired outcome or meet overall planning objectives. Once a pathway or set of pathways has been selected, policy analysis is used to select the policy instruments and the intensity with which they must be used in order to put the system on the desired trajectory. The physical accounting components may be used independently of the behavioural components for the purpose of strategic analysis. The behavioural components that relate policies (incentives, subsidies, taxes, regulation) to the decisions of economic actors can be used in conjunction with the physical accounting components to perform policy analysis.

Most if not all the existing energy models (e.g. CIMS, ENERGY2020, MARKAL, NEMS/Maple-C, etc) are based on conceptual designs that focus on the representation of the behaviour of energy producers and consumers and mix the physical and behavioural components in such a way that they are unable to support strategic analysis. Not only is their time horizon too short for strategic analysis, but the future is bounded by past behaviour embedded in statistically estimated parameters such as price elasticities and preferences.

CanESS can be used to create a wide range of energy system scenarios that might involve:

- An energy system scaled to different rates of population and economic growth
- Energy systems with different levels of energy independence
- Fuel switching - increased use of non-emitting energy currencies
- Increased use of biofuels
- Changes in life style
- Improved energy efficiency
- Changes in mode of transportation
- Travel patterns by household and freight intensity
- Changes in the sources of energy
- The introduction and penetration of new technologies for transforming energy sources into energy currencies.

Analyses based on CanESS include:

- Bio ethanol. A study of the penetration of bio-ethanol blends as fuels for the light duty vehicles as an example of the use of systems modelling as a tool for assessing the sustainability technologies - in collaboration with the **National Research Council** – 2004. This study countered the results of life cycle assessments that had lead to the establishment of bio-fuel targets and production subsidies and raised the issue of the potential conflict between the use of crops for feed and fuel.
- Bio diesel. The Potential Impact of Biodiesel Under a Scenario of Increased Penetration of Advanced Diesel Engines in Light Duty Vehicles - **National Research Council** – April 2006.
- Oil Sands. The Potential Impact of an Increased Use of Synthetic Crude Oil and the Dieselisation of the Light-Duty Vehicle Fleet in Canada – **National Research Council** – April 2006. This project led to the elaboration of a process based model of alternative oil sands production technologies.
- A Glimpse at Canada’s Energy Systems in 2050. Workshop hosted in collaboration with **Energy Futures Network** and **Energy Council of Canada**, June 5, 2008, Calgary. Scenario themes included business-as-usual, carbon sequestration, electricity generation from non-emitting energy sources, fuel switching from hydrocarbon fuels to hydricity, and increased energy efficiency
- Natural Gas. CanESS was used to run a range of scenarios based on a range of possible changes in future trends in the production of natural gas from both conventional and non-conventional sources to explore impacts on Alberta and Canada. This project was carried in collaboration with **Energy Futures Network** for the Alberta Department of Energy. This project further developed the natural gas related modules of the Canadian Energy Systems Simulator through updating the supply modules (to reflect recent production history and reserves from conventional and unconventional gas resources plus potential LNG imports) and updating the demand modules to reflect current trends in natural gas use.

Bio-mass Energy Possibilities for Alberta to 2100. This project was carried in collaboration with **Energy Futures Network** for the Alberta Energy Research Institute. The project involved representing biomass available from forestry and agricultural sources in Alberta and the processes required to transform the biomass into energy currencies.

APPENDIX B: CIMS

The following description was provided by Michael Wolinetz, of
M.K. Jaccard & Associates, Inc.
on 27 April 2011.

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 1. CIMS does not include adipic and nitric acid, solvents or hydrofluorocarbon (HFC) emissions. CIMS covers nearly all CAC emissions except those from open sources (e.g., forest fires, soils, and road dust).

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.

Table 1: Sector Sub-models in CIMS

Sector	BC	Alberta	Sask.	Manitoba	Ontario	Quebec	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.

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

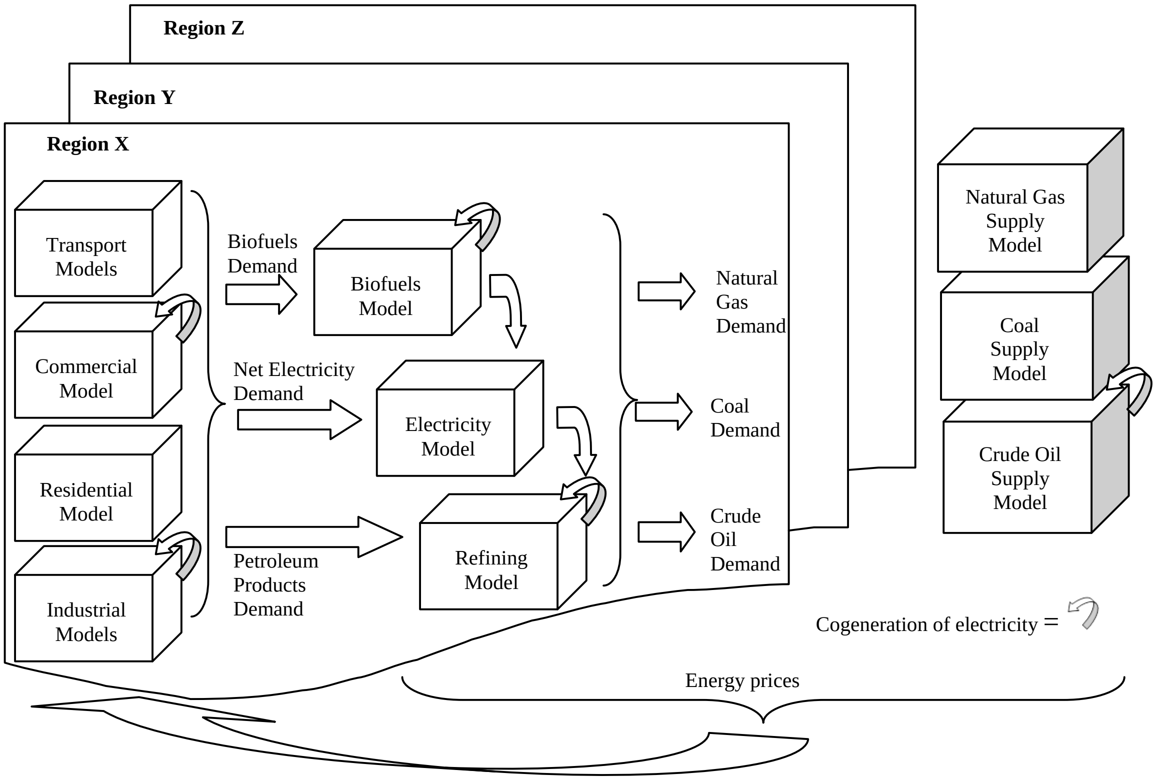
CIMS is an integrated, energy-economy equilibrium model that simulates the interaction of energy supply-demand and the macroeconomic performance of key sectors of the economy, including trade effects. Unlike most computable general equilibrium models, however, the current version of CIMS does not equilibrate 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 34 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 (described later in this section), since Canada is assumed to be a price-taker for these fuels.

