CHEM 103: Chemistry in Context

Unit 3

Energy Sources

Reading: CC Chapters 4, 7, 8, and G&R 4.1, 6, 5

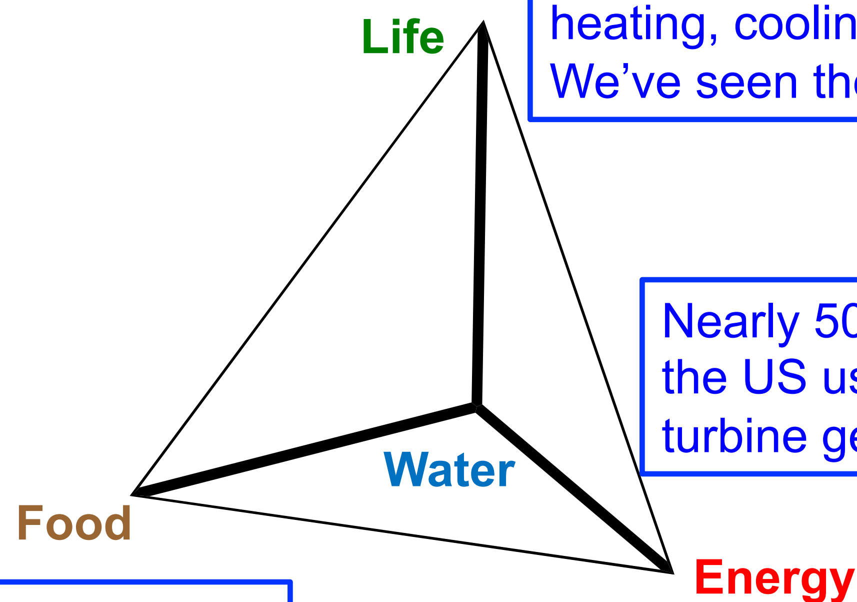
Unit 3.1

Introduction; Fossil Fuels

Colorado State University

Interconnectedness of Issues: Energy

We use energy for transportation, heating, cooling, lights,…
We've seen the impacts combustion



Nearly 50% of the water that the US uses is for thermal turbine generation of electricity

Fertilizer production uses energy

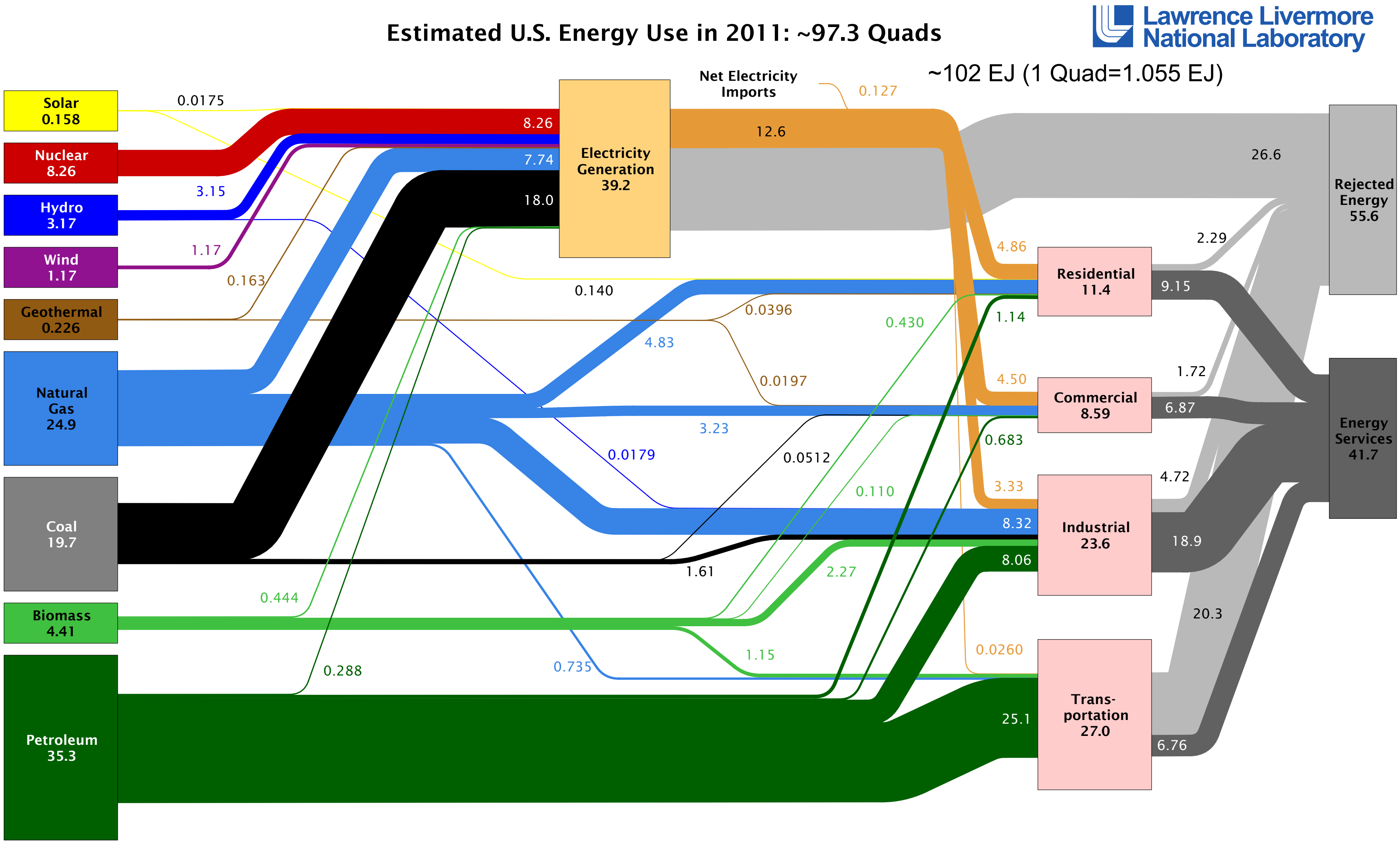
Scale of Energy use

In 2011 the average world citizen used 77 GJ, the average US citizen used 315 GJ.

