ELG4126: Sustainable Power Systems

Concepts and Applications: You should be familiar with

- Introduction (Structure of Power Systems)
- Basic Principles (AC Power)
- Generation
- Transmission Lines
- Transformers
- Power Flow
- Stability
- Transient and Harmonic Studies
- Protection

Related Topics:

Distributed Generation, Renewable Power, Efficiency

Computer Programs:

MathCAD, PSpice, MATLAB / Simulink (PowerSym), PowerWord, EMTDC/PSCAD

An Overview of Power and Energy Systems

Power System Analysis, Computing and Economics

Computing applications
Distribution system analysis
Economics, market organization, cost structures, pricing, and risk management
Intelligent system applications
Reliability, uncertainty, and probability and stochastic system applications

Power System Dynamic Performance

Power system dynamic modeling: components and systems
Power system stability: phenomena, analysis, and techniques
Power system stability controls: design and applications
Power system dynamic measurements
Power system interaction with turbine generators
Dynamic security assessment: techniques and applications, risk-based methods

Power System Operations

Power system dynamic modeling: components and systems
Power system stability: phenomena, analysis, and techniques
Energy control centers
Distribution operation
System control
Operating economics and pricing

An Overview of Power and Energy Systems

Power System Planning and Implementation

Generation system resource planning
Transmission system planning
Distribution system planning
Integrated resource planning and distributed resource planning
Load forecasting
Customer products and services planning and implementation
Industry restructuring planning and policy issues.

Electric Machinery

DC Machines; Permanent magnet machinery systems; Switched and variable reluctance; machines; Integral horsepower induction machinery; Wound rotor induction machinery Single phase induction motors; Electronic drives for electric machinery; Induction generators for grid and isolated applications; Synchronous generators; Motor/generator sets for pumped storage; Synchronous motors materials to electric machinery; Electrical machinery theory Numerical analysis of electric machinery; Power processing equipment; Insulation for electric machinery; Application of magnetic materials to electric machinery; Application of superconducting.

Power System Communications

Communication systems; Communication media; Communication protocols; Communication standardization; Home automation and communication.

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 banks	**Sub-transmission system**	**Capacitor**
Tap changers	**Current transformers**	**Potential transformers**
Protective relaying	**Reactors**	**Metal-oxide varistors**
Transmission system	**Suspension insulators**	**Lightning arrestors**
Generator step-up transformers	**Generators**	

An Overview of Power and Energy Systems

Power System Instrumentation and Measurements

Digital technology for measurements
Electricity metering
High voltage testing
Measurement techniques for impedance elements

Power System Relaying

Digital protection systems
Adaptive protections
Power system protection
Protection of electrical equipment
Relaying communications
Relaying for consumer interface

Substations

Substation automation
Intelligent electronic devices (IEDs)
Programmable logic controllers (PLCs)
Substation design
High voltage power electronics stations
Gas insulated substations (GIS)

An Overview of Power and Energy Systems

Surge Proctective Devices

Design/testing of high voltage surge protective devices (>1000V)
Application of high voltage surge protective devices (>1000V)
Design/testing of low voltage surge protective devices (<1000V)
Application of low voltage surge protective devices (<1000V)

Nuclear Power Engineering

Nuclear power plant controls
Modeling, simulations and control
monitoring and instrumentation

Transformer

Power and instrument transformers
Insulating fluids
Dielectric testing
Audible noise and vibration
Transformer modeling techniques.

An Overview of Power and Energy Systems

Transmission and Distribution Systems

AC transmission and distribution facilities
Lightning phenomena and insulator performance
Overhead line conductors: thermal and mechanical aspects
Corona, electric, and magnetic fields
Towers, poles, and hardware
Capacitors, shunt and series capacitor banks, and harmonic filter banks
HVDC transmission and distribution, FACTS and power electronic applications to ac transmission
Harmonics and power quality
Transients, switching surges, and electromagnetic noise
Maintenance and operation of overhead lines
Work procedures, safety, tools, and equipment
Superconductivity analysis and devices
Distributed resources

Power Generation

Excitation systems
Power system stabilizers
Advanced energy technologies, Renewable energy technologies
Station design, operations, and control
Modeling, simulation and control of power plants
Monitoring and instrumentation of power plants
Control of distributed generation
Hydroelectric power plants, Power plant scheduling, Engineering economic issues
International practices in energy development.

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 – 1×10^3 Watt

  MW – 1×10^6 Watt

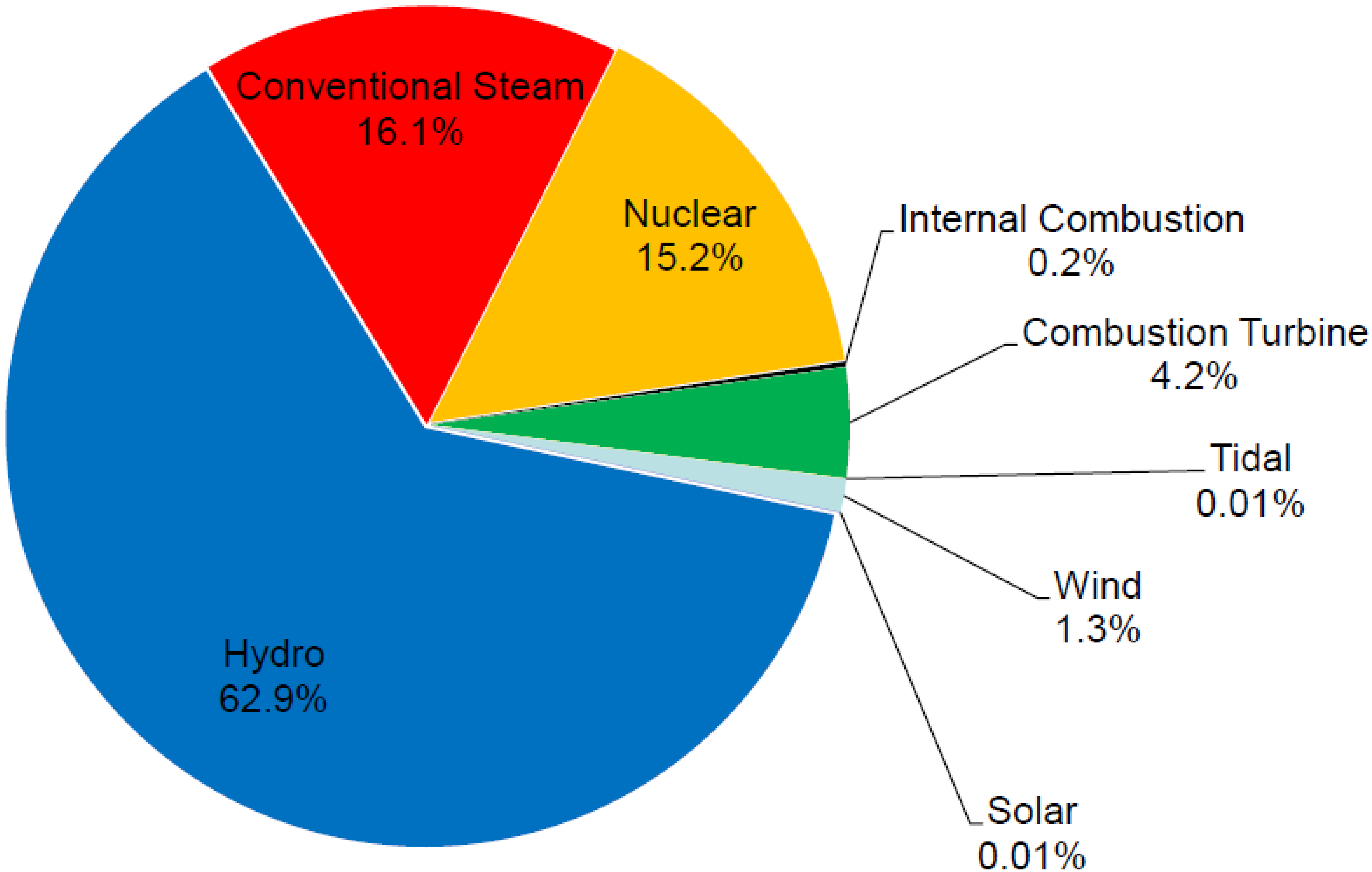
  GW – 1×10^9 Watt
- Installed Canadian generation capacity is about 592 TWh.
- Maximum load of Ottawa may be about 2500 MW.
- Maximum load of uOttawa campus is about 50 MW.

