DECARBONIZING CALIFORNIA'S INDUSTRY SECTOR

California Air Resources Board

Industry Workshop: July 8, 2019

JEFFREY RISSMAN

ENERGY INNOVATION
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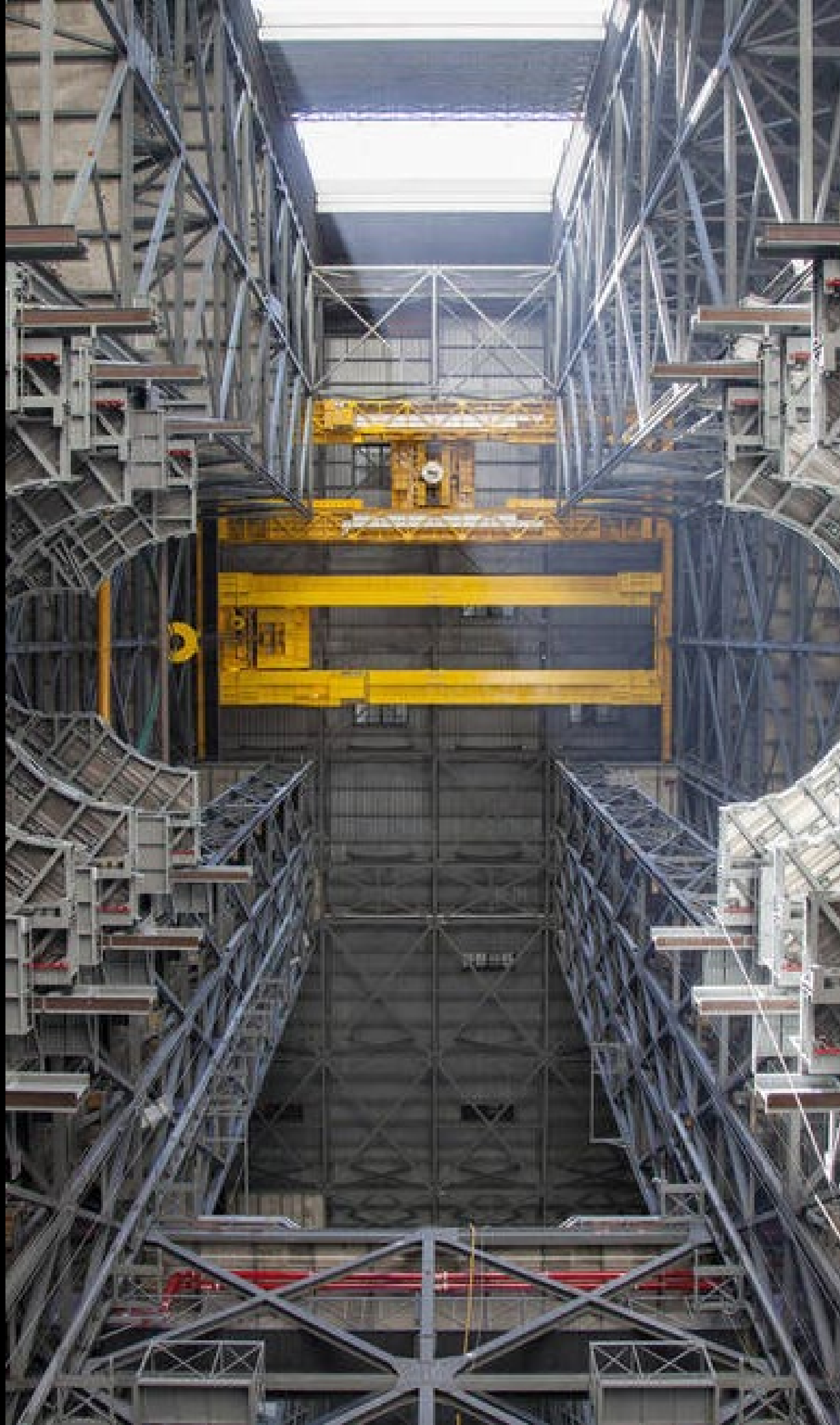
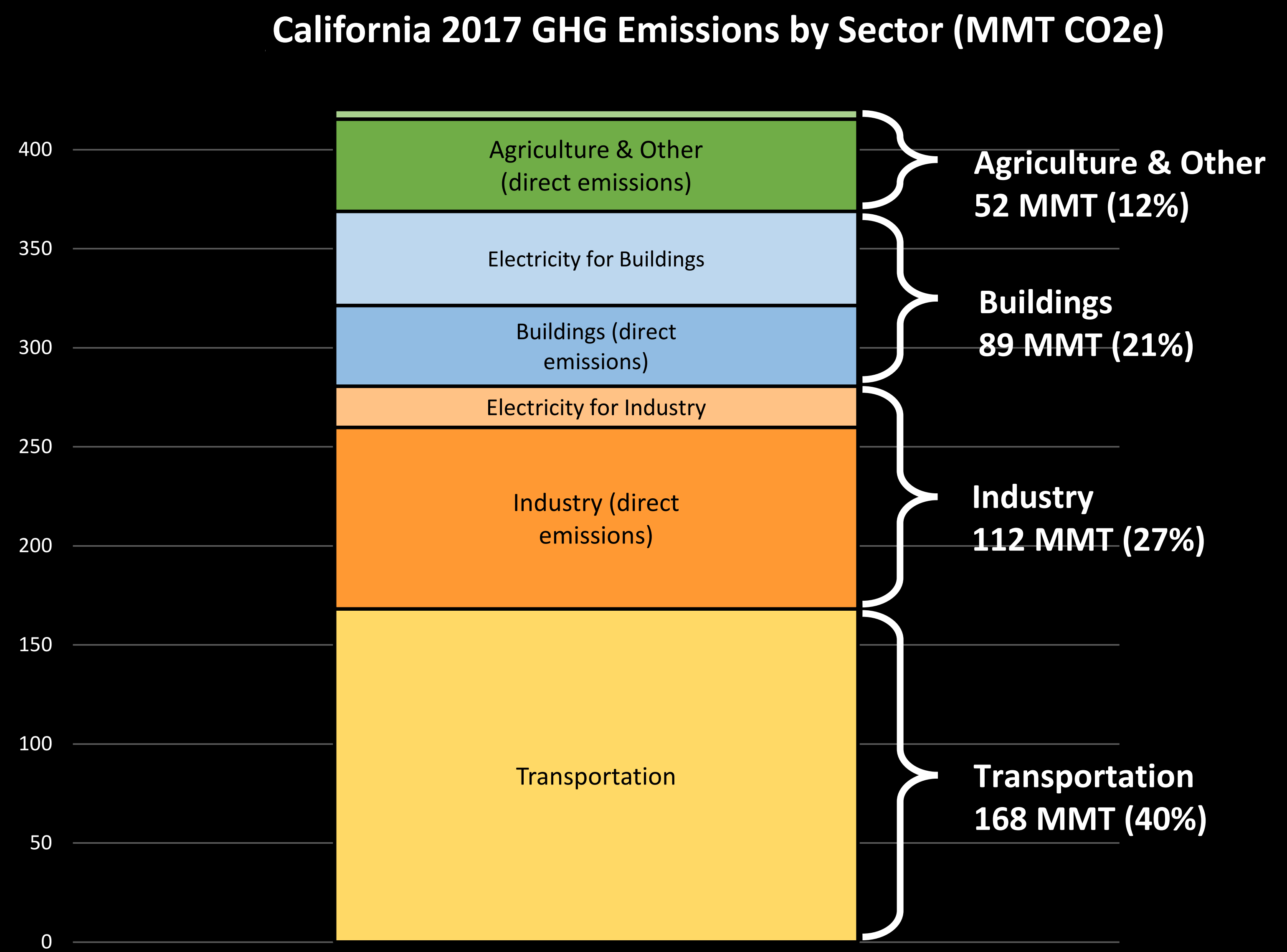