TABLE 3.2

ENERGY		ENERGY SOURCE OR USE
9 kJ	10^4	1.225V Alkaline AA Battery
310 kJ	10^5	Heating a quart (Liter) of water
1.2 MJ	10^6	Snickers bar
1.7 MJ	10^6	12V lead acid battery
10 MJ	10^7	Nutritional energy required by one person per day
140 MJ	10^8	Burning a log of wood
2 GJ	10^9	Energy in 15 gallons of gasoline
11.6 GJ	10^{10}	Energy to heat your house in Colorado in January
100 GJ	10^{11}	Annual US home (northern) heating and electric use
2.9 TJ	10^{12}	Energy in a coal train car full of coal
346 TJ	10^{14}	Energy in a coal train full of coal (120 cars)
9 PJ	10^{16}	Annual output from a 280 MW coal plant
32 PJ	10^{16}	Annual output from a 1 GW nuclear power plant
46 PJ	10^{16}	Energy for a small (pop. 144,000) US city
400 PJ	10^{17}	Energy for a large majority world city
4 EJ	10^{18}	Energy for a large developed world city
26 EJ	10^{19}	Caloric need to feed the world for a year
100 EJ	10^{20}	2011 US energy consumption
115 EJ	10^{20}	2011 China energy consumption
540 EJ	10^{21}	2011 World energy consumption
1 ZJ	10^{21}	Expected world energy demand in 2025

Energy Flow



Source: LLNL 2012. Data is based on DOE/EIA-0384(2011), October, 2012. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Energy Transformation

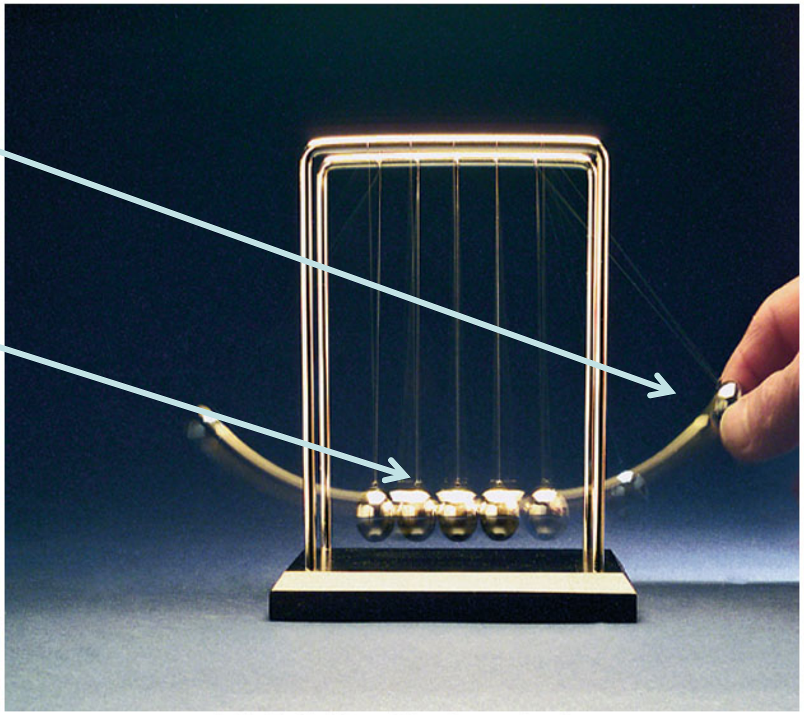
Types of energy:

Potential: stored energy/ energy of position

Kinetic: energy of motion

Forms of energy:

