Capture Sources, Technoeconomics and Infrastructure Development

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Assessment of Opportunities for CCS in California

**CO₂ Source Identification**
- Industry
- Electricity

**Technoeconomics**
- Source/Sink Matching
- Cash flow analysis

**Social Equity & Community Benefits**
- Local Air Quality
- Jobs

**Current CO₂ Emissions**

![Emissions Map](image)

**Marginal Abatement Curve**

Opportunities for CCS in the Industrial Sector

Industry Sources
- 35.8 MtCO$_2$/yr current emissions
- 31.8 MtCO$_2$/yr capturable emissions
- 51 Facilities

Industrial Candidates
- >100,000 tCO$_2$/yr
- Operating and reporting emissions in 2018
- Larger sources at refineries

Current CO$_2$ Emissions

<table>
<thead>
<tr>
<th>Source</th>
<th>Mt/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
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<tr>
<td>CHP</td>
<td>10</td>
</tr>
<tr>
<td>Cement</td>
<td>8</td>
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<tr>
<td>Refineries</td>
<td>6</td>
</tr>
<tr>
<td>Ethanol</td>
<td>4</td>
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</tbody>
</table>

Hydrogen
CHP
Cement
Refineries
Ethanol

Characteristics of Gas Power units in California, 2018

- Electricity Sector emits roughly 62 MtCO₂ (15% of state's total)
- 60% in-state generated.

- Natural gas is the largest source of power generation in California
- 195 gas-fired units in 100 locations

• 25 natural gas combined cycle (NGCC) power plants meet CCS retrofit criteria
• 14 GW total capacity
• 21.6 MtCO$_2$/yr current emissions
• 27.5 capturable emissions MtCO$_2$/yr*

* Capacity factor to increase to 60%

Opportunities for CCS Electricity Sector in California

Retrofit Candidates
• Combined Cycle
• Built after 2000
• No planned retirement
• Capacity >250 MW


CO$_2$ Source Identification
Emission Sources suitable for CCS Retrofit

**Industry:**
- 31.8 MtCO$_2$/yr capturable emissions
- 51 Facilities

**Electricity:**
- 27.5 MtCO$_2$/yr capturable emissions
- 25 NGCCs

**Total:**
- 59.3 MtCO$_2$/yr capturable emissions
- 76 Facilities
Emission Sources suitable for CCS Retrofit

CO₂ Source Identification

Technoeconomics
- Source/Sink Matching
- Cash flow analysis
Comparison of Emissions and Capture Costs by Subsector

Average Emissions for Different CO₂ Capture Sources

- Hydrogen Production
- NGCC
- Cement Production
- CHP
- Refinery
- Ethanol Production

Average Cost for Capture for Different CO₂ Sources

Comparison of Emissions and Capture Costs by Subsector

Emissions per year by individual facility

Capture cost by individual facility


Technoeconomics
With Current Incentives About 20 MtCO₂/yr Could Be Captured Cost Effectively

Marginal Abatement Curve

Policy Incentives
- LCFS at $100/ton
- 45Q tax credit


34 facilities have negative costs = positive revenues (20 MtCO₂/yr)

Technoeconomics

- Hydrogen Production
- NGCC
- CHP
- Cement Production
- Ethanol Production
- Refinery
California Has Abundant and High-Quality CO\(_2\) Storage Resources

**Data Sources**
- National Labs
- U.S.G.S.
- WESTCARB 2003 - 2013
- U.S. DOE and CEC

**Screening Criteria**

**STAGE 1**
- Qualify sites and saline reservoirs
  - Apply LCFS and EPA Class 6 minimum criteria
  - Apply additional "disallowed" conditions

**STAGE 2**
- Develop Exclusion Layer consisting of geographic information (e.g. faulting, seismicity, population density, sensitive habitats, restricted lands)

**STAGE 3**
- Storage Opportunity Identification by merging qualified sites with exclusion layer.

**Storage Capacity (GT CO\(_2\))**

<table>
<thead>
<tr>
<th></th>
<th>Saline Formations</th>
<th>Oil and Gas</th>
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<tr>
<td></td>
<td>70</td>
<td>Low</td>
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<td></td>
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<td>High</td>
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<td>2.1</td>
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California could store 60 Mt/year for more than 1000 years.

