ELG4125
Transmission and Distribution Electric Systems

Electric Power Systems are a technical Wonder!

Electricity and its accessibility are the greatest engineering achievements of the twentieth century, ahead of computers and airplanes!

Course Content

Concepts and Applications:

- Introduction (Components of Power Systems)
- Basic Principles (AC Power)
- Generation
- Transformers
- Transmission Lines
- Power Flow
- Stability
- Transient and Harmonics

Computer Programs:

- Powerworld; MATLAB/Simulink (PowerSym), PSCAD

Other Related Topics:

Distributed Generation, Renewable Power, Efficiency.

Project Themes

You may consider one of the following, but not limited to, themes

Small Hydro Power Plant:
Feasibility Study for Recovery of Plant

Community Power:
Feasibility Study of Developing Wind Power Generation Project.

Consumers Energy:
Control Center in Ottawa: Work on possible projects at the Control Center.

Brief History of Electric Power

- Early 1880’s: Edison introduced Pearl Street dc system in Manhattan supplying 59 customers.
- 1884: Sprague produces practical dc motor.
- 1885: invention of transformer.
- Mid 1880’s: Westinghouse/Tesla introduce rival AC system.
- Late 1880’s: Tesla invents ac induction motor.
- 1893: First 3 phase transmission line operating at 2.3 kV.
- 1896: ac lines deliver electricity from hydro generation at Niagara Falls to Buffalo, 20 miles away.
- Early 1900’s: Private utilities supply all customers in area (city); recognized as a natural monopoly; states step in to begin regulation.
- By 1920’s: Large interstate holding companies control most electricity systems.
- 1935/6: Rural Electrification Act brought electricity to rural areas.
- 1930’s: Electric utilities established as vertical monopolies.

Introductory Terms and Concepts

Power System Components : Electrical Components

- Light bulb
- Socket
- Wire to switch
- Switch
- Wire to circuit box
- Circuit breaker
- Watt-hour-meter
- Connection to distribution system
- Distribution transformer
- Distribution system
- Substation
- Capacitors
- Circuit breakers
- Disconnects
- Buses
- Transformers
- Sub-transmission system
- Capacitor banks
- Tap changers
- Current transformers
- Potential transformers
- Protective relaying
- Reactors
- Metal-oxide varistors
- Transmission system
- Suspension insulators
- Lightning arrestors
- Generator step-up transformers
- Generators

Simple Power System

- Every power system has three major components:
  - **Generation**: source of power, ideally with a specified voltage and frequency.
  - **Load** or **demand**: consumes power; ideally with a constant resistive value.
  - **Transmission system**: transmits power; ideally as a perfect conductor.
- Additional components include:
  - **Distribution system**: local reticulation of power.
  - **Control equipment**: coordinate supply with load.

Power

- Power:
  - Instantaneous rate of consumption of energy,
  - How hard you work!
- Power = Voltage x Current for DC
- Power Units:

Watts	=	amps times volts (W)
kW	–	1 x 10^3 Watt
MW	–	1 x 10^6 Watt
GW	–	1 x 10^9 Watt

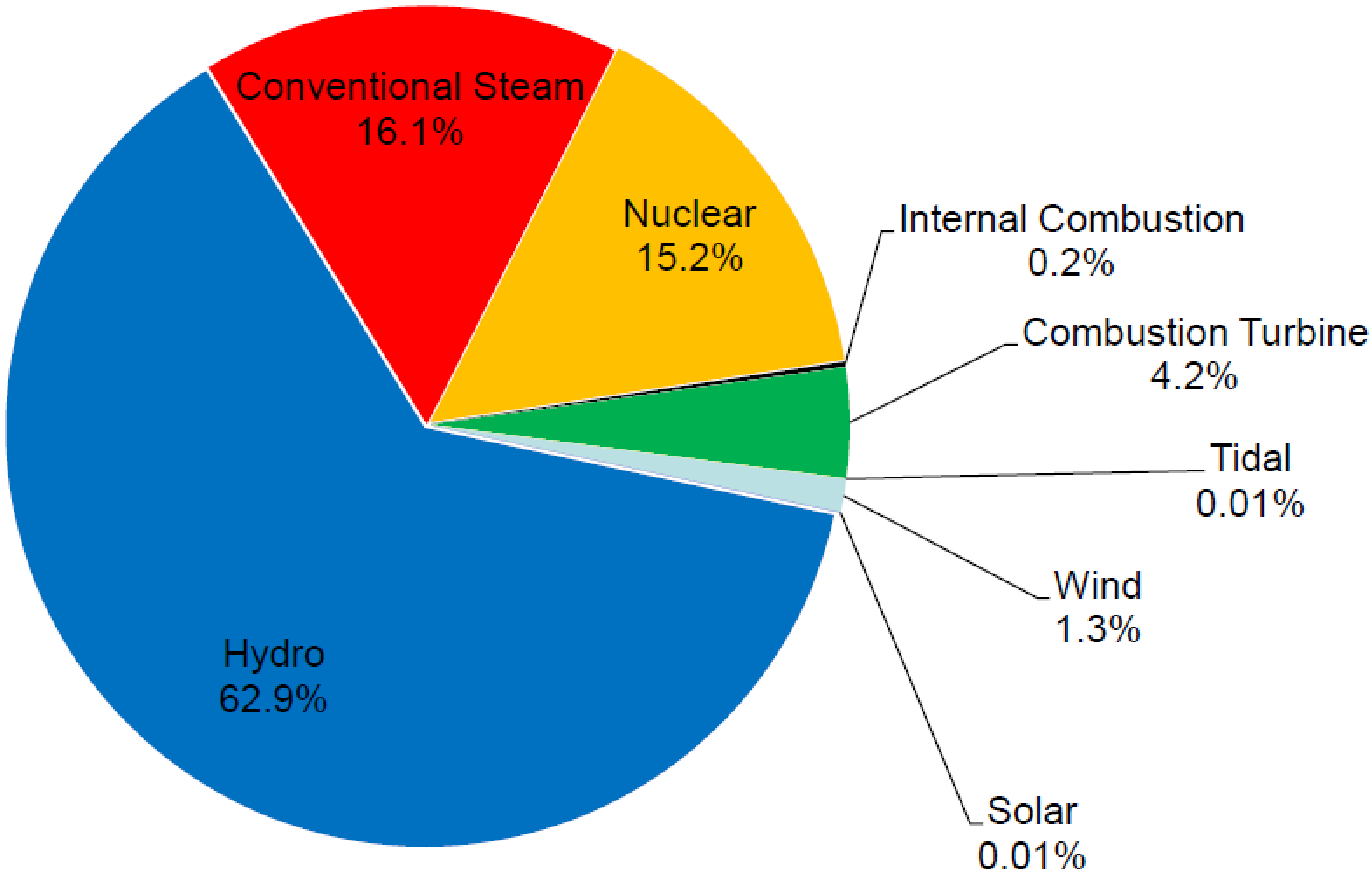
- Installed Canadian generation capacity is about 592 TWh.
- Maximum load of Ottawa may be about 2500 MW.
- Maximum load of uOttawa campus is about 50 MW.

Energy

- Energy:
  - Integration of power over time,
  - Energy is what people really want from a power system,
  - How much work you accomplish over time.
- Energy Units:

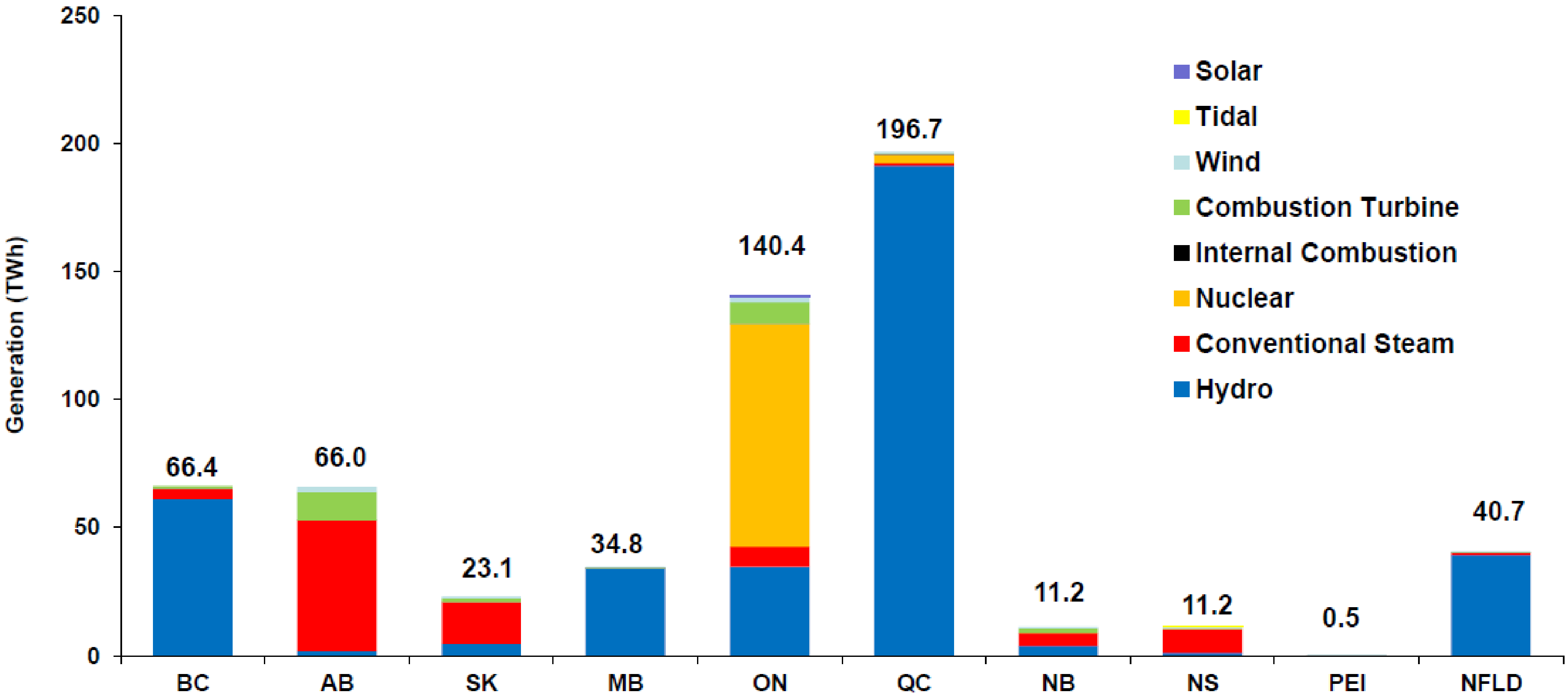
Joule	=	1 watt-second (J)
kWh	–	kilo-watt-hour (3.6×10^6 J)
Btu	–	1055 J; 1 Mbtu = 0.292 MWh