California Industry Emissions in Context



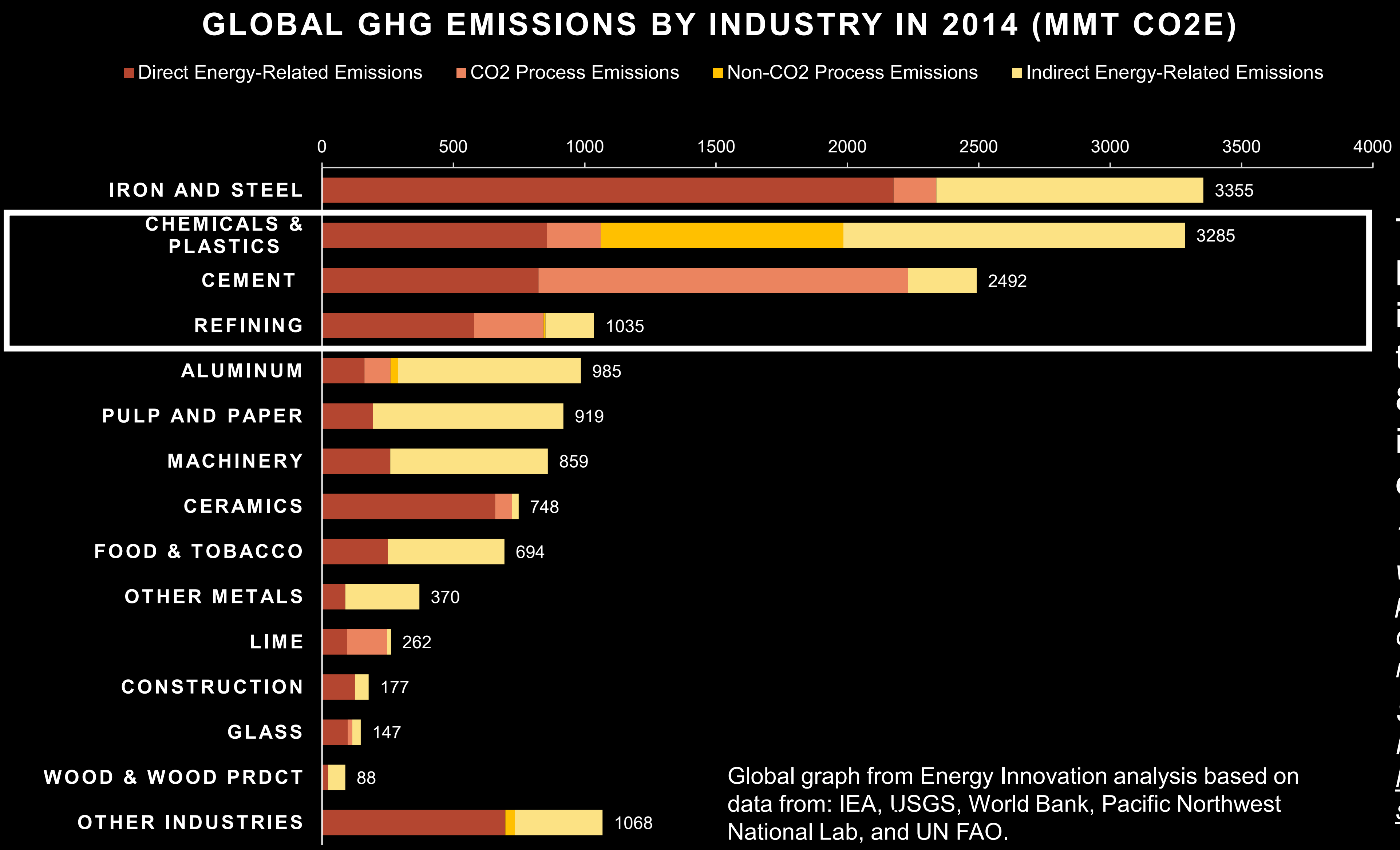
This graph includes energy-related emissions and non-energy “process emissions” from industrial and agricultural operations.

