Lesson 1

Introduction to Energy

Energy in Physics – Money analogy

- We can define some system (for ex: wallet, investments, checking account) and within the system, if we exchange energy between different types then the total amount of energy in that system doesn't change.
- If something from outside puts energy into the system, the total energy of the system will increase.
- If the system loses energy to something outside, the total energy of the system will decrease.

Work and Energy in Physics

- The words "energy" and "work" mean different things in different contexts.
  - **Energy:** Ability to do work
  - **Work**: transfer of energy
- This is somewhat of a circular definition; however, it is sufficient to explain many physical systems and make calculations and predictions about the natural world. It is one of the most important concepts in physics.

Work

- The word means many things in everyday life.
- We defined work as: the transfer of energy.
  - Work = Force x Distance

- Example: if a guy pushes a box across the floor, he is transferring energy into the box. Let's say 2 people each have 1kg box.
  → First person lifts the box up 2 meters then puts it back on the floor.
  - Distance is 2 meters = person did work on the box.

  → Second person holds the box for 1 hour without moving.
  - Although there is a force being applied, no work has been done on the box since it has not moved.

Types of Energy

Chemical: energy stored in certain chemicals or materials that can be released by chemical reactions

- Ex: The burning of wood, paper, coal, natural gas, or oil releases chemically stored energy in the form of heat energy. Also, charged electric batteries or food in your stomach.

Kinetic: the energy an object has due to its motion.

- Depends on the mass of the object and the velocity of the object.
- Also called "Mechanical energy"
    - $K = \frac{1}{2} mv^2$
        - K: Amount of kinetic energy
        - m: Amount of mass
        - v: Velocity of object

Thermal/Heat: the energy associated with random molecular motions within any substance.

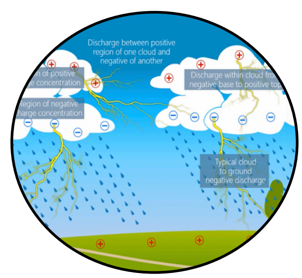
- Increases of heat energy = temperature increase.
- Decreases of heat energy = temperature decrease.
- Heat: the average kinetic energy in the molecules is higher than in colder temperatures

Potential: energy associated with the position of an object when some force is acting on it.

- Most common example: gravitational potential energy
- The higher up an object is, the more gravitational potential energy it has.
- Also called "mechanical energy"

Electric: energy that is stored by charges (+/-) in their electric fields.

- Nothing can be seen with the eye, but the energy is stored and can be released as other forms of energy
- Ex: In storm clouds electrical energy is stored between the ground and clouds which acquire opposite charges.

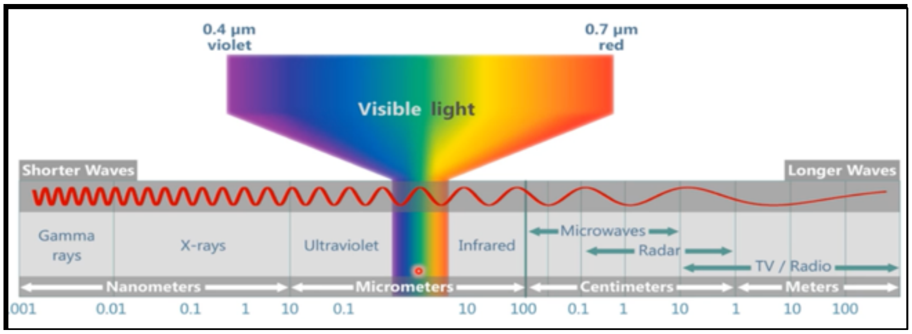


Nuclear/Mass: Einstein's theory of special relativity predicted that there is a correspondence between mass and energy.

- Mass can be converted to energy and vice versa.
- This is the important principal in looking at the energy associated with nuclear reactions.
    - $E = mc^2$
        - E: Amount of mass energy
        - m: Amount of mass
        - c: Speed of light (30 000km/second)

Electromagnetic Radiation (light): can be visible or not. It is in the form of a wave that carries energy.

- Electromagnetic radiation is in the form of a wave that carries energy



Units: How to Quantify Energy

Joule (J)

- The joule is the metric unit of energy. It has its fundamental definition in terms of force and distance. One metric unit of force (the newton) acting through one metric unit of distance (the metre) is equivalent to the expenditure of one joule of energy.
- W = F x D → Force is newton and Distance is meters

British Thermal Unit (BTUs)

- We often encounter the British thermal unit in discussions of fuel and insulation. The unit has a simple definition based on the amount of heat energy which must be given to a known amount of water to increase its temperature by a given amount. One Btu is defined to be the amount of heat energy required to raise the temperature of one pound of water by one degree Fahrenheit.

Calorie (C)

- The calorie, like the Btu, is also defined in terms of the heating of water. It is the amount of energy required to raise the temperature of one gram of water by one degree Celsius, or the amount of energy given off when one gram of water cools by one degree Celsius.
- Note: in North America, when you see amount of energy stored in food as "calories" → actually kilocalories.

Electron-Volt (eV)

- A favourite of particle physicists. This is a very small amount of energy which is useful when working with tiny, charged particles (like electrons). It is the amount of energy an electron gains if accelerated by a 1-volt electric potential.

Lesson 2

Energy Transfer and The Conservation of Energy

Transfer of Energy

Energy Flow: energy can be transformed from one type to another.

- Example 1: Santa is on the top of a hill and slides down to the bottom → Potential energy is transformed into kinetic energy.
- In a situation we can track the transfer of energy from one type to another and there can be many transfers.
- Example 2: A person starts from rest and pushes a box across the floor until he is moving quickly.
  - Scenario a: simple energy flow: Applied force: work done on box → kinetic energy
  - Scenario b: complete energy flow: Nuclear energy → Electromagnetic energy → Chemical energy → chemical energy → applied force: work done on box → Kinetic energy

> More detail: The energy produced in the sun (nuclear energy, there is nuclear fusion in the sun and this produces energy) → that energy is transported to the earth in the form of electromagnetic energy or light → then that energy is converted into chemical energy through photosynthesis in a plant → then a person eats the plant or perhaps eating an animal that ate the plant and this is now chemical energy in a different form that the person has → then he uses that chemical energy transforms that into a force that he applies to the box and there's work done on the box an off the box goes with some → kinetic energy.

