Carbon Management Technology

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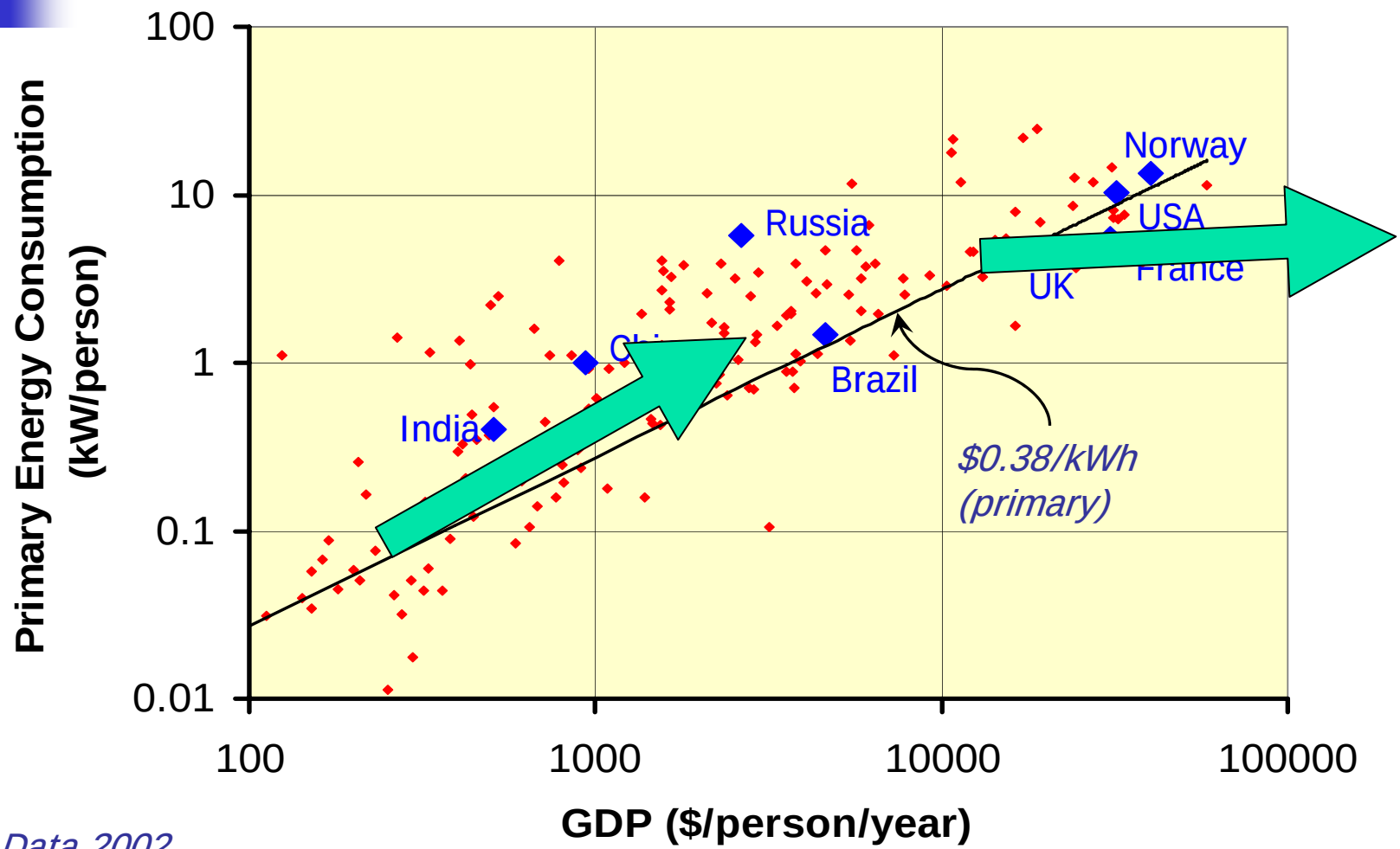
Energy, Wealth, Economic Growth



EIA Data 2002

Today's Energy Infrastructure

- All fossil energy
- plus a little hydro and nuclear energy
- plus a very little renewable energy

Today's technology cannot support a world population of 10 billion people striving for a living standard taken for granted in the developed nations

Resource Will Not Run Out

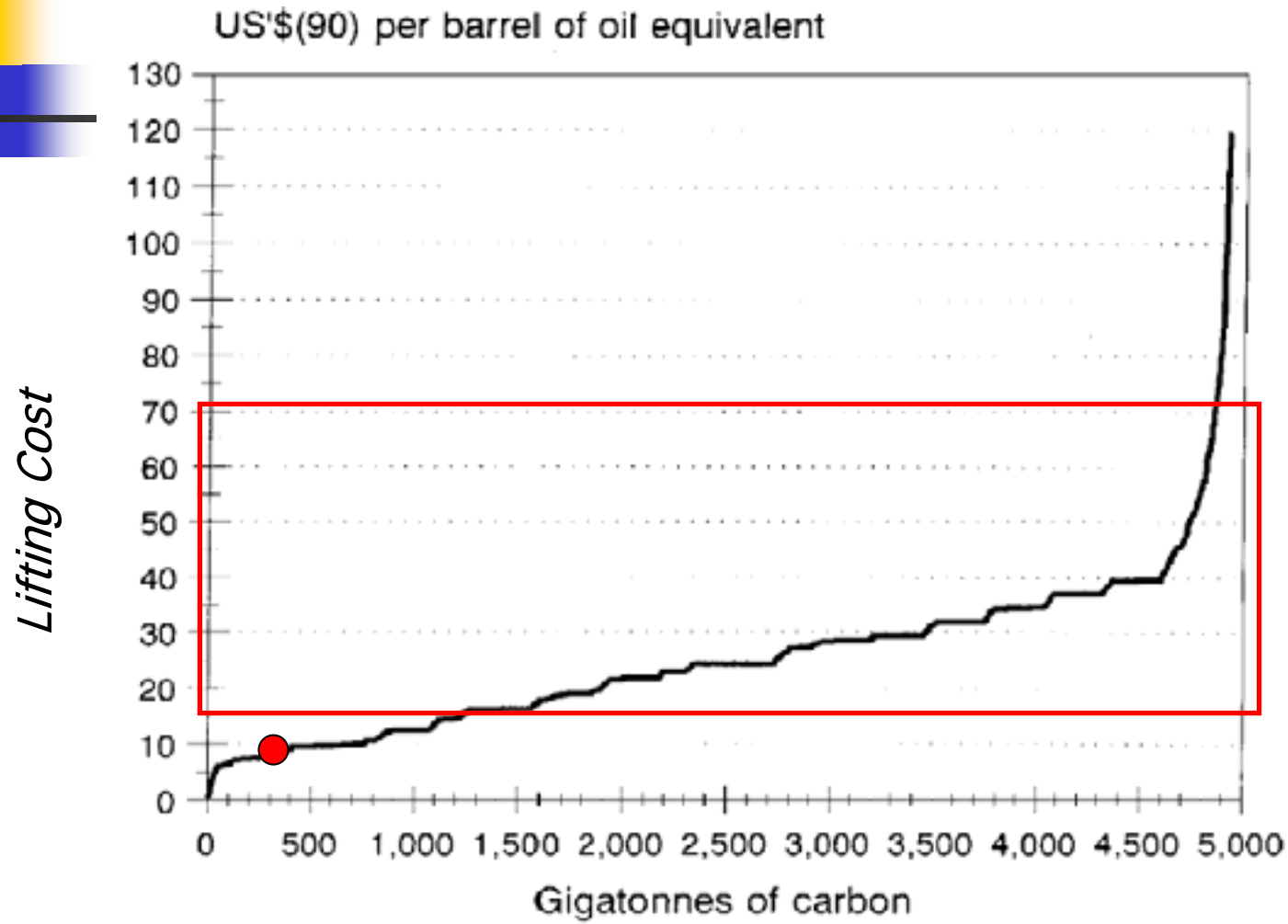
Table 9 Aggregation of global fossil energy sources—all occurrences, in Gtoe[a]