Total Electricity Generation in Canada, 2011 = 592.3 TWh



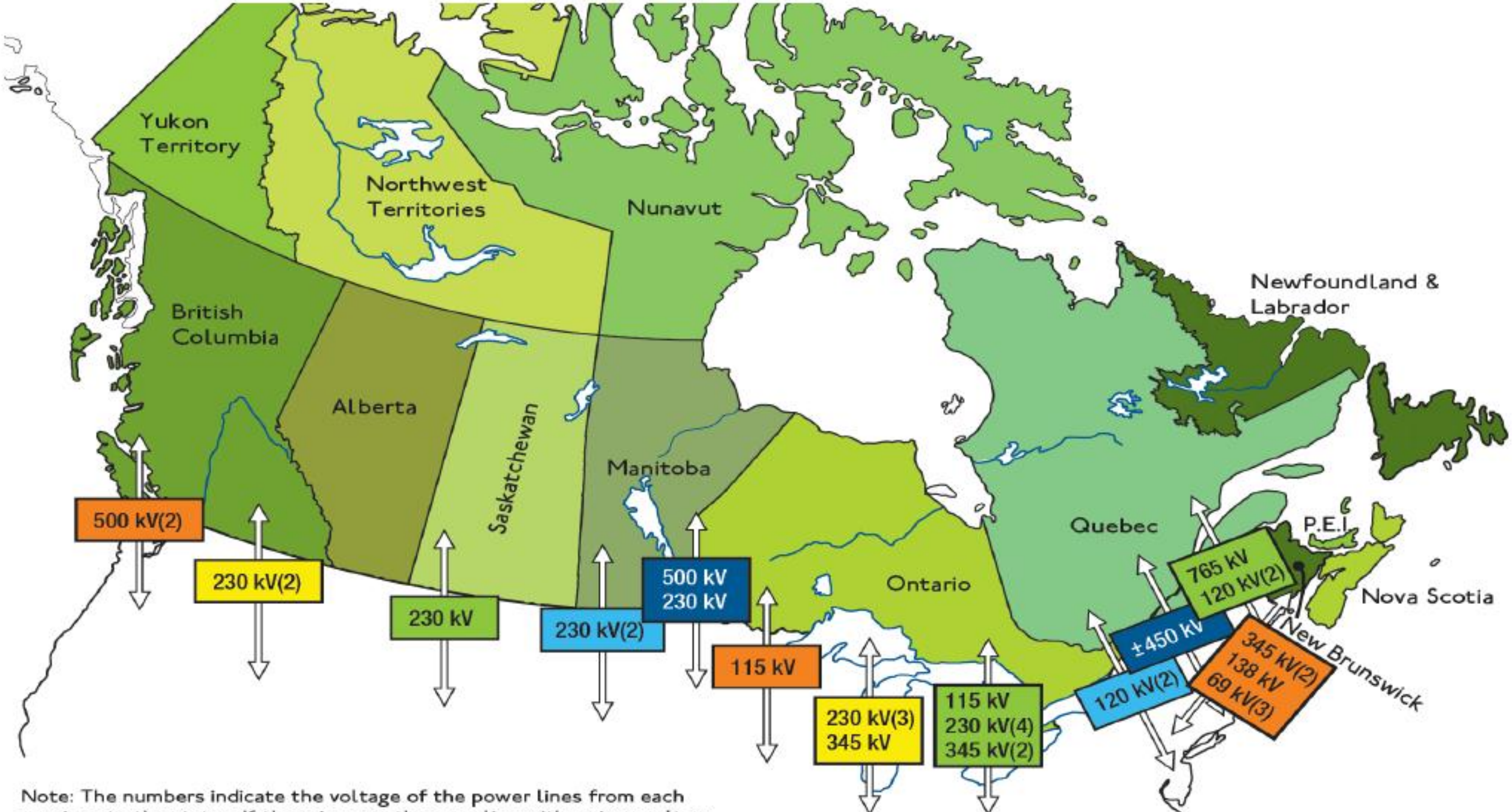
*Numbers may not sum to 100 percent due to rounding.
Source: Statistics Canada, *Survey 2151*, 2011
Retrieved March 21, 2012

Total Electricity Generation in Canada, 2011 = 592.3 TWh



Source: Statistics Canada, *Survey 2151*, 2011
Retrieved March 21, 2012

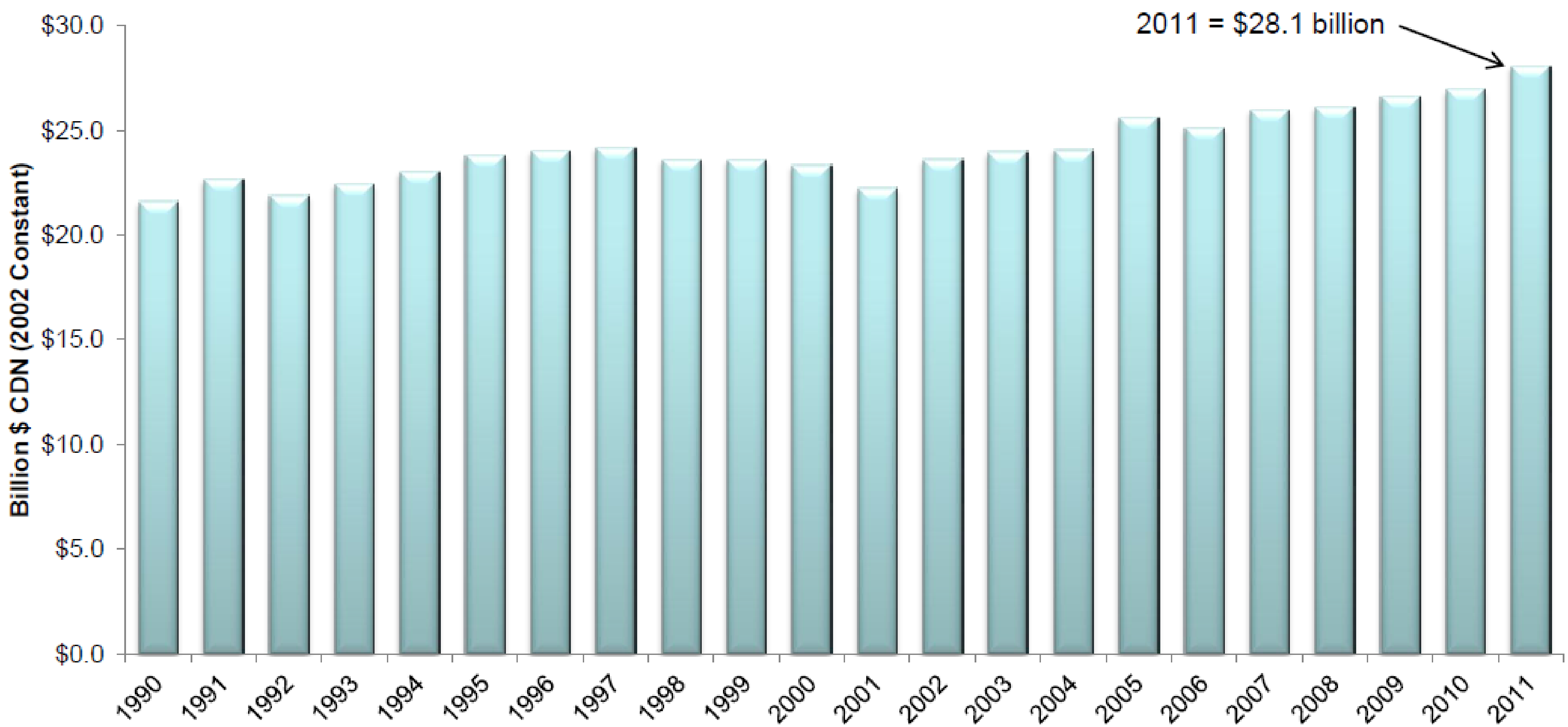
Major Canada-U.S. Transmission Interconnections



Note: The numbers indicate the voltage of the power lines from each province to the states. If there is more than one line with a given voltage, the number of lines is indicated in parentheses.

Source: NEB, Canadian Electricity Association and Natural Resources Canada.

Electric Power Generation, Transmission and Distribution Sector Contribution to Canada's GDP, 1990 – 2011 (billions of constant 2002 dollars)



Source: Statistics Canada, *Survey 1301, 2011*
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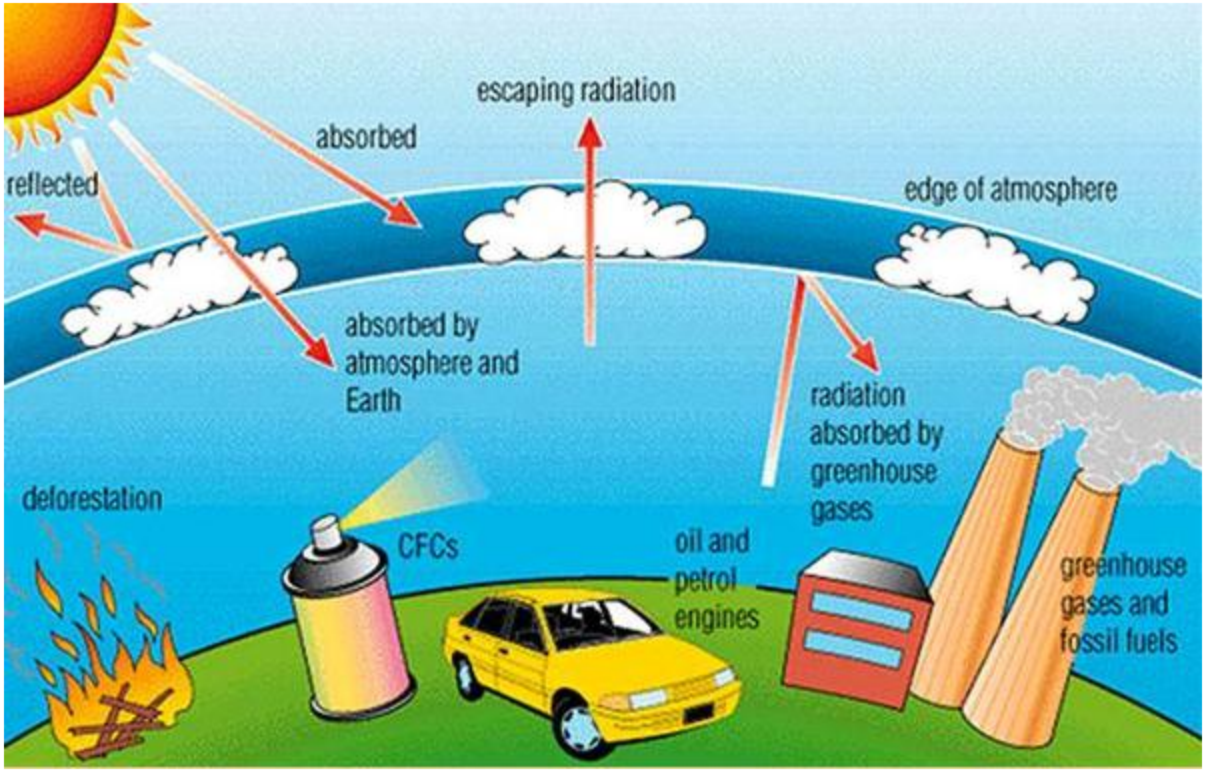
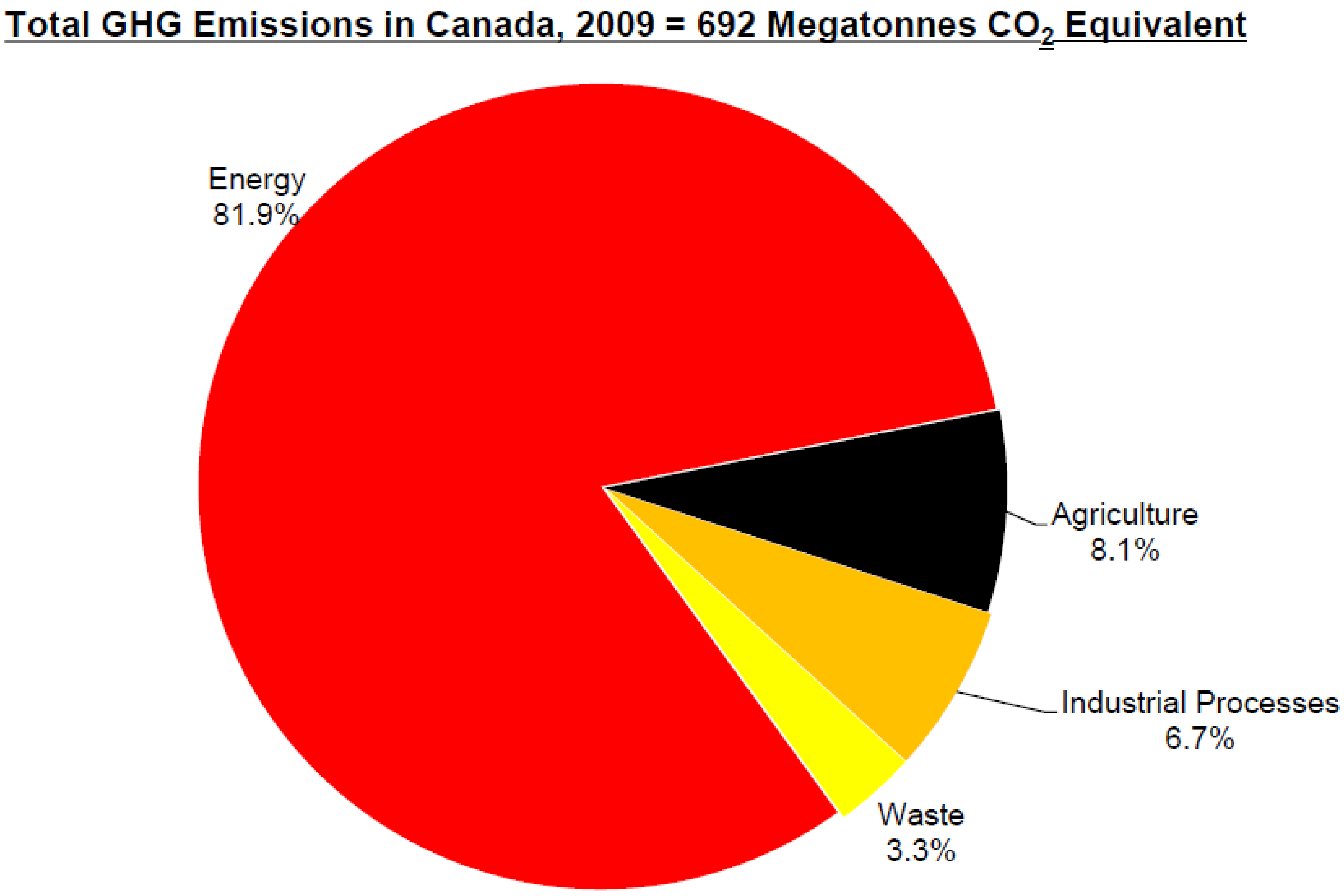
The Greenhouse Effect!



