

ENVS 101 B: Lecture 5

Energy and Climate

At a glance — Energy sources and their costs, the evidence for climate change, and the choices for responding.

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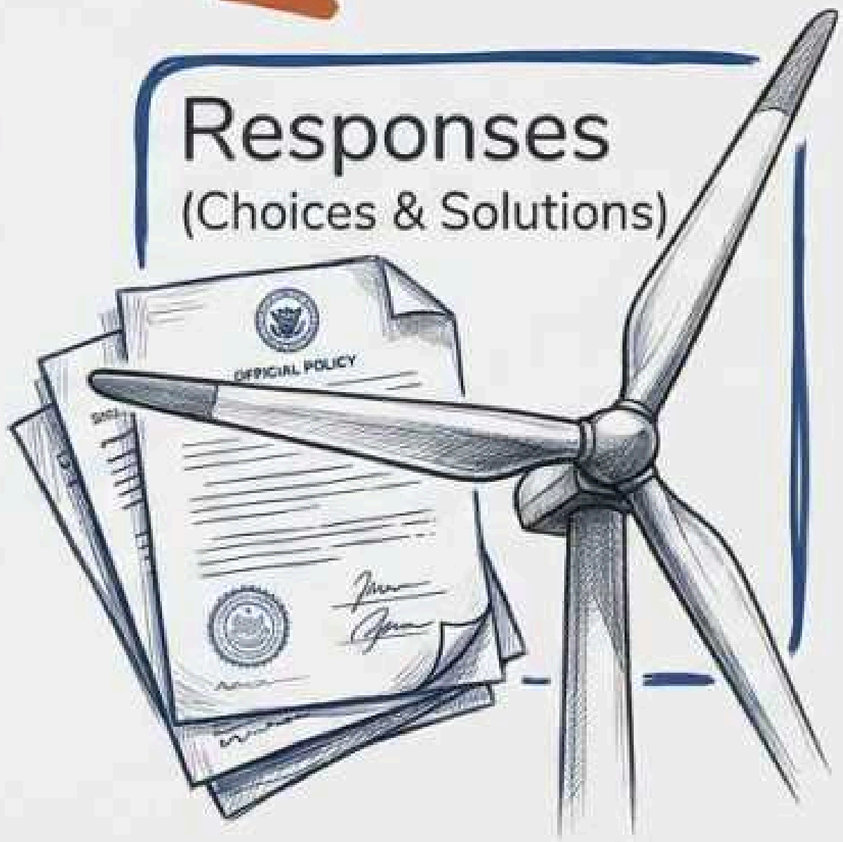
Energy
(Sources & Measurement)



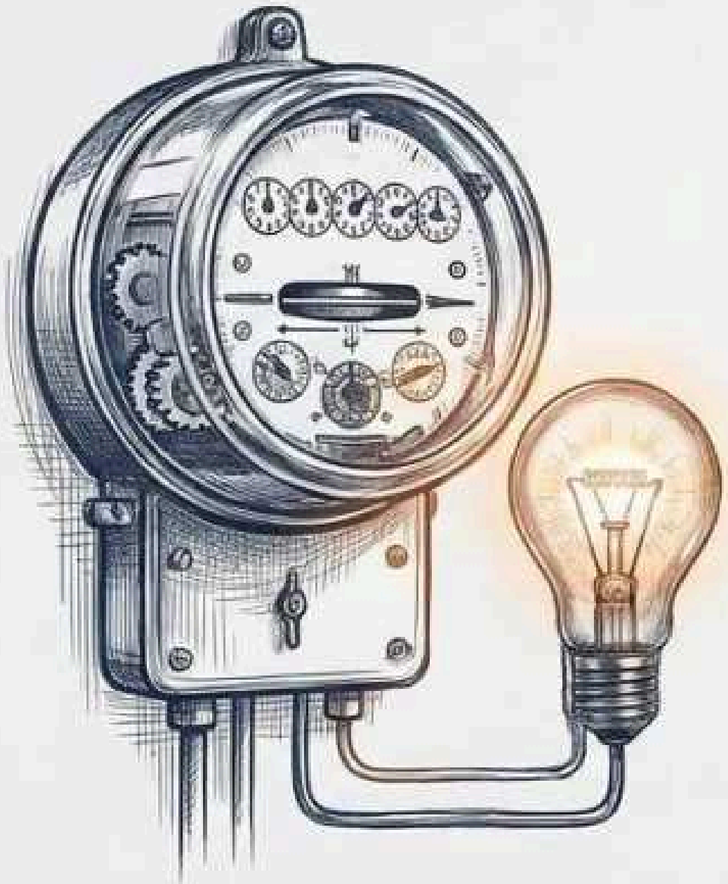
Climate
(Evidence of Warming)



Responses
(Choices & Solutions)



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Energy: Joules (J)

Power (Rate): Watts (W)

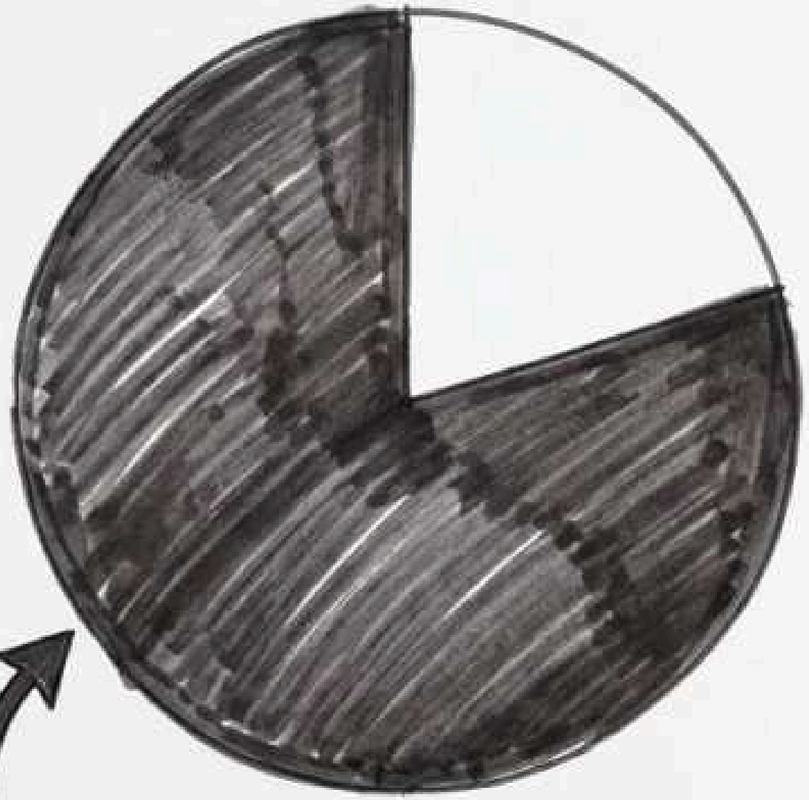
$$1\ \text{Watt} = 1\ \frac{\text{Joule}/}{\text{second}}$$

