the center for negative carbon emissions

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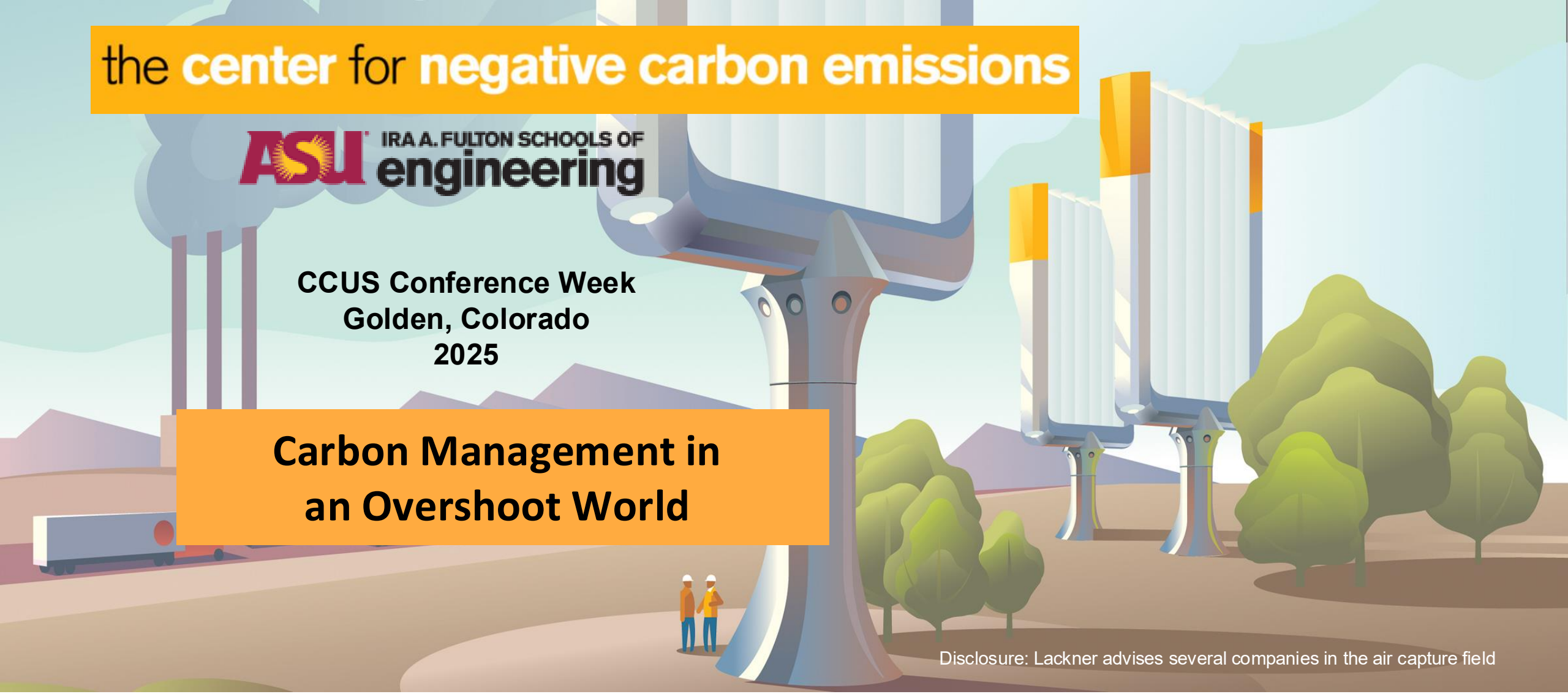
2025

Carbon Management in an Overshoot World



Disclosure: Lackner advises several companies in the air capture field

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We live in an overshoot world

The world has a finite carbon budget

- Fossil carbon enters the mobile carbon pool from naturally sequestered sources
  - 60 years of current CO_2 emissions exceeds:
    - The preindustrial carbon content of the atmosphere
    - The entire carbon in the biomass, mainly trees
- Excess carbon remains in the atmosphere, ocean, biosphere system
  - Natural recovery through geological processes will take tens of thousands of years
  - Climate-relevant timescale ~10,000 years (climate and ocean acidification)
- Excess carbon is the main driver of climate change
  - Climate forcing of 1 tonne of methane over 30,000 years is dominated by the CO_2 produced