Conservation of Energy

Law of conservation of energy:

- The total energy in an isolated region (or "system") cannot change.
- Isolated system: energy can neither enter nor escape the system.
- The total amount of energy is conserved, it can be transferred from one form to another, but not created or destroyed.
- Note: this is not the same thing as "conserving energy" in the context of things like turning off lights or insulating your house in order to reduce energy use.
- In a closed system energy is conserved, if it is not closed energy is escaping or entering the system.
- The only true closed system is the entire universe.

Scenario a: Light bulb attached to a battery in a perfectly insulated opaque box (isolated system)
What is the energy flow?
Chemical → Electrical → Thermal → Electromagnetic

Where does that energy go?
Decrease in Chemical, Increase in Thermal and Electromagnetic

Scenario b: Light bulb attached to a battery in a box with the lid open (no more conservation of energy).
What is the energy flow?
Chemical → Electrical → Thermal → Electromagnetic

Where does that energy go?
Decrease in Chemical, Increase in Thermal and Electromagnetic

Power

This is another term that has many meanings in language and one specific, well defined meaning in physics.

- Power is the rate at which energy is consumed or produced (amount of energy per time).
- Metric unit is watts (W) which is joules per second (s).
  - Power = Energy / Time

Scenario 1: Appliances that heat up tend to be the highest power. A hairdryer is approx. 1500W. How much energy is used by a hairdryer in 5 minutes?
= (1500J/s) x (300s)
= 450,000J or 450kJ

How does that compare to a TV? (a Tv is about 20W)
= (20J/s) x (300s)
= 6000J or 6kJ

Scenario 2: Imagine a motorcycle accelerates from a stop sign to a speed of 50km/hr. There is power being produced and power being consumed. Explain in terms of energy increase and decrease.
= Produced: Decrease Chemical Energy (gas)
= Consumed: Increase Kinetic Energy (motorcycle and rider)

Lesson 3

Thermodynamics, Heat Engines & Power Generation

Laws of Thermodynamics

1. The change in internal energy of a system equals the net heat transfer into the system minus the net work done by the system.
   - This is the same as the principle of conservation of energy.
     - Example:

2. The second law deals with the direction taken by spontaneous processes.
   a. Many processes occur spontaneously in one direction only – that is, they are irreversible.
   - Spontaneous event: just happens randomly, you don't make it happen.
     - Example 1: We have a hot and cold piece of metal. If you stick then together, you have heat transfer and both pieces of metal will eventually become the same temperature. However, if you take 2 pieces of metal that are the same temperate, there is no spontaneous process.
     - Example 2: A car is driving along, and someone hits the breaks. You then lose energy in form of heat from pressing the breaks.
     - Example 3: You can shoot air out of a compressed bottle of air, but you can't put air back into a compressed bottle.

   b. Heat (or energy) transfer occurs spontaneously from higher to lower temperature bodies, but never in reverse.
     - Example: A glass of ice water. There is a spontaneous energy transfer from the water and the ice. The ice heats up and melts, whereas the water cools down from the ice. This only happens in one direction, hot water → cold water.
   - Entropy: a measure of the disorder (or randomness) of a system.
     Example: You have a box filled with balls that are ordered in a specific way. Green on the bottom, blue on the top. If you shake the box, then you will have less order since everything will get mixed up.
     - Less order = High entropy
     - More order = Low entropy

*Restating the Second Law of Thermodynamics: in an isolated system the entropy of the system, increases over time.
So what? Why might we care about entropies?
Since the total entropy of a system cannot decrease, this limits the amount of useful energy available.

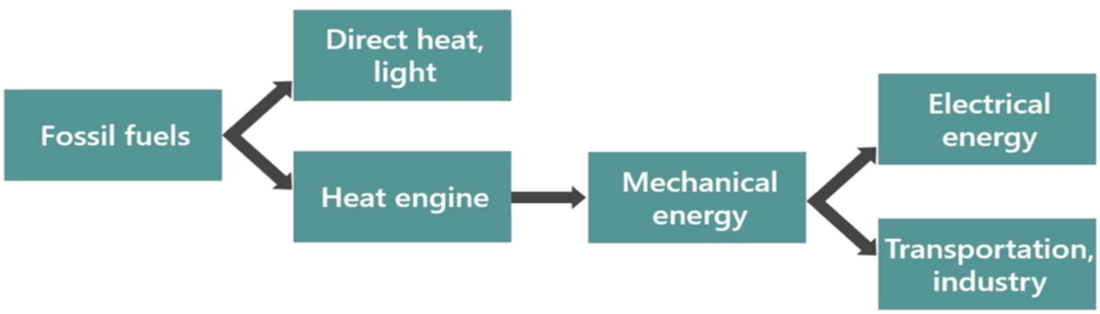
- Initially the system is more ordered, energy stored in the battery and cool box.
- Later, there is less energy in the battery and there is more thermal energy (random motion of molecules) in the box.
- We can't put the energy back into the box.
- The total energy of the system is the same, but there is less useful energy.

More info on the laws of thermodynamics:
https://www.youtube.com/watch?list=PLbnrZHfNEDZxmZmL3fZHPTeoUO8amBox2&v=mGDJO2M7RBg

Heat Engines

Mechanical equivalent of heat

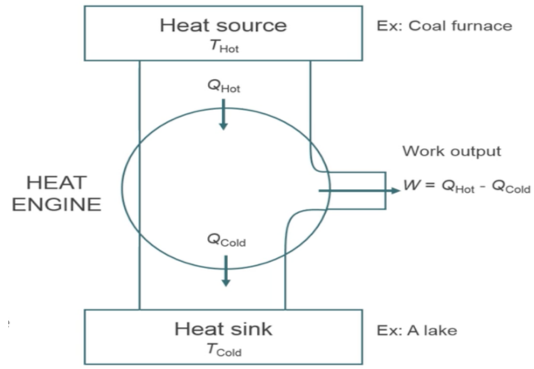
- The heat energy released by a burning single match is about the same amount of energy required to lift a pint of beer up to the top of Montreal's tallest building.
- We must capture this heat energy and convert it into mechanical energy.



Energy content of fuel

- When we burn hydrocarbons heat energy is released through 2 chemical reactions.
- This leaves us with water, carbon dioxide, and thermal energy.
    - **$C + O_2 \rightarrow CO_2$ + heat energy**
    - **$H_2 + O \rightarrow H_2O$ + heat energy**
- Example: Burning heptane
    - $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$ + 1.2 million calories per 100g of C_7H_{16}.
        - C_7H_{16} = heptane
        - $7CO_2$ = carbon dioxide
        - $8H_2O$ = water
        - 1.2 million calories per 100g of C_7H_{16} = heat of combustion

Heat engine



- Any device that can take energy from a warm source and convert a fraction of this energy to mechanical energy.
- It relies on a temperature difference between the heat source (hot) and the heat sink (cold).