Kilowatt-Hour (kWh):
1 kW for 1 hour = 3,600,000 Joules

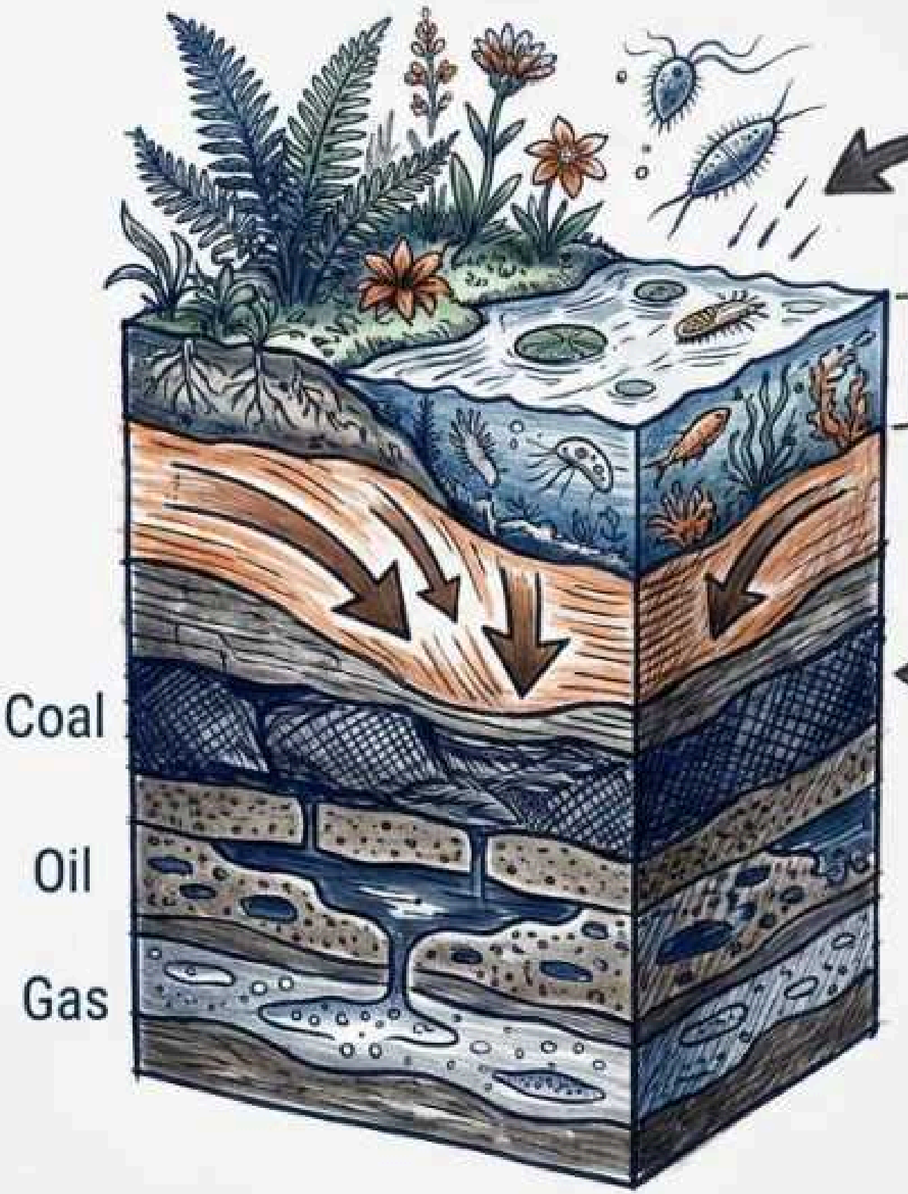
Real-World Context: ~10,000 kWh = Average US Household annual electricity use.

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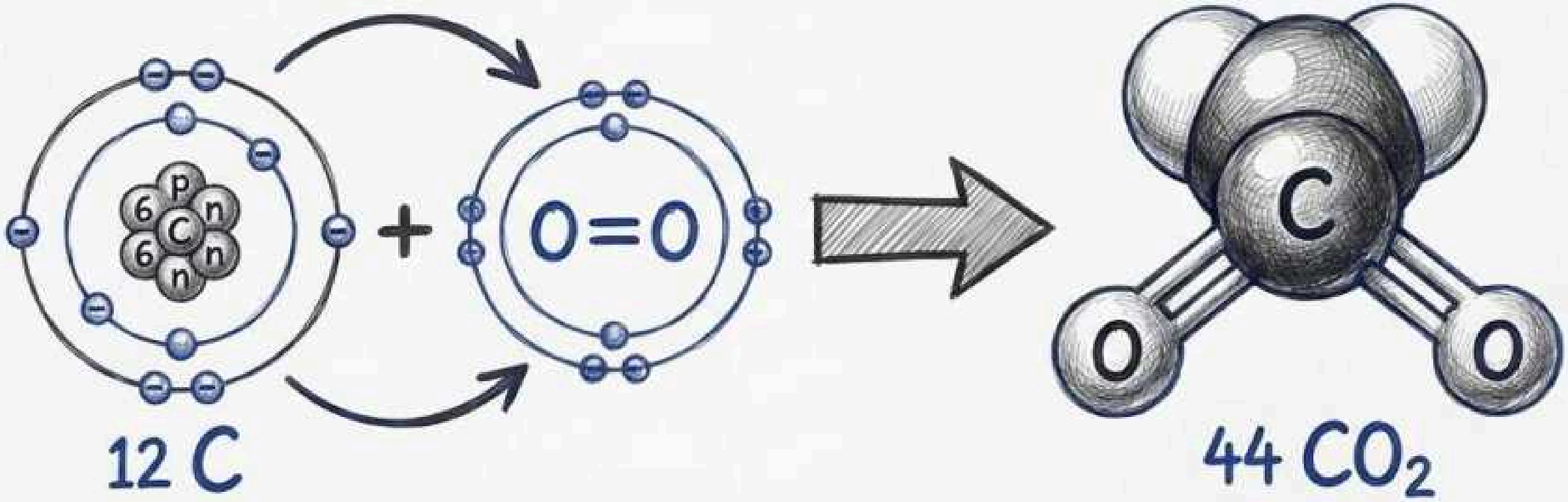
Dominance:
4/5 of global primary energy (Coal, Oil, Natural Gas).



