ENT000510
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COMPARING

Power Generation Options

Greenhouse Gas Emissions

Why is **climate change** an important environmental issue?

In 2001, the Intergovernmental Panel on Climate Change (IPCC) produced a report on the impacts of climate change. In the *Summary for Policymakers* (pp. 7 and 14), the panel assesses the following impacts as "likely" or "very likely":

- ***"More intense precipitation events: increased floods, landslide, avalanche, and mudslide damage."***
- ***"Increased summer drying over most mid-latitude continental interiors and associated risk of drought."***
- ***"Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities."***
- ***"Intensified droughts and floods associated with El Niño events in many different regions."***
- ***"Sea-level rise and an increase in the intensity of tropical cyclones would displace tens of millions of people in low-lying coastal areas of temperate and tropical Asia."***

In Canada, as in all northern countries, climate change is expected to be extremely rapid under the business-as-usual scenario. This means that ecosystems would have to "migrate" about 1,000 km northward in just 50 years. But forests cannot "move" at this speed. Forest fires and major dieback will result, affecting the overall productivity of forests.

Many northern species will also be endangered by climate change, e.g, polar bear, beluga, caribou. In a recent publication entitled *Sensitivities to Climate Change in Canada*, Natural Resources Canada concludes that: "The climate change associated with a doubled atmospheric concentration of CO_2 may virtually eliminate salmon habitat from the Pacific Ocean."

What **pollutants** cause **climate change?**

The main greenhouse gases (GHG) are carbon dioxide (CO_2) and methane (CH_4). Both are directly related to energy systems. Any combustion will produce CO_2. CH_4 is emitted during the extraction of coal and natural gas. Any leakage in the distribution of natural gas will also result in CH_4 emissions, because commercial natural gas is composed of about 95% CH_4. Other greenhouse gases (N_2O, CFC, HFC, PFC) are rarely included in the assessment of energy options, because of the low volumes emitted.

The various GHGs do not have the same effect on the climate. To take their differences into account, the IPCC has produced indicators of ***global warming potential***, relative to CO_2. In most studies, each GHG is converted to an equivalent of CO_2 and added to the inventory. For example, a gram of CH_4 has a ***global warming potential*** of 23, relative to a gram of CO_2 (over a 100-year period). The data in Figure 1 is expressed in CO_2 "equivalent," meaning that CH_4 emissions are included with CO_2 emissions.

Which **energy option** is responsible for **climate change?**

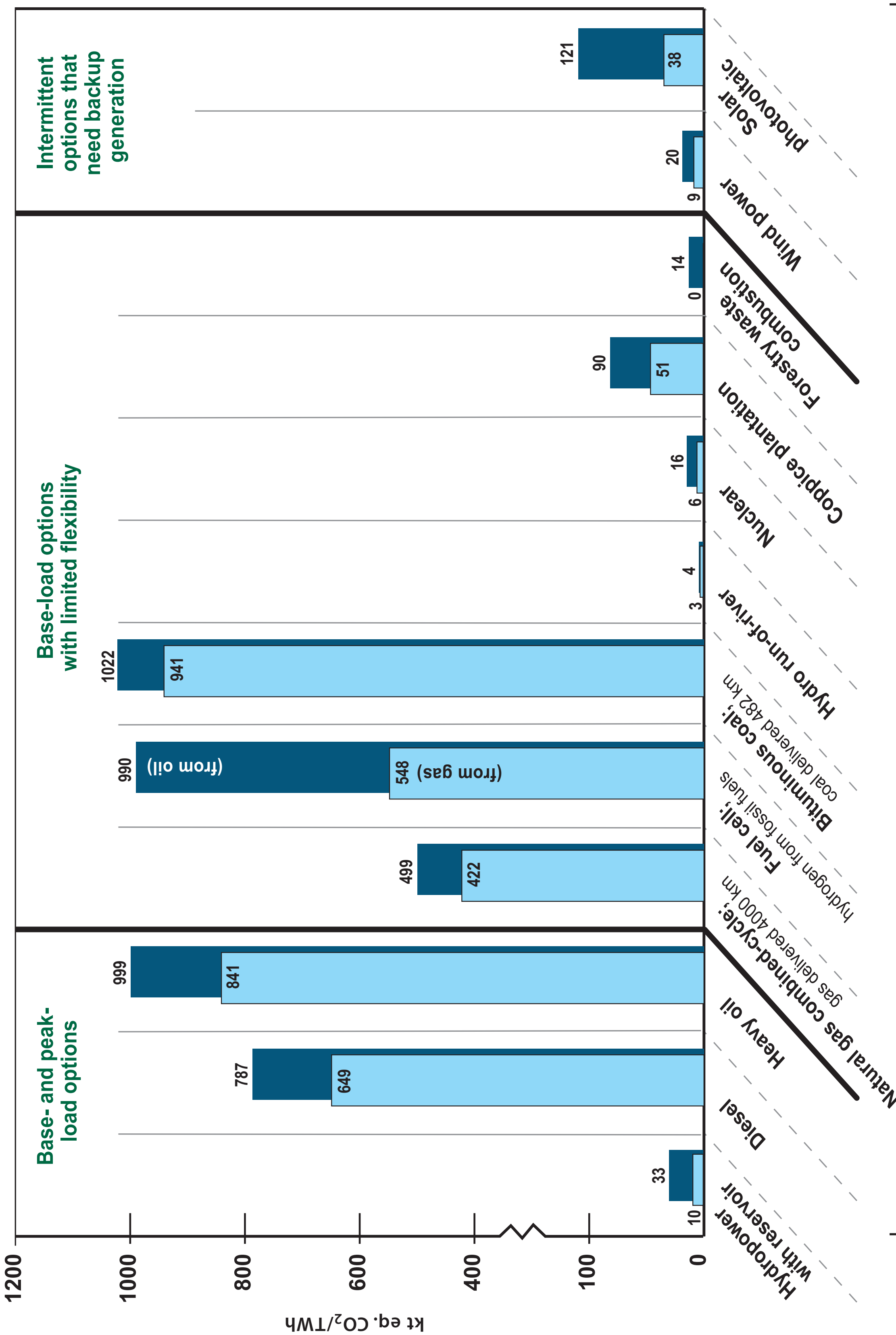
Rigorous comparisons must be based on life-cycle assessment
(see Figure 1 and Table 1)