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:

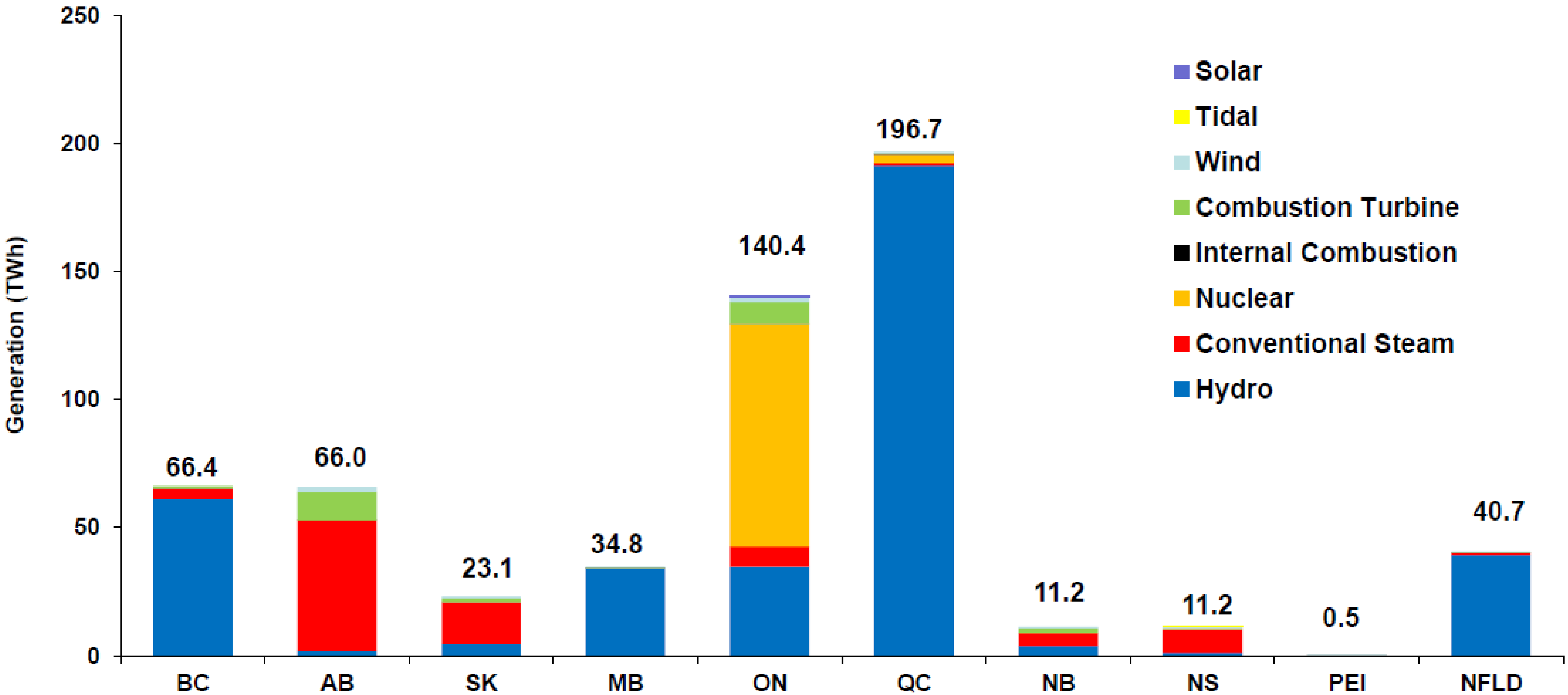
Joule	=	1 watt-second (J)
kWh	–	kilo-watt-hour (3.6×10^6 J)
Btu	–	1055 J; 1 Mbtu = 0.292 MWh

Total Electricity Generation in Canada, 2011 = 592.3 TWh



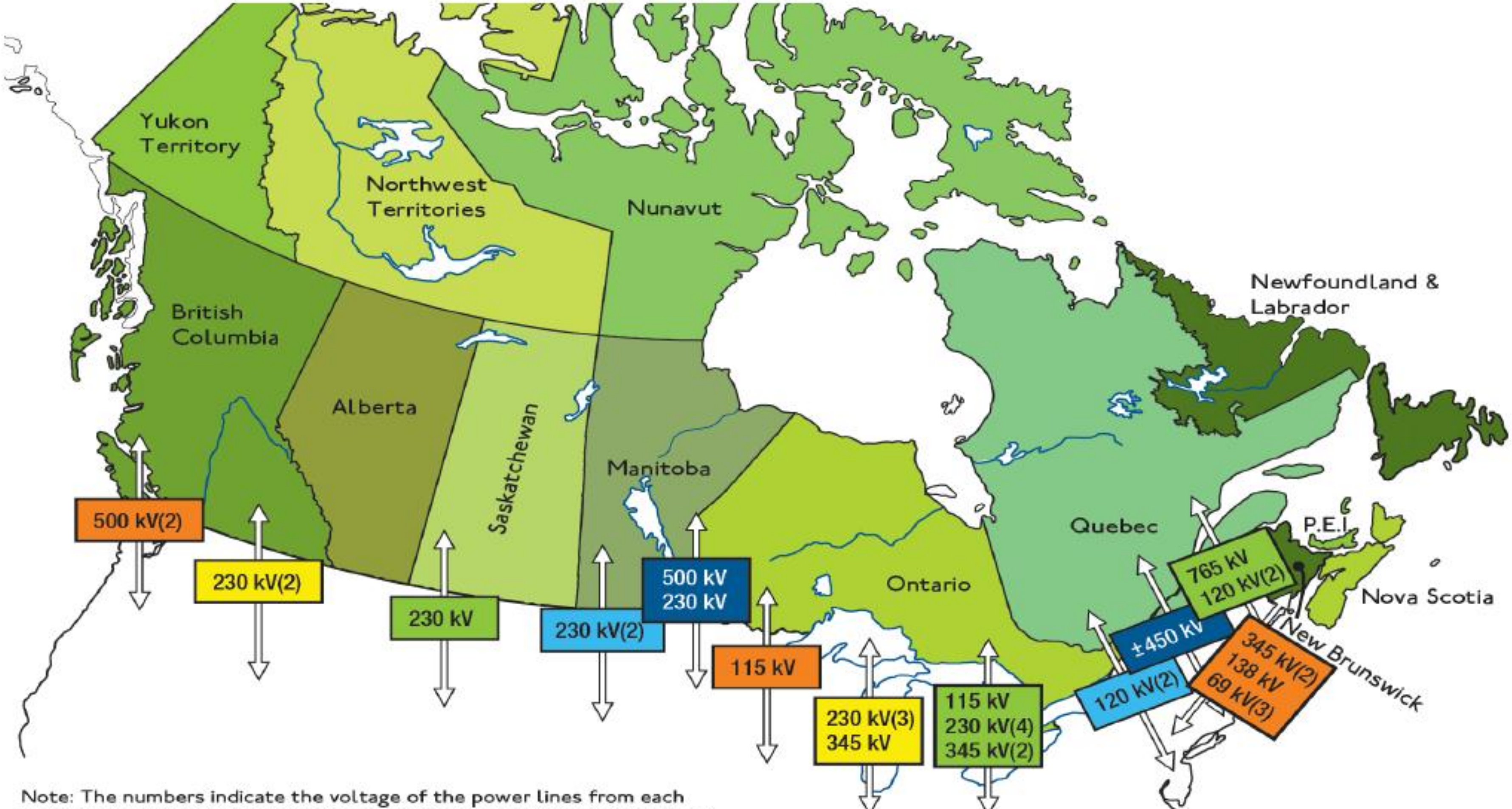
*Numbers may not sum to 100 percent due to rounding.
Source: Statistics Canada, *Survey 2151*, 2011
Retrieved March 21, 2012

Total Electricity Generation in Canada, 2011 = 592.3 TWh



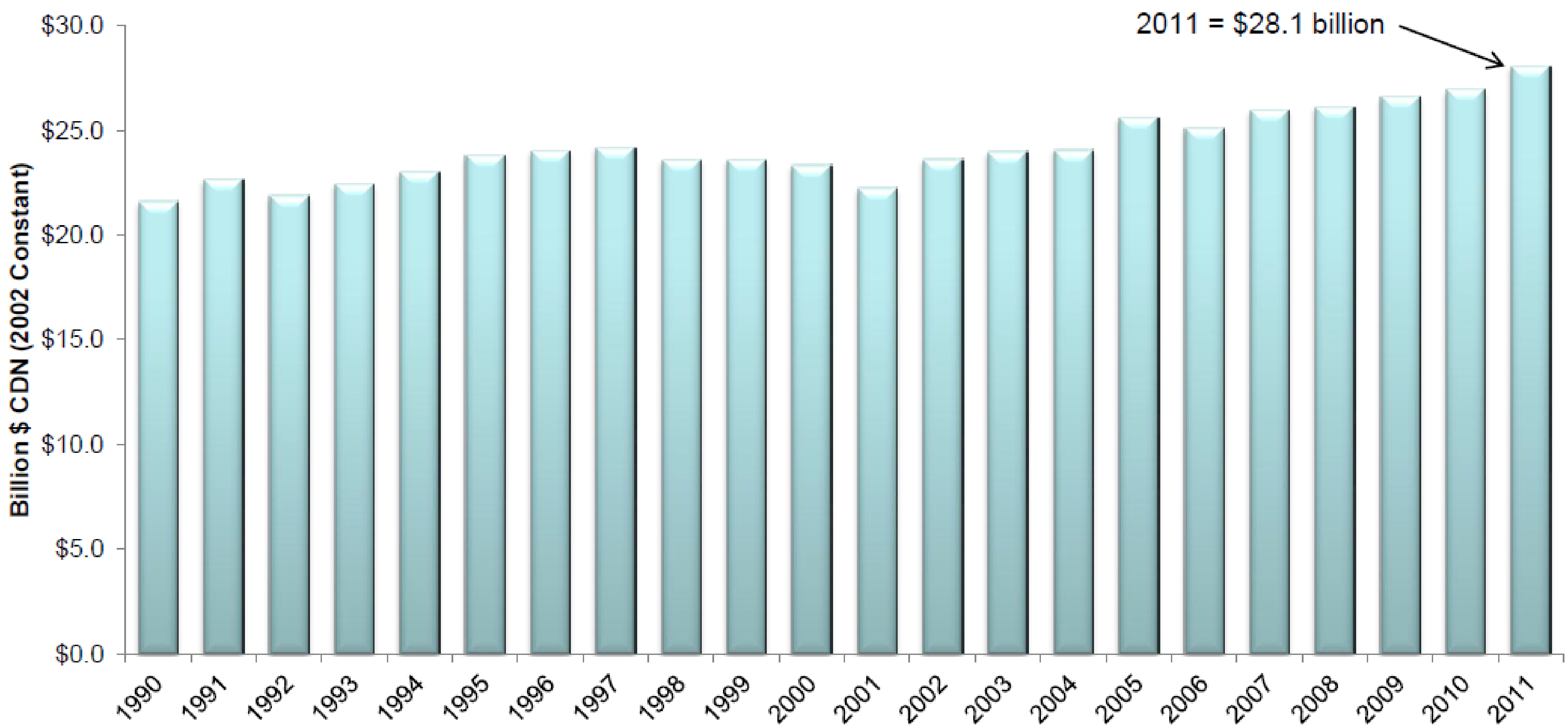
Source: Statistics Canada, *Survey 2151*, 2011
Retrieved March 21, 2012