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).[163] 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.

Figure 34: CIMS energy supply and demand flow model



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

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

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.[164]

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.

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[164] 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.

APPENDIX C: ENERGY2020

The following description of the ENERGY 2020 model is taken from the Western Climate Initiative's "Updated ENERGY 2020 Inputs and Assumptions", July 7, 2010, available at: *http://www.westernclimateinitiative.org/component/remository/func-startdown/266/*

ENERGY 2020 is an integrated multi-region, multi-sector energy analysis system that simulates the supply, price and demand for all fuels. It is a causal and descriptive model, which dynamically describes the behavior of both energy suppliers and consumers for all fuels and for all end-uses. It simulates the physical and economic flows of energy users and suppliers. It simulates how they make decisions and how those decisions causally translate to energy-use and emissions.

ENERGY 2020 is an outgrowth of the FOSSIL2/IDEAS model developed for the US Department of Energy (DOE) and used for all national energy policy since the Carter administration.[165] This early version of ENERGY 2020 was developed in 1978 at Dartmouth College for the DOE's Office of Policy Planning and Analysis.

Model Overview

The basic structure of ENERGY 2020 is provided in Figure 1-1. Energy Demand sector interacts with the Energy Supply sector to determine equilibrium levels of demand and energy prices. Energy Demand is driven by the Economy sector, which in turn provides inputs to the Economy sector in terms of investments in energy using equipment and processes and energy prices. The model has a simplified Economy sector to capture the linkages between the energy system and the macro-economy. However, the model is best run with full integration with a macroeconomic model such as REMI. Given the modular nature of ENERGY 2020, additional sectors or modules from other, non-ENERGY 2020 related, models (macroeconomic, supply such as oil, gas, renewables etc.) can be incorporated directly into the ENERGY 2020 framework.

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[165] *FOSSIL2 was the original version but was renamed to IDEAS a few years ago to reflect its evolutionary development since its original construction.*

