CAETS 2021
ARGENTINA
Engineering a Better World
THE FUTURE OF ENERGY

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Carbon Capture and Storage

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Fundamental Question

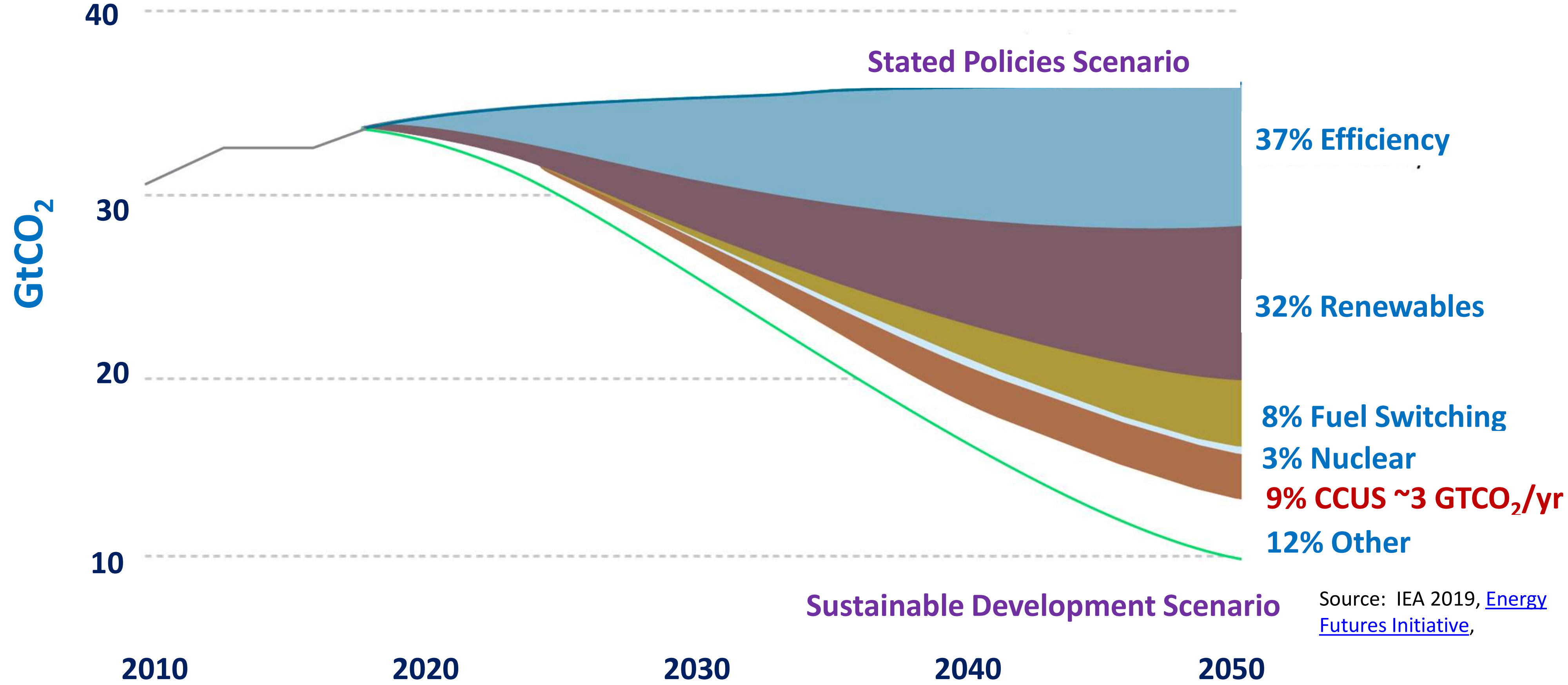
Negative impacts of climate change are now clear. We must reduce our dependence on fossil fuels.

How do we supply the energy the world needs to support a growing population in modern societies while reducing greenhouse gas emissions dramatically?

CCS: An Important Technology to Meet IEA's 2050 Sustainable Development Targets

"Reaching net zero will be virtually impossible without CCUS"

