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ECON 366: Energy Economics

Topic 2.1: Energy Units, Conversion, and Visualization

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Forms of energy

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- Potential: Stored energy
- Kinetic: Energy of motion
- Chemical: Energy stored in the bonds of atoms and molecules
- Nuclear: Energy stored in the nucleus of an atom
- Gravitational: Energy stored in an object's height
- Radiant: Electromagnetic energy travels in transverse waves
- Thermal: Vibration and movement of atoms and molecules within substances
- Electrical: Delivered by charged particles called electrons, typically moving through a wire

Energy Classification

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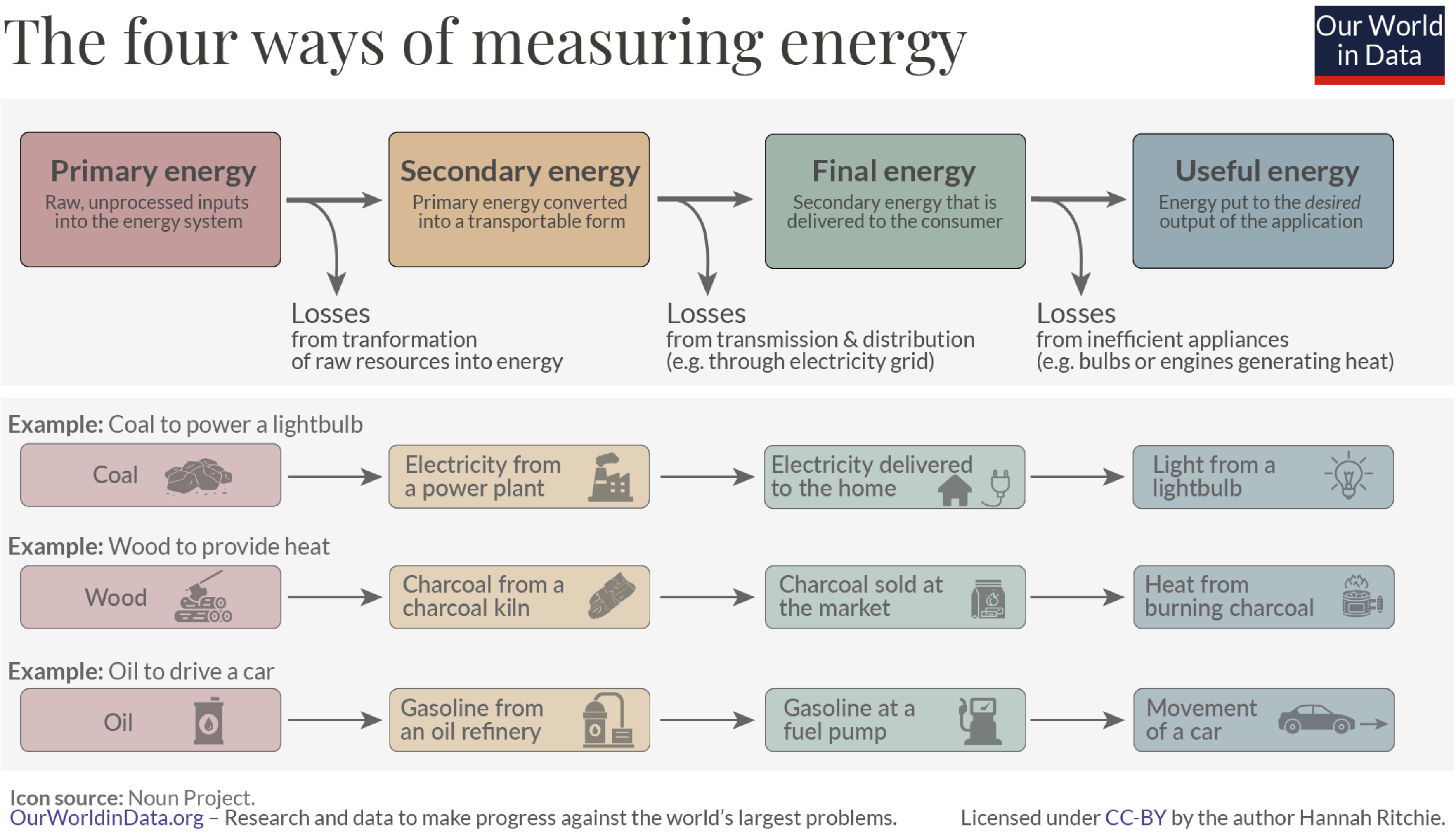

Energy Classification Definitions

Primary energy is the energy as it is available as resources: coal, uranium, oil, gas, etc.

Secondary energy is converted into a transportable form, e.g. electricity, gasoline and diesel, or heat.

Final energy is delivered secondary energy: gasoline at the fuel pump, electricity in your home.

Useful energy is the energy that goes towards the desired output as opposed to waste energy. For example, when you run in internal combustion gasoline engine, some energy is lost as heat.

> Based on this post from Hannah Ritchie

Energy Classification

- Primary vs. Secondary vs. Final vs. Useful Energy
    - See post from Hannah Ritchie mentioned above
- Renewable and Non-Renewable Energy

> Renewable energy is energy derived from natural processes that are replenished at a rate that is equal to or faster than the rate at which they are consumed, e.g. energy generated from solar, wind, geothermal, hydropower and ocean resources.

- *Clean* vs *Dirty* Energy
    - *Clean* energy is a broader category, e.g. may include nuclear, waste heat capture, etc.
- Commercial and Non-Commercial
- Conventional and Non-Conventional
    - *Conventional* tends to be a moving target

Energy Losses

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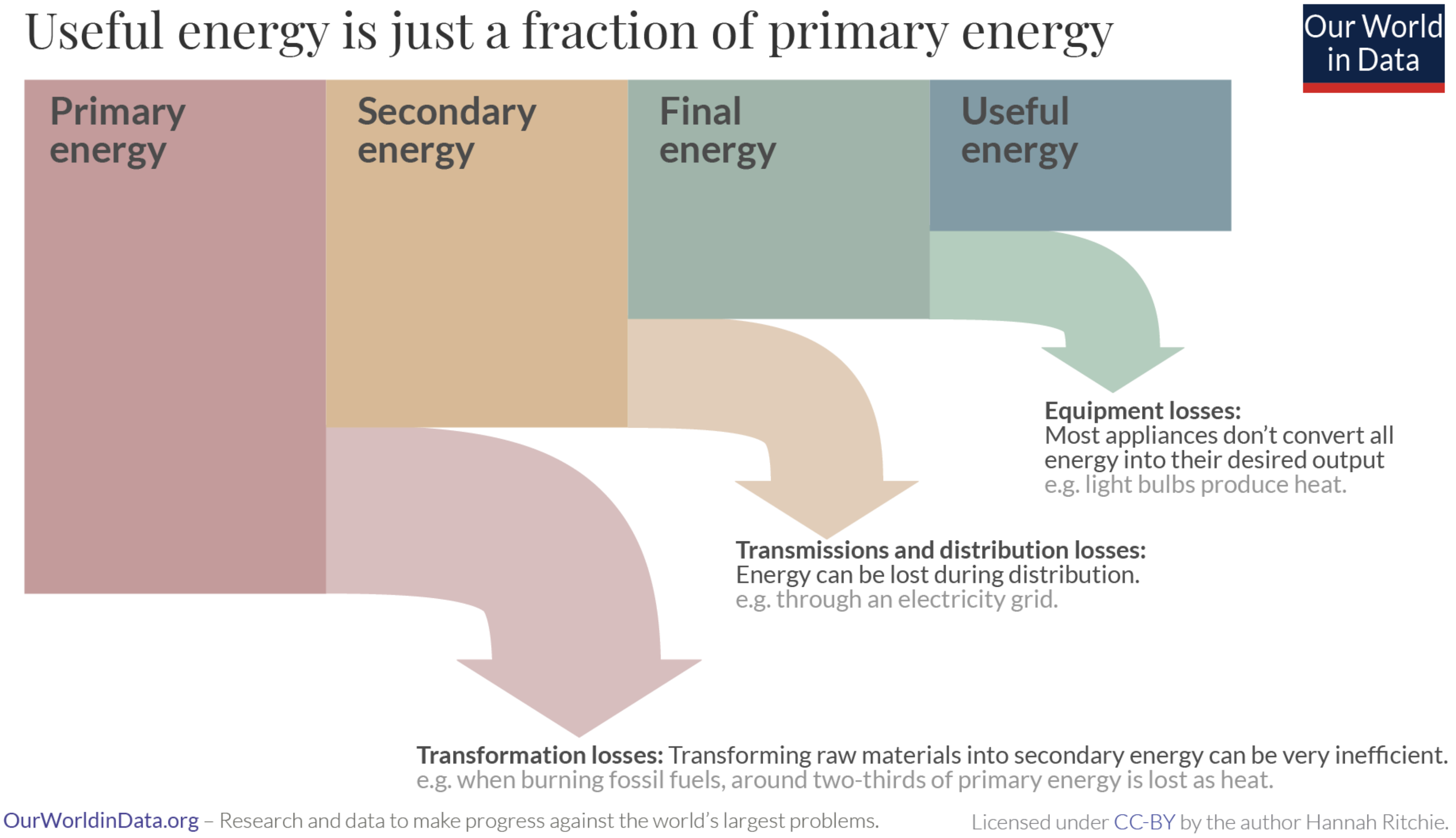