Major Canada-U.S. Transmission Interconnections



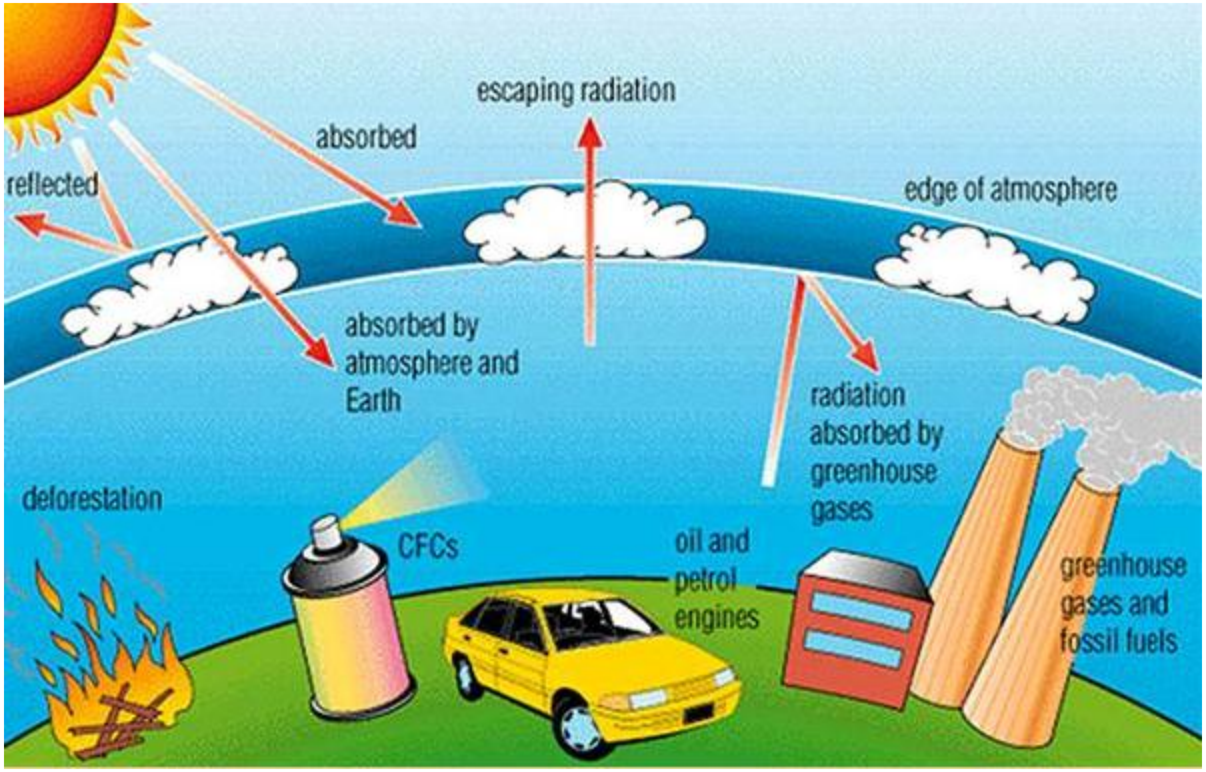
Note: The numbers indicate the voltage of the power lines from each province to the states. If there is more than one line with a given voltage, the number of lines is indicated in parentheses.
Source: NEB, Canadian Electricity Association and Natural Resources Canada.

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



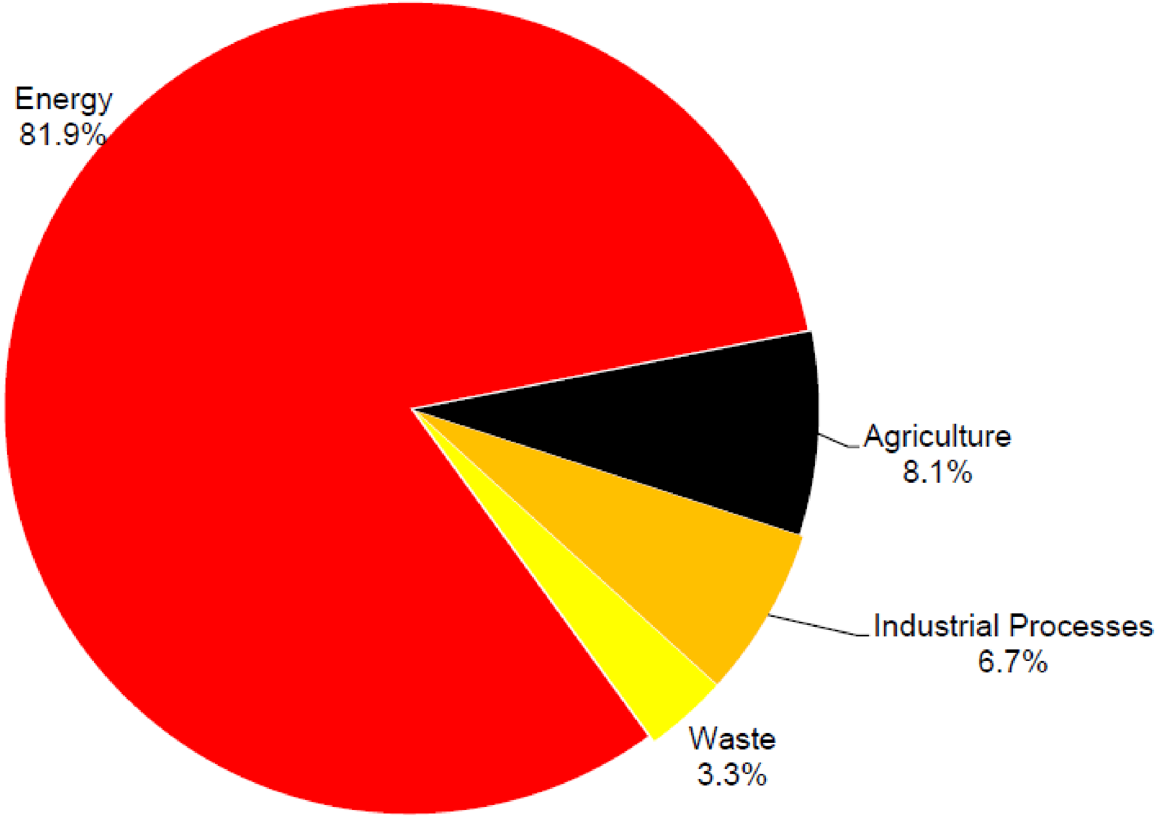
Source: Statistics Canada, *Survey 1301, 2011*
Retrieved March 2, 2012

The Greenhouse Effect!



