Lecture 05
Transportation and mobility

CIVIL-239: Engineering a sustainable built environment

08.10.2025

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Housekeeping

- Assignment 2 due now
- Assignment 3 out today, due Oct 29 (in 3 weeks) before midterm exam
- Indicative feedback
  - This is very helpful for me!

Midterm Exam

- Oct 29, 10:15-12:00
- 3 rooms: AAC 014, 008, 020
  - Last name A-D: 014
  - Last name F-M: 008
  - Last name N-Z: 020
- Closed book and notes
- Covers lectures 1-6
- Mix of multiple choice and open-ended questions
- Not intended to test memorization, but rather understanding of the material

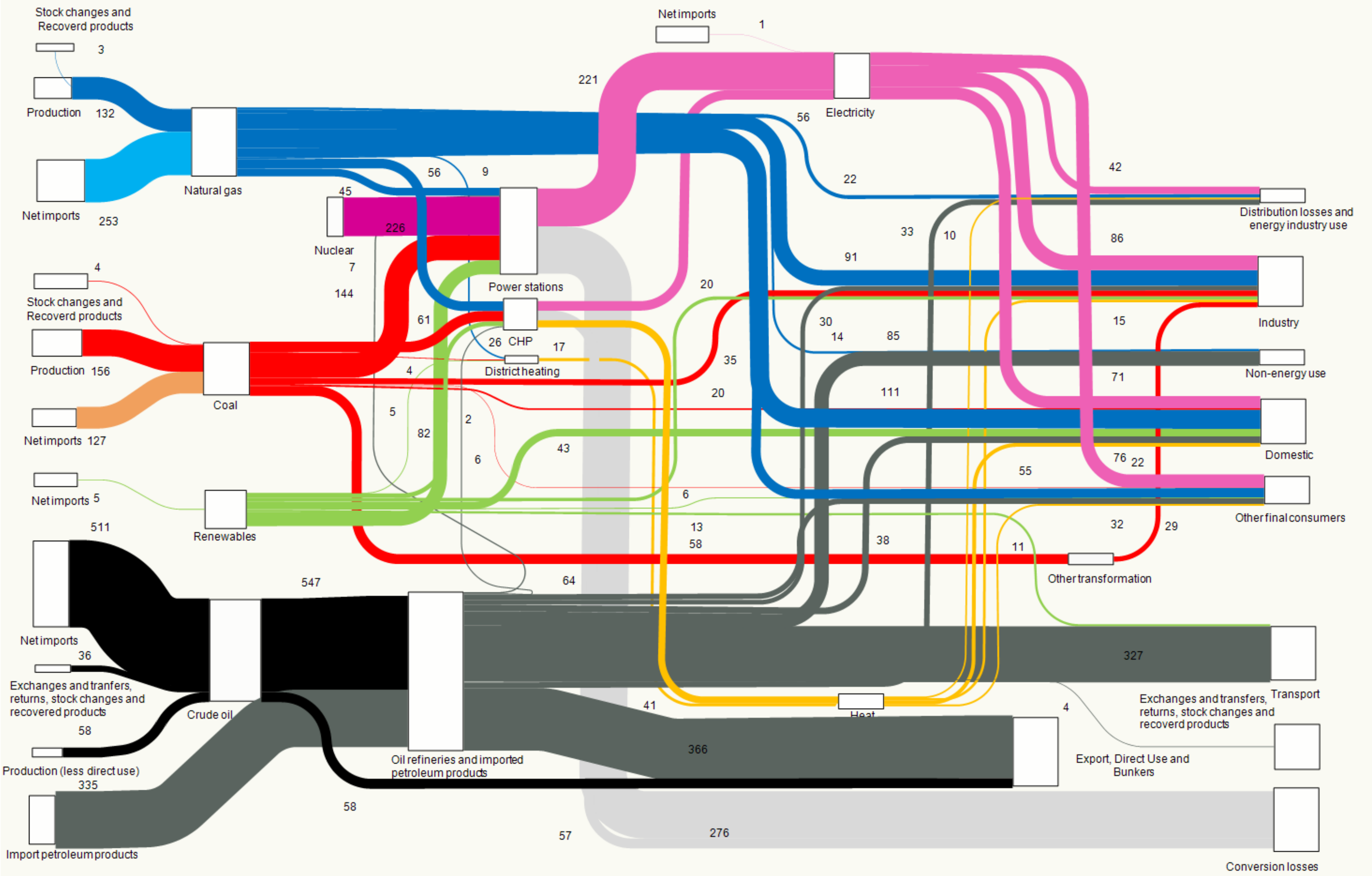
Week	Date	Course Content	Engineering knowledge and tools	Due
	Course introduction			
1	10-Sep	The climate crisis What is sustainability? Sustainability in civil engineering	The role of the built environment in sustainability	
2	17-Sep	Sustainability indicators New economic thinking	The importance of data	
	Buildings and energy			
3	24-Sep	Energy demand: buildings and infrastructure	How design impacts energy demand; Energy and load calcs	Assignment 1
4	1-Oct	Energy supply: Renewables, the grid, and grid integration	Interface between the built environment and energy systems; time-series data analysis	
	Mobility and sustainability			
5	8-Oct	Transportation systems	Link between transportation and energy; systems thinking	Assignment 2
6	15-Oct	Sustainable urban design and active mobility Social systems	System dynamics	
7	22-Oct	No Class - Fall Break		
8	29-Oct	***Midterm exam – CE 1 1***		Assignment 3

Outline

- Energy and carbon emissions from transportation and mobility
- Comparing modes of transportation
    - Aviation
    - Personal vehicles
    - **Working with proper units for energy comparisons**
- Systems thinking introduction and example
    - **Causal loop diagrams**
    - **Feedback loops**

Overview of the EU28 energy system in million tons oil equivalent (MTOE)