Calculating Energy Shares

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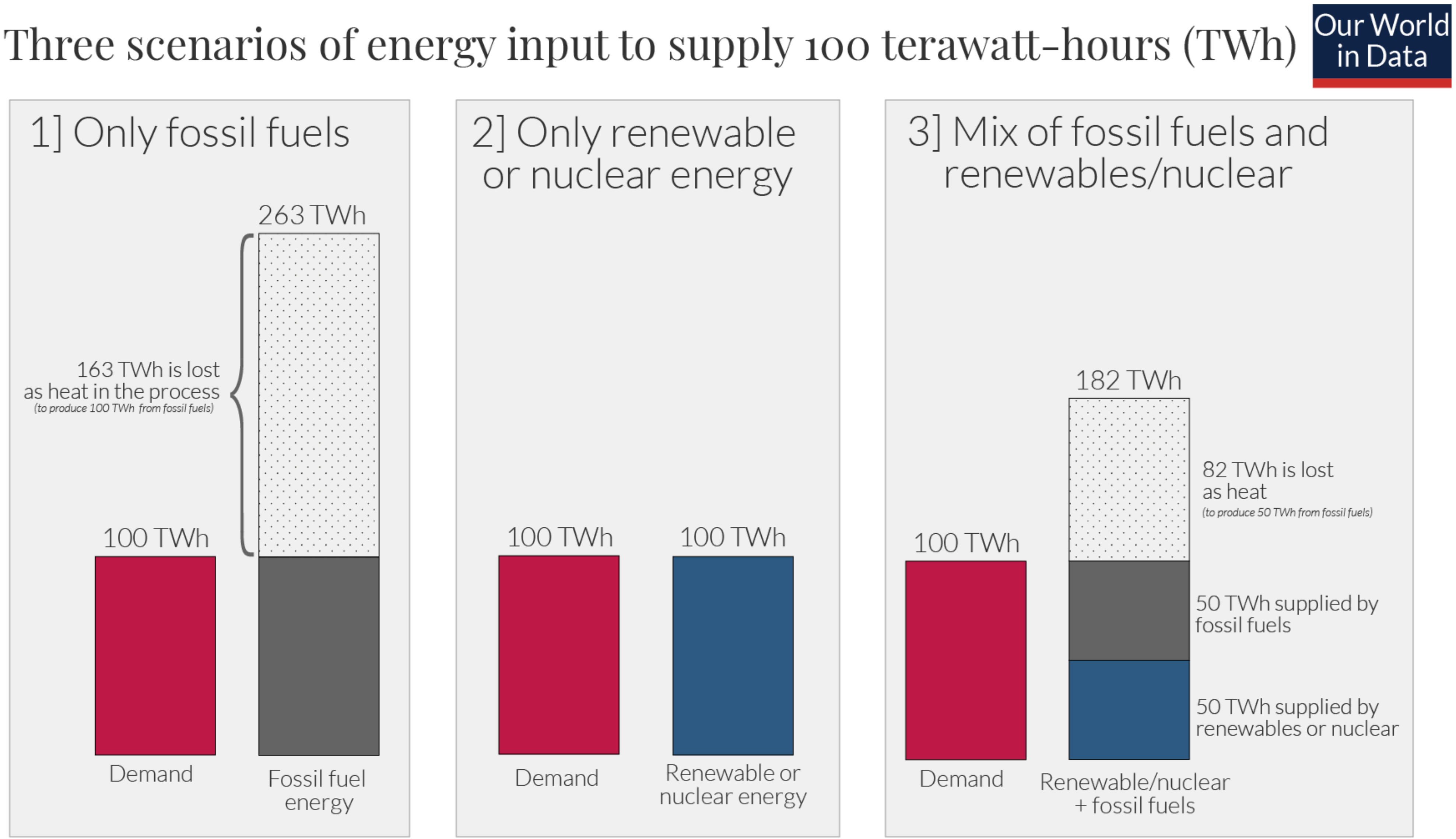
- Direct vs. Substitution Methods for calculating shares of primary energy
  - See yet another post from Hannah Ritchie
- *direct* calculations look at the energy supplied via, for example, oil and natural gas, but does not take account of the energy lost in conversion processes.
- *substitution* method essentially omits the energy wasted in creating that eventual, useful energy that was consumed

Energy Shares



Energy Shares

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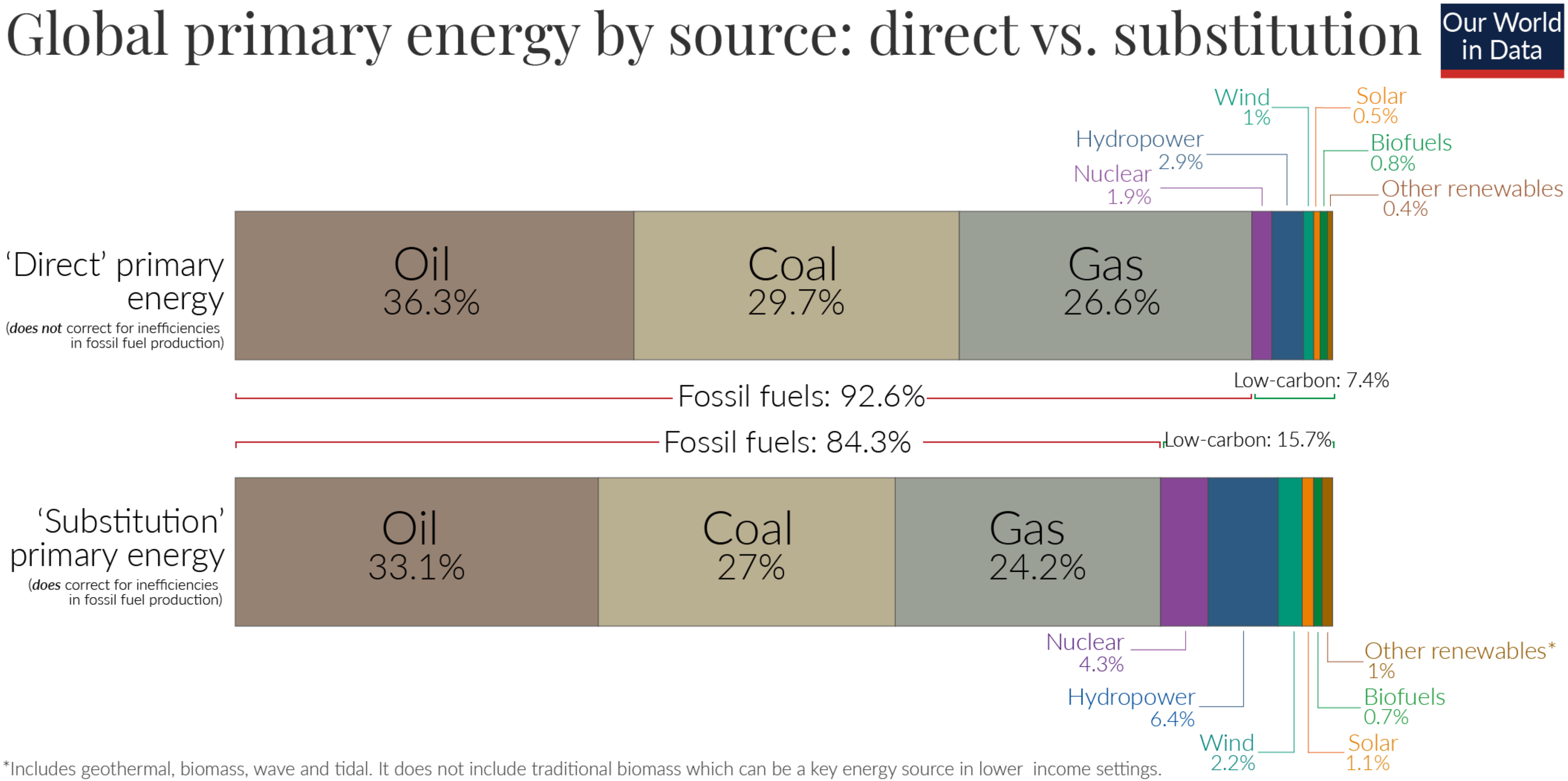

*Includes geothermal, biomass, wave and tidal. It does not include traditional biomass which can be a key energy source in lower income settings.

OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Our World in Data based on BP Statistical Review of World Energy (2020). Based on the energy mix in 2019.

Energy Shares

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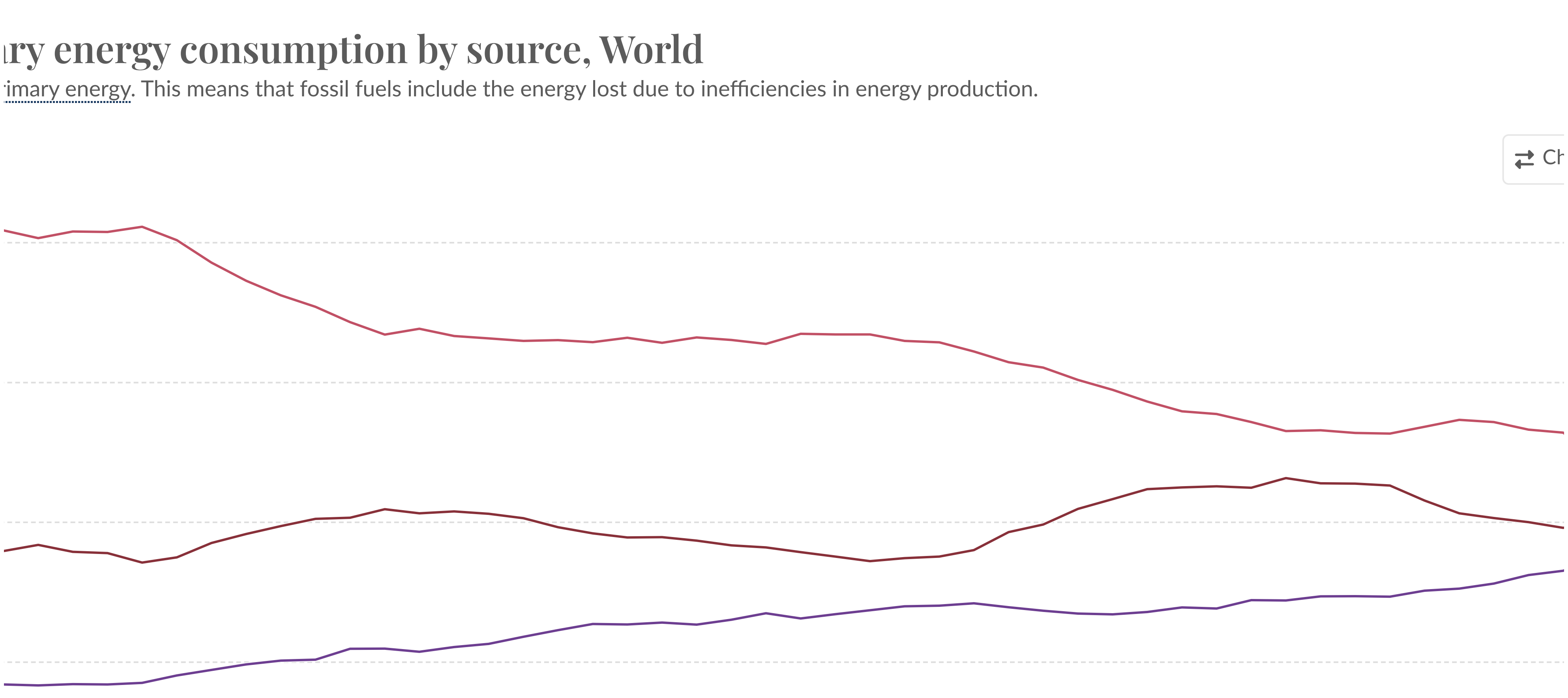