Greenhouse Gas (GHG) Emissions in Canada by Sector, 2009



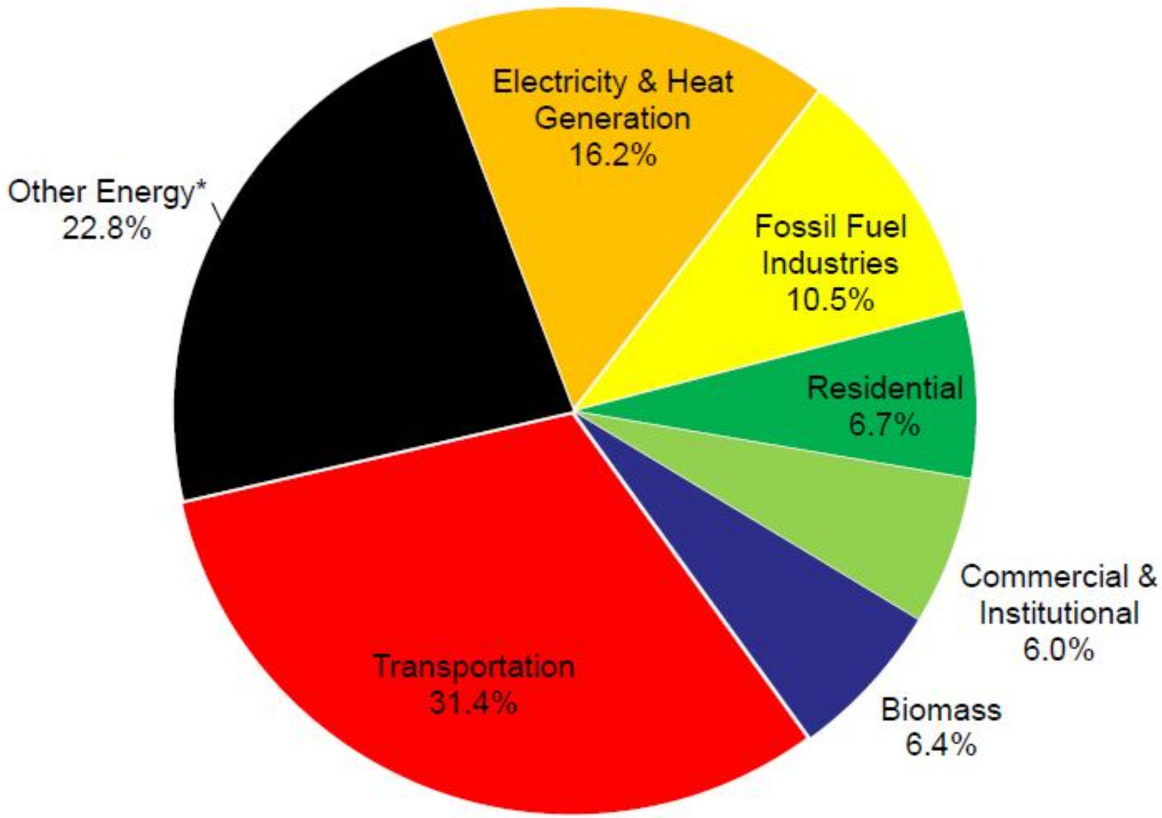
Note: Emissions do not include the following sectors: land use change and forestry, solvent and other product use (negligible amounts) and biomass

Source: UNFCCC, National Inventory Submission for Canada, for 2009, Report date: October 17, 2011

Canadian Electricity Association | Association canadienne de l'électricité

Greenhouse Gas (GHG) Emissions in Canada for Energy Sector, 2009

Total GHG Emissions in Canada, 2009 = 605 Megatonnes CO_2 Equivalent

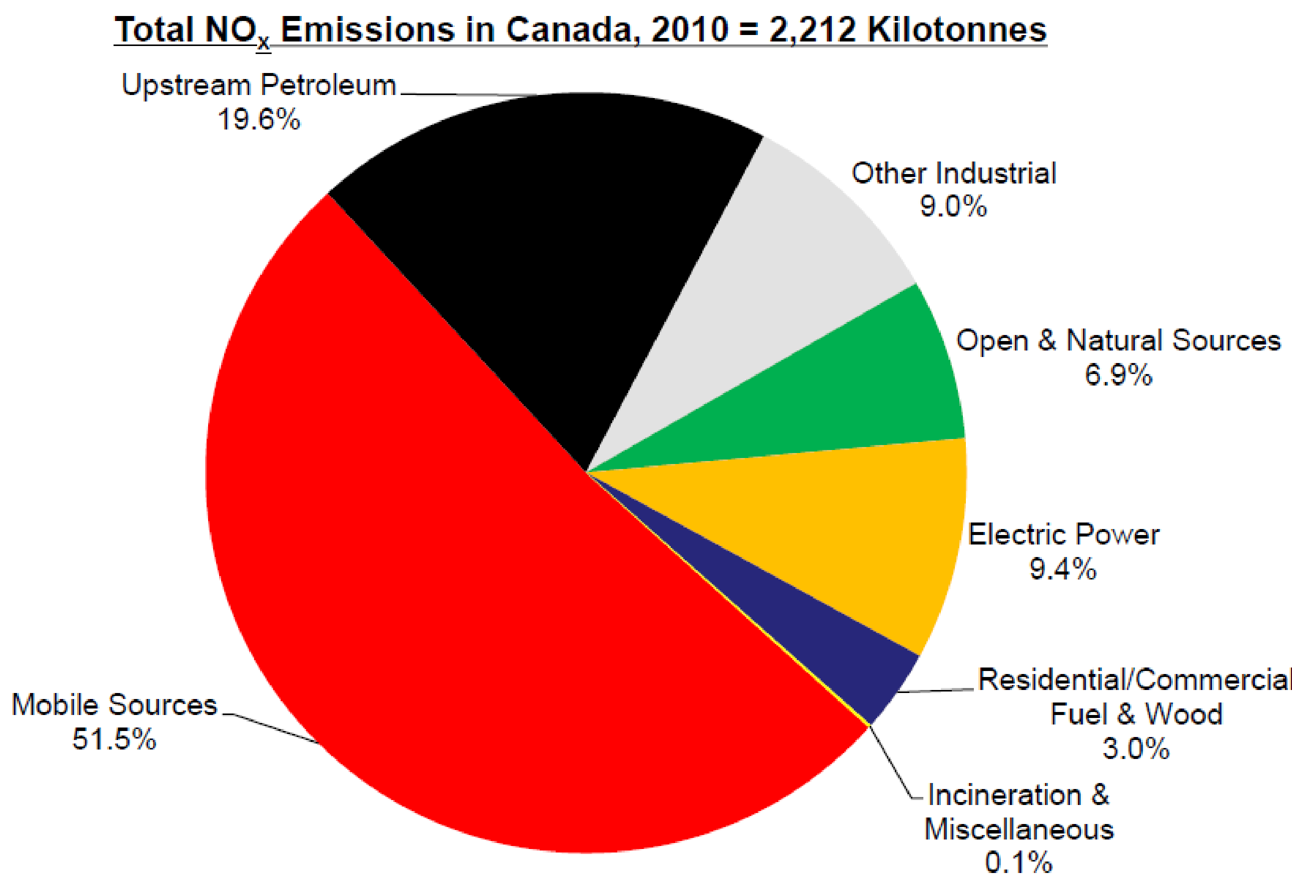


*includes all the other energy sector emission sources, such as mining, manufacturing, and construction, fugitive sources and agriculture/forestry/fisheries

Note: Total energy emissions include emissions from biomass

Source: UNFCCC, National Inventory Submission for Canada, for 2009, Report dated October 17, 2011

Nitrogen Oxide (NO_x) Emissions in Canada by Sources, 2010



Source: Environment Canada, National Pollutant Release Inventory, 2010 Air pollutant emissions summary for Canada