Supply



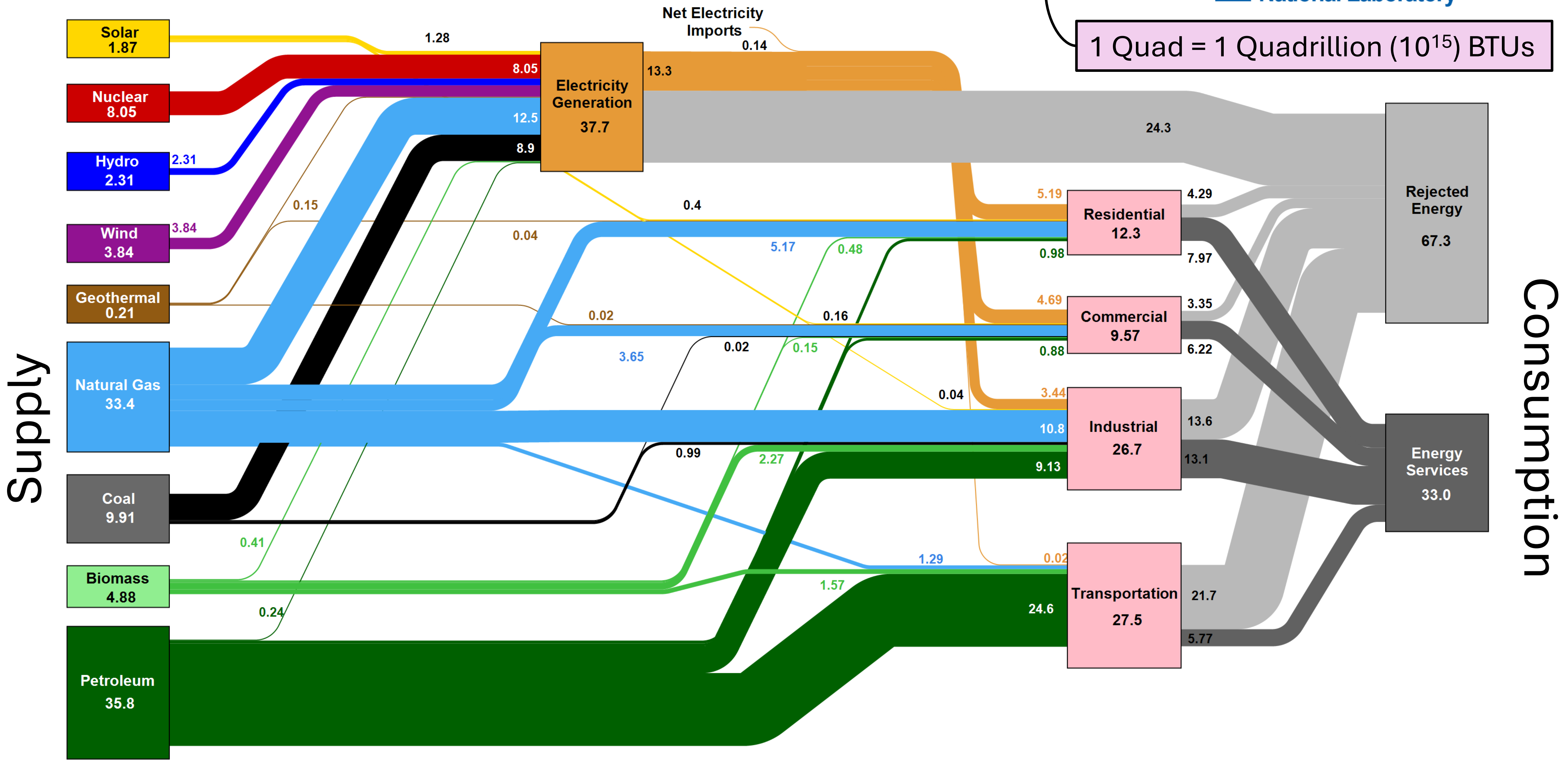
Consumption

Source: European Environment Agency

Estimated U.S. Energy Consumption in 2022: 100.3 Quads

Lawrence Livermore National Laboratory

1 Quad = 1 Quadrillion (10^{15}) BTUs



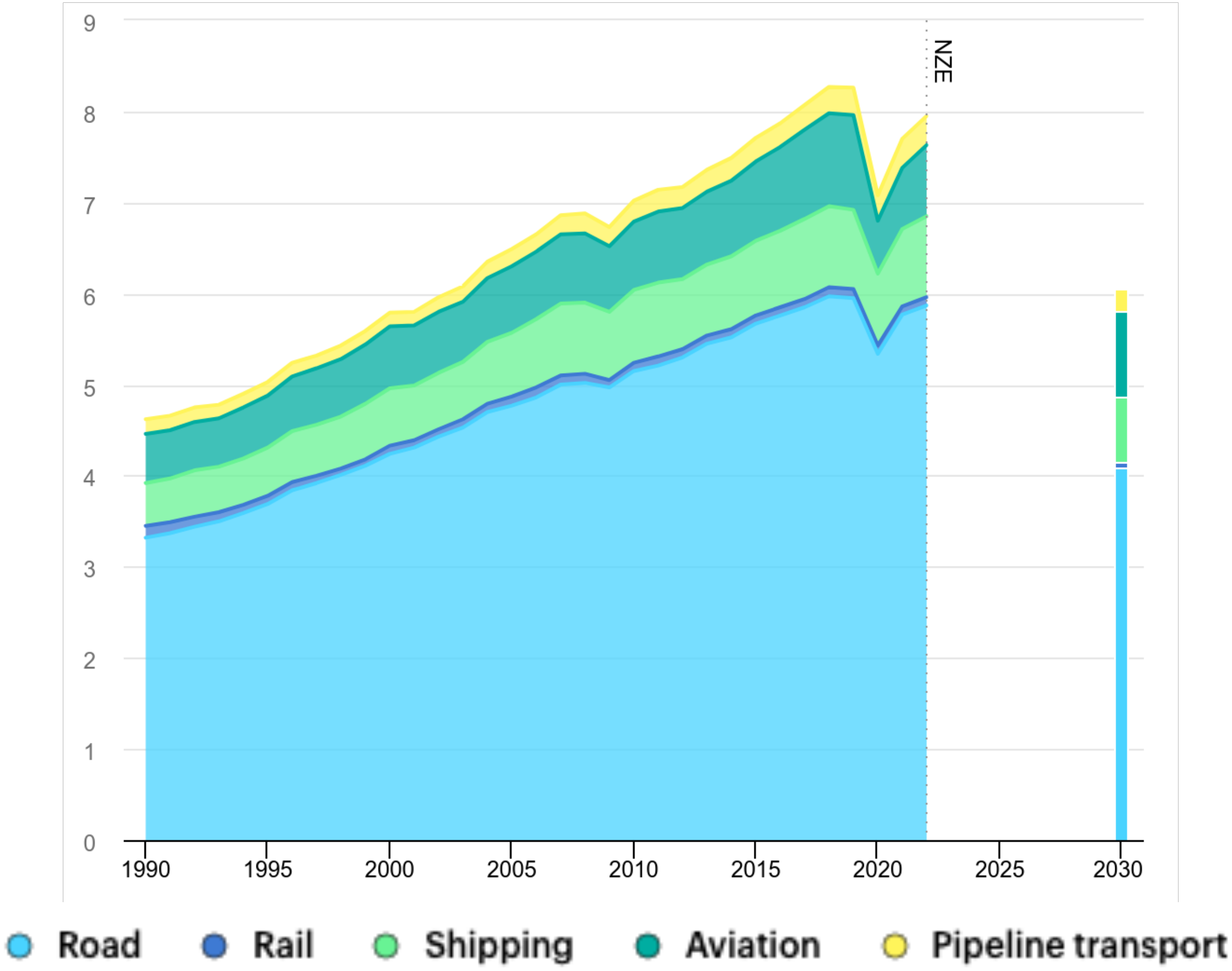
Source: LLNL July, 2023. Data is based on DOE/EIA SEDS (2021). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity 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 0.65% for the residential sector, 0.65% for the commercial sector, 0.49% for the industrial sector, and 0.21% for the transportation sector. Totals may not equal sum of components due to independent Rounding. LLNL-MI-410527

How to read a Sankey Diagram

Spend some time thinking about where the blue numbers come from:

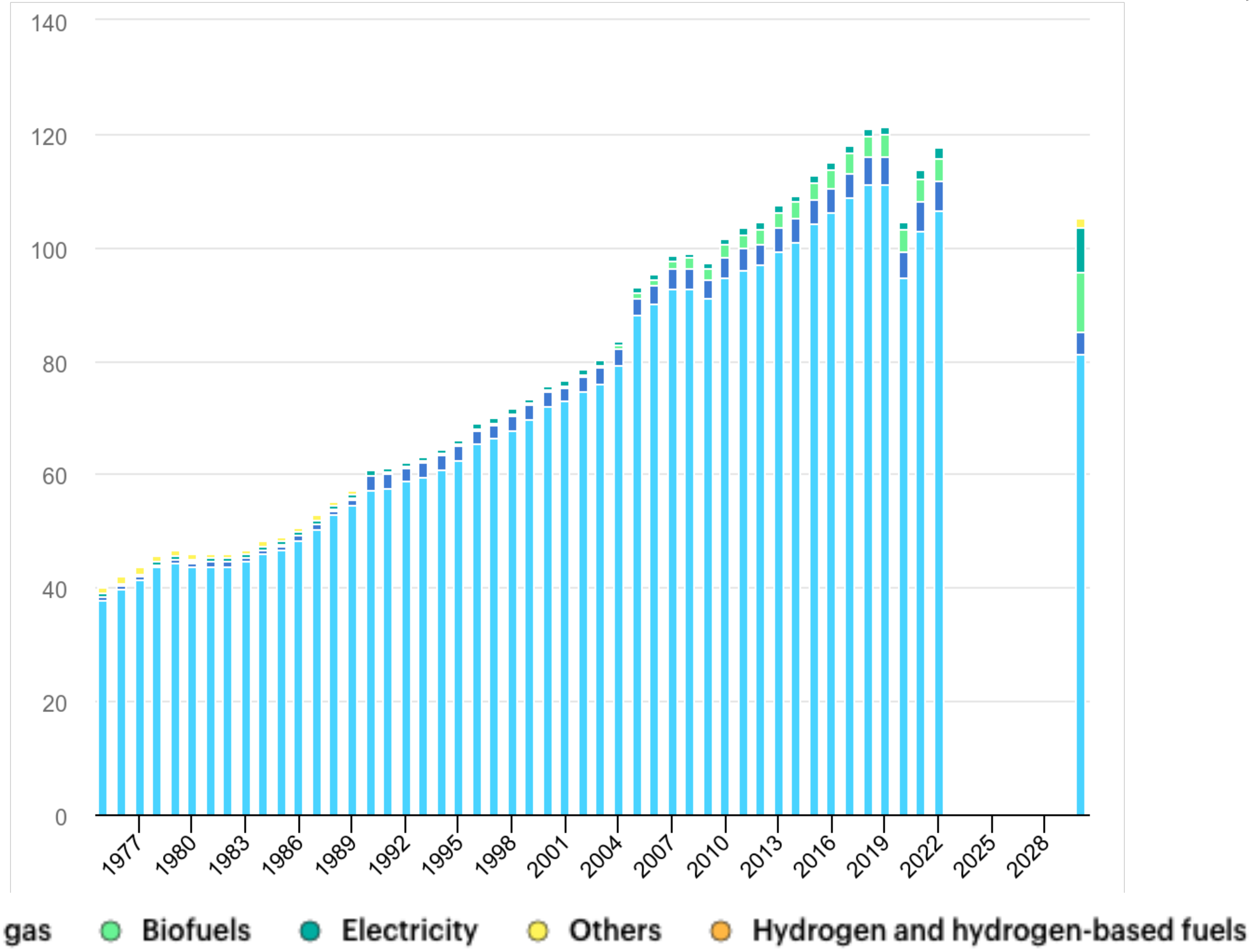
- Petroleum = 35.8 / 100.3 quads total = 36% of all US primary energy
- Petroleum to transport = 24.6 / 35.8 = 69% of all petroleum use
- Transportation = 27.5 / 76.1 = 36% of all sector energy use
- Energy services = 5.77 / 27.5 = 21% of energy input becomes services
- Rejected energy = 21.7 / 27.5 = 79% of energy input is wasted

Global CO2 emissions from transport (Gt CO2)



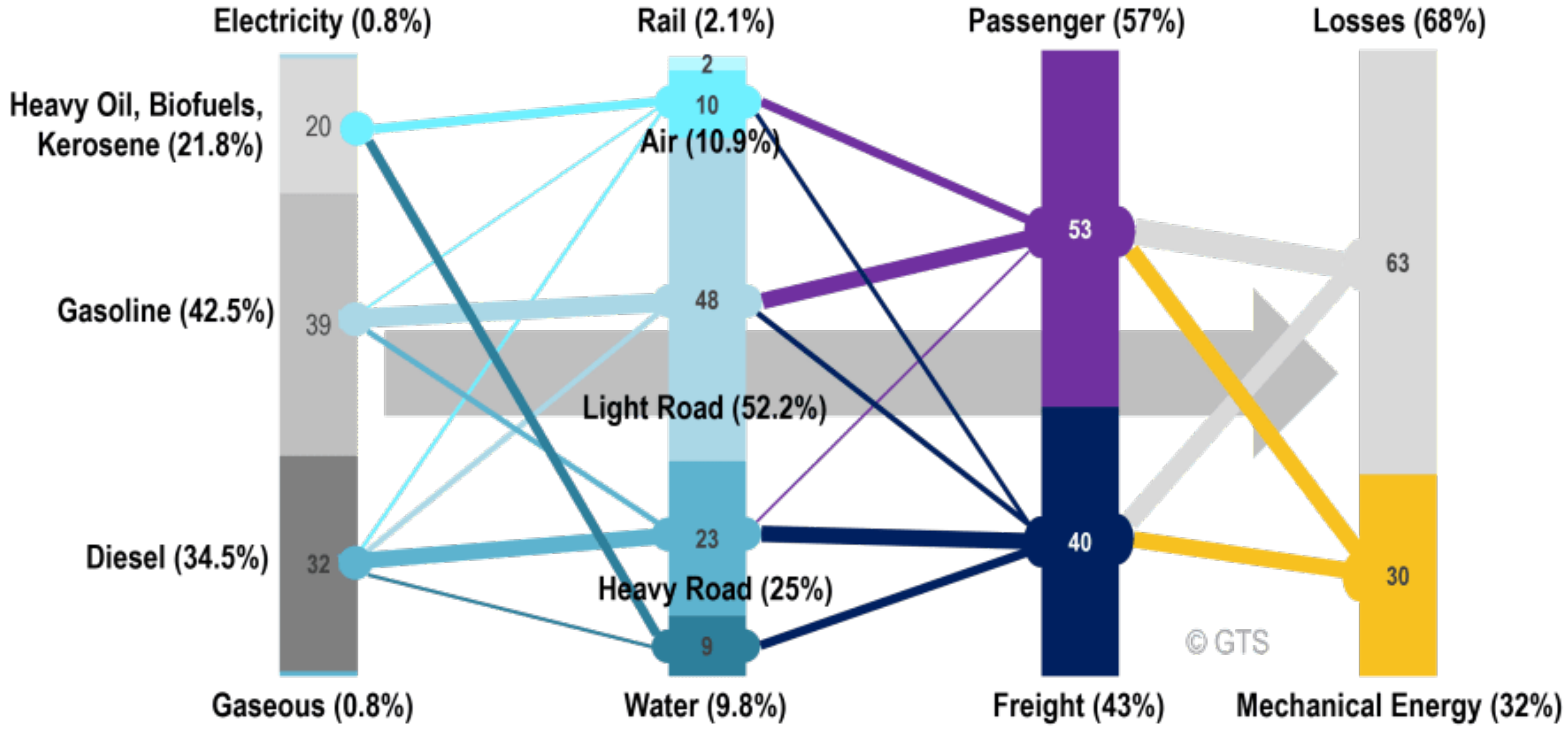
IEA (2023), Global CO2 emissions from transport by sub-sector in the Net Zero Scenario, 2000-2030

Energy consumption in transport by fuel (EJ)



IEA (2023), Energy consumption in transport by fuel in the Net Zero Scenario, 1975-2030

Sankey Diagram of Transportation Energy



Note: lots of wasted energy. Transportation systems are not very energy efficient!