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

Total GHG Emissions in Canada, 2009 = 692 Megatonnes CO_2 Equivalent

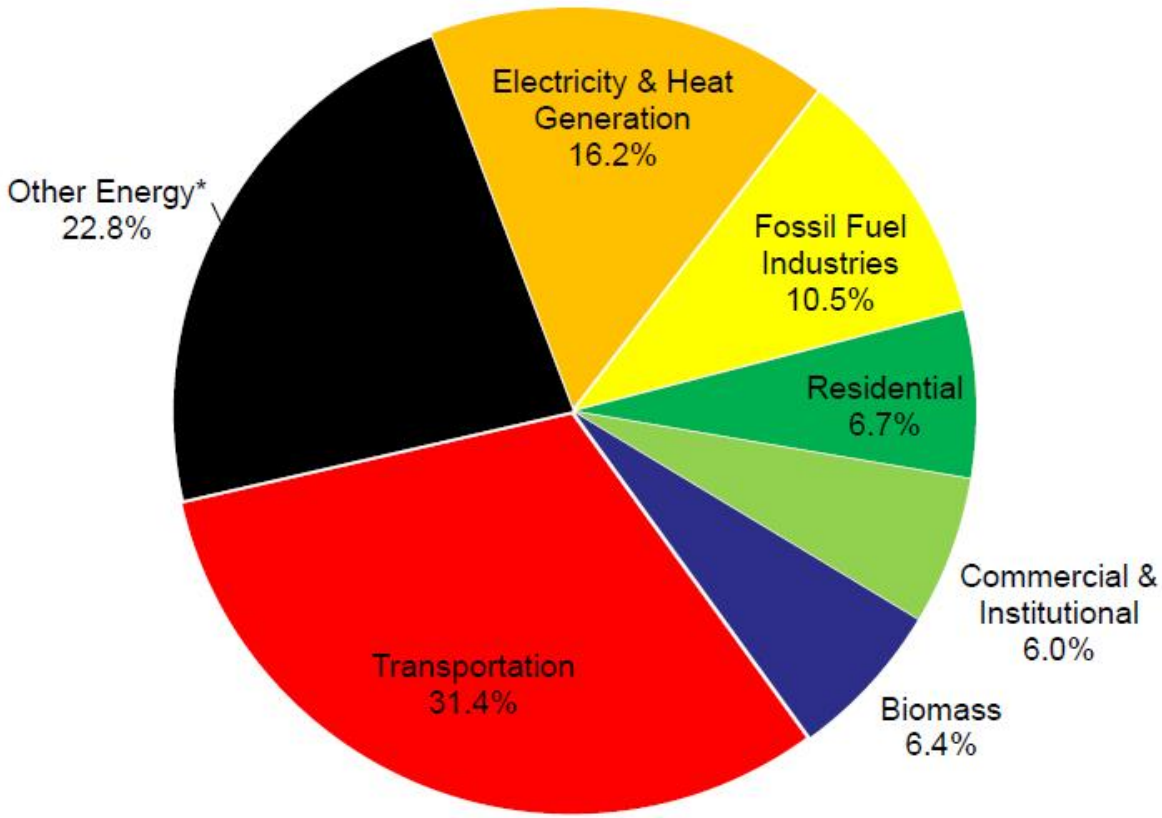


Note: Emissions do not include the following sectors: land use change and forestry, solvent and other product use (negligible amounts) and biomass

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

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

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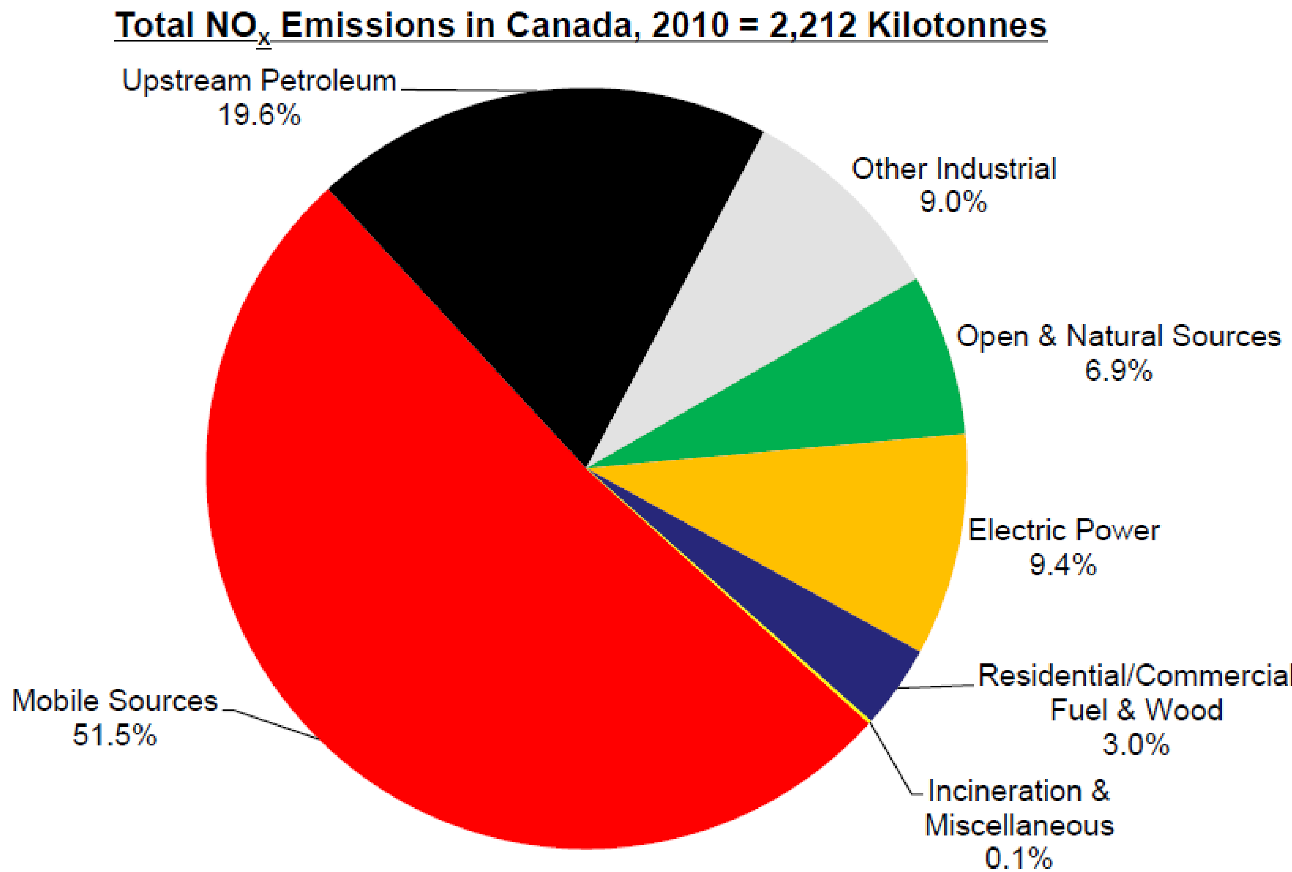
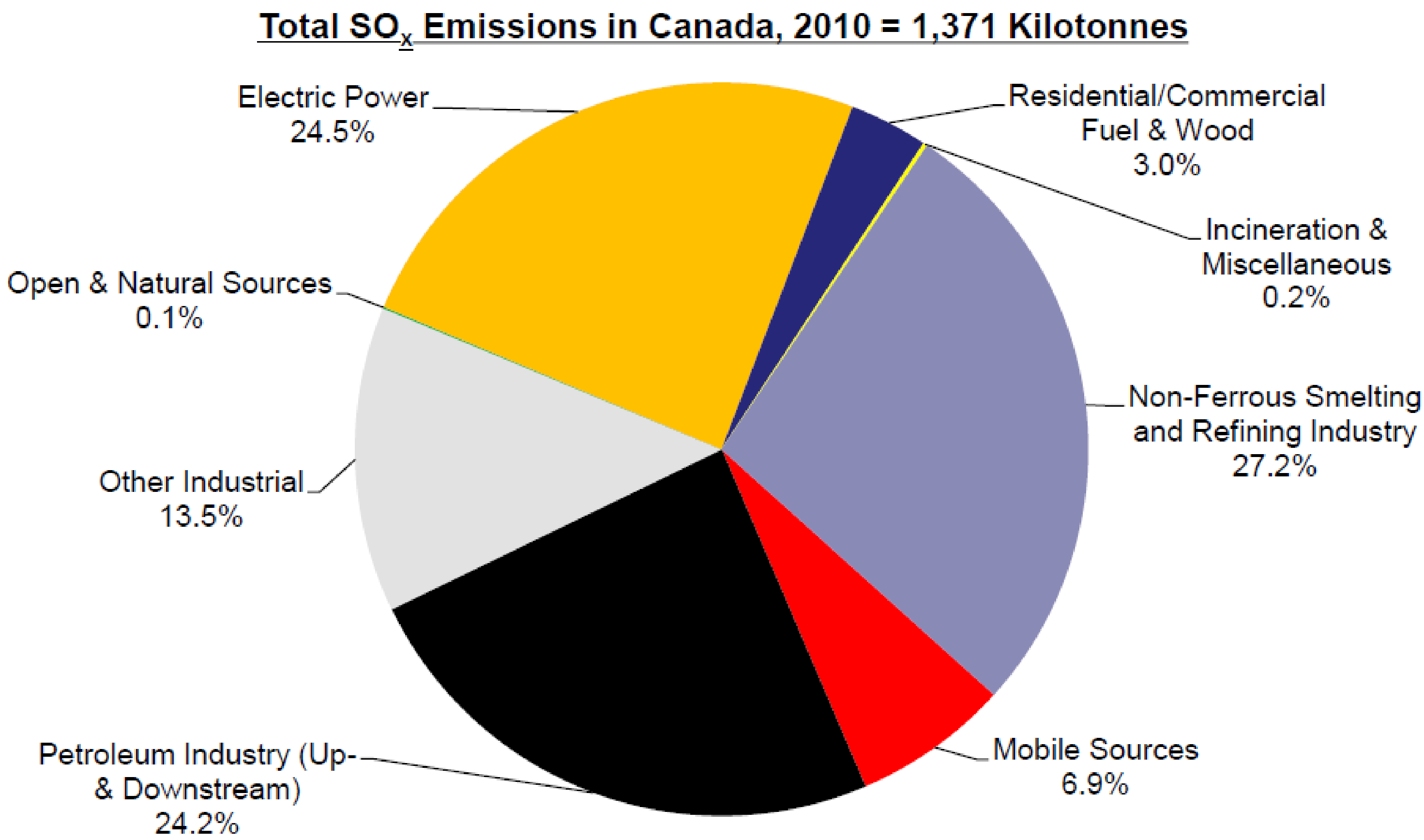
Nitrogen Oxide (NO_x) Emissions in Canada by Sources, 2010