Infrastructure Buildout for 60 MtCO$_2$/yr CCS

Co-located capture and storage • 3 ethanol plants, 6 NGCC, 6 CHPs and 1 cement plant

1. Northern California Gathering System and Storage Hub • 8 hydrogen 4 refineries, 5 CHPs, and 3 NGCC

2. Southern California Gathering System and Storage Hub • 8 hydrogen, 5 refineries, 4 CHPs, 1 cement, and 5 NGCC

3. Desert and Salton Sea Gathering Systems • 5 cement, 1 CHP, 6 NGCC

4. Central California and S. Bay Gathering System • 1 cement, 5 NGCC

**Investor Cash Flow – Ethanol Plant**

1. Initial capital is made available to the ProjectCo from investors.
2. This includes tax equity investors who are essentially buying the 45Q tax credits.
3. Once operational, the capture facility receives CO₂ from the ethanol production facility and stores it within the permitted geologic storage location onsite and the ethanol facility generates LCFS credits from its capture efforts.
4. LCFS credits can be sold at market rates and receive LCFS revenues, a portion of which is contributed to the ProjectCo.
5. A portion of earnings resulting from the LCFS credit sale may eventually be transferred to investors in the form of a dividend (cash distribution).
6. Since tax equity investors are only obliged to contribute 50 percent of the cost of 45Q tax credits upfront, there will be ongoing investments through the lifecycle of the capture operation.

**Modeled Investor Cash Flow**

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<thead>
<tr>
<th>Year</th>
<th>Investor Cash Flow (US$M)</th>
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<td>2022</td>
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<tr>
<td>2045</td>
<td>(7)</td>
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</tbody>
</table>

**Technoeconomics**
Modeled Investor Cash Flow

1. Initial capital is made available to ProjectCo from investors.
2. This includes tax equity investors who are essentially buying the 45Q tax credits.
3. Once operational, the capture facility receives CO₂ from the NGCC production facility and stores it within the permitted geologic storage location onsite. Since tax equity investors are only obliged to contribute 50 percent of the cost of 45Q tax credits upfront, there will be ongoing investments through the lifecycle of the capture operation.

Technoeconomics
Investor Cash Flow – Refining Complex/Hub

1. Initial capital is made available to the ProjectCo from investors.
2. This includes tax equity investors who are essentially buying the 45Q tax credits.
3. Once operational, the capture facilities generates LCFS credits from its capture efforts.
4. LCFS credits can be sold at market rates, a portion of which is contributed to the ProjectCo.
5. A portion of earnings resulting from the LCFS credit sale may eventually be transferred to investors in the form of a dividend (cash distribution).
6. Since tax equity investors are only obliged to contribute 50 percent of the cost of 45Q tax credits upfront, there will be ongoing investments through the lifecycle of the capture operation.
7. CO₂ transportation and storage are contracted services, for which the ProjectCo enters into a typical “take-or-pay” arrangement with other infrastructure suppliers.

Technoeconomics
• **Ethanol**: Low capture cost, LCFS eligible, conveniently located. Ethanol is a clear early target for CCS project development.

• **Hydrogen and Refining**: medium capture costs, but with LCFS and 45Q credits they net a positive revenue. **CHP** facilities in California are associated with either refining operations, upstream oil and gas operations, or non-petroleum industry applications. Hub opportunities...

• **Cement**: Low capture costs, not LCFS eligible. Geographically disadvantaged (CO$_2$ P/L needed)

• **NGCCs**: Relatively high capture costs, not LCFS eligible, need additional incentives.
Technoeconomics
- Source/Sink Matching
- Cash flow analysis

Social Equity & Community Benefits
- Local Air Quality
- Jobs
Social Equity and Community Benefits

Local Air Quality Improvements

- Some industrial facilities with high CO₂ emissions also emit high levels of criteria air pollutants such as sulfur dioxide (SO₂), nitrous dioxide (NO₂), and particulates
- Post-combustion carbon capture requires reduction of these other pollutants creating local air quality benefits

Local Economic Activity

- CCS projects can stimulate local economic activity, including new construction, operations, and maintenance jobs
- Multiplier effects across the supply chain can drive additional economic benefits

Job Creation and Preservation

- The economic benefits associated with job training could provide new employment opportunities in the low carbon economy
- CCS activities support employment for skill sets which may otherwise become obsolete in a clean energy transition

Conclusions

• **The Opportunity:**
  - Emissions sources that could be retrofit for CCS and abate nearly 60 MtCO$_2$/yr;
  - 70 Gt of CO$_2$ storage potential in the state; and
  - Identification of project and transportation infrastructure options
  - Community Benefits

• **Next Up: The Challenges**