Source site link

Energy Shares

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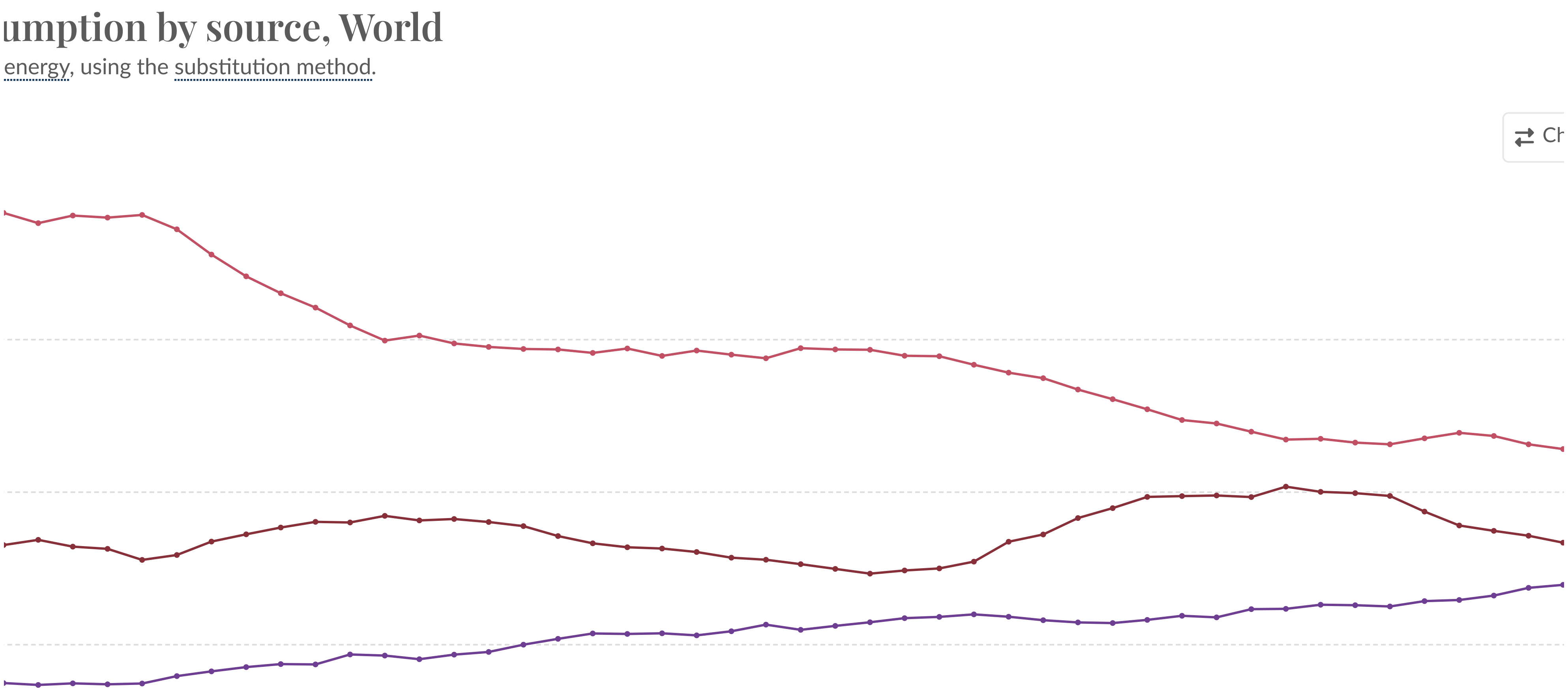

[Source site link](#)

Calculating Energy Shares

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From Hannah Ritchie's post:

- Low-carbon’s share in direct primary energy = % of total primary energy consumption (including all of the inefficiencies of fossil fuel production)
- Low carbon’s share in substituted primary energy = % of useful energy (once we subtract all of the wasted energy in the burning of fossil fuels)

Renewable Energy Generation

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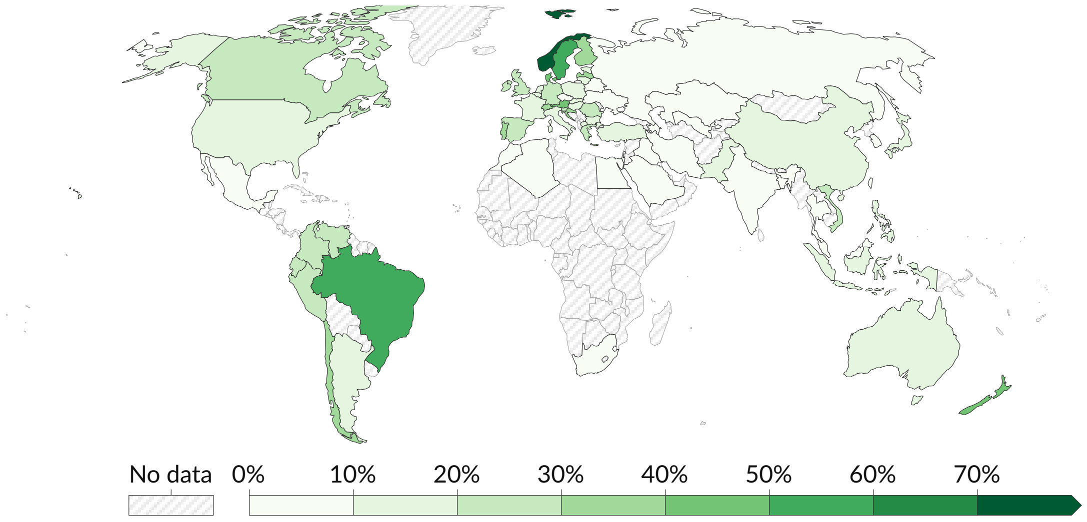
Share of primary energy consumption from renewable sources, 2023

Our World in Data

Measured as a percentage of primary energy using the substitution method. Renewables include hydropower, solar, wind, geothermal, bioenergy, wave, and tidal, but not traditional biofuels, which can be a key energy source, especially in lower-income settings.

Table Map Chart World



Play time-lapse 1965 2023

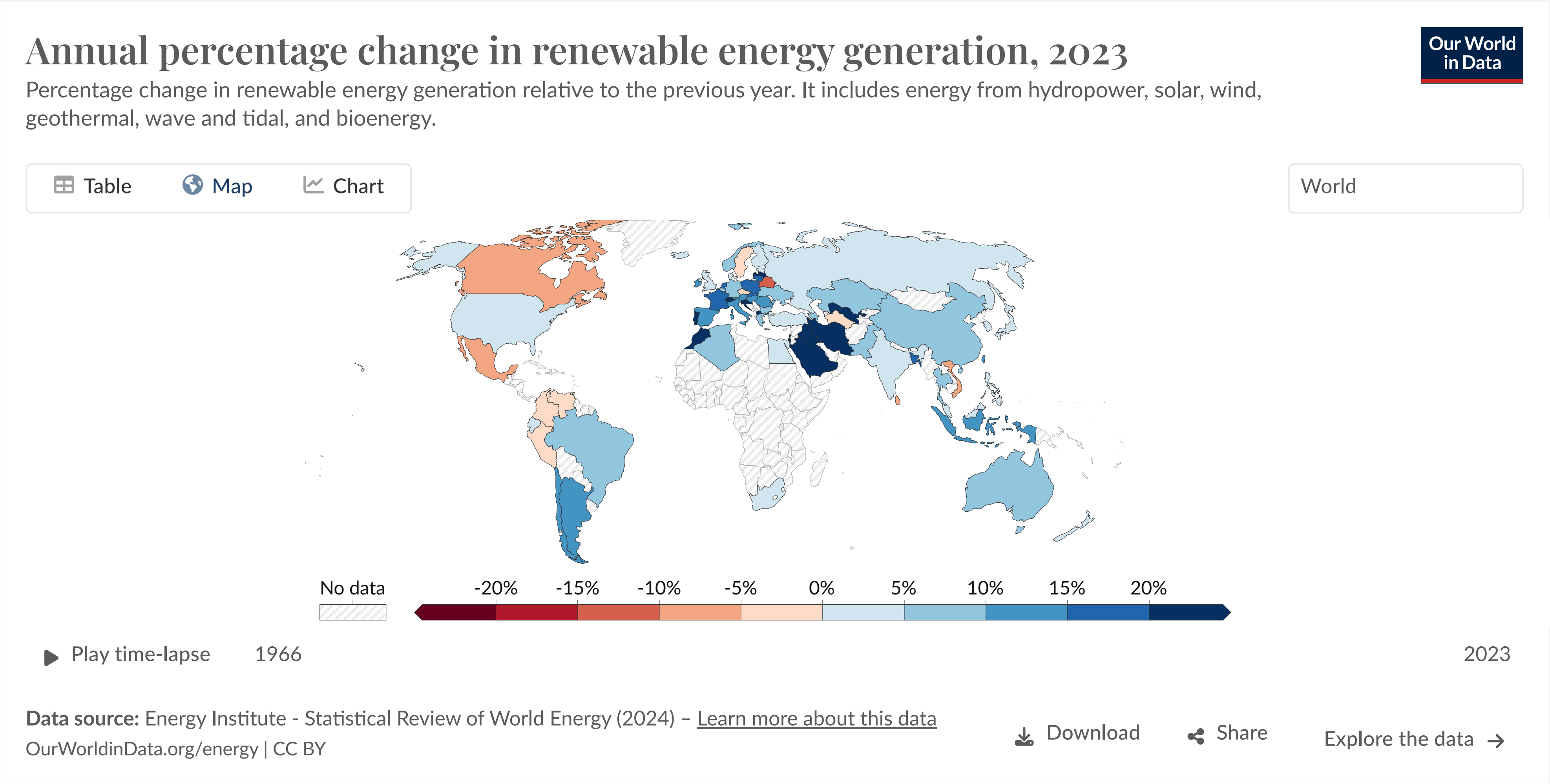
Data source: Energy Institute - Statistical Review of World Energy (2024) – Learn more about this data