Origins: Remains of ancient plants and plankton, buried and transformed over millions of years.

The Trade-off:
Energy-dense, cheap, and easy to move
BUT finite and carbon-emitting.

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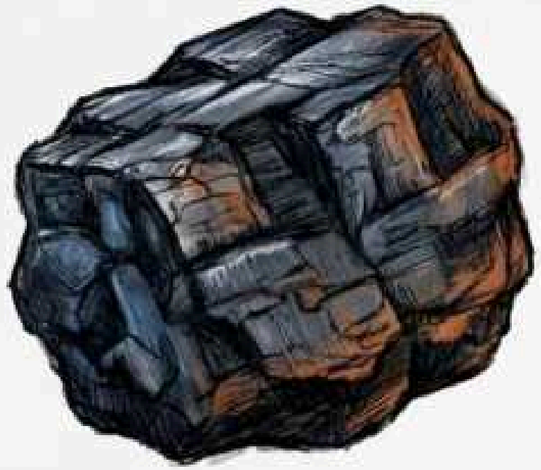
12 C

44 CO_2

The Multiplier: Burning 1 tonne Carbon → $\frac{44}{12} \approx 3.67$ tonnes CO_2

Real-World Example: 1 Liter Gasoline (holds 0.64 kg Carbon)

→ Produces 2.4 kg CO_2



Coal: Most carbon-intensive; highest air pollution.



Natural Gas: Emits ~50% the CO_2 of coal, BUT methane leaks (a strong greenhouse gas) can offset this advantage.

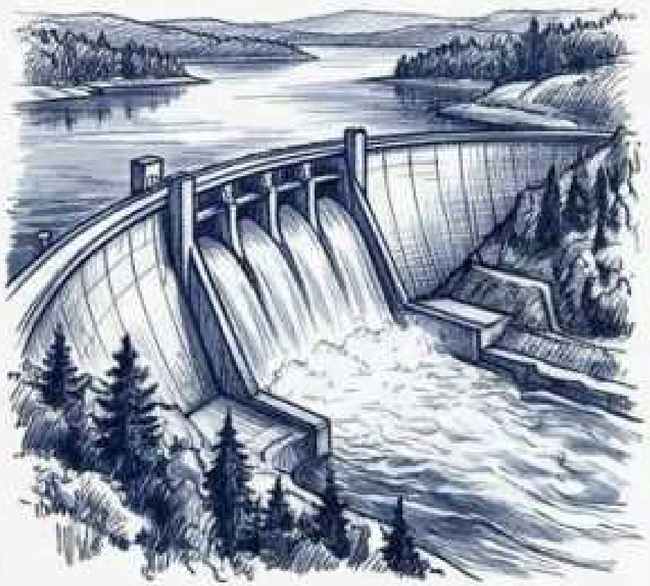


Oil: Dominates the transportation sector.

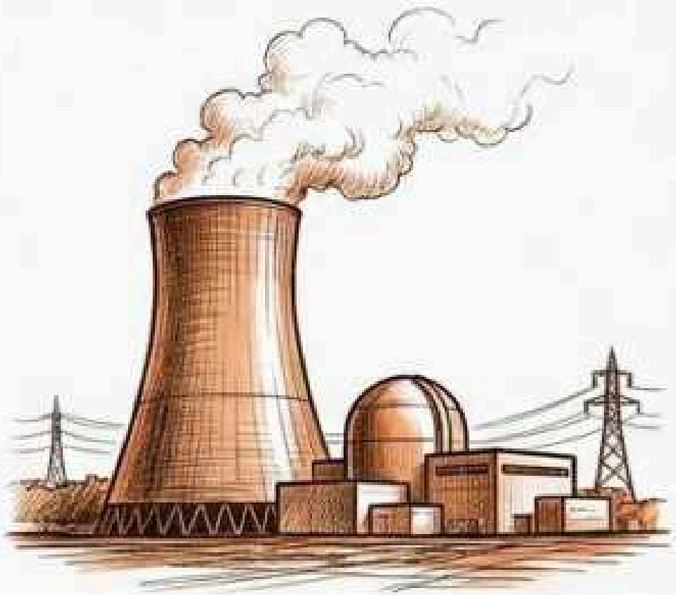
Shared Risks: Spills, accidents, and geopolitical conflict.

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Hydropower: Large & reliable, but alters rivers/fisheries.