All significant greenhouse gases (GHGs) are included, not just CO2.

Emissions from the electricity sector are divided among other sectors proportional to their electricity demand.

Data source:
California Energy Policy Simulator (prerelease)
https://california.energypolicy.solutions

Emissions by Industry



These are the three highest-emitting industries in California, together responsible for 80% of California's industry sector emissions.

The 80% figure includes the whole natural gas and petroleum production and distribution industry, not just refining.

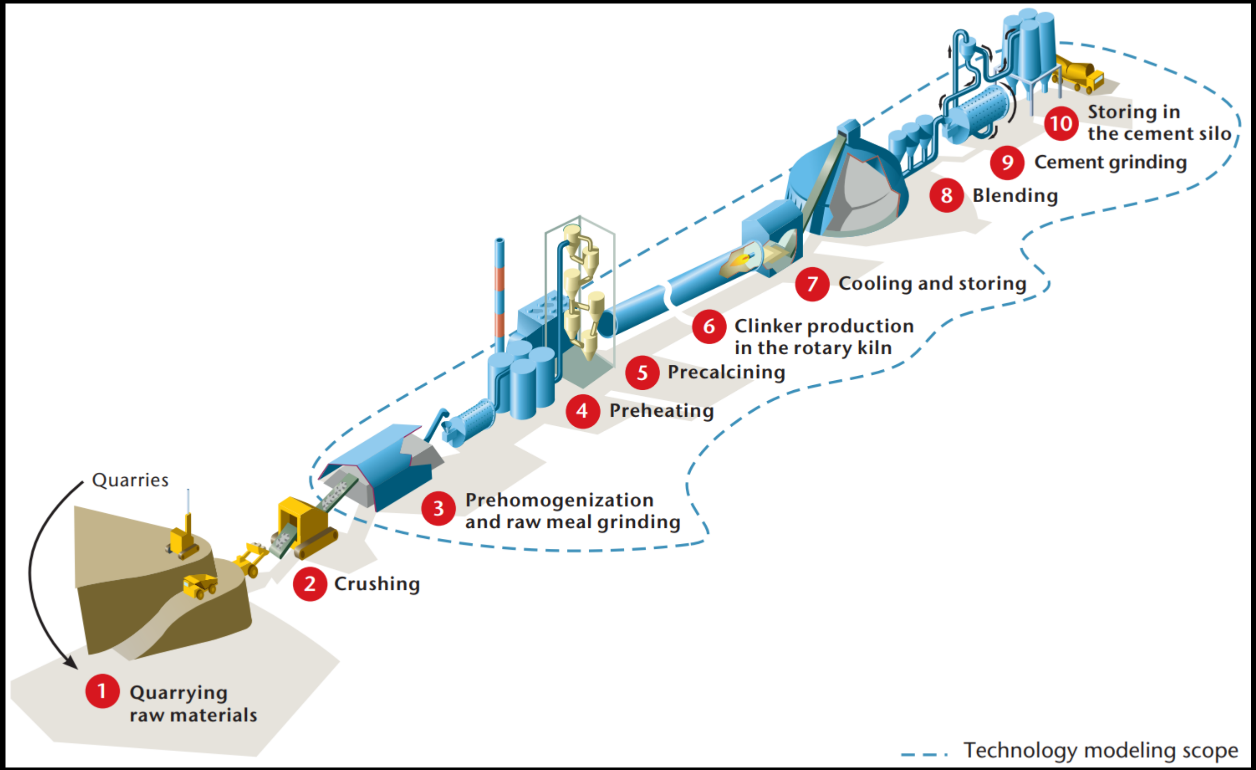
Source: California Energy Policy Simulator (prerelease) https://california.energypolicy.solutions