Retrieved February 24, 2012

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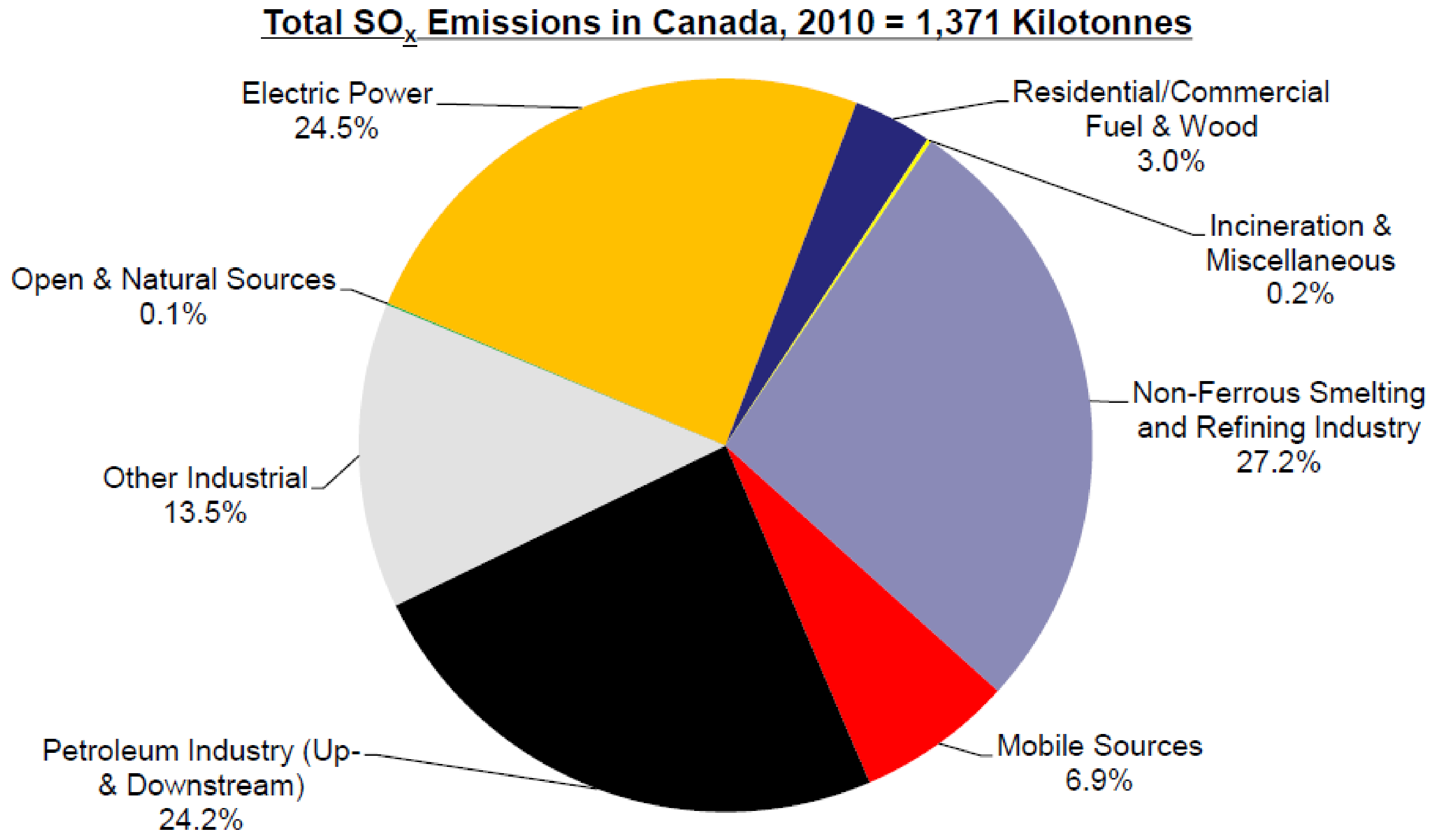
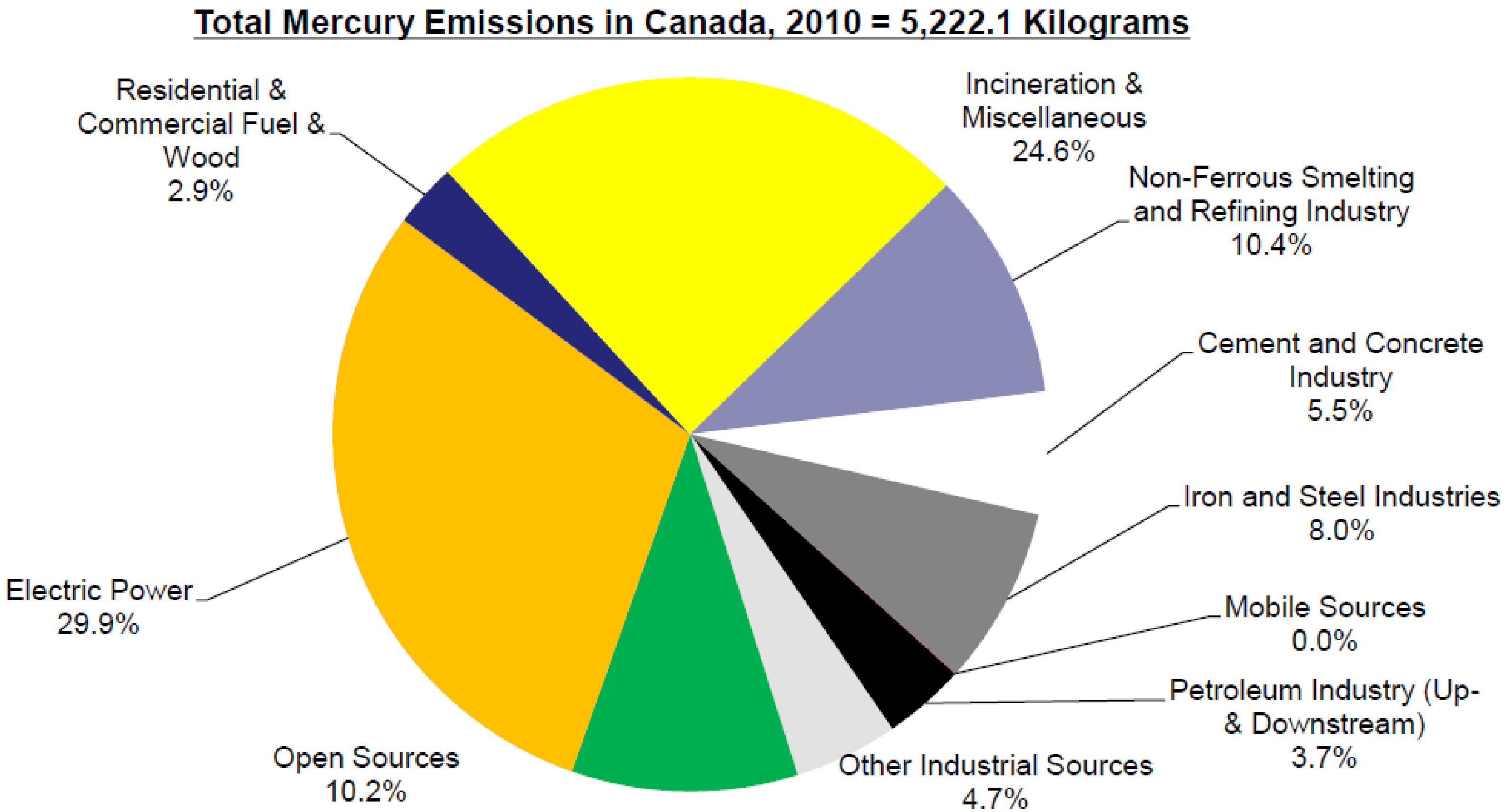
Sulphur Oxide (SO_x) Emissions in Canada by Sources, 2010



Source: Environment Canada, National Pollutant Release Inventory, 2010 Air pollutant emissions summary for Canada

Retrieved February 24, 2012

Mercury Emissions in Canada by Sources, 2010

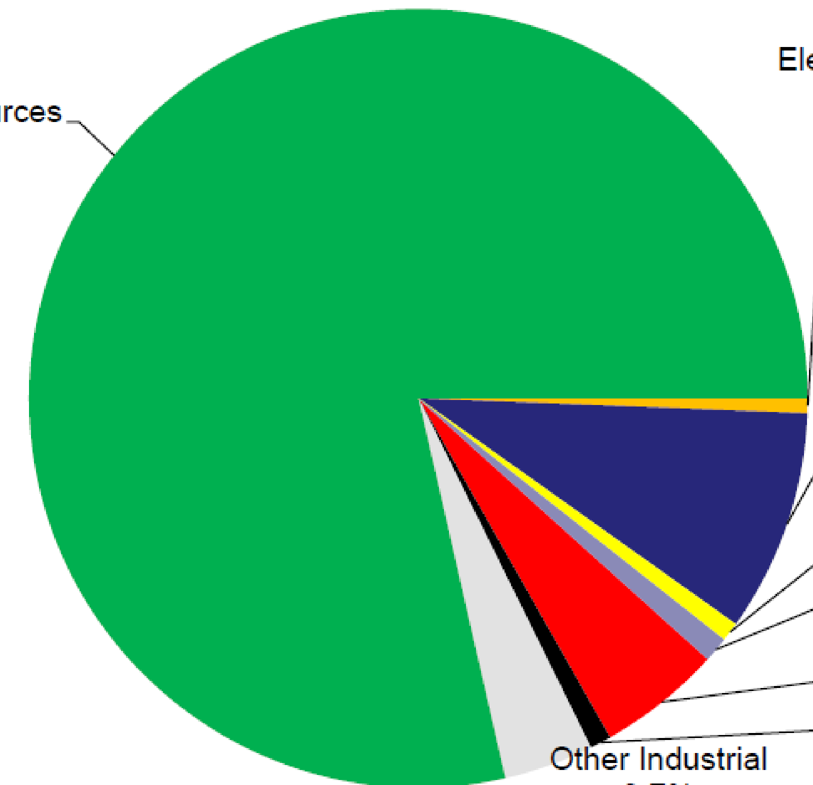


Source: Environment Canada, National Pollutant Release Inventory, 2010 Air pollutant emissions summary for Canada

Retrieved June 19, 2012

Particulate Matter ($PM_{2.5}$) Emissions in Canada by Sources, 2010

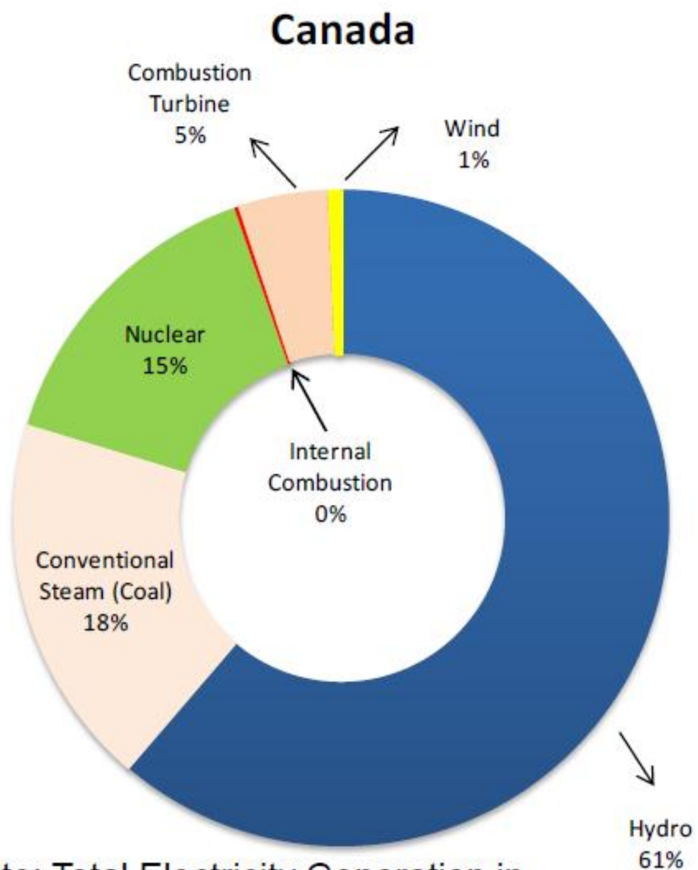
Total $PM_{2.5}$ Emissions in Canada, 2010 = 1187.3 Kilotonnes