	Consumption					
	1860–1994	1994	Reserves	Resources[b]	Resource base[c]	Additional occurrences
Oil						
Conventional	103	3.21	150	145	295	
Unconventional	6	0.16	183	336	519	1,824
Natural gas						
Conventional[d]	48	1.87	141	279	420	
Unconventional	—	—	192	258	450	387
Clathrates	—	—	—	—	—	18,759
Coal	134	2.16	1,003	2,397	3,400	2,846
Total fossil occurrences	291	7.40	1,669	3,415	5,084	23,815

[a]Sources: Historial consumption (46). Reserves, resources, and occurrences, see Tables 2–8.
— = negligible volumes.
[b]Reserves to be discovered or resources developed to resources.
[c]Resource base is the sum of reserves and resources.
[d]Includes natural gas liquids.

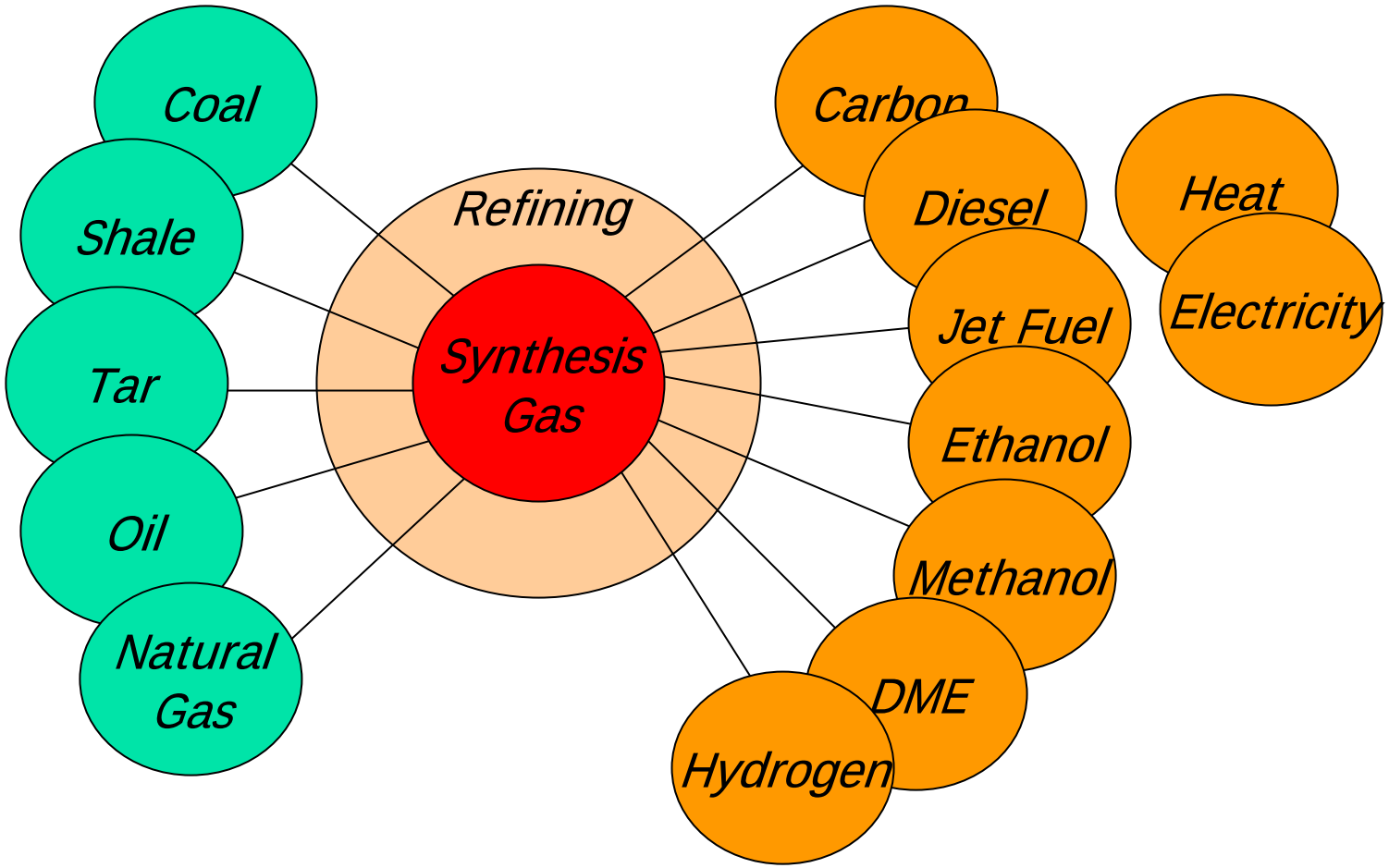
H.H. Rogner, 1997

Carbon as Low Cost Energy