Global graph from Energy Innovation analysis based on data from: IEA, USGS, World Bank, Pacific Northwest National Lab, and UN FAO.

Cement & Concrete Industry

Cement Industry GHG Emissions

- 30-40% from thermal fuels (heating kiln and precalciner)
- 60-70% process emissions from limestone breakdown
- Minor contribution from electricity use



Cement production overview
Source: International Energy Agency and Cement Sustainability Initiative

Cement & Concrete Technologies

Energy Efficiency

- Use a kiln with a precalciner and multistage preheater. This equipment dries input materials using waste heat before they enter the kiln, so less heat is needed to evaporate water.
- Add mineralizers to the raw materials to reduce the temperature at which they convert into clinker.
- Operate the kiln with oxygen-enriched air.
- Use a grate clinker cooler, which is better at recovering usable excess heat than a planetary or a rotary cooler.

Rotary cement kiln
Source: Wikipedia, public domain

Cement & Concrete Technologies

Process Emissions

- Substitute other materials for clinker.
- Explore novel cement chemistries.
- Capture and store process CO2.

Material Efficiency

- Material strength, longevity, building re-use
- More discussion later

World Region	**Clinker to Cement Ratio**
North America	84%
Asia excl. China, India, CIS, and Japan	84%
Japan, Australia, and New Zealand	83%
CIS (Russian Commonwealth)	80%
Africa and the Middle East	79%
Europe	76%
China and India	74%
Latin America	74%
World Average	78%

Source: World Business Council for Sustainable Development

Chemicals Industry

F-Gases

- Refrigerants, propellants, electrical insulators
- Can be replaced with climate-friendly alternative gases

Source: Dasapta Erwin Irawan, CC attribution 2.0

Other Chemicals and Plastics

- Key emissions drivers are fossil fuel combustion for heat (e.g. for steam cracking of hydrocarbons) and to drive other endothermic reactions
- Hydrogen is produced in large quantities as a reactant, e.g. for ammonia production.