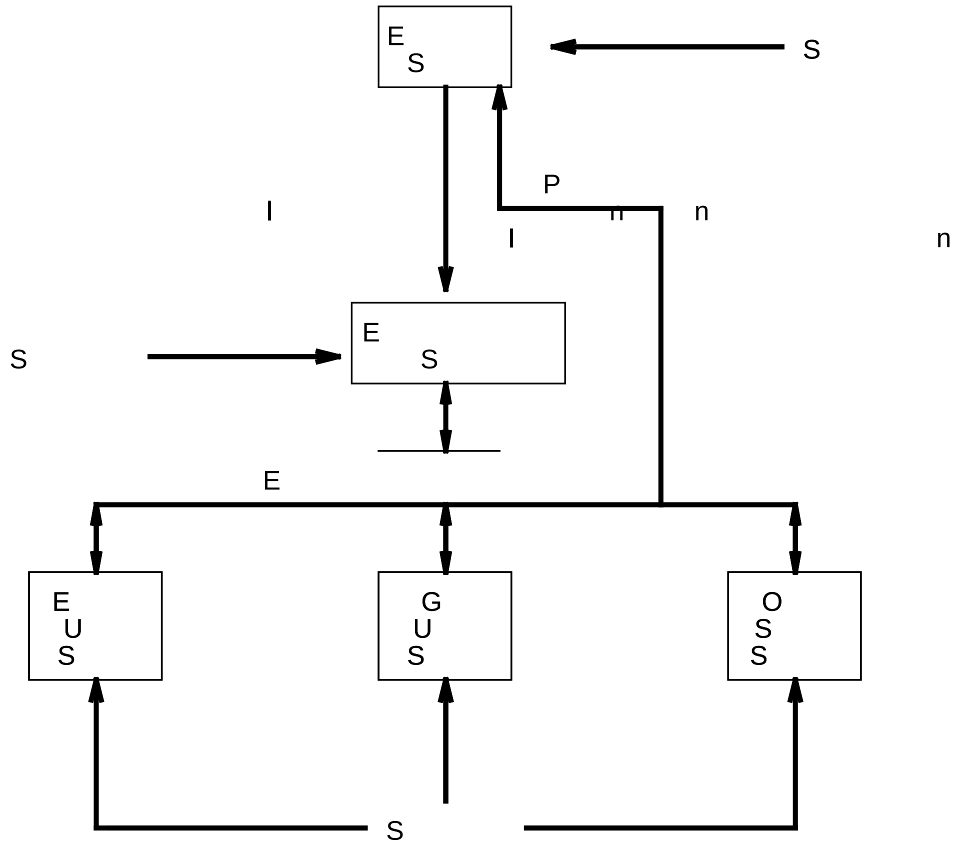


Figure 1.1: ENERGY 2020 Overview

Energy Demand

The demand sector of the model represents the geographic area by disaggregating the four economic sectors into subsectors based on energy services. As many or as few subsectors can be incorporated as required. Multiple technologies, multiple end-uses and multiple fuels are detailed. The level of detail that can be incorporated is of course subject to the data availability. The four economic sectors are:

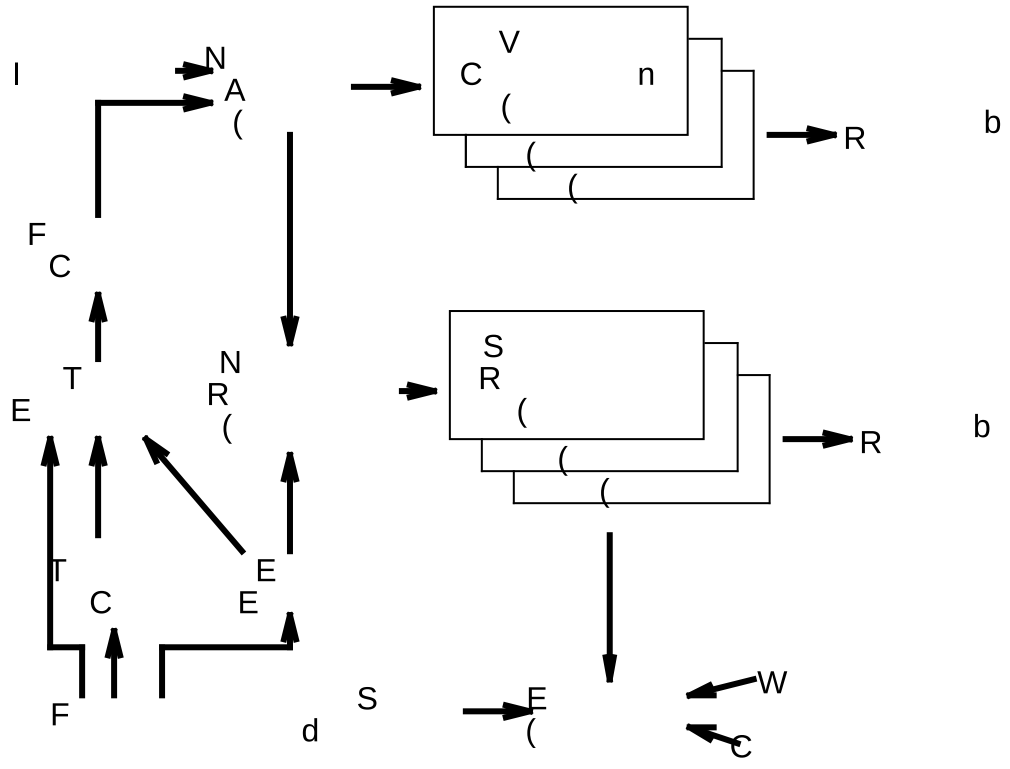
- Residential sector which includes three classes, single family, multifamily and rural/agricultural with 8 end-uses including space heating, water heating, lighting, cooling, refrigeration, other substitutable, and other non-substitutable.
- Commercial sector which is aggregated into one class and end-uses including space heating, water heating, cooling, lighting, other substitutable, other non-substitutable.
- Industrial sector which includes 10 (23 for US) 2-digit SIC categories and is further broken down into process heat, motors, lighting, miscellaneous as the end uses.

- Transportation sector which includes several modes of transportation including automobile, truck, bus, train, plane, marine and electric vehicles. Also, each of the residential, commercial and industrial sectors has separate transportation demands.

For each of the end-uses, up to six fuels are modeled, for example, the residential space heating has the choice of a gas, oil, coal, electric, solar and biomass space heating technologies. Added end-uses, technologies and modes can be added as data allow. For all end-uses and fuels, the model is parameterized based on historical locale-specific data. The load duration curves are dynamically built up from the individual end-uses to capture changing condition under consumer choice and combined gas/electric programs.

A few basic concepts are crucial to an understanding of how the model simulates the energy system. These concepts including, the capital stock driver, the modeling of energy efficiency through trade-off curves, the fuel market share calculation, utilization multipliers and the cogeneration module are discussed below in abbreviated form. Figure 3-1 (Demand Overview) illustrates the demand sector interactions.

Figure 3.2: Demand Overview



Energy Demand as a Function of Capital Stock

The model assumes that energy demand is a consequence of using capital stock in the production of output. For example, the industrial sector produces goods in factories, which require energy for production; the commercial sector requires buildings to provide services; and the residential sector needs housing to provide sustained labor services. The occupants of these buildings require energy for heating, cooling, and electromechanical (appliance) uses.

The amount of energy used in any end-use is based on the concept of energy efficiencies. For example, the energy efficiency of a house along with the conversion efficiency of the furnace determines how much energy the house uses to provide the desired warmth. The energy efficiency of the house is called the capital stock energy or process efficiency. This efficiency is primarily technological (e.g. insulation levels) but can also be associated with control or life-style changes (e.g. less household energy use because both spouses work outside the home.) The furnace efficiency is called the device or thermal efficiency. Thermal efficiency is associated with air conditioning, electromotive devices, furnaces and appliances.

