The Electrical Grid - Part 2
Achieving Low Greenhouse Gas Emissions

OSPE Energy Seminar

This presentation can be downloaded at
www.ospe.on.ca/presentations

OSPE Energy Task Force
September 2015
The Electrical Grid – Part 2
Achieving Low Greenhouse Gas Emissions

Outline

This seminar is the second in a series of 4 seminars

✧ Part 1 – How It Works
✧ Part 2 – Achieving Low Greenhouse Gas Emissions
✧ Part 3 – Current Challenges
✧ Part 4 – Potential Solutions
The Electrical Grid – Part 2
Achieving Low Greenhouse Gas Emissions

Outline

✧ Greenhouse Gas (GHG) Emissions from Each Technology.
✧ Consumer Load Demand – Weekly and Annual.
✧ Generation Production Profiles.
✧ Using Storage Economically.
✧ Integrated Generation Solutions.
✧ Reducing Greenhouse Gas Emissions in Other Sectors.
✧ Using Electricity to Facilitate Carbon Reduction in Other Sectors
✧ Q/A
Greenhouse Gas (GHG) Emissions from Each Technology

- Each technology has a different emission profile.
- The most significant emissions relate to the fuel used by the plant including production, transportation and consumption.
- Plant life time emissions are impacted by the fuel that is used to construct, maintain and decommission the plant.
- As our fuel supplies become cleaner the life cycle emissions will also drop.
# The Electrical Grid – Part 2

## Achieving Low Greenhouse Gas Emissions

### Greenhouse Gas (GHG) Emissions from Each Technology

<table>
<thead>
<tr>
<th>Primary Fuel</th>
<th>Lifecycle Emissions kg CO₂ per MWh (1)</th>
<th>Plant Operating Emissions kg CO₂ per MWh (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1,001</td>
<td>973</td>
</tr>
<tr>
<td>Oil</td>
<td>840</td>
<td>Not available</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>469</td>
<td>398</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Nuclear</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>Wind</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Solar PV</td>
<td>46</td>
<td>0</td>
</tr>
</tbody>
</table>

1) Lifecycle Emission Data is from IPCC and reported on the CNA website.

These values will trend lower for future plants as we use more zero emission energy for construction.
The Electrical Grid – Part 2
Achieving Low Greenhouse Gas Emissions

Customer Load Demand – Typical Week

Low Demand Week Profile
(typically a spring week)

High Demand Week Profile
(typically a hot summer week)


Diagrams Courtesy of Market Intelligence & Data Analysis Corporation
Customer Load Demand – Typical Year

- 2011 average annual grid capacity factor was 63%.
- 2011 maximum demand was 2.4 x minimum demand.


Diagrams Courtesy of Market Intelligence & Data Analysis Corporation
The Electrical Grid – Part 2
Achieving Low Greenhouse Gas Emissions

Generation Profiles - Nuclear

Low Demand Week Profile
(typically a spring week)

High Demand Week Profile
(typically a hot summer week)

Projections using actual IESO data for 2011 projected to 2021 using 2013 LTEP capacity projections for 2021 with no load growth.

Diagrams Courtesy of Market Intelligence & Data Analysis Corporation
The Electrical Grid – Part 2
Achieving Low Greenhouse Gas Emissions

Generation Profiles - Hydroelectric

Low Demand Week Profile
(typically a spring week)

High Demand Week Profile
(typically a hot summer week)

Projections using actual IESO data for 2011 projected to 2021 using 2013 LTEP capacity projections for 2021 with no load growth.

Diagrams Courtesy of Market Intelligence & Data Analysis Corporation
Generation Profiles - Wind

Low Demand Week Profile (typically a spring week)

High Demand Week Profile (typically a hot summer week)

Projections using actual IESO data for 2011 projected to 2021 using 2013 LTEP capacity projections for 2021 with no load growth.

Diagrams Courtesy of Market Intelligence & Data Analysis Corporation
Generation Profiles - Solar

Low Demand Week Profile (typically a spring week)

High Demand Week Profile (typically a hot summer week)

Projections using actual IESO data for 2011 projected to 2021 using 2013 LTEP capacity projections for 2021 with no load growth.