Rogner 1997

Fossil fuels are fungible

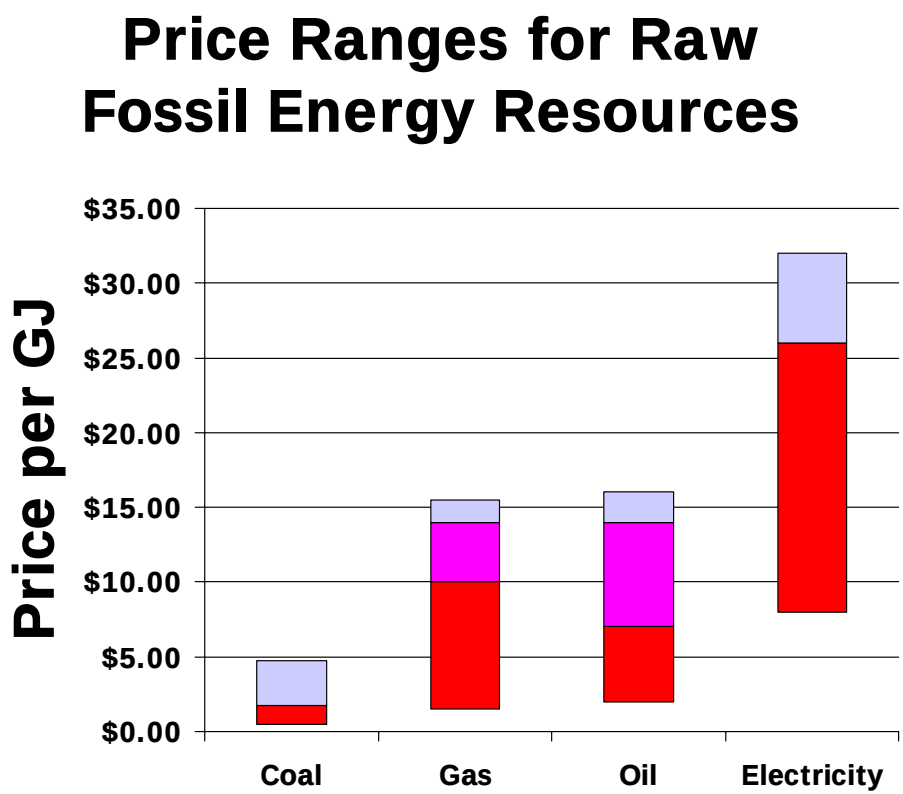


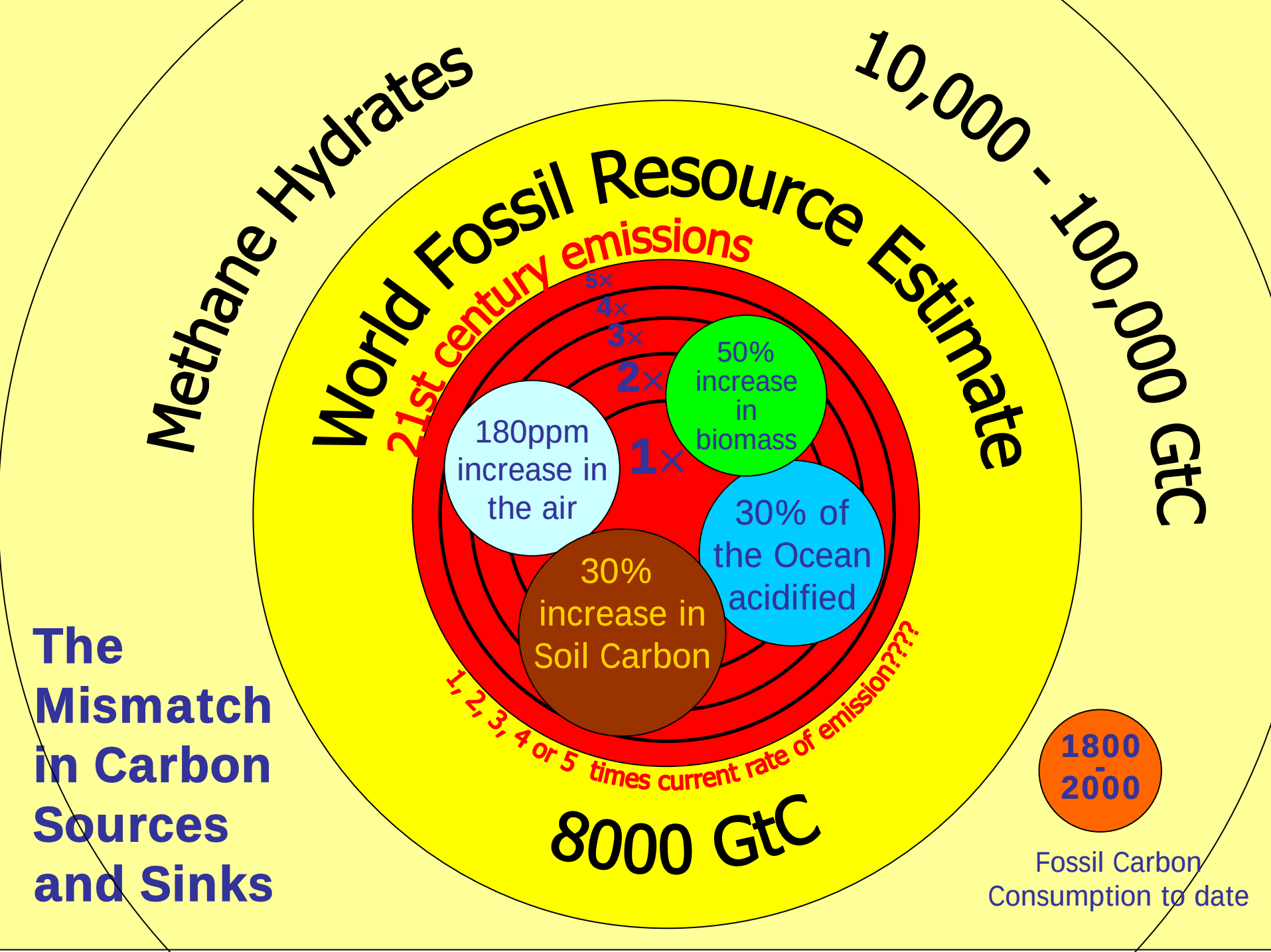
The hydrogen economy cannot run on electricity

There are no hydrogen wells

Tar, coal, shale and biomass could support a hydrogen economy.

Wind, photovoltaics and nuclear energy cannot.





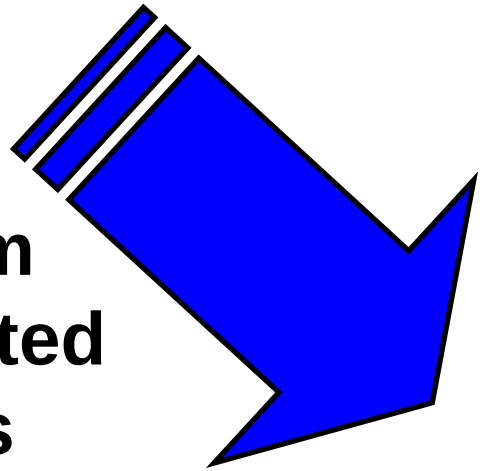
The Mismatch in Carbon Sources and Sinks

A Triad of Large Scale Options
backed by a multitude of opportunities

- Solar
  - Cost reduction and mass-manufacture
- Nuclear
  - Cost, waste, safety and security
- Fossil Energy
  - Zero emission, carbon storage and interconvertibility

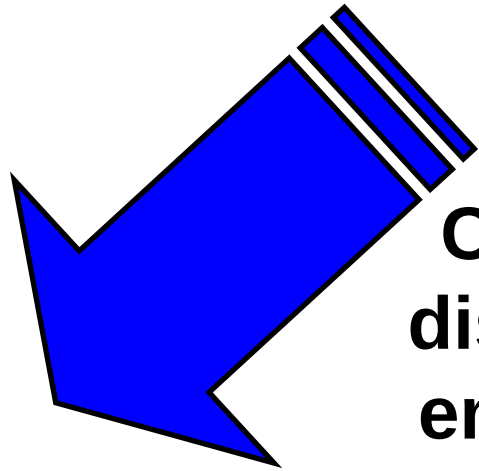
Markets will drive efficiency, conservation and alternative energy

