The Real Cost of Electrical Energy

Energy Policy Presentation

This presentation can be downloaded at:
http://www.ospe.on.ca/?page=adv_peochap

OSPE Energy Task Force

November 2014

ONTARIO SOCIETY OF PROFESSIONAL ENGINEERS

The Real Cost of Electrical Energy

Outline of Presentation

- Data Sources
- Electricity Demand and Supply
- Cost to Meet Demand Profile
- Electricity Pricing
- Cost Impact of Dispatching Generation (Load Following)
- Simplifying Assumptions
- Electricity Costs for Solar, Wind, Nuclear and Natural Gas
- Summary
- Q&A period.

Data Sources for Today's Presentation

- The Ontario generation (except for solar) and customer demand data was obtained from the IESO website (http://www.ieso.ca). Detailed analysis was done in 2011 but load data for 2012 and 2013 has not changed much.
- Solar flux data comes from the Canadian Weather for Energy Calculations (CWEC) dataset for Toronto, Environment Canada. Solar generation output simulations were produced courtesy of CarbonFree Technology using PVsyst simulation software.
- Electricity production cost data was obtained from the 2013 Feed-In-Tariff (FIT) rates for wind and ground based solar and from the *Projected Costs of Generating Electricity, 2010 Edition*, Organization for Economic Co-operation and Development, median case with carbon tax removed for natural gas.
- If you are interested in the other energy related seminars or to download this presentation, please visit OSPE's website at:

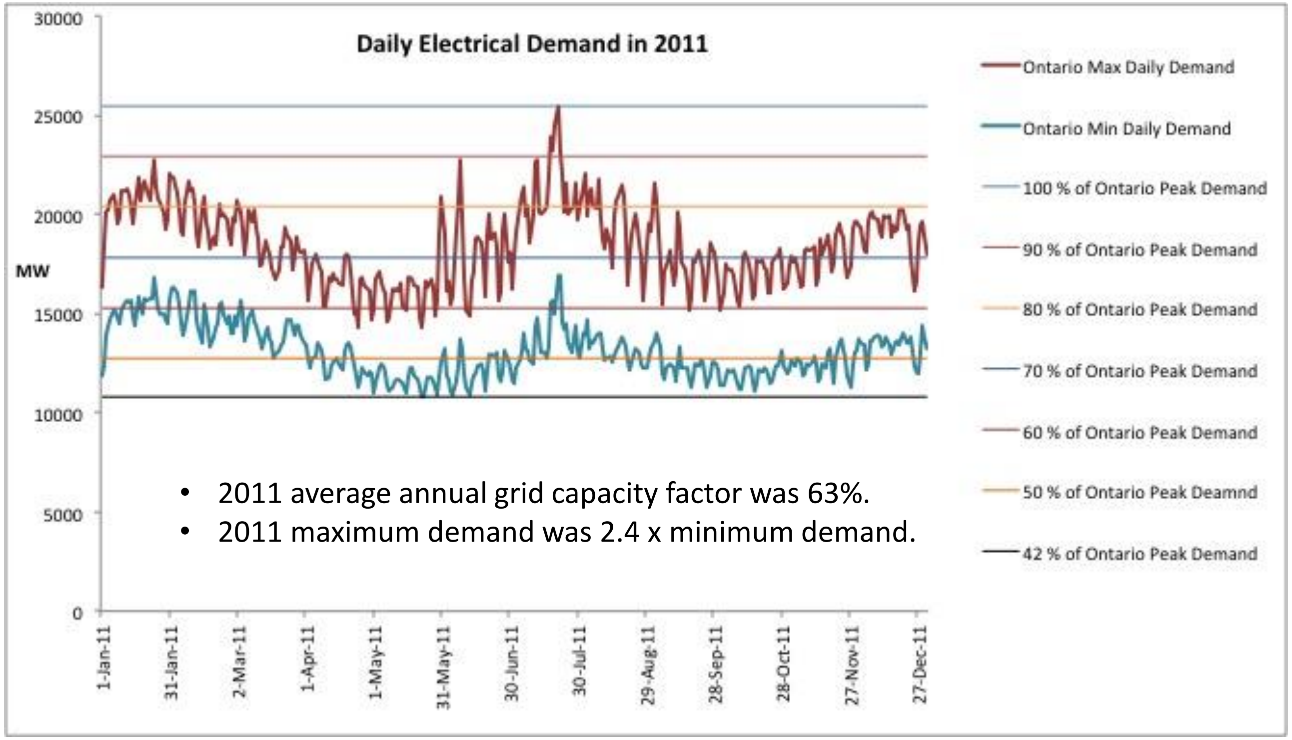
  http://www.ospe.on.ca/?page=adv_peochap