Efficiency

- The efficiency of a heat engine tells us how much of the input heat energy is turned into useful mechanical work.
- Example: if for every 1000J of energy put into the heat source, 50J is converted to mechanical energy, the efficiency is:
    - Efficiency = (Work done / energy put into the system) X 100
    - Efficiency = (50/1000) X 100 % = 5 %
- As a result of the second law of thermodynamics, it is not possible to turn all of the input energy into mechanical energy.
    - French physicist *Nicolas Leonard Sadi Carnot* proved that the best efficiency possible by a heat engine is:
        - Efficiency (best) = (1 - T cold / T hot) X 100 %

Note: we must use the Kelvin temperature scale which is relative to absolute zero (-273 degree C)
→ 0 degree C = 273k → C → K = add 273

Example:

- Typical temperature in a coal fired electric power plant might be 825K in the boiler (source) and use a cold-water cooling tower (sink) at 300K. What is the efficiency that could ever be possible in this type of power plant?
  = Efficiency (best) = (1 – T cold / T hot) X 100 %
  = **Efficiency (best) = (1 – 300/825) X 100 %**
  = **64 %**

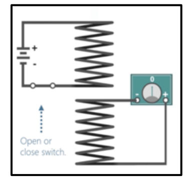
Generation of Electricity

Faraday

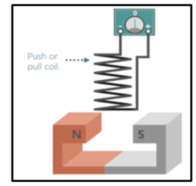
- After discovering that currents can produce magnetic field, people experimented to see if magnetic fields could produce currents.
- *Michael Faraday* (1791-1867) was trying to produce a current with a magnetic field, but it was not working. He noticed that the current was produced for a short time when the current producing the magnetic field was switched on or off. Therefore, he deduced that it

could be changing magnetic fields that produce currents (he did a series of experiments to investigate).

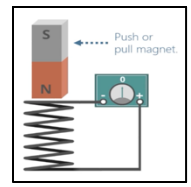
Faraday's Experiments



1. Opening/closing a battery powered switch will create momentary current.



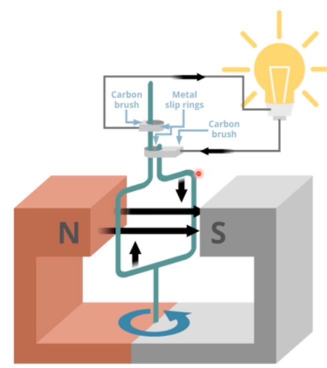
2. Pushing the coil into the magnetic field or pulling it out momentarily creates a current.



3. Pushing a bar magnet into a coil or pulling it out momentarily creates a current.

Faraday's Law of Induction

- This law describes how changing magnetic fields throughout a wire coil results in an electrical current through that coil.



Electrical Generator

- Through the process of electrical induction mechanical energy can be transformed into electrical energy.
- By turning the wire loop (which takes mechanical energy), the magnetic field passing through the look changes which generates a current (electrical energy).

Generation of Electricity

- Most of the electricity we use is from a conversion of mechanical energy to electrical energy using a generator.
- The mechanical energy can come from many sources: burning fossil fuels to turn turbines, wind, water.

Power Plants

- Typical efficiency of an electrical power plant for converting chemical energy in the fuel into electric energy. The best new plants now achieve nearly 42%.

*More info on Electricity Generation: https://www.youtube.com/watch?v=20Vb6hlLQSg

Lesson 4

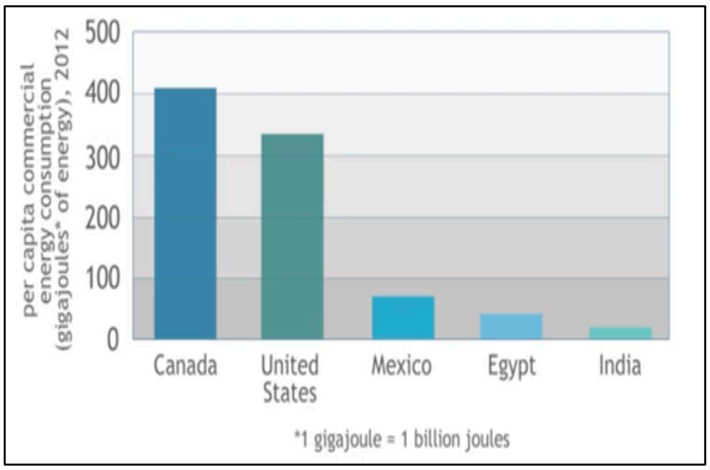
Energy and the Earth

Energy Consumption

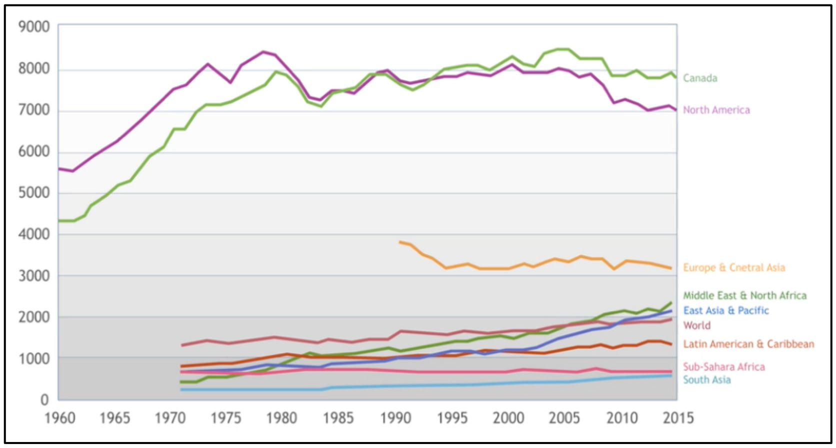
Energy used per Capita

- The amount of energy used on average by each person in a country.
    - Total amount of energy / the # of people in that country
- The amount of energy used per person varies greatly from country to country.
- In general, wealthier countries use more energy per person.
- Approximately 20% of the world's population live in highly developed countries.
- Canada uses more energy per person than the US, why?
    - Canada = big cold country = transportation/heating cost are different

