Sustainable Energy Transformation Technologies, SH2706

Lecture No 1

Title:
Part I: Preliminaries

Henryk Anglart
Nuclear Engineering Division
Department of Physics, School of Engineering Sciences
KTH
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Outline of the Lecture

- Objectives of the course
  - Contents and main topics
  - Expected learning outcome
- Conventions and standards
  - Units
  - Notation
  - Auxiliary data
- Sustainable energy transformation
  - Where are we now?
  - What are the major issues?

Objectives of the course

- Main topics
  - Energy supply and needs today
  - Energy resources available to humans
  - Energy degradation (exergy destruction)
  - Energy transformation technologies to extract useful work
  - Environmental and economic aspects of energy transformation
- Expected learning outcomes
  - Explain current energy supply and needs issues
  - Explain what energy resources are available
  - Explain and analyse energy degradation paths
  - Explain and analyse energy transformation technologies
  - Reflect on energy transformation sustainability

Conventions and Standards

- Units
  - SI units (new from 2019)
  - Conversion factors
- Notation
  - compromise between physics, thermodynamics, fluid mechanics, and heat transfer
  - provided list of symbols
- Auxiliary data
  - isotope data
  - steam-water properties

Energy

- Energy (lat. *energi'a*, gr. ενεργεια: action, drive) is an abstract concept, that can be traced back to Galileo Galilei time
- The concept has been further developed in XIX century, where several naturally occurring phenomena, such relationships between work, heat and motion, could be explained
- One of the fundamental observations was that of the energy preservation and impossibility of destroying or creation of it
- However, energy can be used when one form of energy is transformed into another one (or several other forms)

Energy

- Energy (E) is frequently defined as the ability to do work
- In physics, energy is a quantitative property that must be transferred to an object by doing a work on this object or by heating the object
  - thus work and heat are energy forms in transition
- Energy is a conserved quantity: the law of energy conservation states that energy cannot be created or destroyed; it can only be transformed from one form to another
  - for example, in a conservative mechanical system the total energy is conserved and consists of the kinetic and the potential energy, which can be transformed to each other

Energy Forms

- In physics we distinguish various forms of energy of macroscopic systems:
  - Internal energy
  - potential energy
  - kinetic energy
- Depending where in matter the energy is located, we distinguish:
  - chemical energy (located in atoms and/or molecules)
  - nuclear energy (located in nuclei)
- Primary versus secondary energy
  - primary energy: as present in the natural environment
  - secondary energy: various forms of energy as transformed

Energy Transformations

- Energy transformation is a process in which energy changes its form from one to another; e.g. from kinetic to thermal energy
- Certain energy transformations can be complete:
  - for example, the kinetic energy of a certain object moving with a given velocity and colliding with a stationary wall is completely transformed into heat
- However, there are energy transformations in which only limited amount of energy can be transformed from one form to another:
  - internal energy cannot be completely transformed into mechanical energy

Energy Units

- The SI unit of energy is joule, where 1 J = 1 newton x 1 meter = 1 kg m^2 s^{-2}
- For practical purposes, more energy units are in use
- Depending on the application, we can distinguish energy units applicable to:
  - microscales (energies relevant to nuclear and atomic/molecular scales)
  - mesoscales (energies relevant to a human scale)
  - macroscales (energies relevant to a whole country or the whole world)

Energy Units

Nuclear and Atomic Physics

- 1 electron volt = 1 eV = 1.60219×10^{-19} J = 0.160219 attojoule (aJ)
- 1 MeV = 10^6 eV
- Due to mass and energy equivalence, the energy can be expressed in mass units, and vice-versa
- 1 atomic mass unit = 1 amu = 1 u = $1.6605389 \times 10^{-27}$ kg = 931.494043 MeV/c^2

Energy Units
Mesoscales

- 1 cal = 4.1870 J
- 1 Btu = 1.054350×10^3 J
- 1 kWh = 3.60 MJ (megajoule)
- 1 erg = 10^{-7} J = 10 μJ (microjoule)
- 1 MWd = 86.40 GJ (gigajoule)

