UCDAVIS

SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

An Institute of Transportation Studies Program

Modeling Low-Carbon Transitions in California Using an Economy-Wide Energy-Economic-Environment Model

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Why Modeling?

- **California faces significant challenges to meet its 2050 climate goal and requires roadmaps to guide its policies.**
- **"Energy paradox": recognize that market-based instrument may be inefficient and ineffective in addressing end-use energy efficiency and demands.**
- **The purpose of the modeling exercise is not to *predict* the future, but to *understand* LEAST-COST TECHNOLOGY MIX assume perfect decision making and perfect market and to derive policy lessons.**
- **Transport sector presents the most significant challenge in meeting the climate and energy goals .**

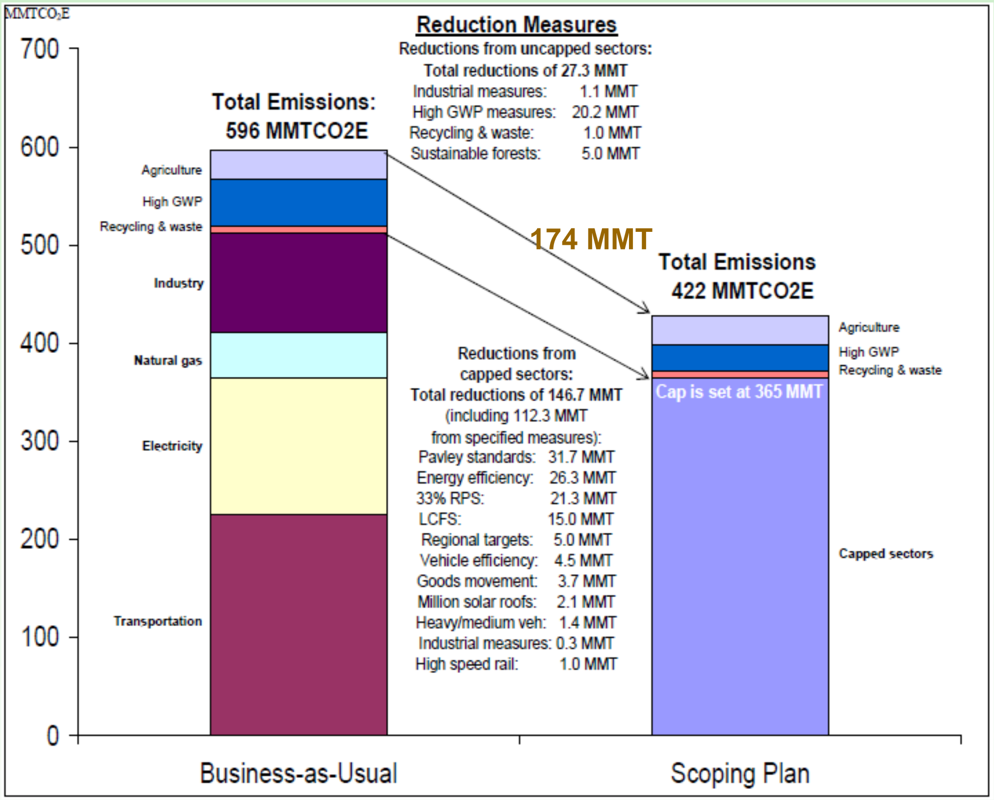
Modeling Questions that We'd Like to Explore in Low-Carbon Scenarios

- Technology Assessment
  - Analysis of competitiveness of technologies (e.g. electricity generation, future advanced vehicle technologies) or energy chains under different economic assumptions and market barrier removal
- Resource/Energy Use and Price Changes
  - Future energy demand affected by supply, demand and policies
- Environmental Policy Analysis
  - Effects of emission taxes, emission cap-and-trade systems, emission intensity standards, RFS, RPS, and technology forcing regulations in affecting technology adoptions, demand, and energy costs?
  - Potential leakage effects outside of the regulated region/sector(s)
  - Incentives mechanisms, such as Investment subsidies, that can overcome market barrier
- Economic Impacts
  - Changes in energy-related GDP, investment costs, etc.
- Alternative Decision Making
  - Decision making under uncertainties: Perfect foreseight v.s. limited foresight; hedging, stochastic uncertainty analysis
  - Endogenous technological learning, learning clusters, R&D and spillover

California GHG Emissions Goals and Mitigation Measures

- **1990 level by 2020, and 80% GHG reduction from 1990 level by 2050**

CA 2020 Scoping Plan



CARB 2009 Scoping Plan

- Cap-and-trade (23%)
- Energy efficiency (18%)
- 33% RPS (15%)
- Vehicle efficiency (25%)
- Low Carbon Fuel Standard (10%)
- Trucks, vehicles, rails , and goods movement (6%)