Note: numbers are from 2014 and global (source: IPCC) which is why they are different compared to slides 7/8

Source: The Geography of Transport Systems

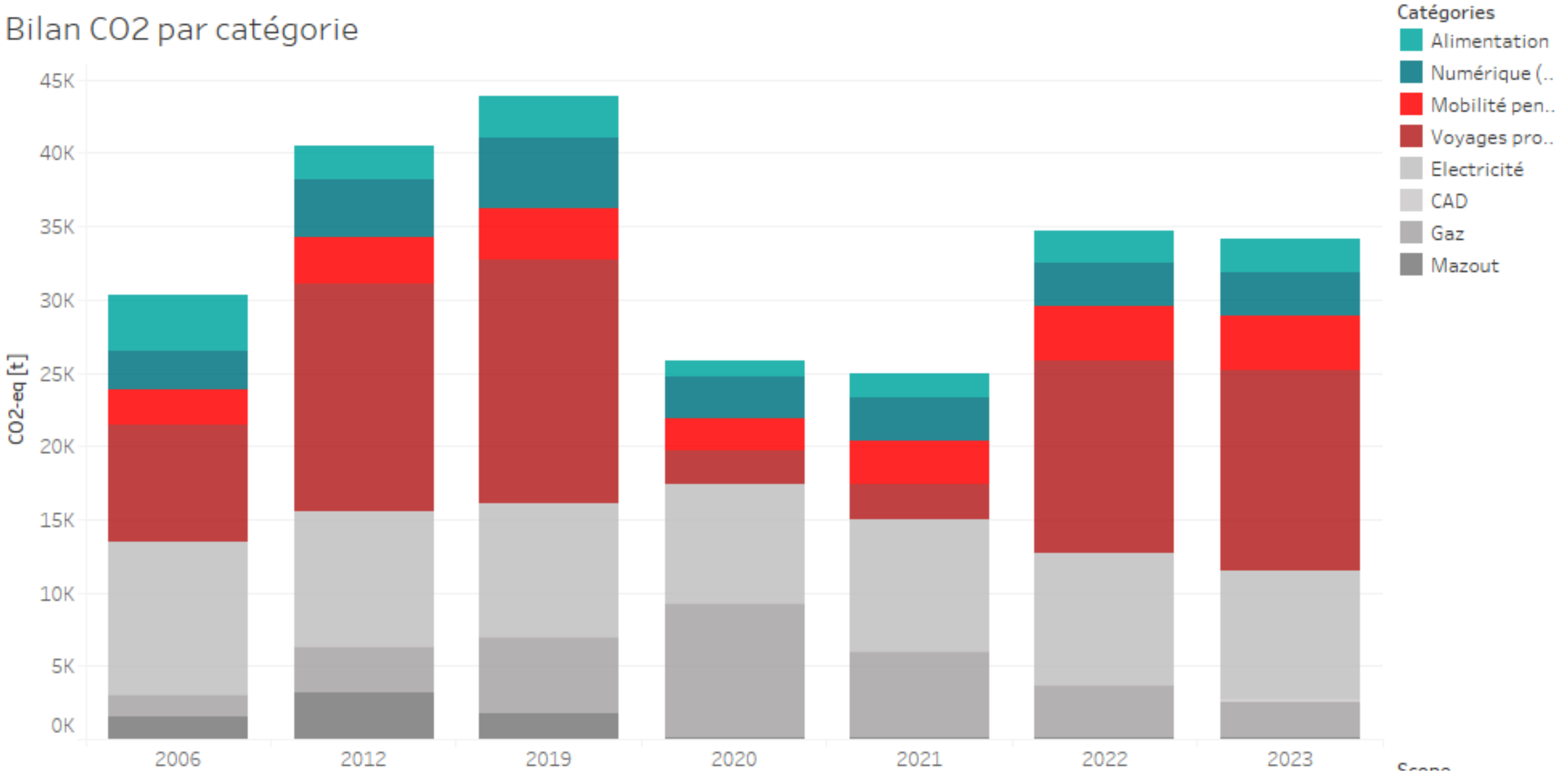
EPFL’s Total Carbon Emissions

34,166
tonnes de CO2-eq émises par l’EPFL pour l’année 2023

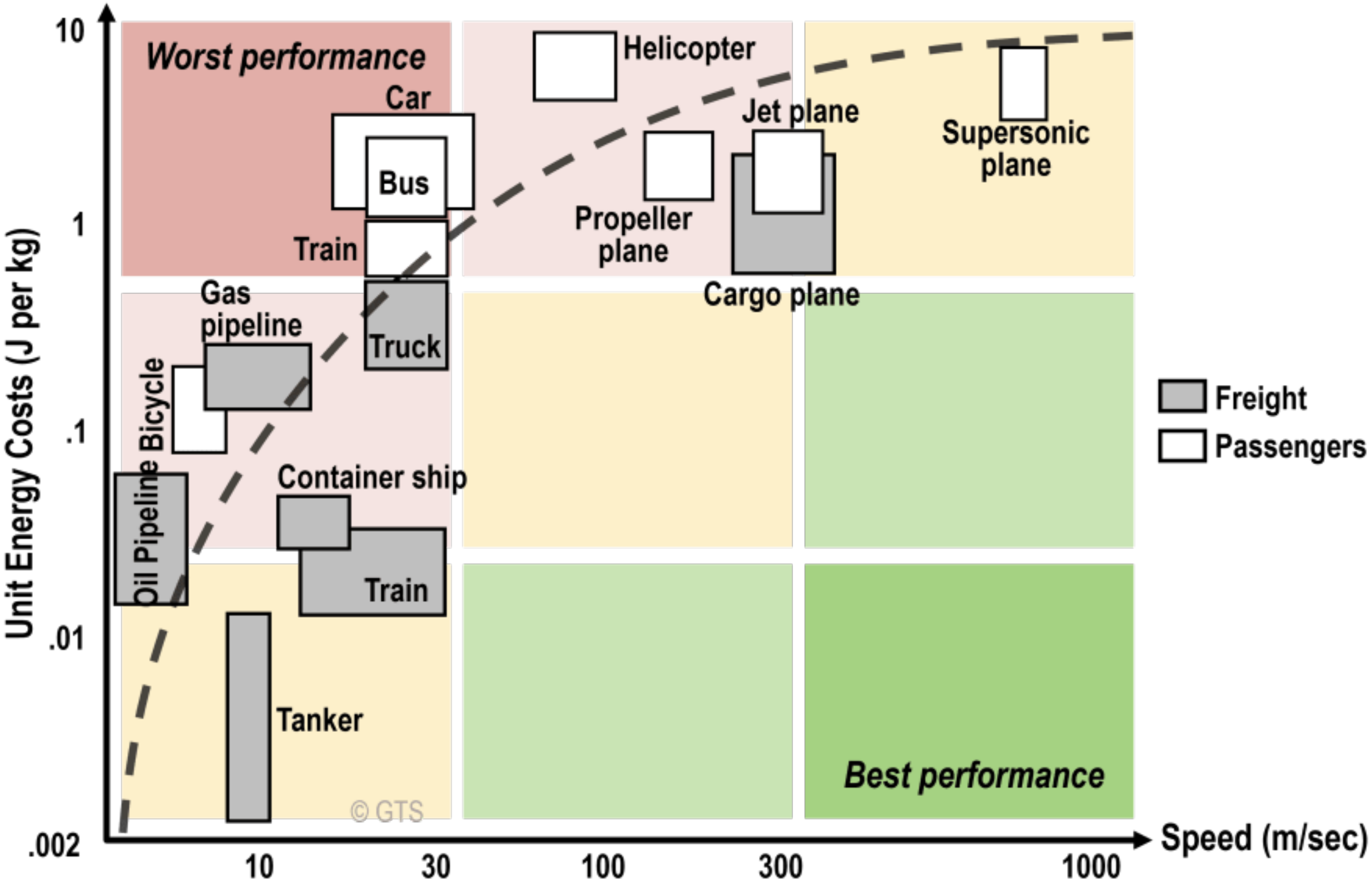
Année
2023

Catégories
Multiple values

Années
Multiple values



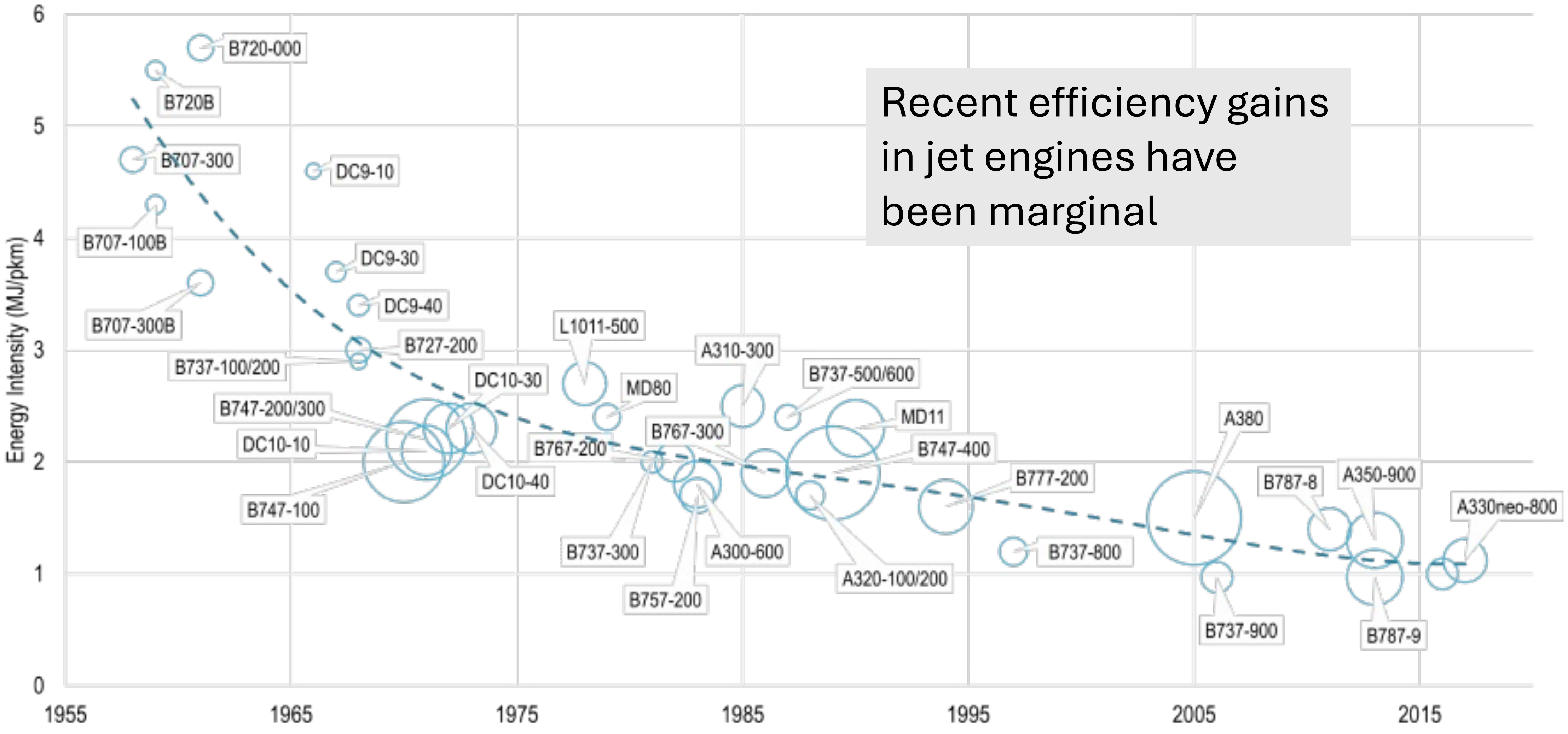
Transportation energy vs. speed



Source: The Geography of Transport Systems

Visualizing air travel carbon emissions

Why is it so hard to decarbonize air travel?