To compare energy options fairly, all emissions from an energy system should be included. Recent studies, called life-cycle assessments, include emissions from fuel extraction, processing and transportation, as well as from power plant construction and electricity generation. Figure 1 and Table 1 present the results of life-cycle assessments (LCAs), with typical data for eastern North America.

For each fossil fuel, Figure 1 includes two results: one for the technology typically in operation, and another for a high-performance modern technology (commercially available). For renewable sources, such as hydro or wind power, it is impossible to select one "modern technology," as performance depends mainly on site-specific conditions. For these options, Figure 1 includes two results: one for a typical existing project, and one for a very good site that will be available in the near future.

extraction
processing
transportation
construction
generation

Figure 1 – Life-cycle assessment of greenhouse gas emissions (kt eq. CO_2/TWh)



For each option:
the higher emission rate is based on typical existing technology
and the lower emission rate is based on the best available commercial technology for fossil fuels or on very good sites for renewable energy.

NOTES:
Typical results for North America.
Options presented in decreasing order of level of service.

*Table 1 – **Life-cycle assessment of greenhouse gas emissions** (kt eq. CO_2/TWh)*

	Typical results for North America			Technical comments
Generation options (classified by level of service)	**Best commercial technology** (very good sites for renewables)	**Typical existing technology**	**Source of data**	**Notes on thermal generation** • Assessment without cogeneration • Scrubbing of SO_2 would increase GHG emissions from coal and oil.
Hydropower with reservoir	**10** reservoir = 40 km² /TWh	**33** reservoir = 160 km² /TWh	HQ	Estimates include gross emissions from boreal reservoirs, which overestimates their real net emissions.
Diesel	**649** Plant eff. 43%	**787** Plant eff. 35%	NRCAN industry data	
Heavy oil	**841** Plant eff. 38%	**999** Plant eff. 32%	NRCAN industry data	
Heavy oil from oil sands	**1019** Plant eff. 38%	**1177** Plant eff. 32%	Cdn Climate Change Secretariat	Extraction/processing: Oil sands 203 kt CO_2 /TWh Conventional oil - 25 kt CO_2 /TWh Added emissions = 178 kt CO_2 /TWh
Natural gas combined-cycle turbines; gas delivery 4000 km	**422** Plant eff. 58%	**499** Plant eff. 49%	US NREL + efficiency change	Extraction/processing about 50 kt /TWh Transportation 4000 km = about 65 kt /TWh
Fuel cell; hydrogen from fossil fuel	**548** H from gas; Cell eff. 55%	**990** H from oil; Cell eff. 55%	US NREL reforming + efficiency	Gas delivered over 4000 km
Bituminous coal; coal delivered 482 km	**941** Plant eff. 35%	**1022** Plant eff. 32%	US NREL	• Surface mining; average user by river • For farthest user: emissions + 6%
Lignite		**1340**	Dones	
Peat		**1300**	Kivisto	
Hydro run-of-river	**3**	**4**	HQ, Vattenfall, Dones	
Nuclear	**6**	**16**	Vattenfall, Dones	
Short rotation coppice plantation	**51** Plant eff. 30%	**90** Plant eff. 30%	Matthews, UK + distance changes	Coppice transportation distances = 20 km (for 51) and 100 km (for 90)
Forestry waste combustion	**0**	**14**	Vattenfall + correction for CH_4 from wastes	Zero rate assumes that, if not used, some waste would decay and create CH_4 emissions.
Wind power	**9**	**20**	White	2 sites in Wisconsin, average use factor of 24%
Solar photovoltaic	**38**	**121**	Vattenfall, Dones	Emissions from fabrication process

