IEPR Presentation: Inter-Model Comparison of California Energy and Climate Policy Models

10 April, 2014

California Energy Commission

Anthony Eggert
Sonia Yeh
Geoff Morrison
Raphael Isaac
Christina Zapata

UC DAVIS
Overview

• Acknowledgments
• A few words about models, scenarios and forecasts
• Model comparison overview and findings
• Observations and key takeaways
• Questions
Acknowledgements

We wish to sincerely thank the members of the Steering Committee of the California Climate Policy Modeling (CCPM) forum, including: Louise Bedsworth (California Governor’s Office of Planning and Research), Jim Bushnell (University of California (UC), Davis), Steve Cliff (California Air Resources Board, CARB), Ashley Conrad-Saydah (California Environmental Protection Agency, Cal/EPA), Richard Corey (CARB), Joshua Cunningham (CARB), Nicole Dolney (CARB), Guido Franco (California Energy Commission, CEC), Karen Griffin (CEC), Bryan Hannegan (National Renewable Energy Laboratory, NREL), Daniel Kammen (UC Berkeley), Ryan McCarthy (CARB), Robin Newmark (NREL), Cliff Rechtschaffen (California Governor’s Office), David Roland-Holst (UC Berkeley), John Weyant (Stanford), and Jim Williams (Energy + Environmental Economics, Inc., E3). We also appreciate the contributions, helpful insights and detailed modeling results provided by key modelers including Mark Delucchi (UC Davis), Jeffery Greenblatt (Lawrence Berkeley National Lab, LBNL), Mark Jacobson (Stanford), Mike Kleeman (UC Davis), Jimmy Nelson (UC Berkeley), Max Wei (LBNL), and Christopher Yang (UC Davis). Support for the modeling forum workshop was provided by Pacific Gas & Electric, Energy Foundation, and Environmental Defense Fund.
“Essentially, all models are wrong... ...but some are useful”

Professor George Box, University of Wisconsin
A few words about scenarios

“Scenarios are stories that consider “what if?” questions. Whereas forecasts focus on probabilities, scenarios consider a range of plausible futures and how these could emerge from the realities of today. They recognize that people hold beliefs and make choices that lead to outcomes.”

And ‘forecasting’...

**Figure 5. Average annual Brent spot crude oil prices in three cases, 1980-2040**

2011 dollars per barrel

- **High Oil Price**
- **Reference**
- **Low Oil Price**

Track record of EIA’s "Annual Energy Outlooks" (AEOs) for the past 25 years shows that the Administration’s forecasts consistently missed both the direction and magnitude of changes in world crude oil price.
Except that porcupines are allergic to raisins...
California’s Goals:
Reach 1990 levels by 2020 and 80% reduction by 2050

\[ \text{MMT CO2e} = \text{Million metric tonnes of carbon dioxide equivalent} \]

- 1990 Levels
- 431 MMT CO2e/yr
- 86 MMT COe/yr
- 80% below 1990 Levels

UC Davis
Sustainable Transportation Energy Pathways

UC Davis
Policy Institute for Energy, Environment and the Economy
Need for Mid-term GHG Target

• Update to AB 32 Scoping Plan (2014):
  
  “A mid-term statewide emission limit will ensure that the State stays on course to meet our long-term goal and continues the success it has achieved thus far in reducing emissions.” (CARB, 2014, p. 39)

• Governor’s Environmental Goals and Policy Report (2013):
  
  “…the state needs a mid-term emission reduction target to provide a goalpost to guide near-term investment and policy development. A mid-term target will allow us to gauge current actions relative to our climate goals and serve to provide a clear sign of the state’s commitment to achieving long-term climate stabilization. This commitment will send a strong signal of support for the innovators and entrepreneurs to drive technology and development to tackle the challenge of climate change.” (OPR, 2014, p. 6)
Model Questions

• How might California’s energy system evolve to 2030 & 2050:
  – Greenhouse Gas (GHG) trajectories?
  – Fuel mix and technology mix?
  – Infrastructure build rate?
  – Air quality?

• What assumptions drive these results?

• What are common insights across models? Where do they diverge?
## CA Energy Models/Reports Reviewed

<table>
<thead>
<tr>
<th>Model</th>
<th>Group (lead)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARB VISION</td>
<td>California Air Resources Board (CARB)</td>
</tr>
<tr>
<td>BEAR</td>
<td>UC Berkeley (Roland-Holst)</td>
</tr>
<tr>
<td>CA-TIMES</td>
<td>UC Davis (Yang, Yeh)</td>
</tr>
<tr>
<td>CCST View to 2050</td>
<td>CCST (Long)</td>
</tr>
<tr>
<td>CCST (Bioenergy)</td>
<td>CCST (Youngs)</td>
</tr>
<tr>
<td>E-DRAM</td>
<td>UCB/CARB (Berck)</td>
</tr>
<tr>
<td>Energy 2020</td>
<td>ICF/CRA</td>
</tr>
<tr>
<td>GHGIS</td>
<td>LBNL (Greenblatt)</td>
</tr>
<tr>
<td>IEPR 2013/CED 2013</td>
<td>California Energy Commission (CEC)</td>
</tr>
<tr>
<td>LEAP-SWITCH</td>
<td>UC Berkeley/LBNL (Nelson, Wei)</td>
</tr>
<tr>
<td>MRN-NEEM</td>
<td>EPRI/CARB</td>
</tr>
<tr>
<td>PATHWAYS</td>
<td>E3/LBNL (Williams)</td>
</tr>
<tr>
<td>Wind Water Solar (WWS)</td>
<td>Stanford/UCD (Jacobson, Delucchi)</td>
</tr>
</tbody>
</table>