- Mechanical
- Radiant (light)
- Electrical
- Chemical
- Nuclear



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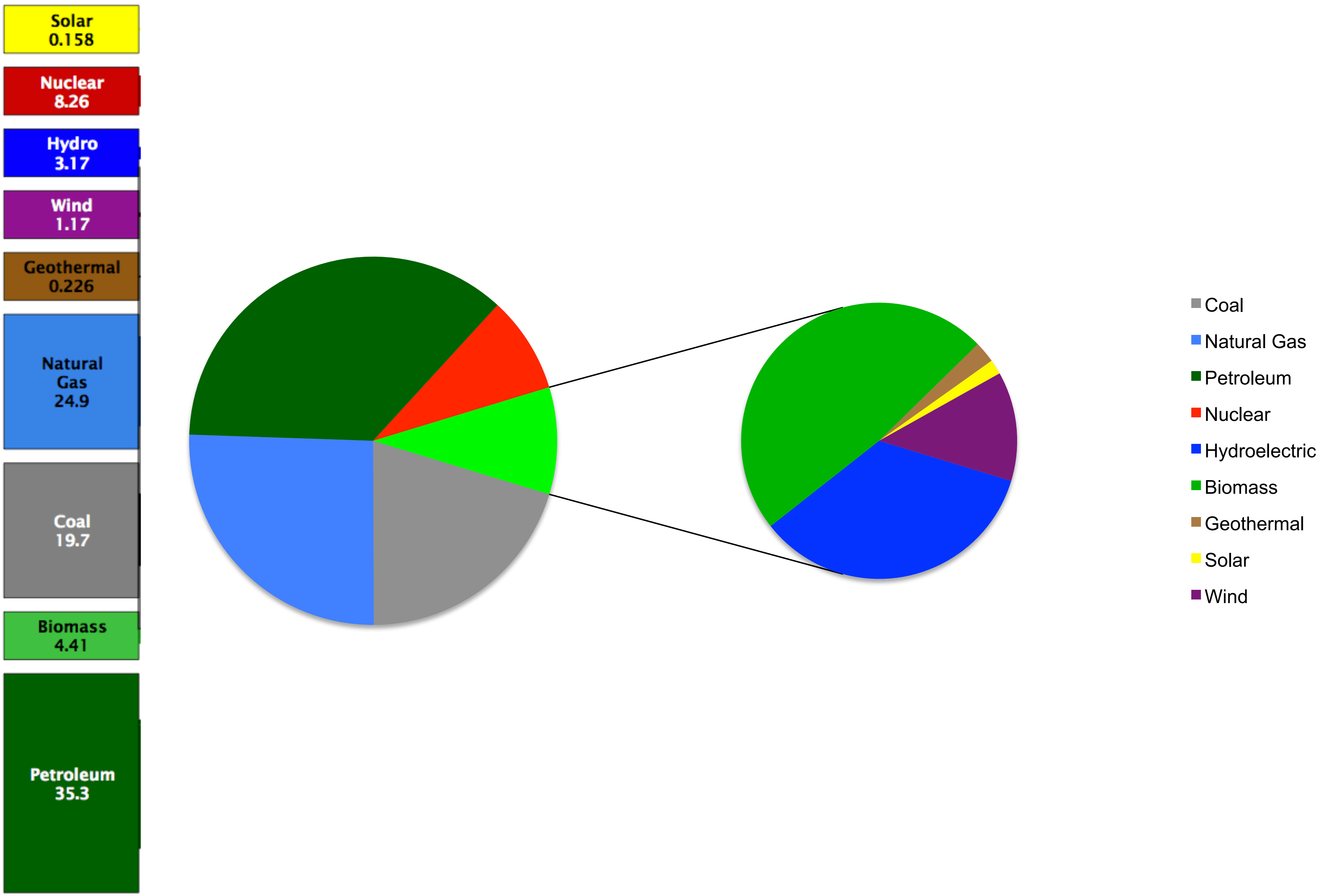
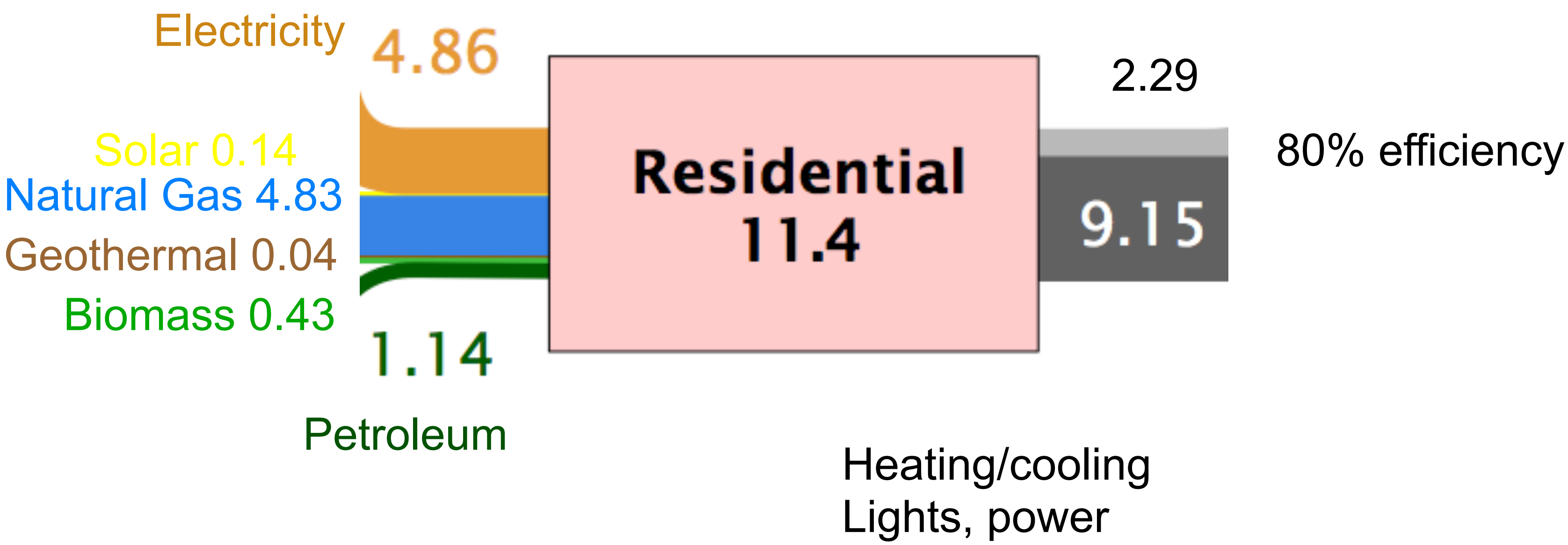
1st Law of thermodynamics: Energy is neither created nor destroyed (but we can & do transform it)

2nd Law of thermodynamics: Entropy always increases (limits efficiency of heat-driven processes)