- **2020-2050 ???**

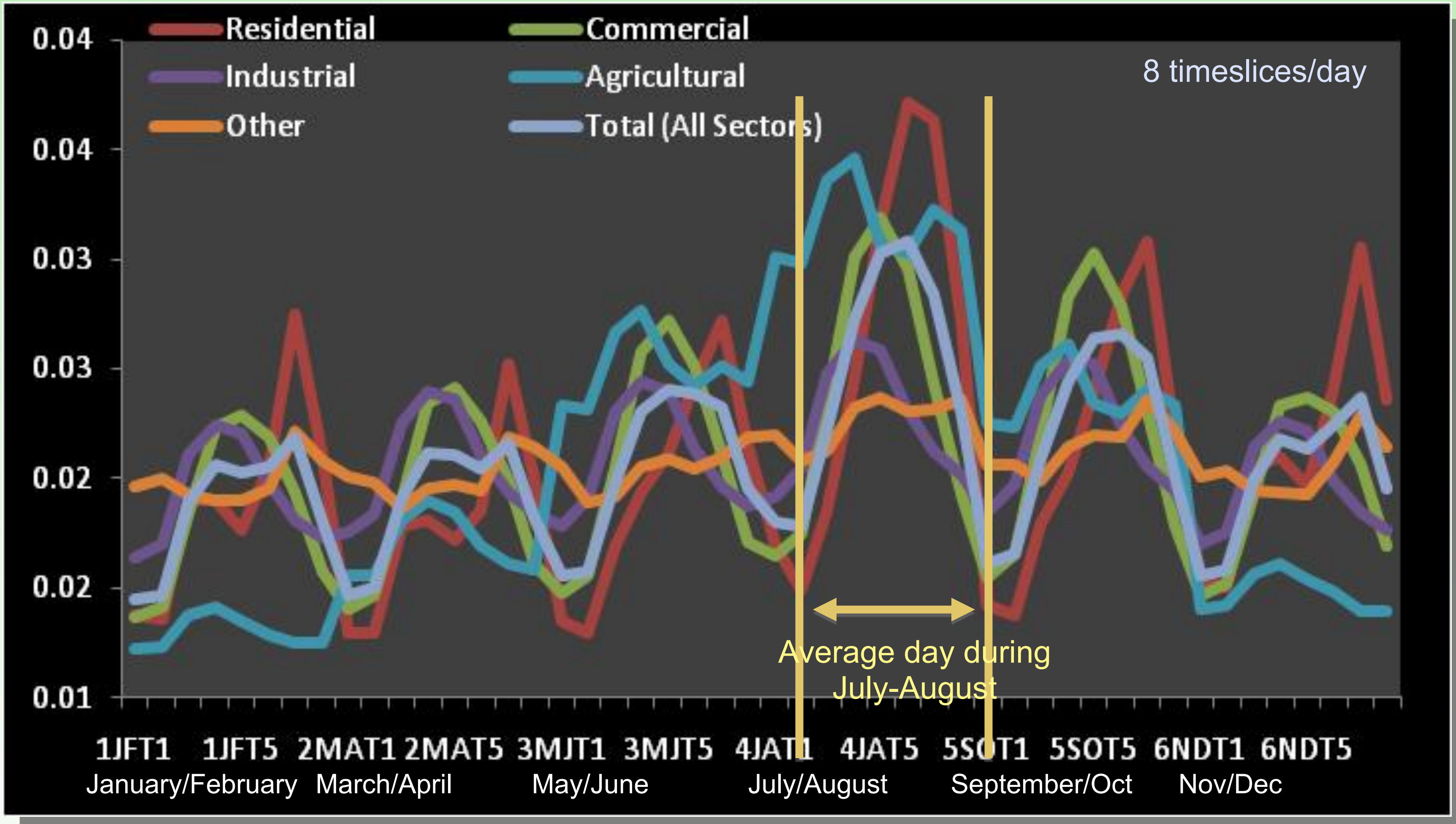
The CA-TIMES Model

- **CA-TIMES (The Integrated MARKAL-EFOM1 System) model is an Energy–Economy–Engineering–Environment (4E) model for the California energy system.**
- **Funded by the California Air Resources Board (2010 - 2012)**
- **Improvement over current statewide energy modeling tools for CA**
- **Model covers <u>all sectors</u> of the <u>California</u> energy system (not Rest of World)**
  - **Primary energy resource extraction, imports/exports, electricity production, fuel conversion (e.g., refineries), and the residential, commercial, industrial, transportation, and agricultural end-use sectors**
- **The model is a set of MS Excel data files that fully describes the underlying energy system (technologies, commodities, resources and demands for energy services).**
  - **MARKAL and TIMES are model "shells". We tailor the model to CA – thus, data driven.**
- **Rich in "bottom-up" technological detail – describes in detail technology operation, efficiency, availability, fuel production/demand, retrofit, and retirement in flexible time slices.**
  - **Hundreds to thousands of technologies and commodities**
- **Depicts production, trade, transformation and use of energy and materials, and associated emissions, as a Reference Energy System (RES) network.**
- **Identifies most cost-effective pattern of resource use and technology deployment over time under various technological, behavioral, resource, and policy constraints.**

California-TIMES Model: Policies Represented

- **Reference Case**
  - Taxes on transportation fuels (gasoline, diesel, jet fuel,…)
  - Misc. electricity charges and fees (by end-use sector)
  - Biofuel subsidies (ethanol, biodiesel)
  - Biofuel import tariffs (sugarcane ethanol)
  - CAFE (light-duty vehicle efficiency) standards (EPA-NHTSA harmonized stds. to 2016)
  - Electric vehicle subsidies (BEVs, PHEVs)
  - GHG perform. stds. for elec. gen. ("no new coal" in CA)
  - Renewable Portfolio Standard (33% by 2020)
  - Renewable elec. production and investment tax credits
  - Renewable Fuels Standard (biofuels mandates)
- **Deep GHG Reduction Scenario**
  - All the same policies as in the Reference Case + …
  - Economy-wide GHG emissions caps
    - Bring emissions back down to 1990 levels by 2020
    - 80% reduction below 1990 levels by 2050
  - Increasingly stringent light-duty vehicle GHG emissions standards from 2017 to 2025
  - Energy efficiency standards for Ind, Com, Res, and Ag end-use sector techs.

California Electricity Demand by Timeslice



- **Residential has the most "peaky" time slices in summer early afternoons**

Electricity Demand, Wind and Solar Availability in California by Timeslice

Total ELC Demand (share of year)

		T1 0:00 => 3:00	T2 3:00 => 6:00	T3 6:00 => 9:00	T4 9:00 => 12:00	T5 12:00 => 15:00	T6 15:00 => 18:00	T7 18:00 => 21:00	T8 21:00 => 24:00
JF	January/February	1.4%	1.5%	1.9%	2.1%	2.0%	2.1%	2.2%	1.8%
MA	March/April	1.5%	1.5%	1.9%	2.1%	2.1%	2.0%	2.2%	1.8%
MJ	May/June	1.6%	1.6%	2.0%	2.3%	2.4%	2.4%	2.3%	2.0%
JA	July/August	1.8%	1.8%	2.2%	2.7%	3.0%	3.1%	2.8%	2.3%
SO	September/October	1.6%	1.7%	2.1%	2.4%	2.6%	2.7%	2.5%	2.0%
ND	November/December	1.6%	1.6%	2.0%	2.2%	2.1%	2.2%	2.4%	2.0%

Wind Speeds (m/s)

		T1	T2	T3	T4	T5	T6	T7	T8
JF	January/February	5.3	5.2	5.0	4.9	5.2	5.1	5.2	5.4
MA	March/April	8.9	8.4	7.4	6.7	7.3	8.4	9.3	9.3
MJ	May/June	10.5	9.7	8.5	7.7	8.2	9.6	10.7	10.7
JA	July/August	9.9	8.6	7.1	5.9	6.9	8.9	10.9	11.0
SO	September/October	6.9	6.3	5.6	4.9	5.5	6.1	6.6	7.2
ND	November/December	5.9	5.7	5.1	4.9	5.5	5.6	6.1	6.1