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

Retrieved February 24, 2012

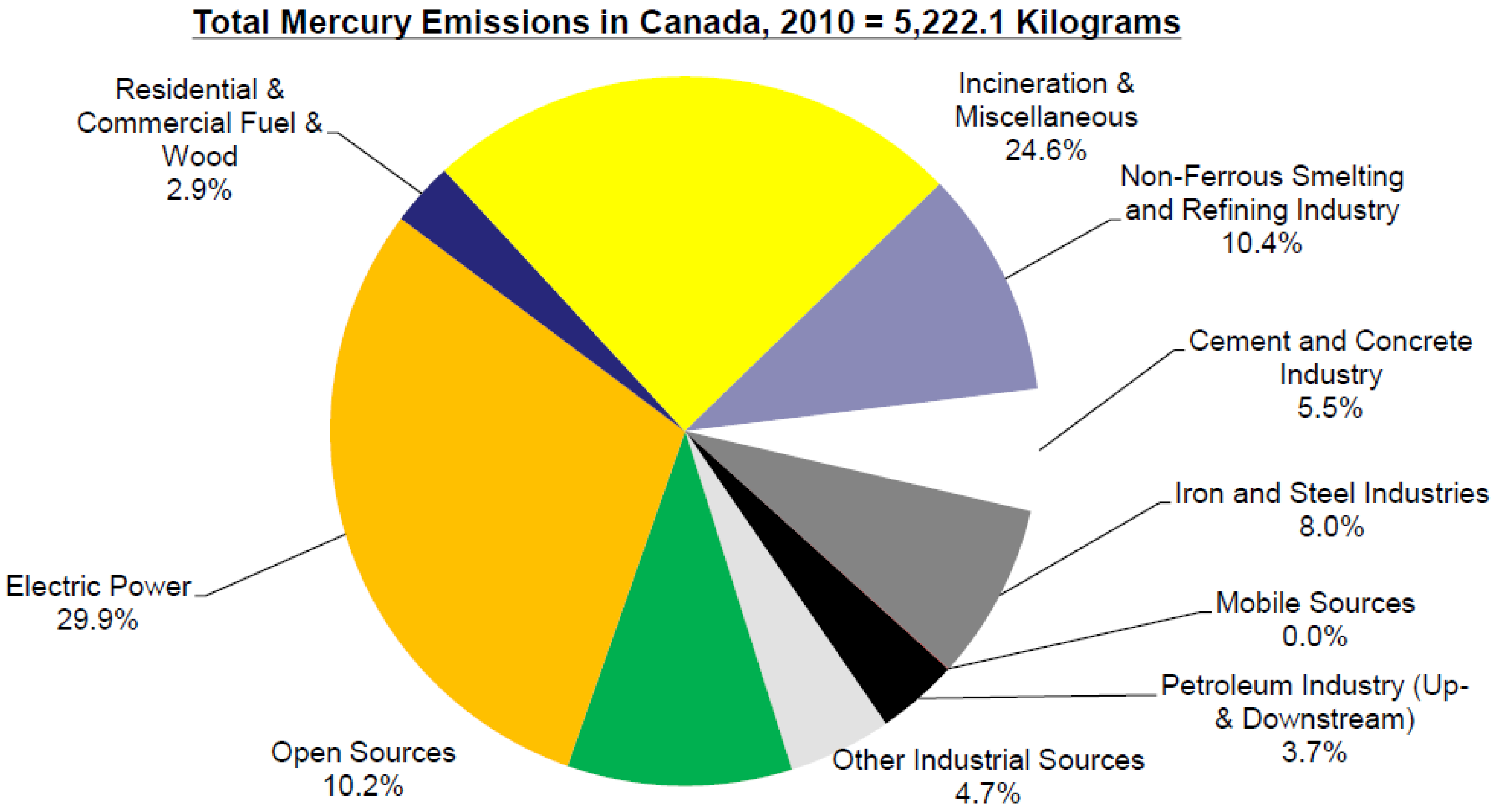
Sulphur Oxide (SO_x) Emissions in Canada by Sources, 2010



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

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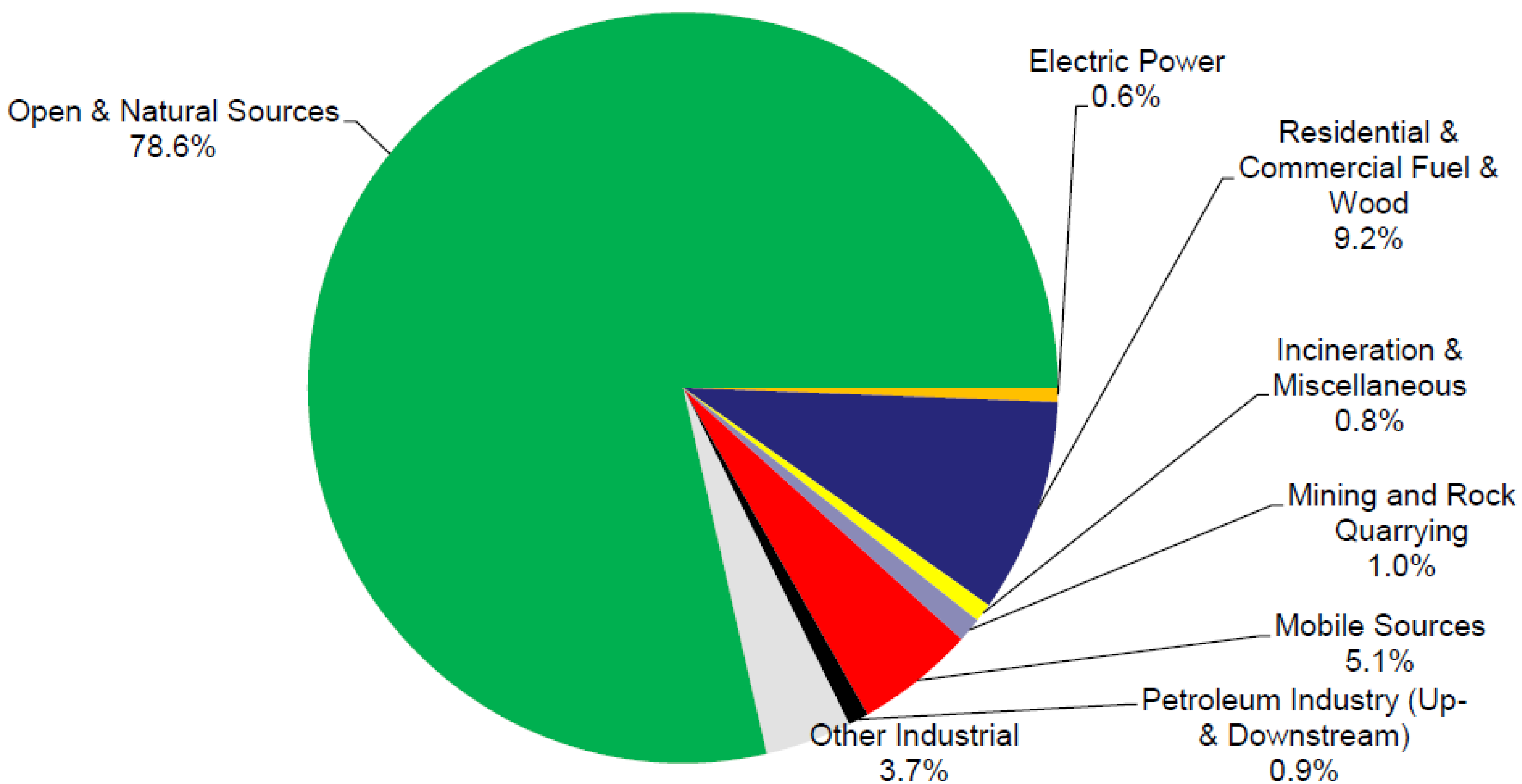
Particulate Matter ($PM_{2.5}$) Emissions in Canada by Sources, 2010