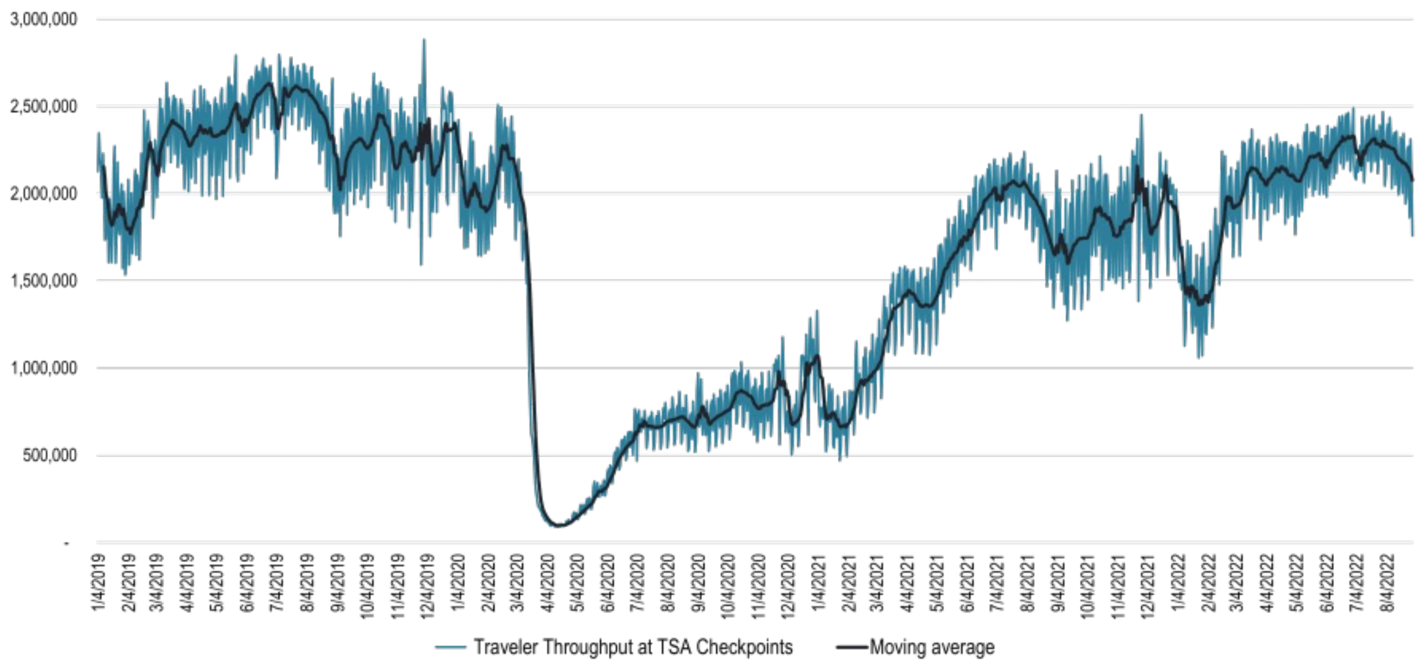


Recent efficiency gains in jet engines have been marginal

Source: The Geography of Transport Systems

Why is it so hard to decarbonize air travel?

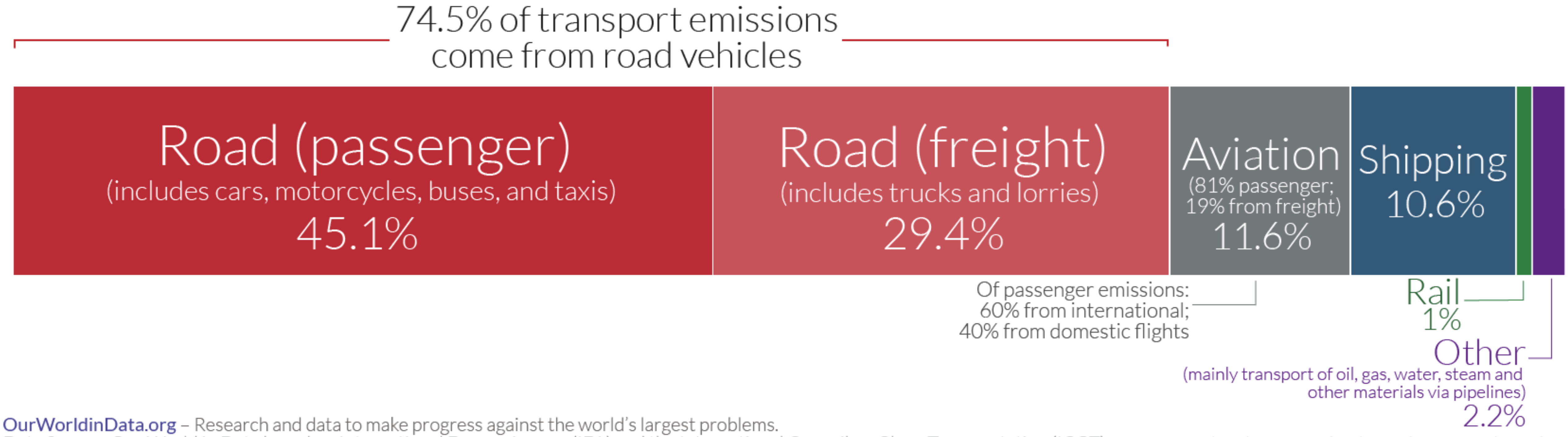
- Sustainable Aviation Fuels (SAFs)
  - Derived from biomass
  - Expensive
  - Still have environmental impacts (e.g. land use change)
- Zero-emission planes
  - Use electricity or hydrogen
  - Expensive
- Changing behavior
  - We have already bounced back from COVID
  - But trains are a good substitute for shorter trips



Source: The Geography of Transport Systems

Global CO_2 emissions from transport

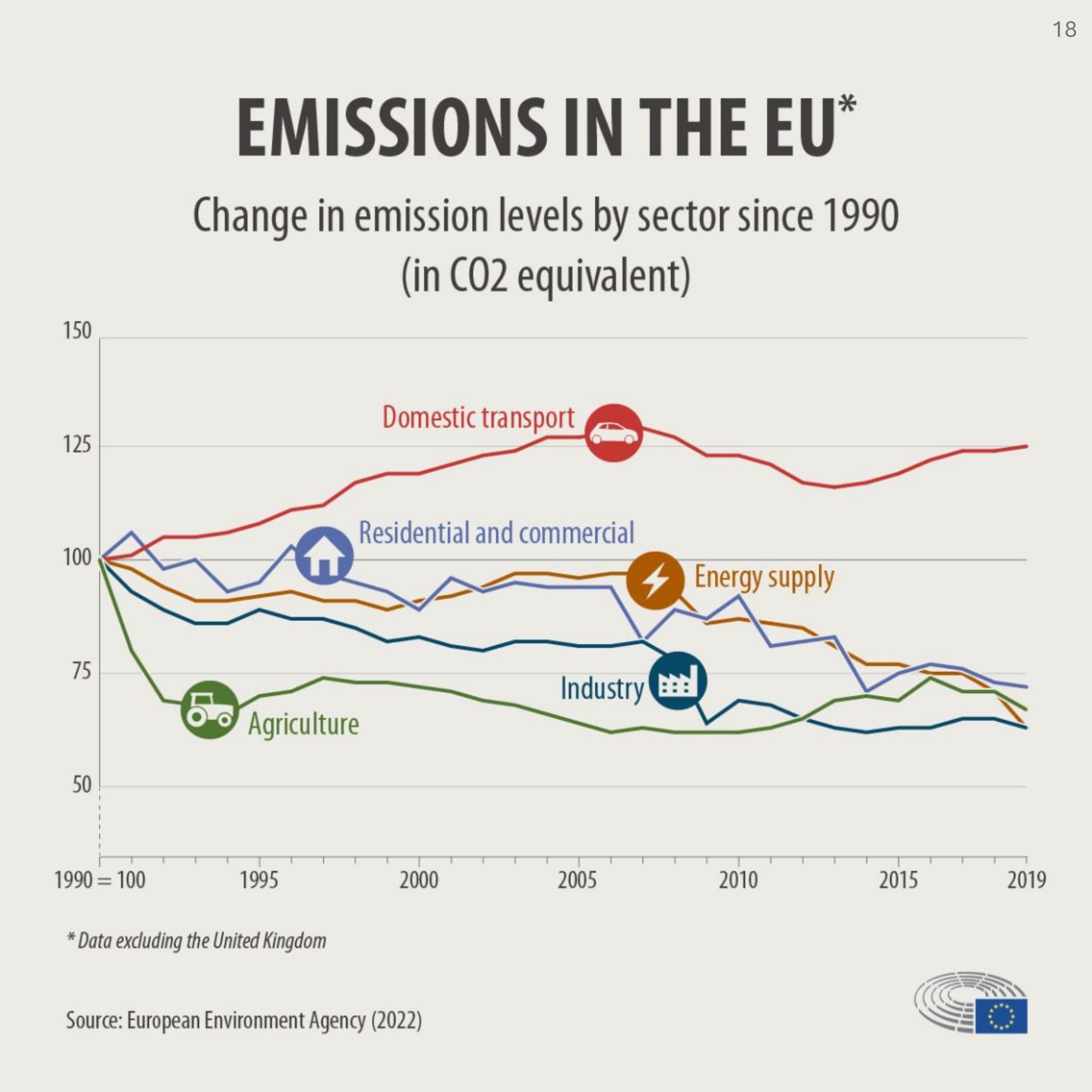
This is based on global transport emissions in 2018, which totalled 8 billion tonnes CO_2.
Transport accounts for 24% of CO_2 emissions from energy.



OurWorldinData.org – Research and data to make progress against the world's largest problems.
Data Source: Our World in Data based on International Energy Agency (IEA) and the International Council on Clean Transportation (ICCT).

Relative change in CO2 emissions by sector

- Every sector except transport has seen improvement in emissions compared to 1990
  - e.g. efficiency improvements in buildings



How to reduce emissions from personal vehicles?

- Improve fuel efficiency
- Switch to electric vehicles
- Switch to other forms of transit
- How to quantify impacts?