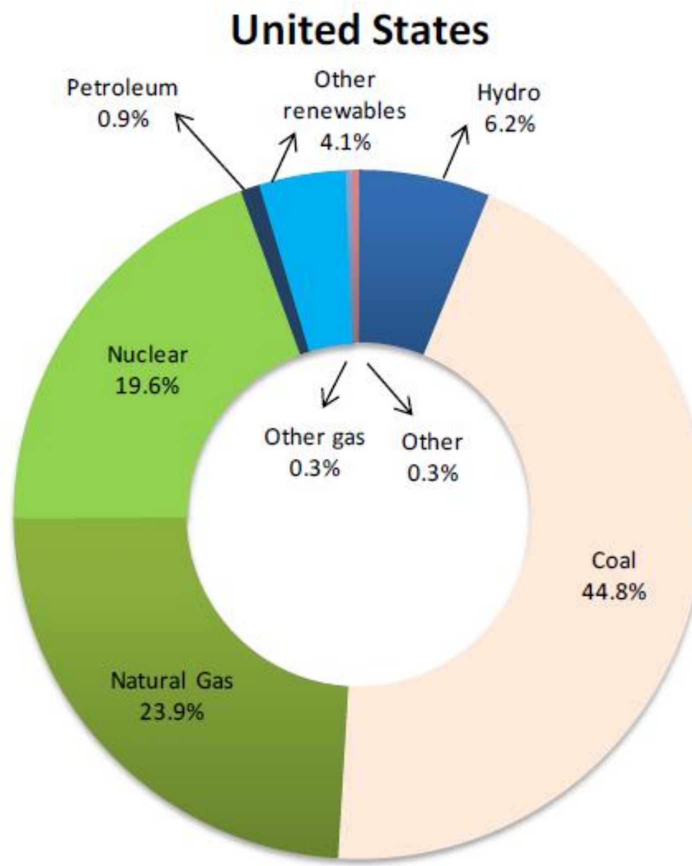
Source: Environment Canada, National Pollutant Release Inventory, 2010 Air pollutant emissions summary for Canada

Retrieved June 19, 2012

Electricity Generation in the US and Canada by Fuel Type,[1] 2010

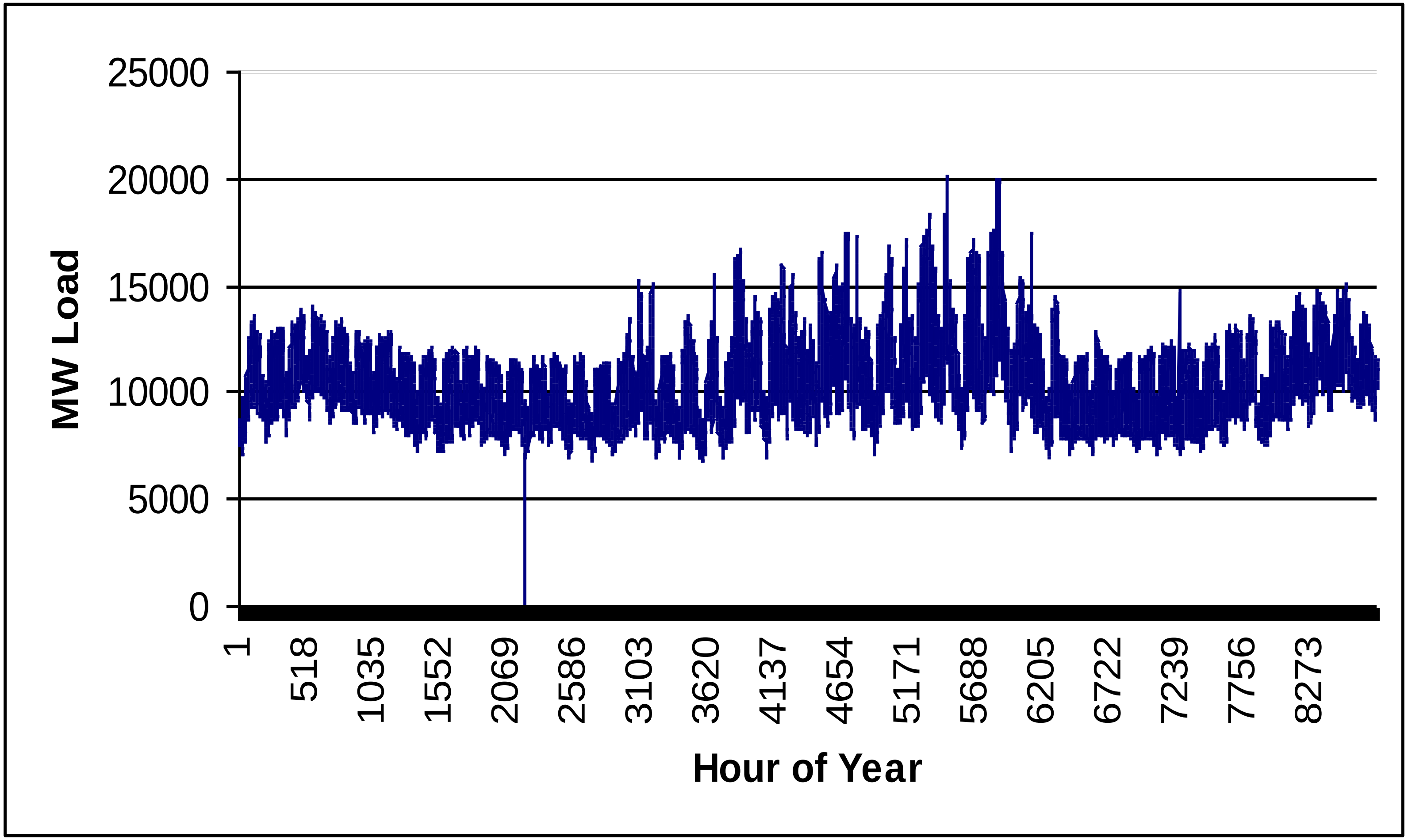


Note: Total Electricity Generation in 2010 = **511 TWh**



Note: Total Electricity Generation in 2010 = **4125 TWh**

Example Yearly Electric Load



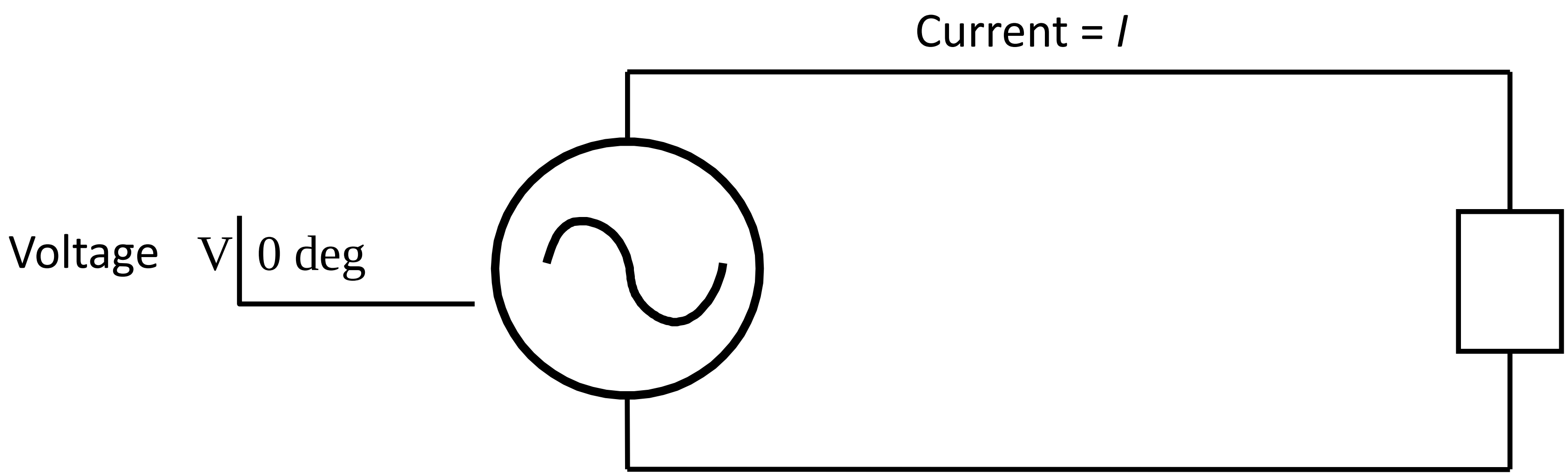
Review of Basic Electric Circuits

- Phasor Representation in Sinusoidal Steady State
- Power, Reactive Power, and Power Factor
- Power Factor Correction
- Three Phase Circuits
- Real and Reactive Power Transfer Between AC Systems
- Apparatus Ratings, Base Values, and Per Unit Quantities
- Energy Efficiency
- Read Example 2.1; Example 2.2; Example 2.3; Example 2.5.

Review of Electromagnetic Concepts

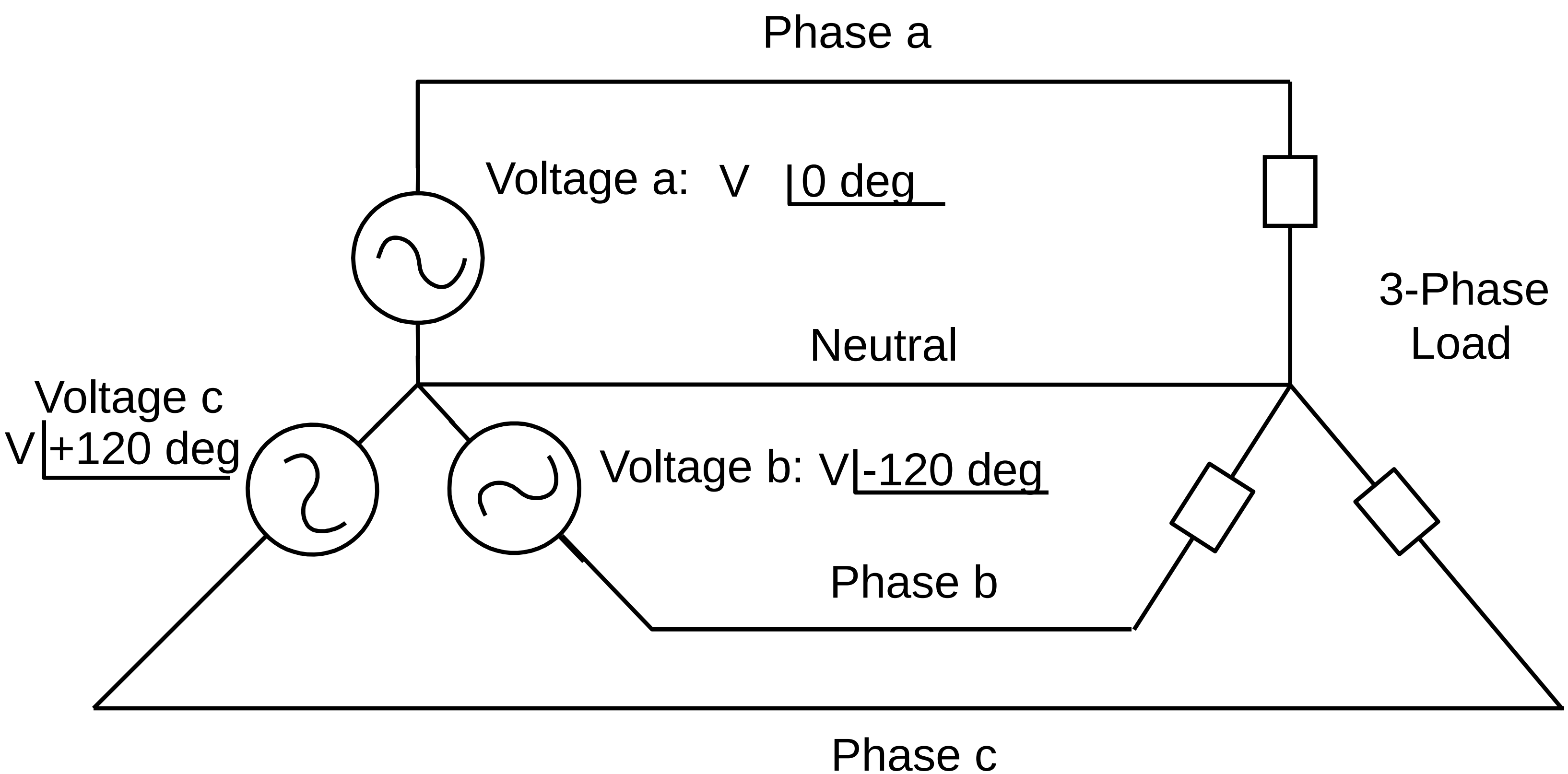
- Ampere’s Law
- Flux Concepts
- Ferromagnetic Materials
- Inductances
- Faraday’s Law
- Leakage and Magnetizing Inductances.