Net Zero Carbon Economy



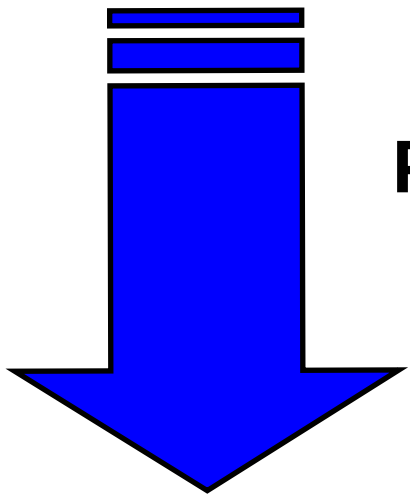
CO_2 from concentrated sources

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



CO_2 from distributed emissions

Capture from air



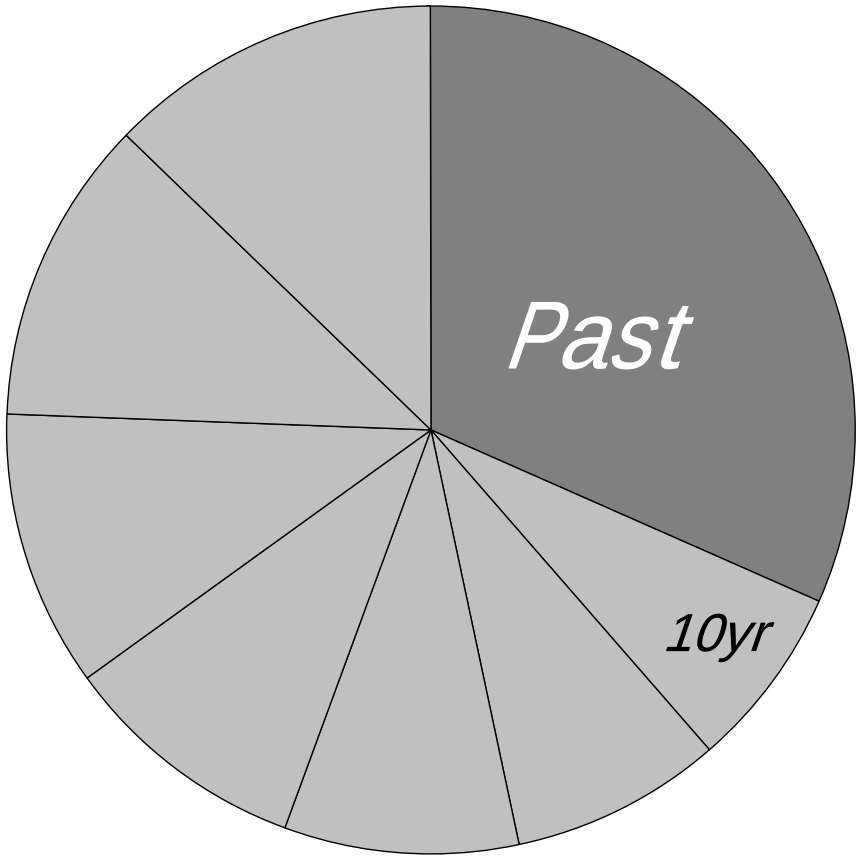
Permanent & safe disposal