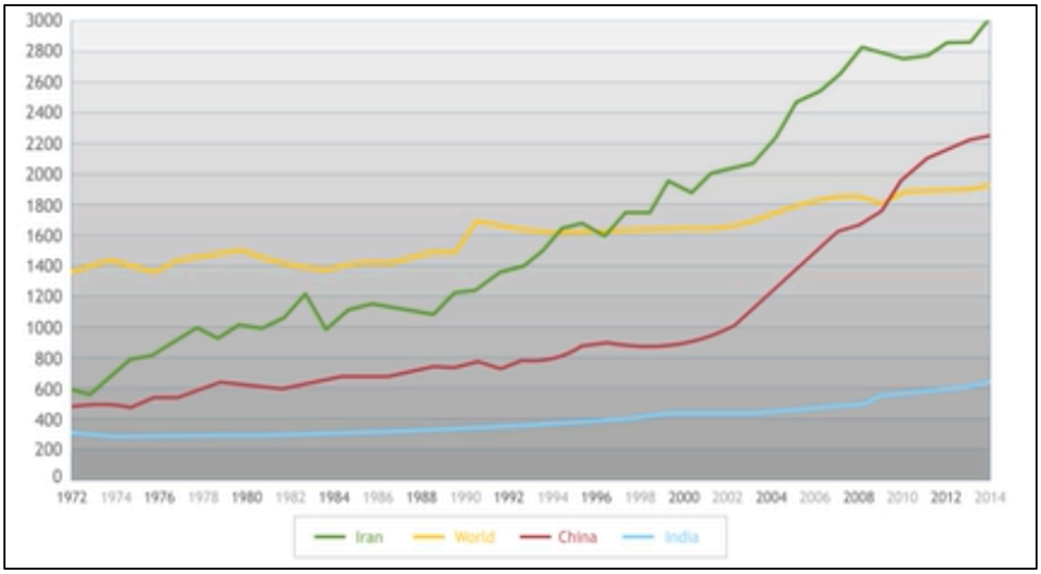
Energy used per capita in 2012



Energy used per capita by year

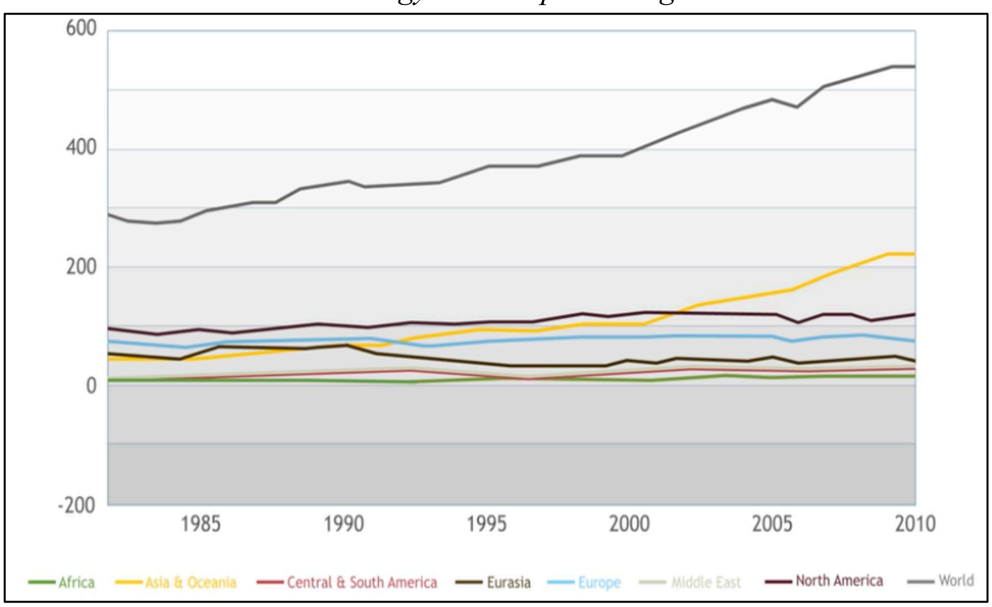


Some Rapid Growth



- Yellow: World Average
- China has doubled their energy use
- India: 40% increase in energy use

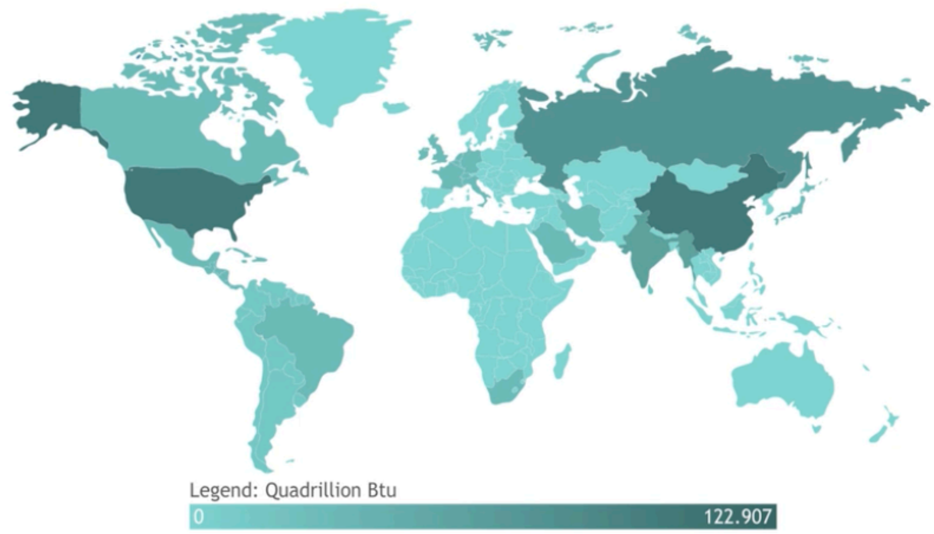
Total Energy Consumption: Region



- Units are in Quadrillion BTU
- Asia & Ocean are increasing rapidly because of china

