Sustainable Use of Fossil Energy Resources

A Challenge to Technology, Policy, and International Cooperation

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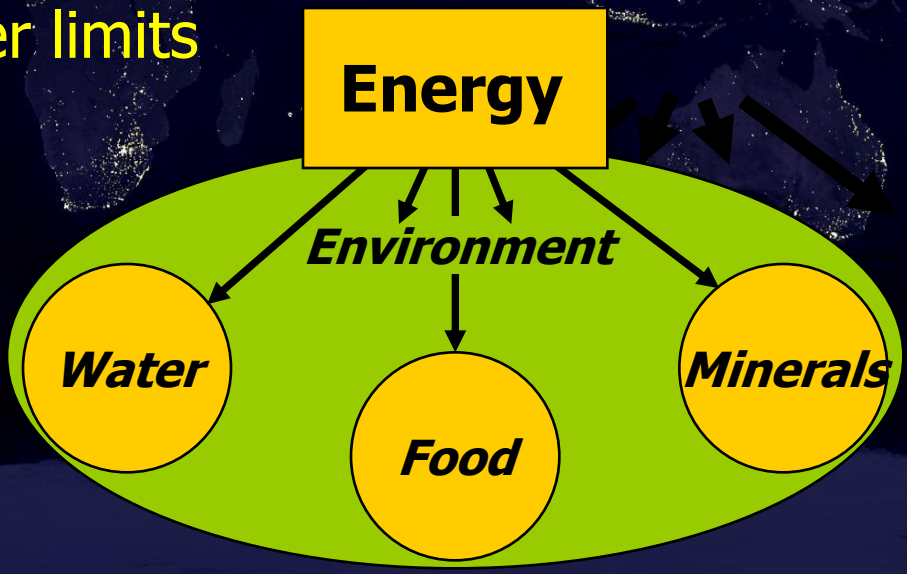
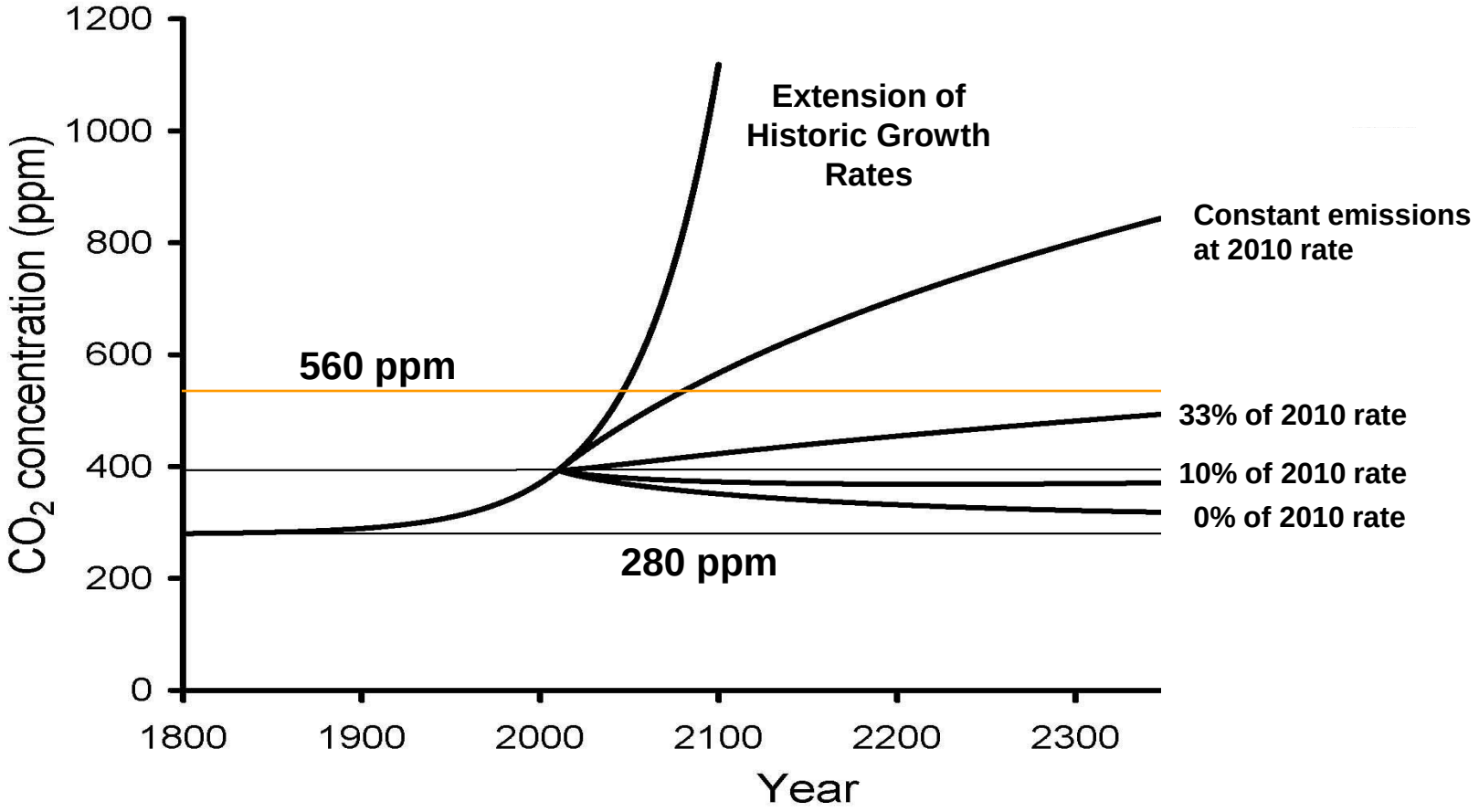
May, 2008

Sustainable energy development is not about limiting access to energy

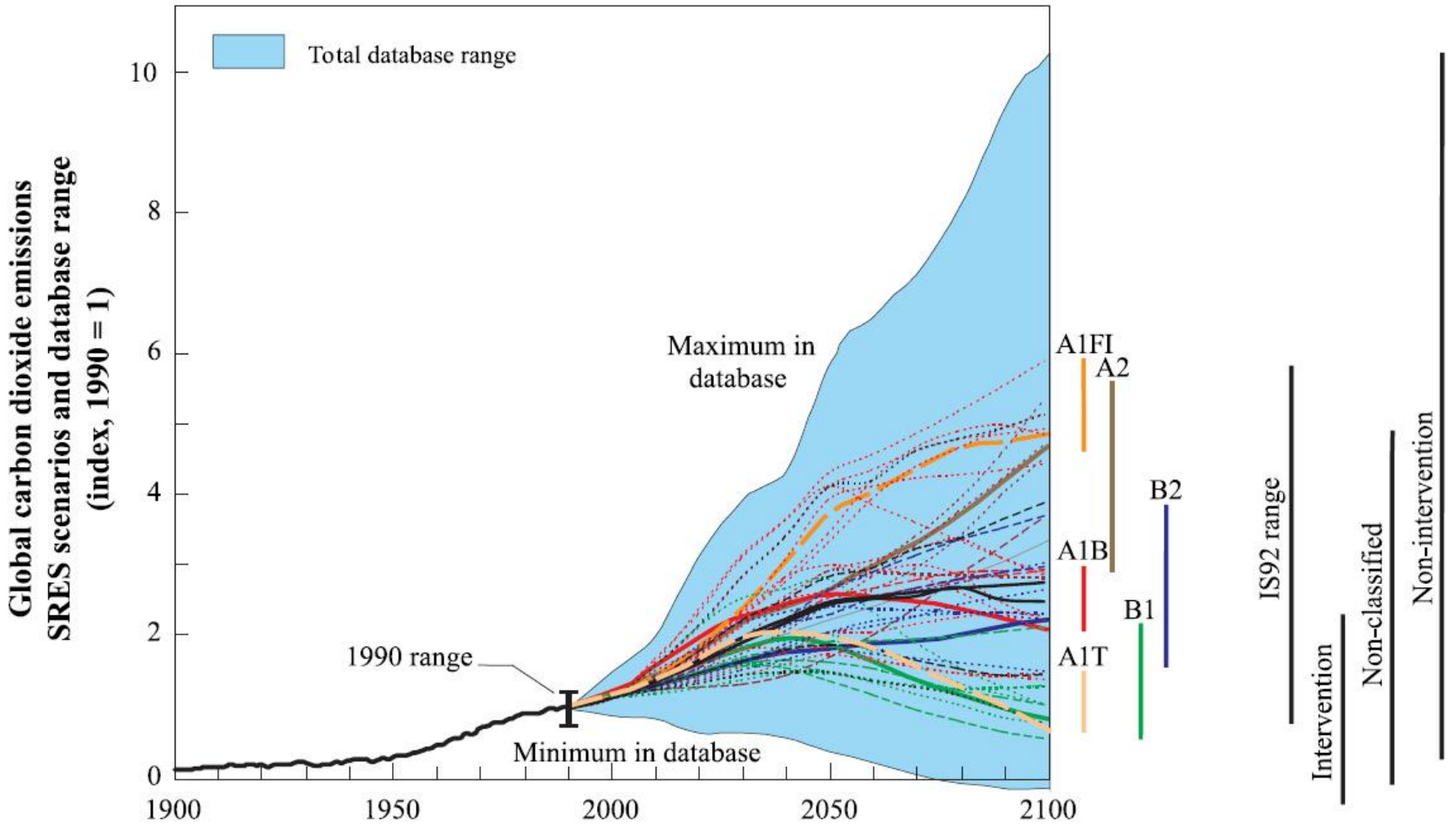
- low cost, plentiful, and clean energy for all
- Energy is central to sustainable growth
- Energy can overcome all other limits

