Mobile Sources in California’s Energy Future:
Getting to 80% GHG Reductions
Through Electricity and Fuels Strategies

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Presentation to CARB, CEC and CPUC staff
CalEPA Building, Sacramento, CA
15 July 2011
60% Reduction Median Case (150 MtCO₂/yr)

80% Reduction Target (77 MtCO₂/yr)
## Strategies for Getting to 80%

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>GHG Impact</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>100% effective CCS</td>
<td>Small</td>
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<tr>
<td>2.</td>
<td>Eliminate fossil/CCS (use nuclear instead)</td>
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<tr>
<td>3.</td>
<td>100% ZELB for load balancing</td>
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<td>4.</td>
<td>Net-zero GHG biomass</td>
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<td>5.</td>
<td>Behavior Change (10% reduction in demand)</td>
<td>Moderate</td>
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<td>6.</td>
<td>Biomass/CCS (20% of electricity, offsets fuels)</td>
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<td>7.</td>
<td>Hydrogen (30% replacement of HC fuels)</td>
<td>Large</td>
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<td>8.</td>
<td>Biomass/Coal/CCS (make fuels + electricity)</td>
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<td>9.</td>
<td>Double biomass supply</td>
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<td>10.</td>
<td>Fuel from sunlight (need net-zero carbon source)</td>
<td>Transformative</td>
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<td>11.</td>
<td>Fusion electricity</td>
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<td>12.</td>
<td>Others?</td>
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Getting to 80%: Single Strategies from the Median Case

![Getting to 80%: Single Strategies](chart.png)
## 100% Effective CCS?

<table>
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<tr>
<th>Capture technology</th>
<th>Main constituents</th>
<th>CO₂ capture limit</th>
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<tbody>
<tr>
<td>Post-combustion</td>
<td>CO₂ (dilute), N₂, O₂, H₂O</td>
<td>~90%</td>
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<tr>
<td>IGCC pre-combustion</td>
<td>CO₂, CO, CH₄, H₂S</td>
<td>~92%</td>
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<tr>
<td>Oxyfuel combustion</td>
<td>CO₂, O₂, H₂O</td>
<td>96-99%</td>
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</table>

### Conclusions:
- >90% capture is costly, >95% is very costly
- 100% capture is unlikely without breakthroughs
- Would not save much CO₂ in median case (6 MtCO₂/yr)

### But:
- Important incremental savings in CCS-heavy cases
  (fossil/CCS, biomass/CCS, biomass/coal/CCS, Nat. gas H₂)
Elimination of CCS

- Slightly greater CO$_2$ savings than 100% CCS (due to reduced refining emissions), *but*:
- CCS is probably needed for more than fossil electricity production, so unlikely to eliminate, unless technically- or cost-prohibitive
100% Zero-Emission Load Balancing

Questions:

• How much ZELB is actually required for each scenario?
• How much flexible load capacity is there, and at what cost? What can spur adoption & investment?
• Energy storage is likely to be “backstop” technology, unless costs beat spinning reserves and/or peak generation with natural gas. Are current RD&D investments sufficient?
• Can storage efficiency be increased?
• How do we solve the “GW-day” problem?
• Can gas turbines be cost-effective with CCS?
Net Zero GHG Biomass

• Can lifecycle costs be reduced to zero?
• 22 MtCO$_2$/yr savings over median case
• Important to reduce net emissions from where they are today (>50% of fossil fuels), but not so critical to reduce below ~20%.
• Research questions:
  – Can we produce a cost curve for net GHG biomass emissions?
  – Given other energy component strategies, what is a reasonable net GHG biomass target?
Behavior Change

• Many behaviors identified to reduce energy use in the 10-20% range:
  – Greater extremes in variables, including building & water temperatures, light levels, moisture content, etc.
  – Right-sizing of homes, appliance capacities, etc.
  – Trading time for convenience, e.g., “smart” wash cycles
  – More use of manual/“natural” effort, e.g., manual egg beaters, air-drying clothing, playing the guitar instead of watching TV, biking vs. driving
  – Lifestyle decisions regarding location, degree of privacy (detached vs. shared home), car ownership/use (big impact on transportation energy)

• Technology-enablers important, such as room dependent space conditioning and occupancy sensors

• 24 MtCO$_2$/yr savings from median case with ~10% demand reduction
New research (CEC grant to LBNL) finds that:

- Behaviors targeting fuel use (e.g., transportation) have larger GHG savings, so policy may choose to focus on these.