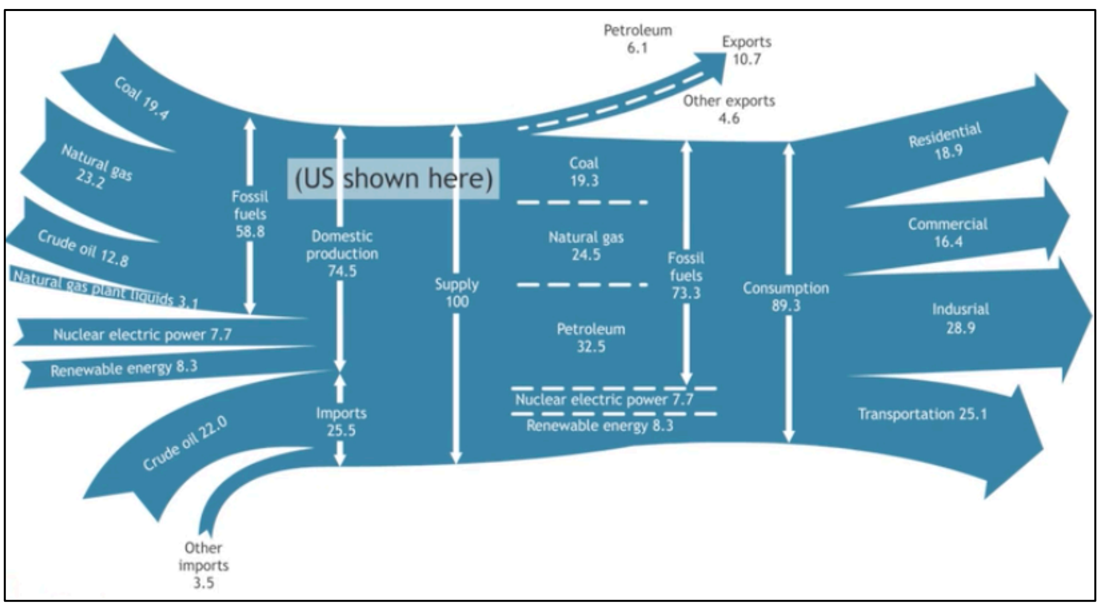
Total Energy Consumption: By Country

China	123
United States	98
Russia	31
India	25
Japan	19
Canada	14
Germany	13
Brazil	13
Korea, South	11
Iran	11
Saudi Arabia	10
France	10



- The darker colour shows more energy consumption per year
- Here, we multiply by the amount of people in the country, therefore China, US and Russia are top 3

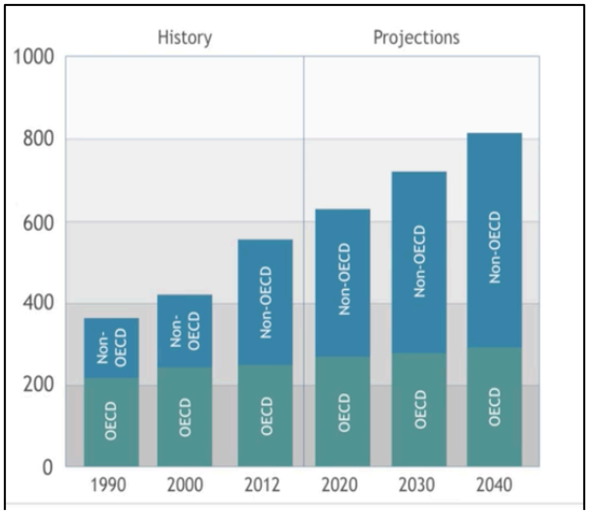
Energy Used Per Capita in the US

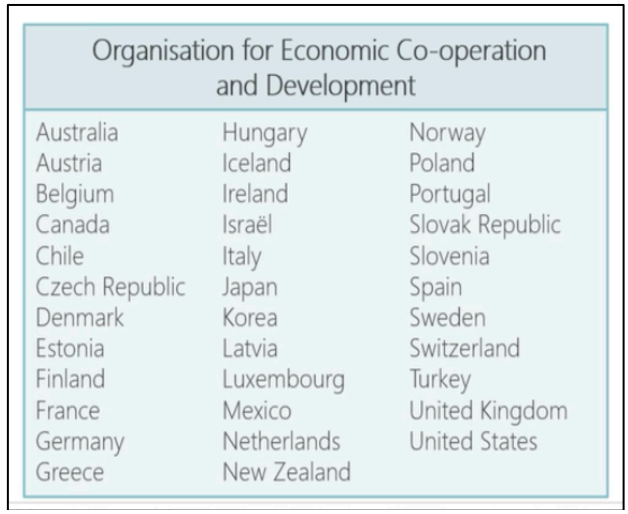


- Left side = energy production
- Right side = energy consumption
- The exact numbers regarding how energy is consumed varies from country to country
- In general, developed countries have similar distributions as shown here for the US
- The production varies more for each country

Projected Energy use for the future

- Projections for world energy consumption show an increase overall.
- OECD countries (mostly considered highly developed) show a slower rate of growth than non-OECD countries.

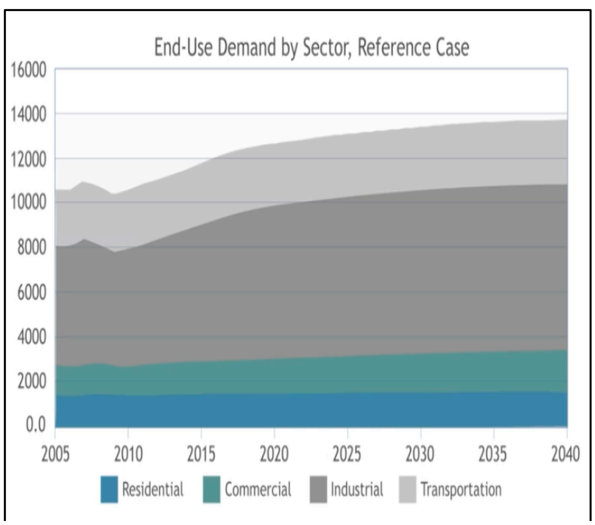


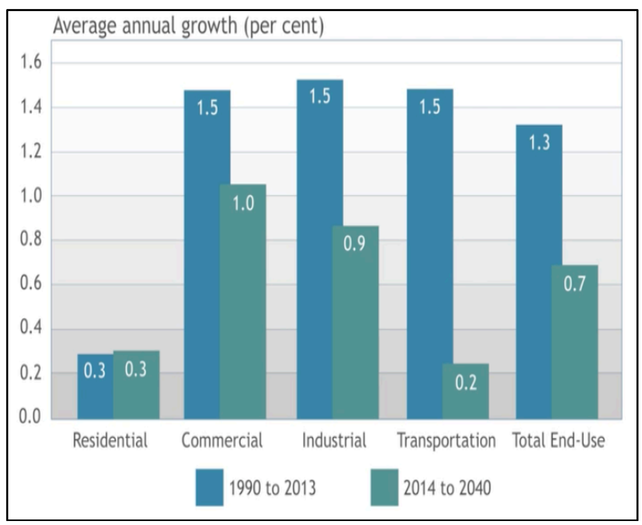


Organisation for Economic Co-operation and Development		
Australia	Hungary	Norway
Austria	Iceland	Poland
Belgium	Ireland	Portugal
Canada	Israël	Slovak Republic
Chile	Italy	Slovenia
Czech Republic	Japan	Spain
Denmark	Korea	Sweden
Estonia	Latvia	Switzerland
Finland	Luxembourg	Turkey
France	Mexico	United Kingdom
Germany	Netherlands	United States
Greece	New Zealand	

Projected Energy use for Canada

- Canada shows growth similar to average OECD countries





Renewable and Non-renewable Energy

Definitions:

- Non-renewable resources: are those that could be exhausted within a relatively short time as a result of our exploiting them.
- Renewable resources: can never be consumed to completion.