Geological Storage
Mineral carbonate disposal

Dividing The Fossil Carbon Pie

900 Gt C

total

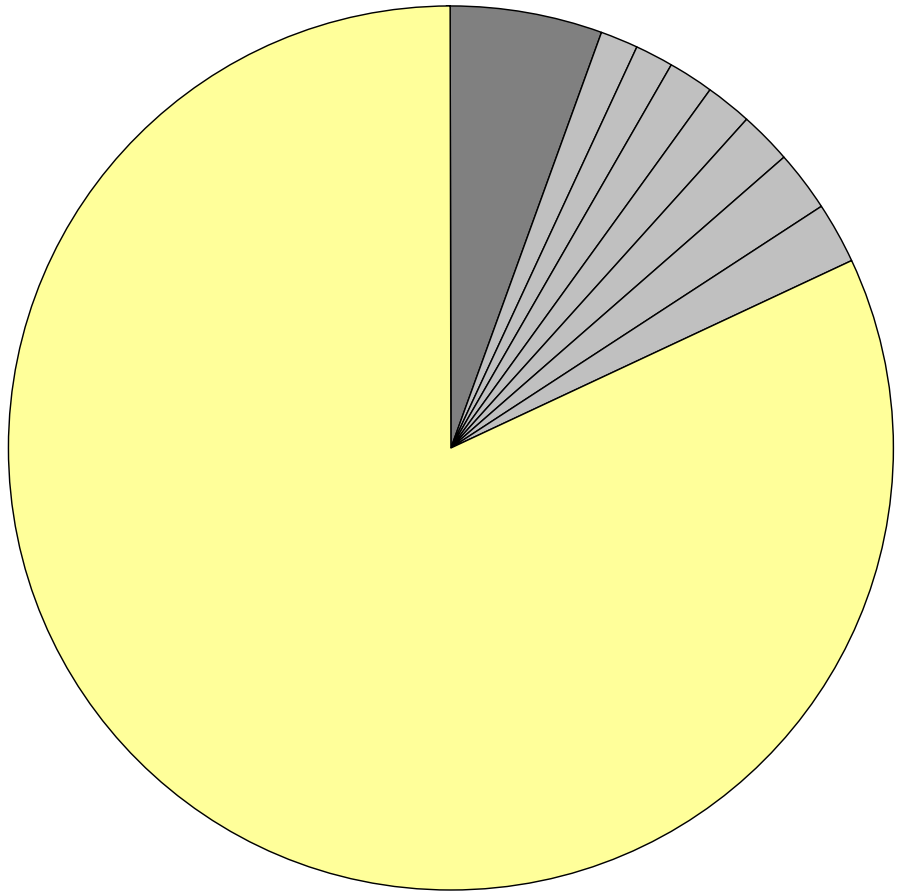


550 ppm

Removing the Carbon Constraint

5000 Gt C

total



Storage Life Time

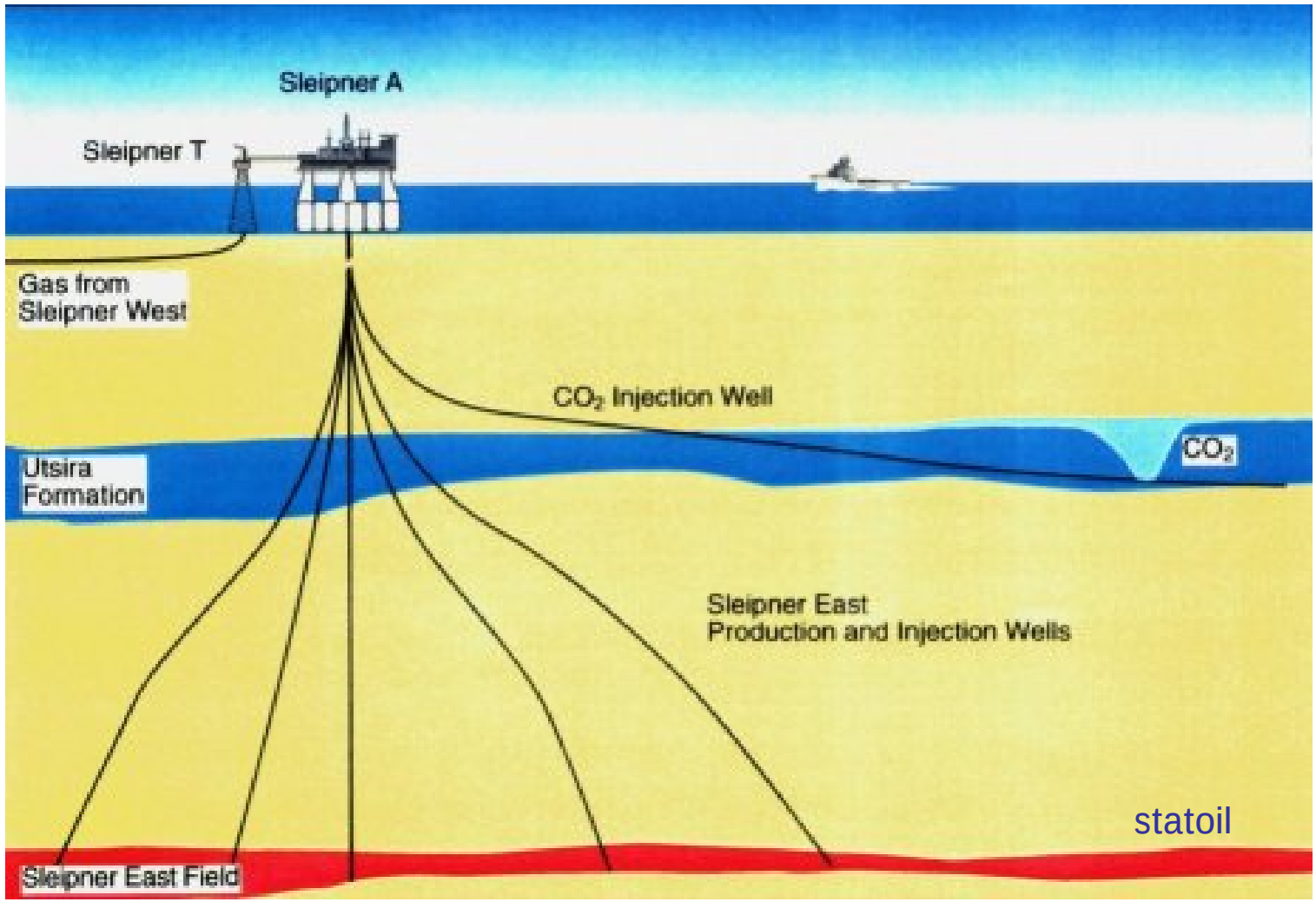
Storage

5000 Gt of C