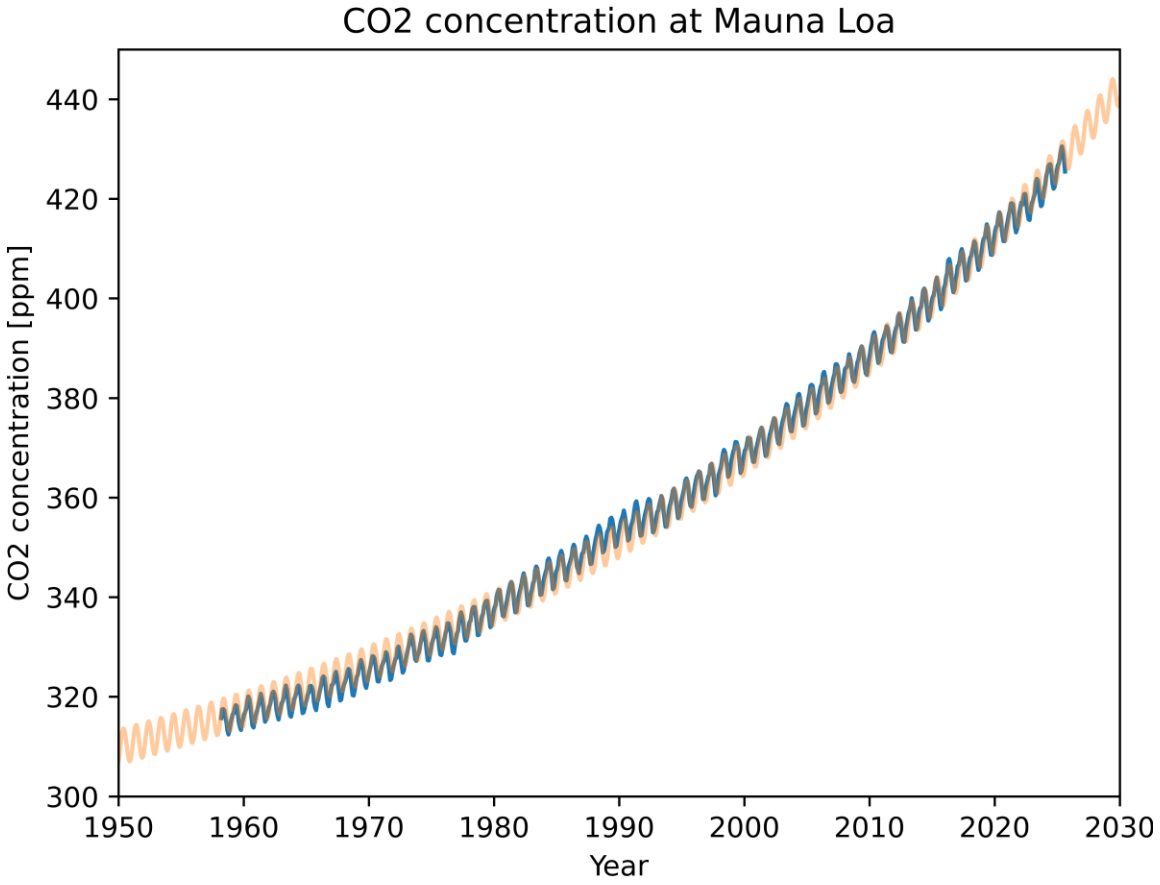
We are not paying back our carbon loan

Separate carbon from greenhouse gases

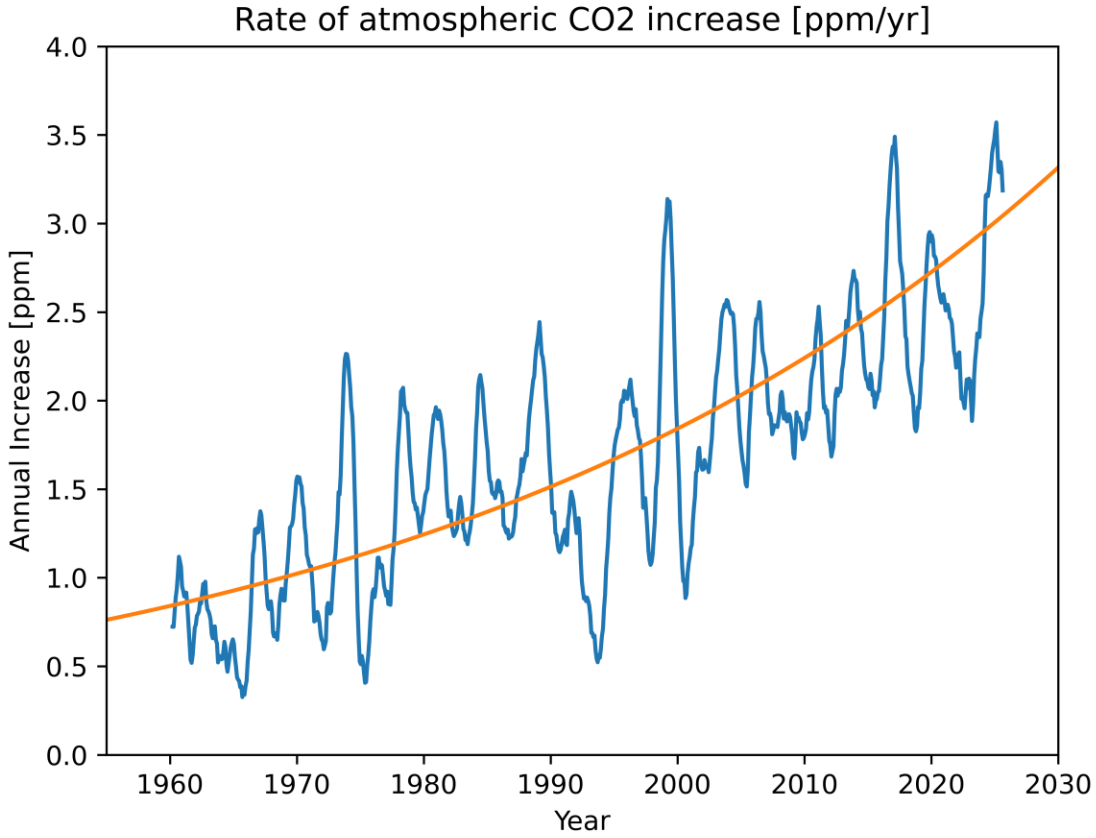
The world is passing thresholds

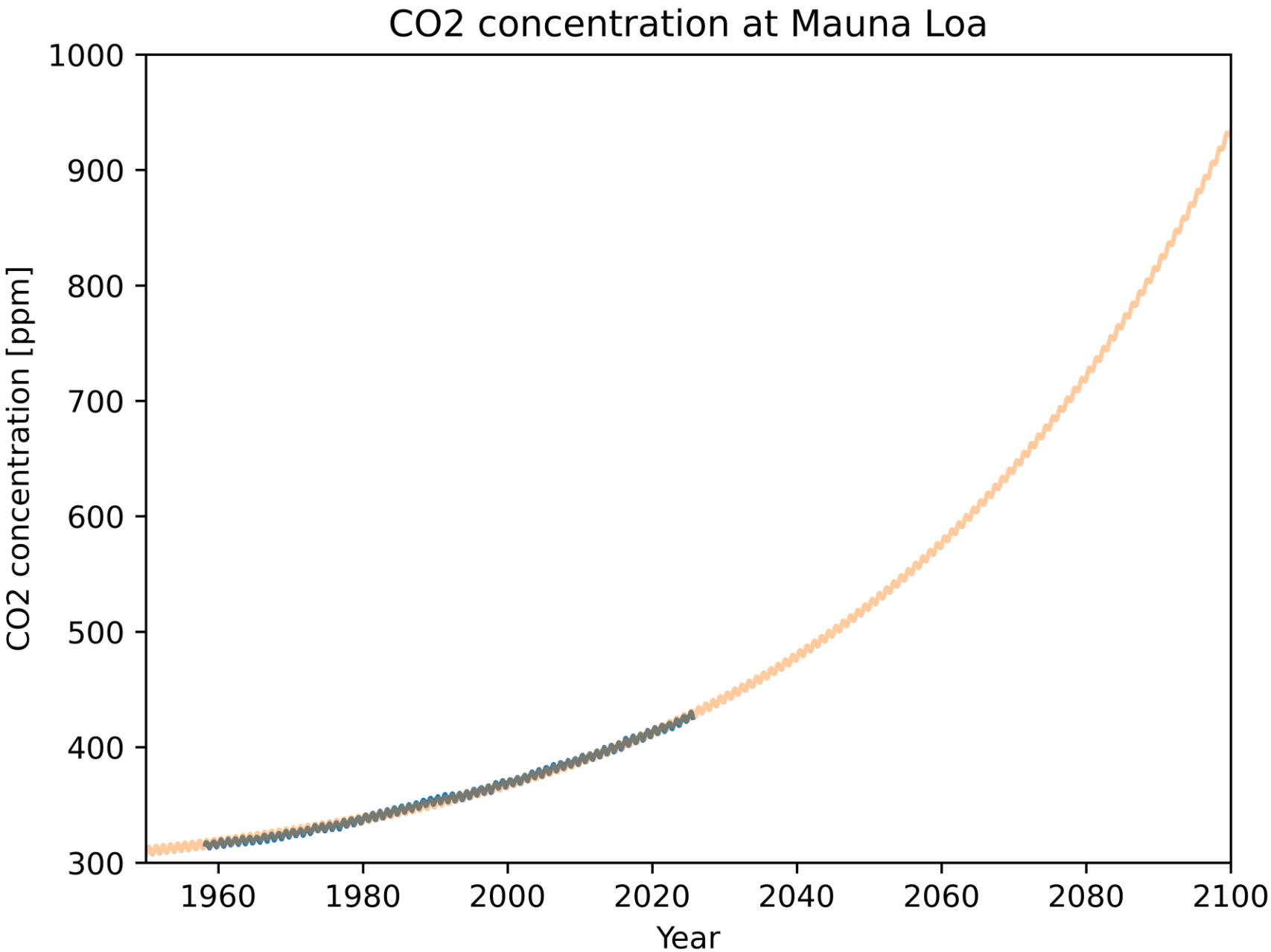
- 350 ppm in the air (breached around 1990)
  - Jim Hansen considered this the highest safe CO_2 level
- 1.5-degree warming (breached around 2023)
  - Target set at the Paris Conference in 2015
- Breaching 450 ppm is unavoidable
  - The post-Kyoto long term goal
- Holding the line at 2-degree warming is difficult and unlikely
  - Between 450 and 500 ppm, Paris agreement considered the upper limit acceptable

Tipping points?



1.9% compound growth