OurWorldinData.org/energy | CC BY

Download Share Explore the data →

Source site link

Renewable Energy Generation is Growing Fast



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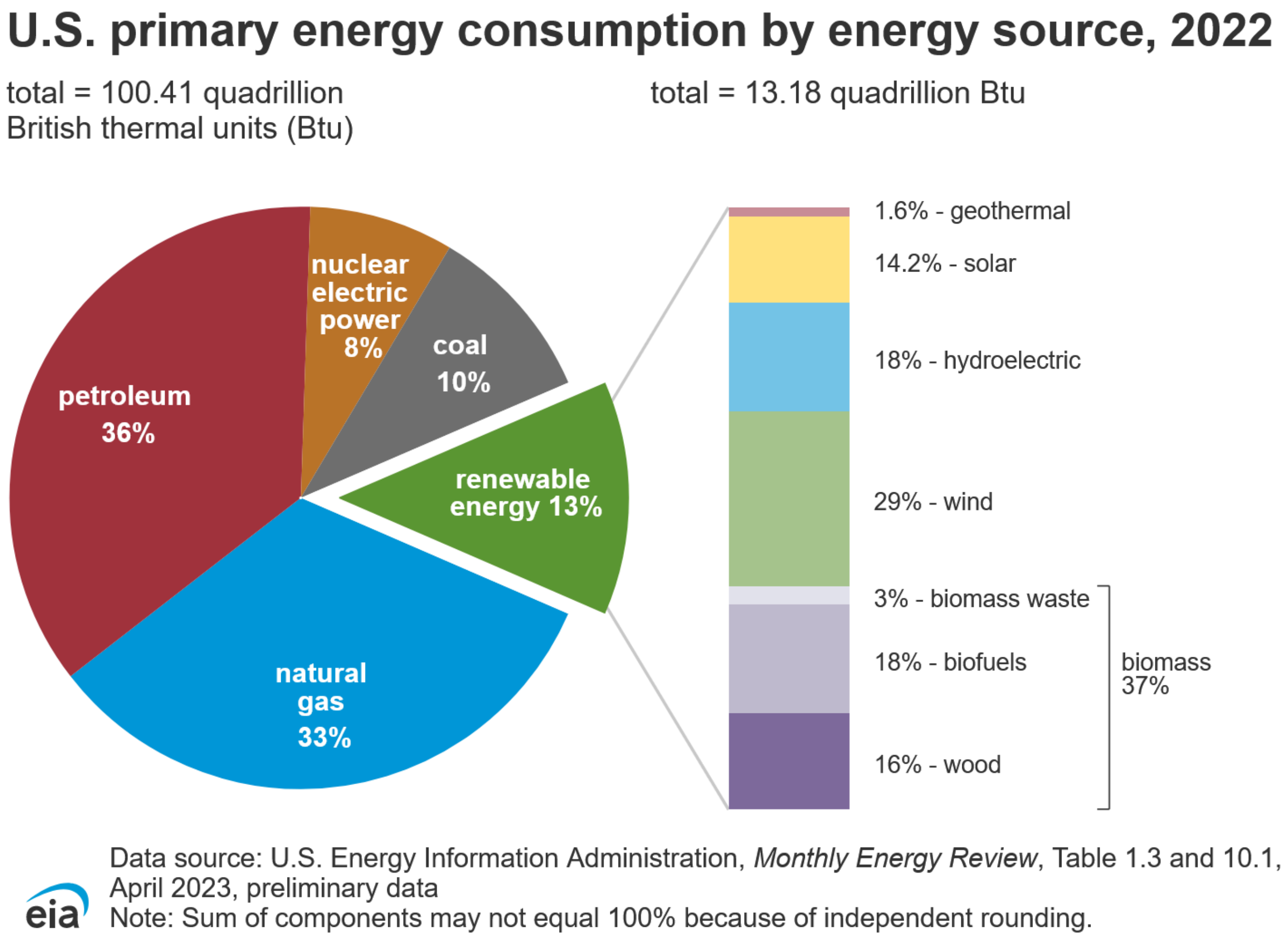
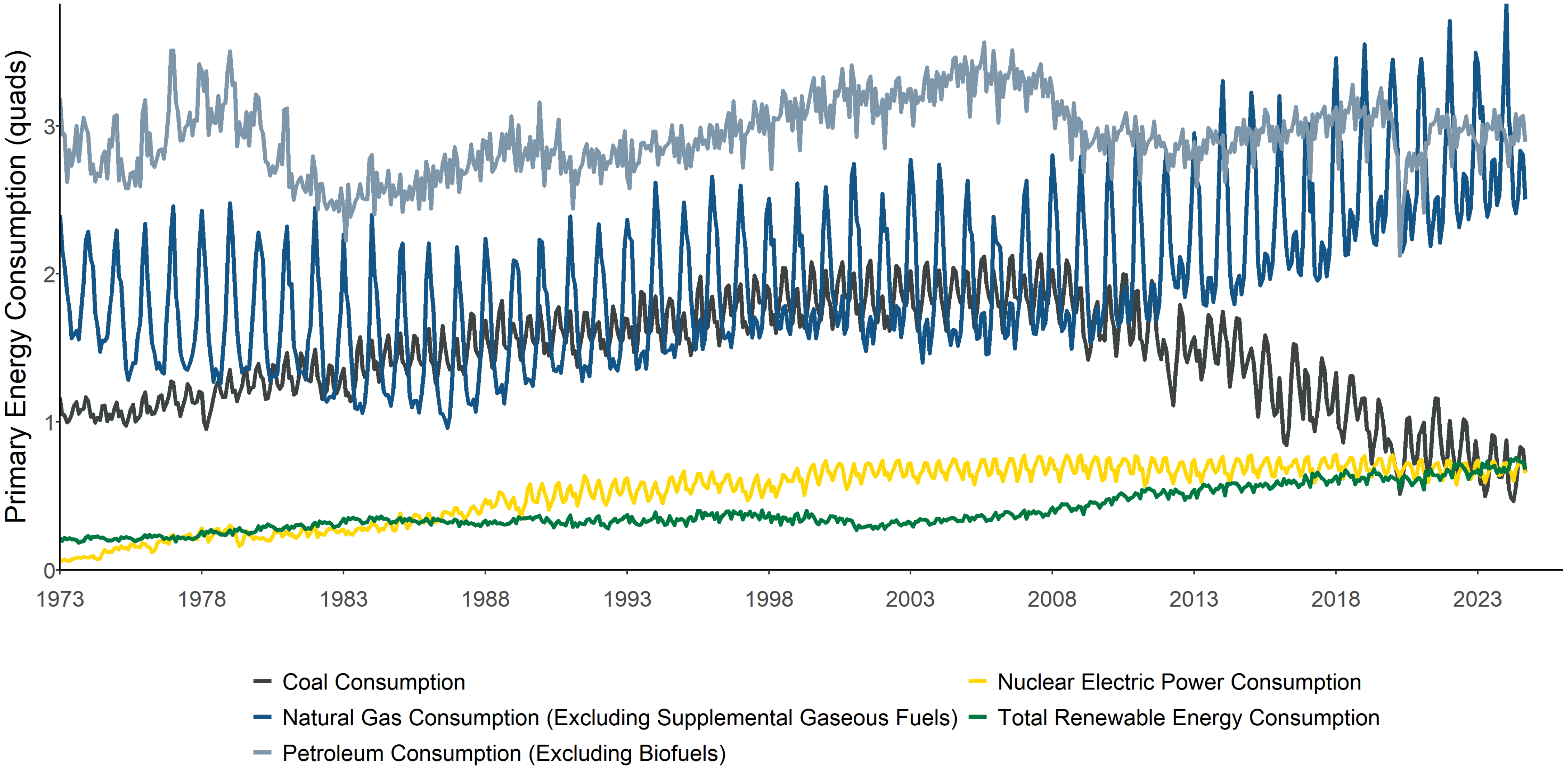
Clean vs. Dirty Energy



This will be the first and (I hope) last pie chart we use in this class

US Primary Energy



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Canadian Primary Energy Production