Source: pxhere, public domain

Chemicals Technologies

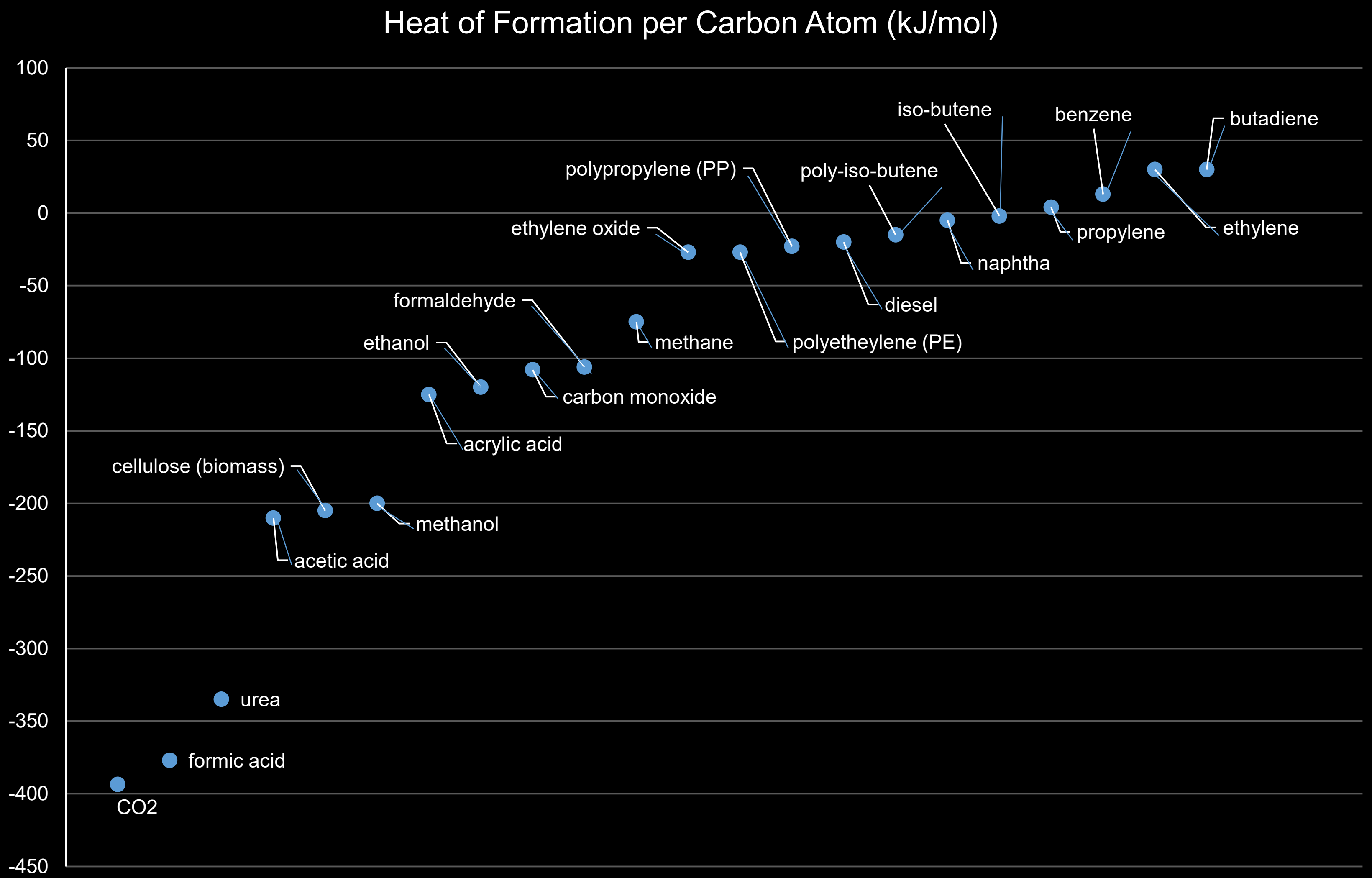
Novel Chemical Pathways and Catalysts

- Novel catalysts can lower input energy requirements of a variety of reactions
- For example, olefins may be produced via dimethyl ether through "dry reforming" of methane
- Methane pyrolysis, a technique under development, can split natural gas into hydrogen and solid carbon, avoiding CO2 emissions

Electrification

- Electricity may be used to provide the heat to drive many reactions.
- Electricity may also be used to generate hydrogen (through electrolysis of water)

Chemicals: CO2 Use



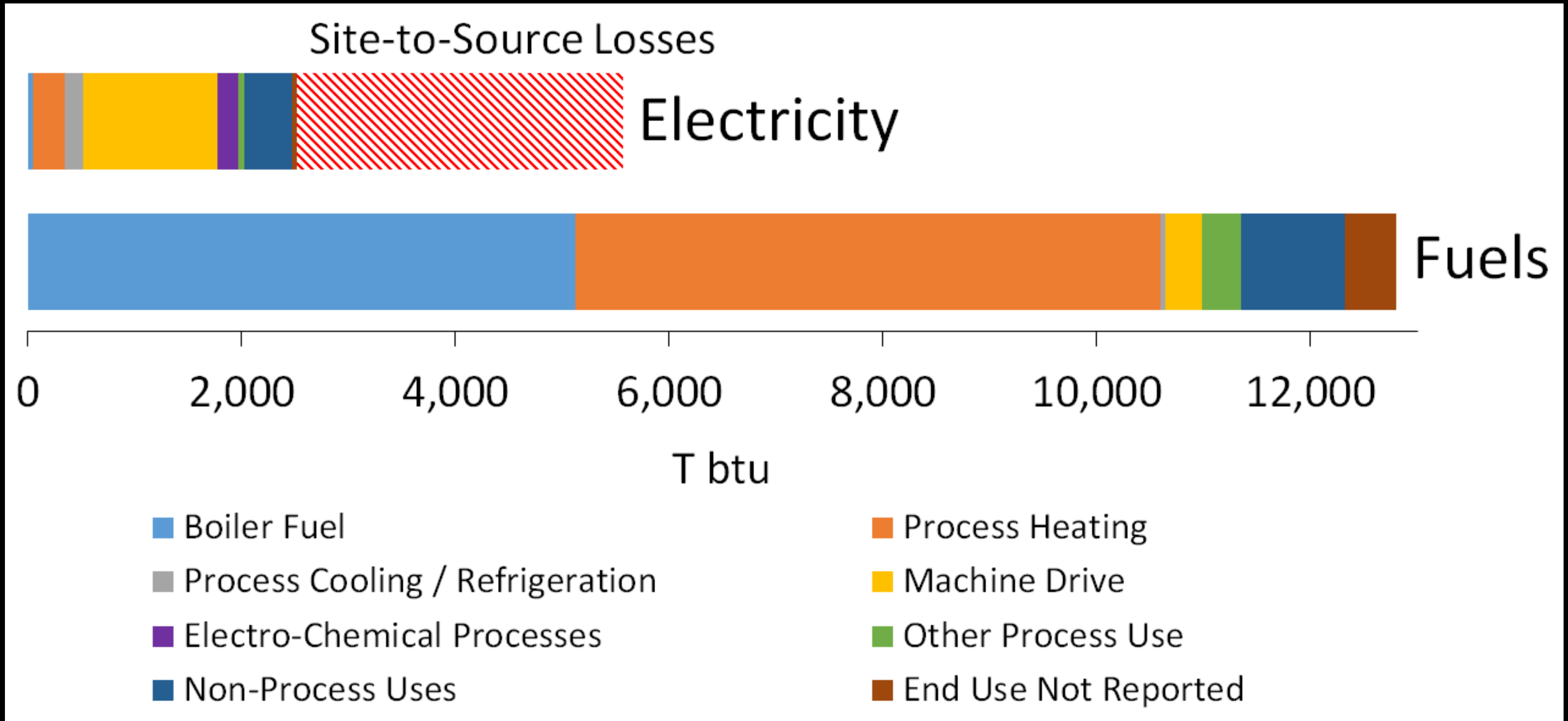
Re-use of CO2 is promising to make certain molecules whose chemical structure is similar to CO2, such as urea and formic acid.