Single-Phase Circuit



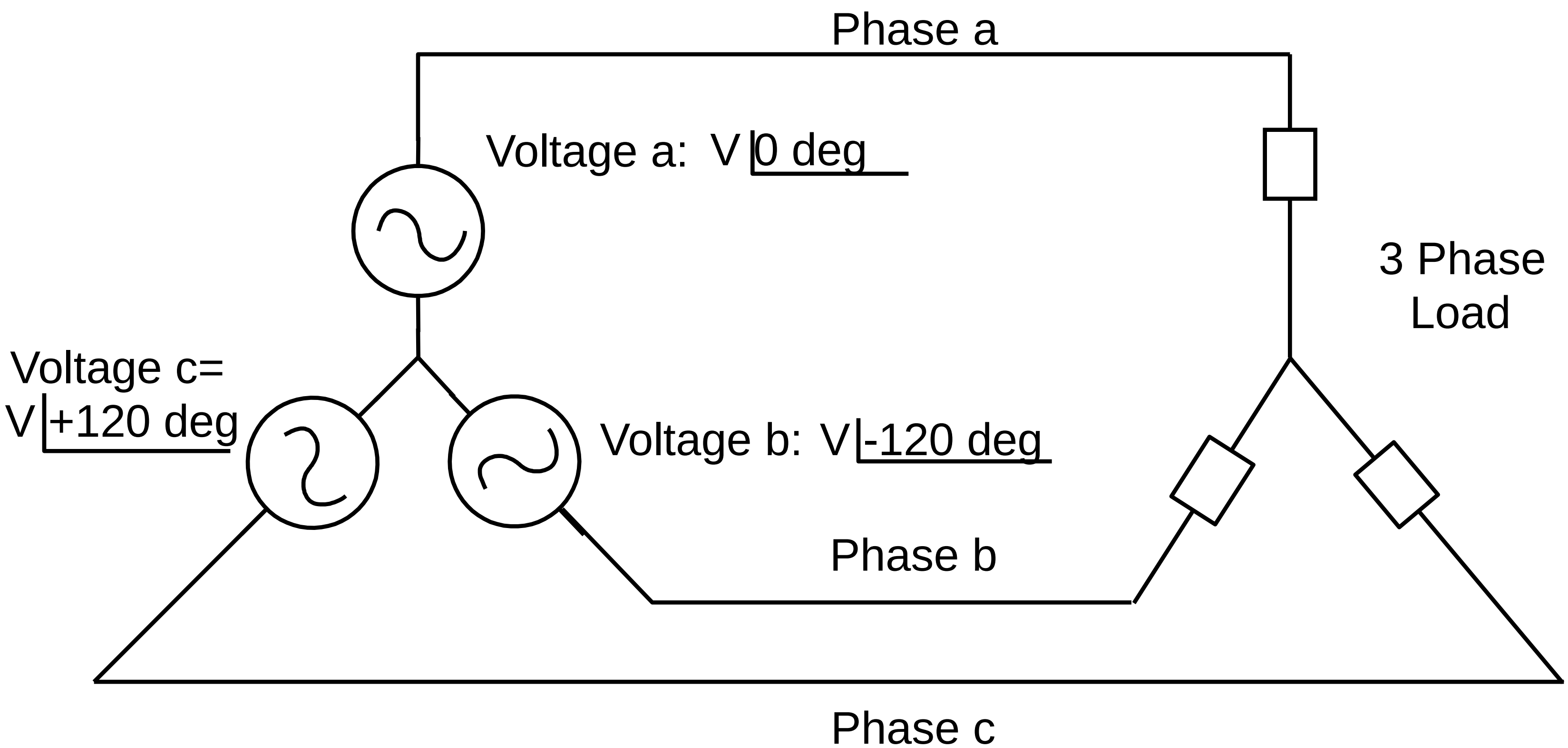
This circuit requires 2 wires to deliver power to the load

Three-Phase Circuit



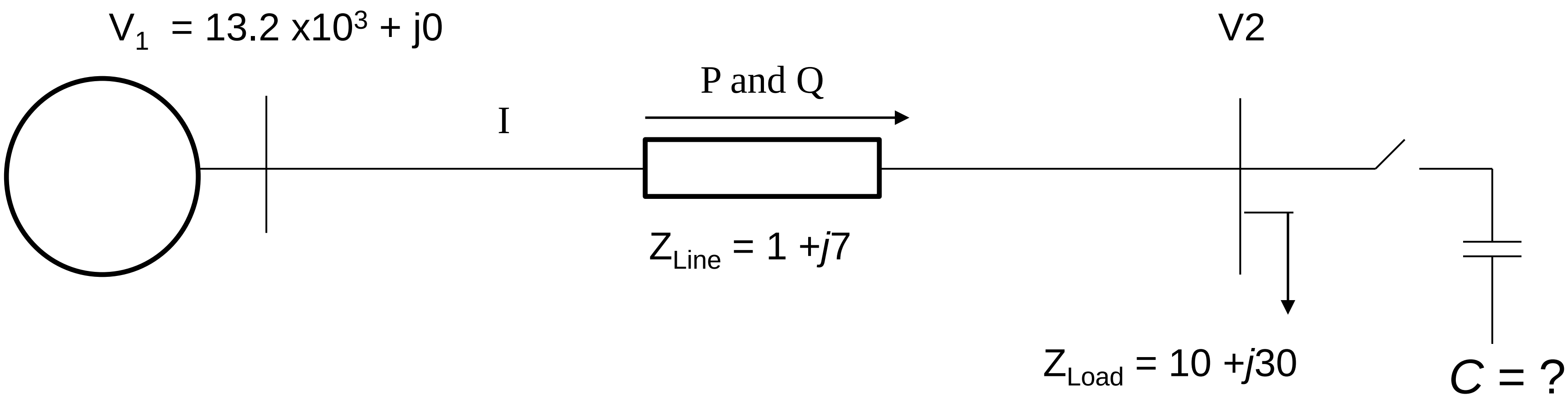
If the three phase load is "balanced" the neutral carries no current and can be eliminated.

Three-Phase Circuit Without a Neutral Wire



From Two-Line Diagram to One-Line Diagram

Voltage Drop and Reactive Power Compensation



Calculate the voltage at the receiving end of the line. If the voltage is too low, compute the size of the capacitor which will recover the voltage to the same value of the sending end. Calculate the value of C.

The Per Unit System

- Allows engineers to analyze a single phase network where:
  - All P and Q quantities are three phase
  - Voltage magnitudes are represented as a fractional part of their standard or "base" value
  - All phase angles are represented in the same units as normally used.

- Each region of the power system is uniquely defined by a standard voltage determined by the transformer windings, this sets base voltage.
- The entire system is given a base power to which everything in the power flow is referred.

Advantages

- Per-unit representation results in a more meaningful and correlated data. It gives relative magnitude information.
- There will be less chance of missing up between single - and three-phase powers or between line and phase voltages.
- The p.u. system is very useful in simulating machine systems on analog, digital, and hybrid computers for steady-state and dynamic analysis.
- Manufacturers usually specify the impedance of a piece of apparatus in p.u. (or per cent) on the base of the name plate rating of power ( ) and voltage ( ). Hence, it can be used directly if the bases chosen are the same as the name plate rating.
- The p.u. value of the various apparatus lie in a narrow range, though the actual values vary widely.
- The p.u. equivalent impedance (Zsc) of any transformer is the same referred to either primary or secondary side. For complicated systems involving many transformers or different turns ratio, this advantage is a significant one in that a possible cause of serious mistakes is removed.
- Though the type of transformer in 3-phase system, determine the ratio of voltage bases, the p.u. impedance is the same irrespective of the type of 3-phase transformer. (Yç D , D ç Y, D ç D , or Yç Y).
- Per-unit method allows the same basic arithmetic operation resulting in per-phase end values, without having to worry about the factor '100' which occurs in per cent system.

Conversion Procedure

Specify the MVA base. Typically this will be related to the rating of a generator, transformer, or transmission line. Just choose the one that will result in the least amount of computation. This base will remain constant throughout the system.

At any location in the circuit, specify a voltage base. This will typically be the nominal voltage for that particular location.

Determine the voltage base for all other areas in the circuit by adjusting by the turns ratio every time a transformer is encountered.

Having specified the voltage and MVA base throughout the system, current and impedance bases may be determined as:

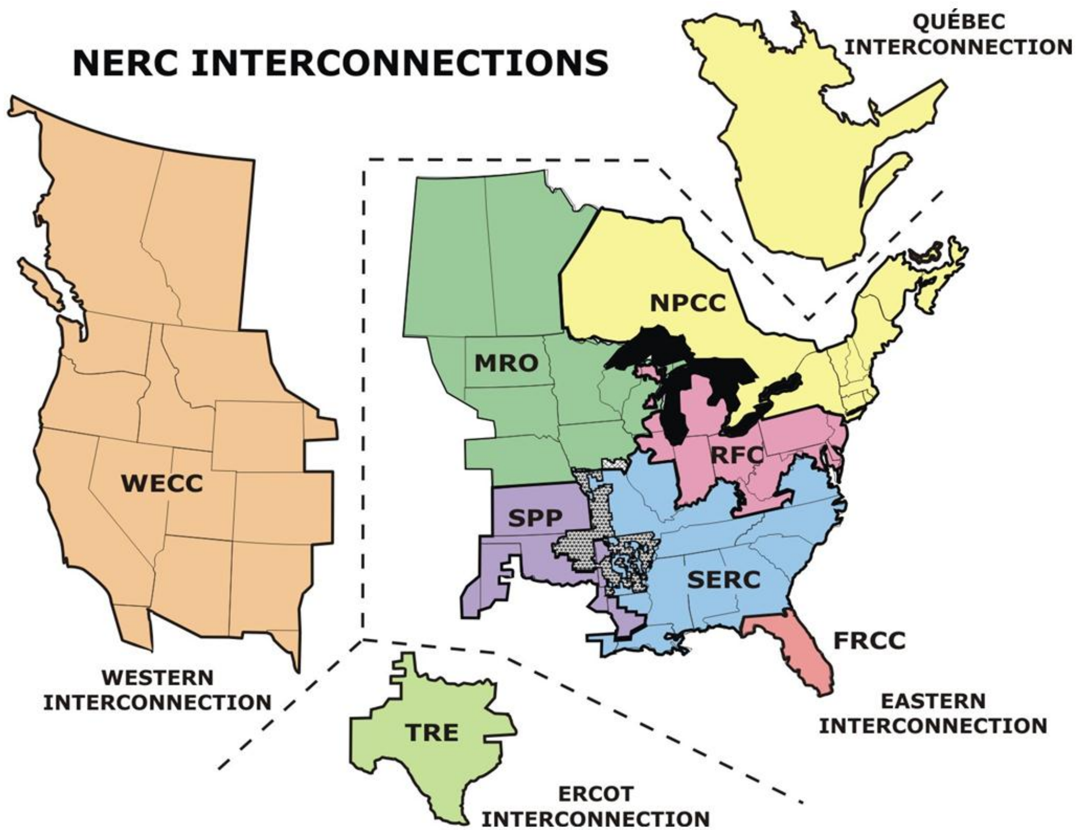
For each value, the per unit quantity is the actual value divided by the base value.

For 3phase circuits, the following relationships must also be included.

Nature of Power Systems in North America

Thousands of Generators, all Operating in Synchronization, Connected by about 300,000 km of Transmission Lines at 230 kV and Above!