IEA, September 2020



Source: IEA 2019, Energy Futures Initiative,

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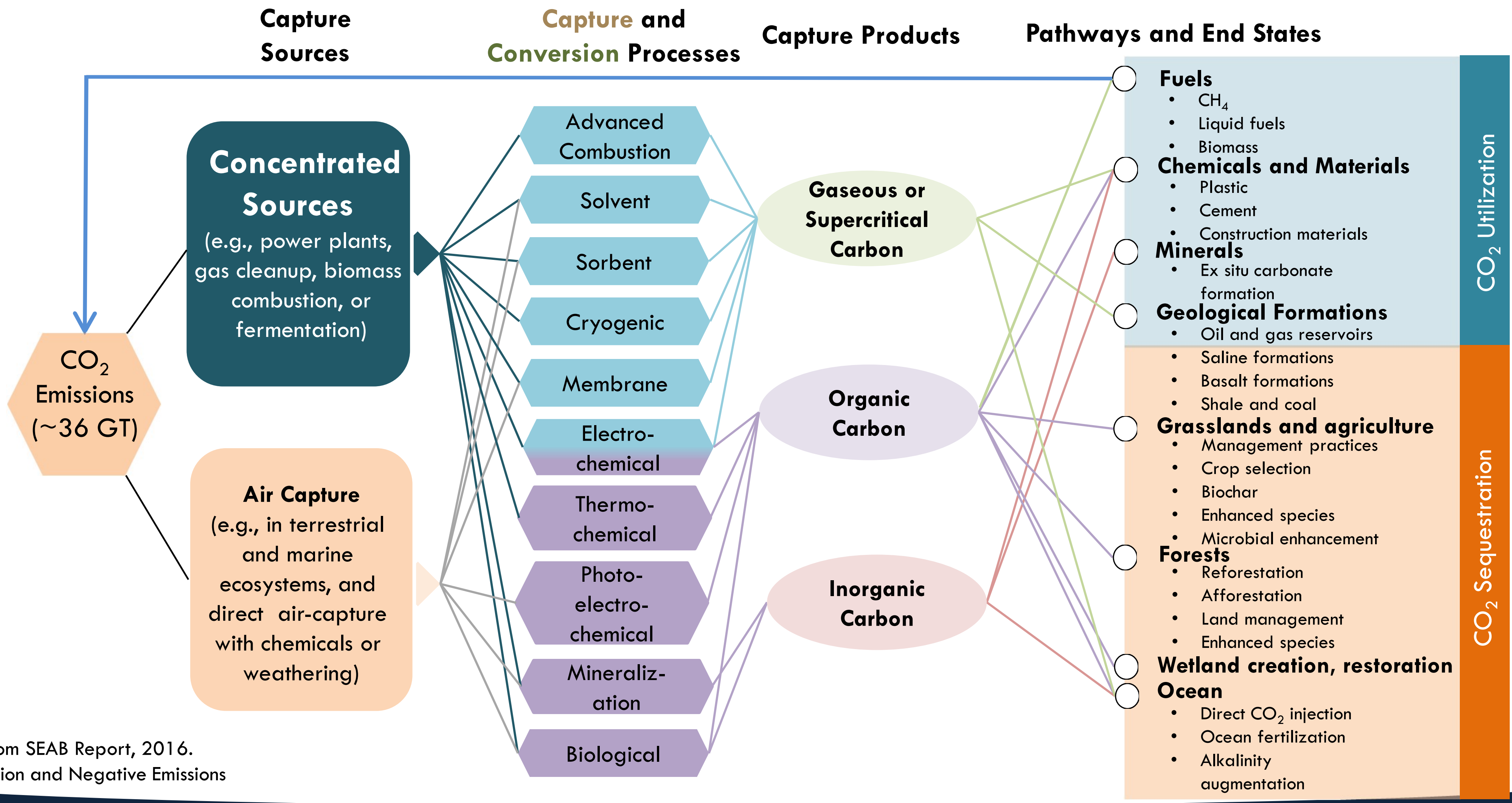
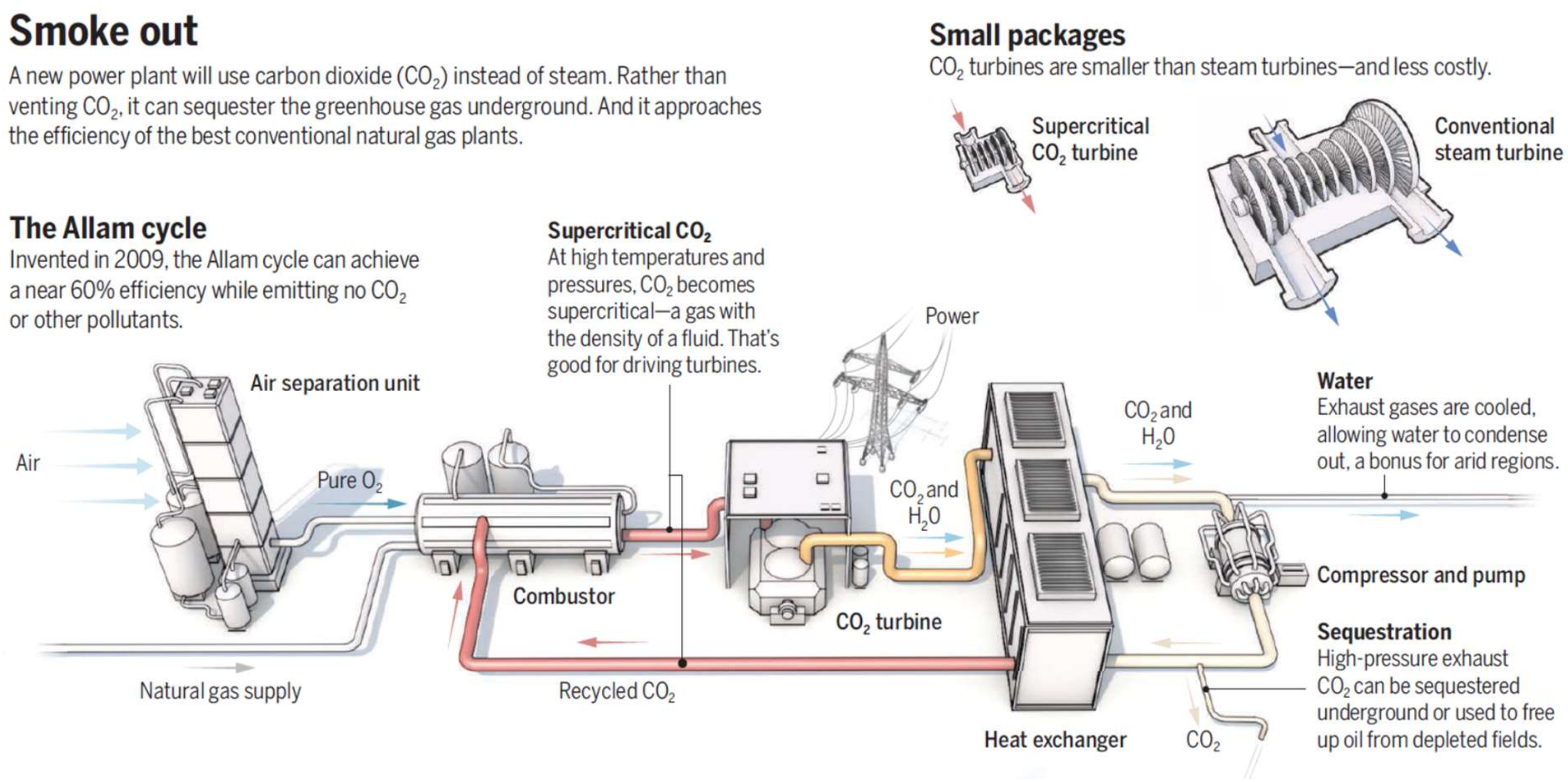
Options for Carbon Capture, Use, and Sequestration



Modified from SEAB Report, 2016.
CO_2 Utilization and Negative Emissions

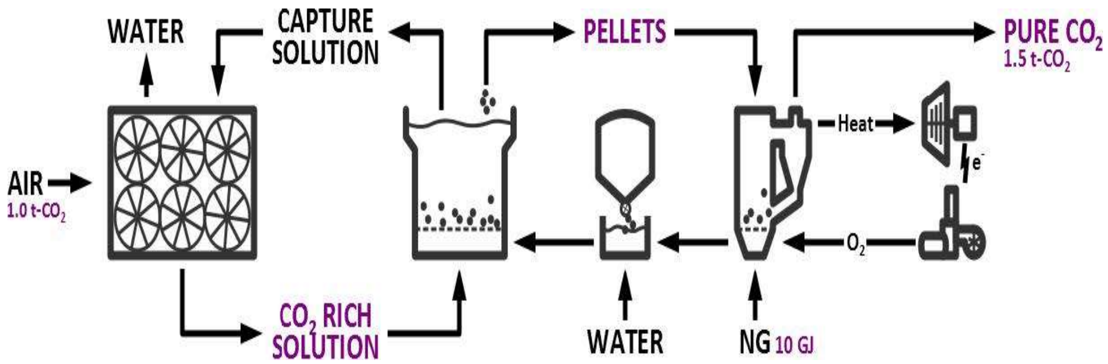
Low-cost capture of CO_2 from natural gas power generation: Net Power Supercritical CO_2 Power Plant