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

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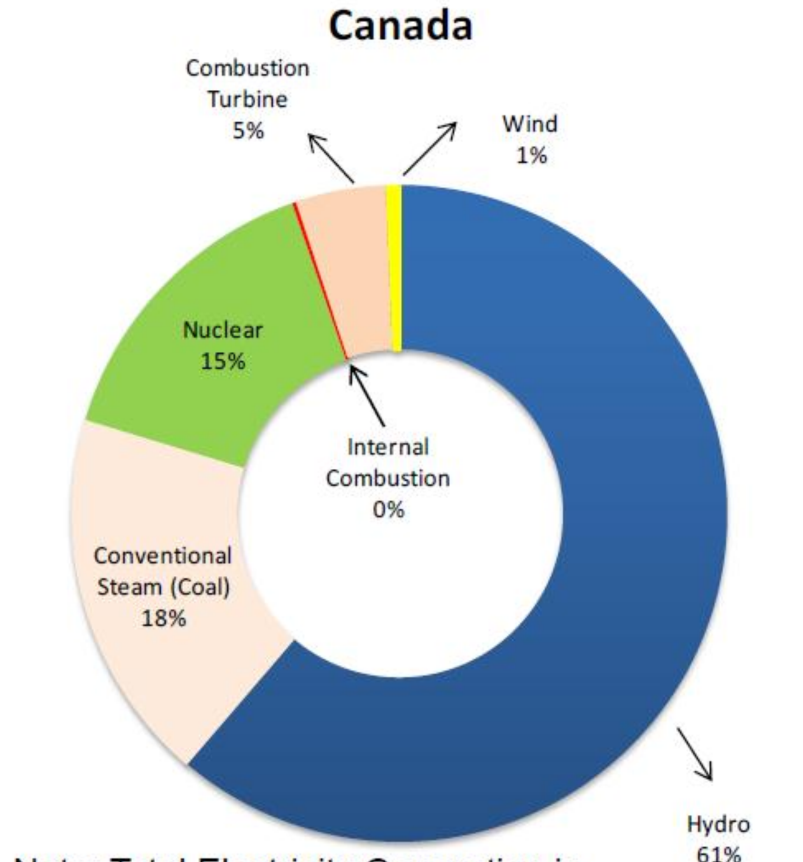
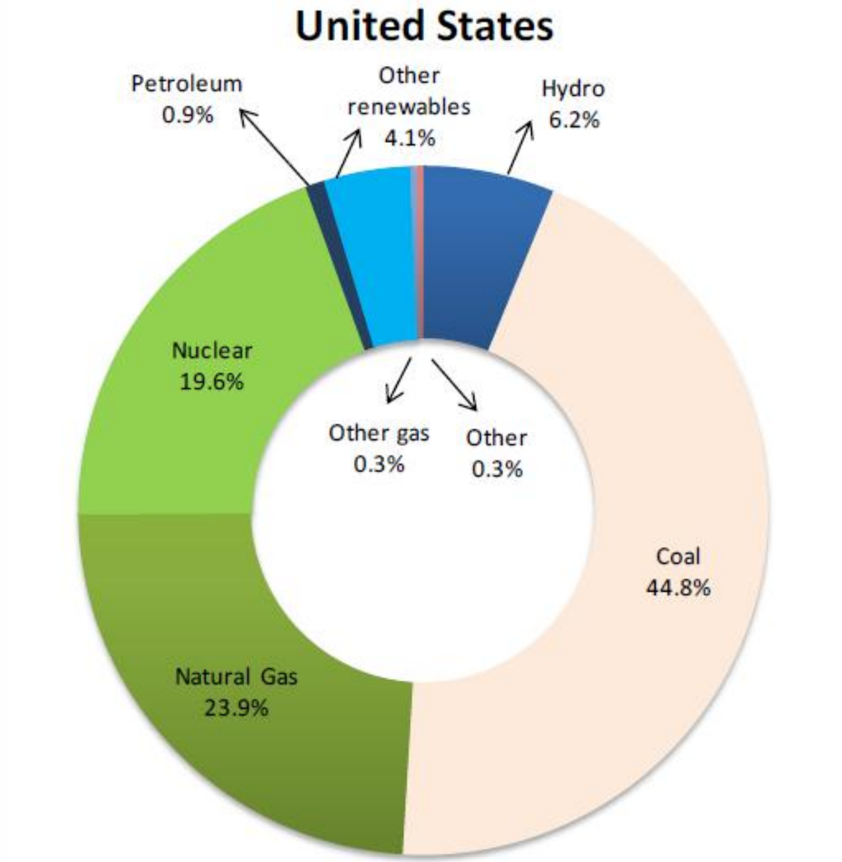
Electricity Generation in the US and Canada by Fuel Type,[1] 2010