Fuel efficiency example

- SUV: 10 L / 100km
- Energy density of vehicle fuel: 34.2 MJ/L
- What is the energy consumption in kWh over 100km?

$$\frac{10\ L}{100\ km} \times \frac{34.2\ MJ}{L} \times \frac{10^6\ J}{MJ} \times \frac{1\ W}{1\ \frac{J}{s}} \times \frac{1\ h}{3600\ s} \times \frac{1\ kW}{1000\ W}$$

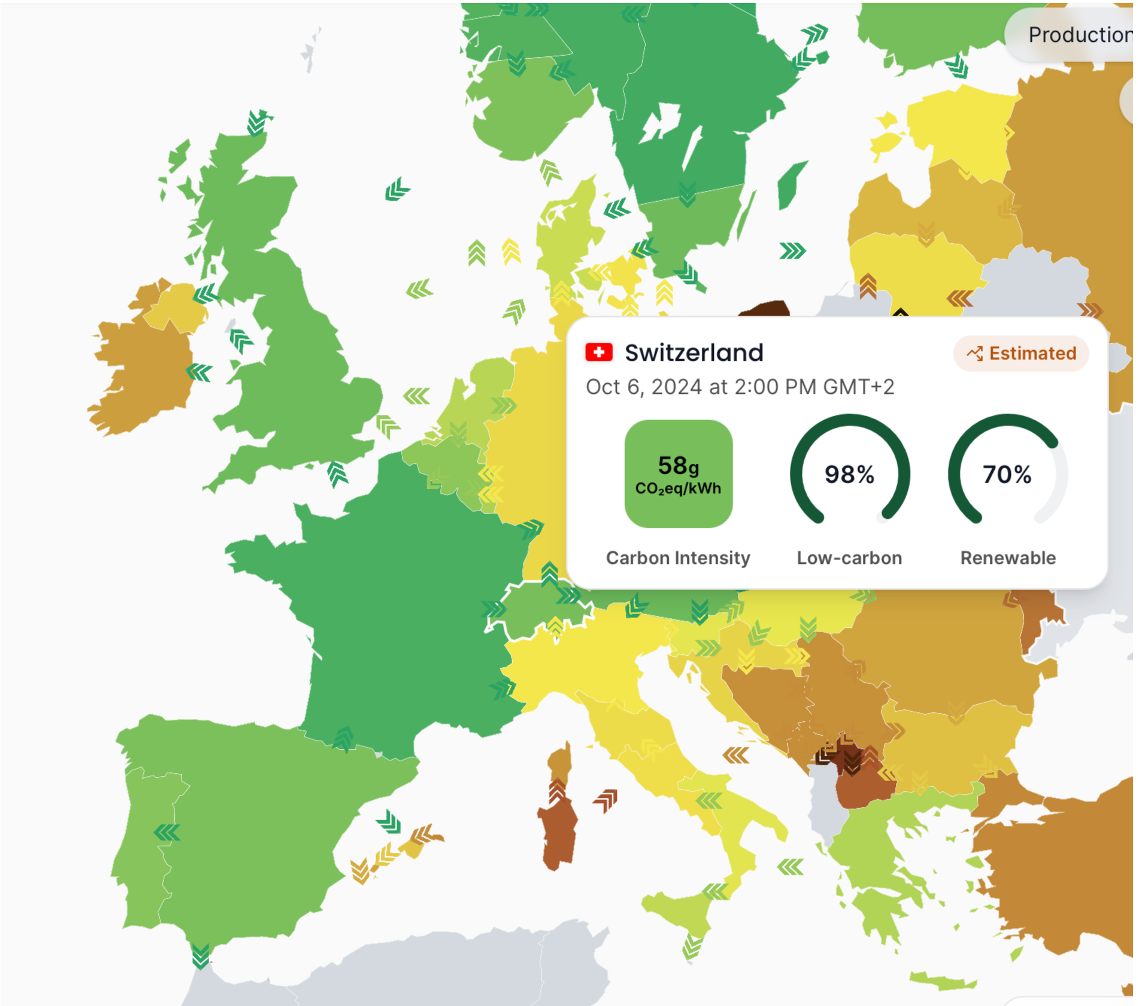
$$= 95\ \frac{kWh}{100\ km}$$

Improving fuel efficiency

- Sport Utility Vehicle (SUV):
  10 L/100km → 95 kWh/100km
- Hybrid:
  4 L/100km → 38 kWh/100km
- Electric vehicle?
  - Data taken from Tesla Model 3 Wikipedia page:
  - Battery: 57.5 kWh
  - Range: 438 km
  - 13.1 kWh/100km

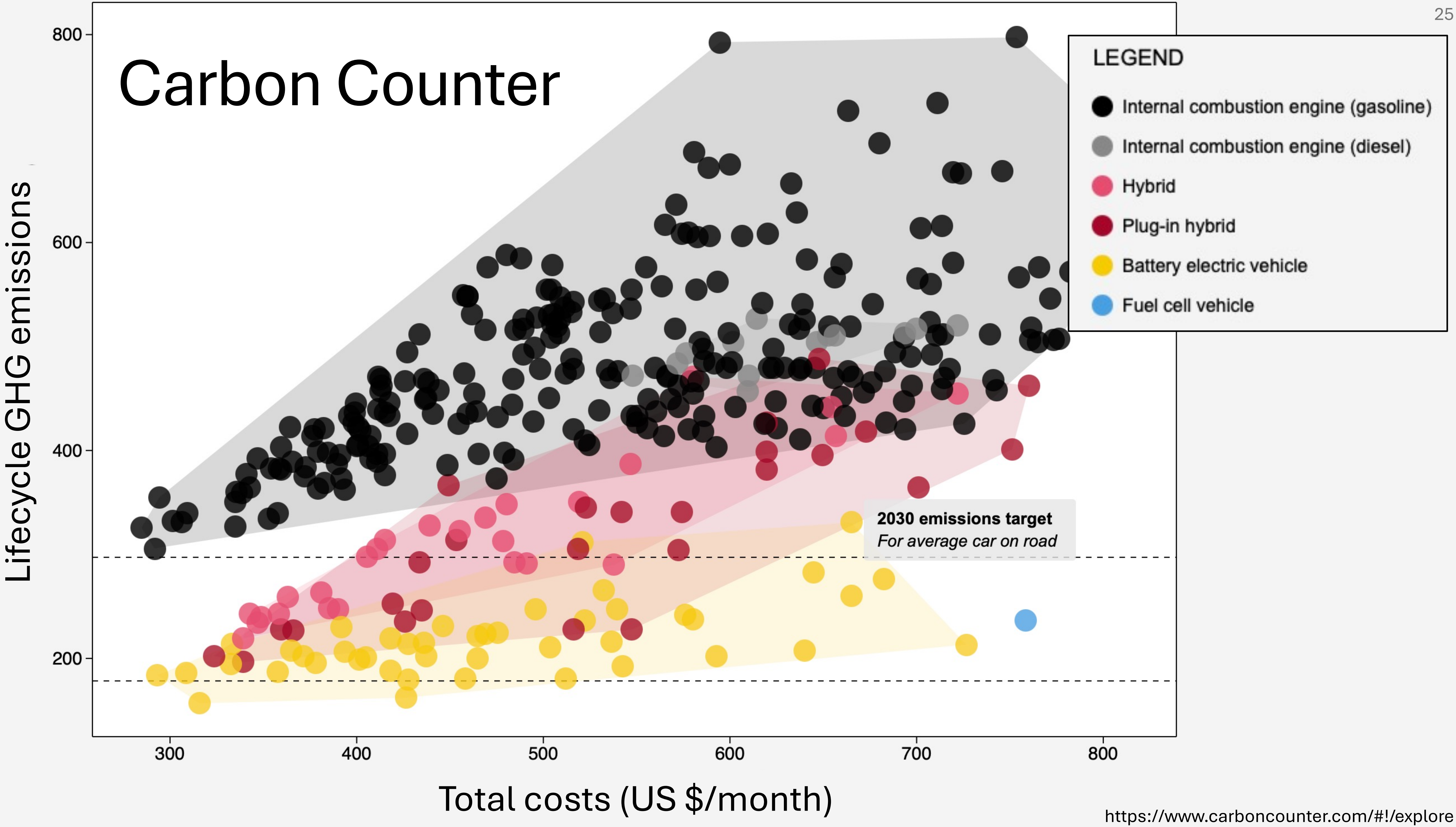
What about emissions?

- This is a function of the electric grid
- Swiss grid: ~58gCO_2eq/kWh
- Vehicle fuel: ~263gCO_2eq/kWh (reference)
- EVs are more efficient for both:
  - Energy consumption per distance traveled
  - CO2 emissions per energy consumed
- Operational CO2 emissions are much lower for electric vehicles



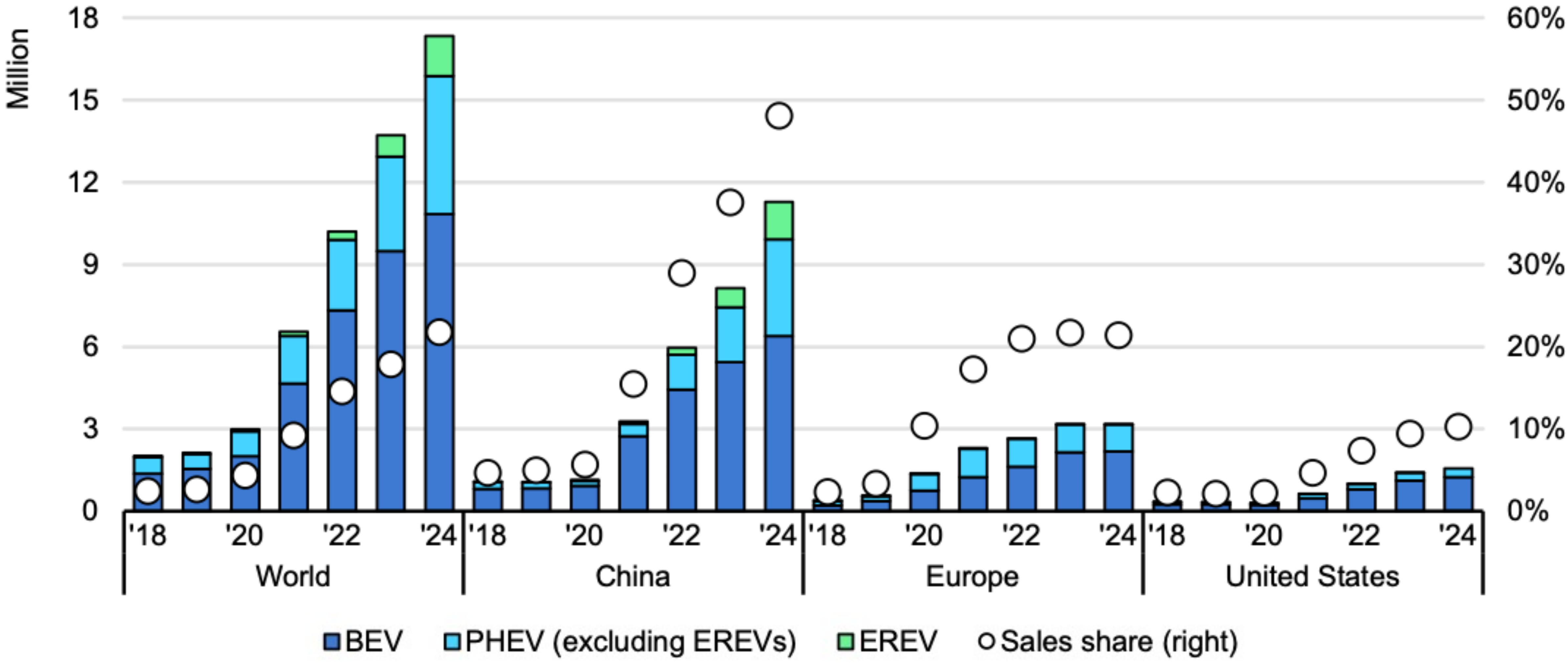
What about manufacturing?