- Supercritical CO_2 is the working fluid in this oxyfuel combustion design
- Efficiency near 60%
- Very low added cost of CO_2 separation (the price is the cost of the oxygen separation)
- Competitive COE (projected, at least)

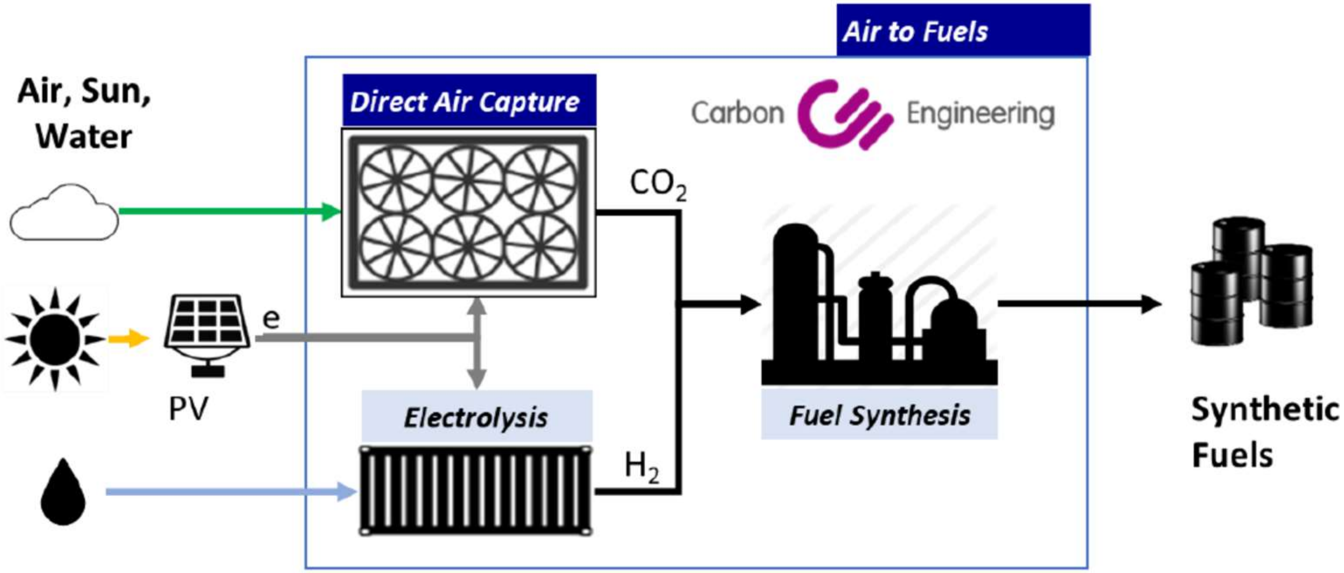


Source: Service, Fossil power, guilt free, Science, 25 May 2018, 356 (6340), 796-799

Direct Air Capture
(Carbon Engineering Version)