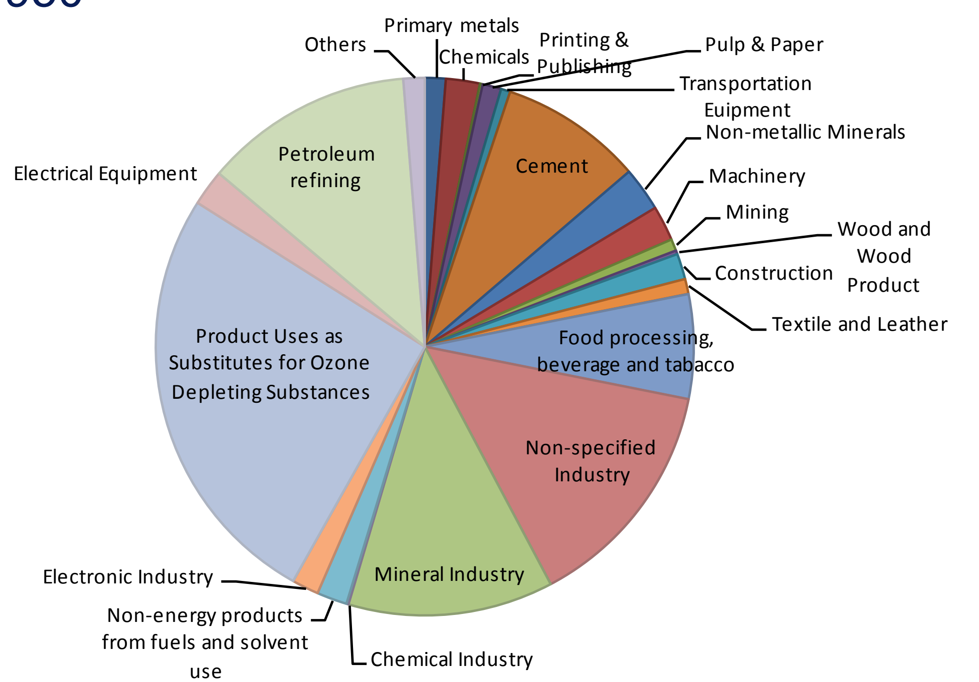
Solar Insolation (W/m^2)

		T1	T2	T3	T4	T5	T6	T7	T8
JF	January/February	0.0	0.0	315.9	668.6	609.8	246.7	0.0	0.0
MA	March/April	0.0	23.7	536.8	723.5	693.5	422.8	0.0	0.0
MJ	May/June	0.0	118.4	680.0	791.0	781.3	583.3	50.0	0.0
JA	July/August	0.0	80.0	619.9	785.6	755.2	535.8	39.2	0.0
SO	September/October	0.0	11.2	549.1	756.5	714.7	352.3	0.0	0.0
ND	November/December	0.0	0.0	377.4	767.1	723.6	234.3	0.0	0.0

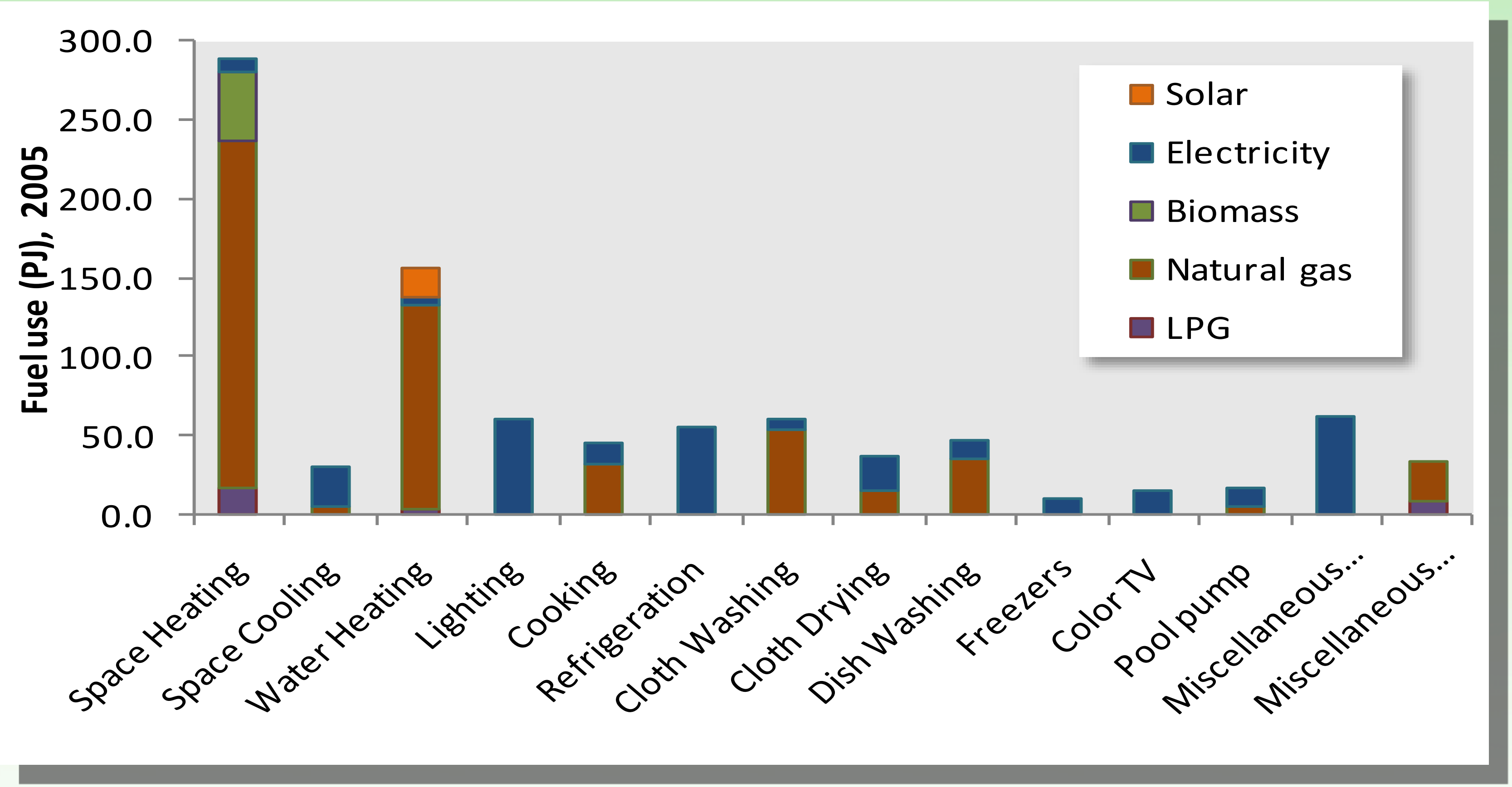
Source: McCarthy and Yang, 2009, University of California, Davis