Non-Renewable Resources

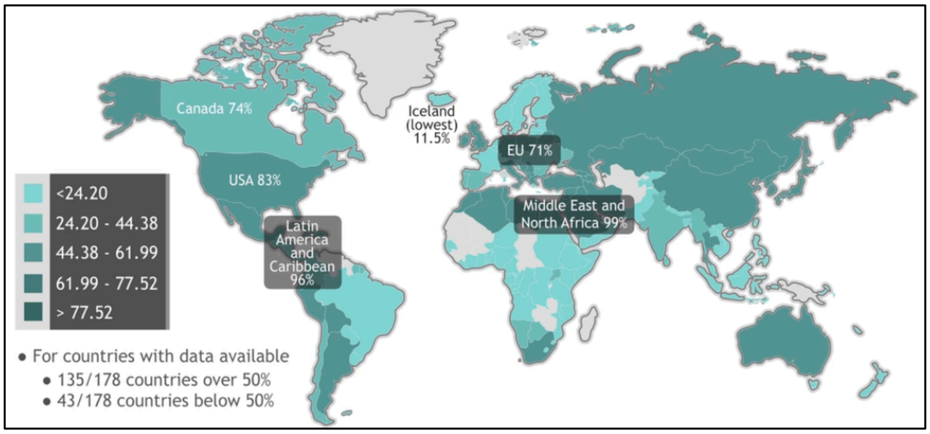
- Fossil Fuels: Coal, Oil, Natural Gas.
  - Can be depleted on a time scale of on average 100s of years.
  - Actually being produced all the time but on a time scale of 100s of millions of years.
  - You can use this much faster than it can be produced.
- Uranium 235
  - Used for nuclear fission power generation.
  - Could be depleted over several decades if used much more vigorously than they are now.
- Geothermal energy (considered both renewable and non-renewable)
  - Thermal energy we get from inside the earth.
  - The lifetime of geothermal sites varies from site to site.
  - Iceland has a lot of geothermal energy use.

Renewable Resources

- Based on solar energy
  - Direct sunlight
  - Wind currents
  - Hydroelectric (evaporation condensation cycle)
  - Ocean currents
  - Ocean thermal
  - Biomass (burning plants or trees)
- Limited only by the lifetime of the sun.
- The rate of use does not affect the lifetime of the source.
- Not based on solar energy.
  - Geothermal: can be locally depleted but will renew over 100s of years.
  - Tidal: comes from the gravitational energy between the Earth and the moon.

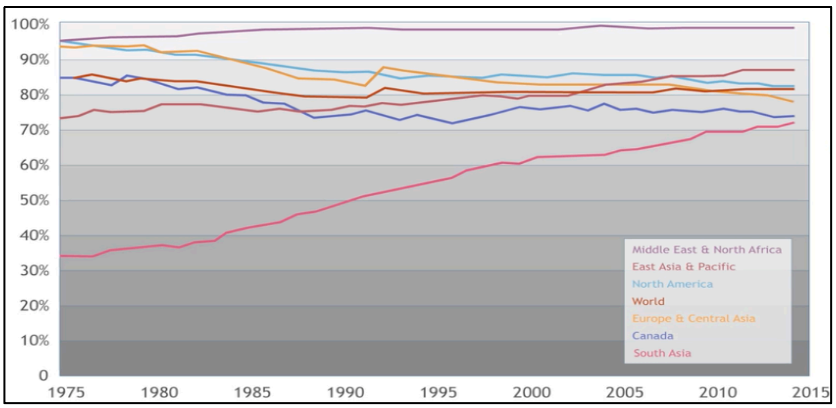
Fossil Fuel Use

Fossil Fuel energy consumption (% of total)



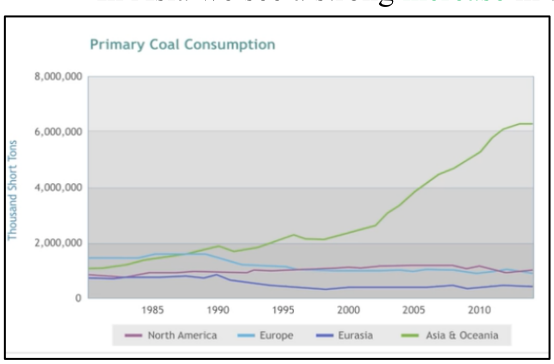
Fossil Fuel Energy Consumption

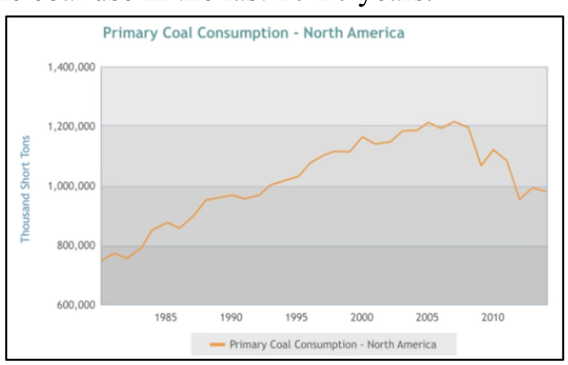
- In highly developed countries, the percent of fossil fuel consumption is decreasing.
- This does not mean that the total consumption is decreasing.



Change in Coal Consumption

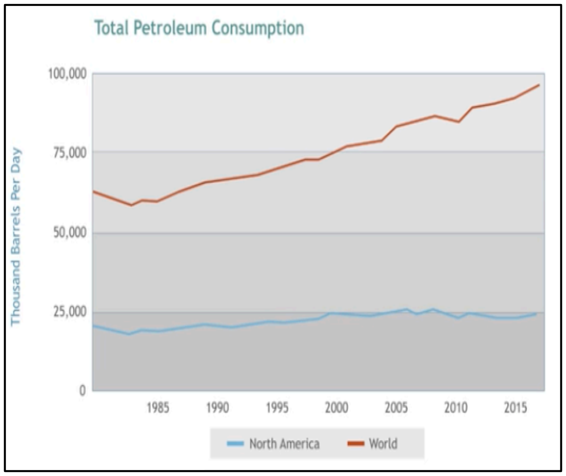
- In North America and Europe, coal consumption has been declining.
  - North America has seen a 20% decline since its peal in 2007.
- In Asia we see a strong increase in the coal use in the last 10-20 years.