Electricity Demand and Supply

- Most electrical grids in North America including Ontario's have:
  - Large daily variation in demand.
  - Large seasonal variation in demand.
  - High ratio of summer maximum demand relative to spring minimum demand.
  - low overall load capacity factor.

The Real Cost of Electrical Energy

Ontario Electricity Demand – Daily Min/Max in 2011



Electricity Demand and Supply

- Every generation technology has advantages and disadvantages (technical, environmental and economic).
- To maximize advantages and minimize disadvantages, jurisdictions should have electricity policies that encourage overall optimization. That will result in a broad mix of supply technologies that produce acceptable technical and environmental performance at the lowest price.
- Picking technology winners can result in sub-optimal performance - typically higher than necessary electricity prices to achieve technical and environmental goals.

The Real Cost of Electrical Energy

Electricity Pricing

- LCOE – Levelized Cost Of Electricity is the total cost of production divided by the energy that will be produced by that plant during its life. Capacity factor has an enormous impact on LCOE. LCOE is used to decide what type of plant gets built.
- The Market Price set in an auction is used to determine which generators are dispatched (allowed to operate). The market prices in many North American jurisdictions no longer cover the total cost of generation due to supply surpluses, guaranteed supply prices and/or government subsidies.
- Exports are transacted between jurisdictions at the market price. The average market price in 2013 in Ontario was 2.65 cents/kWh.
- Ontario consumers pay a Global Adjustment (GA) charge in their electricity bills, To ensure grid revenue and expenses balance. The average GA in 2013 in Ontario was 5.92 cents/kWh.
- Total Delivered Price is comprised of the market price + GA + transmission, distribution and other regulatory charges. In 2013 the total delivered price of electricity to residential consumers was about 14 cents/kWh (before taxes and rebates).

The Real Cost of Electrical Energy

Electricity Pricing

- The Ontario Energy Board (OEB) has forecast of the cost of electrical "energy" from Nov 1, 2014 to Oct 31, 2015 based on existing supply contracts will be:
  - Hydroelectric: 4.8 cents/kWh
  - Nuclear: 6.2 cents/kWh
  - Wind: 12.3 cents/kWh
  - Natural Gas: 16.0 cents/kWh (low capacity factor/peak service)
  - Bio-energy: 19.8 cents/kWh
  - Solar: 47.4 cents/kWh
- 2015 average = 9.5 cents/kWh (about 16 cents/kWh delivered to homes).
- The full OEB report is at:

http://www.ontarioenergyboard.ca/oeb/_Documents/EB-2004-0205/RPP_Price_Report_Nov2014_20141016.pdf