The model simulates investment in energy using capital (buildings and equipment) from installation to retirement through three age classes or vintages. This capital represents embodied energy requirements that will result in a specified energy demand as the capital is utilized, until it is retired or modified.

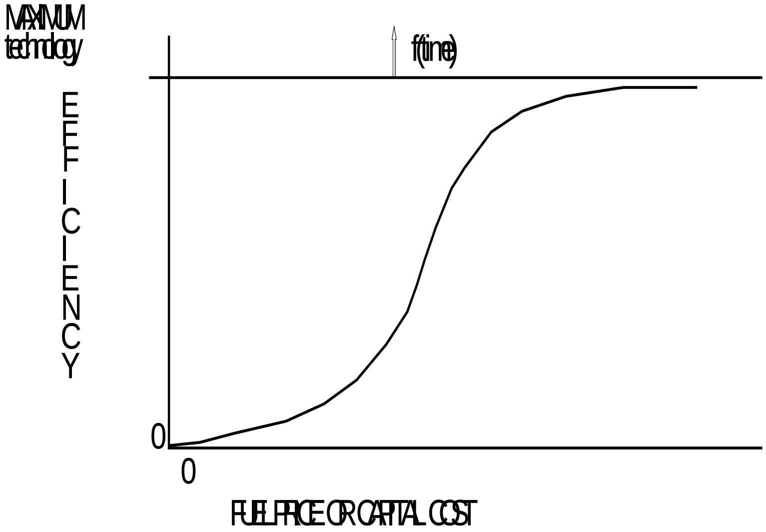
The size and efficiency of the capital stock, and hence energy demands, change over time as consumers make new investments and retire old equipment. Consumers determine which fuel and technology to use for new investments based on perceptions of cost and utility. Marginal trade-offs between changing fuel costs and efficiency determine the capital cost of the chosen technology. These trade-offs are dependent on perceived energy prices, capital costs, operating costs, risk, access to capital, regulations and other imperfect information.

The model formulates the energy demand equation causally. Rather than using price elasticities to determine how demand reacts to changes in price, the model explicitly identifies the multiple ways price changes influence the relative economics of alternative technologies and behaviors, which in turn determine consumers' demand. In this sense, price elasticities are outputs, not inputs, of the model. The model accurately recognizes that price responses vary over time, and depend upon factors such as the rate of investment, age and efficiency of the capital stock, and the relative prices of alternative technologies.

Device and Process Energy Efficiency

The energy requirement embodied in the capital stock can be changed only by new investments, retirements, or by retrofitting. The efficiency with which the capital uses energy has a limit determined by technological or physical constraints. The trade-off between efficiency and other factors (such as capital costs) is depicted in Figure 3.3 (Efficiency/Capital Cost Trade-Off). The efficiency of the new capital purchased depends on the consumer's perception of this trade-off. For example, as fuel prices increase, the efficiency consumers choose for a new furnace is increased despite higher capital costs. The amount of the increase in efficiency depends on the perceived price increase and its relevance to the consumer's cash flow.

Figure 3.3: Efficiency/Capital Cost Trade-Off



The standard the model efficiency trade-off curves are called consumer-preference curves because they are estimated using cross-sectional (historical) data showing the decisions consumers made based on their perception of a choice's value. Many planners are now interested in measure-by-measure or least-cost curves which use engineering calculations and discount rates to show how consumers should respond to changing energy prices. Another analysis focuses on the technical/price differences in alternative technologies and the incentives needed to increase the market-share or market penetration of a specific technology. This perspective on the choice process uses market share curves. The model allows the user to select any of these three types of curves to represent the way consumers make their choices. Shared savings, rebate, subsidy programs, etc. can be tested using any of the curves.

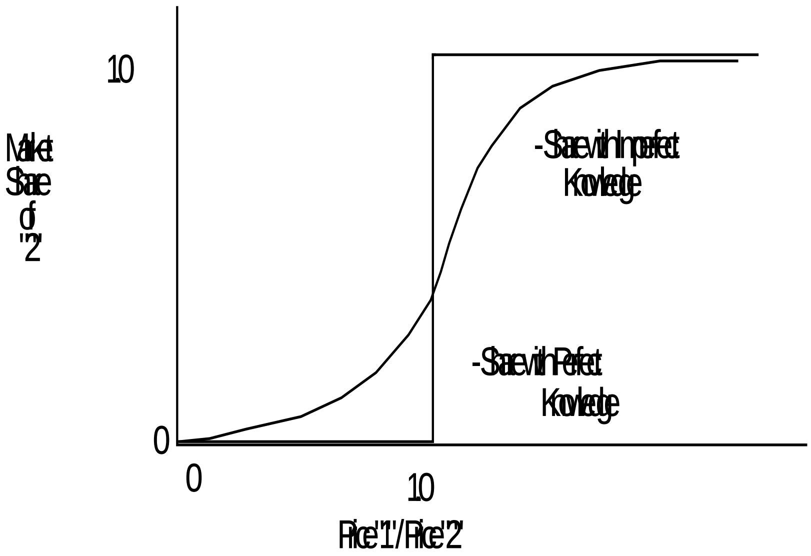
Cumulative investments determine the average embodied efficiency. The efficiency of new investments versus the average efficiency of existing equipment is one measure of the gap between realized and potential conservation savings.

The model uses saturation rates for devices to represent the amount of energy services necessary to produce a given level of output. Saturation rates may change over time to reflect changes in standard of living or technological improvements. For example, air conditioning has historically increased with rising disposable incomes. These rates can be specified exogenously or can be defined in relation to other variables within the model (such as disposable income).