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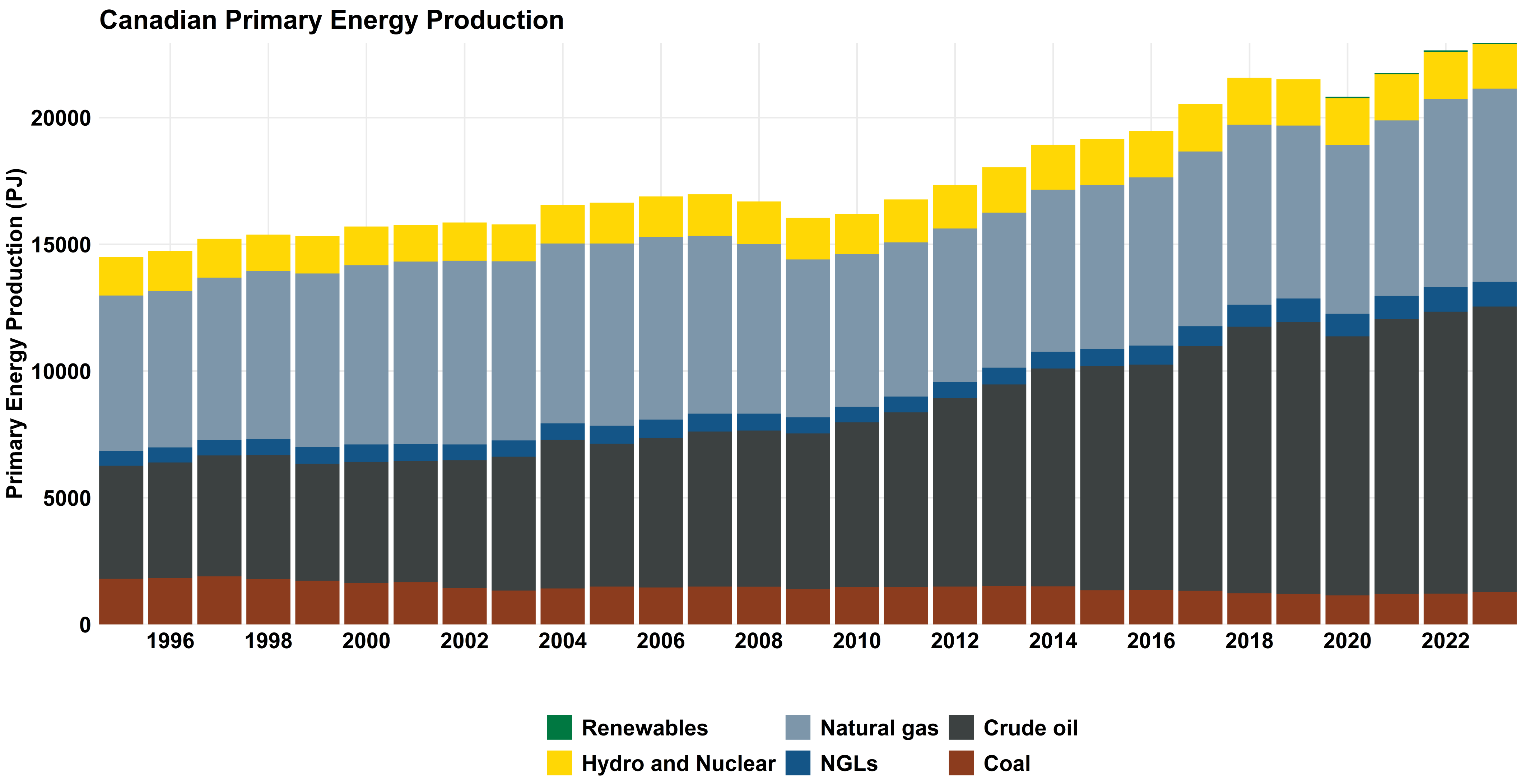
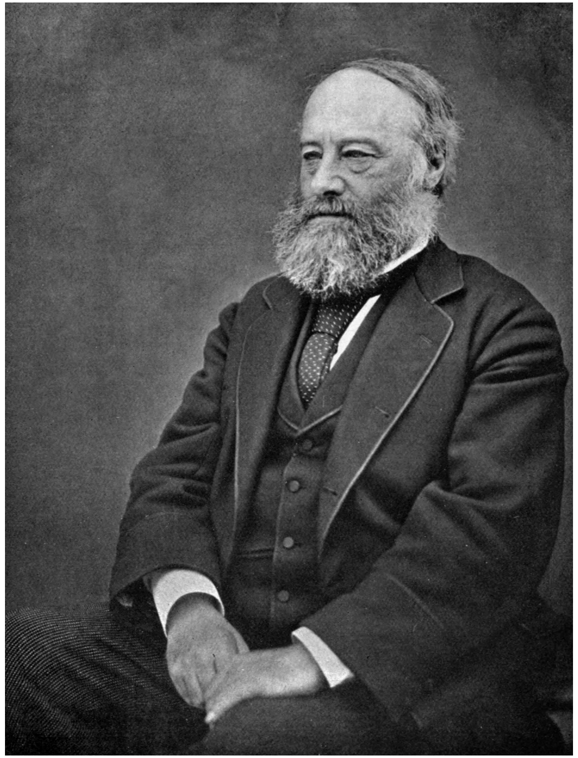


Measurement Classifications

- Volume or mass units: gallons, liters, barrels, cubic meters, tons, tonnes, cords
- Energy value: Calories, Joules, Watts, British thermal unit (BTU), barrel or tonne of oil equivalent (boe or toe)
- Market value: $, €, £, etc.



> "Wherever mechanical force is expended, an exact equivalent of heat is always obtained"
>
> - James Prescott Joule, 1843

Richard Feynman on units of energy

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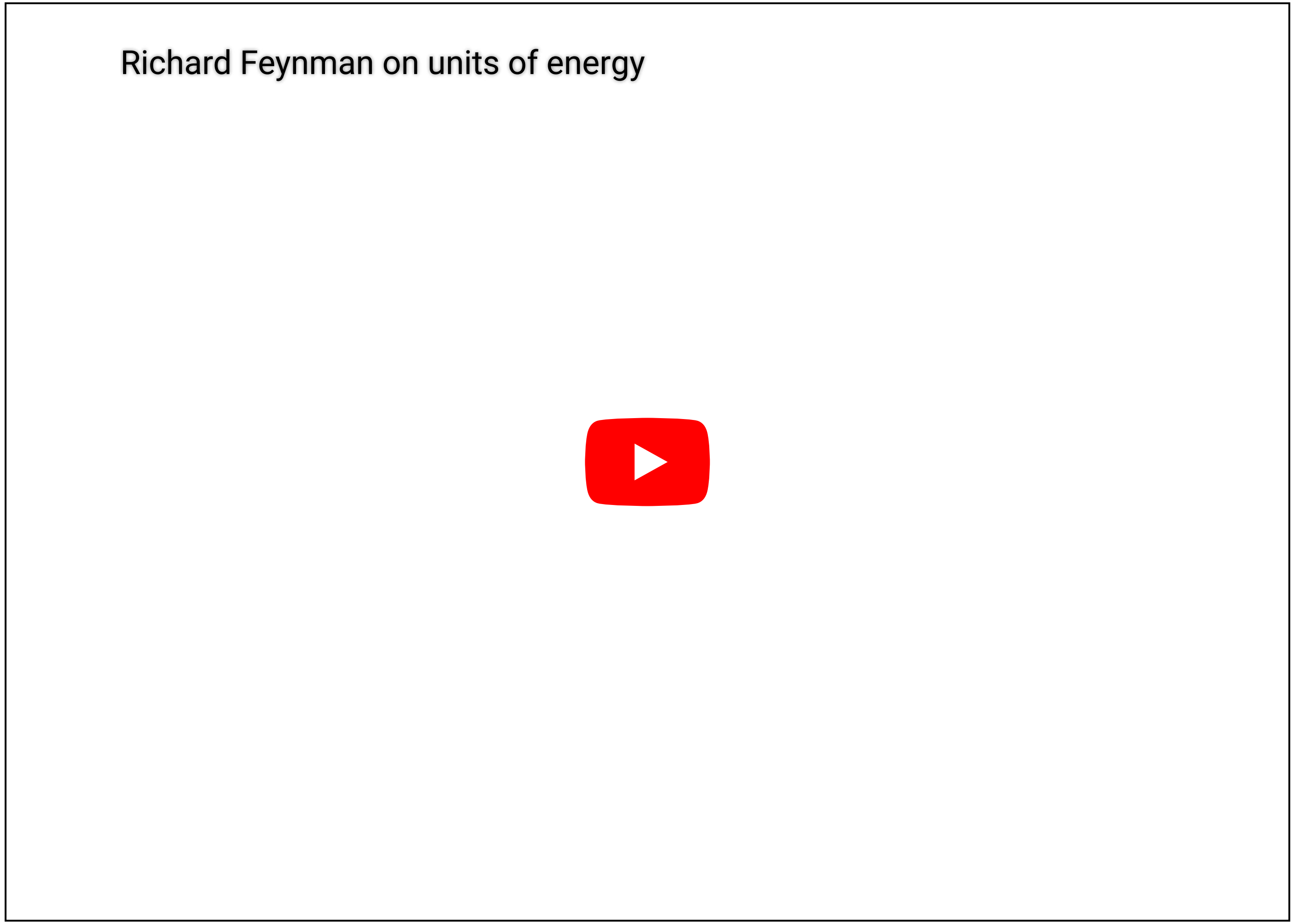

Units

- Newton (N) = $kg \cdot \frac{m}{s^2}$
- Joule (J) = 1 N · m = $kg\frac{m^2}{s^2}$ = Watt · Second
  - J = Watt · s.
- What is a Watt?
  - Hint: Watt=Work/time
- How many J's do average Albertans use annually?
  - 130,000,000,000 J
- Perhaps, we should choose a different unit?
  - 130,000,000,000 J = 130 GJ
- What about for all Albertans?
  - Scale up to a petajoule, PJ, or 10^{15} Joules

Units

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Where might you run into some of these units?