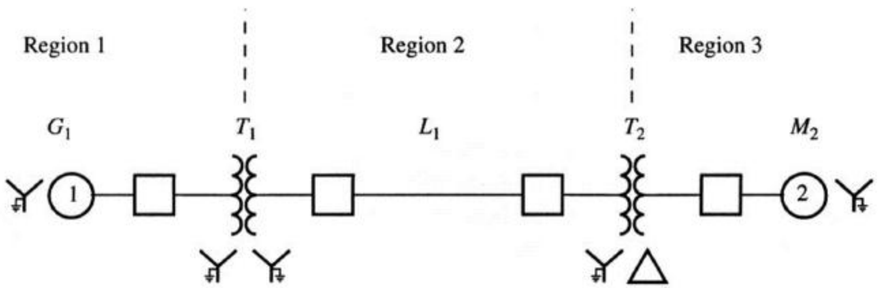
Advantages: Continuity; Reliability of Service; Low Cost!

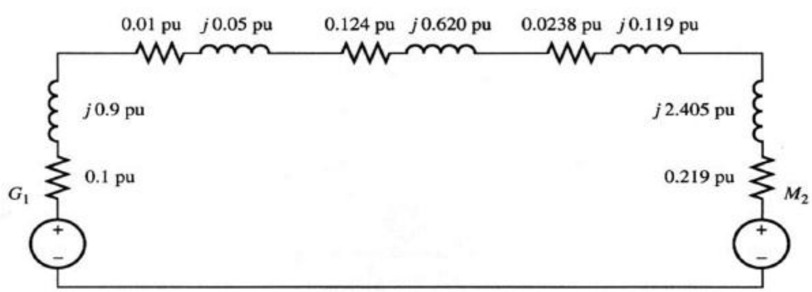


Representation of Power Transmission Systems

Power systems are very complicated electrical networks that are geographically spread over large areas. They are usually three phase networks; each power circuit consists of three conductors and all devices such as generators, transformers, breakers, disconnects etc. are installed in all three phases. The power systems are so complex that a complete diagram showing all the connections is impractical.

It is desirable, that there is some concise way of communicating the basic components of power systems. This is done by using Single Line Diagrams (SLD).





PowerWorld Simulator
http://www.powerworld.com/

Refer to the Course Textbook

- Visit: www.powerworld.com/GloverSarmaOverbye
- Read Section 1.5 of the Textbook!
- Follow Up: Figures 1.6 to 1.8.

Electric Energy and the Environment

- **Choices:**
  - **Hydro:** Drop in the River; Run-of-River
  - **Fossil Fuels:** Coal; Natural Gas; Oil
  - **Nuclear:** Fusion; Fission Reactors
  - **Renewable:** Wind; Photovoltaic; Fuel cells; Biomass
- **Consequences:**
  - Greenhouse Gasses
  - Sulfur Dioxide
  - Nitrogen Oxides
  - Mercury
  - Thermal Pollution

Wind Energy

$\dot{m} = \rho A V$ (Mass Flow Rate in kg/s)

- ρ = Wind density in kg/m^3
- A = cross sectional area in m^2
- V = Wind velocity in m/s.

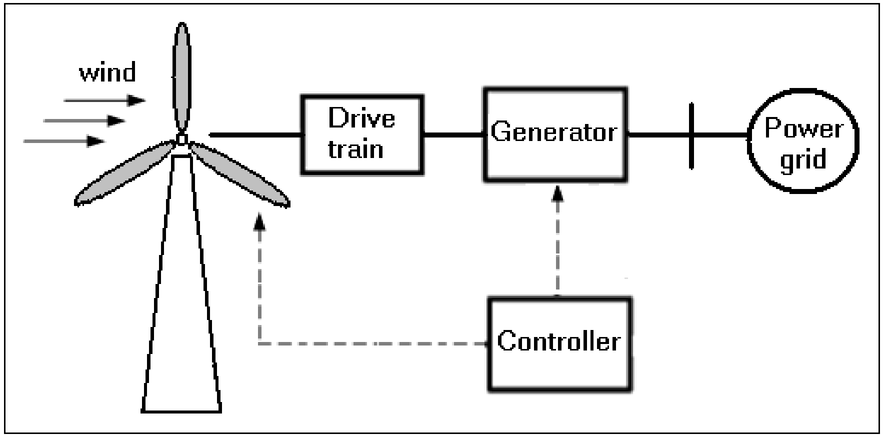
$P_{tot} = \frac{1}{2}\dot{m}V^2 = \frac{1}{2}\rho A V^3$ (Rate of Kinetic Energy)

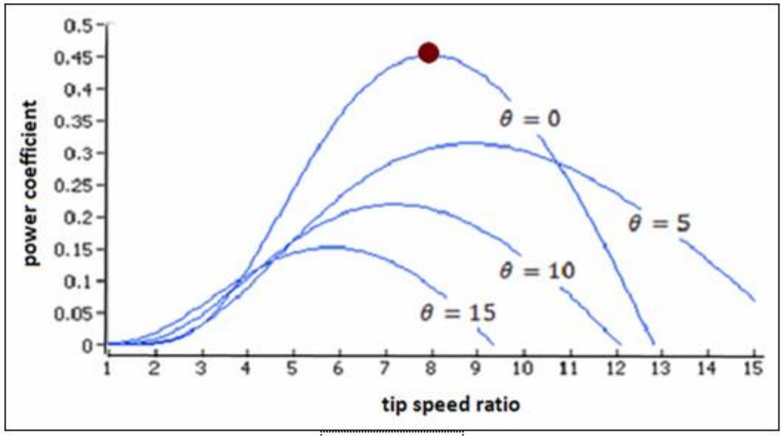
$P_w = C_p P_{tot}$

C_p= Coefficient of Performance with a maximum value of 0.5926. This C_p is a function of the tip-speed ratio $\lambda = \omega_m r/V$, where r is the radius of the turbine blades and ω_m is the turbine rotational speed.

Wind Energy

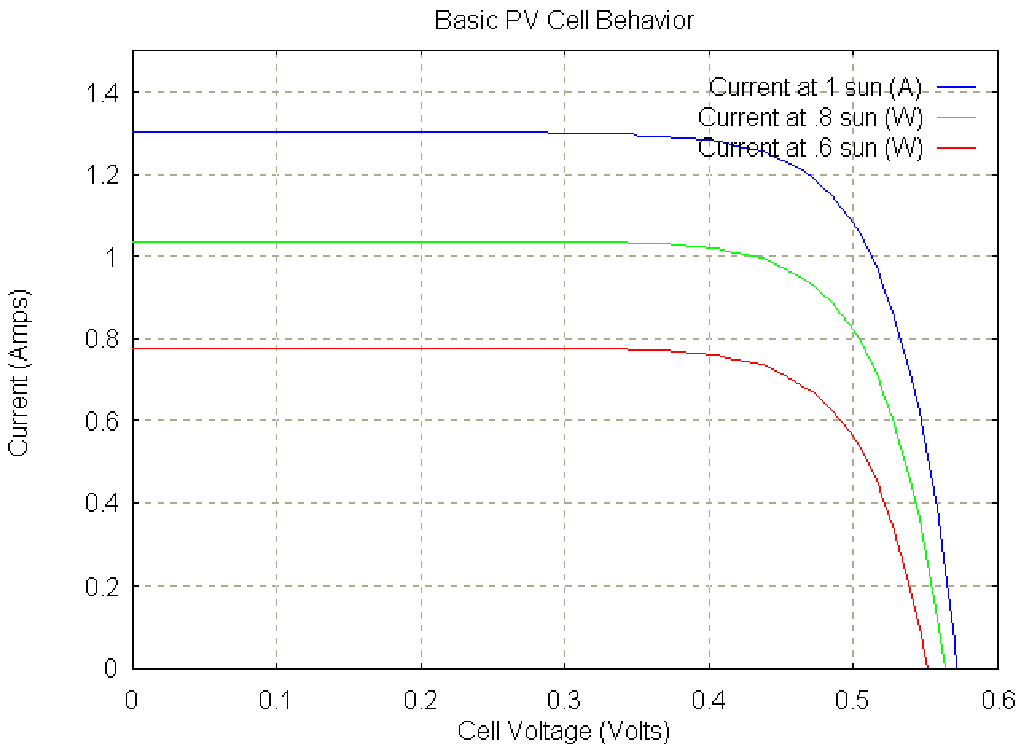
- *Θ* = Pitch angle



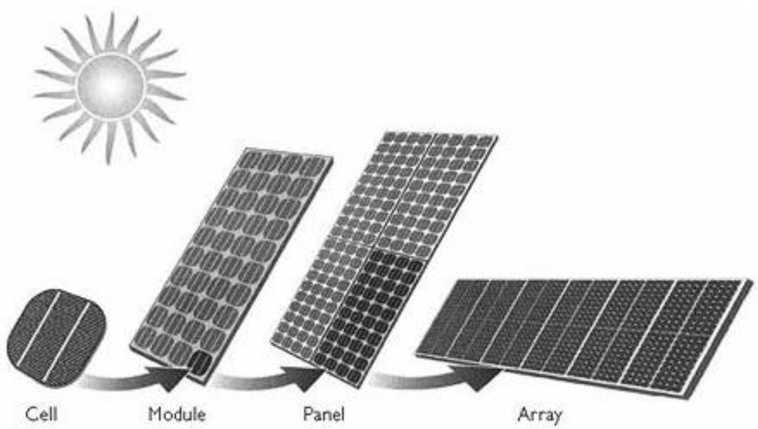


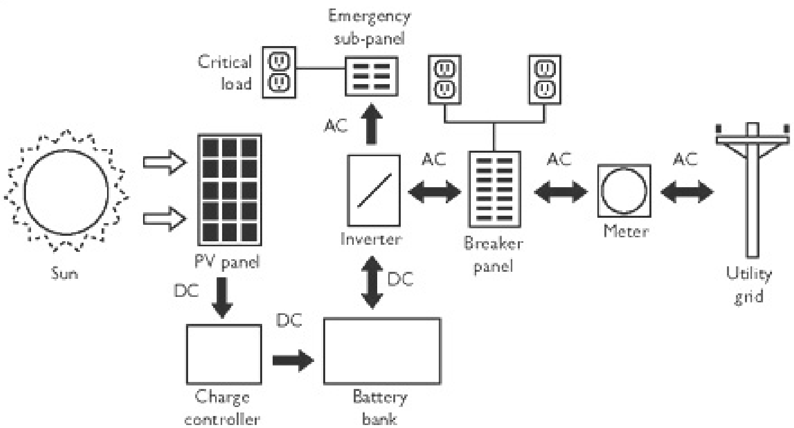
Photovoltaic Energy

- Photovoltaic cells consists of *pn*-junction where due to incident photons in the sun's ray cause excess electrons and holes to be generated above their normal equilibrium. This causes a potential to be developed and results in the flow of current if an external circuit is connected.
- The following figure shows the *v*-*i* characteristic of the photovoltaic cell.



Components of Photovoltaic System





Distributed Generation

- Smaller in Power Rating
- Spurred by Renewable Resources
- Generate Electricity Local to the Load; Minimize the Cost of Transmission and Distribution in addition to Minimizing Losses.
- Utilize the Heat Produced as a Byproduct rather than Throwing it as is Common on Central Generation.
- An Ultimate Advantage would be when the Cost of Wind and Photovoltaic Energy Decrease Significantly.