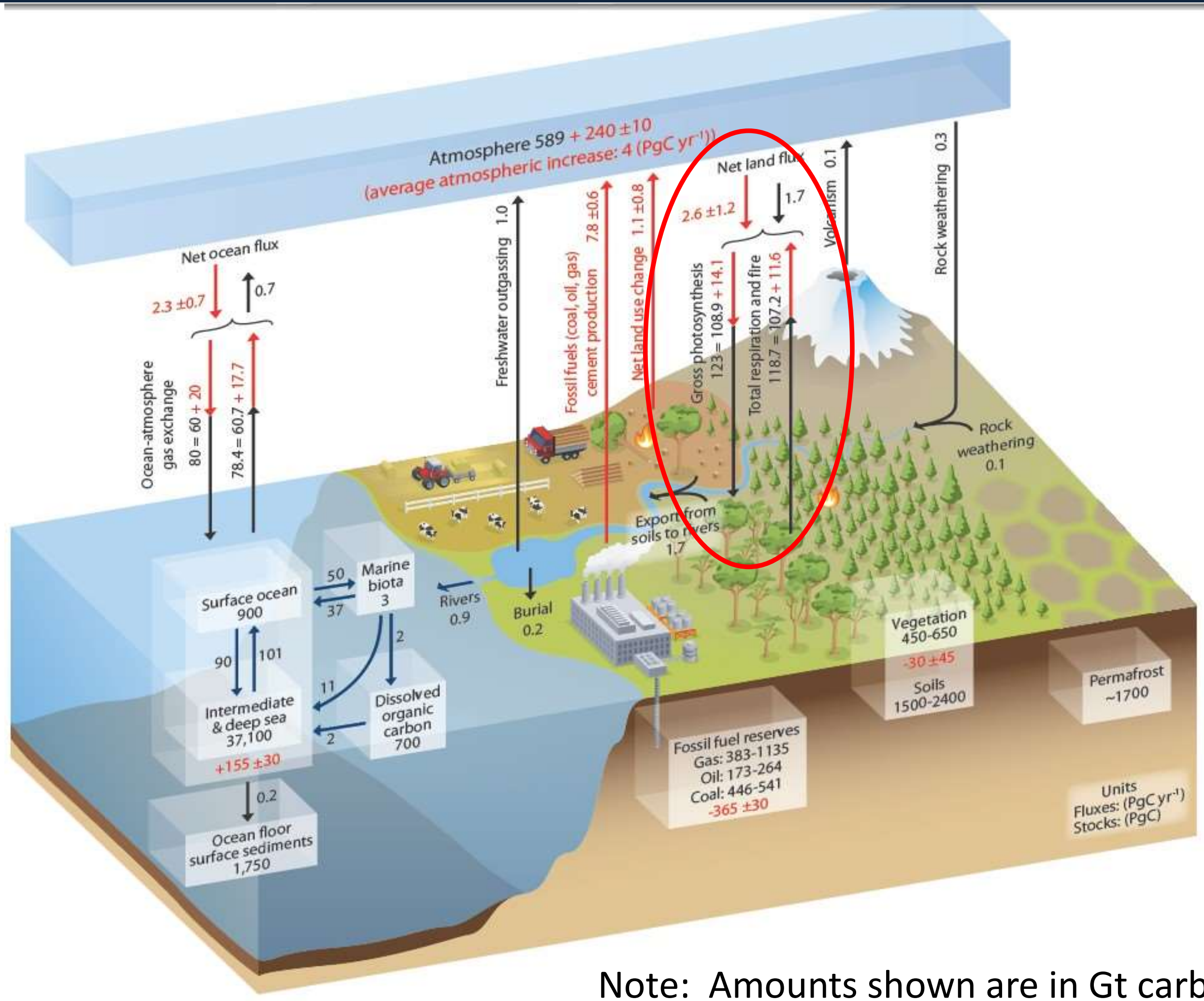


Source: Oldham, Senate EPW testimony, 2/27/17



- Capture CO_2 with KOH solution
- Cost said to be ~$100/t
- H_2 from electrolysis
- FT synthesis of a liquid fuel
- Every conversion step has efficiency < 1
- Every step has a substantial energy cost

Biological systems move very large quantities of carbon around the planet – enhance these and store some carbon?



- Reduced deforestation
- Afforestation (forests in new places)
- Forest management
- Restored soil carbon
- Modified agricultural practices
- Coastal blue carbon (carbon storage in coastal wetlands)
- BECCS (bioenergy with CCS – electricity, liquid fuels, heat)
- ~5 $GtCO_2$/yr worldwide at <$100/t

Note: Amounts shown are in Gt carbon/yr – multiply by 3.7 for $GtCO_2$/yr

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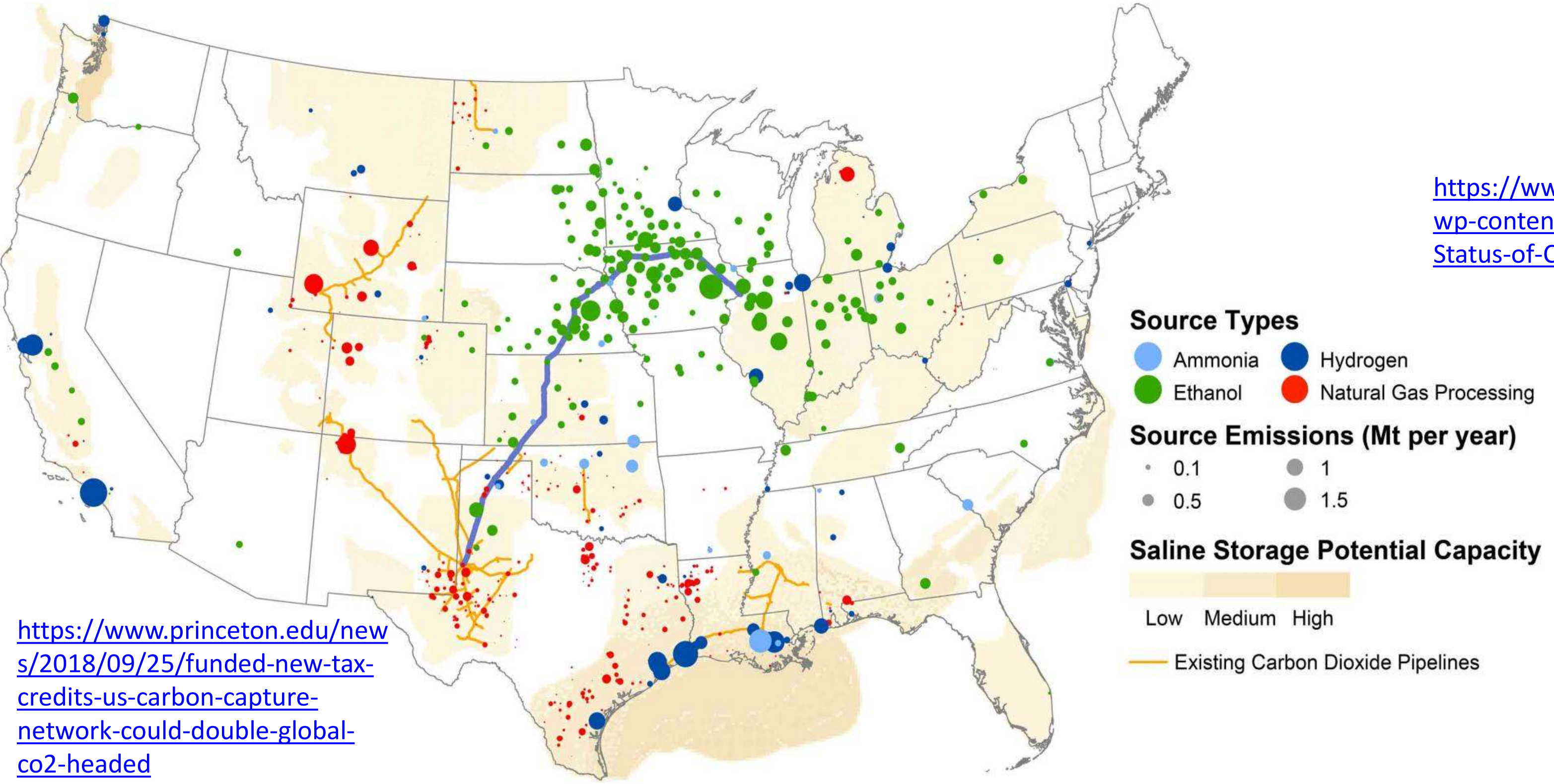
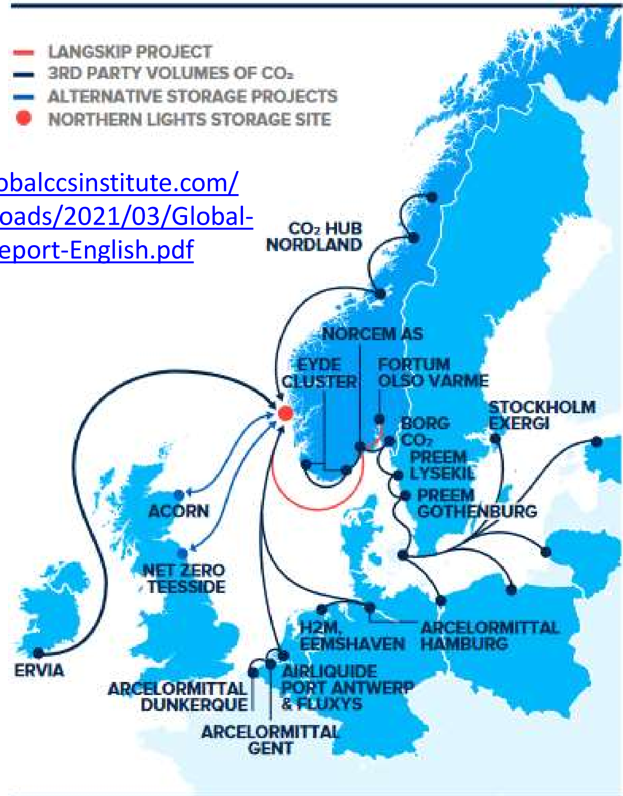
CO_2 Transportation