Diagrams Courtesy of Market Intelligence & Data Analysis Corporation
The Electrical Grid – Part 2
Achieving Low Greenhouse Gas Emissions

Generation Profiles - Combined

Low Demand Week Profile
(typically a spring week)

High Demand Week Profile
(typically a hot summer week)

This excess clean energy has to be curtailed (wasted) or exported, typically at low prices.

Diagrams Courtesy of Market Intelligence & Data Analysis Corporation
Natural gas generation is flexible and is used for:

- Meeting demand when the capacity of other sources are insufficient.
- Act as backup for intermittent (variable) sources like wind/solar.
- Spinning reserve (provide fast acting reserve for unexpected demand or unexpected generation outages). Spinning reserve requires flexible generation that can quickly change output either under speed governor demand or IESO dispatch demand.
- Longer term reserve for contingencies (eg: planning errors).
- Natural gas plants can operate continuously but typically have a low capacity factor in Ontario of under 20% due to their backup and reserve role.
Storage can soothe out the imbalances between generation and consumer demand. Unfortunately, storage is expensive and wastes energy in the 2-way energy conversion process.

- Pumped hydroelectric storage costs the greater of $7,000/kW or $50/kWh and wastes 20% of the energy it stores.
- Battery storage costs the greater of $1,000/kW or $500/kWh and wastes 20% of the energy it stores.
- Compressed gas storage costs the greater of $1,000/kW or $100/kWh and wastes 40% of the energy it stores.
- Flywheel storage costs the greater of $2,000/kW or $2,000/kWh and wastes 1% of its rated energy capacity each hour.

Storage has to be used sparingly to keep electricity prices low.
Integrated Generation Solutions

✧ No single generation technology is capable of supplying the entire consumer demand except natural gas generation.

✧ Unfortunately, gas-fired plants have high fuel costs, high greenhouse gas emissions and also emit soot and \( \text{NO}_x \) into the environment.
  ✧ \( \text{NO}_x \) is a combination of \( \text{NO} \) and \( \text{NO}_2 \).
  ✧ \( \text{NO}_x \) combines with soot and other organic compounds to create smog and ozone which damage lung tissue especially children with asthma. In the upper atmosphere ozone filters out UV radiation.
  ✧ \( \text{NO}_2 \) in the presence of moisture forms nitric acid. In low concentrations it creates nitrates in the soil that is good for plants.
  ✧ \( \text{NO} \) and \( \text{NO}_2 \) are held in balance in the atmosphere by the effects of sunshine and ozone.
Integrated Generation Solutions

- Nuclear is dependable but has limited load following capabilities and produces nuclear wastes. The public is also fearful of the impact of major accidents.
- Hydroelectric has limited capacity, floods large land areas and is affected by weather.
- Wind and solar are intermittent (variable) sources and are affected by weather. They are more costly to integrate into the power system than hydroelectric, nuclear or natural gas generation.
- Bio-energy has limited capacity and has limited load following capabilities when it is obligated to supply local heating demands.
Lowering GHG Emissions Economically

- Governments appear to be headed toward carbon emission reduction goals across the entire economy as compared to 1990 of:
  - 30% by 2030
  - 50% to - 80% by 2050
  - 100% by 2100.

- Achieving 80% carbon reduction in operating emissions in the power system is technically quite straightforward but at a cost.

- If all goes according to the 2013 Long Term Energy Plan, in 2015 Ontario will achieve an 80% carbon emission reduction from 1990 levels in its electrical power system generating plants.

- That’s nearly 35 years ahead of the Intergovernmental Panel on Climate Change (IPCC) 2050 target!
Lowering GHG Emissions Economically

✧ How did Ontario do it?
✧ It replaced its coal fired plants with nuclear generation, gas-fired generation and added some hydroelectric, wind and solar capacity.
✧ Ontario’s progress (rounded to nearest 10):

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating kg CO₂/MWh</td>
<td>190</td>
<td>30</td>
</tr>
<tr>
<td>Lifecycle kg CO₂/MWh</td>
<td>220</td>
<td>60</td>
</tr>
</tbody>
</table>
Lowering GHG Emissions Economically

How did other countries compare with Ontario in 2010 (rounded to nearest 10) in lifecycle emissions?