- check you phone/laptop charger (Apple 29W charger, for e.g.)
- check your breaker panel at home - you'll see breakers in amps (15A, 20A, 30A, 40A and maybe 100A breakers)
    - Household circuits are 120 volts or 240 volts (think *pressure* of the electricity)
    - Amps multiplied by volts equals watts, so a 15A breaker at 120 volts (usual room outlets) have a capacity of 15*120=1,800W.
- check your hairdryer (1500W?)

How much energy do appliances use?

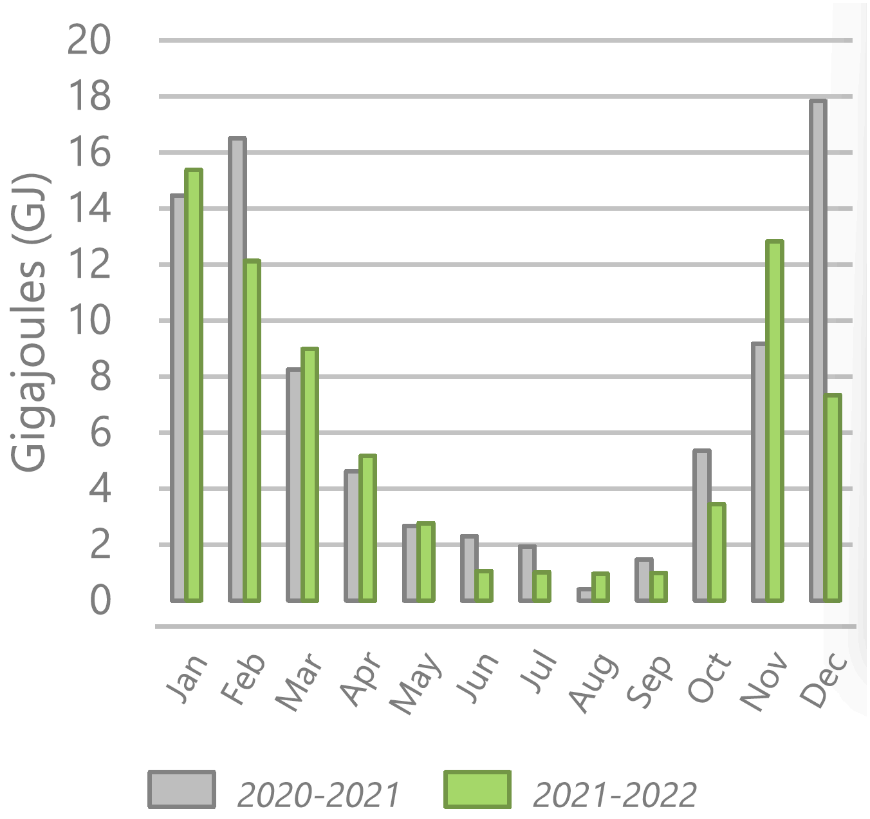
Appliance	Wattage	Hours Per Month	Monthly Consumption (kWh)	$/Month ($0.1524/kWh)
Block Heater	500	120-480	240	$36.58
Clothes Dryer	5000	6-28	140	$21.34
Clothes Washer	500	7-40	20	$3.05
Dishwasher	1300	8-40	52	$7.92
Hair Dryer	1000	1-10	10	$1.52
Kettle	1500	1-10	10	$1.52
Range - Oven	12,500	10-50	625	$95.25
Refrigerator	500	150-300	150	$22.86

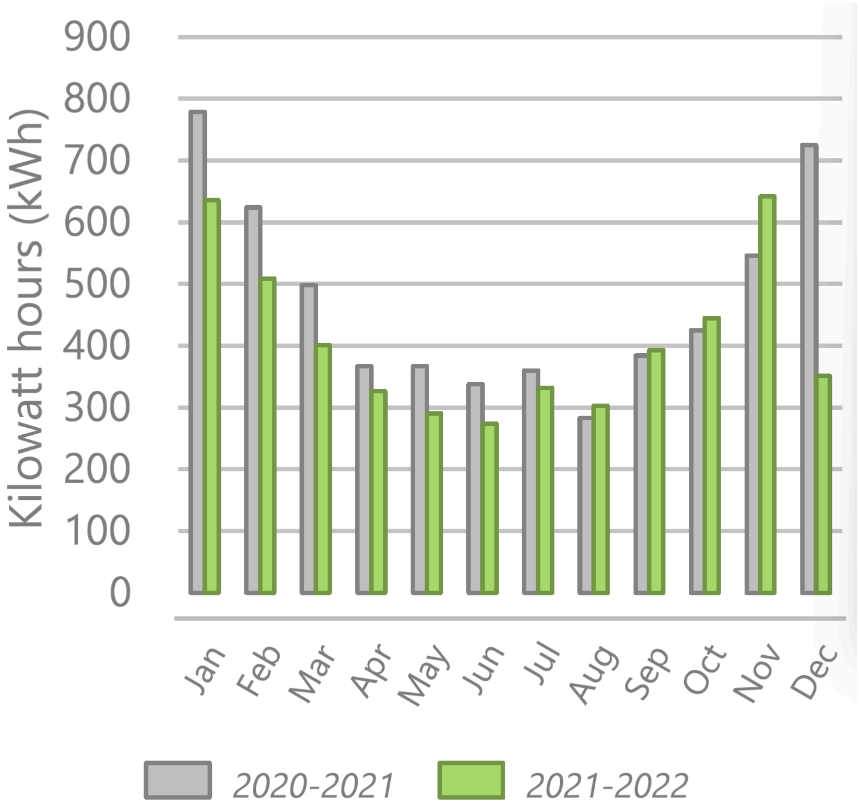
Units

Where might you run into some of these units?

- check you phone/laptop charger (Apple 29W charger, for e.g.)
- check your breaker panel at home - you'll see breakers in amps (15A, 20A, 30A, 40A and maybe 100A breakers)
    - Household circuits are 120 volts or 240 volts (think *pressure* of the electricity)
    - Amps multiplied by volts equals watts, so a 15A breaker at 120 volts (usual room outlets) have a capacity of 15*120=1,800W.
- why are you likely to blow a breaker if you run the toaster and the kettle at the same time?

Units in practice





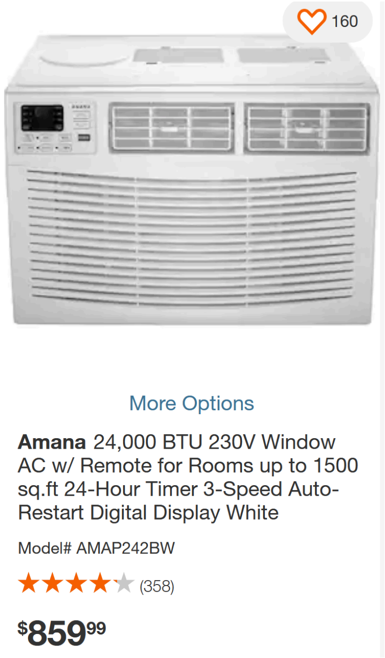
Mechanical energy measurements: kWh

- Typically, electricity is billed per kWh
- What is the relationship between kWh and Joules?
  - 1 kW = 1 kJ/s (a flow)
  - 1 kWh = 1 $\frac{kJ}{s} \times \frac{3600s}{hour}$ = 3600kJ
- How many kWh's do average Albertans use annually?
  - Albertan households use 124.6 GJ of energy per year
  - 124,600 MJ $\times \frac{1kWh}{3.6MJ} \approx$ 34,600 kWh

Thermal energy: Btus and Calories

- Calorie = energy needed to cool or heat one gram of water by one degree C.
- British thermal unit (Btu): amount of energy needed to cool or heat one pound of water by one degree F.
- Question: What does mBtu mean? mmBtu?
- Various conversions:
  - 1 Btu $\approx$ 252.164401 cal
  - 1 Btu $\approx$ 0.947817 kJ

- Common usage - a 24,000 Btu air conditioner means what, exactly?



- Sized by how many Btu of heat it can remove in one hour

Commercial measures: toe and tce

- toe (tonne of oil equivalent) is the amount of energy released by burning one tonne (metric ton) of crude oil
  - 1 toe $\approx$ 7.25 barrel of oil equivalent
  - 1 toe = 41.87 gigajoules (GJ)
  - 1 toe = 39,683,205 Btu (39.7 mmBtu)
- Converting the other way:
  - One tonne of gasoline is 1.070 toe
  - One tonne of diesel oil is 1.035 toe
  - One tonne of Liquefied petroleum gas (propane) is 1.130 toe
- 1 ton of coal equivalent = 1 tce = 29.3076 GJ

Conversion Factor Reference

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General conversion factors for energy

To:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
terajoule (TJ)	1	2.388×10^{2}	2.388×10^{-5}	9.478×10^{2}	2.778×10^{-1}
gigacalorie (Gcal)	4.187×10^{-3}	1	1.000×10^{-7}	3.968	1.163×10^{-3}
million tonnes of oil equivalent (Mtoe)	4.187×10^{4}	1.000×10^{7}	1	3.968×10^{7}	1.163×10^{4}
million British thermal units (MBtu)	1.055×10^{-3}	2.520×10^{-1}	2.520×10^{-8}	1	2.931×10^{-4}
gigawatt hour (GWh)	3.600	8.598×10^{2}	8.598×10^{-5}	3.412×10^{3}	1

Conversion factors for mass

To:	kg	t	lt	st	lb
From:	multiply by:				
kilogramme (kg)	1	1.000×10^{-3}	9.842×10^{-4}	1.102×10^{-3}	2.205
tonne (t)	1.000×10^{3}	1	9.842×10^{-1}	1.102	2.205×10^{3}
long ton (lt)	1.016×10^{3}	1.016	1	1.120	2.240×10^{3}
short ton (st)	9.072×10^{2}	9.072×10^{-1}	8.929×10^{-1}	1	2.000×10^{3}
pound (lb)	4.536×10^{-1}	4.536×10^{-4}	4.464×10^{-4}	5.000×10^{-4}	1

Conversion factors for volume

To:	gal US	gal UK	bbl	ft^3	l	m^3
From:	multiply by:					
US gallon (gal US)	1	8.327×10^{-1}	2.381×10^{-2}	1.337×10^{-1}	3.785	3.785×10^{-3}
UK gallon (gal UK)	1.201	1	2.859×10^{-2}	1.605×10^{-1}	4.546	4.546×10^{-3}
barrel (bbl)	4.200×10^{1}	3.497×10^{1}	1	5.615	1.590×10^{2}	1.590×10^{-1}
cubic foot (ft^3)	7.481	6.229	1.781×10^{-1}	1	2.832×10^{1}	2.832×10^{-2}
litre (l)	2.642×10^{-1}	2.200×10^{-1}	6.290×10^{-3}	3.531×10^{-2}	1	1.000×10^{-3}
cubic metre (m^3)	2.642×10^{2}	2.200×10^{2}	6.290	3.531×10^{1}	1.000×10^{3}	1

Source: IEA (2019), "World energy balances".