- Life cycle assessment (LCA) accounts for the environmental impact across the complete life cycle of a product
  - Material extraction
  - Manufacturing
  - Fuel usage (what we've covered)
  - End-of-life
- We will cover LCA in the next unit of this class
- In general, EVs have a bit more CO2 emissions in the manufacturing stage but still have lower life-cycle emissions



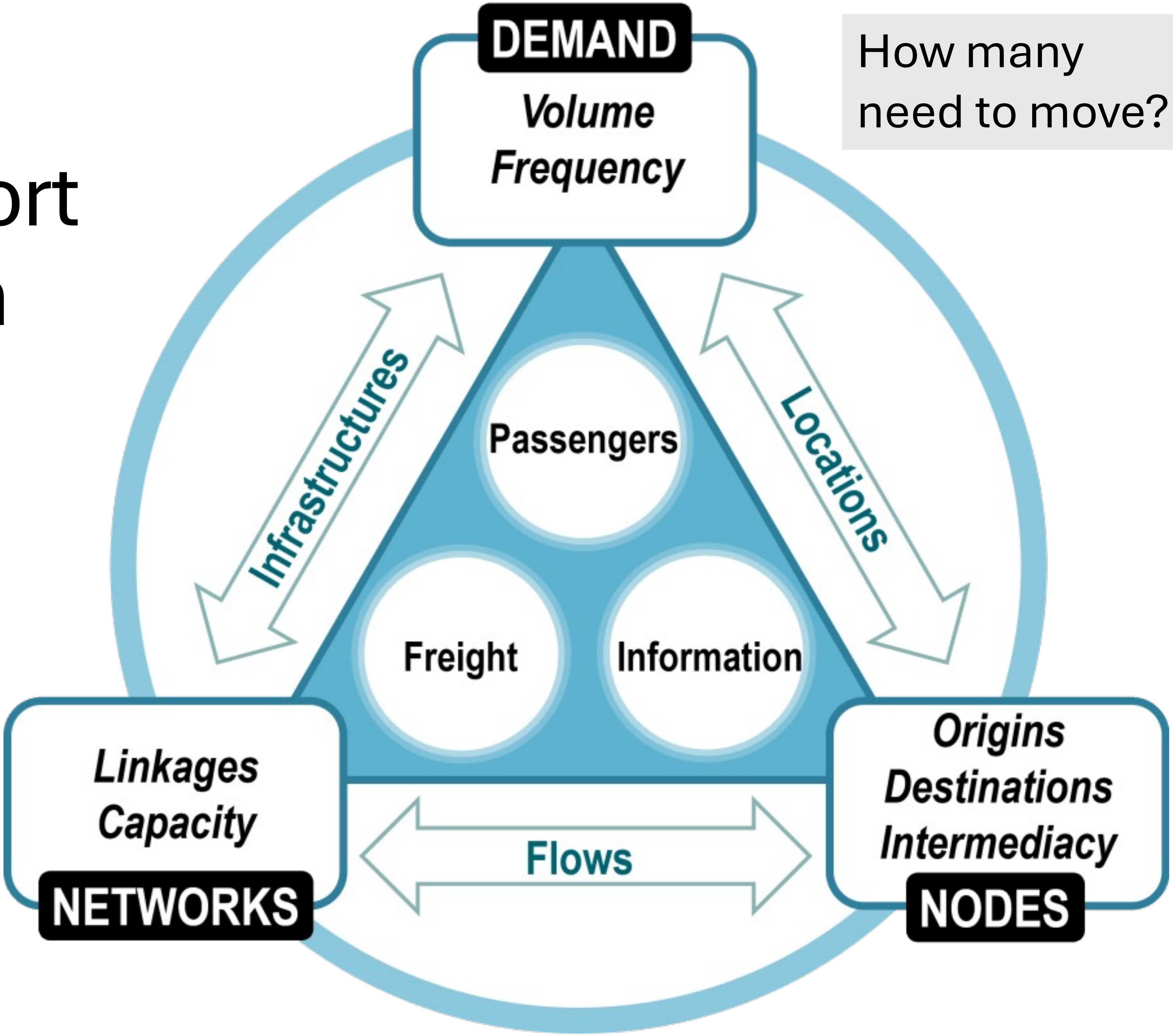
https://www.carboncounter.com/#!/explore

Global electric vehicle sales



Source: International Energy Agency

The transport system



How many need to move?

How can they get there?

Where do people/things need to go?

Source: The Geography of Transport Systems

What is transportation?

- The intentional movement of people, goods, or services
- Modes:
  - Road (personal vehicles, buses, trucks)
  - Rail
  - Air
  - Water
  - Non-motorized
- Why do we move people and things?
  - Economic growth
  - Social connectivity

What is mobility?

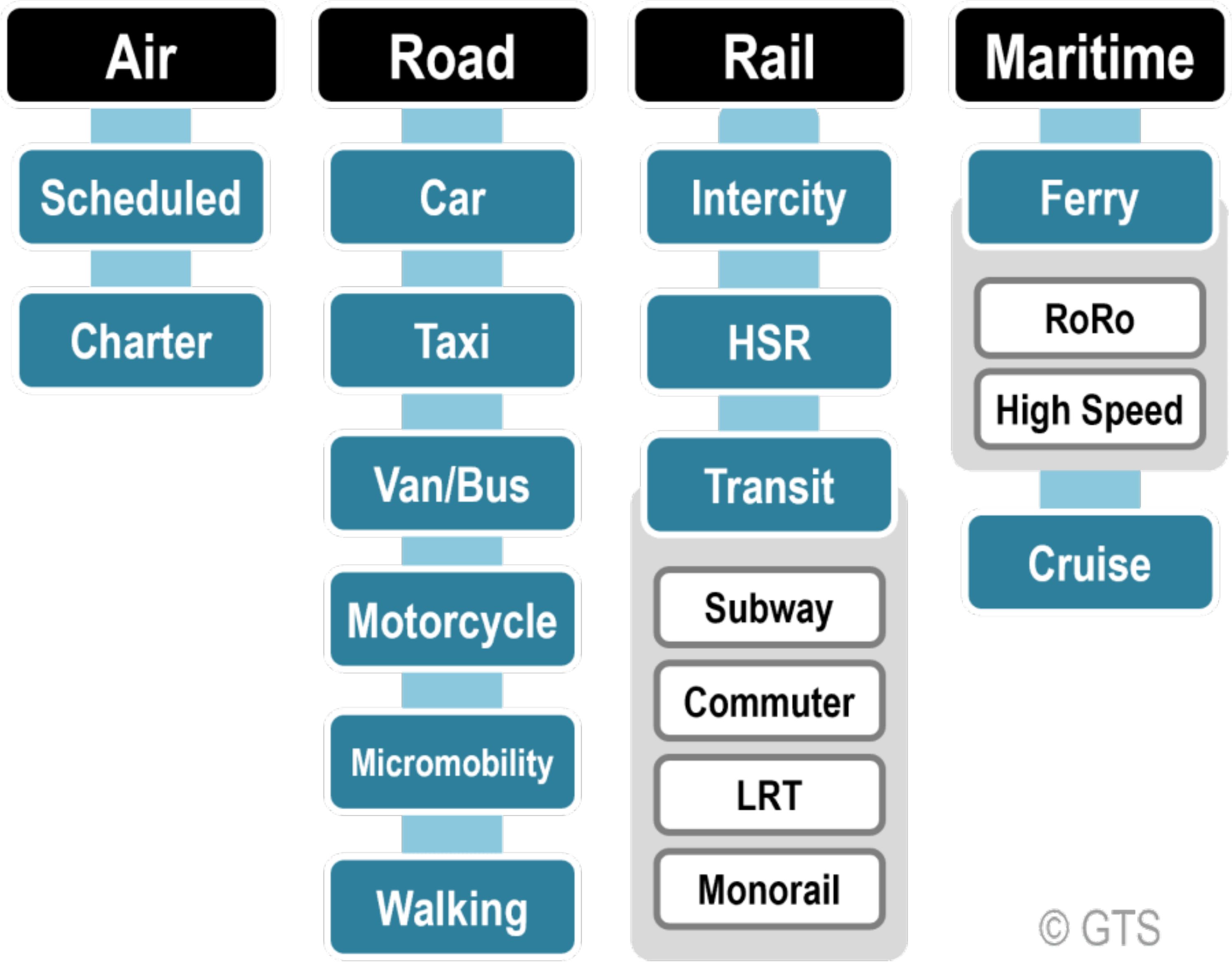
- Mobility is the level of ease with which we can achieve transportation of people
- It creates the ability to access:
  - Jobs
  - Education
  - Housing
  - Services
  - Leisure

What is transportation engineering?

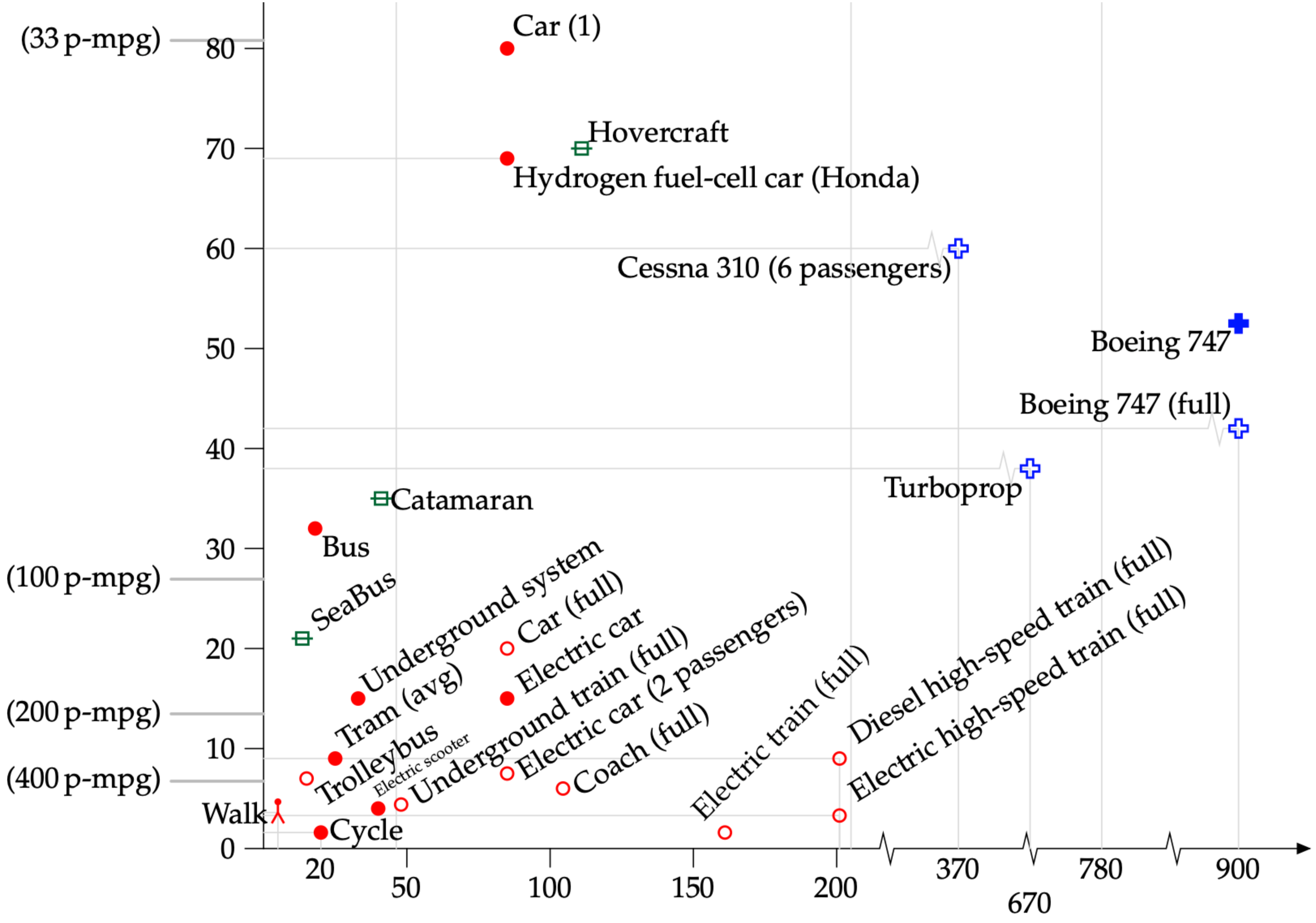
- Planning and design
  - Long-term
  - Example: Street design – intersections, car lanes, bike lanes, sidewalks
- Maintenance
  - Medium term
  - Example: Reparation of roads as they degrade over time
- Operation
  - Short term
  - Example: Bus timetables for those operating on the street