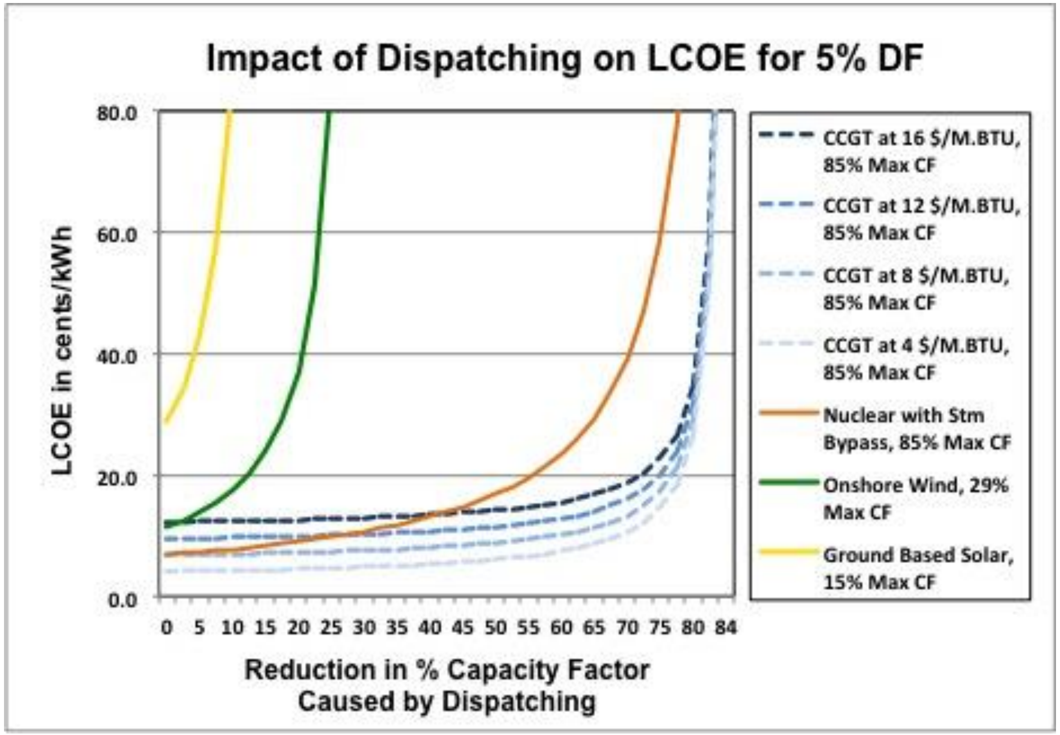
The Real Cost of Electrical Energy

Cost Impact of Dispatching Generation (Load Following)

- The prices in the previous slide are not the real cost of each technology going forward because those costs include older depreciated plants and also reflect the preferred status that each technology is given on the grid as a result of market rules and contractual relationships. For example:
  - Inflexible nuclear and run-of-the-river hydroelectric can bid large negative market prices. That means their energy must be accepted first.
  - Wind and solar can bid into the market at prices down to -1 cent/kWh. That means their energy must be accepted second.
  - Flexible nuclear can bid into the market at prices down to -0.5 cent/kWh. That means their energy must be accepted third.
  - Natural gas plants have the lowest priority. Ontario has no coal plants and only one dual fired natural gas/residual oil plant – Lennox GS.
  - These preferential access rules make all technologies, except natural gas, run at an artificially lower cost of delivered energy than if they had to supply the entire customer load.

The Real Cost of Electrical Energy

Cost Impact of Dispatching Generation (Load Following)



Abbreviations:

- **LCOE = the levelized cost of electricity = total lifetime costs divided by energy produced.**
- **DF = discount factor**
- **CCGT = Combined Cycle Gas Turbine**
- **M.BTU = Million British Thermal Units**
- **CF = Capacity Factor**

Note: Data is for existing plants. Wind and solar are shown using Ontario 2013 FIT rates.

The Real Cost of Electrical Energy

Simplifying Assumptions

- A better way to understand the "real" cost of each technology is to determine what it would cost to deliver all the customer demand with that technology.
- Unfortunately, only natural gas and coal have the flexibility to provide the entire electrical demand. Other technologies require support from storage or gas/coal.
- Most developed jurisdictions do not have sufficient hydroelectric capacity to supply the entire load so we will not address a pure hydroelectric grid.
- Most developed jurisdictions are striving to substantially reduce greenhouse gas emissions so we will use storage to supplement each technology.
- Consequently, we will look at the total cost of supplying a modern grid with :
    - solar with storage (zero greenhouse gas emissions)
    - wind with storage (zero greenhouse gas emissions)
    - nuclear with storage (zero greenhouse gas emissions)
    - flexible natural gas only (storage adds no value)

The Real Cost of Electrical Energy

Simplifying Assumptions

- A centralized hydroelectric storage facility is used at an estimated cost of $5,000 per kW (typical for a large hydroelectric facility with multi-day storage capability). Centralized hydroelectric storage is the cheapest storage technology for grid sized facilities. However the cost is very sensitive to local geographic conditions and can vary widely. The ideal location is one were the cost is primarily driven by the MW power capacity (dam size) and where the required MWh energy storage capacity (pond size) is provided at little or no additional cost.
- Investment rate of return for storage is assumed similar to renewables, consequently LCOE for storage is:
    - 23.0 cents/kWh at 29.0% capacity factor (CF)
    - 51.3 cents/kWh at 13.0% CF
    - Actual capacity factor is determined during energy discharge and cannot exceed 50% minus the efficiency loss factor for the facility.