Energy Units

Macroscales, fuel-oriented

- 1 tonne of oil equivalent = 1 toe = 11.63 MWh = 41.868 GJ
- 1 barrel of oil equivalent = 1 boe = 0.1364 toe
- 1 tonne of coal equivalent = 1 tce = 0.70 toe
- 1 Ttoe = 1 tera toe = 10^{12} toe
- 1 Ptoe = 1 peta toe = 10^{15} toe
- 1 MWd = 86.4 GJ
  - Note: sometimes, when converting fuel-oriented units into electrical units (e.g. toe into MWh), an average efficiency of thermal generating units is applied. For example, with the efficiency 39%, 1 toe = 11.63 x 0.39 MWh = 4.5357 MWh. To avoid confusion, one should use MWh_e for the “electrical” energy

Energy Units

- Appendix E contains Tables with Energy Conversion Factors. Example below shows Table E.12. In particular, we note that 1 toe = 1.163e4 kWh = 11.63 MWh

Table E.12

Energy Conversion Factors at Mesoscale

$\downarrow \times \searrow = \rightarrow$[a]	kJ	BTU	kWh	toe	tce
kJ[b]	1	0.9478	2.778×10^{-4}	2.388×10^{-8}	3.4123×10^{-8}
BTU[c]	1.055	1	2.931×10^{-4}	2.519×10^{-8}	3.600×10^{-8}
kWh[d]	3600	3.412×10^{3}	1	8.597×10^{-5}	1.228×10^{-4}
toe[e]	4.1868×10^{7}	3.9682×10^{7}	1.163×10^{4}	1	1.429
tce[f]	2.93076×10^{7}	2.7780×10^{7}	8.141×10^{3}	0.7000	1

[a] See Table E.5 for explanation.
[b] A kilojoule (kJ) is equal to 1000 J.
[c] A British Thermal Unit (BTU) was originally defined as the amount of heat required to raise the temperature of 1 pound of liquid water by 1 degree Fahrenheit at a constant pressure of one atmosphere.
[d] A kilowatt-hour (kWh) is equal to 3.6 GJ.
[e] A ton of oil equivalent (toe) is defined by the International Energy Agency to be equal to 41.868 GJ.
[f] A ton of coal equivalent (tce) is defined by the International Energy Agency to be equal to 29.3076 GJ.

Sustainable energy transformation

- Current status
  - Statistical data on energy supply and usage
- Sustainability goals

World Energy Supply

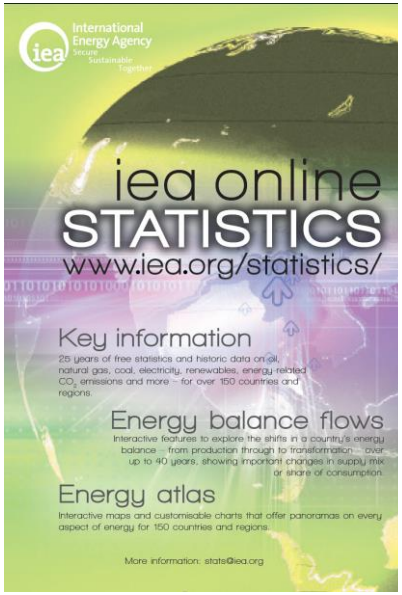
- By **energy supply** we mean extraction of the primary energy and its transformation into energy forms that are suitable for final usage

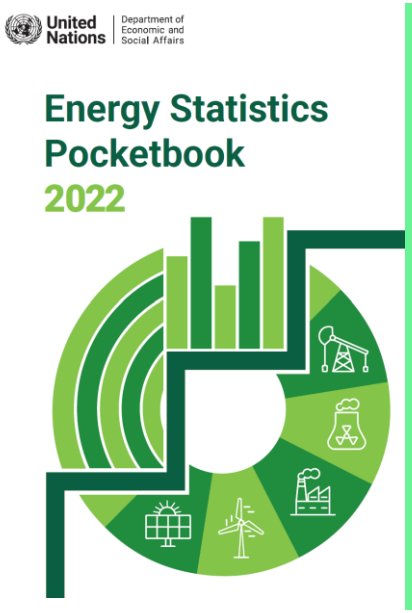
- By **energy usage** we mean transformation of useful (or secondary) energy into energy services (e.g. illumination, warm housing, food, transportation)