200 years at 4 times current rates of emission

Current Emissions: 6Gt/year

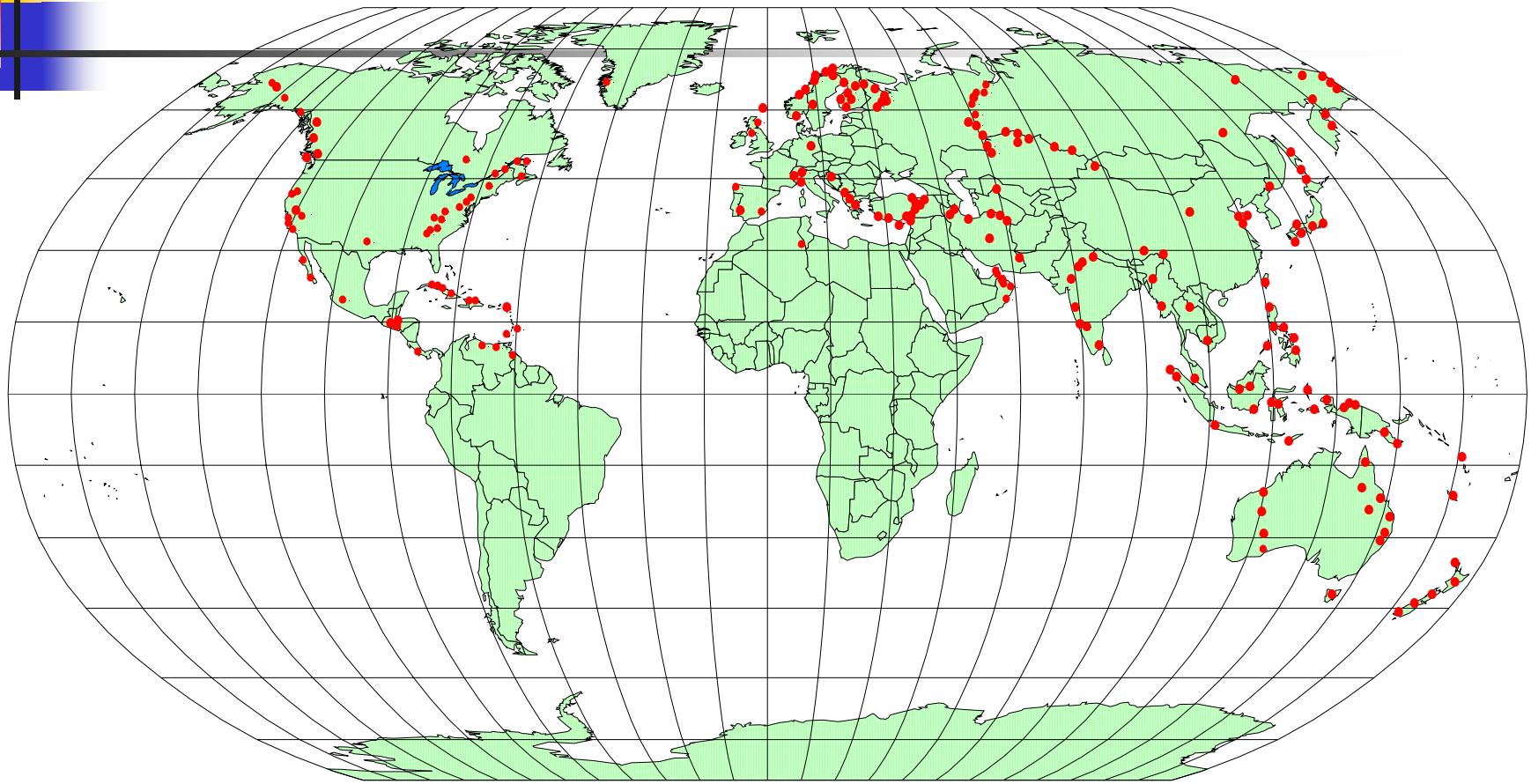
Underground Injection



Rockville Quarry

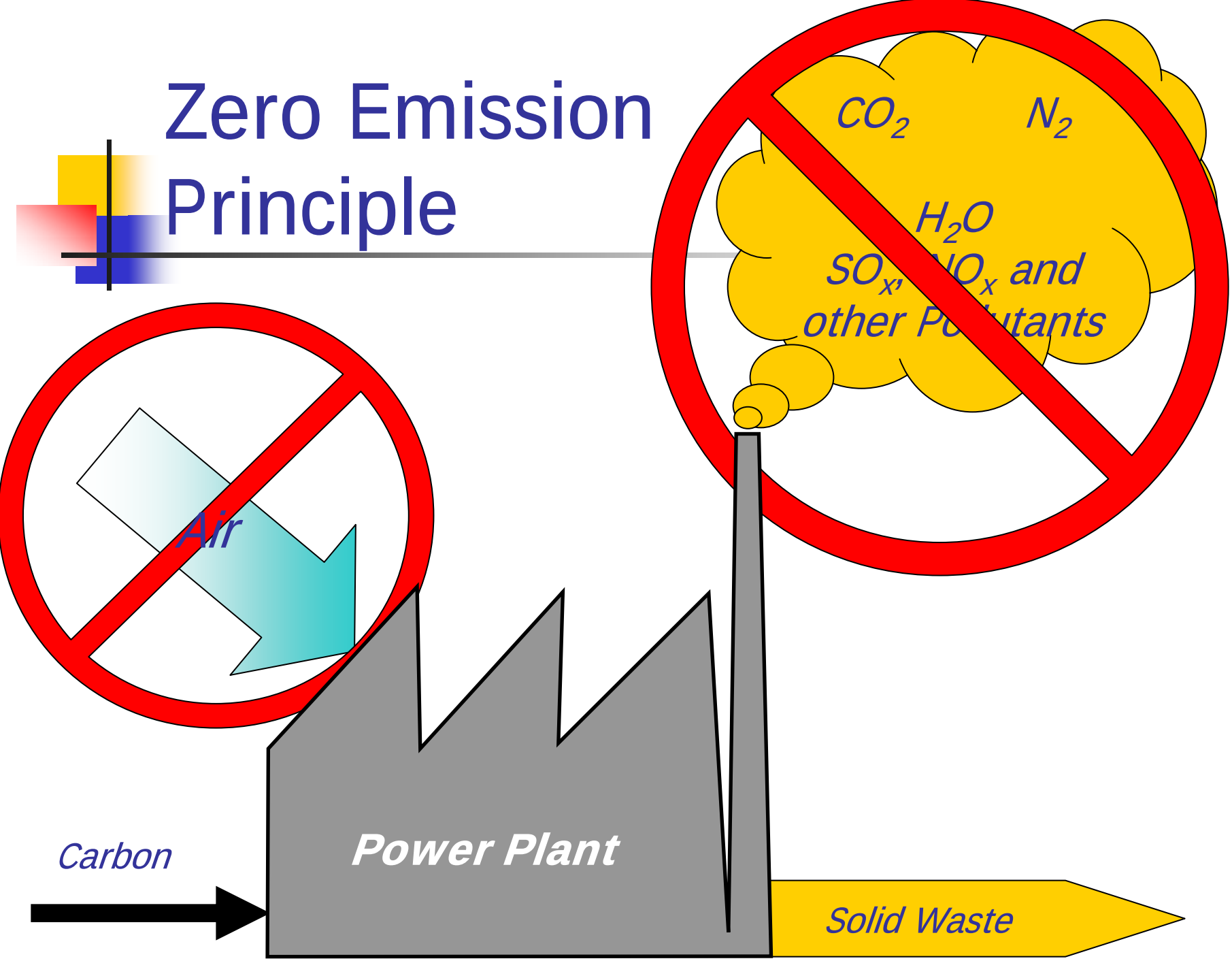
$$Mg_3Si_2O_5(OH)_4 + 3CO_2(g) \rightarrow 3MgCO_3 + 2SiO_2 + 2H_2O(l) + 63kJ/mol\ CO_2$$