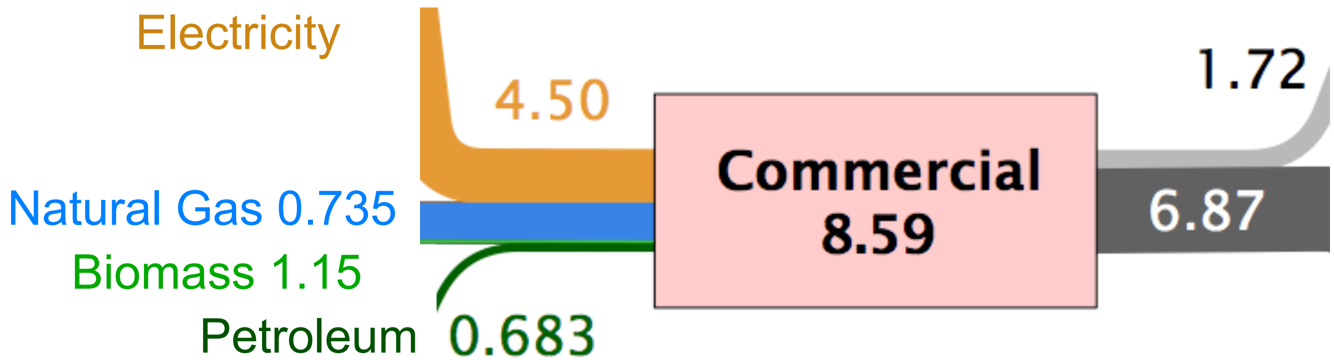
Energy Sources



Energy Uses: Residential



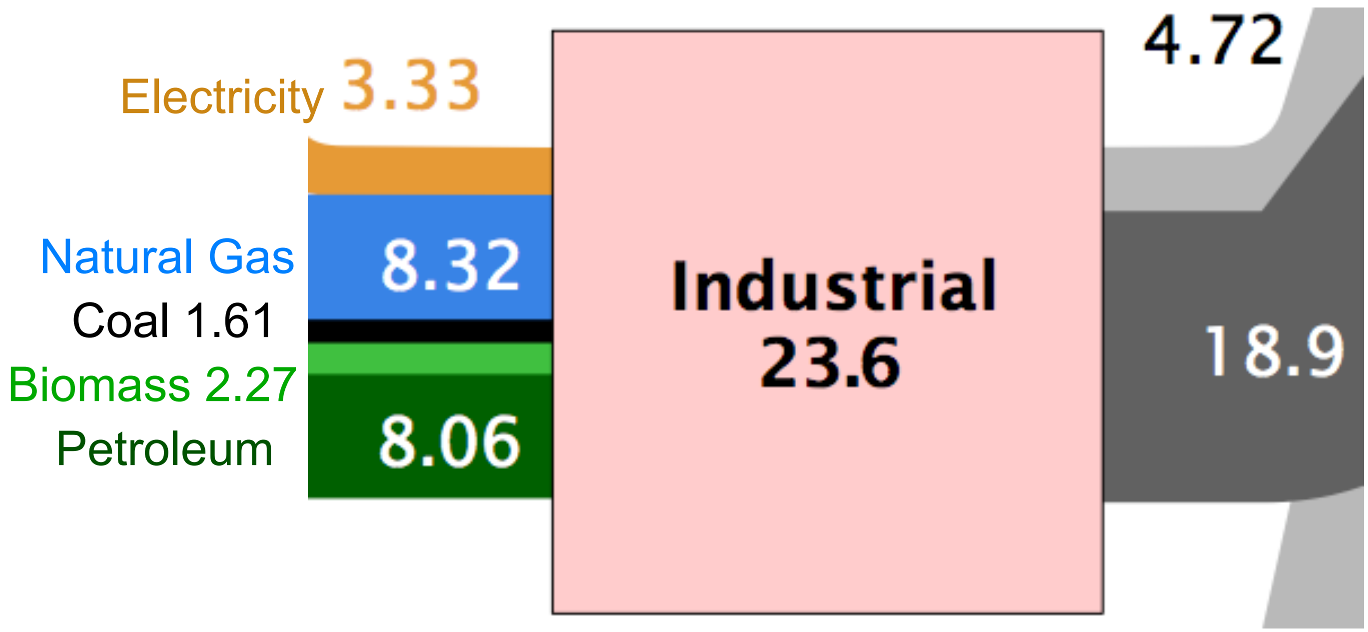
Energy Uses: Commercial



80% efficiency

Heating/cooling
Lights, power

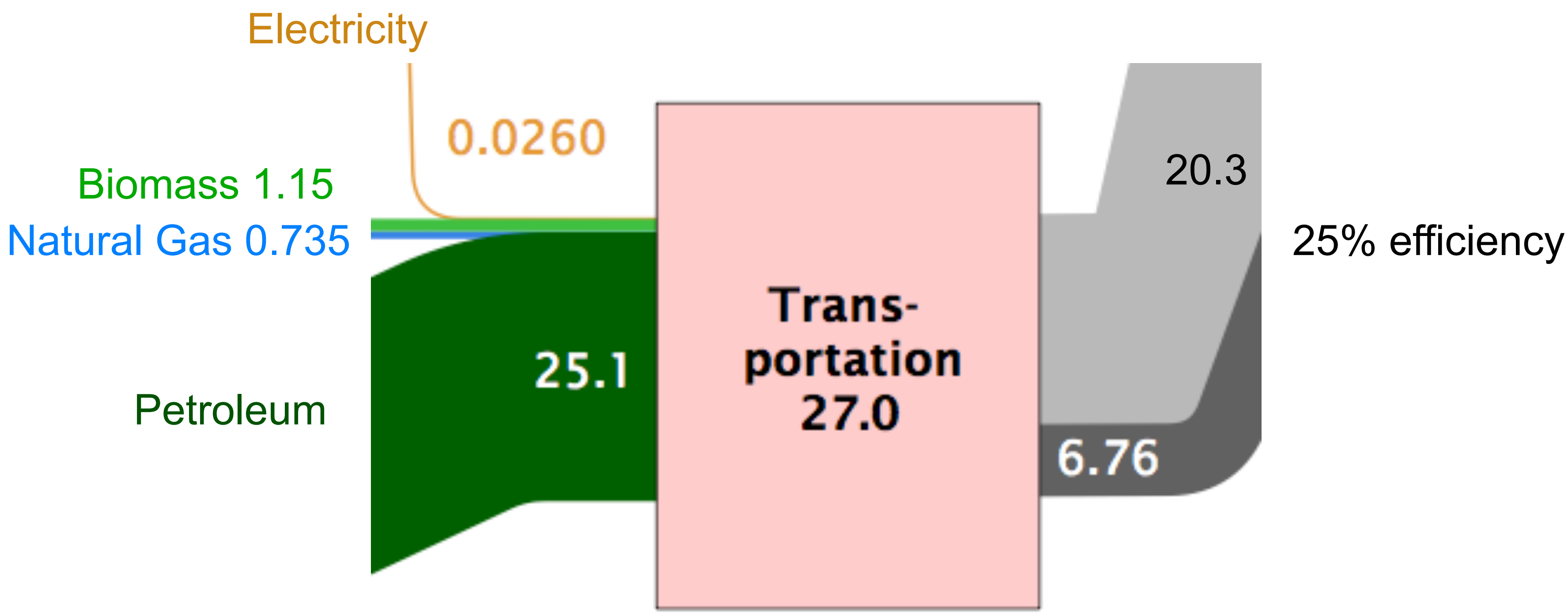
Energy Uses: Industrial