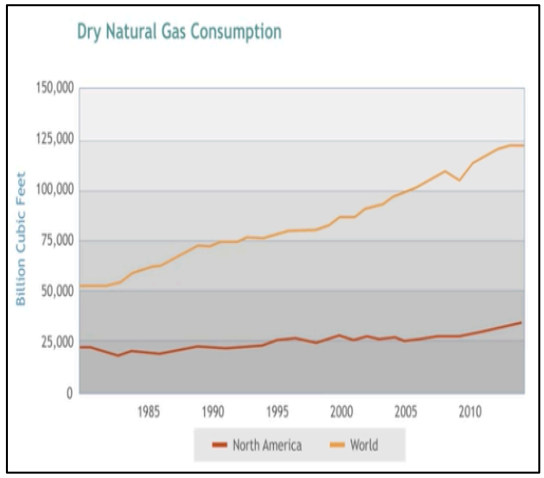




Change in Oil & Natural Gas Consumption

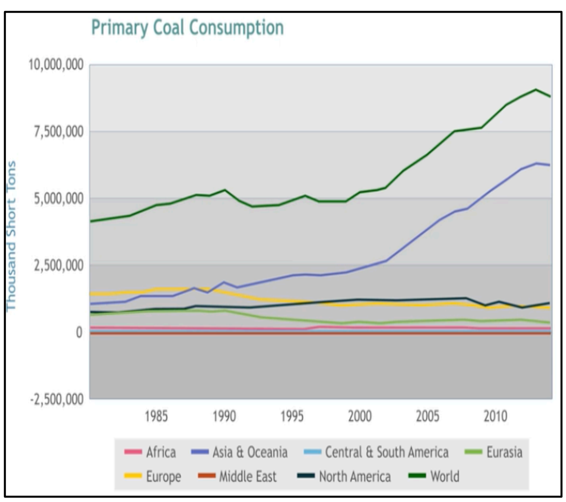
- Meanwhile in North America:
  - Petroleum consumption has plateaued.
  - Natural gas consumption has been increasing.

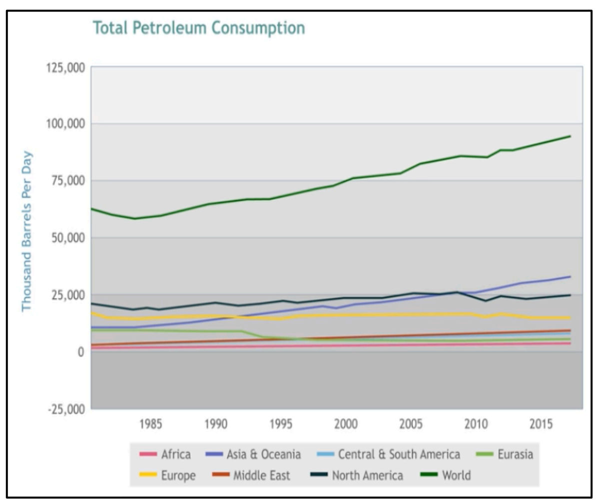




Coal/Petroleum Consumption by World Region

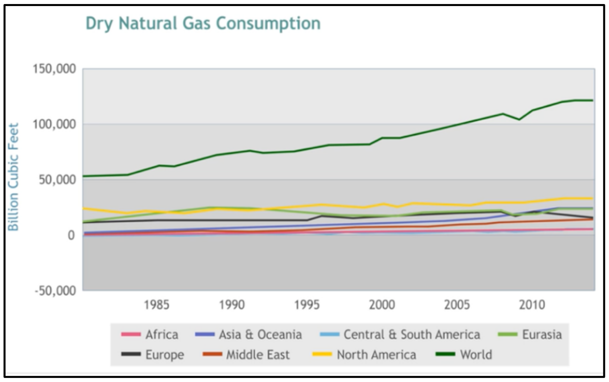
- Coal:
  - Consumption growing rapidly in Asia
- Petroleum:
  - Europe and North America still major consumers, although use has plateaued.
  - Asia has become main consumer and use is increasing





Natural Gas Consumption by World Region

- Natural gas consumption increasing in North America.
- North America highest consumer.
- Use is also increase in many regions.