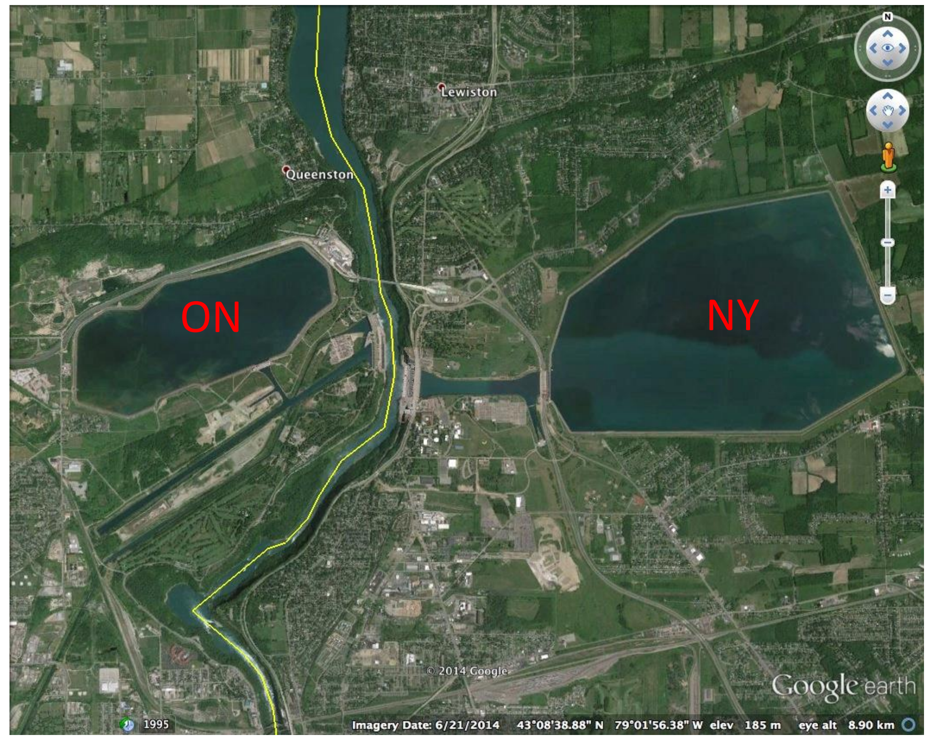
Simplifying Assumptions

- Storage is used to allow solar, wind and nuclear to match demand continuously for the entire year.
- Storage (in/out) energy loss is 20%. Pumps and turbines must be operated in sequence to ensure they operate close to their maximum energy efficiency point.
- The required land area for the storage pond is assumed to be available. Very large land areas are needed for hydroelectric storage because falling water does not contain much energy. For example the large storage facilities at Niagara Falls in New York (Lewiston PGS) and Ontario (Niagara PGS) only store energy for about 10 hrs.
- The present transmission and distribution charges will rise proportionally with the rise in installed peak generating capacity.
- Low capacity factor energy technologies like solar and wind will require additional installed peak generating capacity to collect enough energy to fill the storage to meet demand later when energy is not available from the wind or sun.