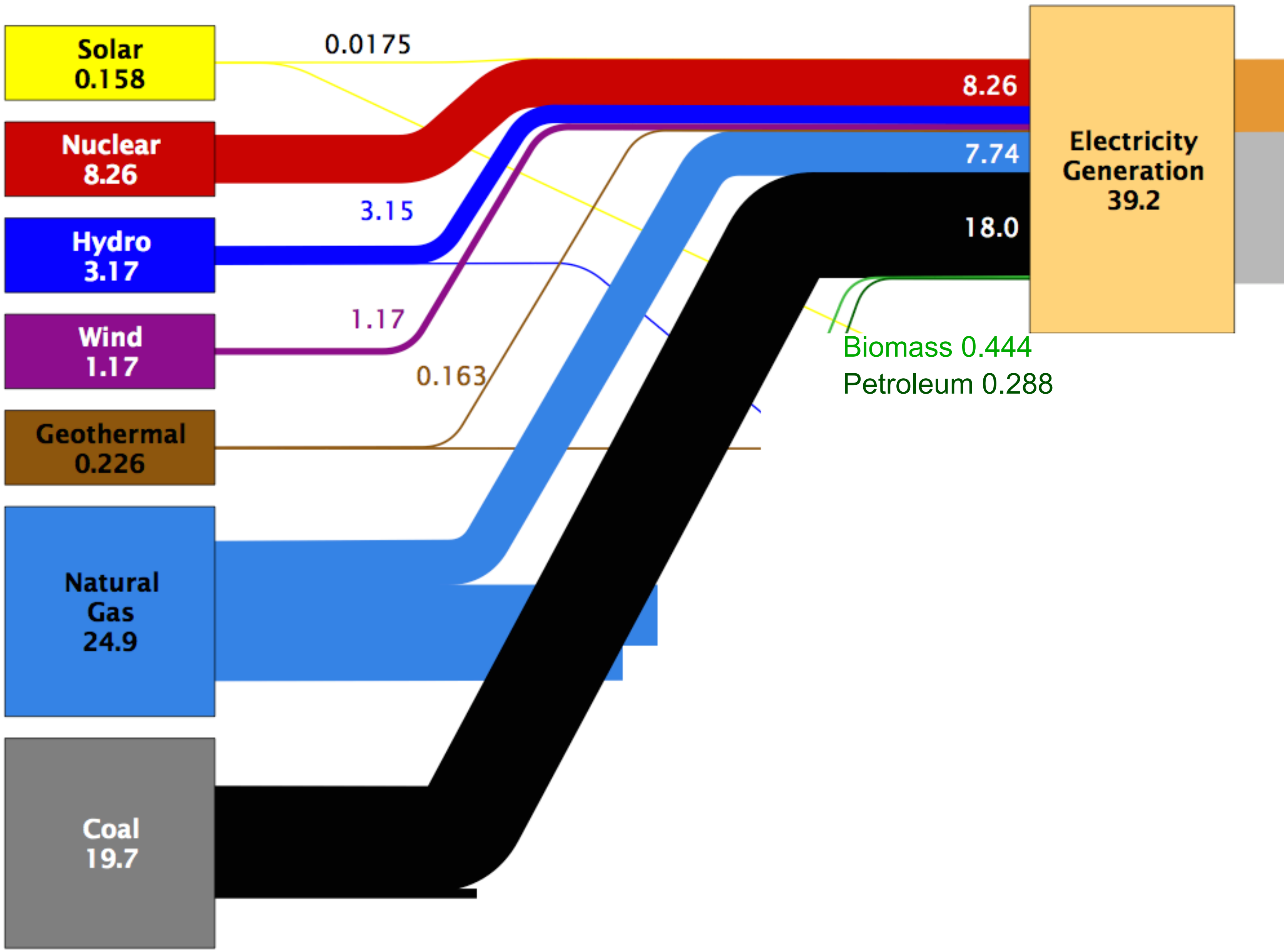
80% efficiency

Manufacturing (steel, plastics, electronics,…)

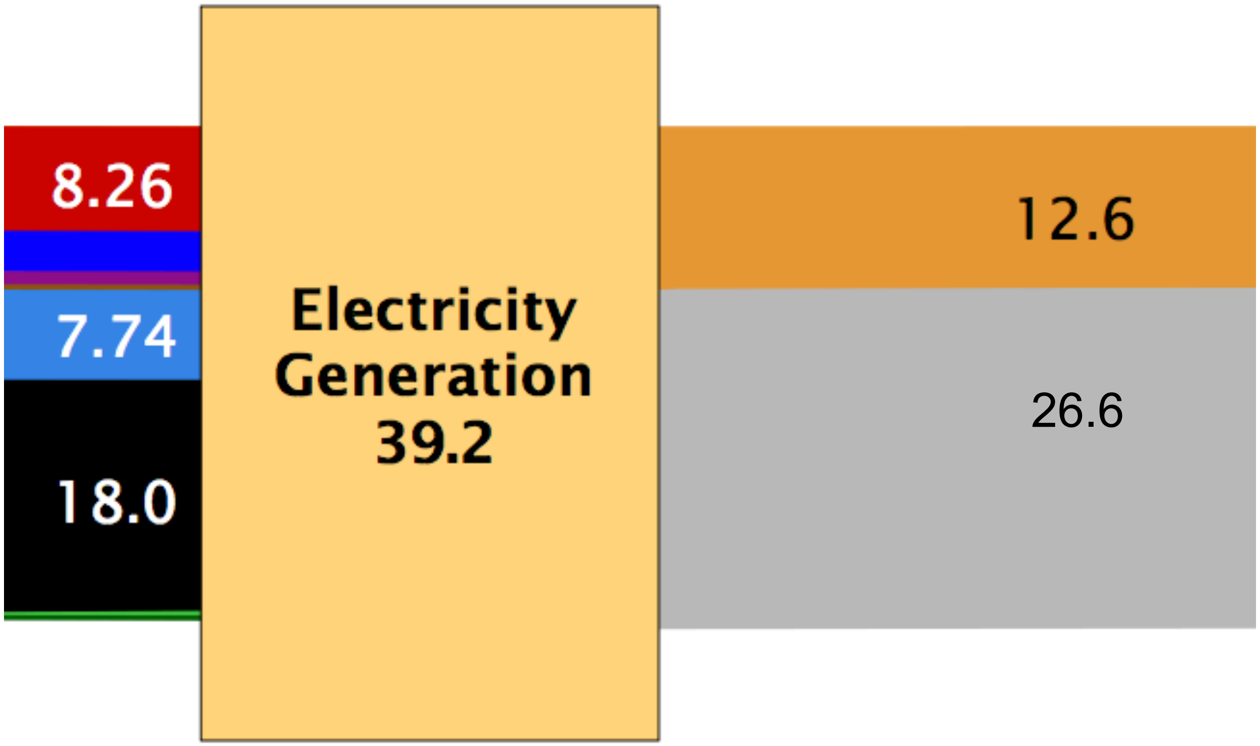
Energy Uses: Transportation



Electricity sources



Electricity efficiency

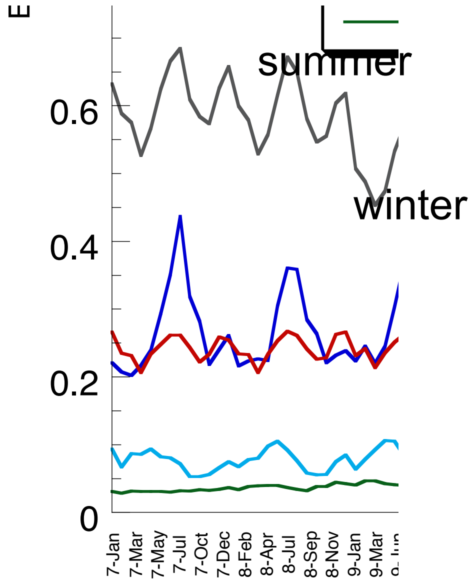


32% efficiency

"rejected"