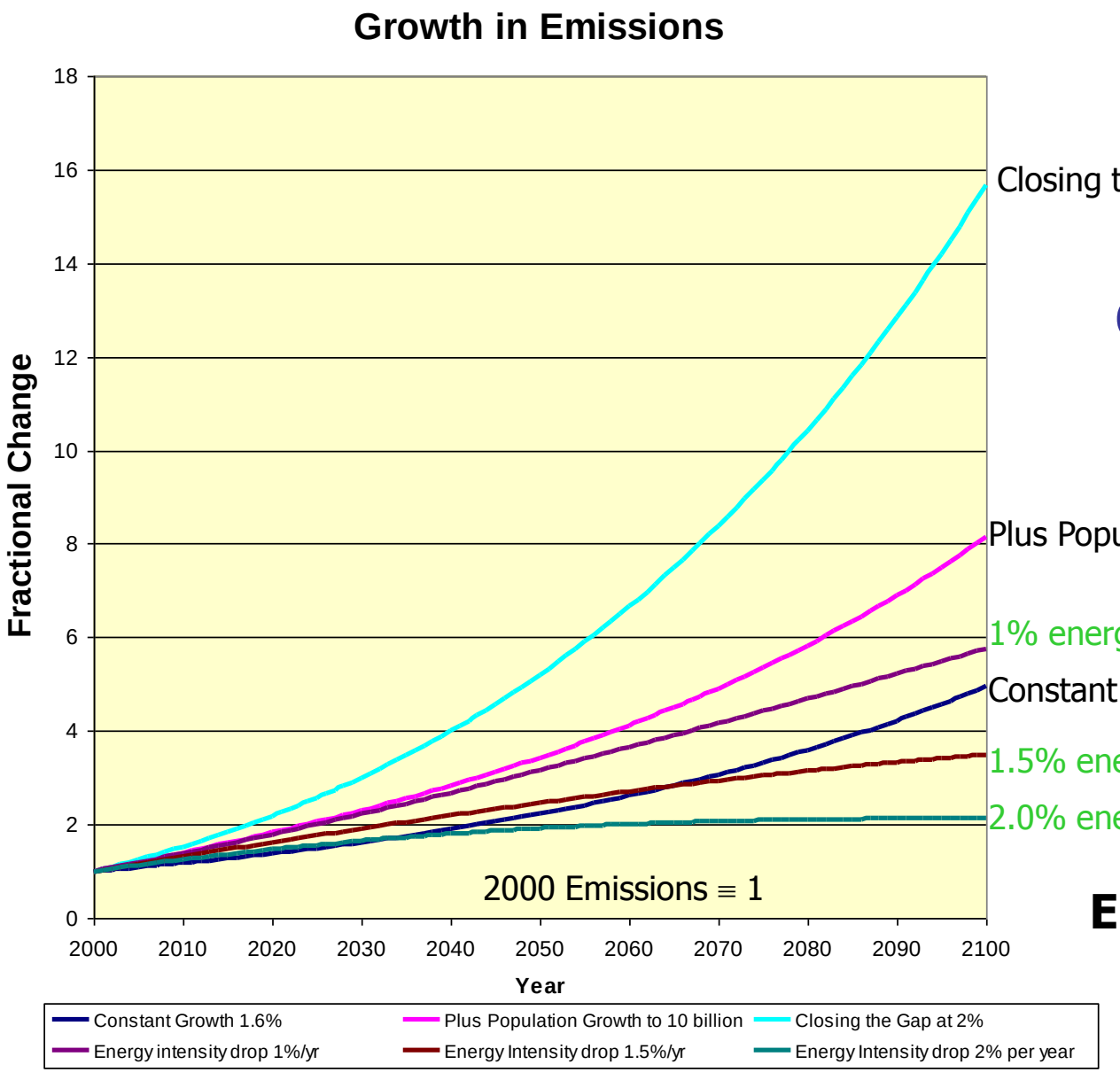


The Challenge:
Holding the Stock of CO_2 constant



IPCC Model Simulations of CO_2 Emissions





Historic Opportunity

Emissions in 2100 < 0.33

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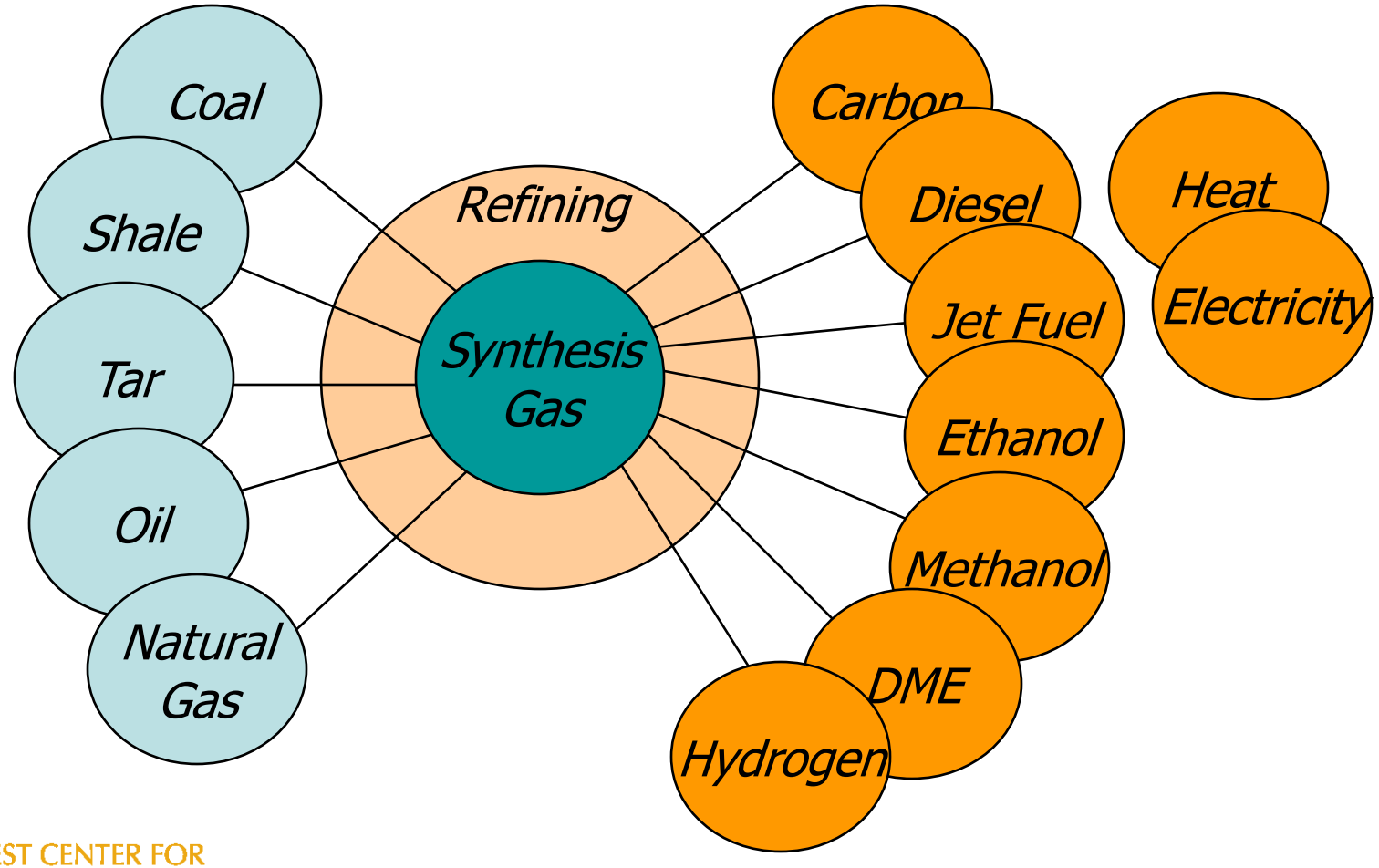
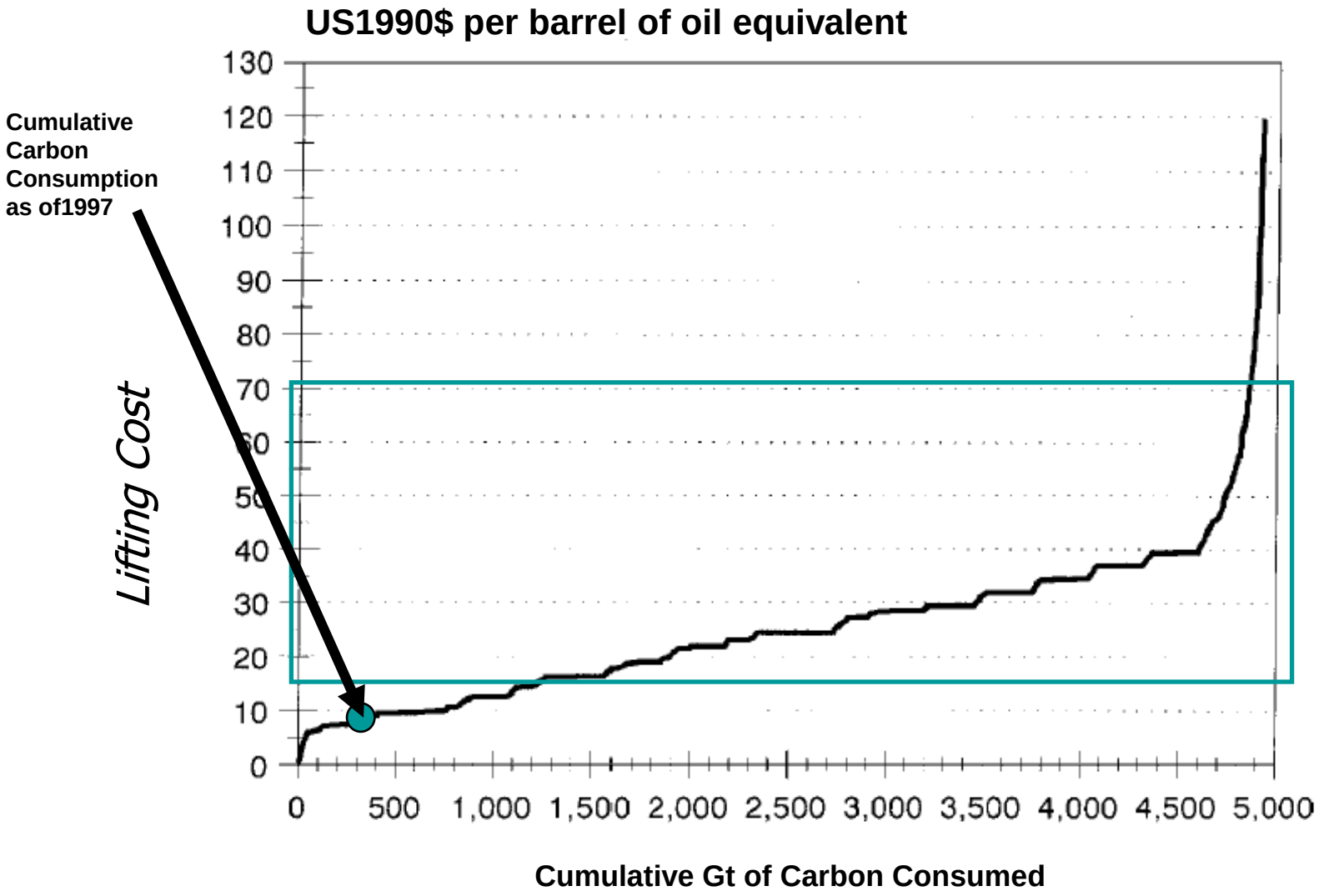
Fossil fuels are fungible