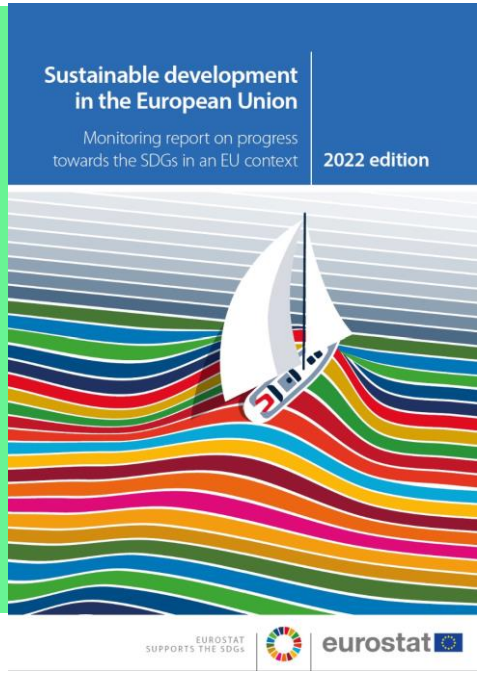
Energy Supply Chain

- Primary energy
  - crude oil, coal, uranium
- Transformation of the primary energy
  - refinery, power plant
- Energy forms proper for final use
  - fuel oil, electricity
- Energy usage
  - boiler, refrigerator, stove, electric motor, car
- Energy services
  - warm housing, food, clothes, goods, transportation