The Real Cost of Electrical Energy

Pumped Hydroelectric Storage – at Niagara Falls

http://www.opg.com/power/hydro/niagara_plant_group/adambeckpgs.asp



Ontario reservoir = 300 ha
New York reservoir = 770 ha

The Real Cost of Electrical Energy

Simplifying Assumptions

- We will use the Ontario grid data for the purposes of analyzing a real grid situation. The analysis was done in 2011:
  - highest peak "power" demand in 2011 was 25,407 MW in July (24,927 in 2013)
  - electrical "energy" demand was 141.5 TWh (141.3 TWh in 2013)
  - grid capacity factor (CF) was 63%.
  - minimum power demand was 42% of summer maximum demand
- The data above does not include net exports. We have not included exports because currently Ontario exports energy at below its total cost of production. It is not economic to deliberately overbuild supply to export at a loss. However, if the excess capacity already exists, exporting at a loss can be attractive if the price received for exports is higher than the cost of fuel.
- There has been no load growth since 2011 so the 2011 analysis is still applicable.

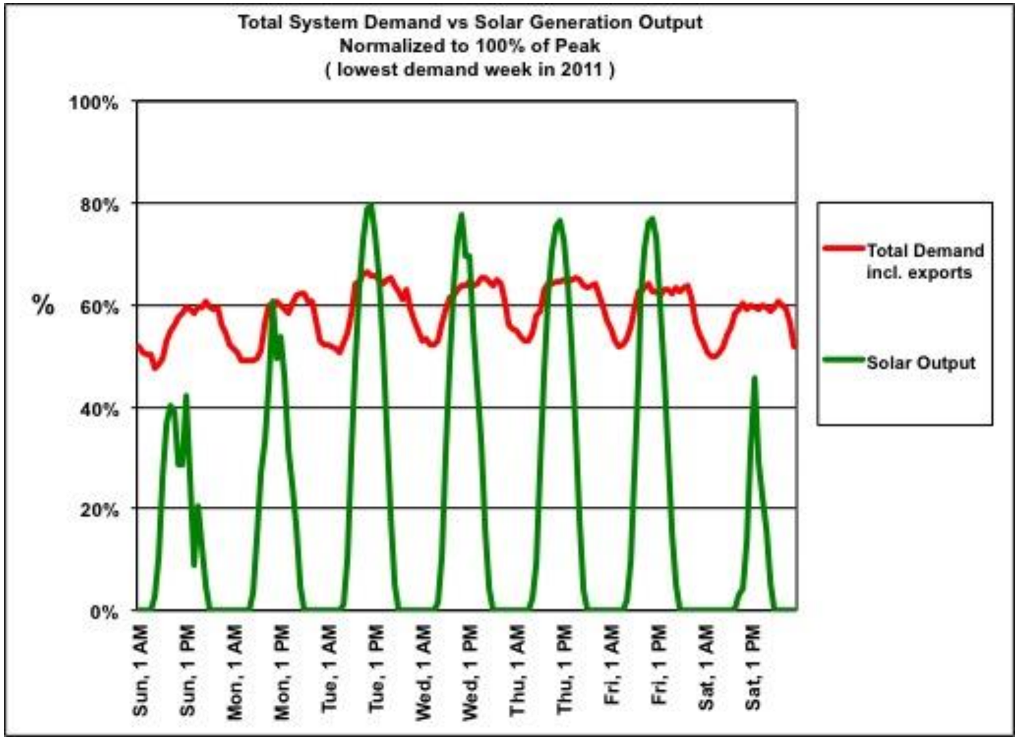
A Solar Powered Grid with Storage

The Real Cost of Electrical Energy

Ground Mounted Solar Tracking PV Facility

The Real Cost of Electrical Energy

Solar Production Profile – Typical Week



- To ensure a dependable supply of electricity with only solar generation, we need significant amounts of storage to fill in the gap between two curves.
- We also need to capture enough solar energy above the red line to supply the customer demand when the sun is not shining.

The Real Cost of Electrical Energy

Solar PV Costs for Dependable Energy

- If we use only solar PV with storage to deliver 25,407 MW of 2011 peak power demand and 141.5 TWh of energy we would need:
  - 139,366 MW of installed solar PV capacity (at 15% CF in Ontario) is required for a 25,407 MW grid (includes 15% operating reserve and storage losses).
  - 115,179 MW of long term storage with 29.1 TWh (253 hrs) of reservoir storage capacity is required.
  - Ground based solar PV energy costs 28.8 cents/kWh at 2013 FIT rates.
  - the additional cost for the long term stored energy is 76.7 cents/kWh (at 8.7% CF for the long term storage).
  - The total “energy” cost for would be **76.6 cents/kWh**.
  - total electricity price delivered to a residential customer door would be **89.5 cents/kWh** (excluding taxes).