$$\text{efficiency} = 1 - \frac{T_{low}}{T_{high}}$$

Electricity Seasonal uses & sources



Power Plant

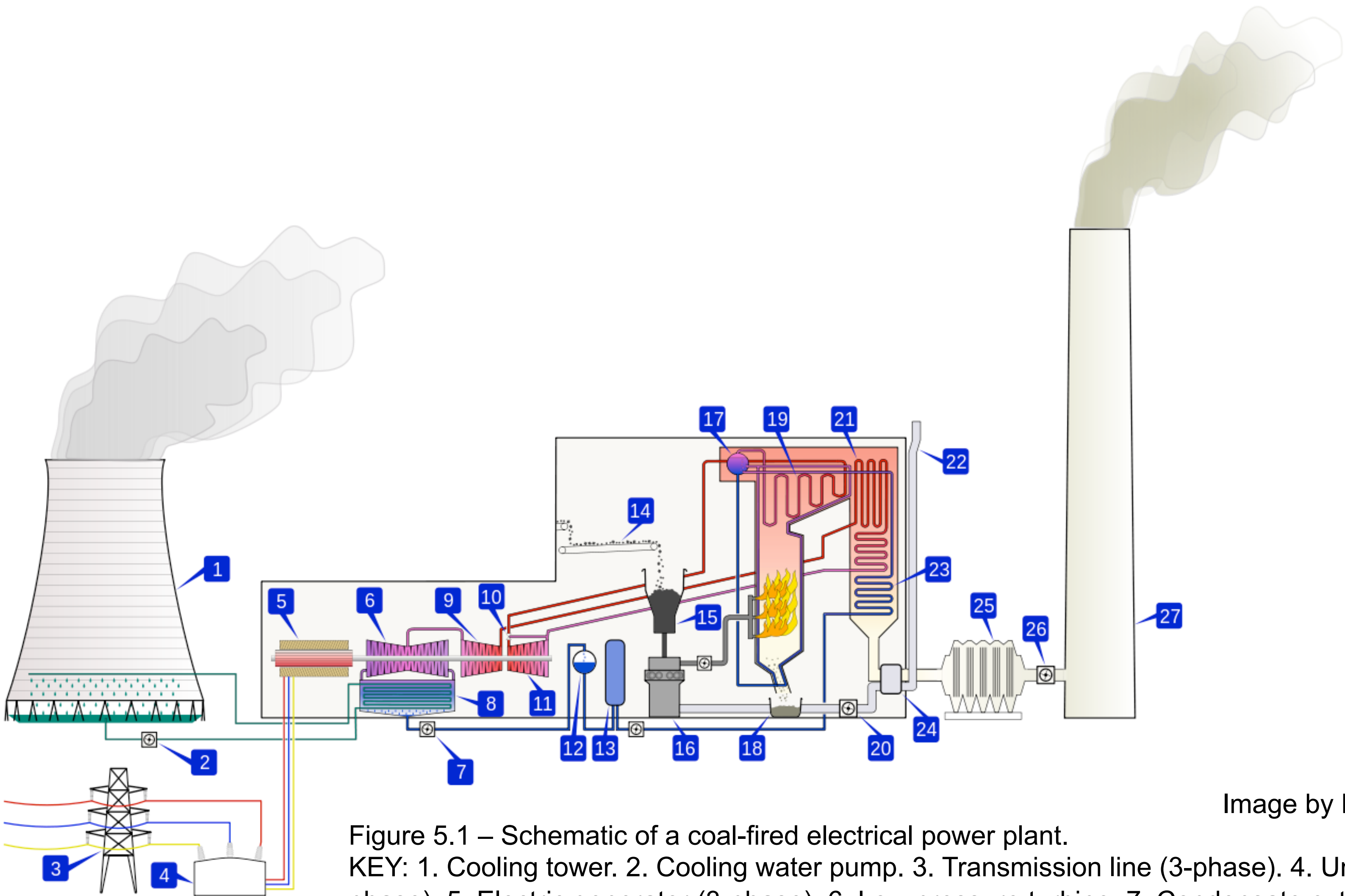


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Figure 5.1 – Schematic of a coal-fired electrical power plant.
KEY: 1. Cooling tower. 2. Cooling water pump. 3. Transmission line (3-phase). 4. Unit transformer (3-phase). 5. Electric generator (3-phase). 6. Low pressure turbine. 7. Condensate extraction pump. 8. Condensor. 9. Intermediate pressure turbine. 10. Steam governor valve. 11. High pressure turbine. 12. Deaerator. 13. Feed heater. 14. Coal conveyor. 15. Coal hopper. 16. Pulverised fuel mill. 17. Boiler drum. 18. Ash hopper. 19. Superheater. 20. Forced draught fan. 21. Reheater. 22. Air intake. 23. Economiser. 24. Air preheater. 25. Precipitator. 26. Induced draught fan. 27. Chimney Stack.