Key World Energy Statistics



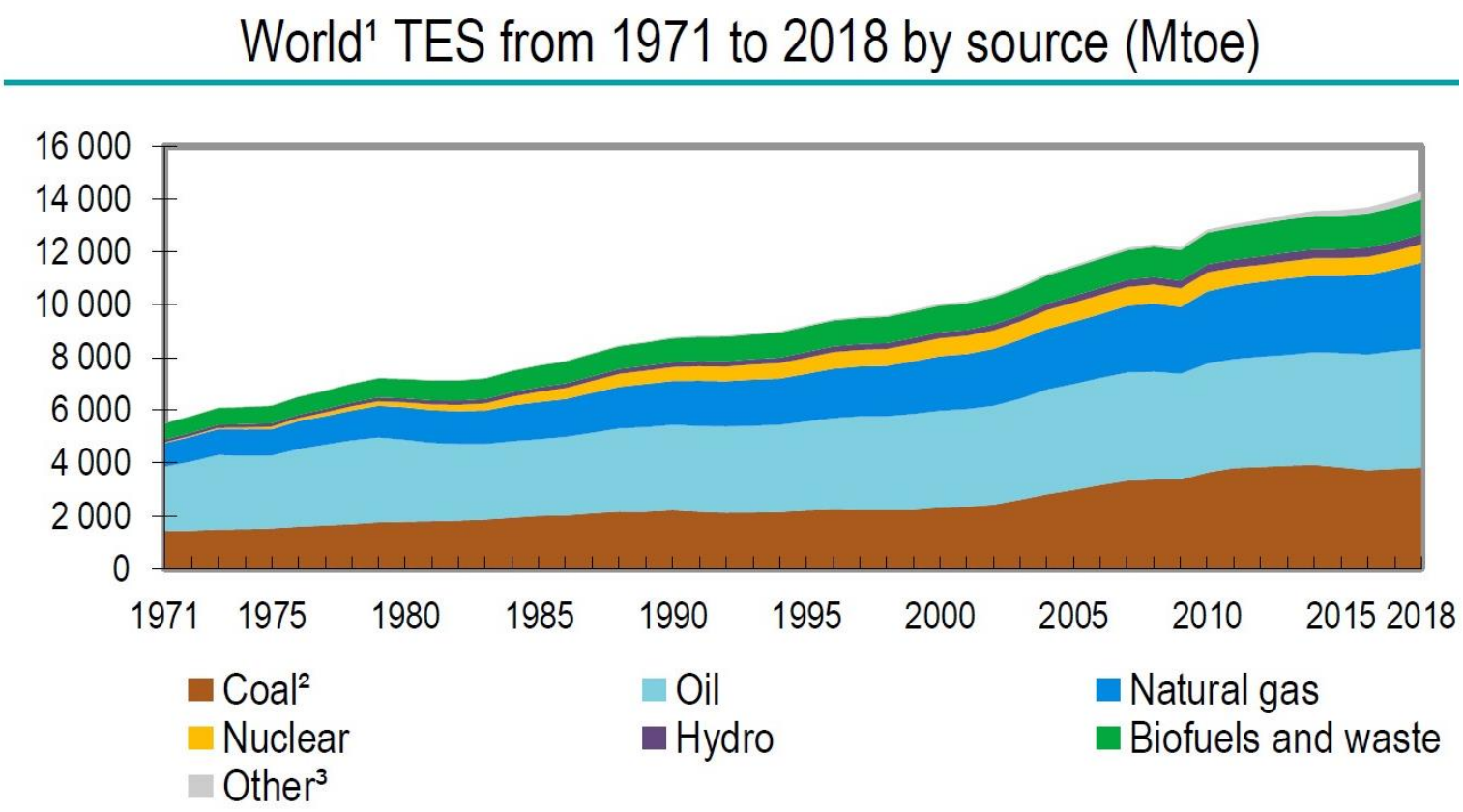


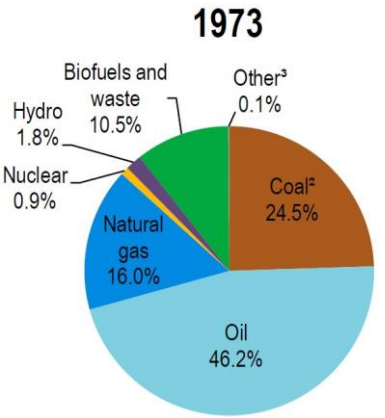


Total Energy Supply

- TES – Total Energy Supply – is one of the key parameters given in statistics
- TES is made up of production + imports – exports – international marine bunkers – international aviation bunkers
- For the world total, international marine and aviation bunkers are not subtracted from TES