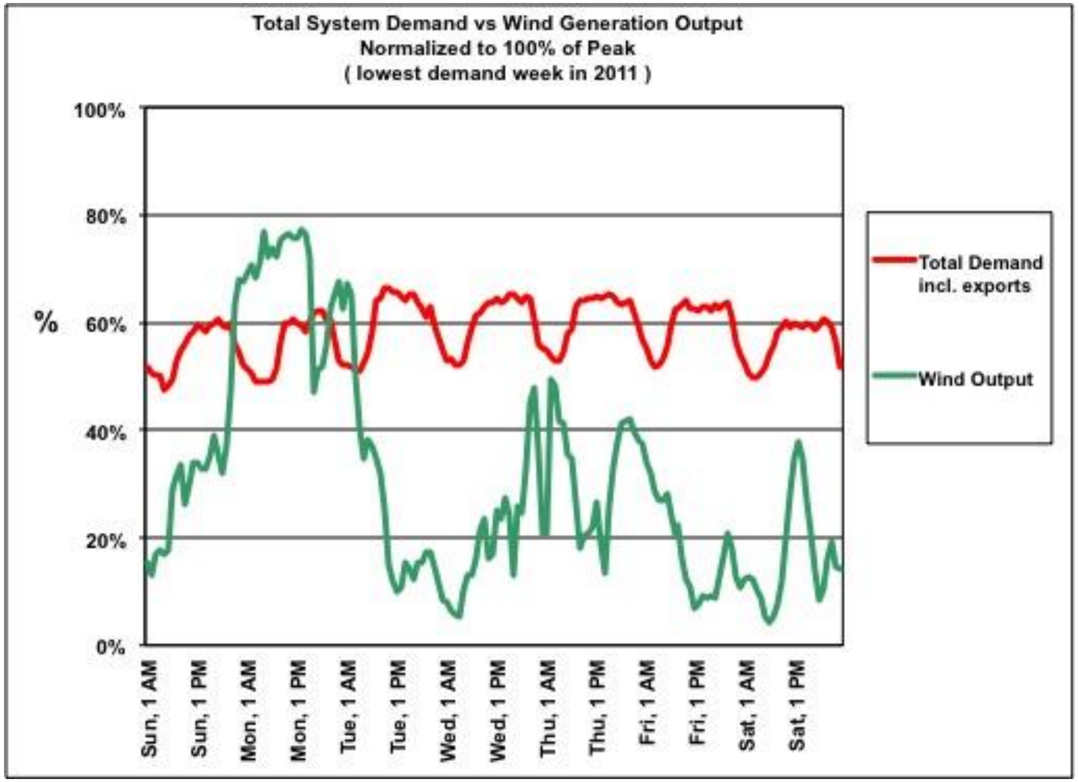
A Wind Powered Grid with Storage

The Real Cost of Electrical Energy

Wind Turbine Facility

The Real Cost of Electrical Energy

Wind Production Profile – Typical Week



- To ensure a dependable supply of electricity with only wind generation, we need significant amounts of storage to fill in the gap between two curves.
- We also need to capture enough wind energy above the red line to supply the customer demand when the wind is not blowing.

Wind Turbine Costs for Dependable Energy

- If we use only wind turbines with storage to deliver 25,407 MW of 2011 peak power demand and 141.5 TWh of energy we would need:
  - 59,213 MW of installed wind turbine capacity (at 29.5% CF in Ontario) is required for a 25,407 MW grid (includes 15% operating reserve and storage losses).
  - 40,541 MW of long term storage with 22.0 TWh (542 hrs) of reservoir storage capacity is required.
  - Wind energy costs 11.5 cents/kWh at 2013 FIT rates.
  - the additional cost of the long term stored energy is 51.3 cents/kWh (at 13% CF for the long term storage).
  - the total “energy” cost would be **28.3 cents/kWh**.
  - total electricity price delivered to a residential customer door would be **35.4 cents/kWh** (excluding taxes).