UC Davis
Sustainable Transportation Energy Pathways
### Qualitative Comparison

<table>
<thead>
<tr>
<th>Development</th>
<th>ARB-VISION</th>
<th>BEAR</th>
<th>CA-TIMES</th>
<th>GHGIS</th>
<th>LEAP-SWITCH</th>
<th>PATHWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling team(s)</td>
<td>CARB</td>
<td>UC Berkeley</td>
<td>UC Davis</td>
<td>LBL/ARB</td>
<td>LBL, UCB</td>
<td>E3/LBL</td>
</tr>
<tr>
<td>Software</td>
<td>Excel</td>
<td>GAMS</td>
<td>GAMS</td>
<td>Excel</td>
<td>AMPL</td>
<td>Excel</td>
</tr>
</tbody>
</table>

| Structure | | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|
| Sectors modeled | Transportation | All | All | All | All | All |
| Solution algorithm | Fleet turnover/spreadsheet | General Equilibrium | Optimization or Partial Equilibrium | Scenario-based | Spreadsheet (LEAP) + Optim. (SWITCH) | Backcasting |

### Features

- **Endogenous tech learning**
  - Yes/Represented
  - Limited
  - None/Not represented

- **Spatial disaggregation in CA**
  - Yes/Represented
  - Limited
  - None/Not represented

- **Vehicle stock turnover**
  - Yes/Represented
  - Limited
  - None/Not represented

- **Power plant stock turnover**
  - Yes/Represented
  - Limited
  - None/Not represented

- **Models criteria pollutants**
  - Yes/Represented
  - Limited
  - None/Not represented

- **Uses electricity dispatch model**
  - Yes/Represented
  - Limited
  - None/Not represented

- **Interactions with out-of-state**
  - Yes/Represented
  - Limited
  - None/Not represented

- **Perfect foresight to 2050?**
  - Yes/Represented
  - Limited
  - None/Not represented

### Economics

- **Measures economic welfare effects of climate policy**
  - Yes/Represented
  - Limited
  - None/Not represented

- **Ability to analyze impacts of carbon**
  - Yes/Represented
  - Limited
  - None/Not represented

### Transparency

- **Documentation**
  - Yes/Represented
  - Limited
  - None/Not represented

- **Model available online**
  - Yes/Represented
  - Limited
  - None/Not represented
Population Assumptions

BEAR – DOF (2013)

CA 2050 - U.S. Census (2005)

CA-TIMES - DOF (2013)

E-DRAM - DOF (2003)

Energy 2020 - IEPR (2009)

GHGIS - DOF (2013)

IEPR 2013 - IHS Global Insight for Mid projection

LEAP-SWITCH - AEO (2011)

VISION - AEO (2011)

WWS - U.S. Census (2009)
Business As Usual (BAU) Scenarios

- Long et al., 2011
- Williams et al., 2012
- Nelson/Wei et al., 2013
- Yang et al., 2014
- ARB Scoping Plan, 2008
- Roland-Holst, 2012
- ARB Scoping Plan, 2014

MMT CO2e/yr

Historic

80 in '50 AB32 Target

2000 2010 2020 2030 2040 2050
Reaching 80 in ‘50 Goals
Reaching 80 in ‘50 Goals
Annual vs. Cumulative Emissions?

**Annual Emissions** = Economy-wide emissions each year (e.g. all emissions in 2010)

**Cumulative Emissions** = The sum of annual emissions since the year 2010
(e.g. emissions in 2010 + emissions in 2011 +... emissions in year X)
Annual vs. Cumulative Emissions?

**Annual Emissions** = Economy-wide emissions each year (e.g. all emissions in 2010)

**Cumulative Emissions** = The sum of annual emissions since the year 2010 (e.g. emissions in 2010 + emissions in 2011 +.... emissions in year X)
• In mitigation scenarios, electricity and hydrogen provide 3-13% of Light Duty Vehicle (LDV) delivered energy in 2030 and 57-87% by 2050.

• Total transportation energy drops by as much as 70% from 2010-2050 due to increased vehicle efficiency and changes in Vehicle Miles Traveled (VMT).
Liquid Biofuels are Important but Assumptions Matter!