Rigorous comparisons must consider:

• the level of reliability and flexibility

In Table 1, options are presented in decreasing order of level of service. This issue is important, because storing electricity in large quantities is very expensive and a reliable electricity supply must be achieved by generating electricity at the same time as it is consumed. If the balance between production and consumption is not maintained, frequency fluctuations will result, with major impacts on electrical equipment such as computers or appliances. Many ancillary services are required to provide reliable electricity:

- Presence during the maximum peak load
- Capacity to meet hourly and daily variations in load
- Frequency and voltage control, to keep transmission voltages within the required ranges
- Regulation, to maintain minute-to-minute generation/load balance

Generation options are not all equally capable of providing such services. Reliable electricity networks cannot depend only on "must-run" generation such as nuclear energy or on intermittent energy such as wind power, which requires a backup option to compensate for fluctuations. In comparison, hydropower with reservoir or diesel plants can provide all the services required for reliable electricity.

• the many purposes of hydro projects

The assessment of hydropower is exceptional, because a reservoir can have many purposes, such as modulating power generation, irrigation, flood control and water supply. If irrigation uses a lot of water, this may reduce the overall electricity generation, thereby affecting the performance of a project (per kWh). To make a fair comparison among power generation systems, the assessment of hydropower should include only projects designed strictly to generate electricity, or else the parameters should be corrected to attribute impacts to other purposes.

generation
modulation
irrigation

Main findings concerning GHG emissions

- The options with the **lowest emissions are run-of-river hydropower, wind power and nuclear**. We should remember, however, that their production cannot be modulated to meet peak demand; often, fossil fuels will be needed to support these options.
- **Hydropower with reservoir** has a slightly higher emission rate. Overall, it should be considered as the option with **the best performance**, because of its reliability and other potential services such as flood control, irrigation, and water supply. (There is still uncertainty, however, concerning GHG emissions from tropical reservoirs, an issue discussed in detail in another fact sheet.)
- **Coal** (modern or old plant) clearly **has the highest emission factor**, with twice the emissions of natural gas combined-cycle turbines.
- **Heavy oil also has a very high emission rate.** If the oil is extracted from oil sands, the emission factor is as high as for coal.
- **Among fossil fuels, natural gas combined-cycle turbines have the best performance.** The reported emission rates include emissions associated with delivering the gas over 4,000 km (typical for northeastern consumption). Emissions could be about 12% less for plants located close to gas wells. The emission rate could be further reduced with cogeneration. This is discussed in the next pages.
- **Biomass can have an excellent performance**, notably the use of forestry wastes within industries. The performance of biomass plantations is dependent on the energy expended in exploitation activities. The reported emission rates for short-rotation coppices depend on the average distance between the power plant and the source of biomass (20 and 100 km).

Expectations created by "new" technologies

- ### Fuel cells and hydrogen production

  Fuel cells consume hydrogen and emit no direct GHG emissions. They have raised high expectations concerning GHG reductions, but life-cycle assessments show that these expectations are unfounded. Currently, the only low-cost option to produce hydrogen is natural gas reforming, with a life-cycle emission rate higher than burning gas in a combined-cycle turbine. If fuel cells are used in regions without gas distribution, the reforming of oil leads to emissions similar to those of coal-fired generation.