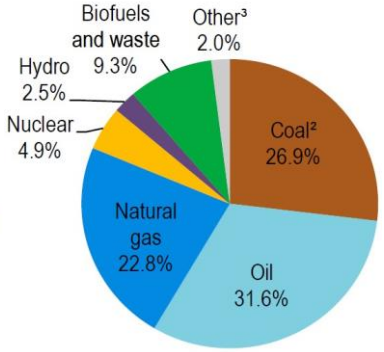
Total Energy Supply





6 098 Mtoe

2018



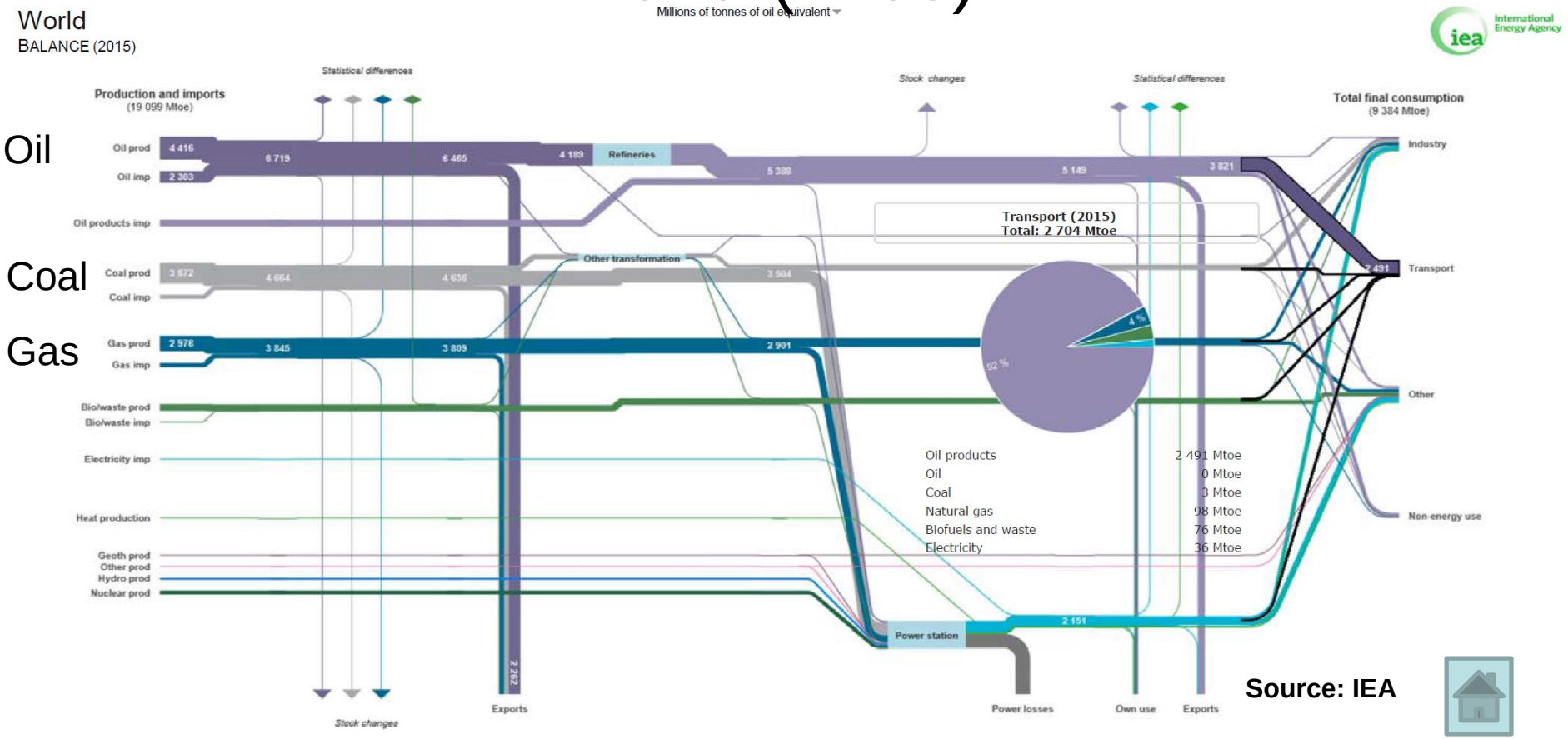
14 282 Mtoe

IEA Sankey Diagram

- Sankey can be accessed on: https://www.iea.org/Sankey/
- Can be used to visualize energy transformations for various regions/countries and energy sectors
- EXERCISE: use IEA Sankey diagram tool an arbitrary country and:
  - Plot the diagram of energy balance in 1975 and 2018
  - Plot the total final consumption versus time for time interval 1975 through 2018. Use units PJ and years on the plot axes
  - Make a similar plot for a fraction fossil fuels (%) used in transport