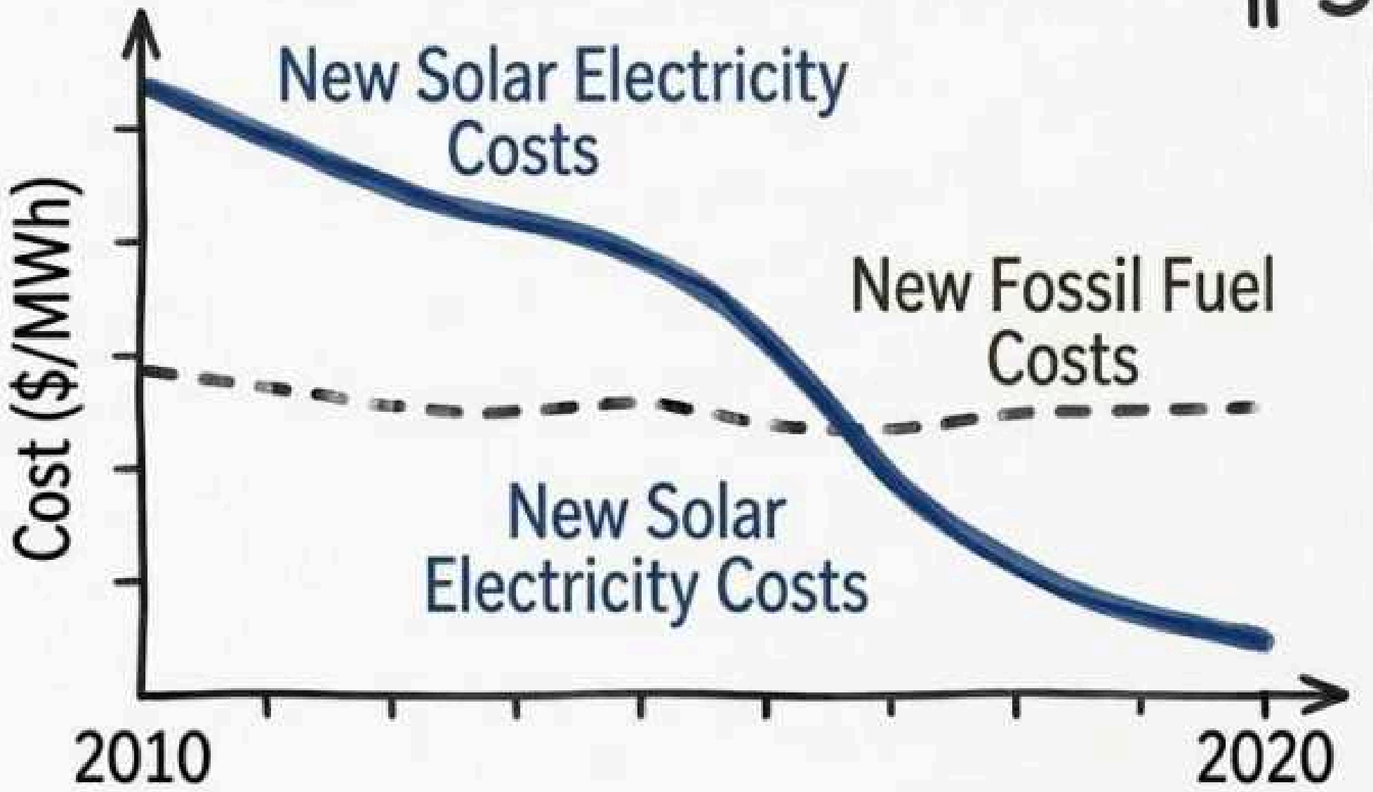
Nuclear: Steady & low-carbon, but raises cost, waste, and accident concerns.



Wind & Solar: Clean operation, but variable (weather-dependent). Needs storage/flexible grid.

Others: Geothermal & Biomass.

Cost Evolution (2010–2020):
New solar electricity cost fell 85% to 90%. Wind fell substantially as well.



The New Reality: In many places, new renewables are now cheaper than new fossil plants.

The New Challenge: Grid design, energy storage, and speed of deployment.

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Capacity Factor: The fraction of time a plant produces at full power on average.





Solar Farm (1 MW):

1 MW × 20% CF × 8,760 hours/year

= 1,752 MWh

Wind Turbine (2 MW):

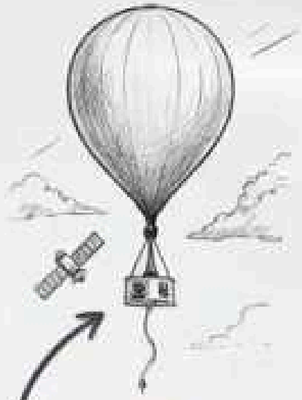
2 MW × 35% CF × 8,760 hours/year

= 6,132 MWh (~600 homes)

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Evidence of Warming:

Independent sources align perfectly





Measurements:

Land/sea thermometers, weather balloons, satellites

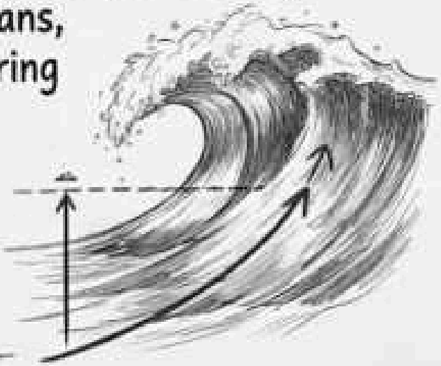


Global Average Surface Temperature Trend

Physical Changes:

Shrinking glaciers/Arctic ice, rising oceans, earlier spring





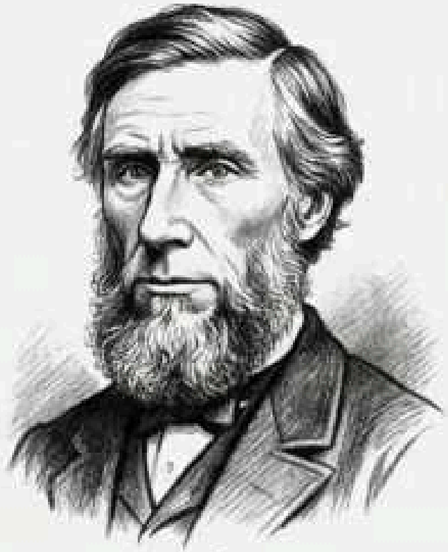
The Core Metric:

Global average surface temperature is up 1.2°C since the late 1800s.

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1820 1859 1896

1820s (Joseph Fourier): Suggested the atmosphere warms the Earth.

1859 (John Tyndall): Demonstrated that CO_2 and water vapor absorb infrared radiation.

1896 (Svante Arrhenius): Calculated that doubling CO_2 would warm the planet by several degrees.

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The Last 800,000 Years (Ice Cores):
Historical CO_2 range stayed between 180 - 300 ppm.

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Current State: Now above 420 ppm.

1958 - Present (The Keeling Curve):
Direct measurements at Mauna Loa show a steady rise.

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Radiative Forcing (Extra Heat Trapping):

$$\Delta F = 5.35 \times \ln\left(\frac{C}{C_0}\right)$$

Current Impact:
Going from 280 → 420 ppm produces about 2.2 Watts/m^2.

A Full Doubling:
Produces approximately 3.7 Watts/m^2 extra warming force.