A Nuclear Powered Grid with Storage

The Real Cost of Electrical Energy

Nuclear Generating Station Facility

Pickering NGS - Photo courtesy of OPG

The Real Cost of Electrical Energy

Nuclear Costs for Dependable Energy

- If we use only nuclear with storage to deliver 25,407 MW of 2011 peak power demand and 141.5 TWh of energy we would need:
  - 19,260 MW of nuclear capacity (at 85% CF) is required for a 25,407 MW grid (includes 15% operating reserve and storage losses).
  - 9,079 MW of long term storage with 2.6 TWh (471 hrs) of reservoir storage capacity is required.
  - new nuclear energy was estimated at 8 cents/kWh at 5% discount factor (government funding) based on a multi-unit CANDU EC6 reactor, ref: 2011 SNC Lavalin estimate. However, more recent studies in the USA & UK suggest energy from new nuclear plants will cost 12 to 16 cent/kWh respectively).
  - the additional cost of the long term stored energy is 68.8 cents/kWh (at 9.7% CF for the long term storage).

New Build Cost (cents/kWh)	Energy Price (cents/kWh)	Total Delivered Price (cents/kWh)
8	11.8	17.7
12	**15.8**	**21.7**
16	19.8	25.7

ONTARIO SOCIETY OF PROFESSIONAL ENGINEERS

A Natural Gas Powered Grid (without storage)

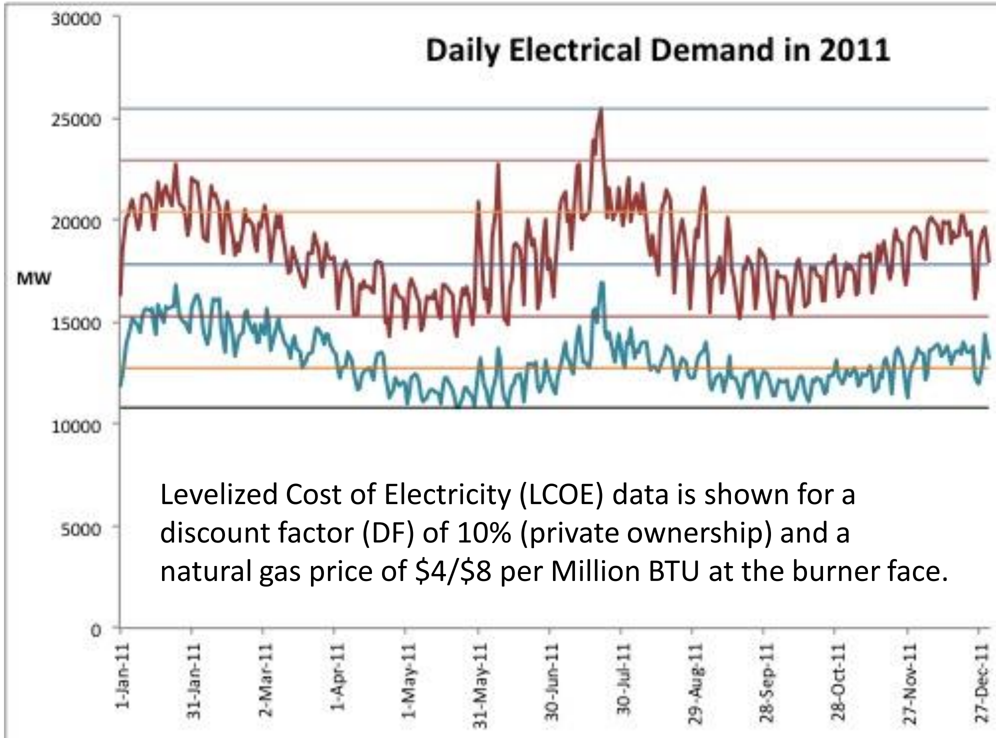
The Real Cost of Electrical Energy

Natural Gas Generating Station Facility

Halton Hills Generating Station
http://www.transcanada.com/docs/Key_Projects/HH_Fact_Sheet.pdf

The Real Cost of Electrical Energy

Cost to Meet Demand Profile Using Natural Gas Plants



Levelized Cost of Electricity (LCOE) data is shown for a discount factor (DF) of 10% (private ownership) and a natural gas price of \$4/\$8 per Million BTU at the burner face.