Fossil fuels are not running out



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H.H. Rogner, 1997

A Triad of Large Scale Options

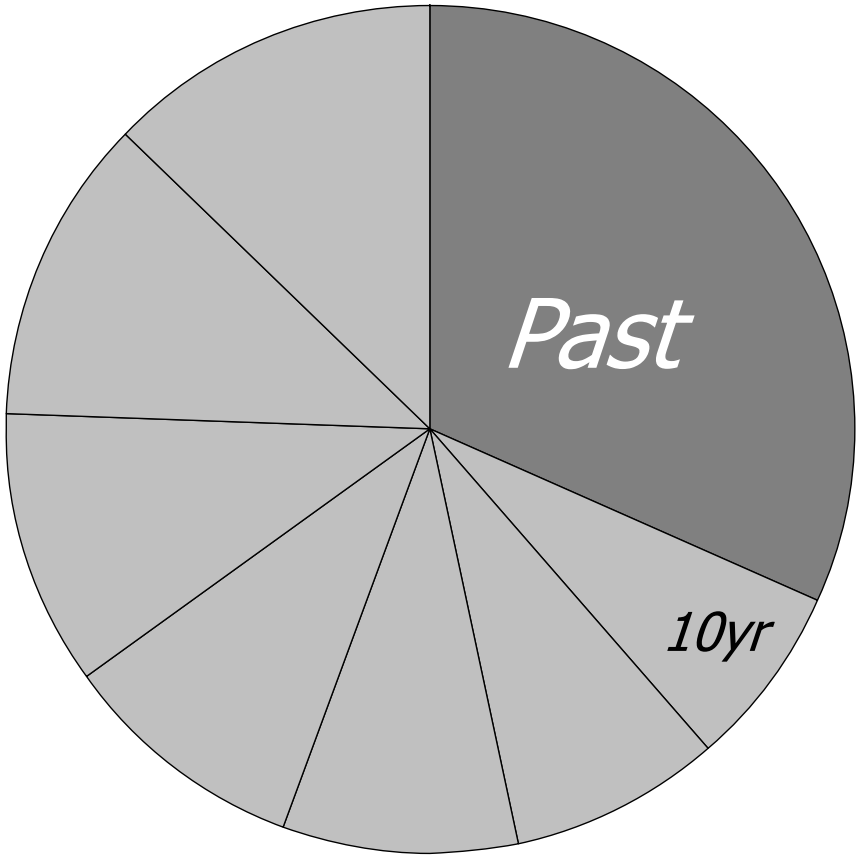
- Solar
  - Cost reduction and mass-manufacture
- Nuclear
  - Cost, waste, safety and security
- Fossil Energy
  - Requires carbon capture and storage
  - Ability to work with coal, tars and shales