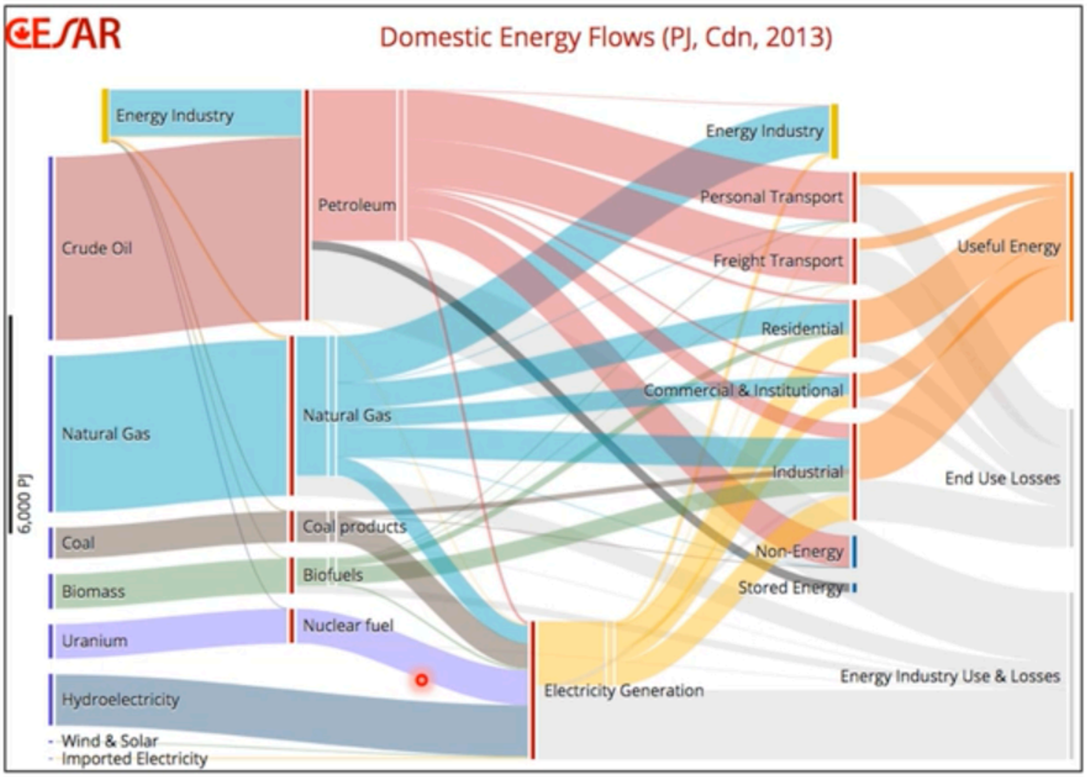


Fossil Fuel Trends

- Overall consumption is increasing.
- Almost all countries are at least 50% dependent on fossil fuels.
- Although the amount of fossil fuel used varies by:
    - Region
    - Type of fuel
- But the overall consumption of petroleum (oil), coal, and natural gas are on the rise.
    - With the exception of the very recent past for coal.

Sankey Diagram: Canada

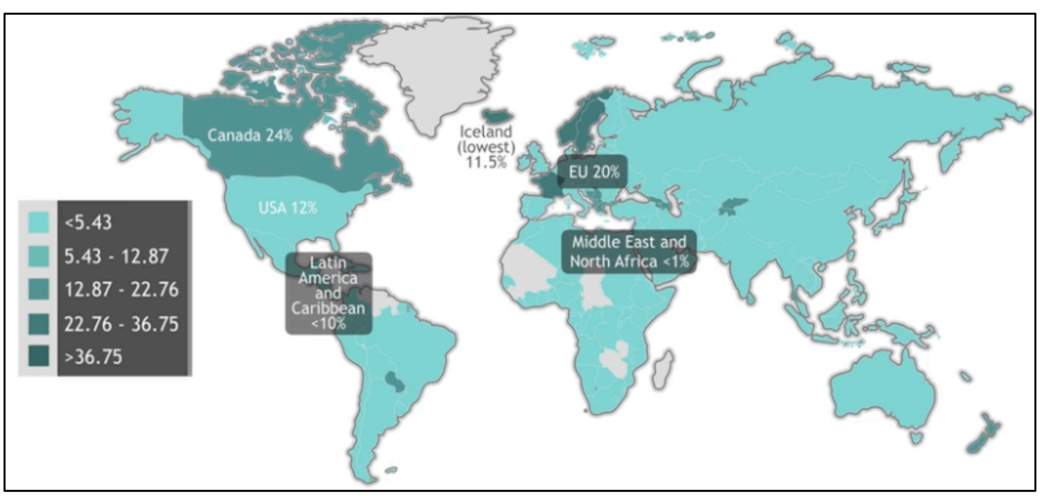
- It tracks the energy use from initial resource to final use.
- The width of each of the lines show the amount of energy.
- In Canada:
    - Coal: used mostly for the generation of electricity.
    - Oil (petroleum products): used widely except for electricity generation.
    - Natural gas: also used in most sectors (not a factor in transportation).
    - The vast majority of renewable energy produced in Canada is hydroelectricity production (bottom left on diagram).
    - Wind and solar are also used for production of electricity.
    - Biomass used is dominated by wood burning by the pulp and paper industry.



Renewable Energy Consumption

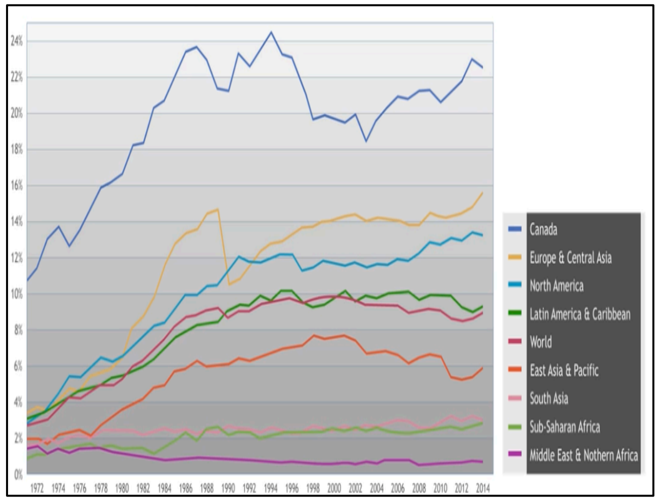
Alternative & Nuclear Energy (% of Total energy use)

- Nuclear energy is NOT a renewable source of energy
- Clean energy is non-carbohydrate energy that does not produce carbon dioxide when generated. It includes hydropower and nuclear, geothermal and solar power, among others.



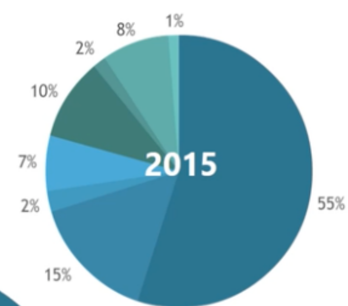
Alternative & Nuclear Energy (% of Total energy use)

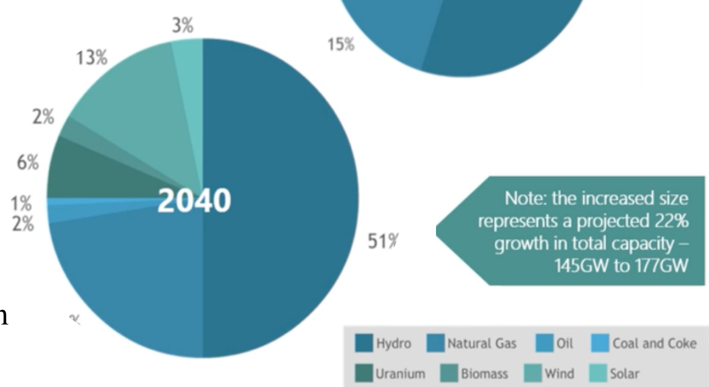
- Alternative energy is becoming more popular.
- There is a strong link between a country's income and the use of alternative energy.



Electricity Generation: Canada

- Canada's main energy consumption is fossil fuels.
- However, electrical power generation is mostly hydroelectric (55%).
- A percentage increase is projected for:
  - Natural gas
  - Wind
  - Solar
- A percentage decrease is projected for:
  - Nuclear
  - Coal (big change)





- For non-hydro renewable substantial growth is projected.
- Almost double is all sources are considered.