Analyzing California’s GHG Reduction Paths using CA-TIMES Energy System Model

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CA-TIMES Model Overview

- CA-TIMES is a bottom-up, linear optimization model of California’s energy sectors
  - Technology and resources details
  - The model makes technology investments and operations decisions for energy supply technologies and end-use technologies
  - Minimizes total system cost of meeting energy service demands with perfect foresight

- CA-TIMES helps us understand the role of technologies, resources and policies in California’s future energy system
  - Integrated model of California energy (demand and supply sectors)
  - Understand cost trade-offs between different uses of scarce resources
  - Scenarios varying technology and resource costs and availability
  - Model California’s energy system under 80% GHG reduction by 2050
Modeling California’s Energy System and Emissions

- Integrated model of California’s energy system
  - Resource supplies – used across many sectors
  - **Endogenous efficiency and technology decisions** drive electricity and fuel demands
  - Electric generation – used across many sectors, timing
  - Economy wide policies

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![Diagram](image-url)
CA-TIMES can be used to answer many questions

- How does a cap on GHG emissions influence the evolution of the energy system in terms of technology adoption and system costs?
  - What technologies are adopted in each sector?
  - What is the optimal mix of efficiency and fuel switching?
  - Which sectors reduce emissions more?
- What is the incremental cost (or savings) of GHG mitigation?
- How can policies and the availability of technologies and resources influence the mitigation strategies and costs?
- How sensitive are the results (technology mix and cost of mitigation) to uncertain input assumptions?
CA-TIMES Modeling Limitations

- Limitations of current implementation of CA-TIMES
  - **Simplified representation** of energy markets
  - **Non-spatial** representation of California energy (single region)
  - **California-only model** so imports and prices are represented by exogenous assumptions
  - One **global decision-maker** optimizes based upon total system cost across all sectors, rather than millions of decision makers
    - Work is ongoing to incorporate consumer heterogeneity and consumers’ vehicle choices into the model
  - **Uncertain assumptions** especially in the face of radical changes to energy system
  - Currently **ignores non-energy emissions**
  - Current implementation does not include endogenous technological learning (ETL), so no connection between technology forcing policies and technology improvements (cost, efficiency)
  - No macroeconomic feedbacks
CA-TIMES Results

• Results from our most recent publications:

• Additional preliminary results
  – Carbon capture and sequestration for biomass systems
Examine Emissions Across Three System Boundaries

- We only account for **energy-related** GHG emissions
  - Ignore cement and other industrial processes, ag and waste emissions as well as natural sources and sinks
  - CARB’s 1990: 427 MMT vs CA-TIMES 391 MMT (difference 36 MMT)

- Capped instate emissions (1)
- Capped + Other instate emissions (1+2)
- Life-cycle CA emissions (1+2+3)
CA-TIMES GHG emissions results

- GHG emissions in **BAU** and GHG scenario (**GHG-Line**)
- **GHG-Line** scenario meets the emissions target up to 2045 and achieves **75%** GHG reduction in 2050
  - CCS and nuclear power are not available in this scenario
  - Ignores out-of-state aviation and marine travel and excludes offsets
  - Significant emissions reduction across all sectors (44 to 81% reduction)
  - Transportation continues to contribute majority of emissions

### BAU

### GHG-Line

- **2020 Target** (391 MtCO2e)
- **2050 Target** 78 MtCO2e
- **26.7% reduction in 2030**
Different GHG Emissions Targets

- **GHG-Step** cap allows more flexibility
- **GHG-Line** makes earlier investments in low-carbon technologies and resources (at higher cost)
- Same level in 2050, but different cumulative emissions (2010-2050)
Total Transport Fuel Use – GHG-Line Scenario

- Decrease in petroleum and increase in biofuels, hydrogen and electricity
- Difficulty in electrifying most transport sectors
- Liquid fuels requirements and limited biofuels availability (7.3 billion GGE) makes it hard to fully decarbonize sector
- Includes fuels for interstate/international aviation and marine

<table>
<thead>
<tr>
<th>Fuel</th>
<th>2010 share (%)</th>
<th>2030 share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum</td>
<td>95%</td>
<td>75%</td>
</tr>
<tr>
<td>Electricity</td>
<td>&lt;0.1%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Biofuels</td>
<td>5%</td>
<td>20%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0%</td>
<td>4.5%</td>
</tr>
</tbody>
</table>

2030 Petroleum usage (vs 2010)
25% reduction across transport
31% reduction for On-Road
38% reduction for LDV
Light-Duty Vehicles

- LDVs are primarily electrified to battery electric (BEVs) and H₂ fuel cell vehicles (FCVs) by 2050
  - 2.4 million vehicles (~1.1M BEV/PHEV, 1.3MFCV) in 2030
  - 11% of VMT supplied by electric-drive vehicles (FCV/BEV/PHEV) in 2030
  - On-road fuel economy is 36 mpgge in 2030 (110 mpgge in 2050)
  - LDV fuel demand is 36% lower than 2010 in 2030 and 77% lower in 2050
  - Petroleum usage is 38% lower than 2010 in 2030 and 98% lower in 2050
Electricity Supply Increases in GHG scenario