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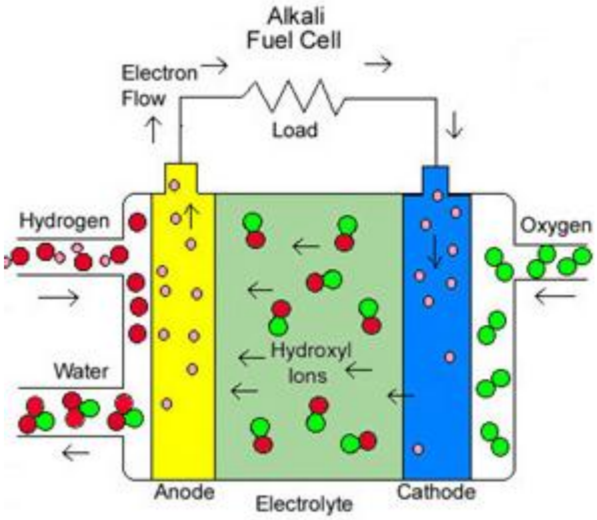
Fuel Cells

- Fuel cells use hydrogen, and possibly other fuels, through a chemical reaction to produce electricity with water and heat as byproducts.
- Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes.



Low Emission and Sustainable Technologies Used for Electricity Generation in Canada

Resource	Advantages	Challenges
Wind Power	No fuel cost, no emissions or waste, renewable source of energy, commercially viable source of power	Less cost competitive than conventional energy source, variable energy resource, transmission issues, environmental concerns with regards to noise and interaction with birds, land use issues
Small Hydro	Low capital costs, many potential sites in Canada, well established technology, able to meet small incremental capacity needs, reduction in GHG emissions	Regulatory approval can be costly and time consuming, access to grid, local opposition to new development
Biomass	Uses landfill gas, wood pellets, and waste products to create electricity, reduces greenhouse gas, high availability of sites	High capital equipment and fuel costs; produces some emissions; access to transmission, competition for biomass materials use
Geothermal Energy	Reliable source of power, low fuel and operating costs, clean and renewable source of energy	High capital costs, connecting to the grid can be difficult, few potential sites in Canada
Solar PV	Reliable, renewable energy source with zero emissions and silent operation, fuel is free, suitable for areas where fossil fuels are expensive or where there is no connection to the grid	Restrictive and lack of grid connection for remote areas, not cost competitive, sun does not always shine and potential varies across regions
Ocean Energy	Costs are expected to decline as technology develops, intermittent, but predictable source of green energy	Potentially intrusive to marine life, investment is needed to promote research and development
Clean Coal	Highly efficient, potential for reduced greenhouse gas emissions	High capital costs, lengthy start-up period

Canadian Electricity Statistics

By the *Global* numbers…

5 Canada's world ranking in primary energy production (2008)

7 Canada's world ranking in primary energy consumption (2008)

22.4 Per cent of Canada's total exports that were energy related (2010)

3 Canada's ranking in Hydroelectricity generation (2009)

By the *Domestic* numbers…

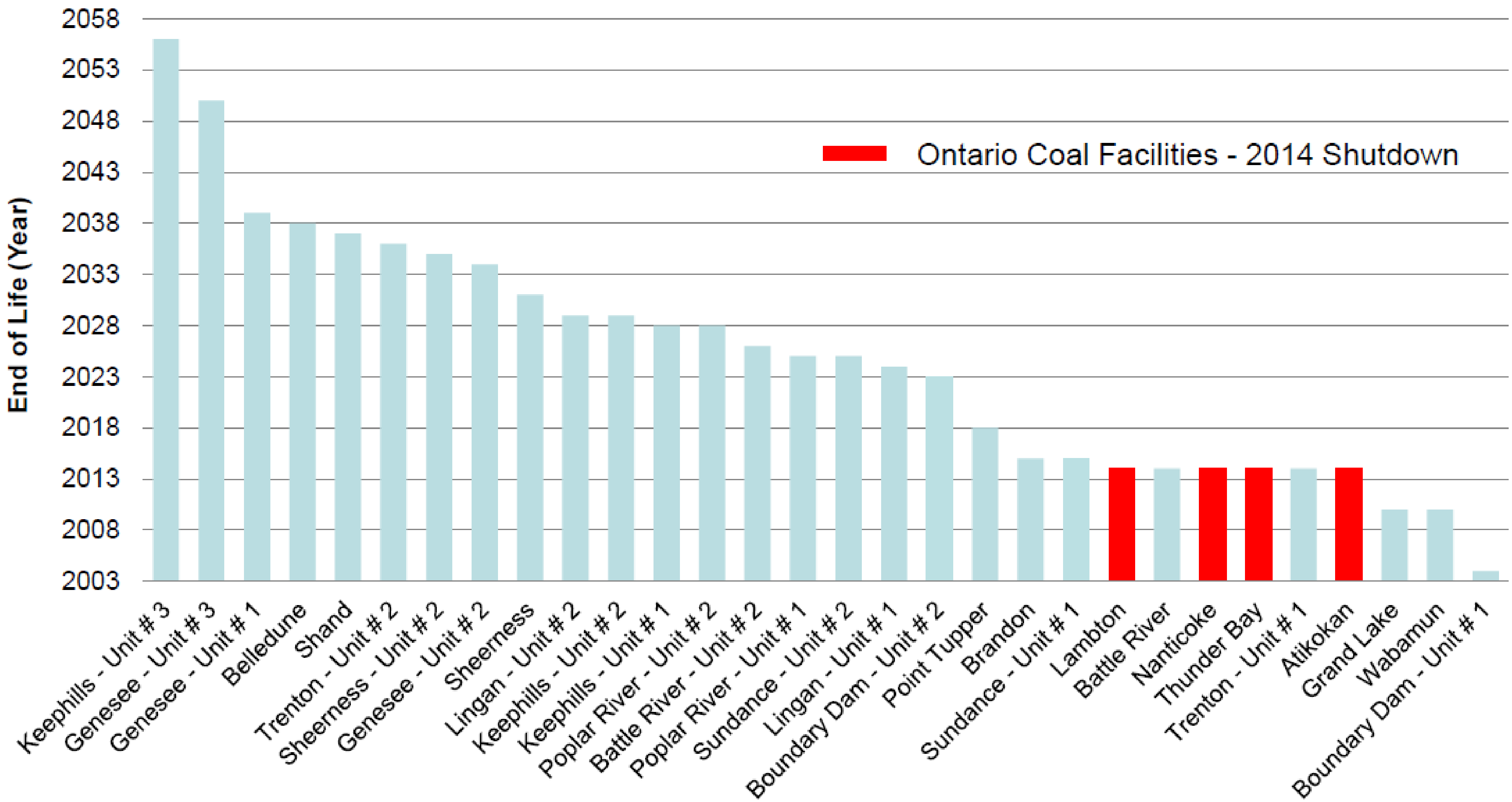
15.2 Per cent of Canada's electricity produced from nuclear generation (2011)

16.1 Per cent of Canada's electricity produced from thermal generation fired by coal (2011)

62.9 Per cent of Canada's electricity generated from hydropower (2011)

592.3 Terawatt-hours of total electricity generation (2011)

Existing Coal Facilities in Canada – End of Life and Regulatory Shut Down



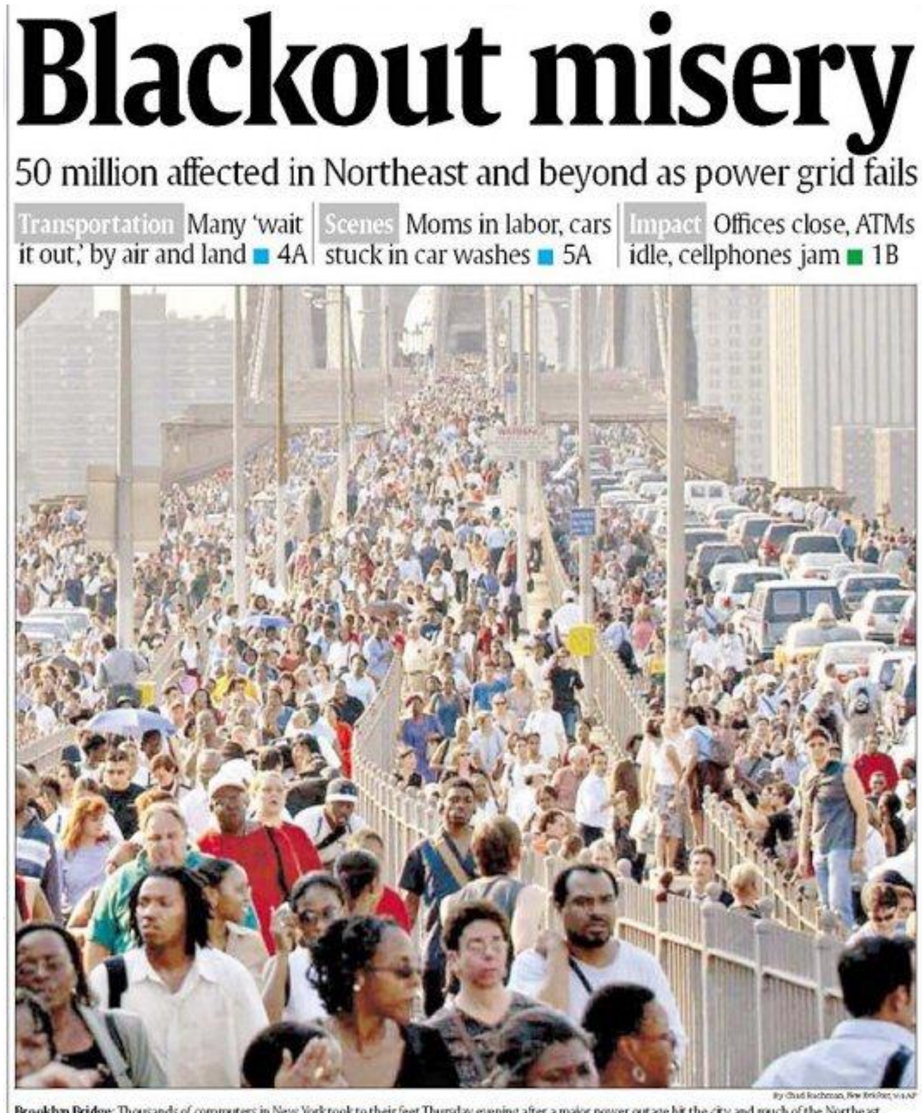
Smart Grid

- A suite of information-based applications through increased automation of the electricity grid *and* the underlying automation and communication infrastructure itself
- Smart grid is posed to deliver grid resilience, environmental performance, and/or operational efficiencies
- Design and implementation of the smart grid integrated system aims to achieve desired customer priorities, interoperability with legacy infrastructure, and be appropriate for use with respect to geographical location and other needs
- Key characteristics or capabilities:
  - Demand response, facilitation of distributed generation, facilitation of electric vehicles, optimization of asset use, and problem detection and mitigation
  - Capabilities supported by development of hard infrastructure, soft infrastructure through stakeholder engagement
  - Expected results in new service offerings, reduced delivery charges, and faster response time
- Security, privacy, implementation cost, and stakeholder engagement requires *collaboration* among vendors, policy-makers, regulators and utilities

Electricity in Canada at a Glance

Indicator	Value
Total Generation in 2011 (Twh)	592.32
Total Demand in 2009 (Twh)	503.4
Average Price in 2011 (¢/kWh) Residential Industrial	 12.15 7.32
Canada – US trade volume in 2011 (Twh): exports/imports	51.4/14.6
Canada – US trade revenue in 2011 (billions $): exports/imports	2.04/0.37
Capital Expenditure on New/Refurbished Infrastructure in 2010 (billion $)	8.8
Environmental Expenditure in 2008 (million $)	1287.9
GHG emissions from Public Electricity and Heat Production Sector (CO_2, CH_4 and N_2O eq. Mt)	98.1

Remember!
August 14th, 2003 Blackout



Blackout misery

50 million affected in Northeast and beyond as power grid fails

Transportation Many 'wait it out,' by air and land ■ 4A | **Scenes** Moms in labor, cars stuck in car washes ■ 5A | **Impact** Offices close, ATMs idle, cellphones jam ■ 1B

Brooklyn Bridge: Thousands of commuters in New York took to their feet Thursday evening after a major power outage hit the city and much of the Northeast.