Efficiency, alternative energy & conservation will help

Dividing The Fossil Carbon Pie

900 Gt C

total

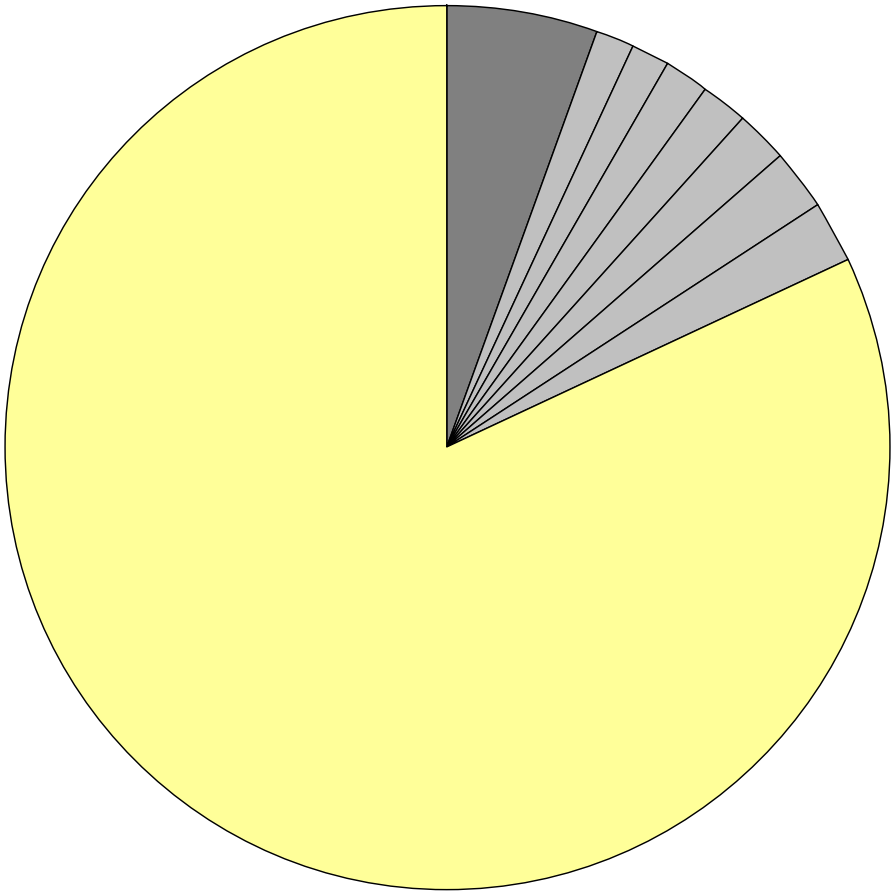


550 ppm

Removing the Carbon Constraint

5000 Gt C

total

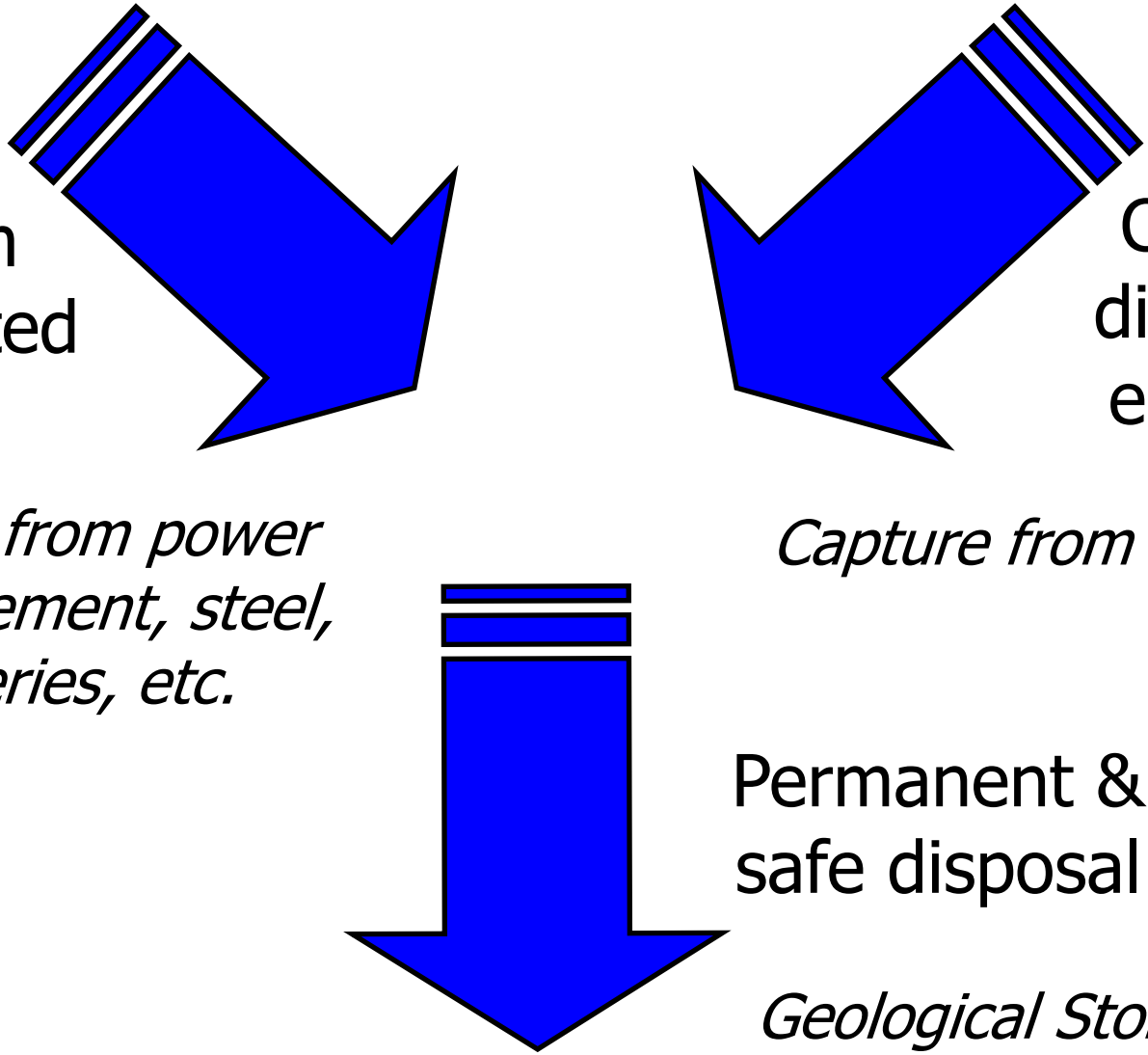


Equity and Fairness
Great Urgency

- Distribution between people
- Distribution between generations
    - Great urgency to get started
        - 450 ppm of $CO_{2\ effective}$ is maybe 20 years away
    - Avoid locking in bad solutions
    - Low cost-opportunities are in China

Unlike slowing down growth, CCS makes it possible to separate paying from doing

Net Zero Carbon Economy



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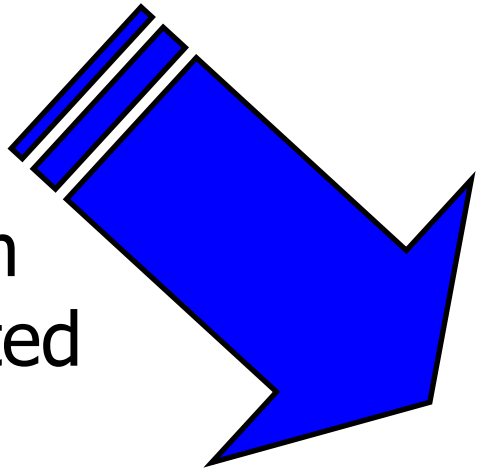
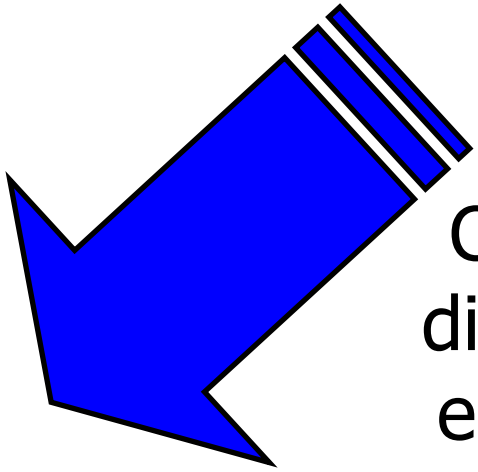


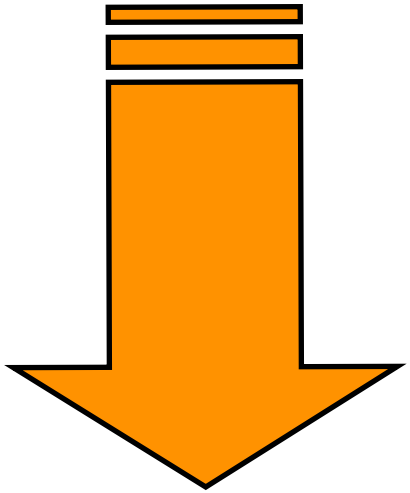
CO_2 from concentrated sources



CO_2 from distributed emissions

Capture from power plants, cement, steel, refineries, etc.