Some have proposed a truly clean and reliable system, with the following steps:

1. Wind power providing electricity to a water electrolysis plant, producing hydrogen.
2. Compression and storage of hydrogen.
3. Fuel cells would consume the hydrogen when electricity is needed.

In theory, this system is interesting because it offsets the intermittent character of wind power. In reality, it is very inefficient: electrolysis has an efficiency of 70%, hydrogen storage needs energy for compression, and fuel cells are 50% efficient. This means that, starting with wind power at 6¢/kWh, the final cost of electricity ends up as more than 20¢/kWh. This system will not be competitive for many decades.

CO_2 scrubbing and sequestration

Another technology that has raised expectations is CO_2 scrubbing and sequestration. The CO_2 must first be "captured" from flue gas and then pumped to an empty oil or gas well, which must be "air-tight." This will be a huge task, as demonstrated by a comparison with SO_2 scrubbing. Even if the sulphur content in coal is only 1% or 2%, SO_2 scrubbing generates huge amounts of waste. Very few plants are equipped with scrubbers, because of the high cost and waste management problems. In the case of CO_2, the carbon responsible for such emissions makes up more than 50% of the coal. CO_2 scrubbing and sequestration is technically possible, but will require huge amounts of energy, creating more pollution. The efficiency of a thermal power plant with a CO_2 removal system can be reduced by 30%. If the storage well is located far away, the energy required for pumping could equal half the energy generated by the plant. Overall, the economic viability and environmental benefits of CO_2 scrubbing are still doubtful.

Cogeneration and the performance of thermal plants

Cogeneration, or Combined Heat and Power (CHP), plants have the potential to improve energy efficiency and reduce GHG emissions. But the word "cogeneration" can be misleading, because some low-efficiency cogeneration units can emit more GHGs than efficient separate equipment (one for industrial heat and another for electricity generation). In many cases, plants have been considered cogeneration plants, even though only a very small fraction of the waste heat is actually used. In many cases, these plants have a worse environmental performance than efficient plants that produce only electricity. Because of this situation, the European Commission is planning a directive on "Quality-CHP."

In theory, a cogeneration plant with full heat utilization can achieve an overall efficiency of 90%. What is the meaning of this maximum efficiency in terms of reducing GHG emissions? In a scenario involving only natural gas (no fuel substitution), if the cogeneration plant replaces a combined-cycle gas turbine with 54% electrical efficiency and a heat boiler at 90% efficiency, the GHG reduction will be about 25% (Eurelectric, p. 53).

In North America, cogeneration plants are rarely very efficient, because the emphasis is more on producing electricity than enhancing the use of waste heat. In order to achieve very high efficiency, the size of the gas turbine must be adapted to the local use of heat, and plants would have to be much smaller than they generally are.

Conclusion: Effective technologies to reduce emissions

Based on LCA, we can conclude that, in the electricity sector, fuel cells and CO_2 scrubbing are unlikely to seriously reduce GHG emissions over the next 20 years. Moreover, the widespread implementation of these technologies is unnecessary when we consider the numerous well-tested technologies that can actually reduce emissions:

- Hydropower, wind power and nuclear energy
- Natural gas combined-cycle turbines, replacing coal
- "Quality" cogeneration in thermal plants
- Energy efficiency measures

Therefore, short-term emission reductions do not require new generation technologies, only measures to favor the proper options.

Note concerning **GHG emissions from reservoirs**

Recent research on aquatic ecosystems supports the following statements:

- Many research programs have confirmed significant GHG emissions at the surface of all types of water bodies (reservoirs, natural lakes and rivers).
- Most of the flooded biomass at the bottom of reservoirs has not decomposed after decades under water.
- After the initial first few years (after impoundment), GHG emissions from reservoirs are similar to those of nearby natural lakes. These emissions, either natural or from old reservoirs, are mainly due to organic carbon that is flushed into reservoirs from surrounding ecosystems.

Thus, emissions measured at the surface of reservoirs must be considered "gross" emissions, that systematically overestimate the level of GHG emissions for which reservoirs are responsible. "Net" emissions must be defined by considering the emissions that would have occurred anyway, in the absence of a dam.

The following GHG emission rates were used in comparing options: 7 kt eq. CO_2/TWh for best sites and 30 for the La Grande complex, with large reservoirs per unit of energy. These are "gross" emissions, measured on boreal reservoirs. They clearly represent pessimistic estimates, because future definitions of "net" emissions will be much smaller.

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