Energy Accounting

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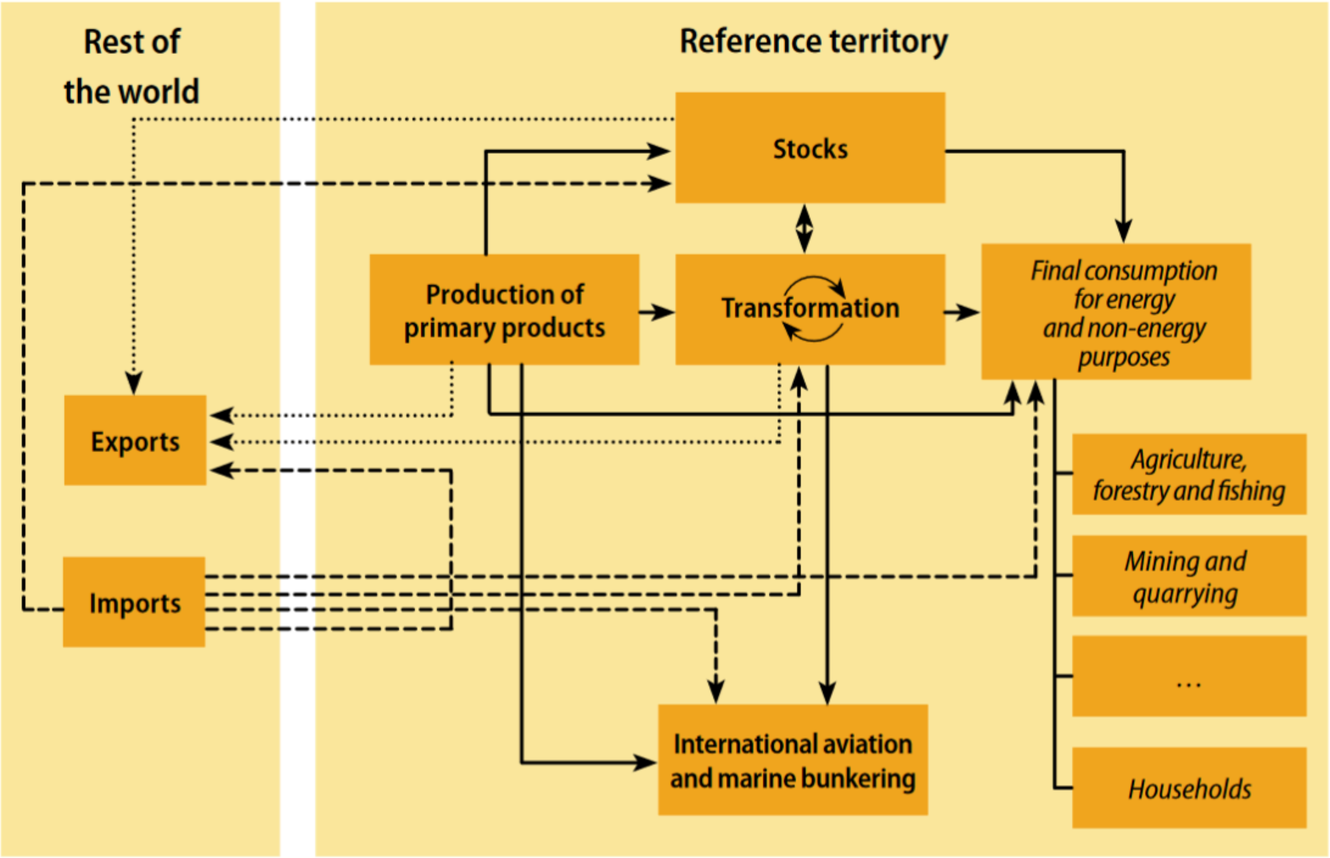
Figure 5.1

Diagram of the main energy flows



[International Recommendations for Energy Statistics (IRES)](#).

Energy Balance

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Table 8.2
Template of an aggregated energy balance

Item code	Flows	Energy products					
							of which:
		E1	E2	E3	...	Total	Renewables
1.1	Primary production						
1.2	Imports						
1.3	Exports						
1.4	International bunkers						
1.5	Stock change (closing-opening)						
1	Total energy supply						
2	Statistical difference						
3	Transfers						
4	Transformation processes						
5	Energy industries own use						
6	Losses						
7	Final consumption						
7.1	Final energy consumption						
7.1.1	Manufacturing, const. and non-fuel mining industries, total						
7.1.1.1	Iron and steel						
7.1.1.2	Chemical and petrochemical						
7.1.1.X	Other industries						
7.1.2	Transport, total						
7.1.2.1	Road						
7.1.2.2	Rail						
7.1.2.3	Domestic aviation						
7.1.2.4	Domestic navigation						
7.1.2.X	Other Transport						
7.1.3	Other, total						
7.1.3.1	*of which*: Agriculture, forestry and fishing						
7.1.3.2	*of which*: Households						
7.2	Non-energy use						

International Recommendations for Energy Statistics (IRES).

You need to know the TPES formula here:

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Canada

2017

SUPPLY AND CONSUMPTION	Coal	Crude oil[1]	Oil products	Natural gas	Nuclear	Hydro	Geotherm./ Solar/ etc.	Biofuels/ Waste	Electricity	Heat	Total
	Million tonnes of oil equivalent										
Production	30.53	249.21	-	153.43	26.35	33.75	2.83	13.56	-	-	509.65
Imports	5.20	45.61	11.51	20.08	-	-	-	1.32	0.85	-	84.56
Exports	-18.50	-180.62	-24.13	-71.05	-	-	-	-1.19	-6.20	-	-301.68
Intl. marine bunkers	-	-	-0.37	-	-	-	-	-	-	-	-0.37
Intl. aviation bunkers	-	-	-0.64	-	-	-	-	-	-	-	-0.64
Stock changes	-0.21	-0.32	-0.32	-1.60	-	-	-	-0.00	-	-	-2.45
TPES	**17.02**	**113.88**	**-13.96**	**100.86**	**26.35**	**33.75**	**2.83**	**13.69**	**-5.35**	**-**	**289.06**
Transfers	-	-10.44	14.36	-	-	-	-	-	-	-	3.92
Statistical differences	0.25	-8.31	11.28	-4.75	-	-	-	0.01	3.08	-	1.56
Electricity plants	-13.78	-	-1.88	-11.23	-26.35	-33.75	-2.78	-1.66	55.61	-	-35.82
CHP plants	-	-	-0.00	-2.49	-	-	-	-0.07	0.99	0.46	-1.11
Heat plants	-0.00	-	-	-	-	-	-	-0.19	-	0.10	-0.09
Blast furnaces	-0.79 e	-	-	-	-	-	-	-	-	-	-0.79
Gas works	-	-	-	-	-	-	-	-	-	-	-
Coke/pat. fuel/BKB/PB plants	-0.03	-	-	-	-	-	-	-	-	-	-0.03
Oil refineries	-	-98.00	95.87	-	-	-	-	-	-	-	-2.14
Petrochemical plants	-	-	-	-	-	-	-	-	-	-	-
Liquefaction plants	-	-	-	-	-	-	-	-	-	-	-
Other transformation	-	2.88	-	-2.85	-	-	-	-	-	-	0.04
Energy industry own use	-	-	-16.13	-31.96	-	-	-	-0.00	-4.18	-	-52.27
Losses	-	-	-	-	-	-	-	-	-6.42	-	-6.42
TFC	**2.66**	**-**	**89.54**	**47.59**	**-**	**-**	**0.04**	**11.78**	**43.74**	**0.57**	**195.93**

Production+imports-exports- net stock additions (i.e closing-opening) - net bunker additions (i.e. closing-opening)

Source: IEA (2019), World energy balances.