CO2 concentration at Mauna Loa
CO2 concentration [ppm]
1000
900
800
700
600
500
400
300
1960
1980
2000
2020
2040
2060
2080
2100
Year

Net Zero Carbon Economy

- Balancing the carbon budget means net-zero carbon going forward
  - Every ton of carbon coming out of the ground will need to be sequestered
  - Point source capture and Carbon Dioxide Removal from the environment (CDR)
  - Or elimination of all fossil fuels
- Overshoot requires net-negative carbon
  - Additional carbon needs to be sequestered, to compensate for ignored emissions
  - Point source capture and even more CDR
  - Elimination of fossil fuels will not provide net-negative emissions

Carbon removal is now unavoidable

What are the options?

- Elimination of fossil fuels
  - Renewable or nuclear energy globally
  - Takes time to implement
  - Cannot lower the CO_2 in the air
- Carbon Capture and Storage at Point Sources
  - Reduces emissions but does not fully eliminate them
- Utilization of CO_2 in lieu of fossil fuel extraction
  - Carbon footprint depends on details
    - Utilization can combine with storage (e.g., in carbon-based infrastructure, or through EOR)
    - Carbon from CDR starts out near neutral, carbon from fossil sources still contributes
- Carbon Capture from the Environment for Storage (or utilization with storage)
  - Can create negative emissions