The Market Share Calculation

Not all investment funds are allocated to the least expensive energy option. Uncertainty, regional variations, and limited knowledge make the perceived price a distribution. The investments allocated to any technology are then proportional to the fraction of times one technology is perceived as less expensive (has a higher perceived value) than all others. This process is shown graphically in Figure 3.4 (Market Share Dynamics).

Figure 3.4: Market Share Dynamics



Short Term Budget Responses

A short-term, temporary response to budget constraints is included in the model. Customers reduce usage of energy if they notice a significant increase in their energy bills. The customers' budgets are limited and energy use must be reduced to keep expenditures within those limits. These cutbacks are temporary behavioral reactions to changes in price, and will phase out as budgets adjust and efficiency improvements (true conservation) are implemented. This causes the initial response to changing prices to be more exaggerated than the long-term response, a phenomenon called "take-back" in studies of consumer behavior.

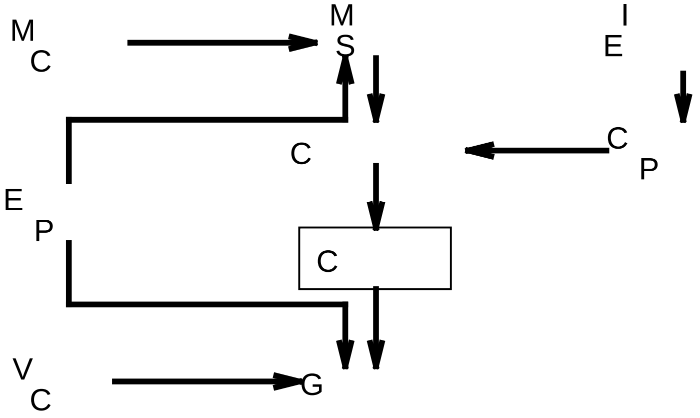
Accounting for Fungible Demand

Some furnaces and processes can use multiple fuels. That is, they can switch almost instantaneously between, for example, gas and oil or coal and biomass as prices or the market dictates. Energy demand that is affected by this short-term fuel switching phenomena is called fungible demand. The model explicitly simulates this market share behavior.

Modeling Cogeneration

Most energy users meet their electricity requirements through purchases from a utility. Some users (industrial and commercial) can, however, convert some of their own waste heat into usable electricity when economics warrant such action. Other users (residential and commercial) can purchase self-generation energy sources such as gas turbines, diesel-generators or fuel cells. Figure 3.4 shows a simplified overview of the cogeneration structure.

Figure 3.5: Cogeneration Concepts



In the model all energy used for heating is a candidate for cogeneration. The cost of cogeneration is the fixed capital cost of the investment plus the variable fuel costs (net of efficiency gains). This cogeneration cost is estimated for all technologies and compared to the price of electricity. The marginal market share for each cogeneration technology is based on this comparison.

Cogeneration is restricted to consumers who directly produce part of their own electricity requirement. Companies which generate power primarily for resale to the electric utility are considered independent power producers and are included in the electric supply model.

Energy Supply:

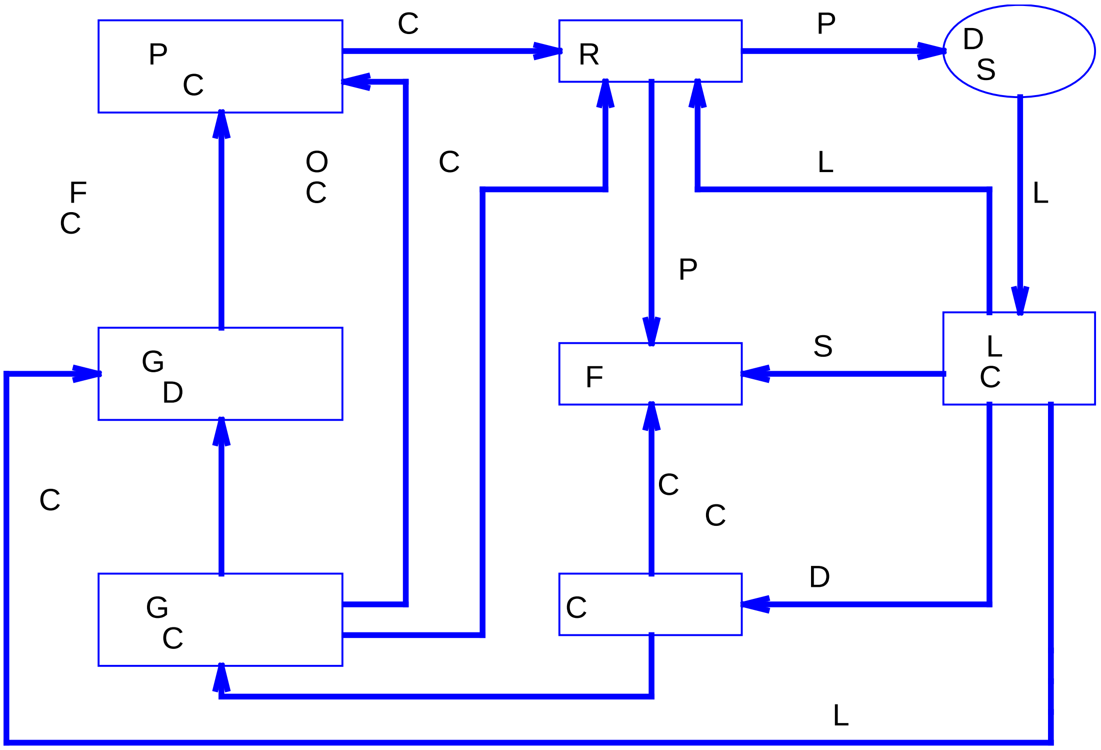
For electric and gas utilities (separate or combined), ENERGY 2020 internally and self-consistently simulates sales, load (by end-use, time-of-use, and class), production (across thirty-six dispatch types), demand side management (by technology), forecasting, capacity expansion (new generation, independent power producers, purchases, and DSM), all important financial variables, and rates (by class, end-use, and time-of-use.)