California Industrial Sector

- Consumed 25% of the state’s total energy input in 2005.
- Major energy inputs.
  - **Natural gas** use continue to increase, and accounts for 36.5% of the state’s end-use natural gas demand in 2005.
  - Industrial sector accounts for over 20% o the state’s **electricity** consumption in 2005, and generates its own electricity through CHP.
  - **Petroleum** is used for direct fuel combustion, and over half is consumed as feedstock in petroleum refining and chemical manufacturing.
  - Largest user of **renewable** fuels, particularly in the forest product industry.
  - **Coal** use has declined since 1950

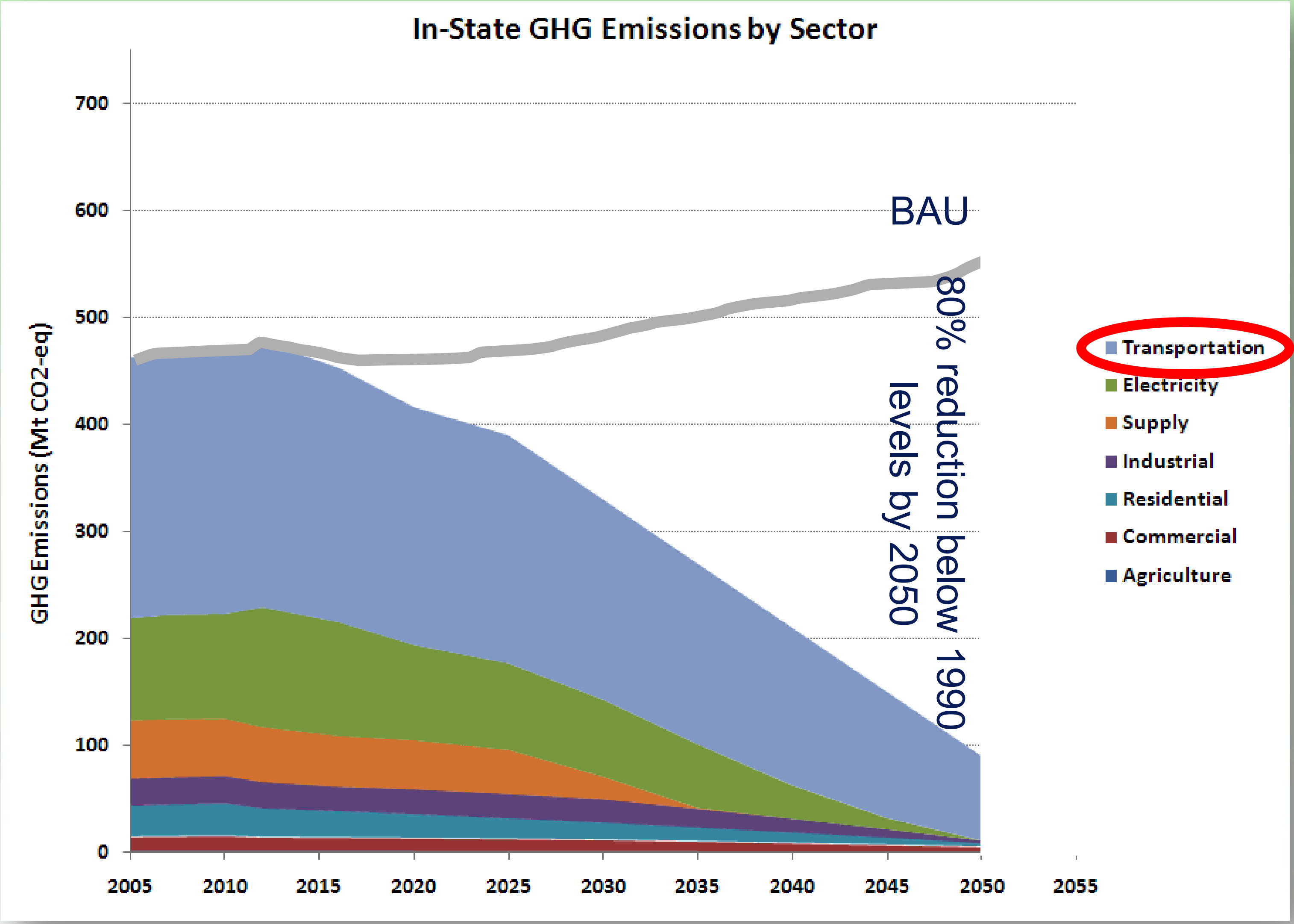


California Residential End Use by Fuel Type, 2005



- **56% natural gas, 33% electricity, 5% wood**

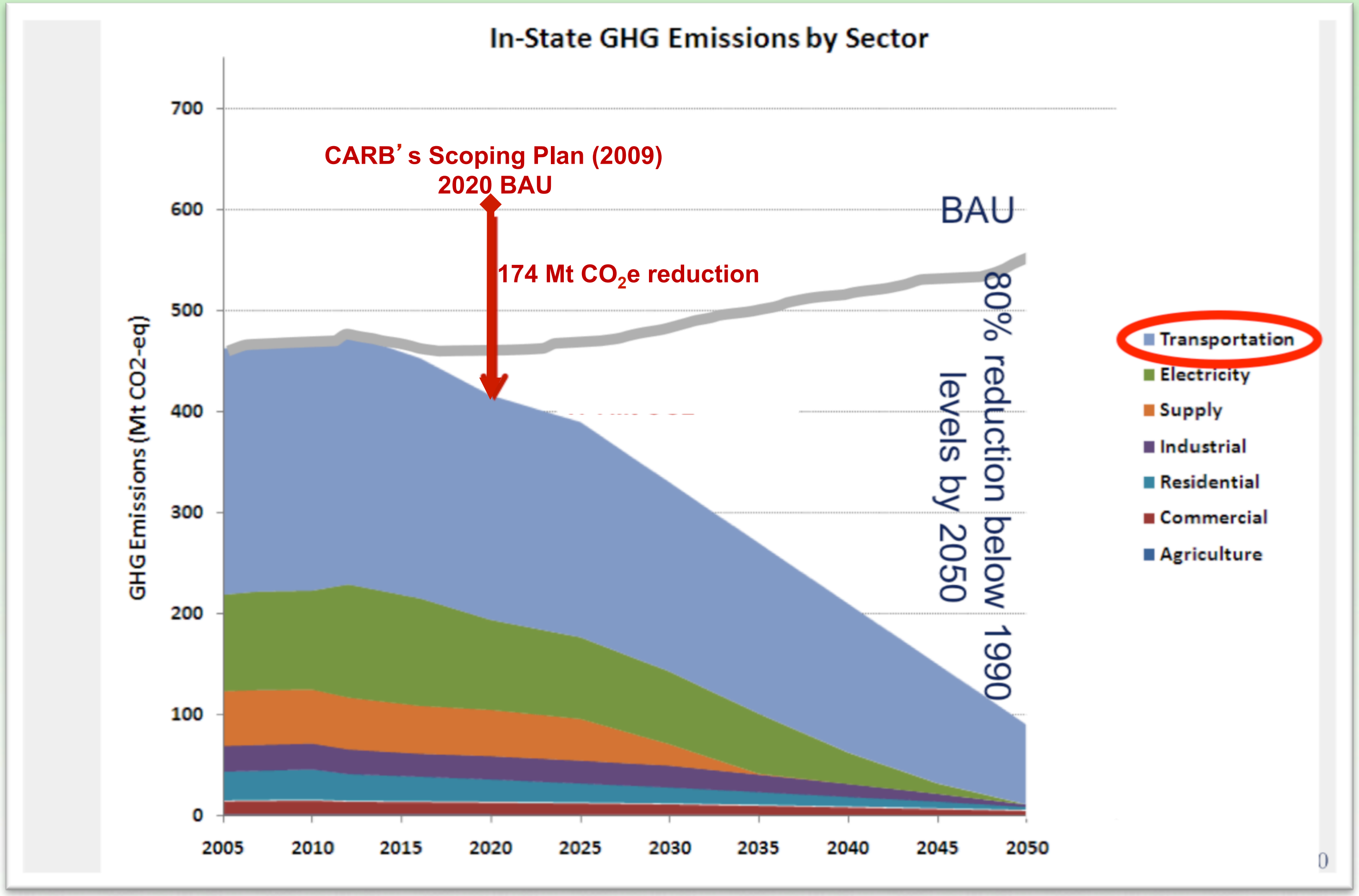
Least-Cost Emission Path to Meet California's Global Warming Solutions Act (AB32)