Rawhide Power Plant

Train tracks, every other day a 55 car train delivers coal from Wyoming

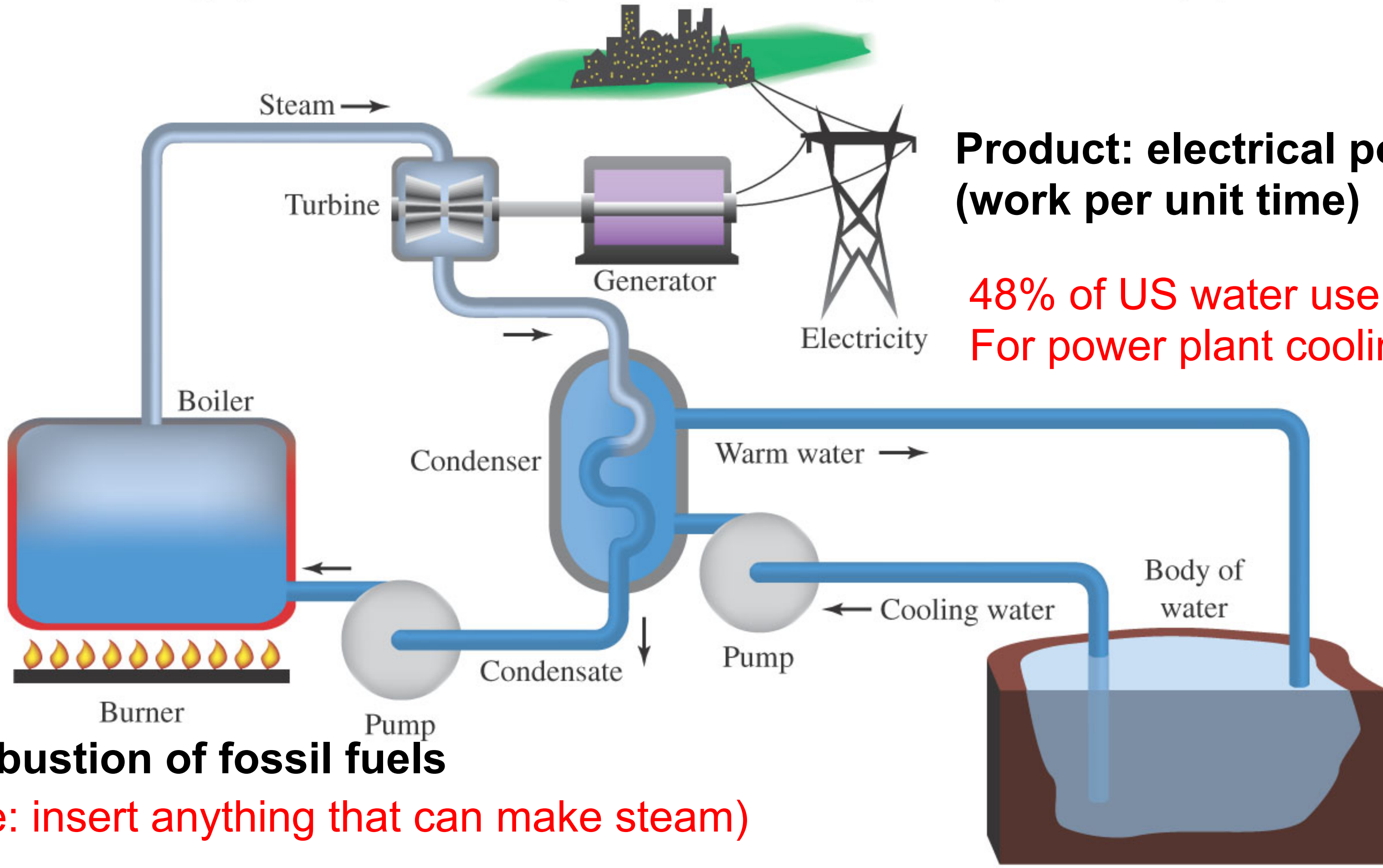
108 MW
Natural gas
turbine capacity

280 MW Coal turbine
(280 MJ/sec 8.8 PJ in a year)

Image ©2012 DigitalGlobe, GeoEye, USDA Farm Service Agency, Map data ©2013 Google

FIGURE 5.2 – Google Maps satellite image of the Rawhide Power Plant of the Platte River Power Authority

Power Plant and Energy Transformation



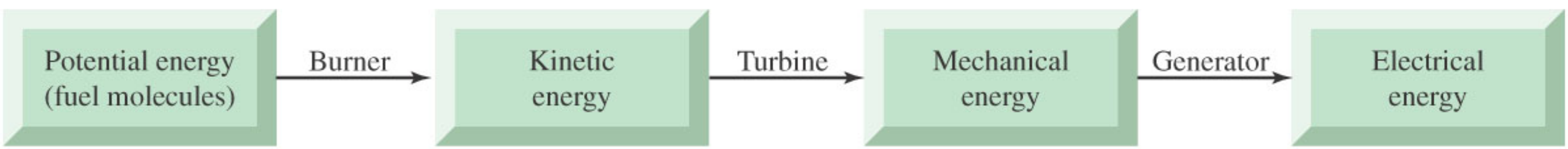
Product: electrical power (work per unit time)

48% of US water use is
For power plant cooling

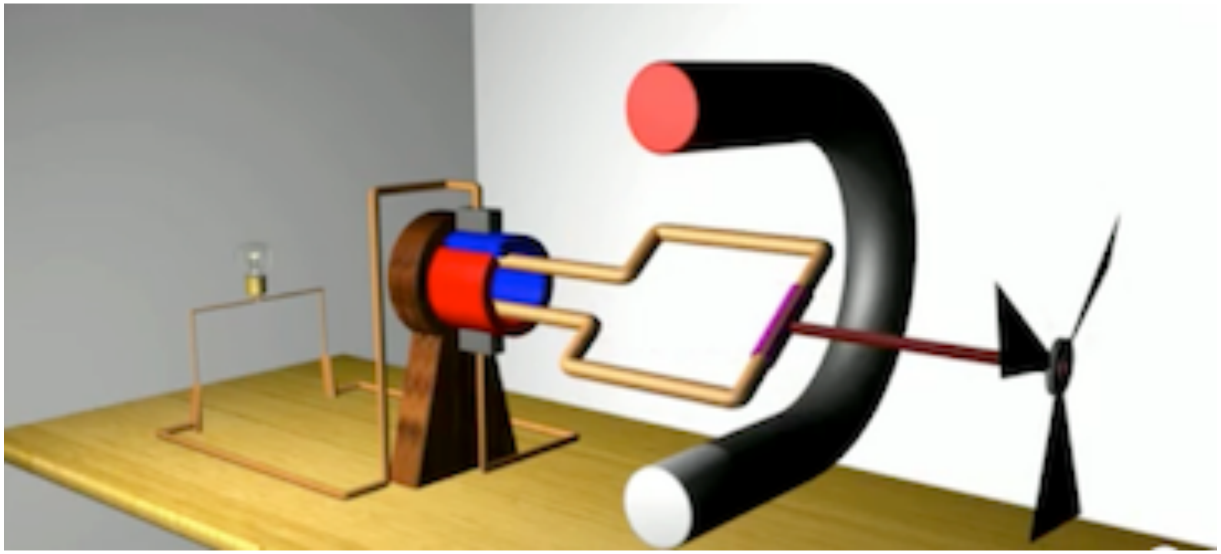
combustion of fossil fuels

(here: insert anything that can make steam)