Market forces will decide

Carbon Negative Technologies is now unavoidable

- An overshoot over the Paris Climate Target is unavoidable
  - It may already have happened
  - The Rio Target set in 1992 may be even more stringent
- Current world politics will likely slow down action
  - Any delay will worsen the overshoot and ultimately increase the need for CDR
- Carbon removal technologies are not yet ready for scale
  - Current cost, maximum feasible scale, or environmental impacts

A transition in 1980 could have simply phased out fossil fuel

Economic constraints

- Cost of CCS, CCUS, CDR, carbon recycling
  - Must be lower than cost of damages and/or adaptation
  - Better be affordable without destroying the economy
  - Must be cheaper than the alternatives
- Nuclear energy is an expensive but viable alternative
  - Failed to succeed because of cost, safety and security risks
  - Nuclear power is a viable but expensive fallback option
- Renewable energy may prove cheap enough to compete
  - Solar electricity is cheaper than methane chemical energy
  - Intermittency is manageable through batteries and synthetic liquid fuels

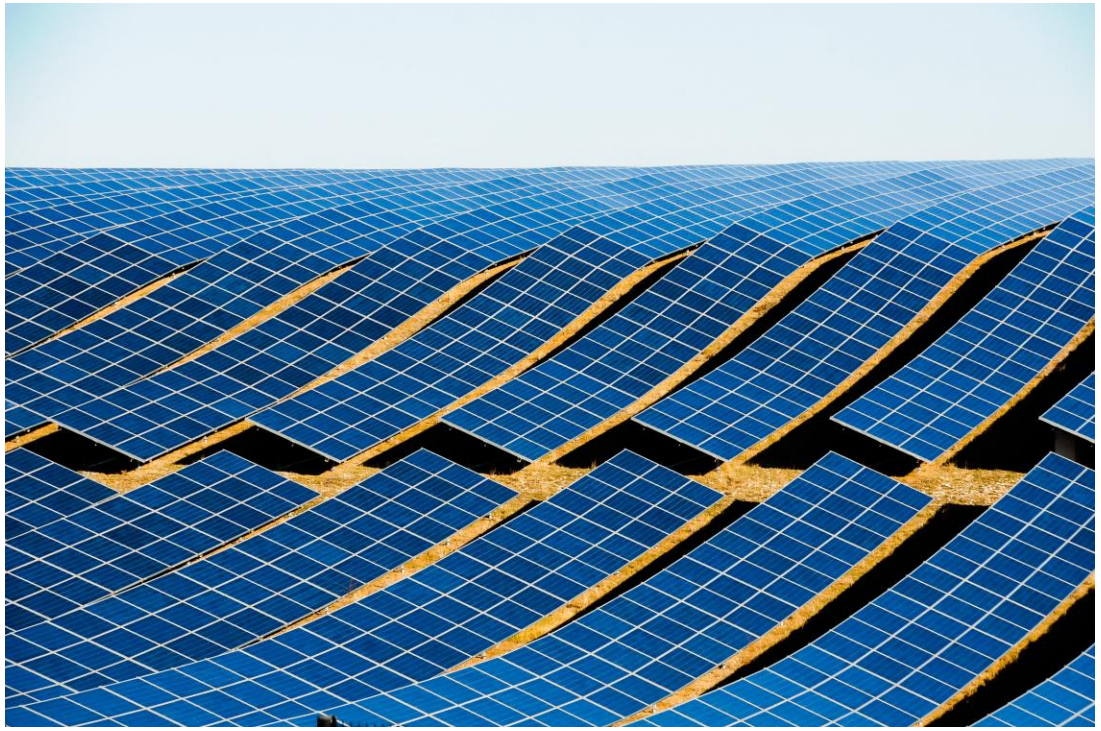
Liquid fuels are not tied to oil, coal and gas

Affordability Thresholds

- $100/tonne of CO_2 avoided:
  - $0.85 on the gallon of gasoline
  - $40/bbl of oil
  - 3 to 10¢ / kWh
- Renders nuclear energy competitive
  - Failed to succeed in the past because of cost, safety and security risks
  - Carbon premium closes the gap
- Renewables, especially photovoltaic electricity
  - Are competitive, but need to manage intermittency

Fossil fuels will fail unless cleaning up proves affordable

Photovoltaic power will challenge fossil energy even without carbon constraints!