However, making other chemicals from CO2 has high input energy requirements.

Heat of formation $\Delta_f H_{(g)}$ of CO_2 and various chemicals per carbon atom (kJ/mol). Chemicals are in the gas phase, except urea, which is in the solid phase. Condensation energy (such as energy associated with water formation in the urea production process) is not considered.
Source: BASF

Electrification

Energy Use by U.S. Manufacturing Sector in 2014



Source: Lawrence Berkeley National Laboratory

In California, in 2017, electricity provided only 21% of industry energy use, while direct fuel combustion provided 79%.

This means that electrification has a large potential to drive decarbonization, but cost and technology barriers must be addressed.

Electrification

Key Challenge

Today, it is cheaper to generate heat (e.g. for boilers, for melting input materials, etc.) by burning fossil fuels rather than by electricity.

Technical Solutions

- Replace systems where heat is used inefficiently. For instance, some process heating applications have thermal fuel efficiencies one third of electricity efficiencies.
  - Boilers themselves are typically efficient, but use of the resulting steam may not be.
- Use electricity to apply heat more precisely to the material (laser sintering, electric arc furnaces).
- Some processes may be redesigned to use non-thermal alternatives to heating, such as ultraviolet light or electron beams.
- Certain processes that don’t need very high temperatures may be served via an industrial heat pump, which is much more efficient than electrical resistance heating.

And/Or make renewable electricity cheaper than thermal fuels

Hydrogen

It is unlikely all industrial processes can be electrified, at least not in the next few decades.

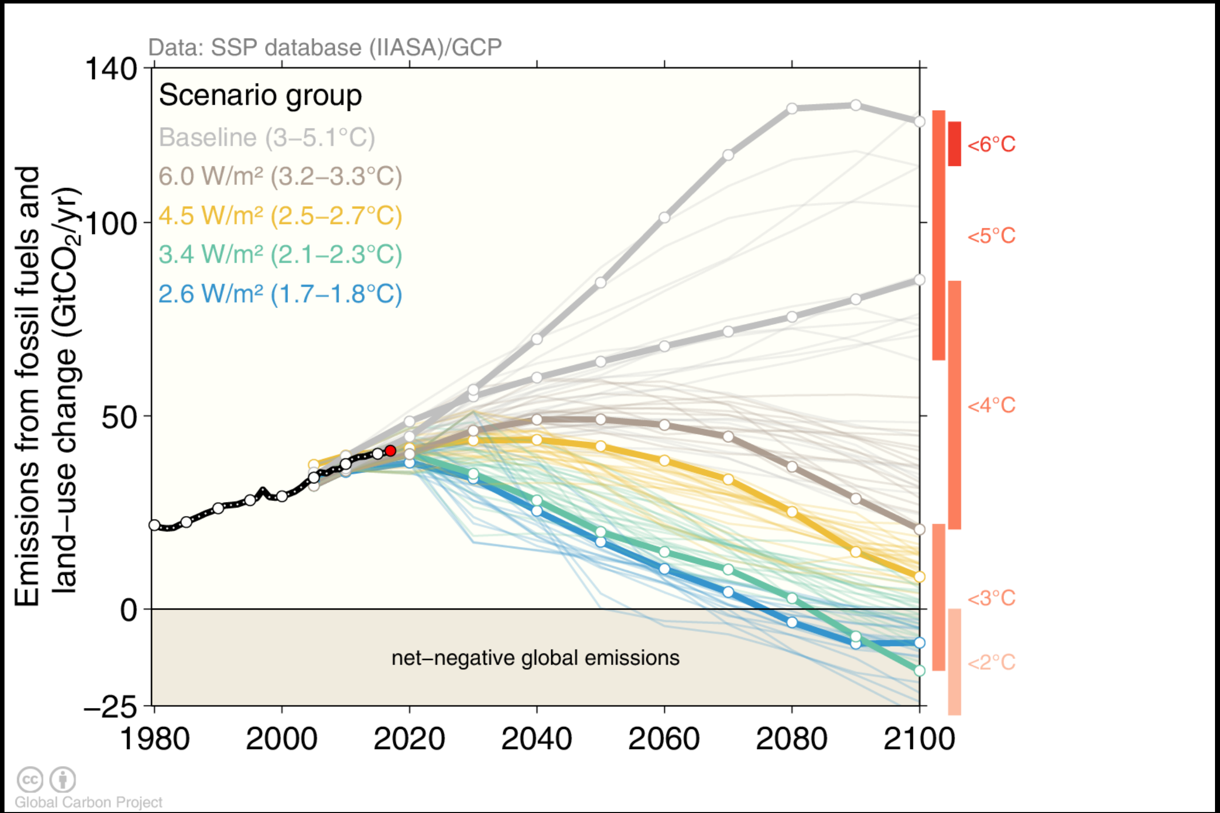
But we need to drive down emissions urgently.