Modes of transportation

- This list is for people
- Many of these modes apply to goods but with different terminology
- Goods can also have other modes (e.g. shipping truck, pipeline)



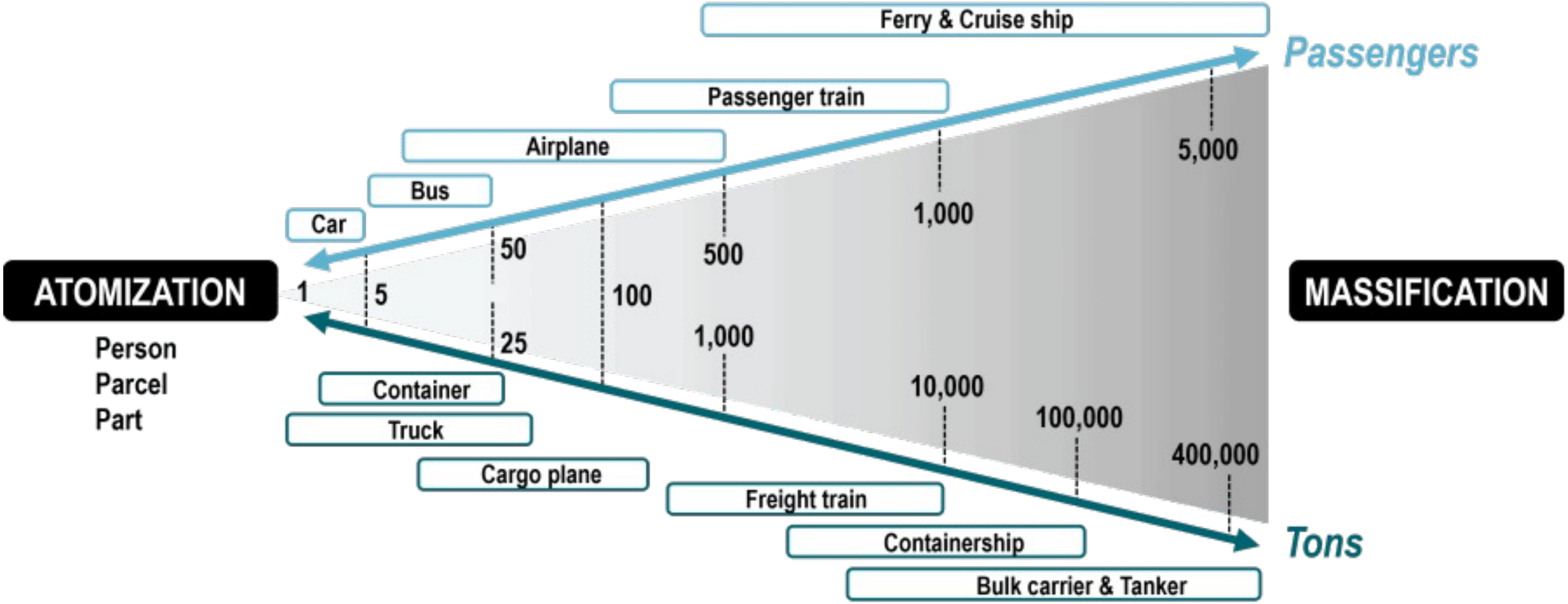
Source: The Geography of Transport Systems



Energy consumption (kWh/person-100km)

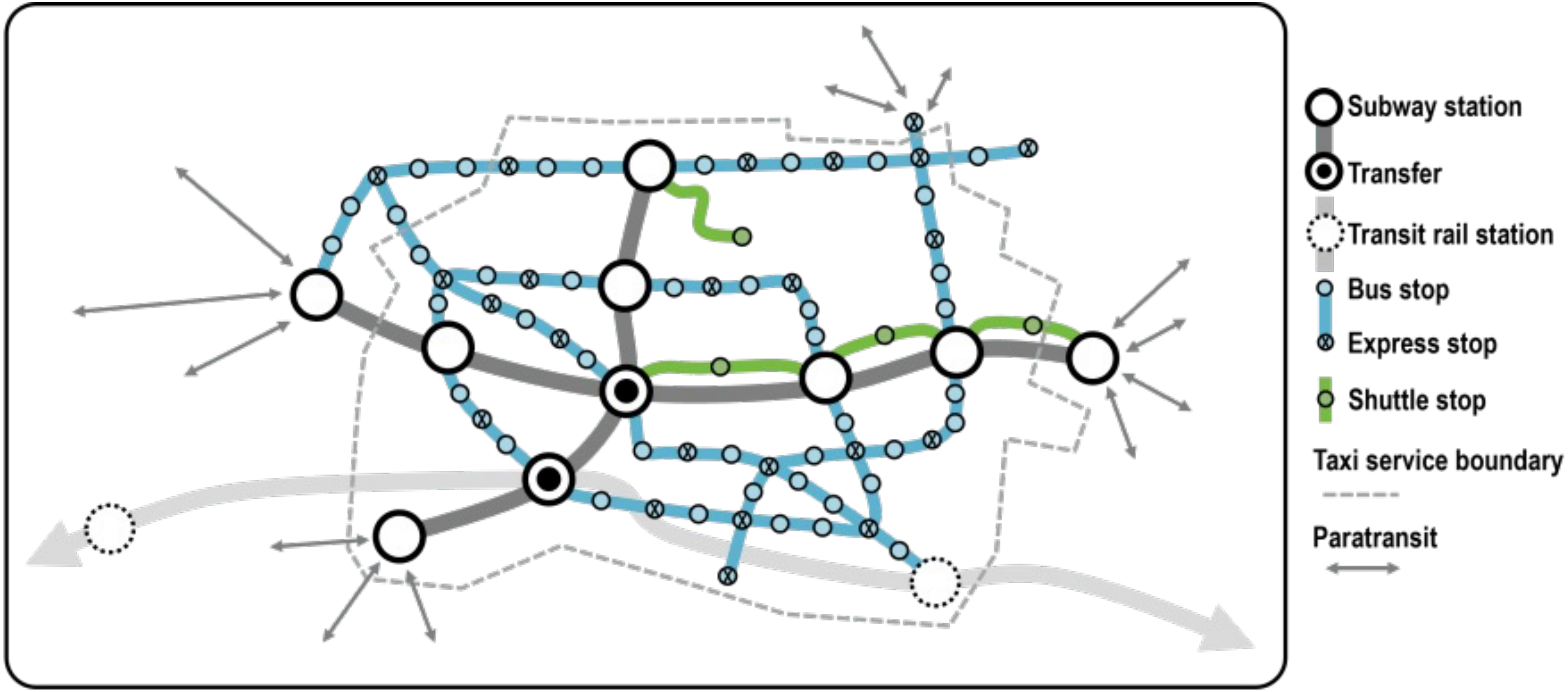
Speed (km/h)

How many people/goods can be moved?