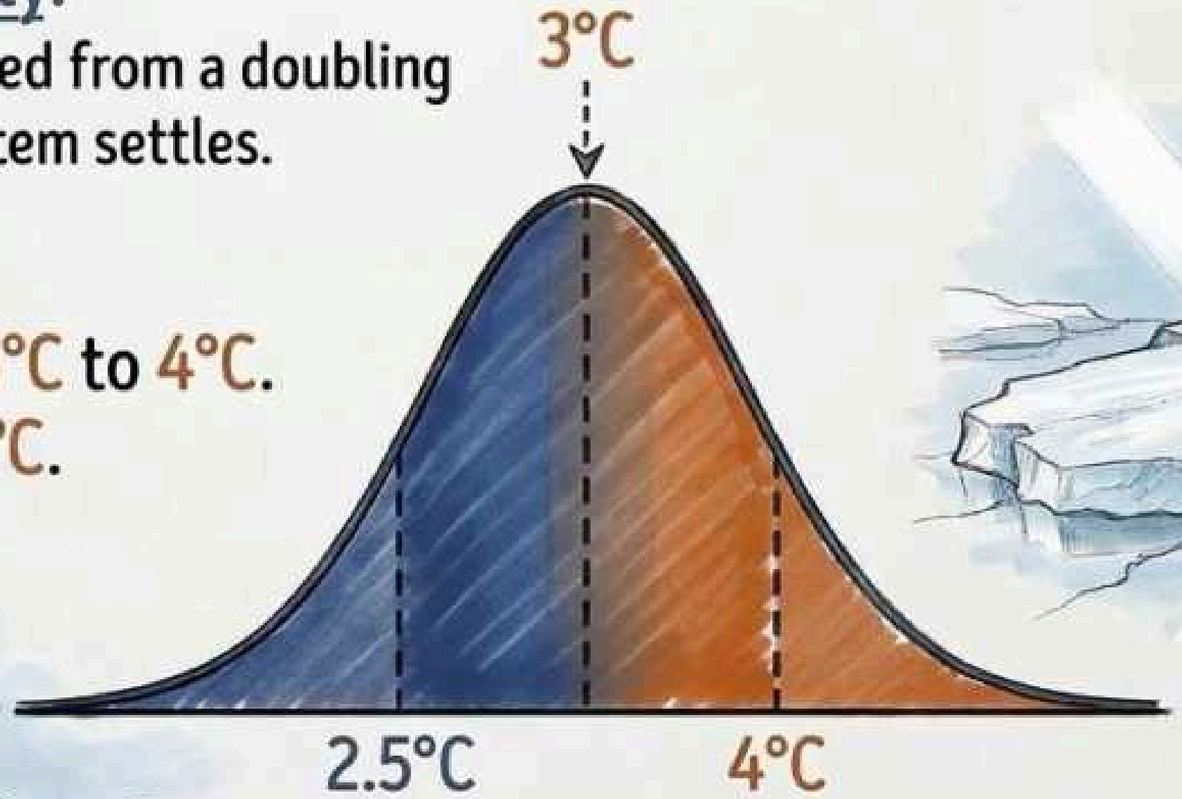
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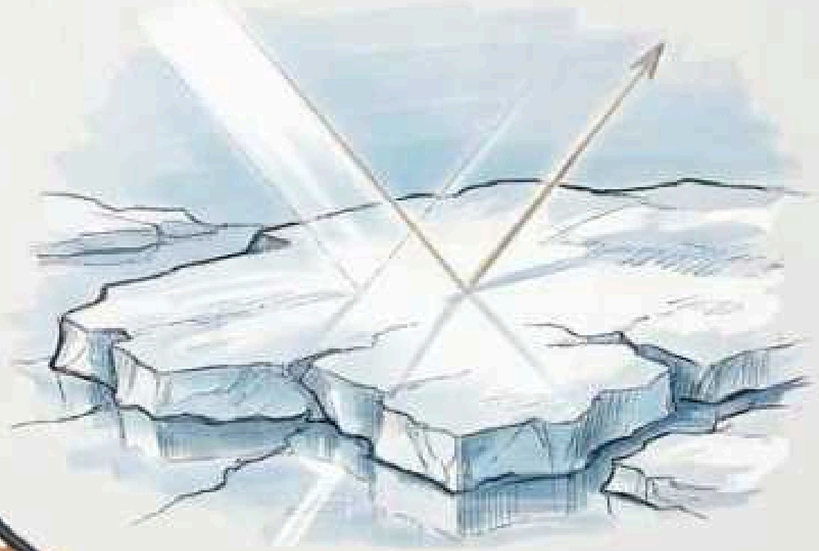
Climate Sensitivity:

The warming expected from a doubling of CO_2 after the system settles.

IPCC Estimates:

Likely Range: 2.5°C to 4°C.
Best Estimate: 3°C.