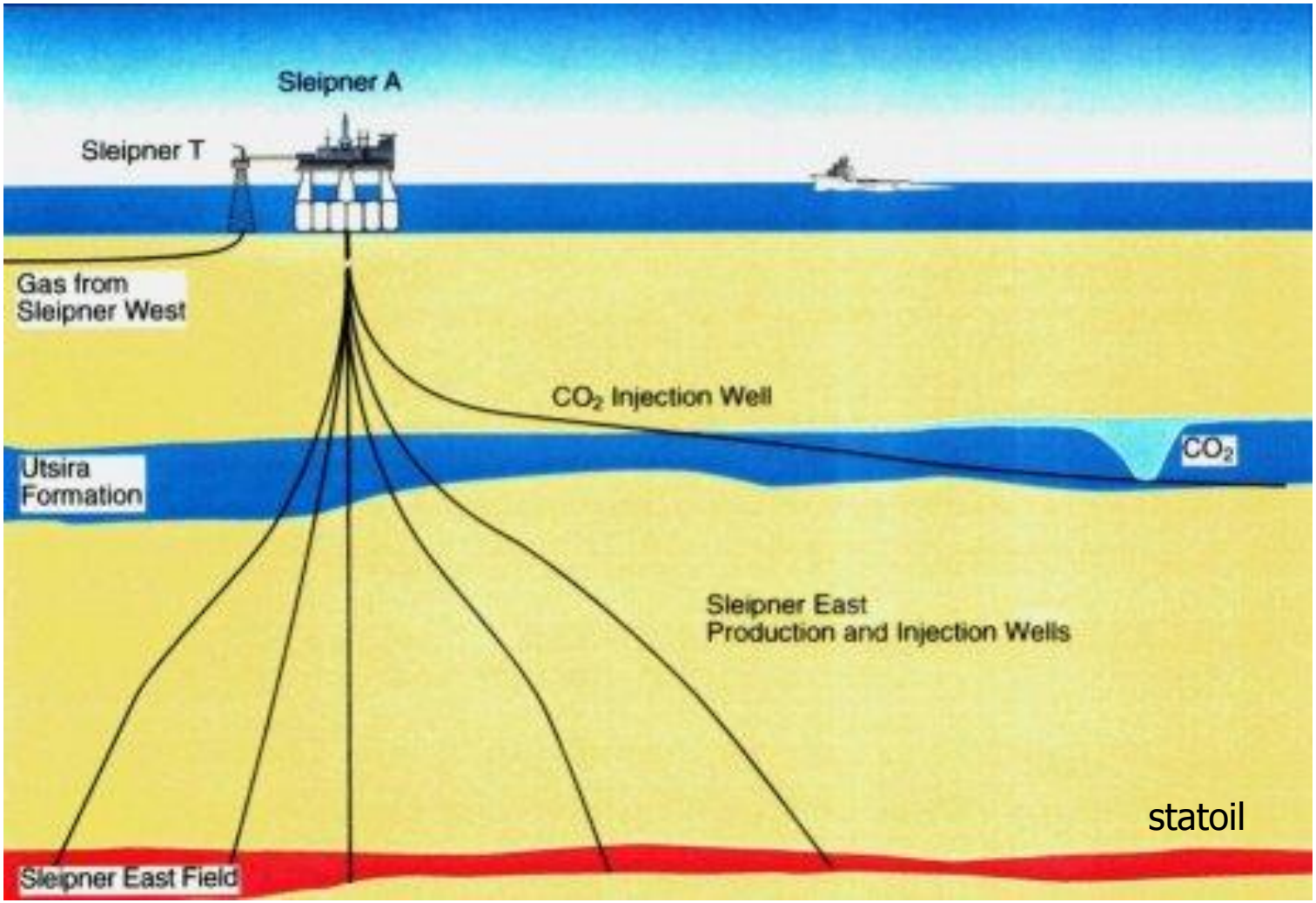
Capture from air



Permanent & safe disposal

Geological Storage
Mineral carbonate disposal

Underground Injection

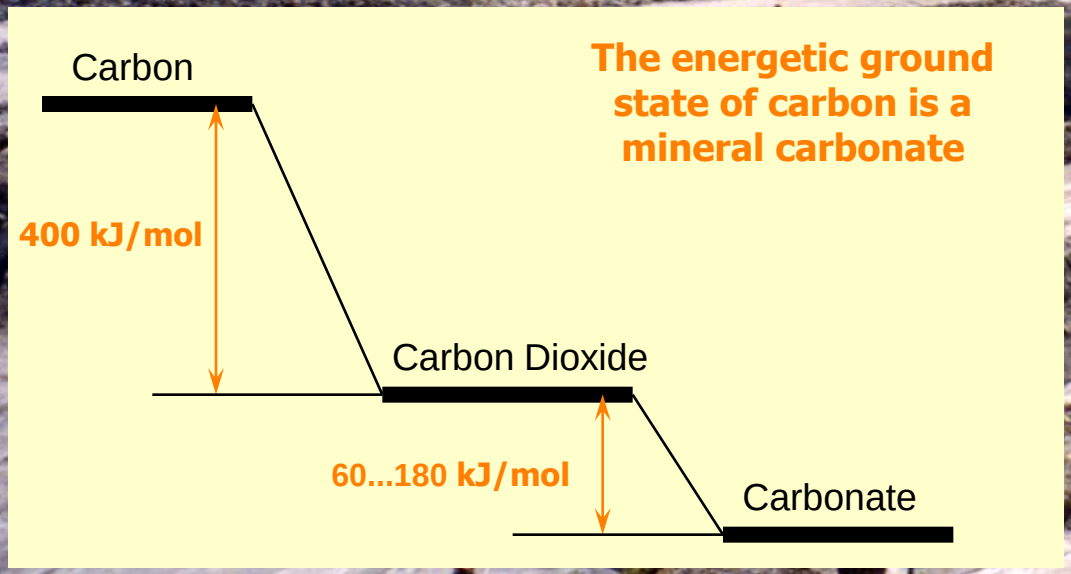


Challenges

- Public acceptance
  - Demonstrate safety, permanence and accountability
  - Emphasize inherent safety features
    - Dissolve CO_2, bind it chemically, eliminate buoyancy
  - Develop monitoring and verification
- Capacity
  - Limited by acceptance
  - May fall short of century-scale need