Pixabay stock

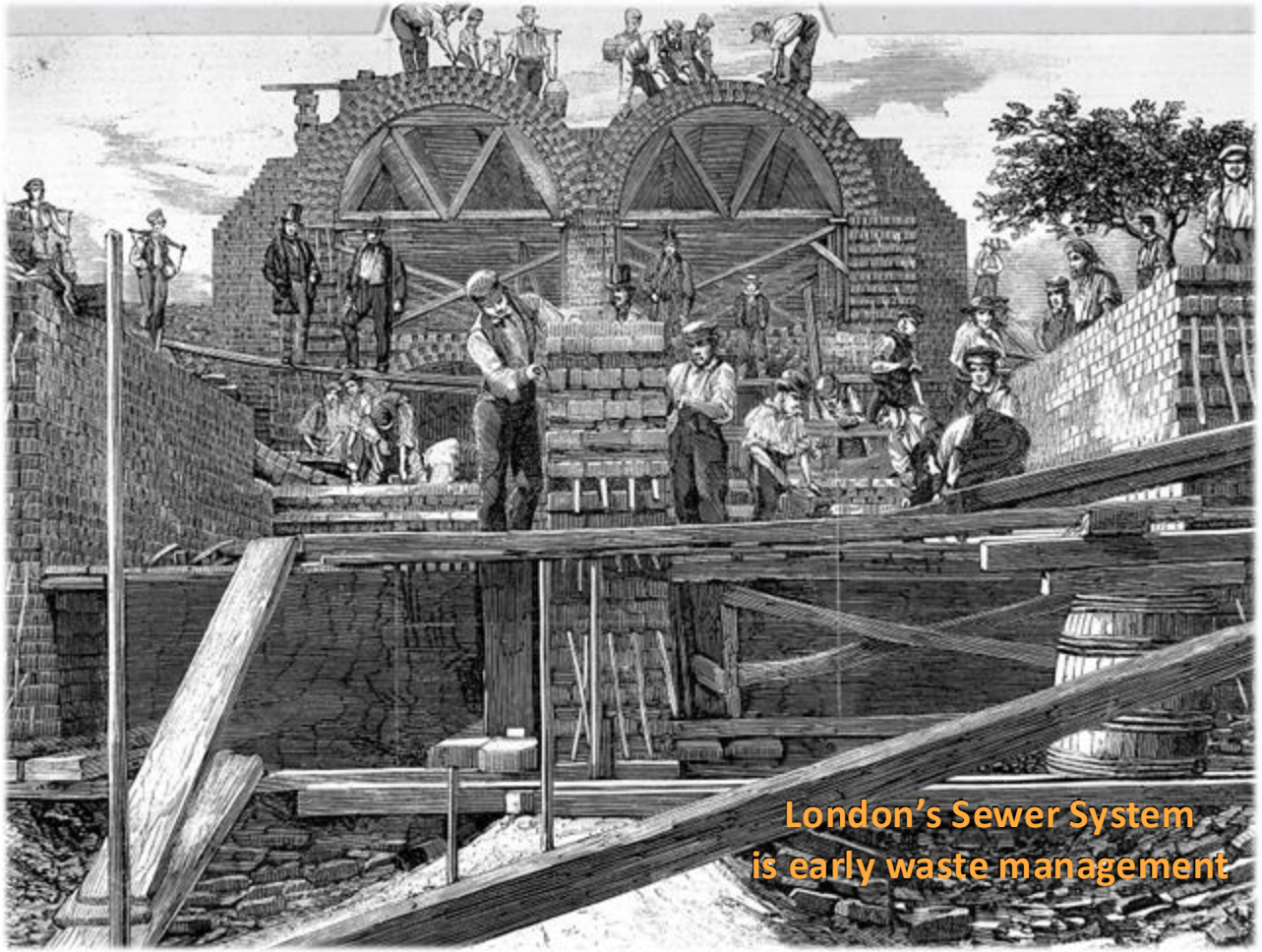
- It is the cheapest source of electricity
- Its energy can be stored in liquid fuels
- Cheap storage and easy transport

Disclosure: Klaus Lackner is a board member of Aircela Inc. founded by a one of his former students. It produces liquid fuels from CO_2 from air

Eliminating the need for fossil fuels …

…or neutralize their waste?