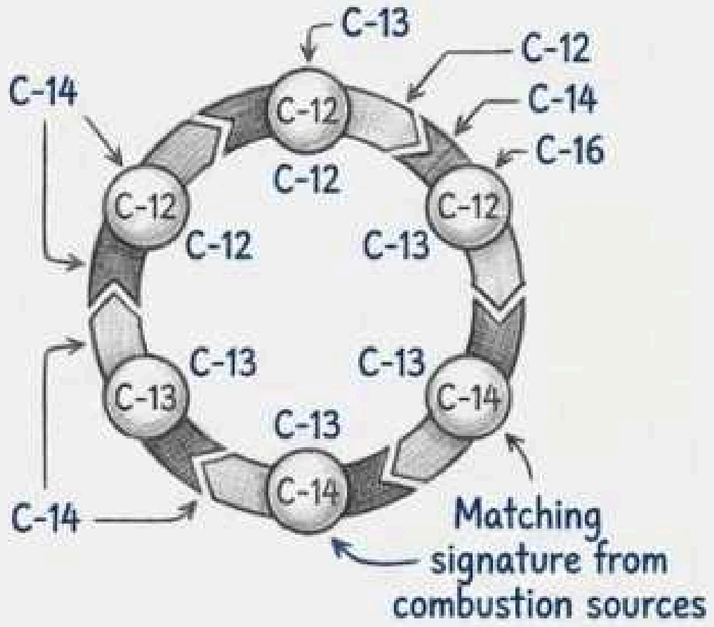


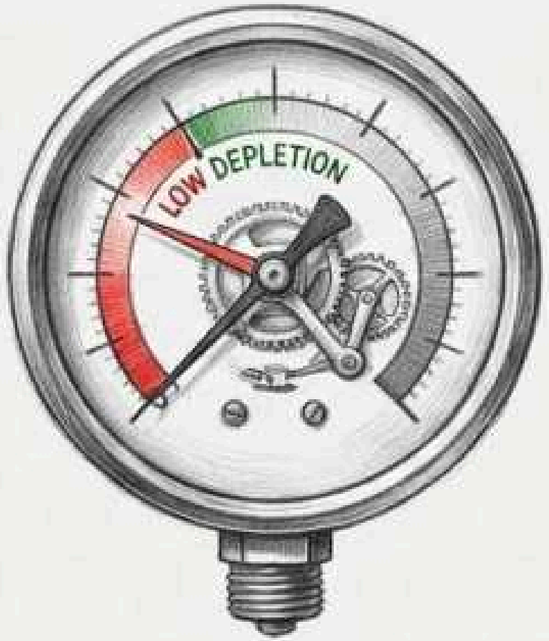


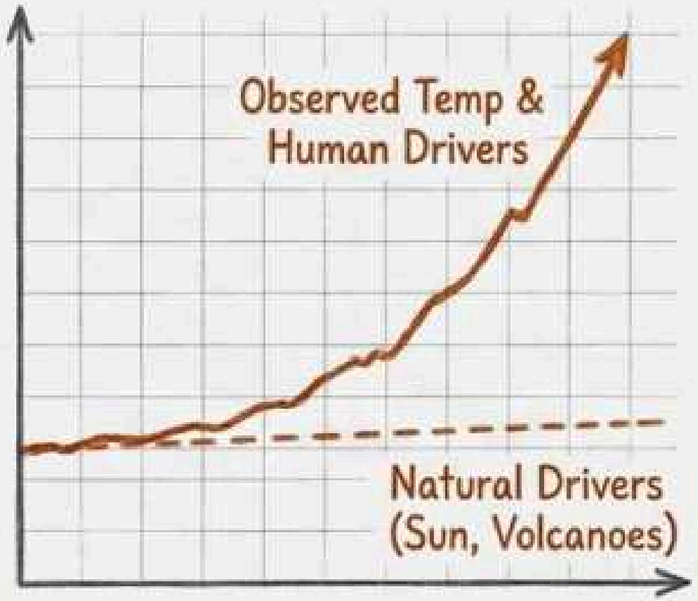
The Uncertainty (Feedbacks): The range remains wide due to secondary reactions in water vapor, ice albedo, and cloud cover.

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Human Attribution (The Fingerprints)







1. Chemical Signature: Extra atmospheric carbon perfectly matches fossil carbon isotopes.

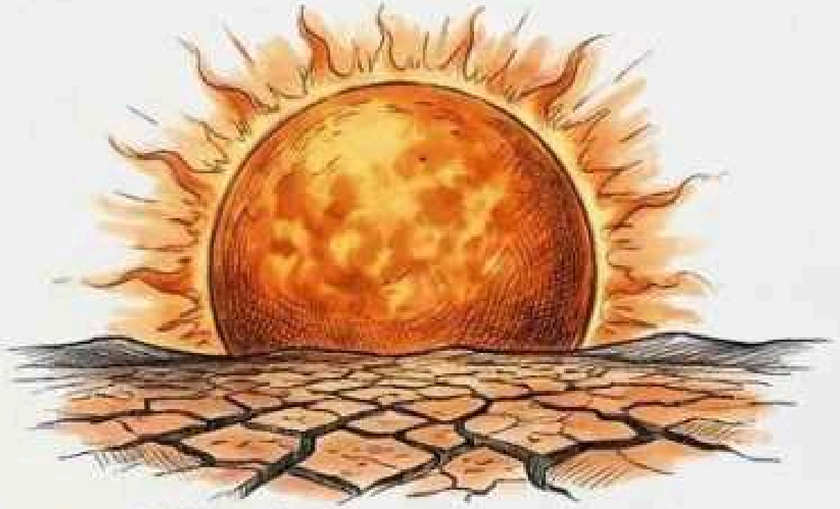
2. Oxygen Depletion: Air oxygen is declining at exactly the rate expected from combustion.

3. Model Failure: Climate models using only natural drivers (sun, volcanoes) completely fail to reproduce the current temperature rise.

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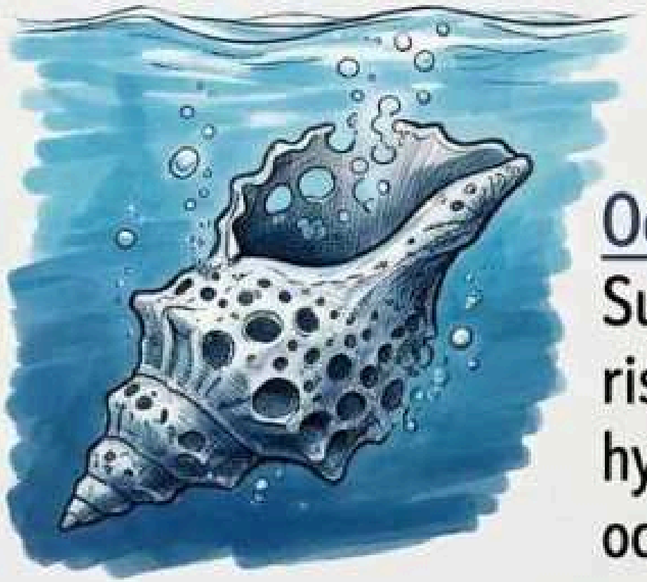
Sea Level Rise: ~20 cm since the late 19th century (thermal expansion + melting land ice).



Extreme Weather: Increased frequency of heat waves and heavy downpours.



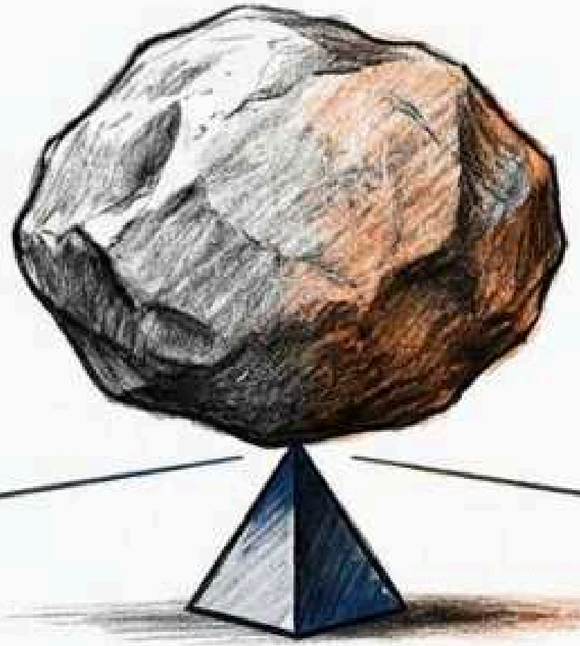
Wildfires: Heightened dry and fire-prone conditions globally.