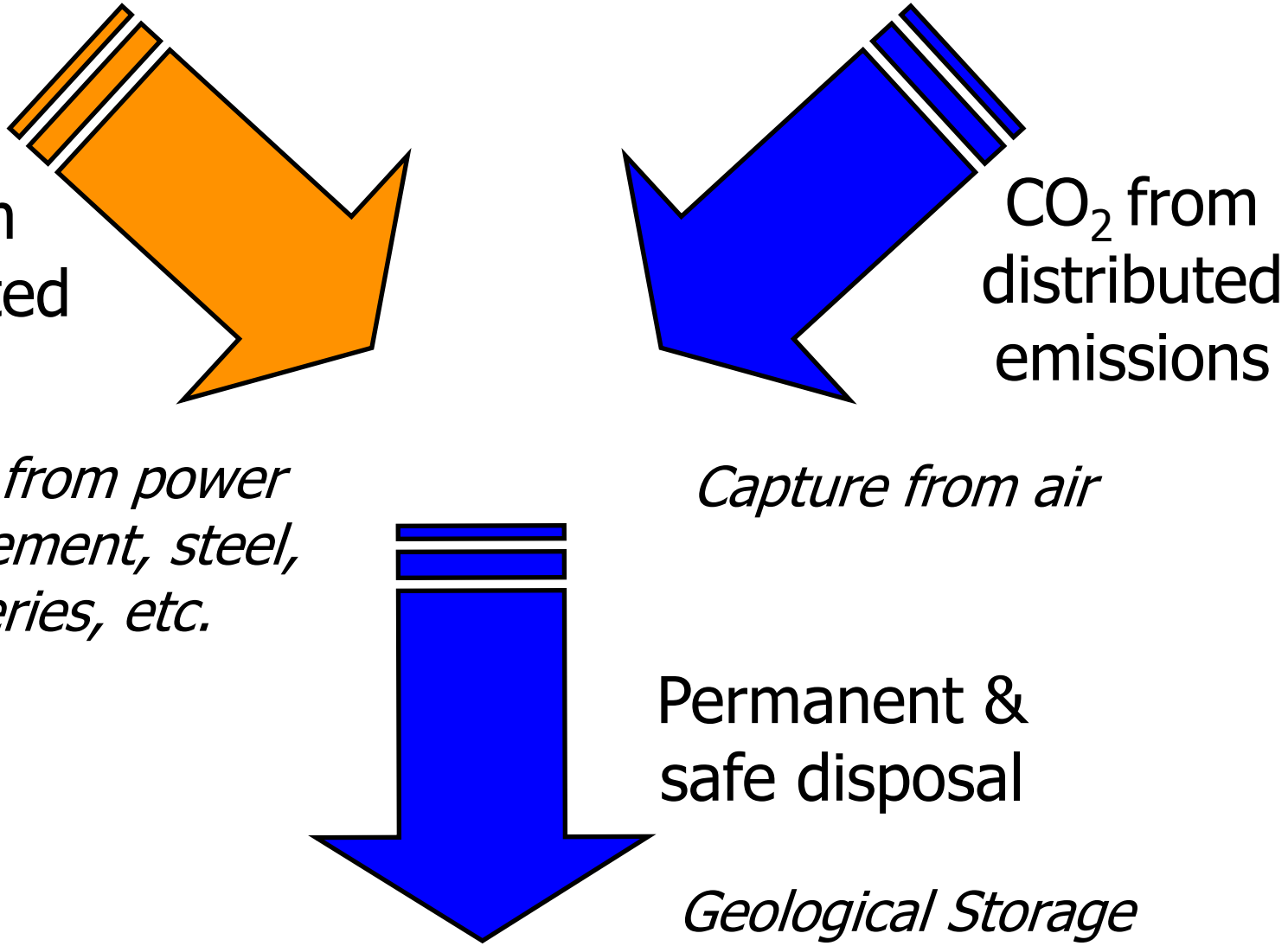
Mineral Sequestration

$$Mg_3Si_2O_5(OH)_4 + 3CO_2(g) \rightarrow 3MgCO_3 + 2SiO_2 + 2H_2O(l) \quad +63kJ/mol\ CO_2$$



Rockville Quarry

Net Zero Carbon Economy

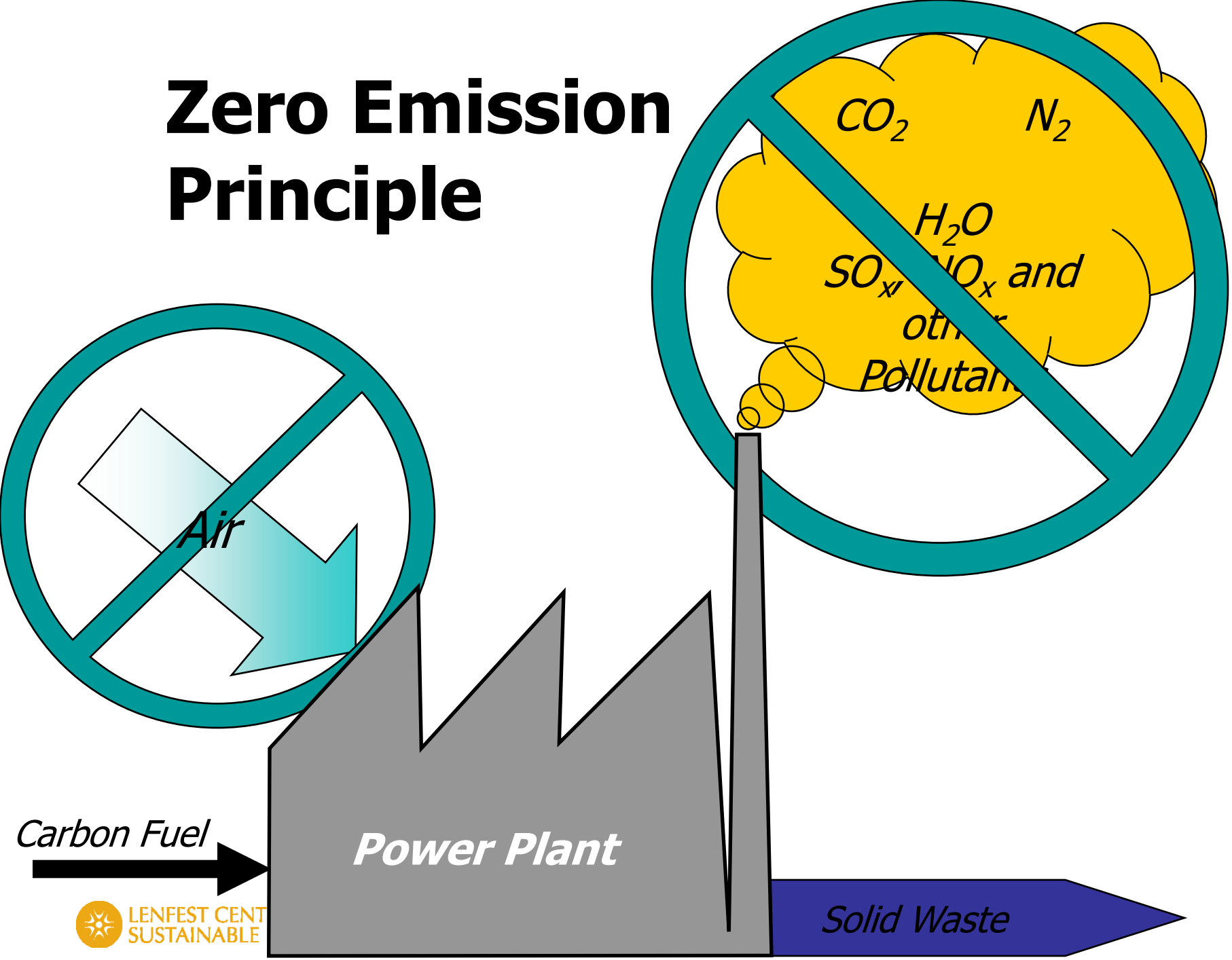


Many Different Options

- Flue gas scrubbing
  - MEA, chilled ammonia
- Oxyfuel Combustion
  - Naturally zero emission
- Integrated Gasification Combined Cycle
  - Difficult as zero emission
- AZEP Cycles
  - Mixed Oxide Membranes
- Fuel Cell Cycles
  - Solid Oxide Membranes