Energy transformation process:



Electric Generator



Nuclear
Fossil Fuel (coal, natural gas)
Solar thermal

} motion of steam

Hydroelectric
Wind
Tides

} motion of water/air

http://www.youtube.com/watch?v=d_aTC0iKO68

Carnot Efficiency

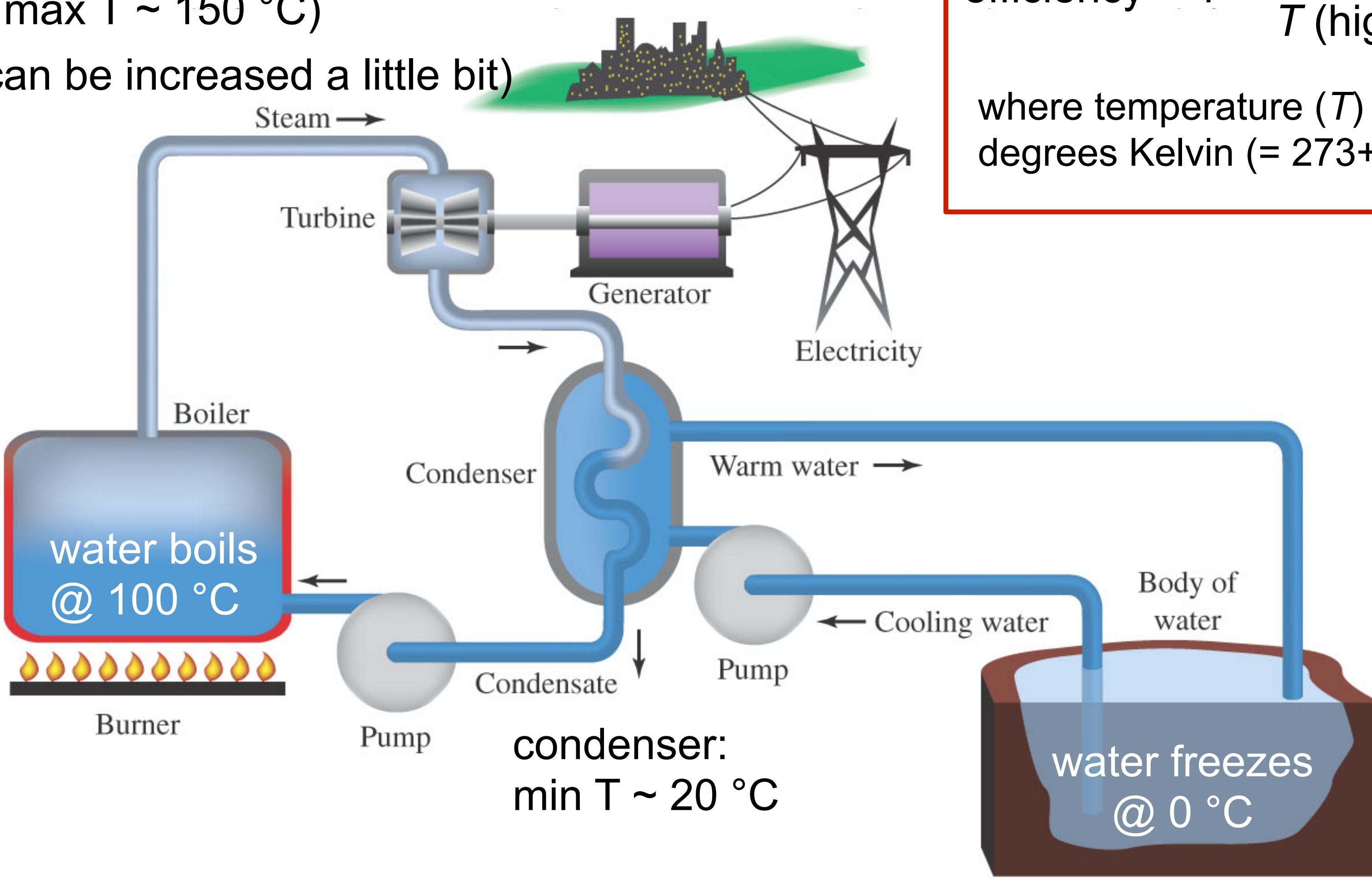
For any heat engine, the efficiency is related to the operating temperatures:

boiler technology:
max T ~ 150 °C)

(this can be increased a little bit)

$$\text{efficiency} = 1 - \frac{T\,(\text{low})}{T\,(\text{high})}$$

where temperature (T) in degrees Kelvin (= 273+°C)



condenser:
min T ~ 20 °C

Energy and Efficiency: a Worked Example

How much natural gas is burnt to keep your house warm?

Givens:
1. It takes 3.5×10^7 kJ to heat a northern US house in January
2. Electric heaters are 98% efficient at converting electrical energy into heat
3. Combustion of 1 g of methane releases 56 kJ of energy (calculated)

Power plants have limited efficiencies as well:

> 2nd Law of thermodynamics: all energy conversions suffer from inefficiencies

Table 4.1 Typical Efficiencies in Power Production

Maximum theoretical efficiency	55–60%	30% more realistic
Efficiency of boiler	90%	
Mechanical efficiency of turbine	75%	
Efficiency of electrical generator	95%	
Efficiency of power transmission	90%	

(entropy limited)

Overall efficiency = 0.6 x 0.9 x 0.75 x 0.95 x 0.9 x 0.98 = 0.34

Heat used x efficiency = heat needed (i.e. the heat produced at the power plant)
Heat used x 0.34 = 3.5×10^7 kJ
→ Heat needed = 1.0×10^8 kJ

$$1.0\times10^{8}\ \text{kJ} \times \frac{1\ \text{g}\ CH_4}{56\ \text{kJ}} = 1.8\times10^{6}\ \text{g}\ CH_4$$

2 metric tons!