https://www.princeton.edu/news/2018/09/25/funded-new-tax-credits-us-carbon-capture-network-could-double-global-co2-headed

https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Global-Status-of-CCS-Report-English.pdf



- Pipeline transportation is well established, costs well understood – hubs and a network will be need for CCUS at scale
- Dedicated Ship transportation of liquid CO_2 to be used in Northern Lights Project
- Truck transportation – only for pilot scale

Subsurface Options for Geologic Storage of CO_2

- Oil and gas reservoirs: enhanced oil and gas recovery.
- Deep formations that contain salt water.
- Coal beds or shales (adsorbed CO_2 replaces adsorbed CH_4).
- Of these storage types, only EOR is economic in the absence of a carbon price
- Basalts?

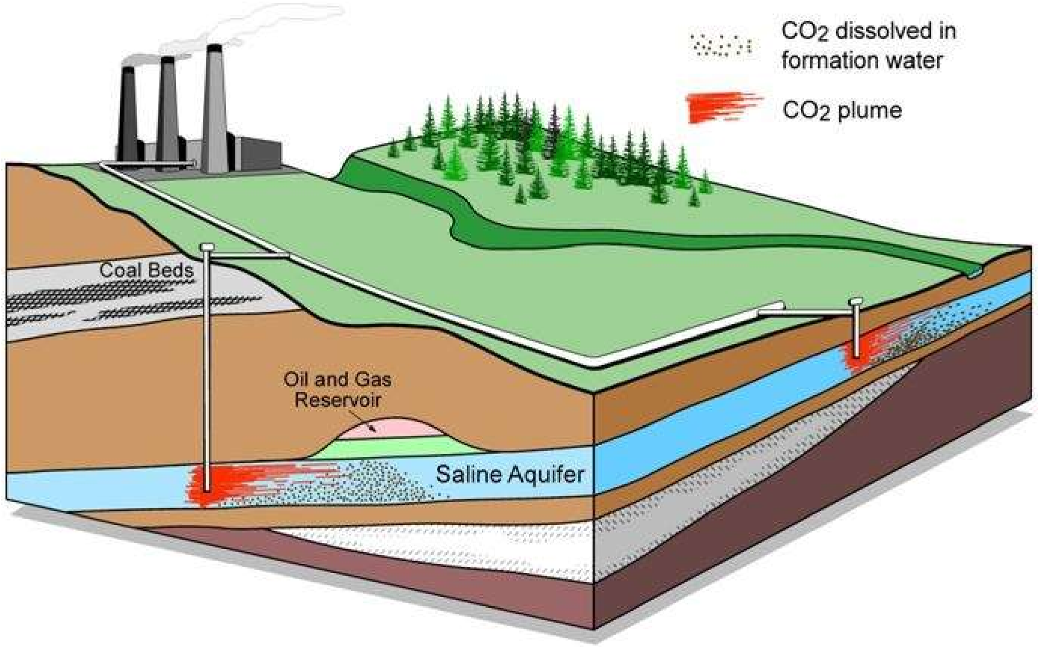
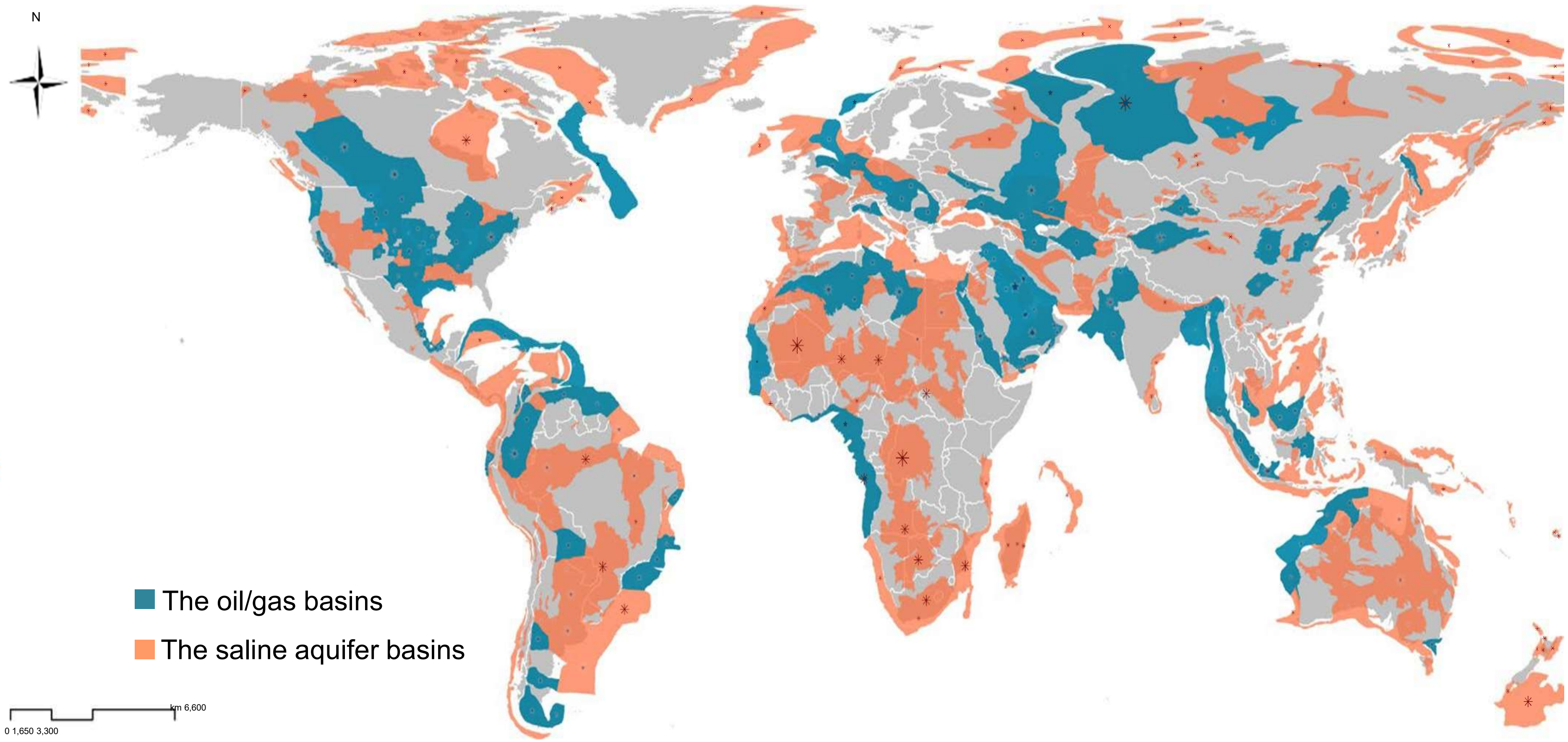