The version currently used in this analysis only has the electricity utility sector (a full fledged natural gas utility sector for Canada is currently unavailable in the model, only a simplified natural gas supply function is used to calculate the supply price response).

With the inclusion of the electric utility sector, the generic supply model turns over the calculation of electricity prices to that sector. The model is capable of endogenously simulating the forecasting of capacity needs, as well as the planning, construction, operation and retirement of generating plants and transmission facilities. Each step is financed in the model by revenues, debt, and the sale of stock. The simulated utility, like its real world counterpart, pays taxes and generates a complete set of accounting books. In ENERGY 2020, the regulatory function is modeled as a part of the utility sector. The regulator sets the allowed rate of return, divides revenue responsibility among customer classes, approves rate base, revenues and expenses, and sets fuel adjustment charges.

The interactions in the electric utility sector are summarized in Figure 3.6

Figure 3.6: Electric Utility Structure Overview



Expansion Planning:

The utility sector endogenously forecasts future demand for electricity. From the forecast it projects the future capacity required meeting future demand by taking into account retirements and plants already under construction. Construction of additional capacity is initiated if future electricity requirements, including reserves, are forecast to exceed available capacity (using seasonal ratings).

If additional capacity is needed to meet forecasted needs, the basic capacity expansion module in ENERGY 2020 determines whether base or peaking capacity is required. The model determines the maximum number of hours that new peaking capacity can be economically operated, before it would be less expensive to construct and operate base load capacity instead. If the forecasted peaking capacity would operate more than that economic maximum, base loads units are initiated, otherwise peaking units are initiated. Any plant type including geothermal, wind, biomass and storage can be considered.

New plants, of a pre-specified minimum size, are initiated when the reserve margin would be violated if the plants were not built or if base load capacity is inadequate to serve base load energy needs at the end of the forecast period. The model does allow the minimum reserve margin to be temporarily violated at the peak if new base load capacity is scheduled to be available within the year. Peaking units are allowed to serve more than the maximum economical number of hours until base load capacity comes on-line.

Minimum plant size is exogenous. The mix of new base load plants (i.e. alternative coal technologies, hydro, or nuclear) is user-specified in the standard ENERGY 2020 configuration. The model also evaluates the financial implications of new construction, including total construction costs, cost schedules, and AFUDC/CWIP. The gross rate on AFUDC equals the weighted average cost of capital. The actual construction progress and financial impacts are simulated on a year by year basis.

ENERGY 2020 can also be configured to consider intermediate load units, firm purchases contracts, external sales, independent power producers, and demand-side options. These options can be optionally selected based on endogenous least-cost analysis or can be chosen by user-specified criteria to meet. A detailed automatic Integrated Resource Planning module that would endogenously choose (with user control) from DSM measures utility and non-utility generation and purchase alternatives using linear programming techniques is now being offered as an enhancement.

Financing:

The ENERGY 2020 utility finance sub-sector simulates the activities of a utility's finance department. It forecasts funding requirements and follows corporate policies for obtaining new funds. The model simulates borrowing and issuing of stock, and can repurchase stock or make investments if it has excess cash. Cash flows are explicitly modeled, as are any decision that affects them. Coverage ratios, intermediate- and long-term debt limits, capitalization, rates of return, new stock issues, bond financing, and short-term investments are endogenously calculated. The model keeps track of gross, net, and tax assets. It also calculates the depreciation values used for the income statement and tax obligations.

For WCI modeling, this element of the model is not used, and a simpler approach to estimating retail electricity prices is used.

Regulation:

The utility sector sets electricity prices according to regulatory requirements. The regulatory procedures use allowed rate-of-return and test year cost and demands to determine allowed revenues. Electricity prices are calculated from peak-demand fractions by allocation of costs. Any other allocation scheme can also be considered. The regulatory sub-sector of ENERGY 2020 automatically factors in a wide variety of regulatory policies and options. More importantly, the model can be readily modified to consider a wide spectrum of scenarios.

The regulatory process revolves around a test year, usually one year forward, when proposed rates will go into effect. The utility sector forecasts test year sales and peak demands by season and customer class, just as it does to determine capacity needs. These test year demand estimates are used to allocate responsibility for system peak, and therefore, generation capacity costs.

Fuel costs for the test year are estimated by dispatching the plants that will be available in the test year, using the dispatching routine explained below. Fuel costs and operating and maintenance costs are adjusted for expected inflation, and these costs are factored into the electricity rates using forecasted sales.

ENERGY 2020 calculates the utility rate-base according to a detailed conventional rate making formula. The model allows the user to adjust allowable costs, and has been used extensively to evaluate alternative rate-base scenarios for individual plants, including allowing return of, but no return on investment, and partial disallowment of construction and interest costs.

The ENERGY 2020 system also includes estimation of avoided costs, which determines when the utility may be required to purchase third party power. Environmental constraints, such as air pollution restrictions, can also be included in the model. If ENERGY 2020 is configured as a regional or state-wide system, municipal utilities, with their unique tax and rate structures, are incorporated. Similarly, regional or power pool interchange is also recognized by ENERGY 2020. As with the other sectors of ENERGY 2020, the regulatory subsector is flexible enough to accommodate any existing or hypothetical circumstance.