World Energy Balance

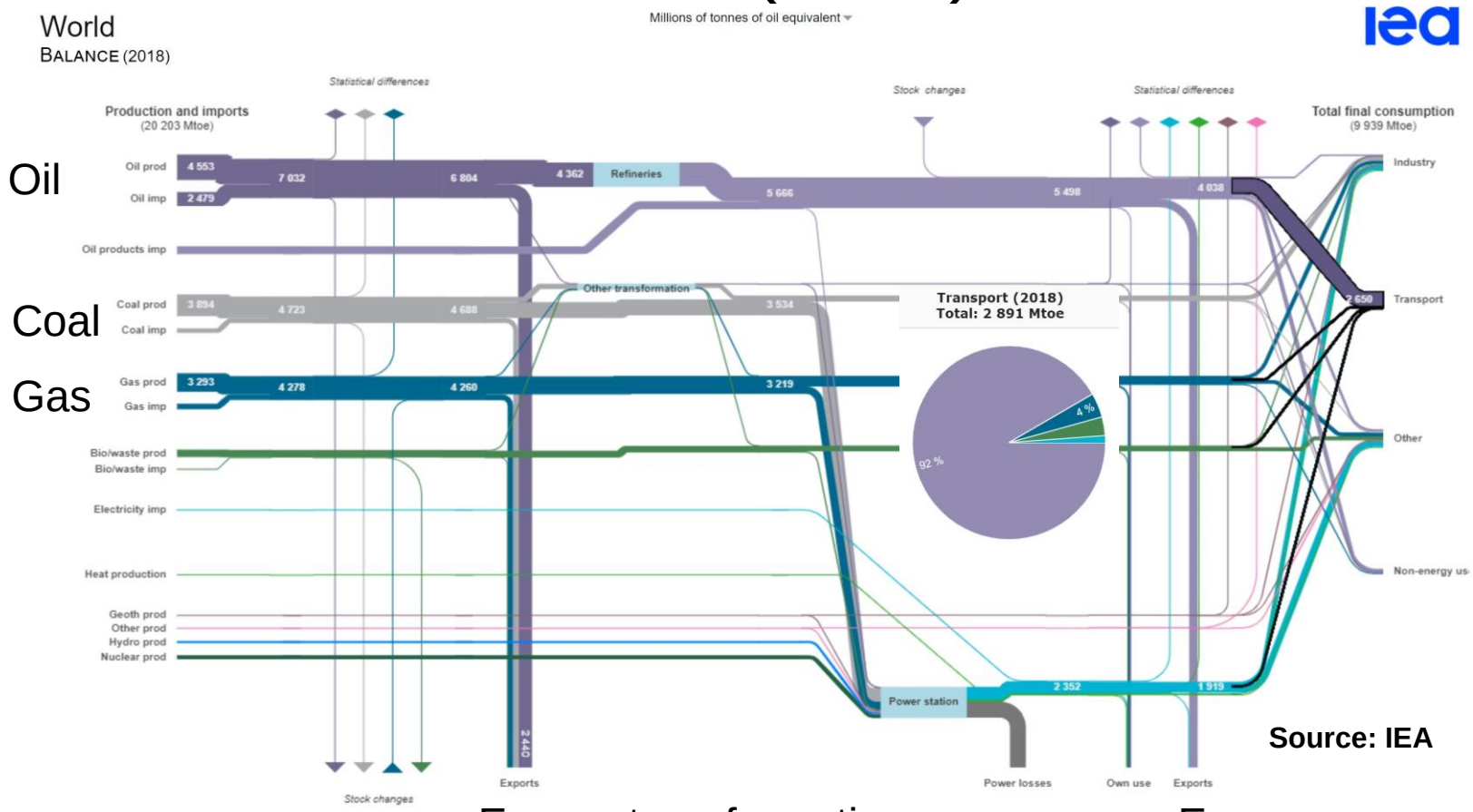
2015 (Mtoe)



Primary energy | Energy transformation | Energy consumption

World Energy Balance

2018 (Mtoe)