Figure 1. Image source: Dan McGee, Alberta Geological Survey

- Storage capacity world-wide is large compared to feasible injection volumes

Subsurface Storage of CO_2 in Porous Sedimentary Rocks

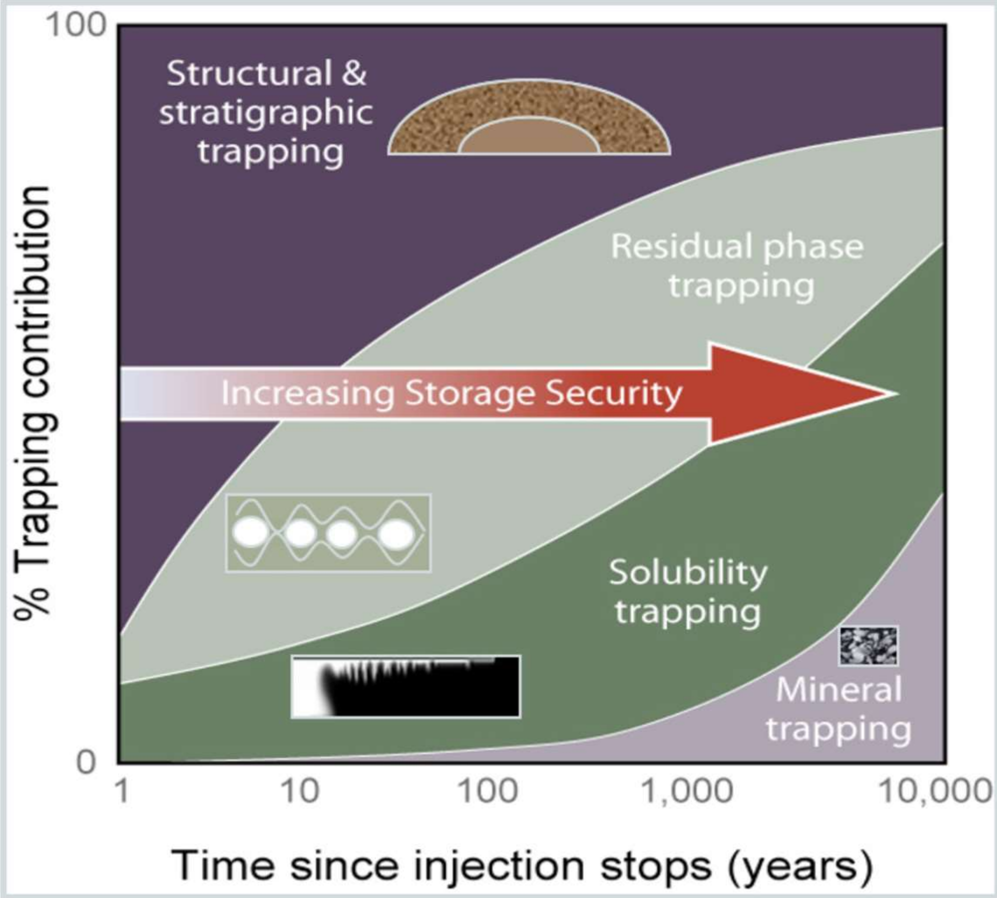


Source: Wei, et al., Nature Climate Change 2021 https://doi.org/10.1038/s41558-020-00960-0

Sedimentary basins with potential for subsurface storage are widely distributed

Trapping Mechanisms in Geologic Storage

- Seal rocks essential to prevent vertical migration of CO_2
- Water invading CO_2 traps bubbles by capillary forces
- CO_2 dissolves in water (and oil)
- CO_2 saturated water is more dense than water
- Mineralization reactions are usually slow, but permanent. Not always available.



Source: http://nap.edu/25210

CO_2 Utilization

Fuel
- CH_4
- Liquid fuels
- Biomass

Chemicals and Materials
- Plastic
- Cement
- Construction materials

Minerals
- Ex situ carbonate formation

Geological Formations
- Oil and gas reservoirs
- Saline formations
- Basalt formations
- Shale and coal

Grasslands and agriculture
- Management practices
- Crop selection
- Biochar
- Enhanced species
- Microbial enhancement