Therefore, we need a zero-carbon, thermal fuel.

Biomass is inefficient and limited in its ability to scale up to meet global energy needs.

Therefore, hydrogen and/or hydrogen-derived energy carriers (e.g. ammonia, methane) are the likely fuels of choice.

Global Emissions Trajectories and Resulting Warming



Source: Global Carbon Project, CC Attribution

Hydrogen

Hydrogen has advantages

- Can be burned for high-temperature heat, useful in many industries
- Hydrogen is a widely-used chemical feedstock
- H_2 burns cleanly (emits only water vapor)

Hydrogen has challenges

- Prone to leaks due to hydrogen's small molecular size
- Can embrittle and diffuse through ordinary metals
- Currently made via steam reforming of methane, which emits CO_2. Electrolysis (splitting water) is promising but not yet financially competitive.

Solutions

- R&D for cheaper electrolysis, or methane pyrolysis (solid carbon output)
- Use special equipment to store and use hydrogen where it makes sense
- Convert hydrogen to ammonia or methane where necessary

Material Efficiency

Most industrial energy use is embodied in input materials

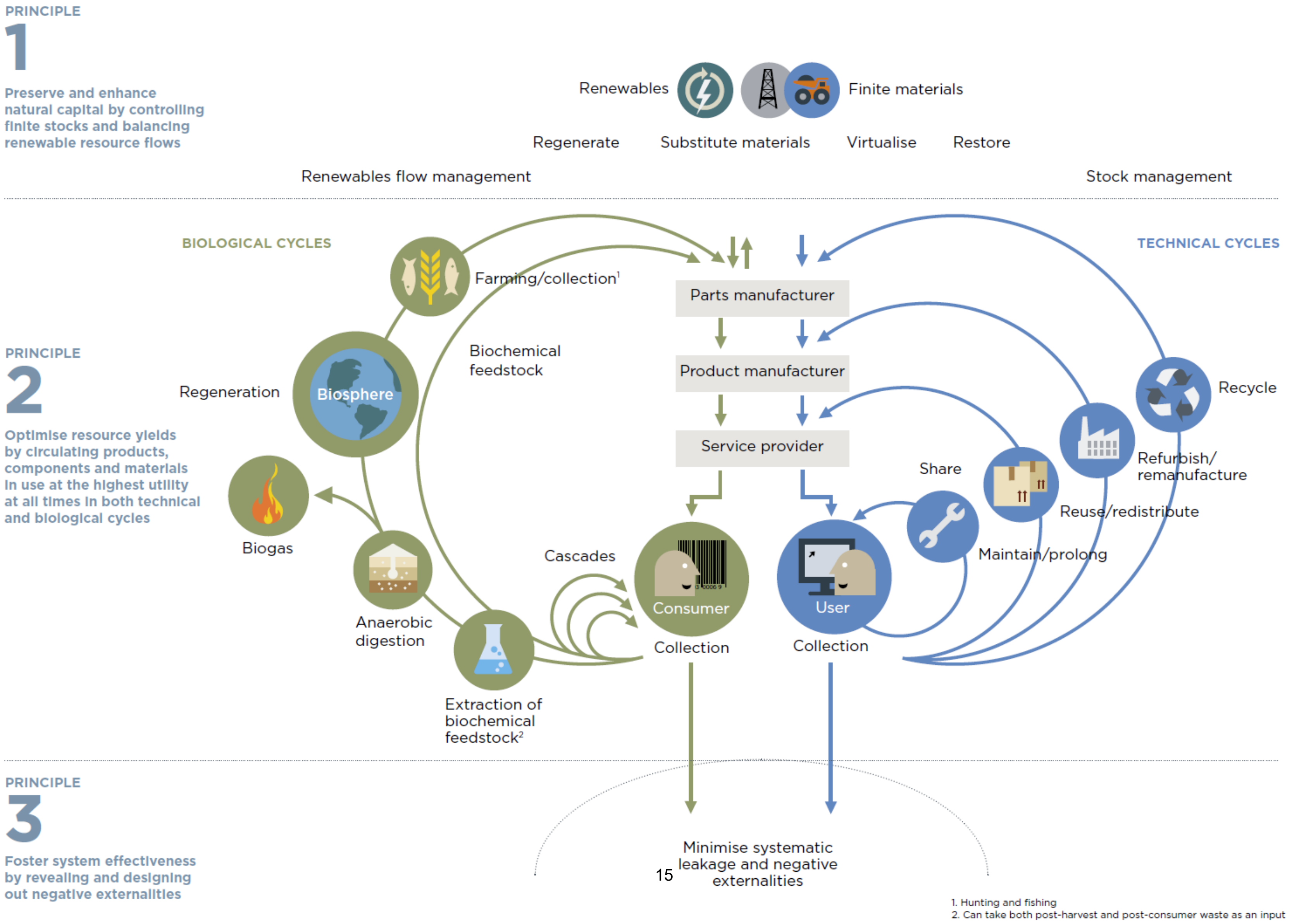
- Design for reduced material (e.g. curved fabric concrete molds, more sizes of steel beams)
- Increased material strength (new chemistries, pre-tensioning concrete, etc.)
- Additive manufacturing (3D printing) allows novel shapes and complexity
- Product longevity
- Intensification of use, the “sharing economy”
- Repurposing / re-use (especially of buildings)