Problem needs solutions on many different timescales

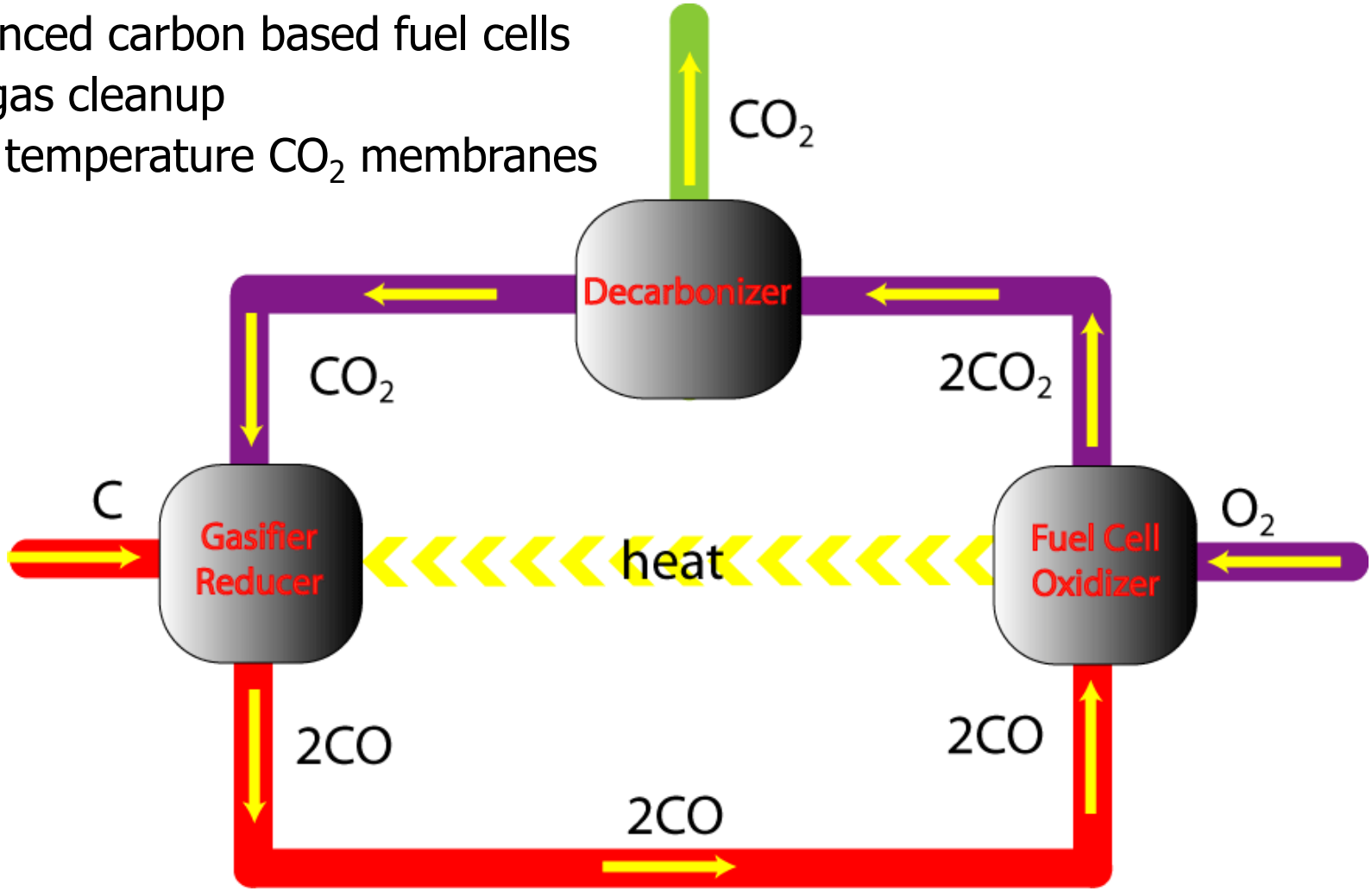
Zero Emission Principle



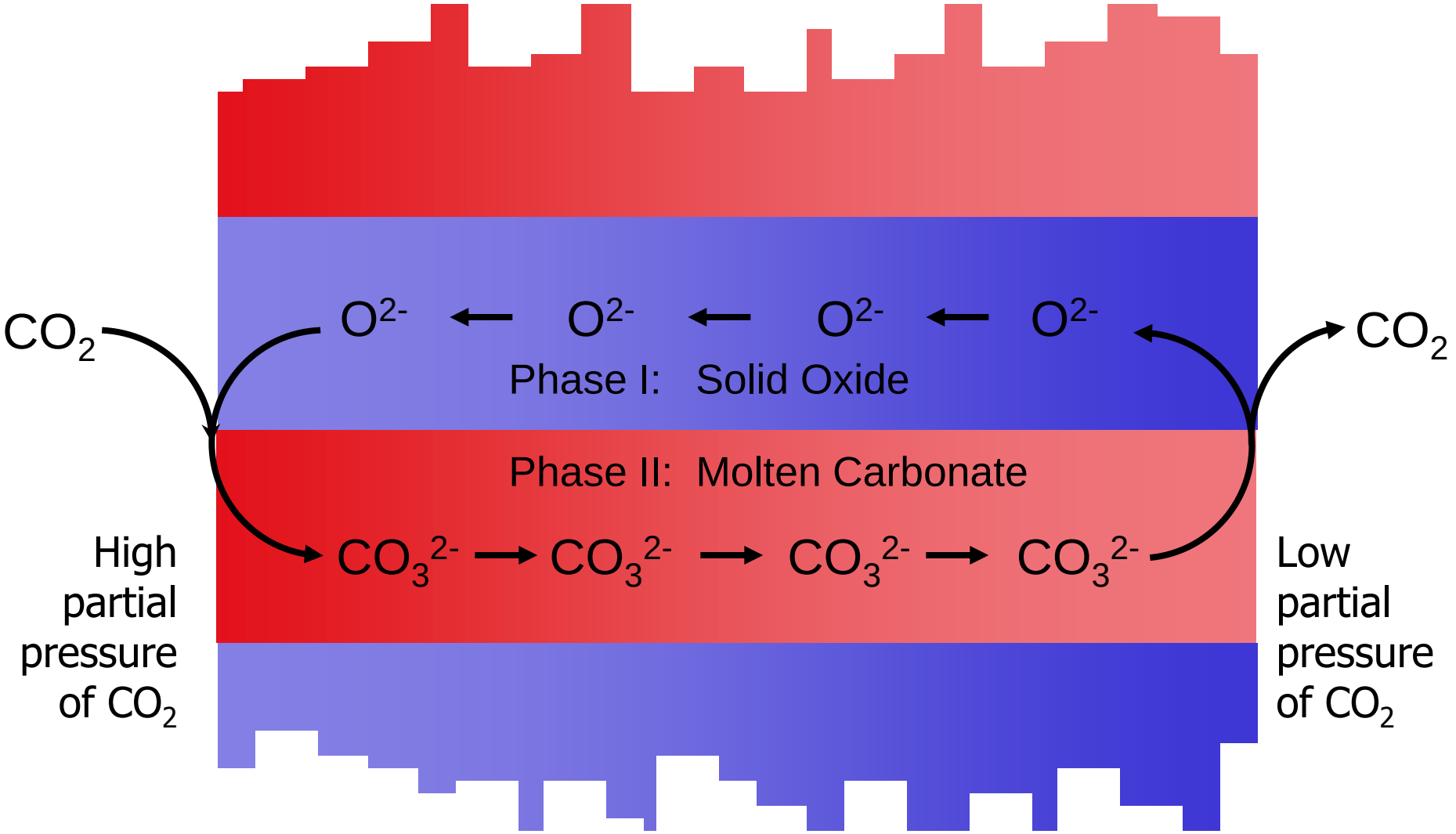
LENFEST CENT
SUSTAINABLE

Boudouard Reaction

- Advanced carbon based fuel cells
- Hot gas cleanup
- High temperature CO_2 membranes



CO_2 Membrane



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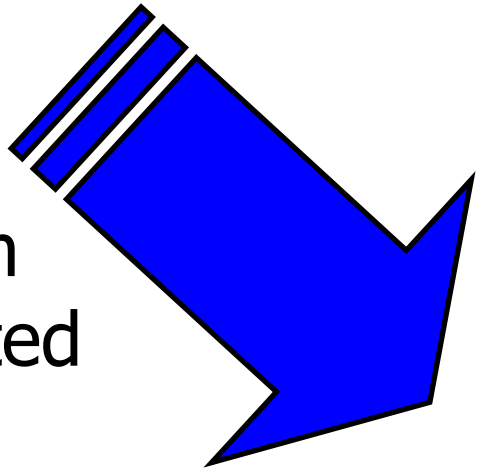

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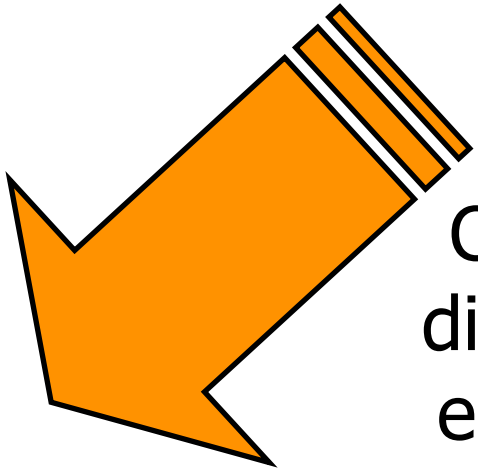