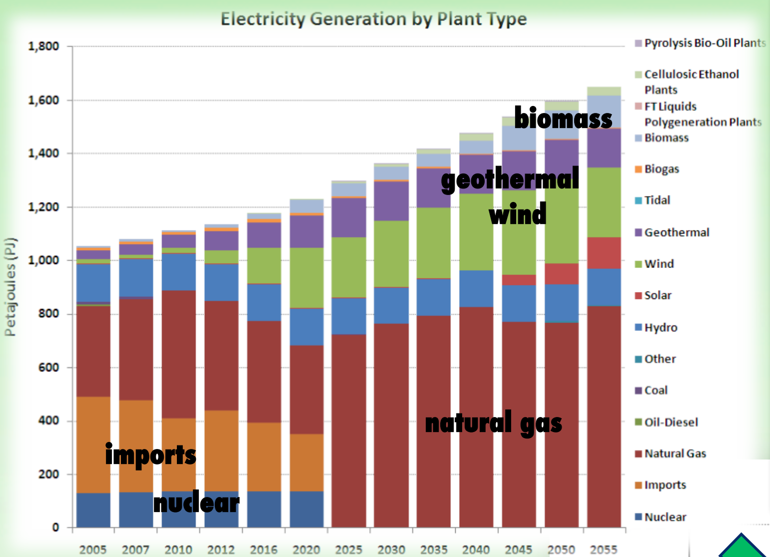
* McCollum, David L. (2011) Achieving Long-term Energy, Transport and Climate Objectives: Multi-dimensional Scenario Analysis and Modeling within a Systems Level Framework. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-11-02

A New BAU is Already Underway to Meet Our 2020 Target

- **Our BAU are lower than CARB's BAU in the Scoping Plan for two reasons:**
  - **lower economic growth**
  - **Implementation of *some* of the mitigation measures, e.g. RPS, CAFE, etc**