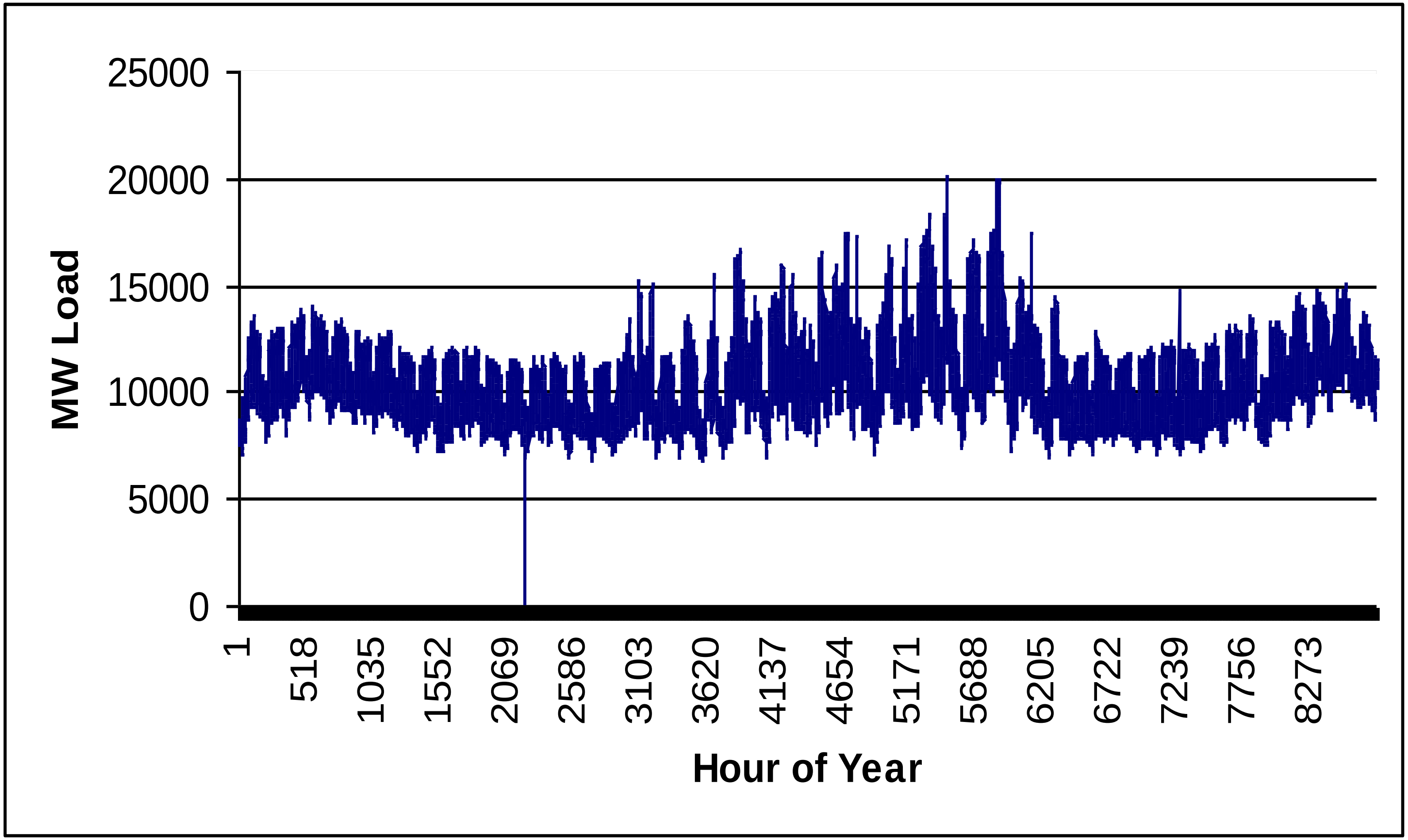


Note: Total Electricity Generation in 2010 = **511 TWh**



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

Example Yearly Electric Load



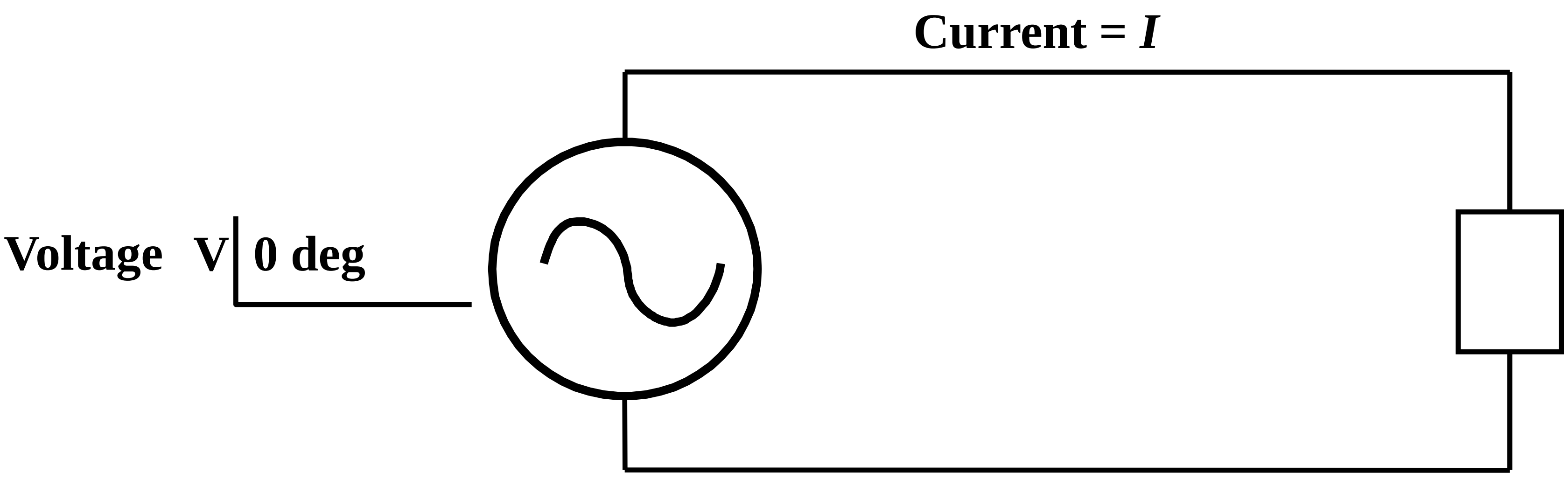
Review of Basic Electric Circuits

- 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

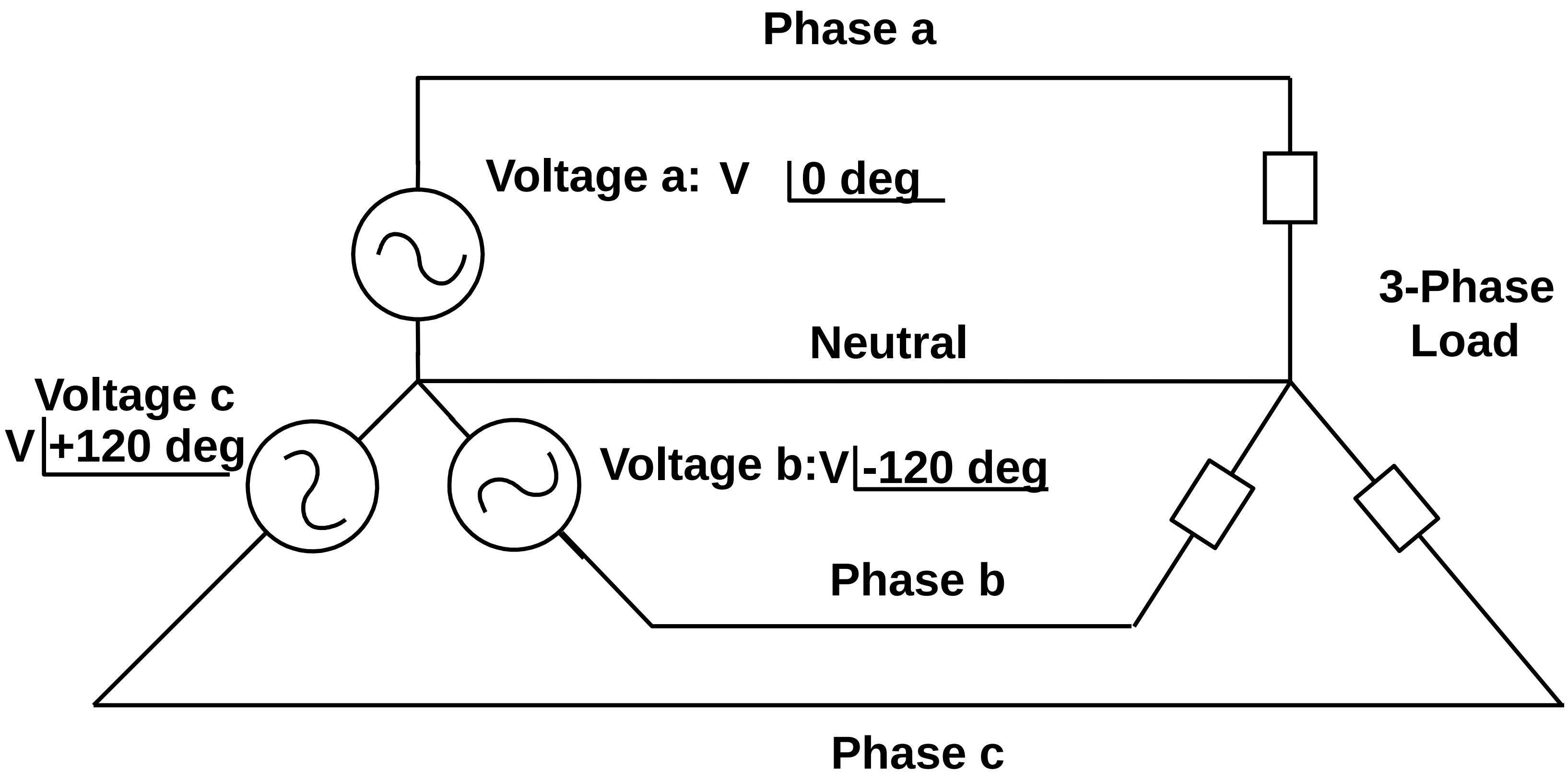
- Ampere’s Law
- Flux Concepts
- Ferromagnetic Materials
- Inductances
- Faraday’s Law
- Leakage and Magnetizing Inductances.

Single-Phase Circuit



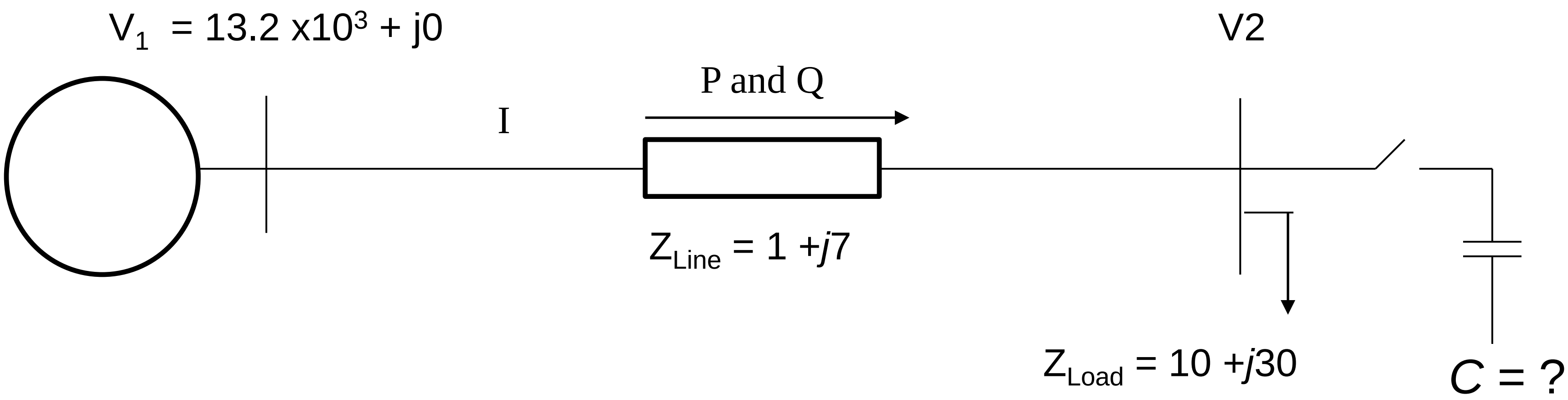
This circuit requires 2 wires to deliver power to the load

Three-Phase Circuit



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

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.

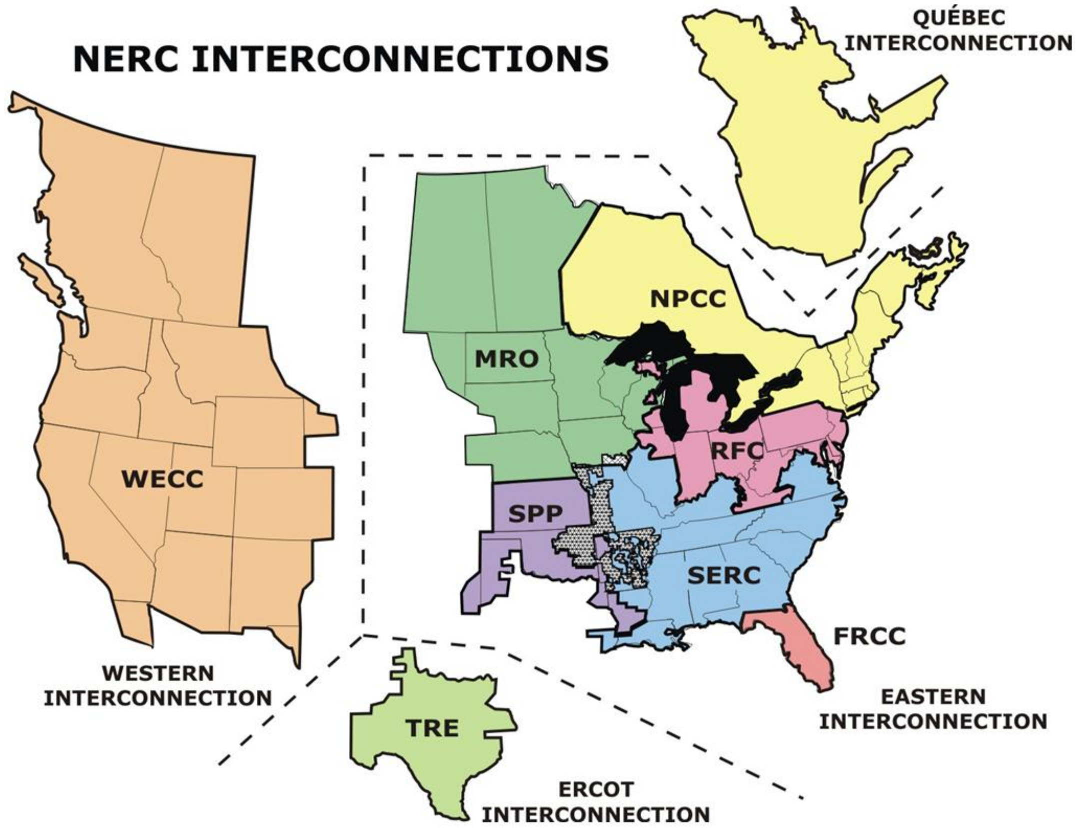
Advantages

- 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.