Ocean Acidification: Surface acidity has risen by 26% in hydrogen ions due to oceanic CO_2 absorption.

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Tipping Points: Thresholds beyond which parts of the system might change abruptly or irreversibly.





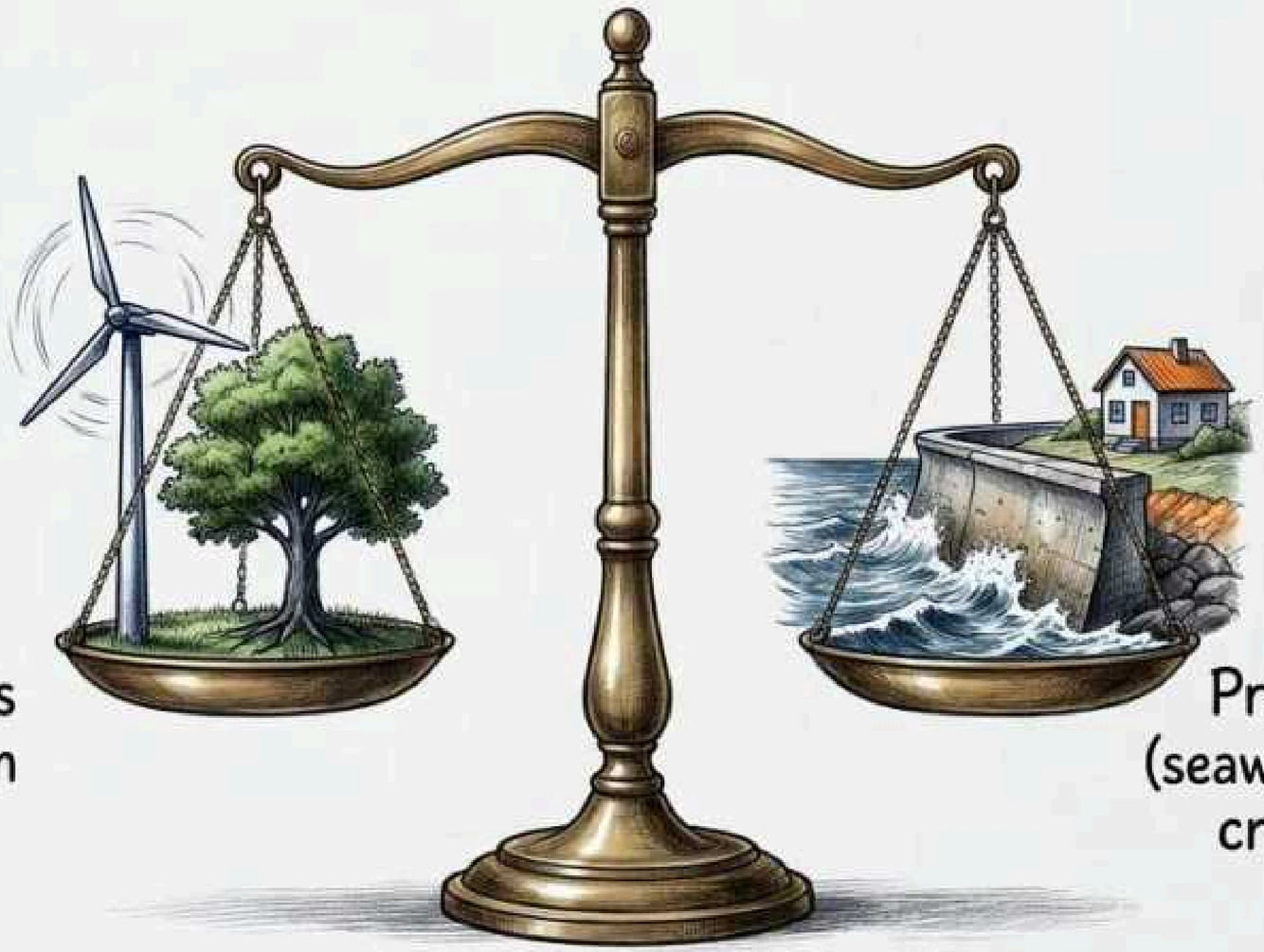


Key Candidates: Loss of Greenland & West Antarctic ice sheets; Dieback of coral reefs; Shifts in ocean circulation.

The Risk: Uncertain threshold proximity motivates early action by risk-minded planners.

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Mitigation:
Reducing emissions or removing carbon from the air.

Adaptation:
Preparing for changes (seawalls, drought-resistant crops, heat warnings)