Forests
- Reforestation
- Afforestation
- Land management
- Enhanced species

Wetland creation, restoration

Ocean
- Direct CO_2 injection
- Ocean fertilization
- Alkalinity augmentation

CO_2 Utilization

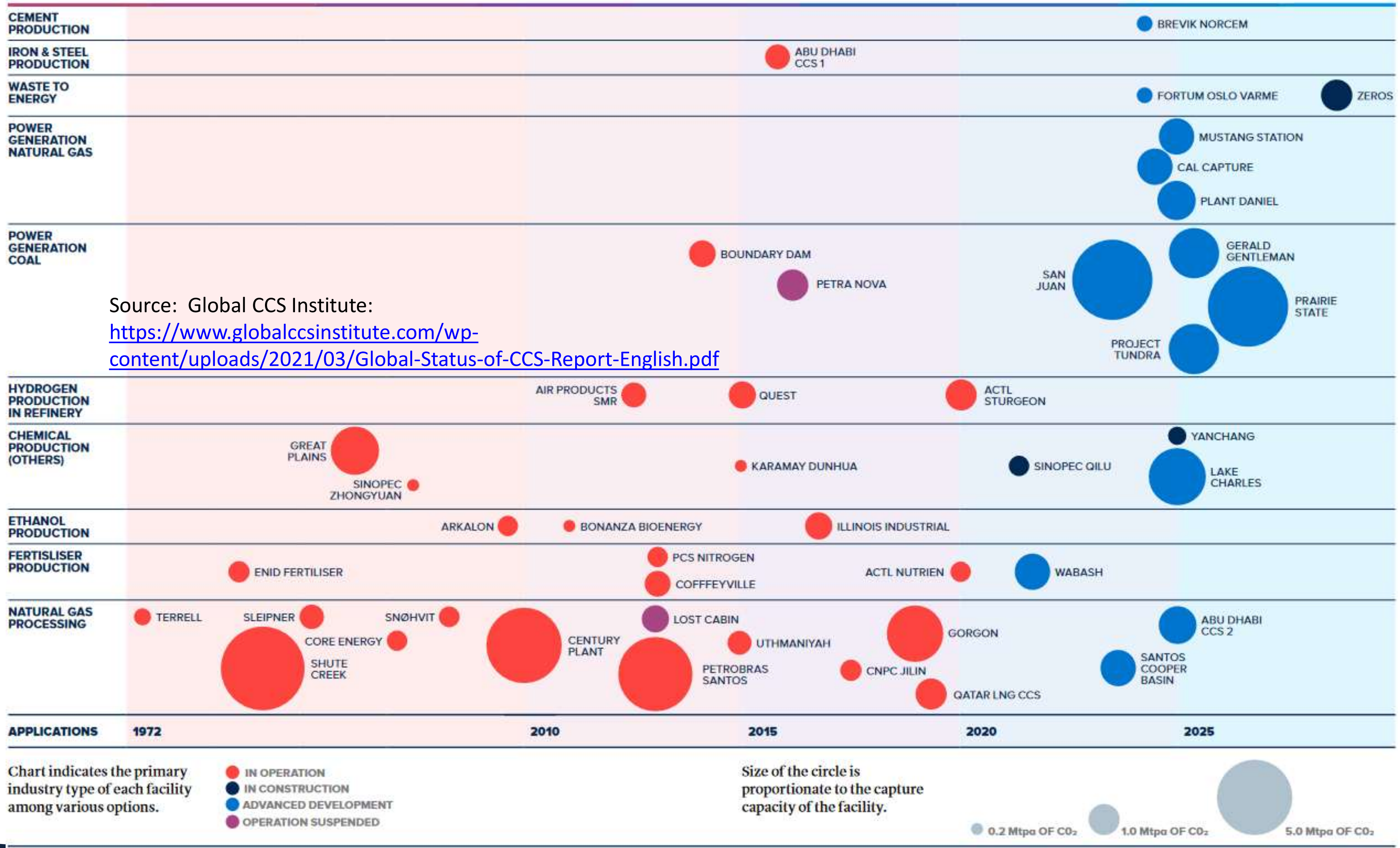
CO_2 Sequestration

- Fuels:
  - Biomass can be used directly as a fuel for power generation (after gathering, transportation, …)
  - Liquid biofuels require more chemical processing
  - Much more energy required to make a fuel from CO_2 (plus H_2) than is stored in the fuel (currently 3-4x)
- With excess solar/wind electricity at <2 cents/kWh, making a liquid fuel might be possible
- Construction materials, cement offer potential opportunities at scale
- Smaller opportunities in chemicals (urea, renewable CH_4)
- Cost competitiveness is a primary issue for all of these
- Very large new systems will be required to do any of these at scale

CO_2 Markets

- The current global market for CO_2 is about 80 million metric tons per year ($MtCO_2$/yr) – includes natural CO_2
- 50 $MtCO_2$/yr of that is used for EOR, and the rest mostly for beverages and food industry uses
- Of 17 large-scale CCS processes operating now, 13 are for EOR (31 $MtCO_2$/yr), 4 involve aquifer injection (4 $MtCO_2$/yr)
- Large-scale CCS will require a very large effort, significant investment and financing, alignment of industrial players around clusters, creation of pipeline networks, government participation, public acceptance, …
- The volumes of CO_2 are quite large: ~ 100 million barrels/day for injection of 3 $GtCO_2$/yr. CCS must be only one element of economy-wide portfolios of GHG emissions reductions

Global CCS Projects 2020



Source: Global CCS Institute: https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Global-Status-of-CCS-Report-English.pdf

If all these new planned projects go forward, the total injection capacity would increase by 175 $MtCO_2$/yr

Hundreds to thousands more projects will be needed to get to the gigatonne scale by mid-century

Conclusions

- The portfolio of CCS technologies is sufficiently developed that deployment at scale is feasible if cost issues are resolved
- CCS should be one of a broader wide-ranging portfolio of technologies for GHG emissions reduction
- Lots of capture technologies available, but only a few have been widely deployed – RD&D continues
- Research on negative emissions technologies is underway – technologies will be needed if slow reduction in GHG emissions continues
- Direct air capture is technically doable, but costly
- None of this will happen at big scale without a carbon price, emissions regulation, and/or continued subsidies, as well as a concerted effort to build hubs, clusters, and pipeline facilities
- The subsurface expertise of the oil and gas industry will be essential to this effort