Source: The Geography of Transport Systems

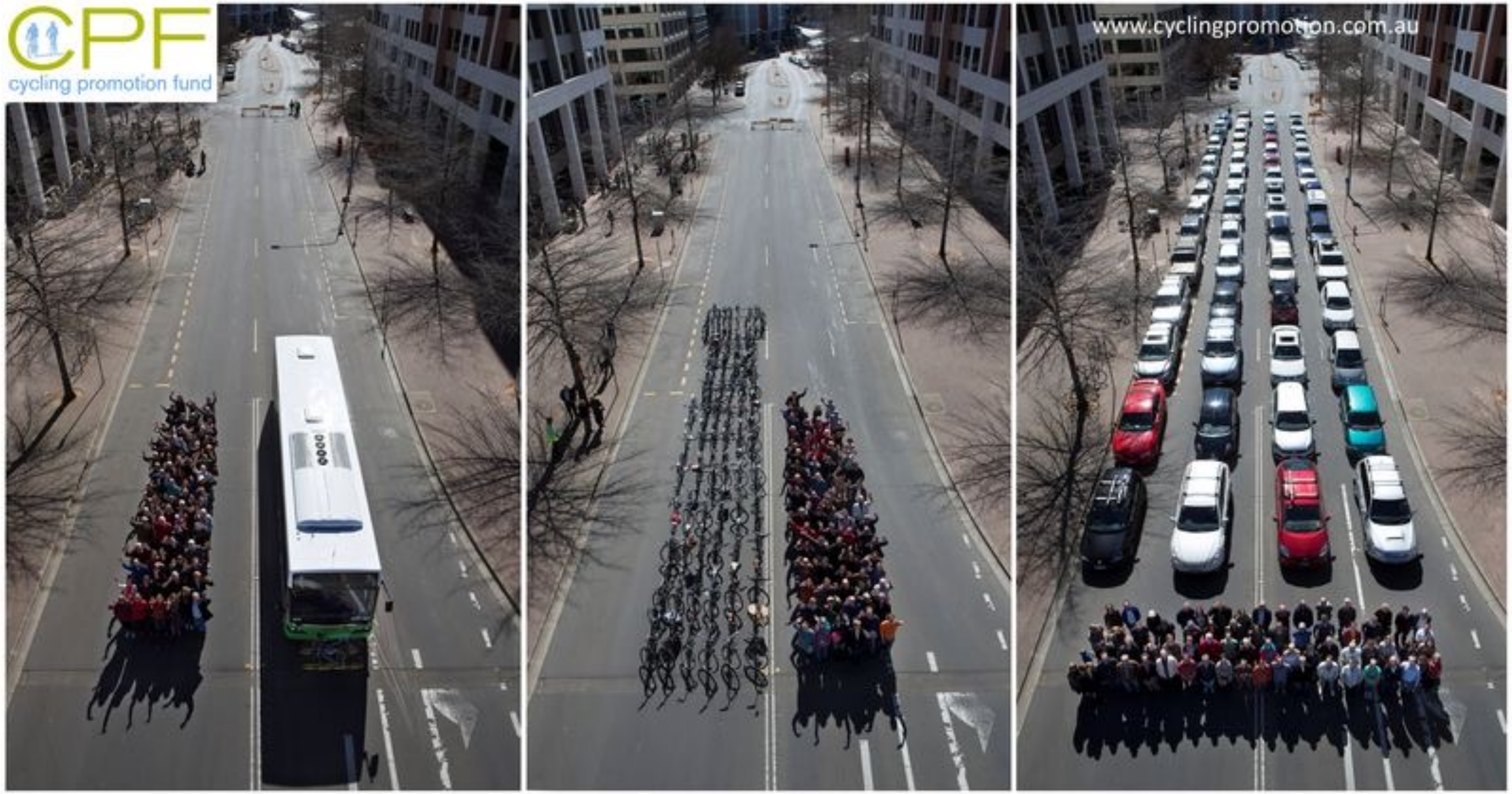
Components of a transportation system



Source: The Geography of Transport Systems

Spatial aspects of mobility

- Personal vehicles are also inefficient with regard to spatial requirements



Transportation is a complex ***system***

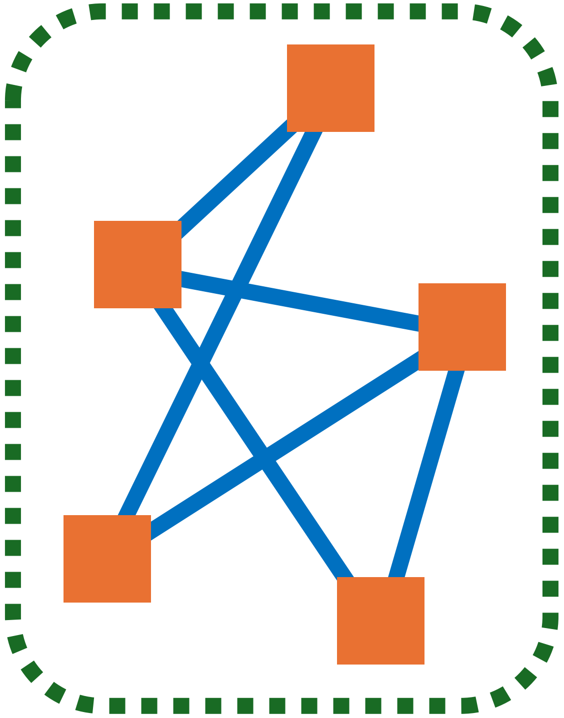
A system is...

a set of elements

interconnected
coherently organized

in a way that achieves something

- Multiple parts without interdependencies are just collections
- The structure helps to drive the system toward its purpose

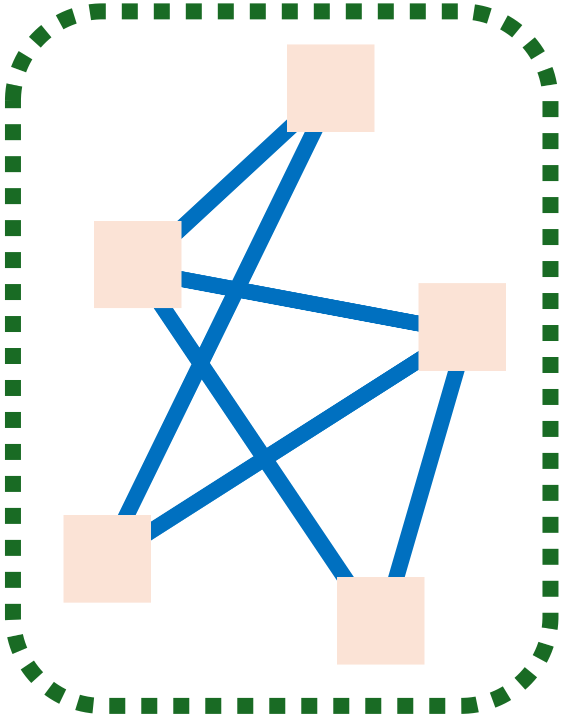


Systems definition: Meadows, 2008

Transportation is a complex ***system***

In systems thinking, we:

- Take a **top-down perspective** rather than bottom-up
  - **Holistic** rather than compartmental
- Focus on **relationships** rather than the individual parts
  - Individual components only have **meaning** in the context of the whole system
- Very important skill for thinking about complex problems that have social, environment, and technical considerations



How to do systems thinking?

- Identify the **components** of the system
- Identify the **connections**
- Identify **feedback loops**
  - Balancing feedback loops: Stabilizes or resists change
  - Reinforcing feedback loops: Amplifies change
- Feedback loops are critical to understanding the dynamic behavior of complex systems over time
- Feedback loops help us identify how small changes or interventions can have big impacts

Systems thinking

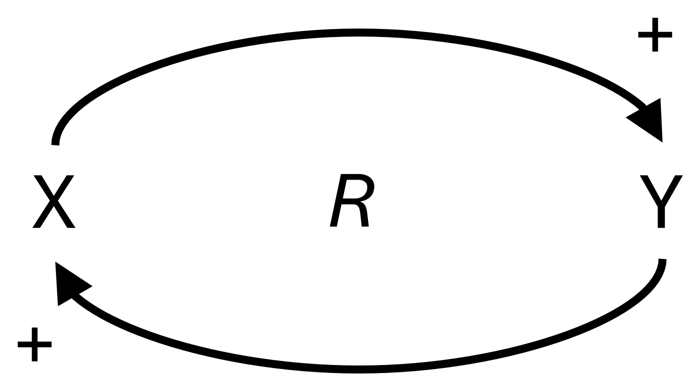
- Video: https://www.youtube.com/watch?v=LTCZZBrhORs

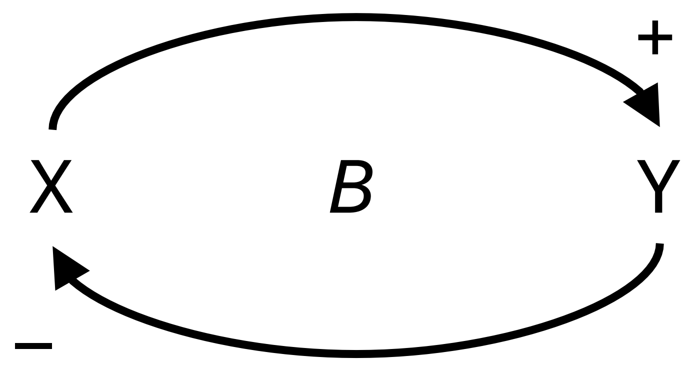
Concepts from the video

- **Jevon's paradox**: when efficiency improvements increase total consumption of a resource rather than reduce it
  - Efficiency is **amount of something useful obtained** per unit **resource** – so we would expect increase in efficiency to decrease resource use
  - Because the **efficiency can decrease the effective cost** (reduced cost of resource), people may end up **using more** of the resource
  - Jevon's paradox is one example of the **rebound effect**, where the rebound results in more consumption after the improvement
- Understanding Jevon's paradox requires systems thinking
  - What is the **resource** in this example? What is the **useful thing obtained**? What is the **feedback loop**?

Visualizing systems with causal loop diagrams

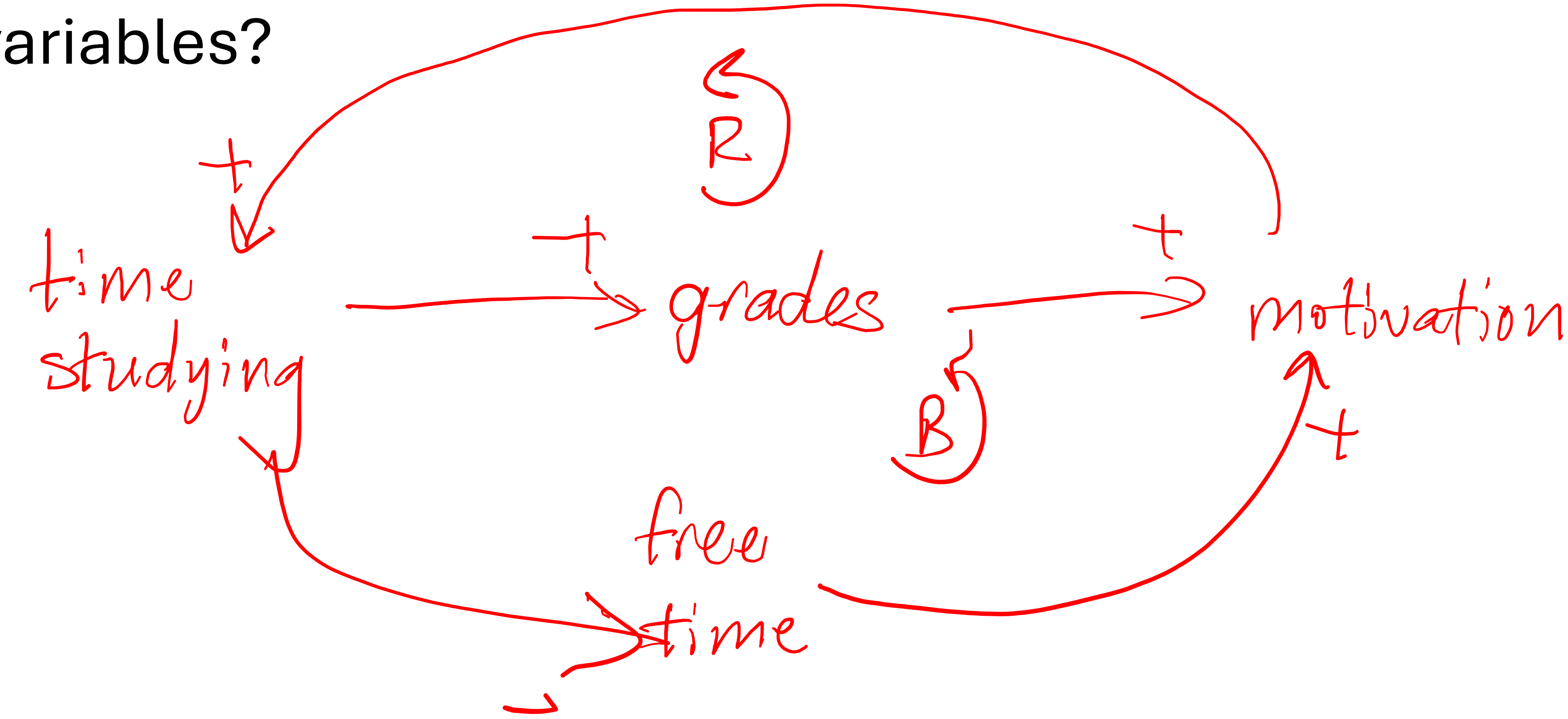
- **Causal loop diagrams (CLDs)** are visual tools to represent how different variables are related and highlight feedback loops
- Components of a CLD:
  - Variables (components)
  - Arrows (connections)
  - Signs (indicate positive or negative relationships)
- Less detail than a stock and flow diagram
  - No need to distinguish between stocks, flows, and other variables





Simple CLD

- Variables: (1) time spent studying, (2) grades
- Other variables?



In-class exercise: Create a CLD

Lausanne is considering adding more bike lanes in particular places in the city. As a new systems thinking, you believe you can help in their decision-making by pointing out the relationships between (1) **number of cyclists**, (2) **real and perceived cycling safety**, (3) **car usa**ge, (4) **vehicle speed**, and (5) **cyclist injuries**. Identify 1 balancing feedback loop and 1 reinforcing feedback loop and draw them in a CLD to explain to the city.