<table>
<thead>
<tr>
<th>Country</th>
<th>kg CO₂/MWh</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>970</td>
<td>Heavy use of coal</td>
</tr>
<tr>
<td>USA</td>
<td>550</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>670</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>70</td>
<td>Very heavy use of nuclear</td>
</tr>
<tr>
<td>Canada</td>
<td>180</td>
<td>Heavy use of hydroelectric</td>
</tr>
<tr>
<td>Ontario (2)</td>
<td>160</td>
<td>Heavy use of nuclear</td>
</tr>
</tbody>
</table>

(2) 2010 Ontario data was estimated by OSPE.
Lowering GHG Emissions Economically

Notes: The above graph appears as *Figure 20: Greenhouse Gas Emissions Forecast* in the Ministry of Energy 2013 LTEP. Emissions in any one year could be higher, or lower, than the projection depending on the specific operating conditions experienced in the system. Data for 1990 came from the Ministry of Environment and Climate Change report titled Ontario’s Climate Change Update 2014.

If we stay below the 5 Mtonne line we will continue to achieve the 80% carbon reduction goal.

This rise is due to the retirement of Pickering Nuclear. Gas-fired generation will be used for base load.
To achieve that goal Ontario’s electricity rates have approximately doubled in about 7 years. Residential rates rose from about 8 cents/kWh to about 16 cents/kWh in 2015.

However, Ontario recently decided to retire 3,000 MW of nuclear capacity in 2020 to make room for more renewable energy – primarily wind and solar.

Ontario’s carbon emissions are expected to double as a result. The reason is that natural gas will be needed to backup up wind and solar when that nuclear capacity is no longer available.

Natural gas plants emit about 400 kg of carbon dioxide per MWh.

Nuclear plants emit zero carbon dioxide.
Environmental activists and policy analysts are now looking to storage to reverse that disappointing trend in emissions.

Storage technology is currently much too expensive to make a wind/solar/storage solution economic.

Also the low capacity factors of wind and solar would require over building the power system to collect the required energy and store it for later use.

If hydroelectric storage was contemplated, we would also have to overbuild our high voltage transmission system. If we wanted to avoid overbuilding transmission, we would have to use batteries close to the generation at 10x to 20x higher cost than hydroelectric storage.
Lowering GHG Emissions Economically

✧ To achieve low emissions we have to choose zero emitting sources like hydroelectric, nuclear, wind and solar or carbon neutral sources like sustainable biomass (ie: you have to grow what you burn).

✧ However, to be an industrial leader within free-trade zones like NAFTA, TPP and CETA we need to keep electricity prices competitive for our industrial and manufacturing sectors.

✧ To keep electricity rates competitive we need to:
  ✧ Use the lowest cost carbon-free sources.
  ✧ Use as little expensive storage as possible.
  ✧ Use carbon-free base-load sources (hydroelectric, nuclear and sustainable biomass) to supply base-load demand.
Lowering GHG Emissions Economically

- A low emission (80% reduction) and low cost (competitive with our trading partners) power system with the current state of technology would therefore contain:
  - Run-of-the-river hydroelectric, inflexible nuclear and inflexible bio-energy plants to supply the base-load demand.
  - Flexible hydroelectric and flexible nuclear to supply some but not all of the incremental peak load (demand above base-load).
  - Natural gas to supplement flexible carbon-free generation to meet the remaining load on the highest demand days & for power system reserve.
  - Hydroelectric, wind and solar with storage for off-grid applications to displace diesel fuel.
However, the public is demanding more renewables (primarily solar and wind) and more conservation to reduce demand.

The public does not appear to be willing to accept more nuclear and its radioactive waste nor more hydroelectric storage with its flooded land areas.

This means we will need to add more solar, wind and other forms of storage to achieve our GHG emission goals.

Ontario’s 2013 Long Term Energy Plan (LTEP) includes all three plus a “conservation first” program.

That plan will result in higher electricity costs and greater expenditure of natural resources to achieve the GHG reduction goals, but with reduced volumes of radioactive wastes to manage and less flooded land.
To achieve 100% reduction in carbon emissions for “normal” power system conditions will require that we eliminate natural gas as a supplementary fuel and only use it for contingencies/reserve.