Delivered Bioenergy in 2050

- ~1 BGGE in 2010
- “Advanced” bio-liquids could power up to ~40% of transportation sector in 2050
- Bio-energy goes to transportation, not to electricity
- Large carbon savings from bioenergy+CCS (more modeling needed!)
Renewable fraction (non-hydro) ranges from 30-51% in 2030 and 36-96% in 2050 (non-WWS)

Total generation goes from 306 TWh in 2013 to 290-990 in 2030 and 245-1380 in 2050

Implied renewable build rate is 0.2-4.2 Gigawatts per year (GW/yr) between today and 2030 and 1.5-10.4 GW/yr between 2030-2050
Criteria Emissions

<table>
<thead>
<tr>
<th>Model</th>
<th>NOx</th>
<th>ROG</th>
<th>PM2.5</th>
<th>CO</th>
<th>SOx</th>
<th>NH3</th>
<th>PM2.5</th>
<th>O3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARB VISION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA-TIMES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHGIS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PATHWAYS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEAP-SWITCH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Coordination needed between 2023 and 2032 ambient air quality goals and long-term climate goals (and between relevant agencies)
- Need for zero and near-zero goods movement in near/mid-term (BAU scenarios do not achieve long-term NAAQS in South Coast and San Joaquin Valley Air Basins)
Key Takeaways

• Different models provide different and useful perspectives and findings
• Achieving a deep reduction in emissions of 80% below 1990 levels appears technically plausible
• Based on those “deep reduction scenarios” (i.e. 80 in 50):
  – 208-396 MMT CO2e/yr in 2030
  – 8-52% reduction in GHG by 2030 from 1990/2020 levels
  – Cumulative emissions vary by as much as 40% in 2050
  – 30-50% renewable grid by 2030
  – 38-94% renewable grid by 2050
• Electrification of end uses (e.g. transport, heat) and expansion of grid are key
  – Need to expand grid by 1.5-2.5 times its current capacity even assuming significant efficiency gains
Key Takeaways (continued)

• Need greater understanding about how to use biomass for energy and fuel
  – More modeling of bio-energy+CCS
  – More modeling of life cycle emissions and other sustainability factors
• Need to address criteria emissions and other non-energy related GHG emissions (e.g. BAU scenarios have non-energy GHG emissions >2050 target)
• Need for better modeling of explicit policies and technologies (within California and beyond)

• **Data availability and data/model transparency is essential**

• Coordination across agencies (and with other jurisdictions) is key
Contact Information

Anthony R. Eggert
Director UC Davis Policy Institute
areggert@ucdavis.edu

Sonia Yeh
Senior Research Scientist
Institute for Transportation Studies
slyeh@ucdavis.edu

Geoff Morrison
Postdoc Researcher
Institute for Transportation Studies
gmorrison@ucdavis.edu

Please see our CCPM summary document and forthcoming white paper here: http://policyinstitute.ucdavis.edu/initiatives/ccpm/
Thank you!
Extra slides (not for printing)
Emission targets in developed world

- US (Copenhagen Accord) – **33%** below 1990 levels by 2030
- Euro Union – **40%** below 1990 levels by 2030 (under negotiation)
- Denmark – **40%** below 1990 levels by 2030
- Netherlands, UK – **50%** between 2022-2027
- Germany – **55%** below 1990 by 2030
- Scotland – **42%** below 1990/5 levels by 2020 and **80%** by 2050
  - Expects to make **60%** reduction target in 2030
Coordination is Key in Meeting 2030 and 2050 Goals

• Between state agencies and with other state goals:
  – Air quality targets for San Joaquin and South Coast regions
  – Water use/quality
  – Health goals
• Between Western states:
  – WECC targets need to be aligned to avoid leakage, expand market for low-carbon technology, provide least cost mitigation measures
• Between modelers and policy makers
Observations from forum

- Models built to examine pathways to 2050 ➔ not specifically focused on maximizing climate benefits by 2030 (except GHGIS)
- Many models limited in ability to consider economic feedback and benefits/costs of policy options
- Limited representation of uncertainty
- Criteria emissions only included in small number of models (and not part of the optimization process)
- Modelers need to work with policy makers more closely to represent the details of the policy design
- Data availability and data/model transparency is absolutely essential.
Income Assumptions

*Some models adjusted from nominal to real growth rates.  
** Some models use personal income while other use GDP

CA 1980-2010 - Personal income (BEA, 2013)

CA 1997-2010 - GDP (BEA, 2013)

CA 2010-2015 – Personal income (DOF, 2013)

E-DRAM - Personal income (DOF, 2003)

CA 2050 - GDP (BEA, 2009) + Regressions

Energy 2020 - Personal income (IEPR, 2009)

BEAR – Per capita GDP (AEO, 2011)

GHGIS - Personal income (from VISION/IEPR, 2013)

VISION - Personal income (AEO, 2011)

IEPR 2013 - Personal income (IHS 2013; Moody's, 2011)
Why Do Inter-Model Comparisons?

- Sweeney, 1983
  - Model comparisons benefit the modeling community “through identification of errors, clarification of disagreements, and guidance for model selection”

- Weyant, 2012
  - Understand Strength/weaknesses of existing methodologies
  - Identify high priority areas for development of new data, analyses, and modeling methodologies

- Two levels of model comparisons:
  - Level 1: compare & contrast inputs & outputs (e.g. review article)
  - Level 2: standardize inputs, compare outputs (SRES, SSPs)