Waste problems have been solved before



https://commons.wikimedia.org/wiki/File:The_main_drainage_of_the_Metropolis_Wellcome_M0011720.jpg

- Waste management is a lucrative service industry that need to be built
- CO_2 waste is global and can be addressed globally
- Carbon recycling will be driven by the cost of waste disposal

CO_2 is the waste stream from fossil fuels

- Cleanup requires a balance between extraction and sequestration
  - Balance need not to be at a single point in time and space
  - Net zero can be achieved through the environment
- Sequestration must last on climate relevant time scales
  - Polluter pays + intergenerational equity
  - Difficult for most utilization
- Net negative carbon economies require CDR technologies
  - Can balance out past emissions and emissions difficult to capture at the source

For every ton of fossil carbon extracted a ton needs to be stored

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Waste management: Collection and Disposal

- Collection
  - Point sources: power plants, steel plants, cement plants, …
  - Distributed sources: atmosphere, biosphere, hydrosphere
- Disposal or Storage:
  - Geological storage
  - Mineral storage
  - Ocean storage
  - Biomass storage
  - Soil storage
  - Storage in the built infrastructure

Blurring the line between CCS and CDR

What scale do we need?

- 40 Gt/yr three different ways
  - Roughly current rate of emissions
  - Emissions at the end of the century of carbon intensity is reduced fivefold
  - Lowering CO_2 in the atmosphere by 100 ppm over 40 years
- How much time do we have?
  - 10 years?
  - 50 years?
  - 100 years?

At this scale even “natural” solutions turn technical

Biological Approaches

- 40 Gt CO2/yr
  - More sunlit area than all of agricultural land
  - Conversion of biomass to stable carbon adds cost and loses carbon
- Competes for land with food production
- Large environmental footprint

Great help in the beginning but technological approaches are needed

What makes for good carbon collection and disposal?

- Permanence
- Accountability
- Minimal environmental footprint
- Public acceptance

What will motivate action?

Paying for carbon emission or removal?

- A “zero” emission requirement is not compatible with taxing emissions
- A removal requirement is sufficient, and will set a carbon price
- Waste management demands a regulatory approach
- Carbon utilization will never be big enough
  - For carbon recycling to solve the problem, fossil fuels would have to be phased out
  - Carbon utilization can lower waste management costs
  - However, carbon dioxide production is too large to utilize

Zero waste is a far-off goal

Who should be responsible for carbon?

- Producer responsibility vs. Emitter responsibility
  - Scope 0 vs. Scope 1, 2, 3
- Simplest and cleanest approach
  - Fossil fuel extractors take care of carbon sequestration and render their product carbon neutral
  - No Life Cycle accounting of carbon
  - Market decides who pays

Carbon Takeback Obligation

Why has it not happened yet?

- Fossil fuel extractors and end consumers have been exempted
  - Scope 1 pushes the problem to the physical emitter
  - Scope 2 clears the power plants and fuel producers
  - Scope 3 exempts the end consumer
- Scope 0 is what comes out of the ground
  - It is well documented, and by matching it with sequestration all emissions can be balanced

Carbon Takeback Obligation

Did it help the oil companies?

- Roughly 40% of a barrel of oil is consumed by automobiles
- This market is about to vanish
- Counterfactual scenario
  - In 2000 oil companies accepted responsibility for carbon, and solved the problem
  - Tesla's customer basis would not have been there, no Tesla, no BYD
  - This is a real opportunity cost to the oil companies
  - Carbon management is a real market (ask OXY)

Carbon Takeback Obligation

Will it ever happen?

- Oil is ceding its top position to tech
  - None of the top ten listed companies in the US are oil companies
  - Tech companies are working on carbon management, but is a distraction
  - With their growing power, carbon takeback will become more popular

Carbon Takeback Obligation

Market pull from regulations?

- Waste removal is a public good
  - It must become a requirement
  - Markets can deliver waste removal
- Carbon Storage needs to be certified
  - So that it is trusted and its value understood
- Markets deliver efficiency and low cost
  - The cost of disposal makes reuse of carbon more competitive

All markets are regulated