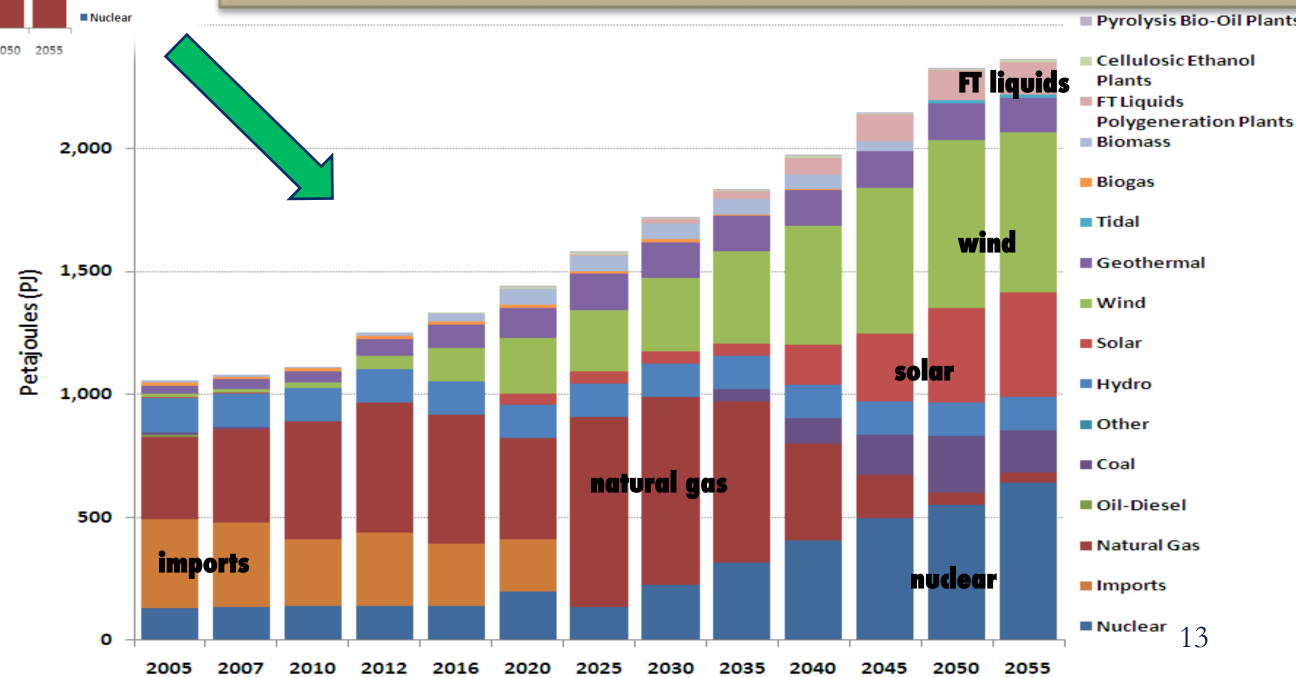


Electricity Generation in the Reference and Deep GHG Reduction Cases

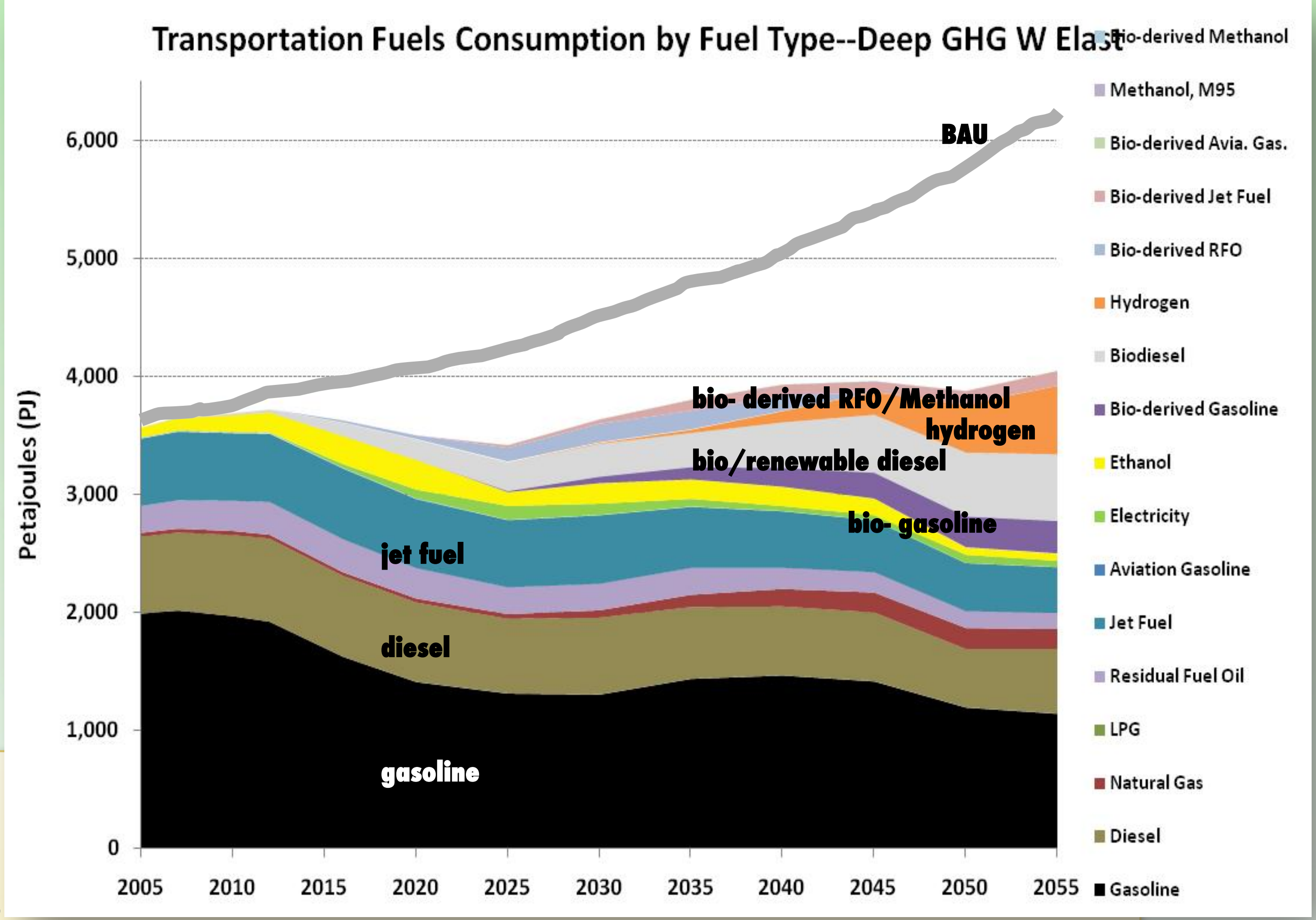


Impacts of Stringent Climate Policy

- Increased electricity demands in the various end-use sectors.
- Natural gas generation is squeezed out in the long term.
- Renewables grow considerably, particularly wind and solar thermal from out-of-state resources.
- Coal IGCC w/ CCS achieves considerable market share.

