DECARBONIZING CALIFORNIA’S INDUSTRY SECTOR

California Air Resources Board
Industry Workshop: July 8, 2019

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California Industry Emissions in Context

California 2017 GHG Emissions by Sector (MMT CO2e)

- Transportation: 168 MMT (40%)
- Industry (direct emissions): 112 MMT (27%)
- Buildings (direct emissions): 89 MMT (21%)
- Buildings: 350 MMT (89%)
- Agriculture & Other (direct emissions): 52 MMT (12%)
- Electricity for Buildings: 250 MMT (61%)
- Electricity for Industry: 200 MMT (50%)

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
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.

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
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.
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

<table>
<thead>
<tr>
<th>World Region</th>
<th>Clinker to Cement Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>84%</td>
</tr>
<tr>
<td>Asia excl. China, India, CIS, and Japan</td>
<td>84%</td>
</tr>
<tr>
<td>Japan, Australia, and New Zealand</td>
<td>83%</td>
</tr>
<tr>
<td>CIS (Russian Commonwealth)</td>
<td>80%</td>
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<tr>
<td>Africa and the Middle East</td>
<td>79%</td>
</tr>
<tr>
<td>Europe</td>
<td>76%</td>
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<tr>
<td>China and India</td>
<td>74%</td>
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<tr>
<td>Latin America</td>
<td>74%</td>
</tr>
<tr>
<td><strong>World Average</strong></td>
<td><strong>78%</strong></td>
</tr>
</tbody>
</table>

Source: World Business Council for Sustainable Development
Chemicals Industry

F-Gases

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

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.
Chemicals Technologies

November 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)
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.
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.
Hydrogen

Hydrogen has advantages

• Can be burned for high-temperature heat, useful in many industries
• Hydrogen is a widely-used chemical feedstock
• H2 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 CO2. 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, pretensioning 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
Circular Economy

**Principle 1**
Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows.

**Biological Cycles**
- Regeneration
- Biochemical feedstock
- Extraction of biochemical feedstock
- Anaerobic digestion
- Cascades
- Consumer
- Collection
- Parts manufacturer

**Technical Cycles**
- Recycle
- Reuse/redistribute
- Service provider
- Virtualise
- Restore

**Renewables flow management**
- Regenerate
- Substitute materials
- Finite materials

**Parts manufacturer**
- Product manufacturer
- Service provider

**Minimise systematic leakage and negative externalities**

Source: Ellen MacArthur Foundation
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