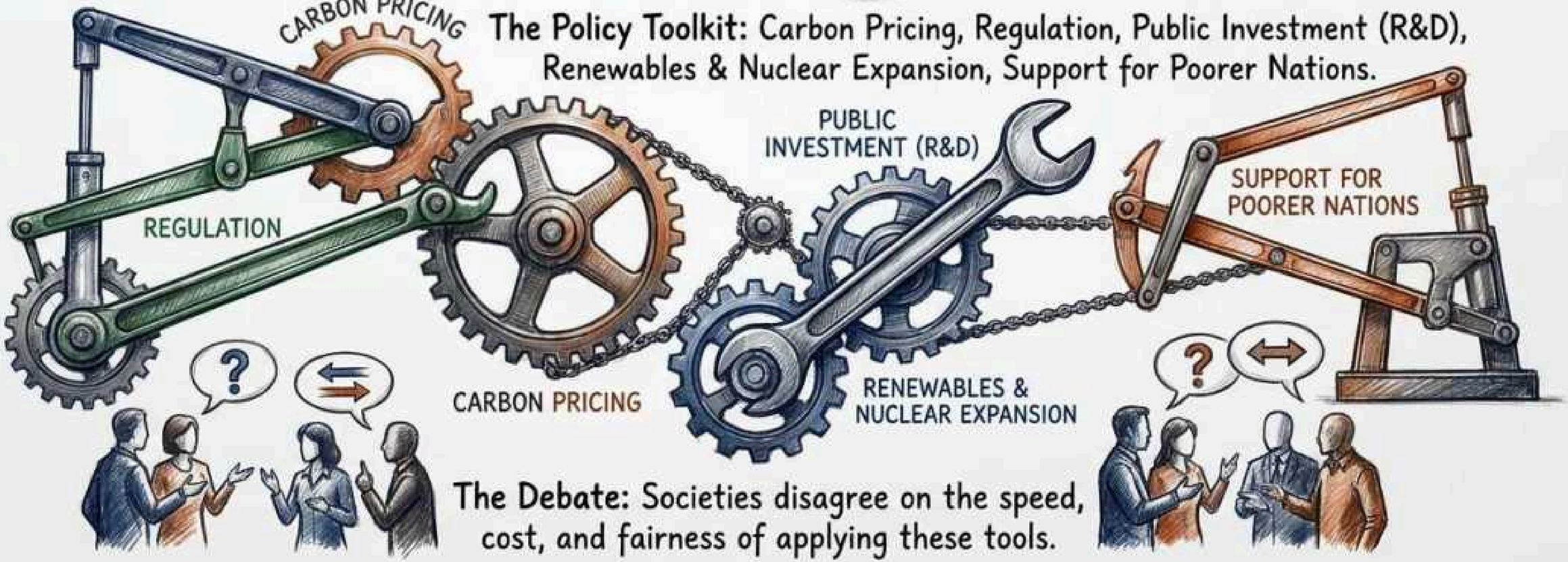
The Reality: Both are necessary. Even strong mitigation leaves some warming; weak mitigation makes adaptation much harder.

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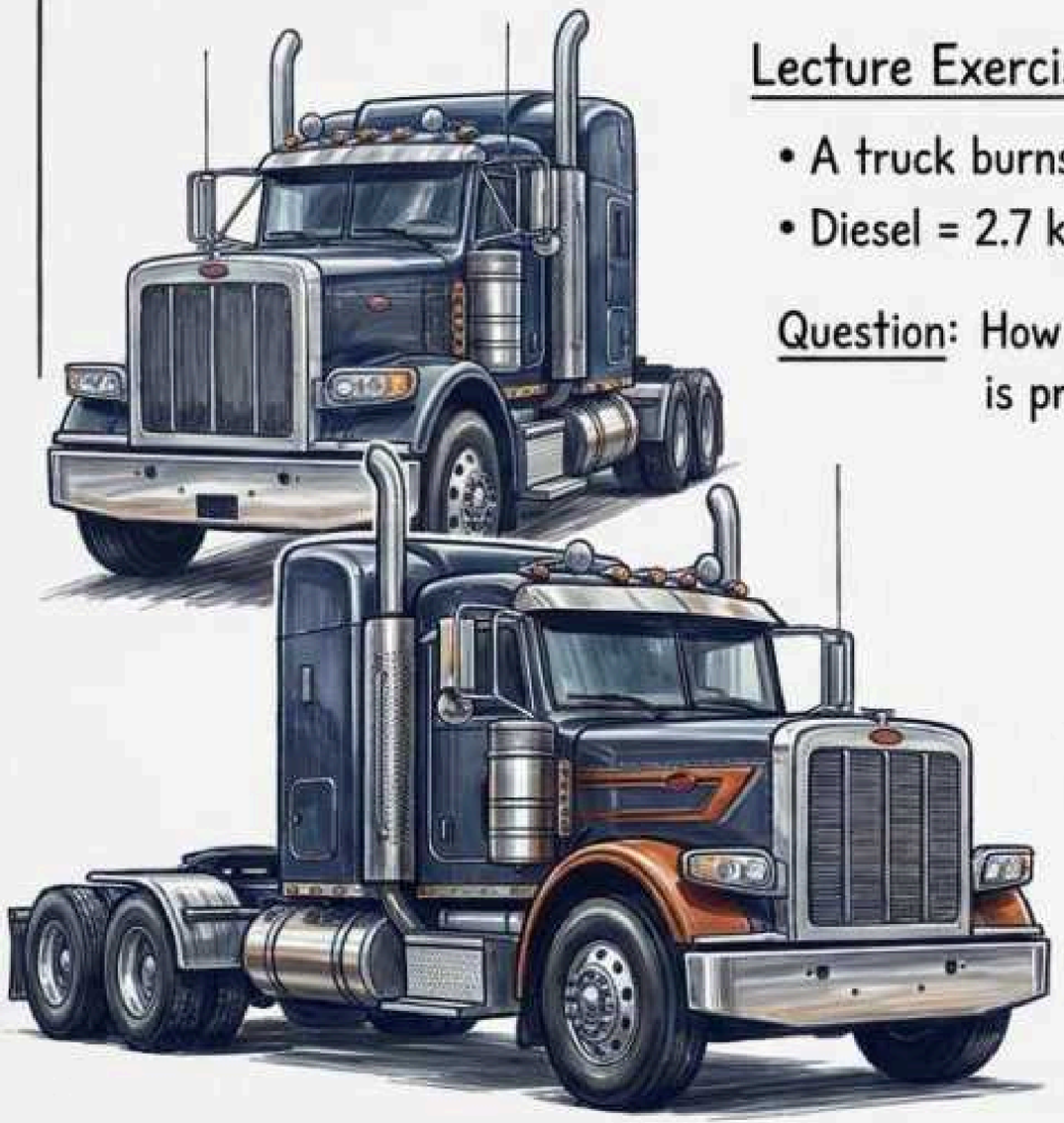
The Paris Agreement (2015): Goal of holding warming well below 2°C (pursuing 1.5°C).

The Policy Toolkit: Carbon Pricing, Regulation, Public Investment (R&D), Renewables & Nuclear Expansion, Support for Poorer Nations.



The Debate: Societies disagree on the speed, cost, and fairness of applying these tools.

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Lecture Exercise 1:

- A truck burns 100 Liters of diesel.
- Diesel = 2.7 kg CO_2 per Liter.

Question: How many kilograms of CO_2 is produced?



Lecture Exercise 2:

- A wind turbine produces 6,132 MWh/year.
- A home uses 10 MWh/year.

Question: Compare the turbine's output to the home usage, and explain what "capacity factor" means in this context.

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Looking Ahead: Lecture 6

Upcoming Topics:

- Pollution (Air, Water, Land)
- Waste Management
- Economic and Political tools societies use to solve environmental problems.

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