Accounting in Practice: Canadian natural gas

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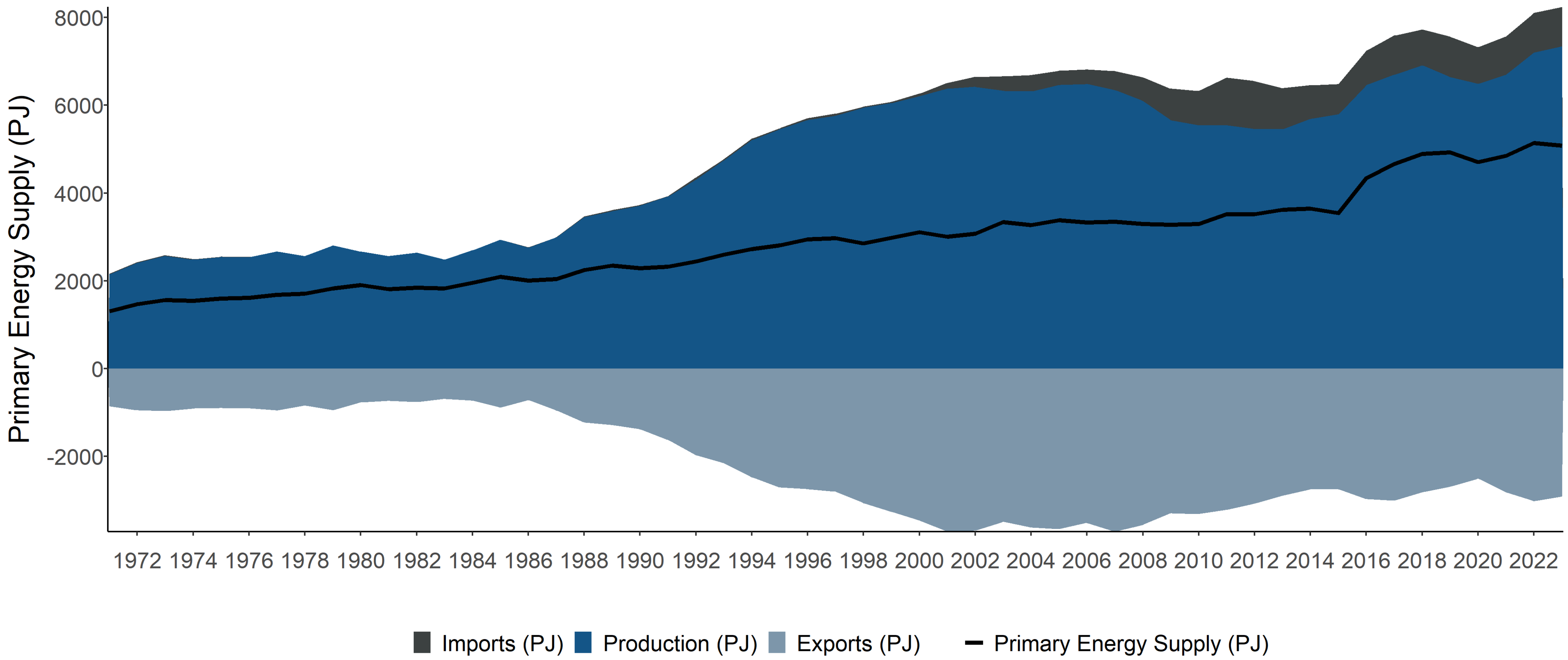

Source: IEA (2024)

Energy Flow Visuals

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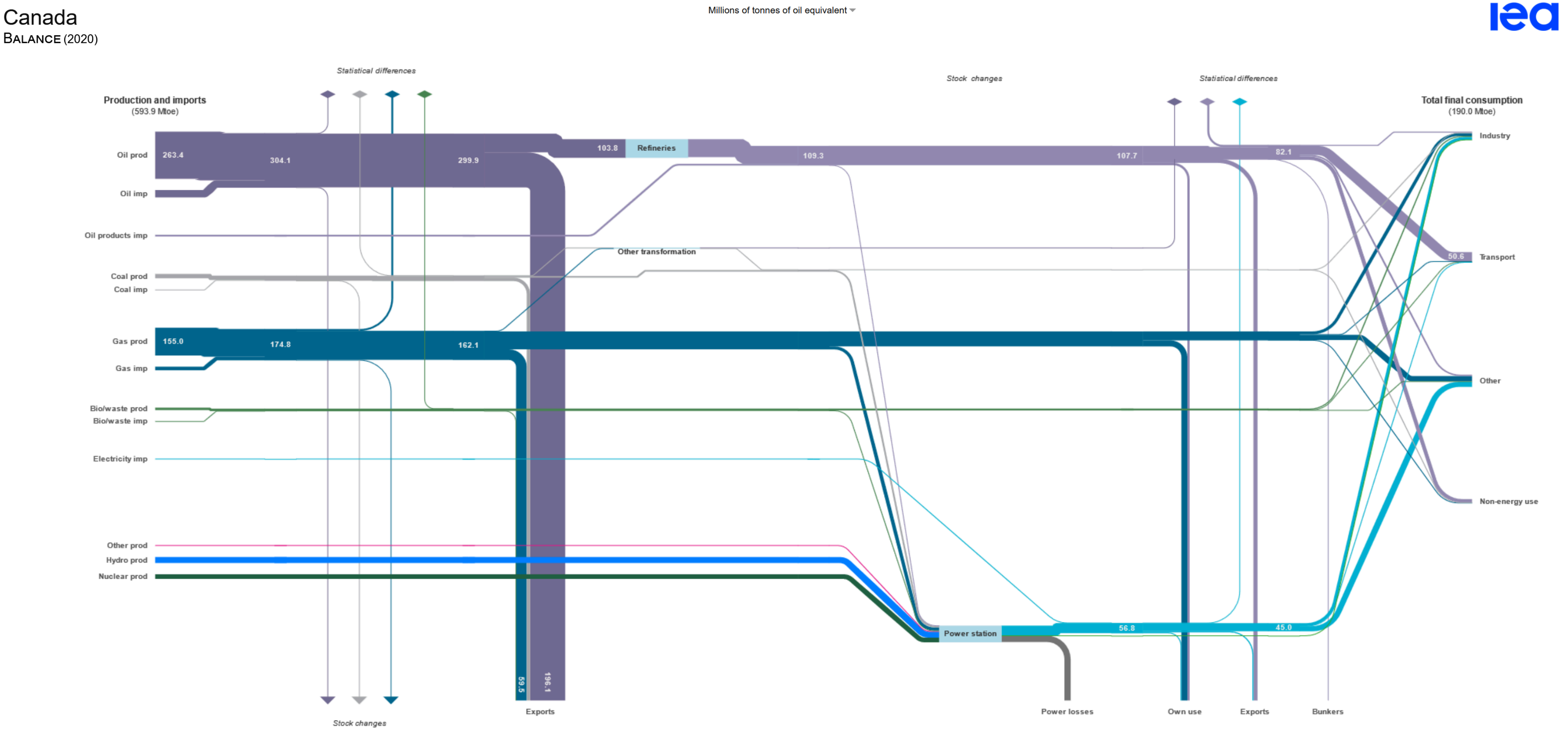
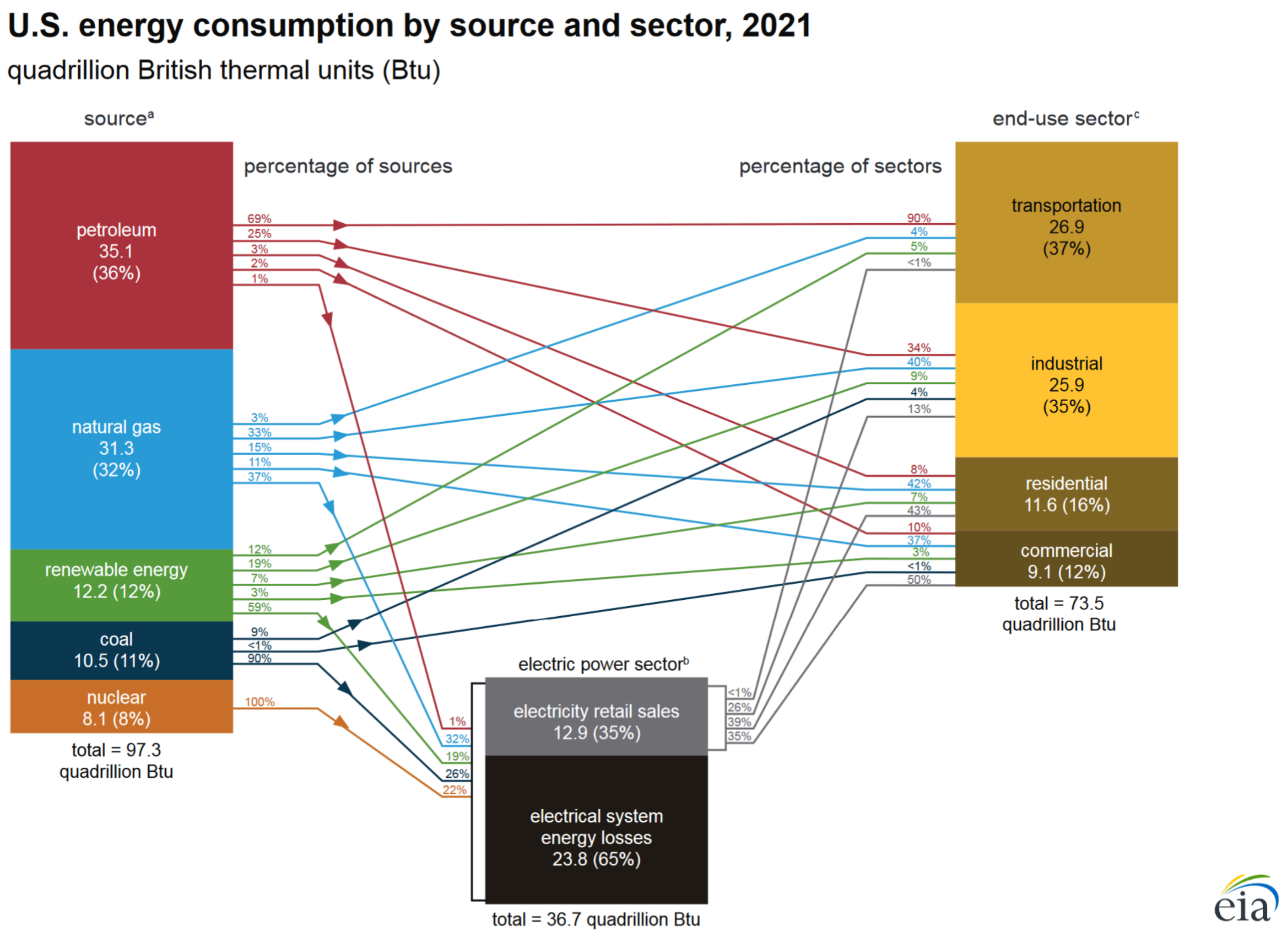


[Source data: IEA (2022), Sankey diagrams, Canada]

Energy Use by Sector and Source



[EIA Energy Facts Explained]