Industrial “behavior”:

- Less raw materials to produce the same products
- More integrated products to reduce total number produced
- Longer-lasting products; longer product design cycles
- Design for ease of recycling or re-use
- Use of less energy-intensive materials (e.g., composite replacements for steel); minimize packaging
- Change from consumer ownership to rental/service model
Biofuels vs. Biomass/CCS

- **Biofuels**: 80 gge biofuels
- **Biomass/CCS**: 1.2 MWh biomass/CCS electricity

**Net GHG**:
- **Biofuels**: -0.1 tCO₂
- **Biomass/CCS**: 0.6 tCO₂
- **Savings**: 39 MtCO₂/yr savings over median case

Net GHG:
- **Biofuels**: 0.1 tCO₂
- **Biomass/CCS**: -0.1 tCO₂
Hydrogen

• CEF assessment of primary roles for H₂:
  – Light-duty vehicles (22%)
  – Some heavy-duty transport (9% trucks, 100% buses)
  – Industrial heat (21%)

• Production options:
  – Electrolysis: very expensive, unless done at high-temperature
  – Thermochemical from coal or natural gas with CCS

• 40 MtCO₂/yr savings over median case

• Research questions:
  – When is hydrogen “better” than electrification or biofuels?
  – Can hydrogen be used in heavy-duty transporation, e.g., airplanes (Jacobson & Delucchi, EnPol, 2011)?
Biomass and Coal with CCS

Example plant design

- 45% Biomass
- 55% Coal

IGCC/FT/CCS plant

- Electricity: 4%
- CO₂ (sequestered): ~60%
- Life cycle GHGs: ~10% of fossil fuels

94 mdt/yr biomass → 12-15 bgge/yr fuels
56 MtCO₂/yr savings

Central Role of CCS

- Huge enabler of:
  - Fossil electricity, including possibly natural gas turbines
  - Biomass electricity to offset fossil fuel in transport
  - Fuel production from biomass + fossil
  - Hydrogen production

- Research needs:
  - Legal resolution of CO$_2$ responsibility (federal issue?)
  - Resource assessment in oil/gas reservoirs & saline aquifers, both inside and outside CA
  - Economic assessment of best role & locations for CCS
  - Membrane capture, IGCC, oxyfuel technologies
  - Pilot plants needed (2 PIER-funded projects underway)
  - Value of >90% capture?
Doubling Biomass Supply

15 bgge/yr total
188 mdt/yr raw biomass

13 bgge/yr fuels

Median case

Fossil Fuels*
Imported Biofuels
CA Biofuels

(2 bgge/yr electricity)

*Not including natural gas for CCS
Doubling Biomass Supply

30 bgge/yr total
376 mdt/yr raw biomass

CA grown?

Imported Biofuels

Additional CA Biofuels

CA Biofuels

(2 bgge/yr electricity)

Where could this land come from?
- Abandoned crop + unproductive timber land
- Increased recovery of existing waste streams
Doubling Biomass Supply

30 bgge/yr total
376 mdt/yr raw biomass

Imported? Requires 3x base imports (22.5 bgge/yr)

Imported Biofuels

CA Biofuels

(2 bgge/yr electricity)
Advanced Technologies

• Fuel from sunlight
  – Would relieve biomass resource constraint
  – Probably necessary if CCS fails or is too expensive

• Fusion
  – Would it really produce cheaper electricity? If so, how would solutions change (e.g., cheap electrolysis)?
  – Might be better baseload solution than nuclear fission, fossil/CCS or geothermal

• What else could help?
Getting to 80%: Example of Multiple Strategies

- Median
- + Biomass/CCS
- + Hydrogen
- + ZELB
- + Behavior Change
- + High Biomass Supply
- + Net Zero GHG

GHG Emissions (MtCO₂e/yr)

- Hydrogen
- Carbon fuels
- Electricity
- Net emissions
- 2050 Target
Conclusions

• 80% solutions are achievable with technical (and for behavior, social) innovation
• Multiple strategies are probably needed
• Key uncertainties/challenges:
  – Biofuels are uncertain, and greatly expanded supplies would change nature of solution
  – CCS is an important enabling technology; will it work at scale?
  – How should hydrogen best be used?
  – Load balancing without emissions needed (storage and flexible loads), particularly for renewables
• Further research needed:
  – Biomass/CCS for electricity
  – Biomass/Coal/CCS for fuels
  – Fuel from sunlight (and possibly fusion)