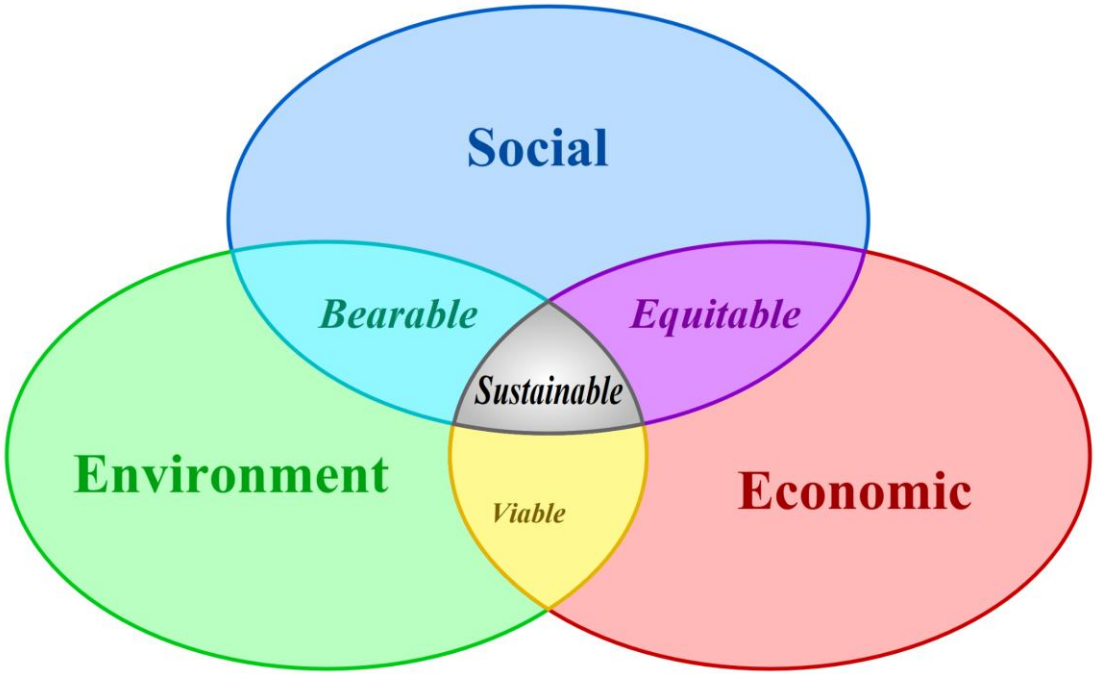
Primary energy | Energy transformation | Energy consumption

Sustainable Development

- Sustainability can be defined as a feature of a process that can be maintained indefinitely by replacing resources used with resources of equal or greater value without degrading the surrounding environment
- Sustainable development concept originates from ideas about sustainable forest management which were developed in Europe during the seventeenth and eighteenth centuries
- In September 2015, the United Nations General Assembly formally adopted the universal, integrated and transformative **2030 Agenda for Sustainable Development**

Sustainable Development

- Sustainable development (or sustainability) is often presented in terms of three pillars: the environment, the economy and the society



Environmental (ecological) – including quality of air, water, food and shelter
Economic – related to GDP (Gross Domestic Product) growth
Social – including politics and culture

Sustainable Development Goals

A collection of 17 global goals set by United Nations Development Programme - Goal #7 concerns energy

Sustainable Energy

- Sustainable energy is energy that is consumed:
  - at insignificant rates compared to its supply
  - with manageable environmental effects

- Sustainable energy system should serve the needs of the present without compromising the ability of future generations to meet their energy needs

- Not all renewable energy (naturally replenished on human timescale) is sustainable:
  - sustainable energy must not compromise the system in which it is adopted to the point of being unable to provide for future need

R/P Ratio

- Reserve-to-production (R/P) ratio is calculated as a ratio of the reserves remaining at the end of any year divided by the production in that year
- Table 2.1 in Compendium contains R/P ratio for fossil fuels in 2018:
  - Oil 50
  - Natural gas 50.9
  - Coal (total) 132
- Similarly, Table 2.2 contains R/P ratio for uranium in 2017:
  - Uranium 291

Renewable Resources

- Renewable resources include:
  - Wind
  - Hydro (moving and stationary water with potential energy)
  - Solar
  - Bio
  - Geothermal

- All these resources have supply limits based on accessibility, economy, and needed raw materials