Peridotite and Serpentinite Ore Bodies

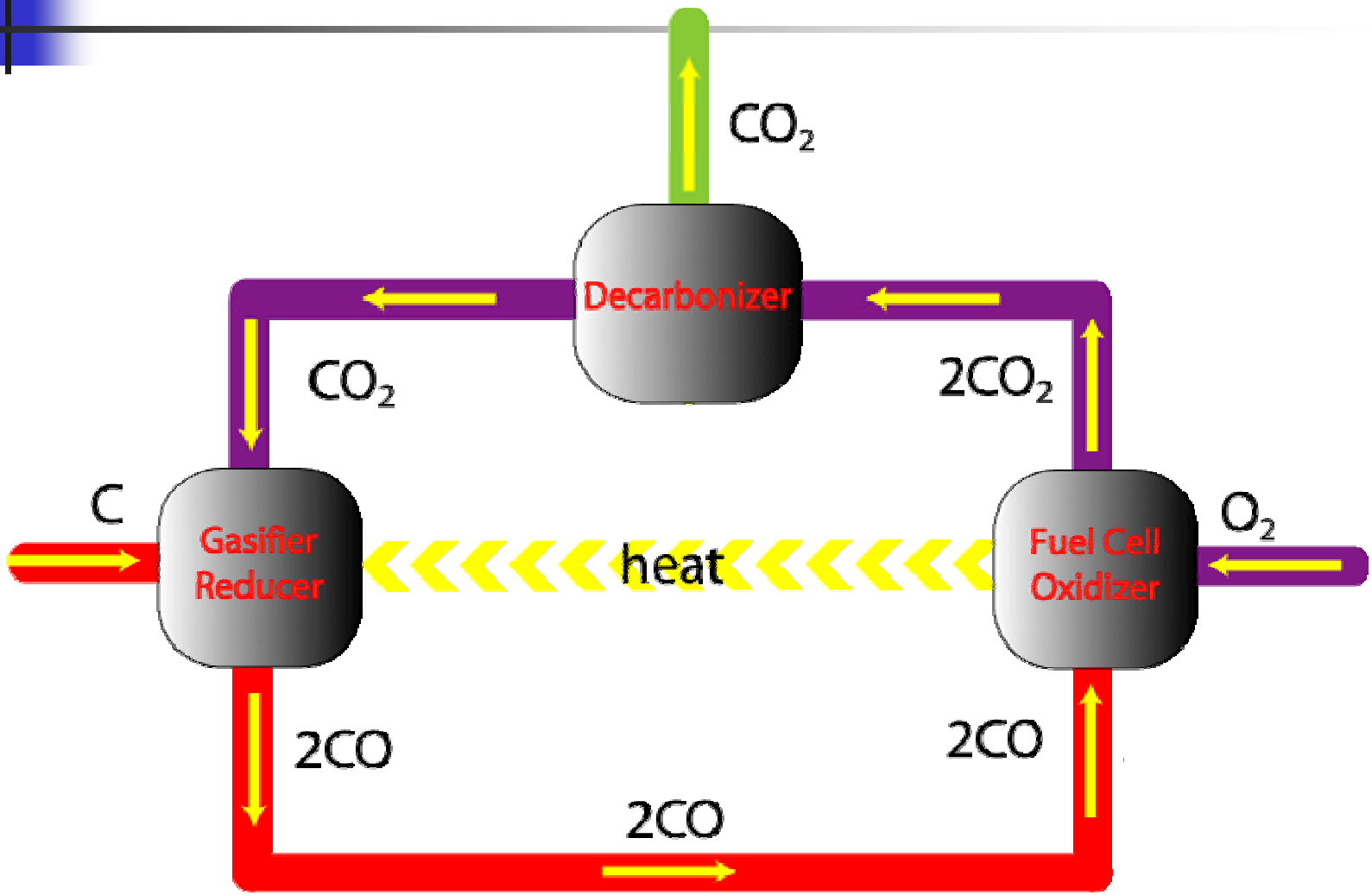


Magnesium resources that far exceed world fossil fuel supplies

Zero Emission Principle



Boudouard Reaction



Carbon makes a better fuel cell

$C + O_2 \rightarrow CO_2$

no change in mole volume

entropy stays constant

$\Delta G = \Delta H$

$2H_2 + O_2 \rightarrow 2H_2O$

large reduction in mole volume

entropy decreases in reactants

made up by heat transfer to surroundings

$\Delta G < \Delta H$

Decarbonizing Energy Carriers

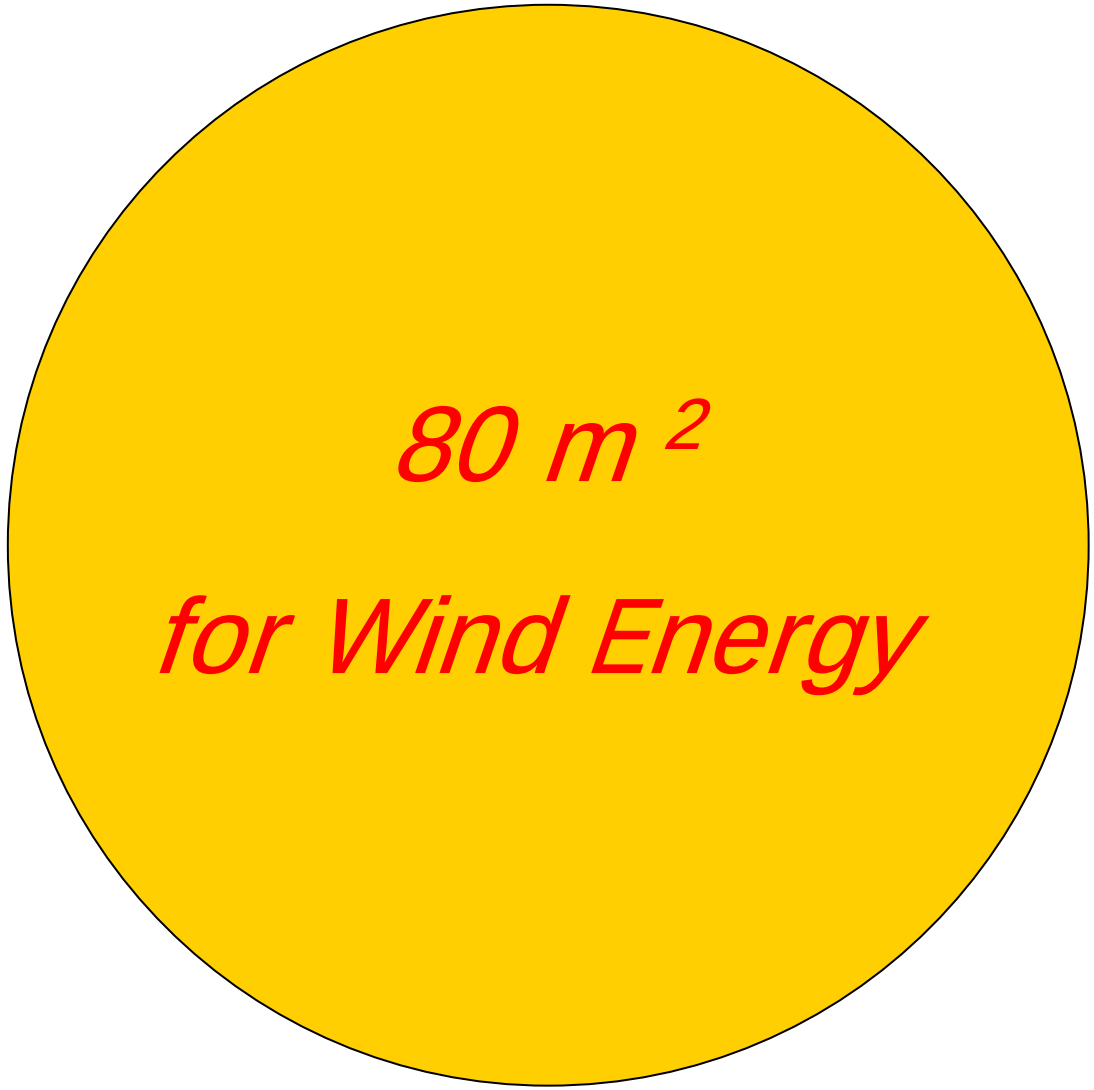
- All Electric Economy
  - Stationary uses
- Hydrogen Economy
  - Heating and transportation
- Extraction of CO_2 from Air
  - Biomass
  - Chemical Extraction


Air Extraction can compensate for CO_2 emissions anywhere
$2NaOH + CO_2 \rightarrow Na_2CO_3$
Art Courtesy Stonehaven CCS, Montreal

How much wind?

(6m/sec)