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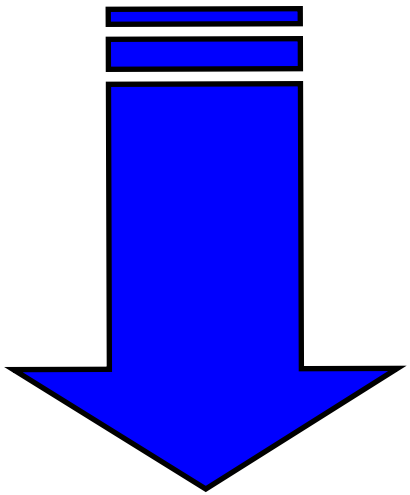

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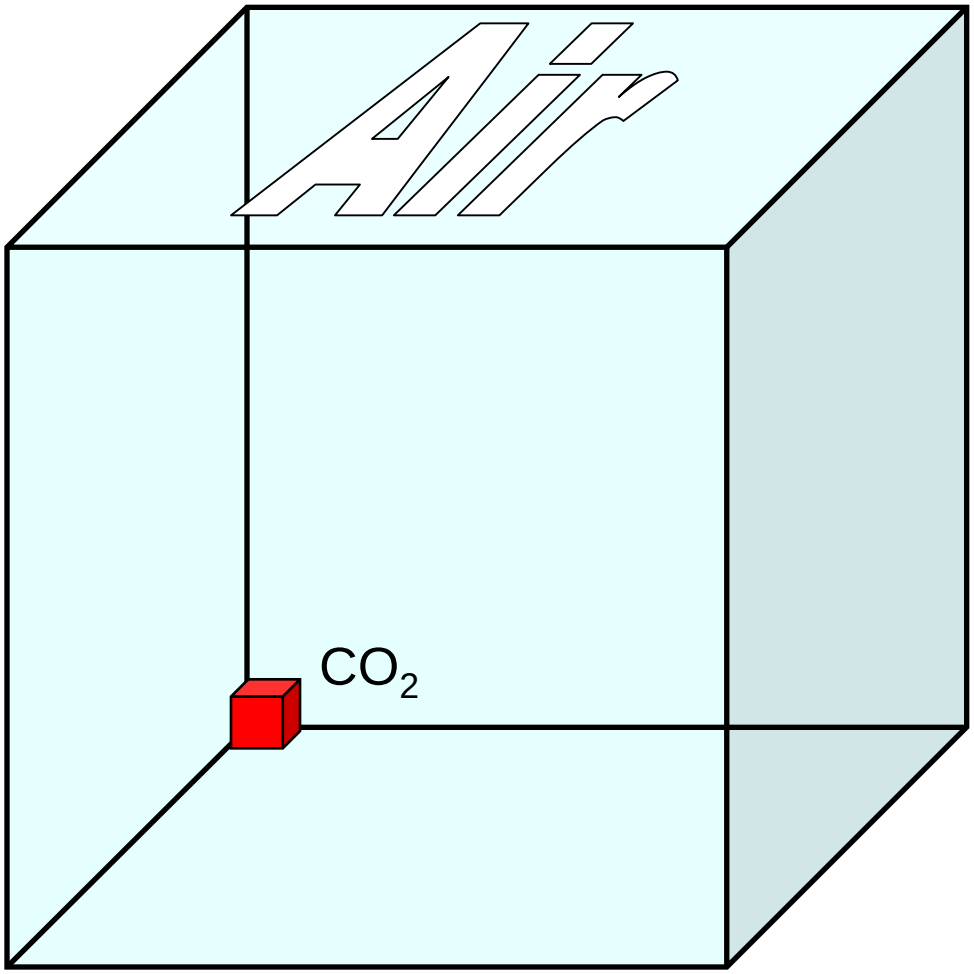

1 m³of Air

40 moles of gas, 1.16 kg

wind speed 6 m/s

$$\frac{mv^2}{2} = 20\,\mathrm{J}$$

0.015 moles of CO_2

produced by 10,000 J of gasoline

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Volumes are drawn to scale

The first of a kind

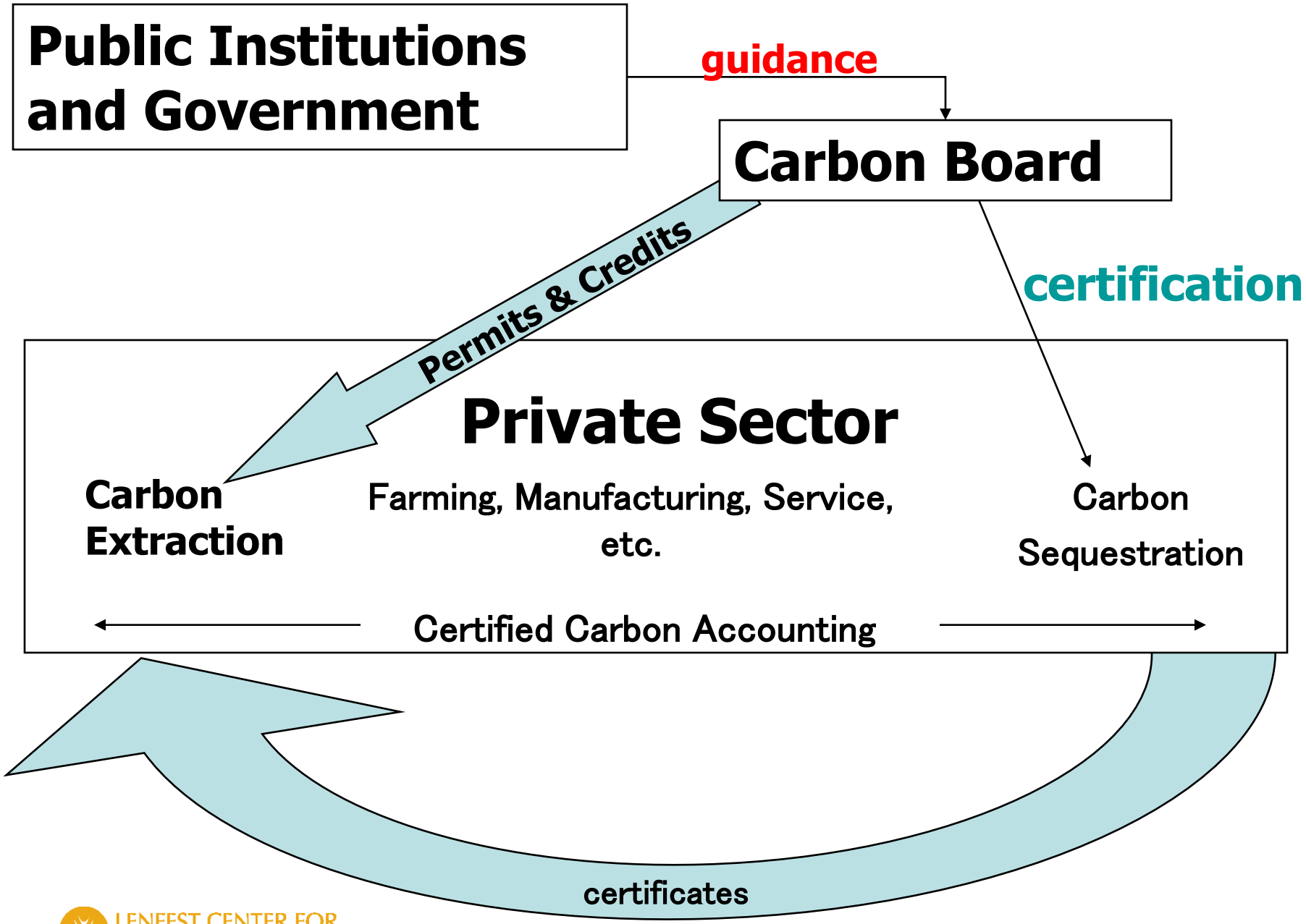
Capture anywhere and anytime

Solution for cars and airplanes

No changes to existing infrastructure

Carbon Capture and Storage for A Carbon Neutral World

- CCS simplifies Carbon Accounting
  - Ultimately, the cap is zero
  - Finite amount of carbon left


Public Institutions and Government
guidance
Carbon Board
Permits & Credits
certification
Private Sector
Carbon Extraction
Farming, Manufacturing, Service, etc.
Carbon Sequestration
Certified Carbon Accounting
certificates

Climate change will trigger a revolution in the world's energy infrastructure

- Existing infrastructure will become obsolete
  - Business as usual will not compete
  - A great opportunity for new ideas
  - A second chance for old ideas

Next twenty years will see new ideas

new markets

new market leaders