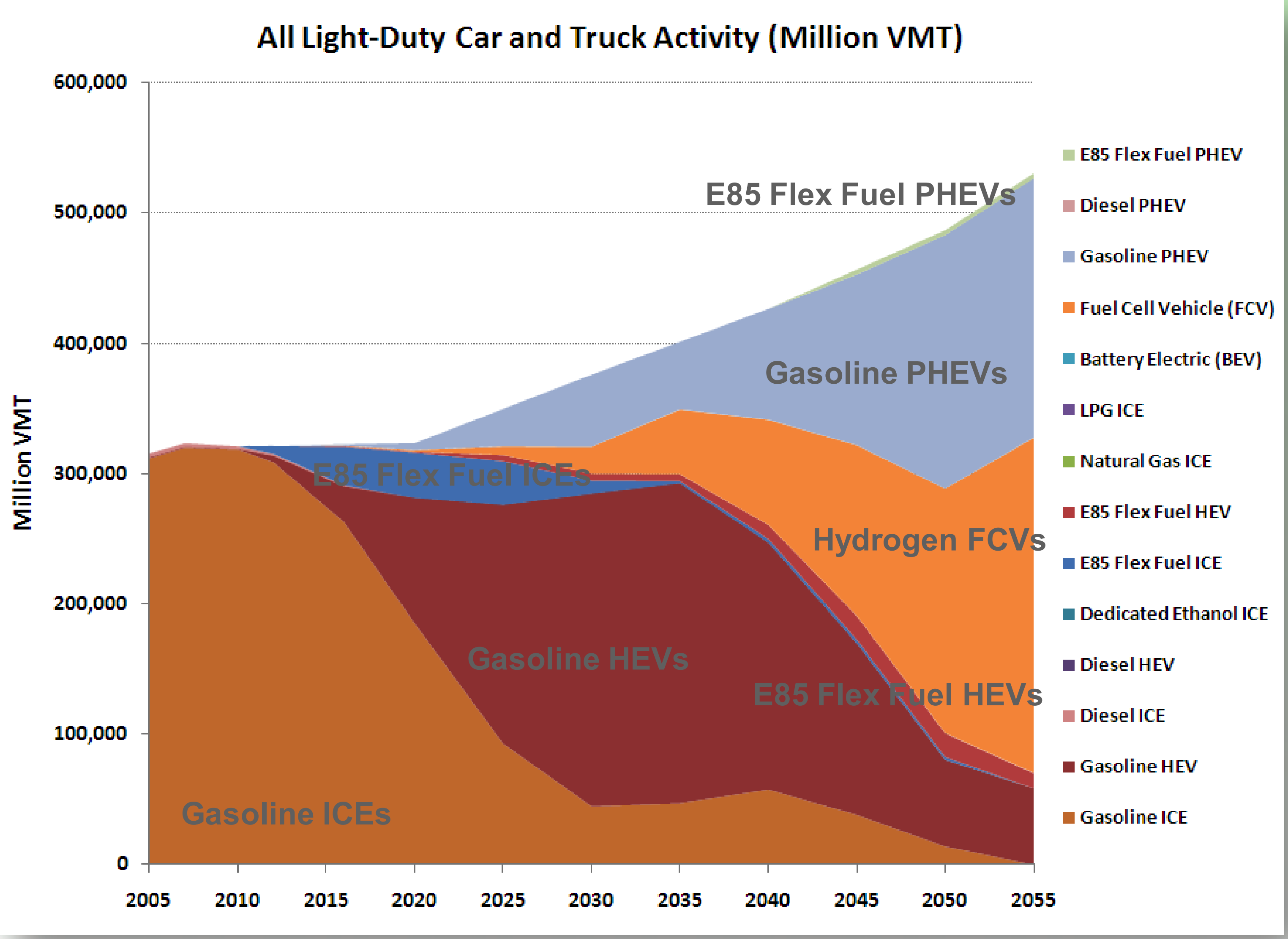


Transportation Fuel Use in the Deep GHG Reduction Cases



- With elastic demand
  - Fuel use -35%
  - LDV efficiency +70%
  - VMT ~0% (4% in 2050): low elasticity and rebound
- Consumption of conventional fossil-based fuels significantly declines.
- Bio-derived diesel, gasoline, jet fuel, and RFO significantly expand.
- Hydrogen also gains significant market share.

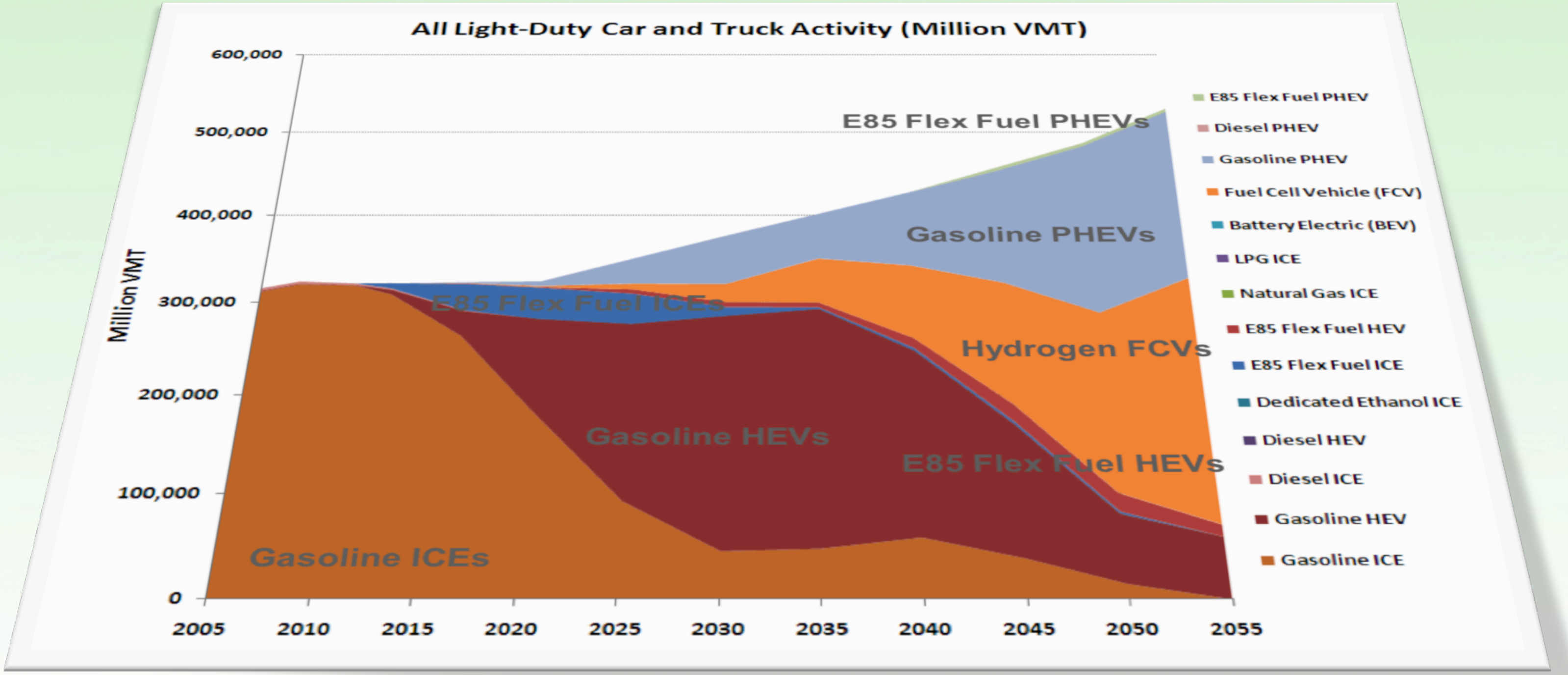
LDV Technologies in the Deep GHG Reduction Scenario



Additional notes on Transportation Scenarios

- **Meeting the transport energy and GHG goals requires highly coordinated efforts between three transportation wedges: efficiency, low-C fuels, and advanced vehicle technology.**

Yeh, Sonia, Alex Farrell, Richard Plevin, Alan Sanstad, and John Weyant. 2008. Optimizing U.S. Mitigation Strategies for the Light-Duty Transportation Sector: What We Learn from a Bottom-Up Model. *Environmental Science & Technology 42 (22):8202–8210.10.1021/es8005805*