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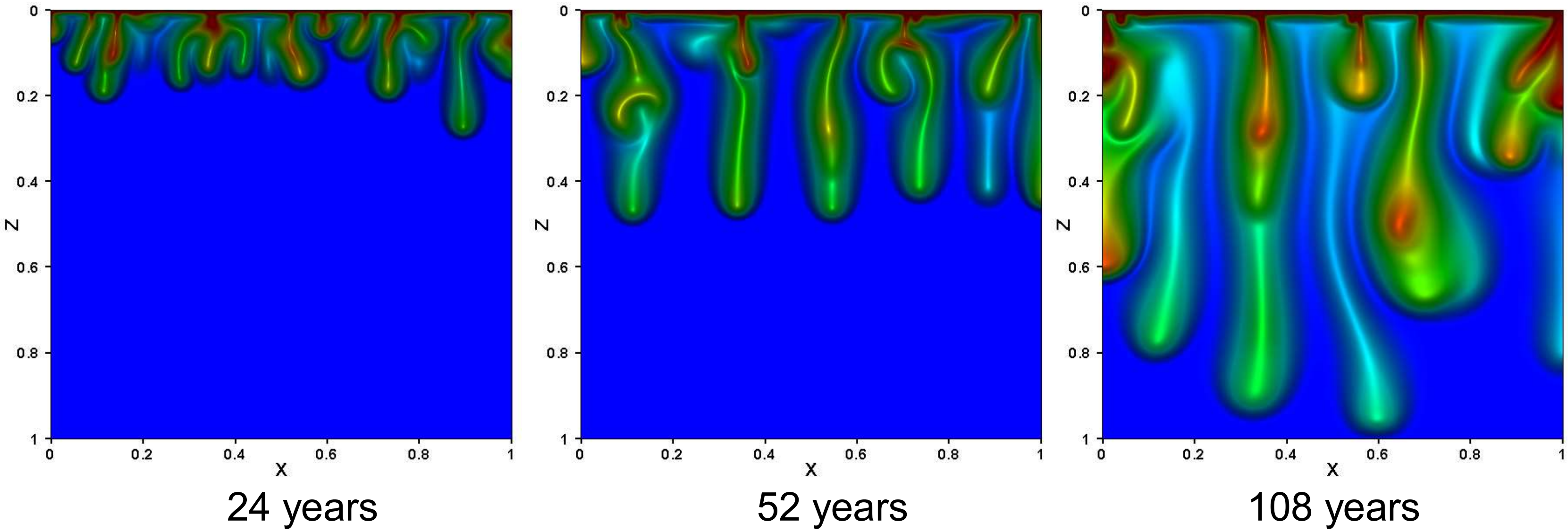
THANK YOU

Lynn Orr

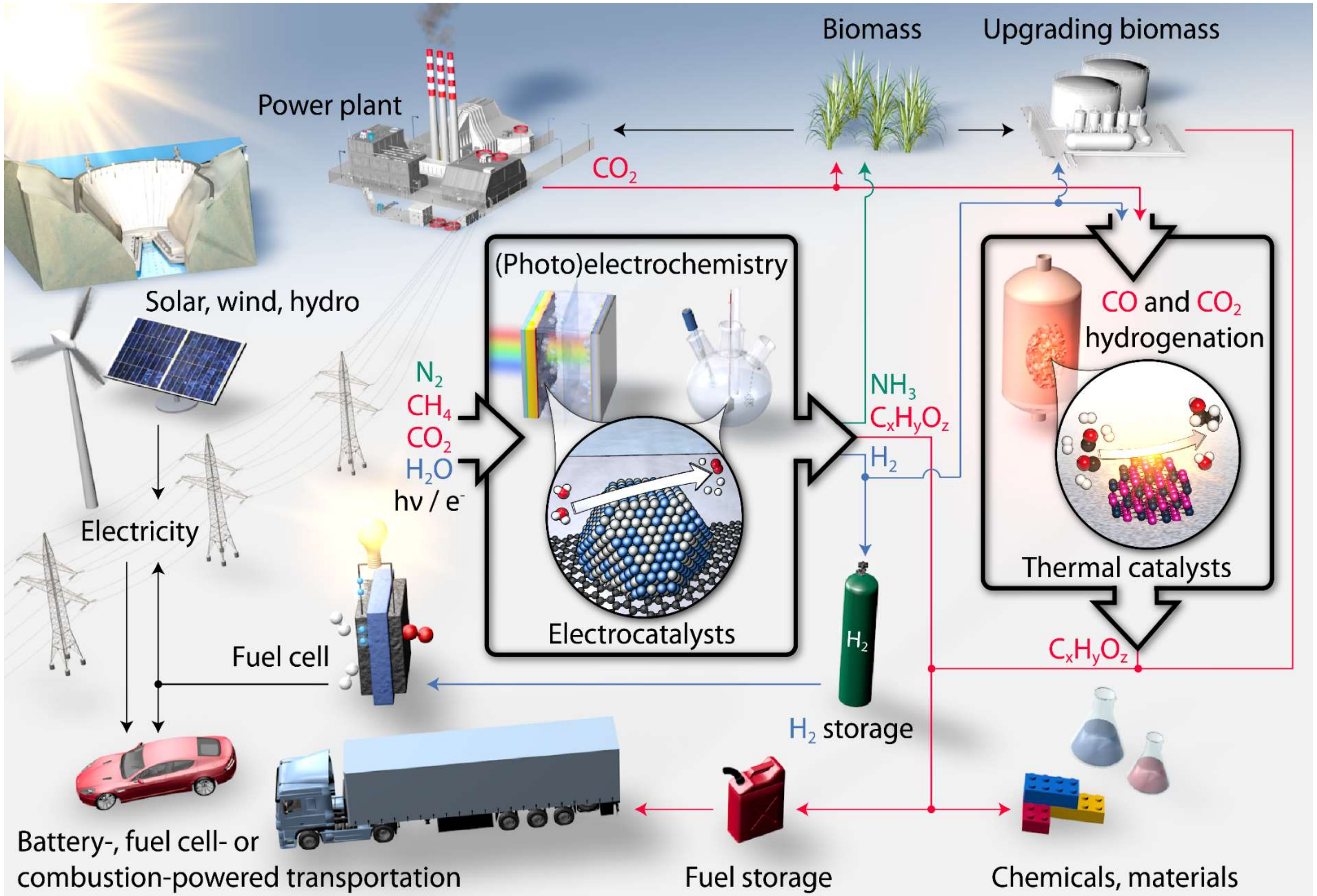
Saline Formation Storage: Dissolution of CO_2 in Brine in Deep Formations



A. Riaz et al. 2006 J Fluid Mech. **548**, 87-111

- CO_2-saturated brine is slightly more dense than brine alone
- More dense brine at the interface will be unstable (but the fingers move more slowly the lower the permeability)
- Time scale: 100s to 1000s of years to dissolve all CO_2
- Capillary trapping of residual CO_2 will eventually occur, immobilizing a trapped gas phase
- An effective seal above the storage zone is essential, preferably multiple low perm layers

Large-Scale Use of CO_2? Recycling Carbon for Fuels



Z. Seh, J. Kibsgaard, C.F. Dickens, I. Chorkendorff, J.K. Nørskov, T. F. Jaramillo, *Science*, **355** 6321 (2017)