Reducing our dependence on natural gas will result in much higher electricity rates because the flexibility that natural gas provides is expensive to provide with other technologies like storage in combination with other clean generation technologies.

To achieve 100% reduction in carbon emissions under all power system conditions will require that we eliminate natural gas.

It is important to realize that as we reduce nuclear and natural gas in the supply mix we will increase the cost of electricity and the amount of natural resources required to supply our electricity needs.
Reducing carbon emissions in other sectors is technically and economically difficult because those sectors do not have ready access to high capacity factor, dependable, carbon-free and affordable sources such as hydroelectric and nuclear generation.

Consequently to reduce emissions in other sectors, we need to make it financially attractive for those sectors (ie: space heating, food processing, transportation, industrial and agricultural) to use carbon-free fuels or electricity for their energy needs.

One method is to put a price on carbon emissions so that cleaner energy or efficiency improvements become cheaper alternatives.

Cap-and-trade or carbon taxes are two methods being used.
Reducing Greenhouse Gas Emissions in Other Sectors

✧ Other than shutting down production, there are several ways to reduce carbon emissions in other sectors:
  ✧ Become more energy efficient in the production process.
  ✧ Switch to carbon-free fuels (wind, solar, carbon neutral biomass and manufactured fuels like hydrogen from water) if they are available and cost effective.
  ✧ Switch to electricity in jurisdictions (like Ontario) where the electricity is carbon-free, if that electricity is cost effective.
✧ Unfortunately, in Ontario, electricity is currently not cost competitive for thermal energy in part because our electricity price plans are not designed to encourage fossil fuel displacement.
The current North American price of natural gas is below $3 per million BTU on the spot market and $4 delivered to your door. That’s equivalent to electrical energy at 1.4 cents/kWh using resistance heaters or 2.8 cents/kWh using a typical heat pump. Therefore to displace natural gas with electricity for its heat value you need to have one or some partial combination of:

- Lower electricity prices (1.4 to 2.8 cents/kWh), or
- Higher natural gas price (above $20 per million BTU), or
- Higher carbon price of (above $300 per tonne of carbon dioxide).

The latter two are not likely to happen any time soon.

BUT ...

Note: The “spot” market price is the price you pay to take delivery immediately. The “futures” market price is the price you pay to take delivery at a future date.
The Electrical Grid – Part 2
Achieving Low Greenhouse Gas Emissions

Using Electricity to Facilitate Carbon Reduction in Other Sectors

✧ Ontario has a growing surplus of carbon-free electricity.
✧ OSPE estimates Ontario curtailed (wasted) 5.3 TWh of carbon-free electricity (spilled water at hydro plants, dumped steam at Bruce nuclear reactors and reduced output at wind farms. In 2015 we started to curtail (reduce output at) solar farms.
✧ OSPE estimates Ontario also exported about 5.3 TWh of carbon-free energy to adjoining power grids in 2014 for less than 1 cent/kWh.
✧ Ontario residents and businesses were not allowed to access that carbon-free electricity at those low prices.
✧ 10.6 TWh is enough energy to power over 1 million homes for a year according to the Ministry of Energy.
Using Electricity to Facilitate Carbon Reduction in Other Sectors

- 10.6 TWh is approximately 7% of Ontario’s annual electricity consumption.
- If we charged Ontario consumers 1 cent/kWh for the carbon-free curtailed electricity it would be cheaper than natural gas on a thermal energy basis.
- Ontario consumers could then displace fossil fuels whenever that low cost electricity was available (as identified by the grid system operators).
- The emission reduction from displacement of natural gas thermal loads by 10.6 TWh of carbon-free electricity would be 2 million tons of CO₂.
Next Seminar

The next seminar will cover Part 3 – Current Challenges

✧ Part 1 – How It Works
✧ Part 2 – Achieving Low Greenhouse Gas Emissions
✧ Part 3 – Current Challenges
✧ Part 4 – Potential Solutions
Questions?

OSPE seminars are available at:
http://www.ospe.on.ca/?page=pres_lib#peo

Are you an engineer and would like to become a member of OSPE? Visit:
http://www.ospe.on.ca/?page=JOIN

Engineering students can now join OSPE for free.