- Electricity demand increases significantly due to electrification in end-use sectors (residential, commercial, industrial, transport)
- *Without nuclear or CCS* in primary scenario, renewable electricity sources are needed to decarbonize electricity generation

**GHG-Line generation (TWh)**

<table>
<thead>
<tr>
<th></th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>90</td>
<td>221</td>
</tr>
<tr>
<td>Solar</td>
<td>78</td>
<td>217</td>
</tr>
<tr>
<td>Geo</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>Tidal</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Biomass</td>
<td>&lt;1</td>
<td>0</td>
</tr>
<tr>
<td>Natural gas</td>
<td>165</td>
<td>53</td>
</tr>
</tbody>
</table>

NG is marginal generator

- RPS renewables
  - 38% in 2030 (Step)
  - 49% in 2030 (Line)
  - 80% in 2050
Balancing Electricity Supply and Demand

- As intermittent renewables grow to greater proportion of the generation mix, balancing demands is critical for system operation
- Natural gas and hydro are flexible, dispatchable generators
- Generation can exceed demand during some model timeslices (annual excess generation ~3-5%)
Efficiency Improvements in End Use Sectors

**Residential Sector Efficiency**

- Max wt GC
- BAU
- GHG-Step
- GHG-Line

**Commercial Sector Efficiency**

- Max wt GC
- BAU
- GHG-Step
- GHG-Line

Doubling of efficiency even in BAU
The incremental cost of the GHG scenario is calculated as the difference in annual cost between the GHG-Line scenario and BAU scenarios:

- Two different BAU scenarios (BAU and BAU-LoVMT)
  - GHG-Line has same VMT demand as BAU-LoVMT and lower than BAU
  - Transport costs are mostly negative compared to BAU because lower VMT means fewer vehicle and fuel purchases (even if they are more expensive)
  - Cost differences rise over time as more expensive, efficient, low-carbon technologies are adopted
  - Costs of industrial/ag sectors mitigation not modeled
2030 Mitigation Costs

• Cost of emissions reduction
  – Depends on which baseline used (BAU or BAU-LoVMT)
  – Currently do not include incremental technology costs for industrial & ag sectors
• Average cost of cumulative emissions reduction ($/tonneCO2e)

Mitigation Cost vs BAU-LoVMT
$23 to 33 billion (4% disc.)
per resident per yr
$26 to $38/person/yr (4% disc.)
% of 2010-2030 GSP (@3.3%/yr)
0.07% to 0.11% (4% disc.)
Sectoral Breakdown of Costs

- Allocate costs to various sectors
- Total additional cost to 2030 is low (when comparing to BAU-LoVMT) and highly negative (compared to BAU)
Carbon capture and sequestration scenarios

- **Role of CCS and biomass**
  - Most carbon captured is from biomass
  - ~20MMTCO$_2$ sequestered in 2030 and ~100MMTCO$_2$ in 2050
  - CCS for biomass is directed towards the production of biofuels (FT)
    - Small amount of electricity production is a byproduct of FT biorefineries

### Sources of CCS Carbon

![Bar chart showing carbon sequestered (MMTCO$_2$) for 2030 and 2050.](chart1)

### 2030 Energy Production from CCS Plants (PJ)

<table>
<thead>
<tr>
<th>Source</th>
<th>Production (PJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofuels</td>
<td>0.9 BGGE</td>
</tr>
<tr>
<td>Biofuels Prod</td>
<td>1.2 TWh</td>
</tr>
<tr>
<td>Biomass</td>
<td>38 Million kgH2</td>
</tr>
<tr>
<td>NG-Elec</td>
<td>5.6 TWh</td>
</tr>
<tr>
<td>NG-H2</td>
<td>76 Million kgH2</td>
</tr>
<tr>
<td>Fossil CCS</td>
<td>43.0</td>
</tr>
<tr>
<td>NG-Elec</td>
<td>1.2 TWh</td>
</tr>
<tr>
<td>NG-H2</td>
<td>10.8</td>
</tr>
<tr>
<td>NG-Elec</td>
<td>9.4</td>
</tr>
<tr>
<td>Biofuels Prep</td>
<td>0.9 BGGE</td>
</tr>
</tbody>
</table>

![Pie chart showing sources of CCS carbon.](chart2)
Key Results from CA-TIMES

• 2030 costs are very low to quite negative depending on the reference scenario
  – $95 per household vs -$3336/HH between 2010 to 2030
  – Additional mitigation cost is less than 0.11% of GSP

• Major shift towards low-carbon, efficient technologies in 2030
  – 2.4 million ZEVs
  – 31% reduction in on-road petroleum use
  – Building service demand efficiency approximately doubles
  – 38-49% RPS renewables in power generation

• Availability of CCS technology has the largest impact on the results
  – Used in electric sector and for negative emission biofuels (bioCCS)
  – Can use more natural gas and biomass provides offsets for petroleum
  – Biofuels production is a more productive use of biomass, even though a lower fraction of carbon is sequestered, it displaces more carbon intensive alternatives in the transport sector vs the electric sector.
Thank you!