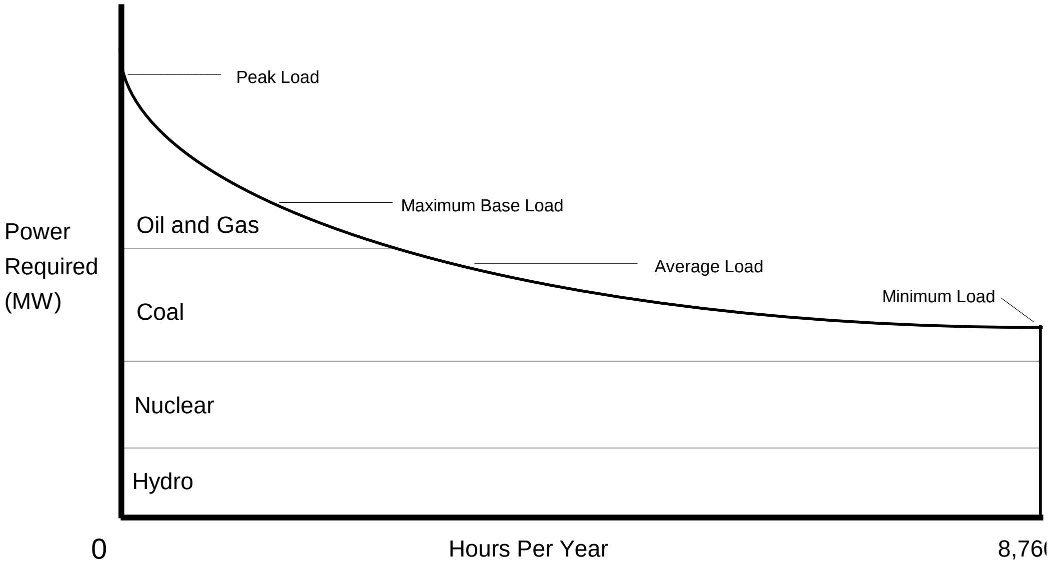
For WCI modeling, this element of the model is not used, and a simpler approach to estimating retail electricity prices is used.

Operations:

Each end-use in ENERGY 2020 has a related set of load shape factors. Typically, these factors define the relationship between peak, minimum and average load for each season. These factors when combined with the weather-adjusted energy demand by end-use and corrected for cogeneration, resale, and load management programs, form the basis of the approximated system load duration curve. Alternatively, unit hourly loads for each end-use for three days per month (average weekday, weekend and peak weekday) are used.

The standard ENERGY 2020 production subsector uses an advanced de-rating or chronological method to estimate the seasonal or hourly dispatch of plants. It purchases power externally when economic or necessary. Plant availability and generation for coal, nuclear, hydroelectric, oil and gas are currently considered, as well as pumped storage, firm purchases, interruptible load, and fuel switching and qualified facilities. Figure 3.7 also shows a typical plant dispatch schedule.

Figure 3.7: Generation from the Load Curve



The ENERGY 2020 system estimates conventional fuel costs based on the unit dispatch, heat rates, and fuel prices (from the supply sector.) Nuclear fuel costs are capitalized and depreciated throughout the re-fuelling cycle. Nuclear fuel expenses also include fuel disposal costs.

ENERGY 2020 explicitly models the costs of maintaining the transmission and distribution (T&D) system. New facility investments are scheduled and incurred endogenously. In addition, the user can specify the decision rules that dictate T&D expenditures. ENERGY 2020 also explicitly models both fixed and variable operation and maintenance costs, power pool interchanges, nuclear decommissioning costs, plant capital additions, plant cancellations, and general administration costs.

Model Applications:

The structure of the model is well tested and has been used to simulate not only US and the Canada energy and environmental dynamics but also those of several countries in Western, Central and Eastern Europe. Current efforts include strategic and tactical analyses for South America deregulation. Further, the model has been used successfully for deregulation analyses in over 50 energy suppliers and in all the US states and Canadian provinces. Several US and

Canadian energy suppliers currently use the model for the analysis of combined electricity and gas deregulation dynamics.[166] The model contains confidence and validity packages that allow it to determine how to take maximal advantage of RTO rules. The ISO NE used the model to find gaps in its rules and to develop more efficient market conditions. The model was used for the CAPX/ISO to model to show, before the fact, many of the "games" played in the California market.

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[166] *ENERGY 2020 is the only model known to have simulated and predicted the dynamics that occurred in the UK electric deregulation. These include gaming, market consolidation and re-regulation dynamics.*

APPENDIX D: RESEARCH APPROACH & SAMPLING

In designing market research, the coverage and granularity (temporal and geographic) of the data will determine the most appropriate methodology (phone or mail surveys, site visits, physical inspection and/or on-site metering, etc.). The methodology combined with the scope and segmentation requirements and level of confidence required will in turn determine sample size and the complexity of the analysis.

Other dimensions of the analysis which will determine study and survey design include:

- **Scope & Coverage** – research could address end uses or extend to technologies, include behaviours, operating characteristics, existing technology saturations, marginal technology shares, plans, energy-efficiency related behaviours, etc.
- **Stratification of data** – the number of sub-sectors or populations addressed in the survey will determine the sample size that must be acquired to obtain a given level of reliability in the results for each segment and dimension of data.
- **Level of Detail** - for example, how many sectors and sub-sectors are of interest, how to segment residential customers (i.e. housing types, ownership characteristics, fuel types, etc.).