Cost of Energy Using Gas Generation

←CF= 0.19%, LCOE= 942 / 945 cents/kWh

←CF= 1.57%, LCOE= 116 / 119 cents/kWh

←CF= 12.99%, LCOE= 16.4 / 19.1cents/kWh

←CF= 44.20%, LCOE= 6.7 / 9.4 cents/kWh

←CF= 78.04%, LCOE= 5.0 / 7.7cents/kWh

←CF= 96.79%, LCOE= 4.8 / 7.5 cents/kWh

←CF= 100%, LCOE= 4.8 / 7.5 cents/kWh

CF = Load Capacity Factor

The Real Cost of Electrical Energy

Natural Gas Costs for Dependable Energy

- Natural gas is not renewable and has operating carbon dioxide emissions of about 400 g/kWh at an average 45% thermal efficiency (using a mix of simple cycle and combined cycle gas turbine plants).
- Ontario currently does not have a carbon tax on fossil fuels. Each $30 per ton tax on carbon dioxide adds about 1 cent/kWh to the cost of gas fired electricity below.
- If we use flexible natural gas plants without storage to deliver 25,407 MW of 2011 peak power demand and 141.5 TWh of energy we would need:
  - 29,941 MW of natural gas capacity at 53.9% CF (includes 15% operating reserve).
  - The resulting energy price is estimated at:

Gas Price $/MBTU	Energy Price (cents/kWh)	Total Price (cents/kWh)
4	6.0	11.9
8	**8.7**	**14.6**
12	11.4	17.3
16	14.1	20.0

Other Costs

- Several other costs have not been included in the analysis:
  - Government tax incentives for various technologies.
  - Health and environmental costs for construction and operation.
  - Insurance subsidies (or accident cost reserves) for nuclear.
  - Decommissioning costs for solar, wind and natural gas. Nuclear plant decommissioning and waste disposal costs are currently included in the operating costs via a reserve fund.

The Real Cost of Electrical Energy

Summary

- Flexible natural gas generation can be used to eliminate expensive storage but we need to accept emissions of 400 g/kWh of CO_2 and fine particulates (soot). For each $30 per ton of CO2 carbon tax, natural gas electricity prices would rise about 1 cent/kWh.
- The **delivered price of electricity** from an electrical grid that employs a single generation technology is estimated below:
  - **Natural Gas : 14.6 cents/kWh** at $8/MBTU for gas, no carbon tax.
  - **Nuclear with Storage: 21.7 cents/kWh** at a 5% DF (government owned or financed – private investors cannot finance nuclear).
  - **Wind Turbines with Storage: 35.4 cents/kWh** at 2013 FIT rates.
  - **Solar PV with Storage: 89.5 cents/kWh** at 2013 FIT rates.

The Real Cost of Electrical Energy

Summary

- A balanced energy mix with minimal storage will produce the lowest electricity price. Ideally:
  - Nuclear and hydroelectric should supply the base load 24 hours a day.
  - Natural gas should supply the peak load and provide backup to renewables.
  - Renewables (wind and solar) should be added only to the extent that grid flexibility and load demand is sufficient to accommodate their variability.
- Electricity prices will trend higher as new generation (regardless of type) and more renewables (primarily wind and solar) are added.
- Technological advances in storage and energy systems from the R&D labs may change the long term picture but major advances will take many years or decades to commercialize.

Questions ?

Notes:

This presentation can be downloaded at:
http://www.ospe.on.ca/?page=adv_peochap

Would you like to become a member of OSPE? Visit:
http://www.ospe.on.ca/?page=JOIN

ONTARIO SOCIETY OF PROFESSIONAL ENGINEERS

www.ospe.on.ca

4950 Yonge Street, Suite 502, Toronto ON M2N 6K1
Tel: 416-223-9961 • Toll Free: 1-866-763-1654