Also material substitution

Coal power plant in Baltimore repurposed as commercial space

Wikimedia Commons, public domain

Circular Economy



Source: Ellen MacArthur Foundation

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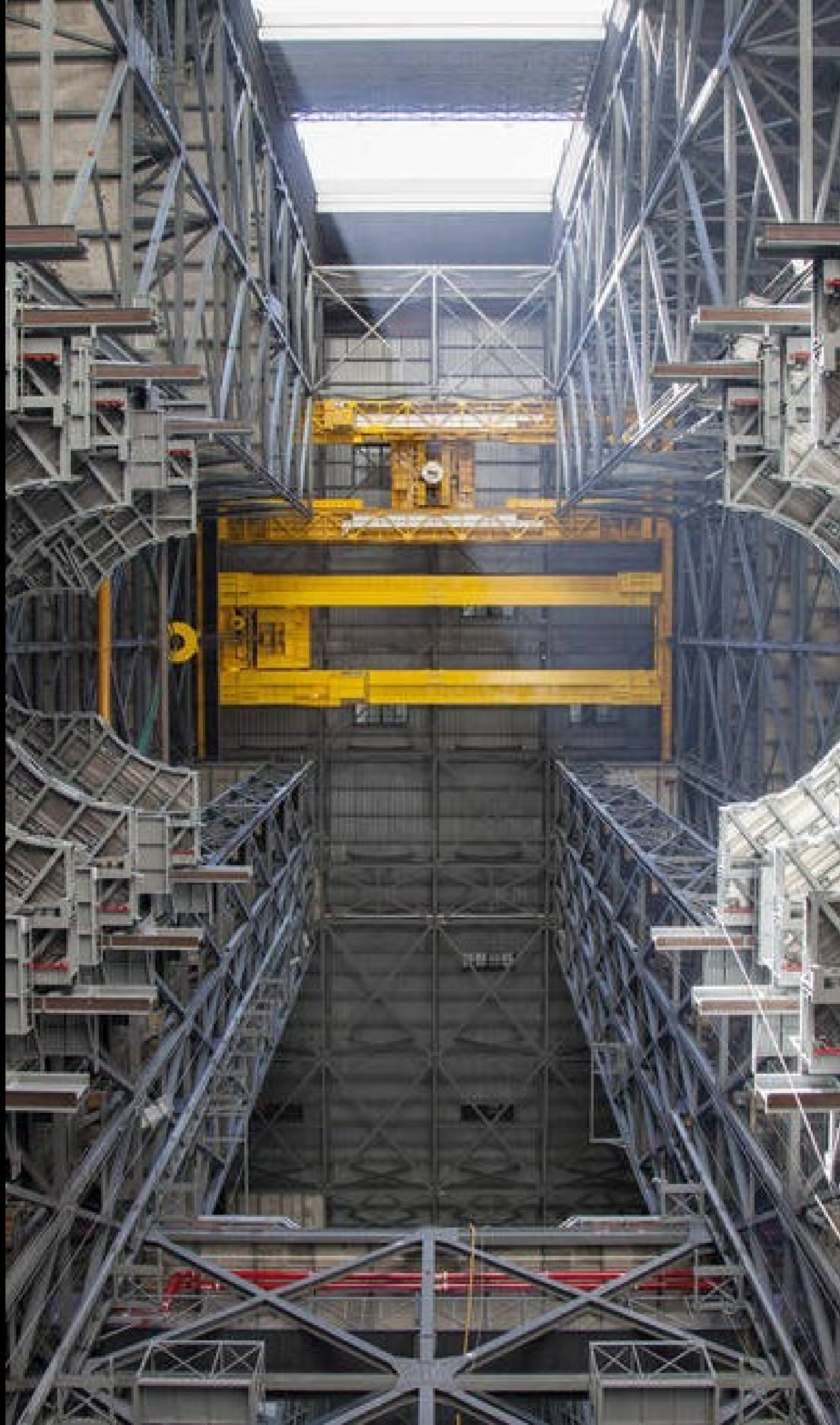

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