Decisions regarding each of these dimensions will determine the overall complexity and cost of the research. Tailoring the research to reflect information needs and known characteristics of the population will allow more meaningful results to be obtained at a lower cost.

Where the population is small, there may be issues with obtaining a sample which will provide a high level of confidence/precision if results are desired at a segment level; however the a high level of precision may be obtained for the segment as a whole.

Sampling Approach Overview

This section presents some general background information on commonly used sampling approaches. It discusses the data that is required for different approaches and the pros and cons to consider when selecting a sampling strategy.

Sampling allows the researcher to learn about a large group by observing a few cases. The sample design is a set of procedures for selecting the sample cases so valid conclusions can be drawn about the population. Good data analysis begins with good sample design, while poor sample design can cripple or destroy an analysis.

A primary principle of good sample design is to control for confounding factors within the study or within study groups. For example, if the energy savings for a residential water heater program are being studied then eligible customers for the non-participant comparison group should also have electric water heaters. This would eliminate the confounding factor of homes without air-conditioning.

A second principle is randomization of sample selection within the eligibility criteria. A random sample is based on selection by chance where each element in the population is selected with a known absolute probability or a knowable relative probability. Selecting a sample by chance eliminates the possibility of selecting on convenience, taste, happenstance or judgment. Using non-random methods for selection can lead to bias in the sample. A biased sample is not representative of the population and will not deliver the true results to a research question. Bias is important to consider within the sample design since it is difficult to recognize after the data is collected. Biased samples can even hide behind statistics that say the results are precise with a high confidence interval.

Population Database

A complete population database is the ideal for any sample design or sample selection. The population database is a listing of each case in the population with relevant information for each case. For program evaluations, the population database is usually built from the program tracking database. It includes the name, address and phone number of participants as well as information on the programs they participated in. Information on installed measures, dates of installation and estimated savings are also frequently used for sample design and analysis of results.

Data needed in the population database is described well in the California Evaluation Framework:

> *"In the context of simple random sampling, the minimum requirement is the information needed to identify each project so that the desired data can be collected for the projects that fall into the sample. The population database generally should also have a suitable measure of the size of each unit in the population. This usually is either the tracking estimate of the savings of each project in the program, or the annual energy usage of each unit in the population."*[167]

In the real world, most population databases are not complete. A careful quality review should be given to the data that is available. Checks should be made for possible biases in the data,

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[167] The California Evaluation Framework. Prepared for the California Public Utilities Commission and the Project Advisory Group, June 2004

either because some customers are not included or there is an absence of eligibility data for a particular group of customers. Checks should also be made on the reasonableness of the range of values in each data field. Understanding the available data, and problems within the dataset, can contribute to a more robust sample design and analysis plan.

Types of Sampling

Statisticians have developed many approaches to sample design. Each of these approaches may be best for a particular application based on the objectives of the study and the availability of the population data. Some of the sampling approaches that are commonly used for impact evaluations are described briefly here.

Simple Random Sampling

Simple random sampling is a method of selecting sample cases out of the population such that every one of the distinct population cases has an equal chance of being selected. It is easy to design a simple random sample for fixed sampling frames and it generally produces unbiased estimates. It is generally done by assigning a random number to each case and then selecting the required number of cases based on an ordering of the random numbers. This method requires that the entire population is known and identified at the time of the sample selection.

Systematic Sampling

In systematic sampling, a sample unit is chosen at a prescribed interval. A random initiator is also often included. For example, if the interval is 20 and the random initiator is 7, the 7th, 27th, and 47th cases etc. would be selected for the sample. Systematic sampling is easy to use, particularly as part of a program rollout, but biases can occur if there are repeating cycles in the data structures. Therefore, not every element may have an equal probability of being selected. It is often used when a sample needs to be selected over time on a continuing basis.

Stratified Random Sampling

A more sophisticated sample design is the stratified random sample. In this method, the sample population is divided into subgroups (i.e., strata) based on a known characteristic such as savings level or energy usage. A sample is then randomly chosen from each strata in one of three ways.

- *Proportional stratification* – sample units are chosen equal to the portion of the population in the strata.

- *Optimal stratification* – sample units are sampled proportional to the standard deviation and the size of each strata. It is sometimes referred to as model-based sampling.

- *Disproportionate stratification* - disproportionate sampling may be used if one strata is of specific interest, or if information is required on each strata in addition to information on the whole population.

Stratified random samples can produce estimates with smaller coefficients of variation than simple random samples. This characteristic makes them an efficient sample design since greater precision and reliability can be gained from a smaller sample size. However, if Optimal or Disproportionate sampling is used, results must be weighted which can complicate analysis. It is important to keep in mind that Disproportionate stratified sampling can reduce the standard error for the population estimate, but the reliability and precision of the data collected for each stratum is equivalent to a simple random sample of the same size for the same sub-population.

Cluster Sampling or Snowball Sampling

Cluster sampling can be used to reduce the geographic distribution of the sample. Groups of customers are randomly selected (e.g., zip codes), then a random sample is selected from within each zip code. Cluster sampling is often used when large distances make data collection more expensive. It can produce unbiased estimates at lower data collection costs than simple random sampling, but typically results in larger coefficients of variation.

Ratio Estimation Sampling

Ratio Estimation is a sampling method that can achieve increased precision and reliability by taking advantage of a relatively stable correlation between an auxiliary variable and the variable of interest. This reduces the overall coefficient of variation. For example, in an appliance rebate program for business customers there is likely a very wide range in the achieved savings per project. This is because the sizes of the businesses can vary from small customers with 5 kW of load to large customers with 5000 kW. Both the average size and the average savings for this group of customers will have very large coefficients of variation.