Wind area that carries 10 kW



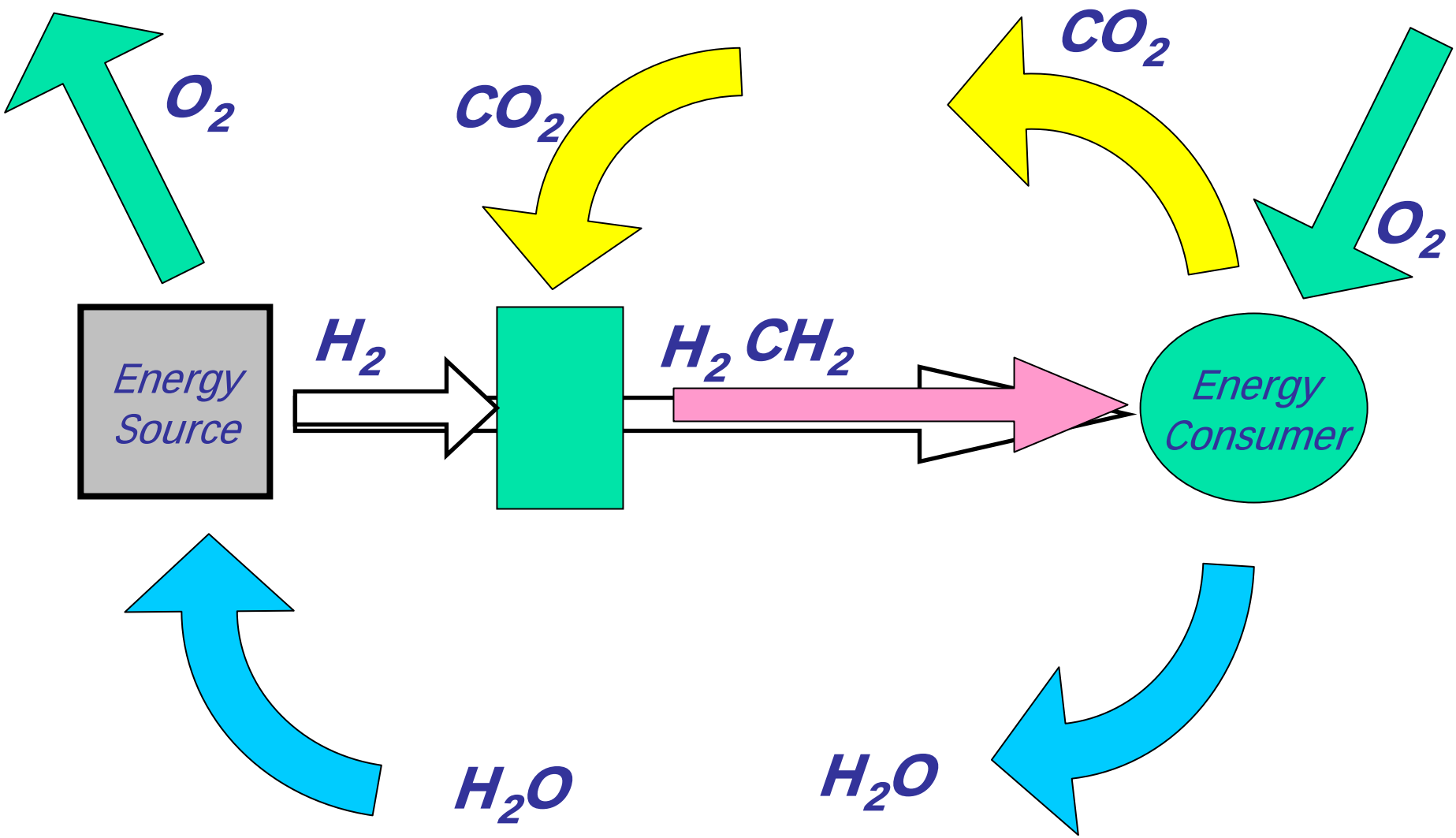
0.2 m 2

for CO_2

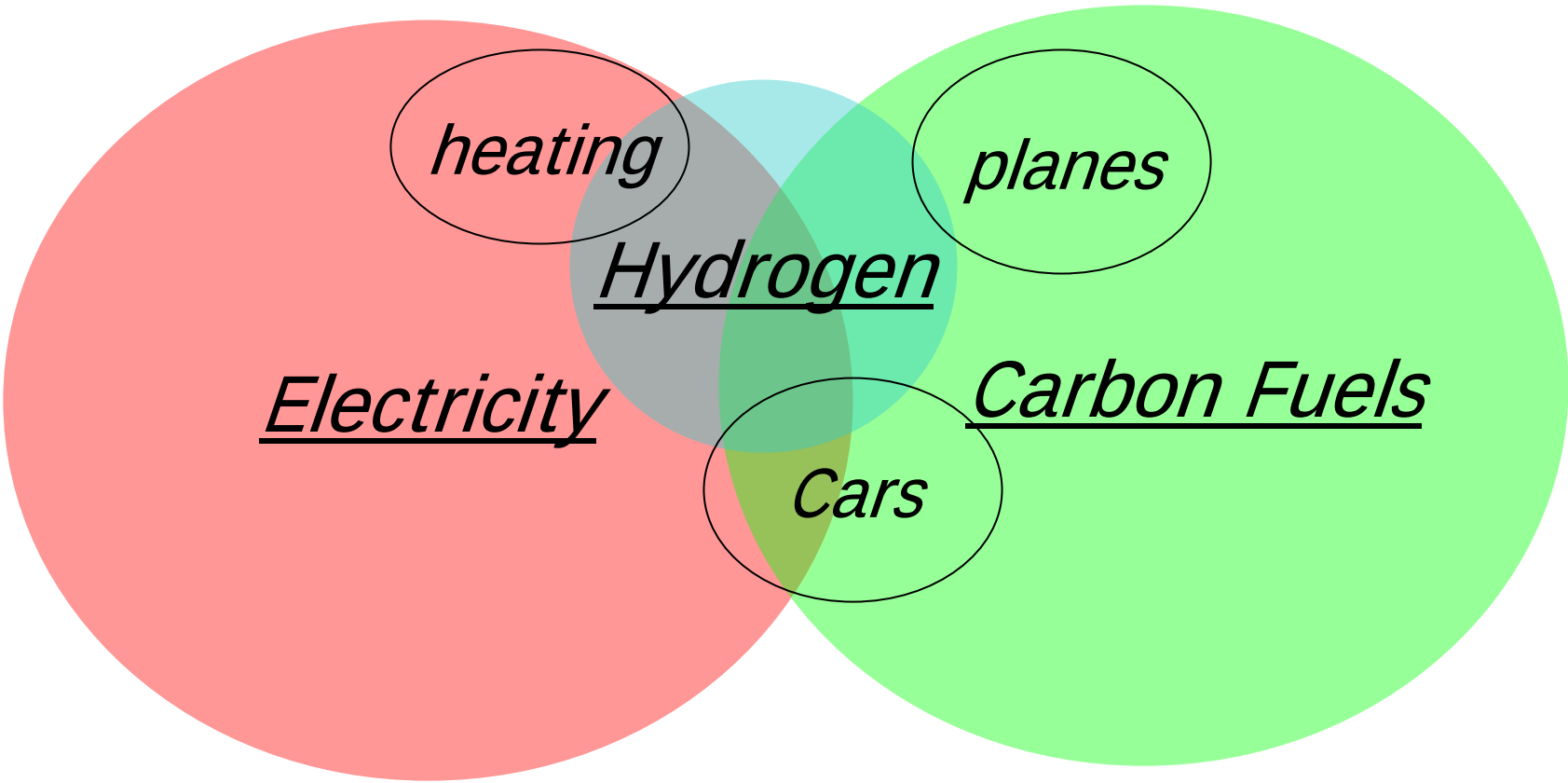
Wind area that carries 22 tons of CO_2 per year

50 cents/ton of CO_2 for contacting

Materially Closed Energy Cycles



Roles of Different Energy Carriers



Connecting Sources to Carriers Carriers to Consumers