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!



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

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.

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.

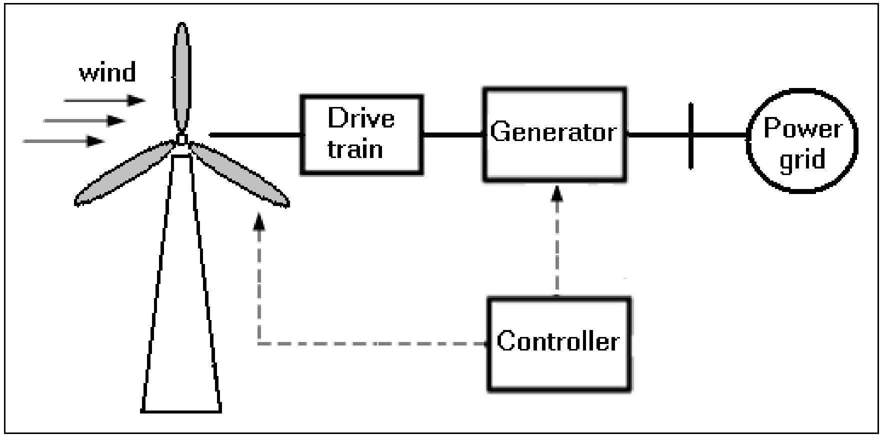
$P_{tot} = \frac{1}{2}\dot{m}V^2 = \frac{1}{2}\rho A V^3$(Rate of Kinetic Energy)

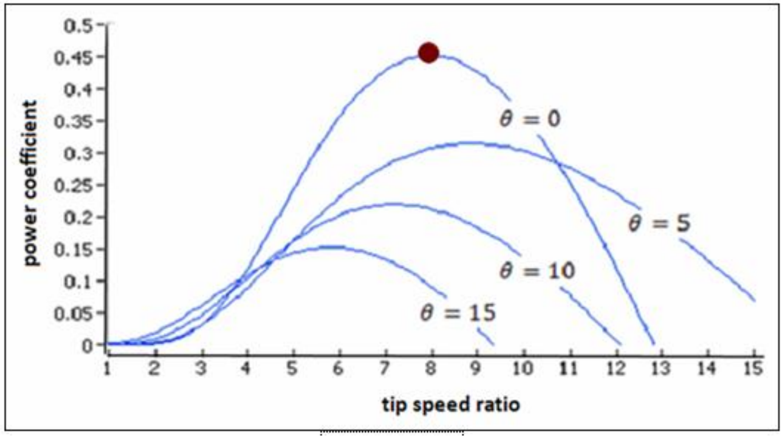
$P_w = C_p P_{tot}$

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

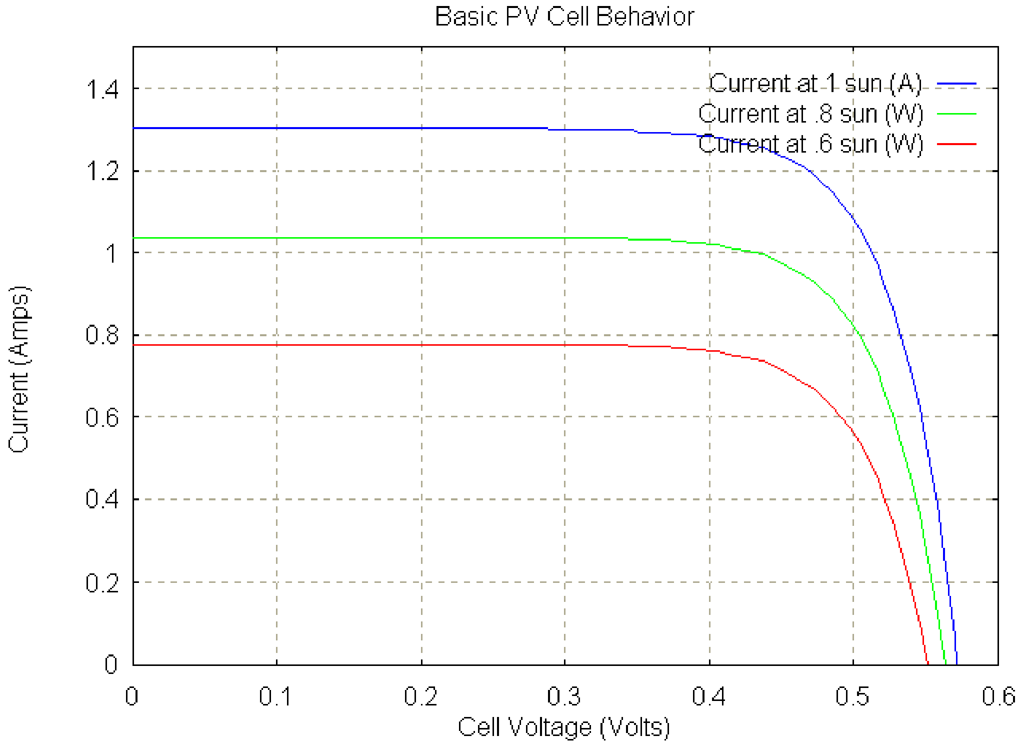
- *Θ* = Pitch angle



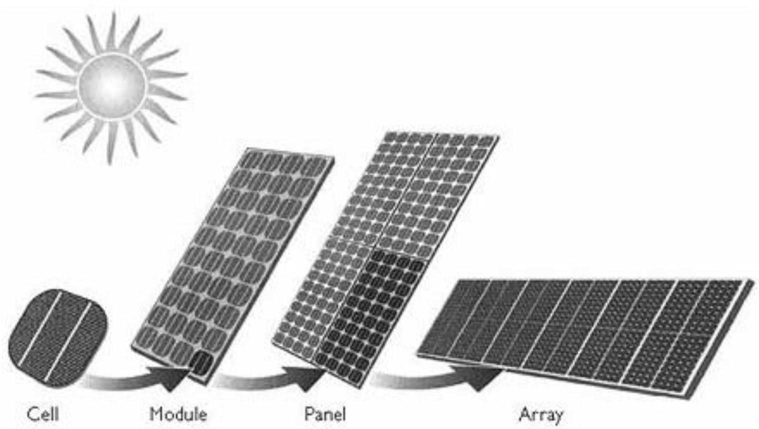


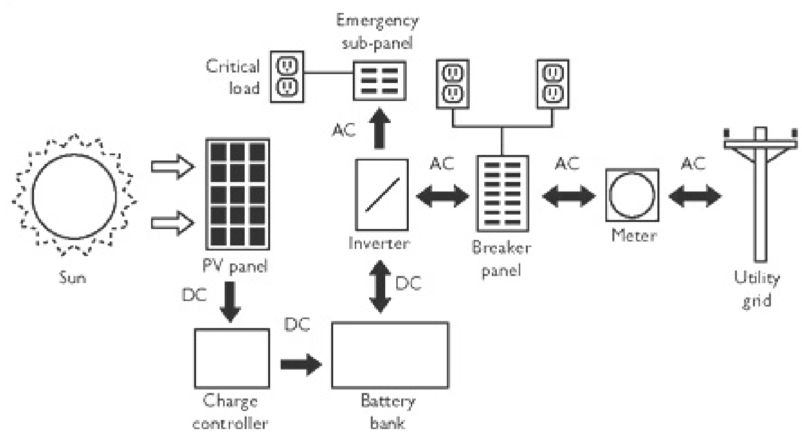
Photovoltaic Energy

- 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.



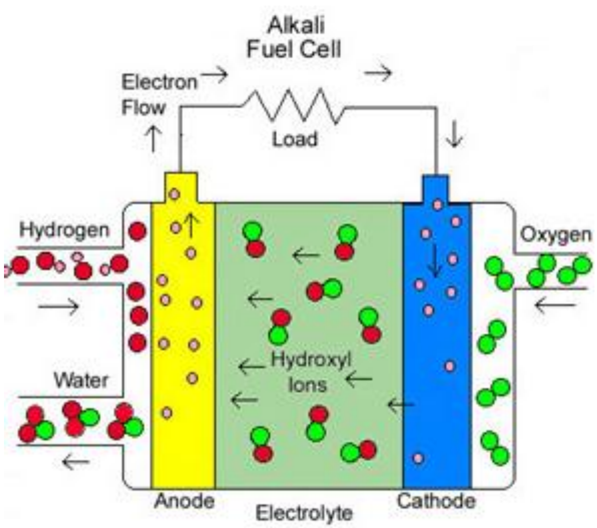
Components of Photovoltaic System





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)