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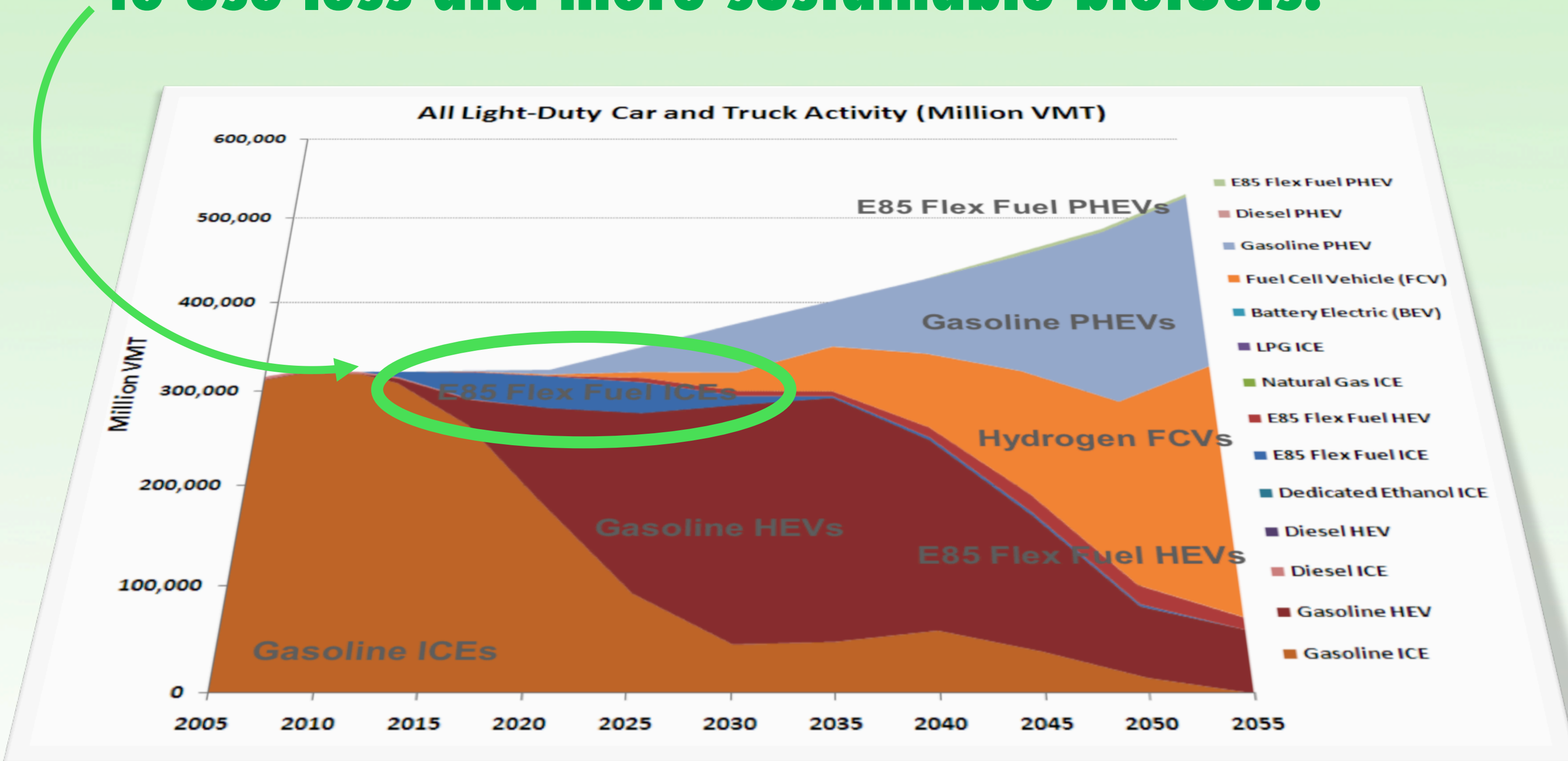

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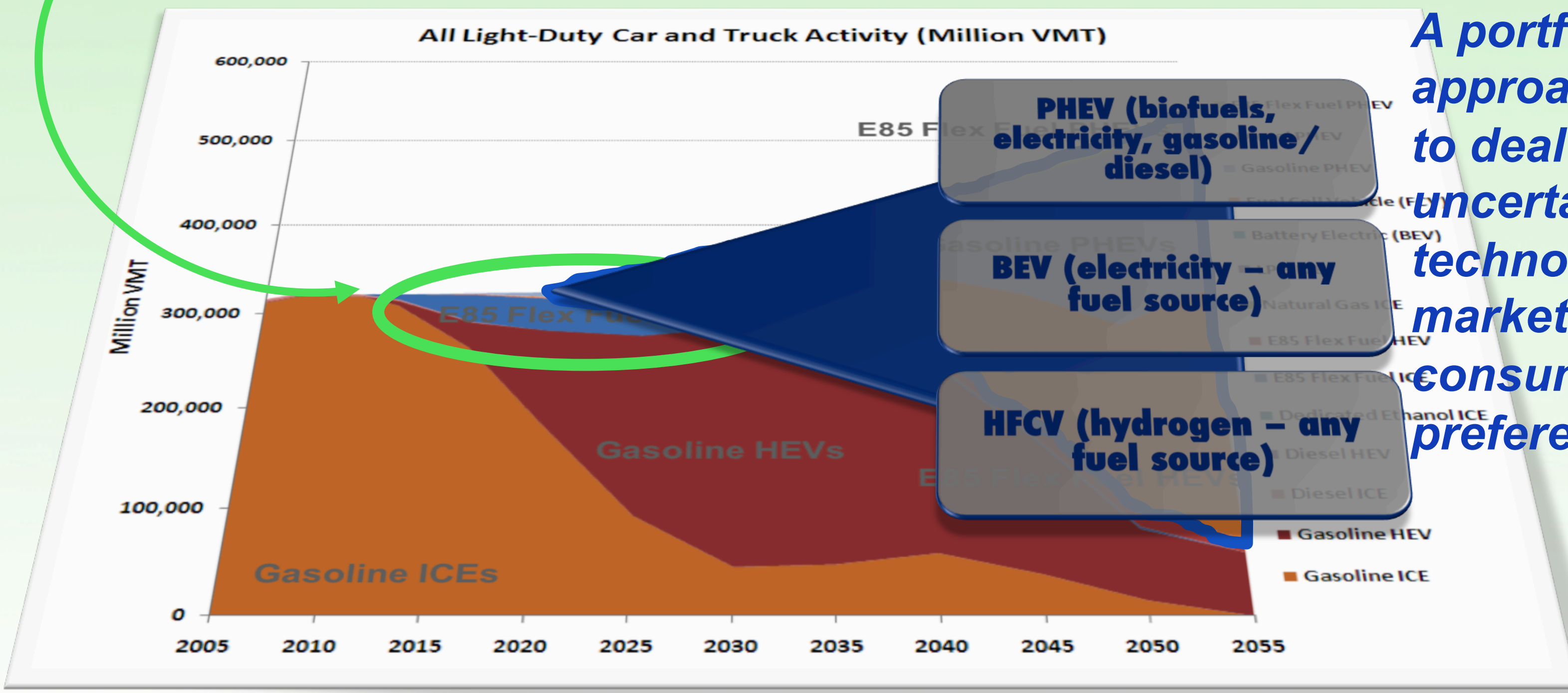
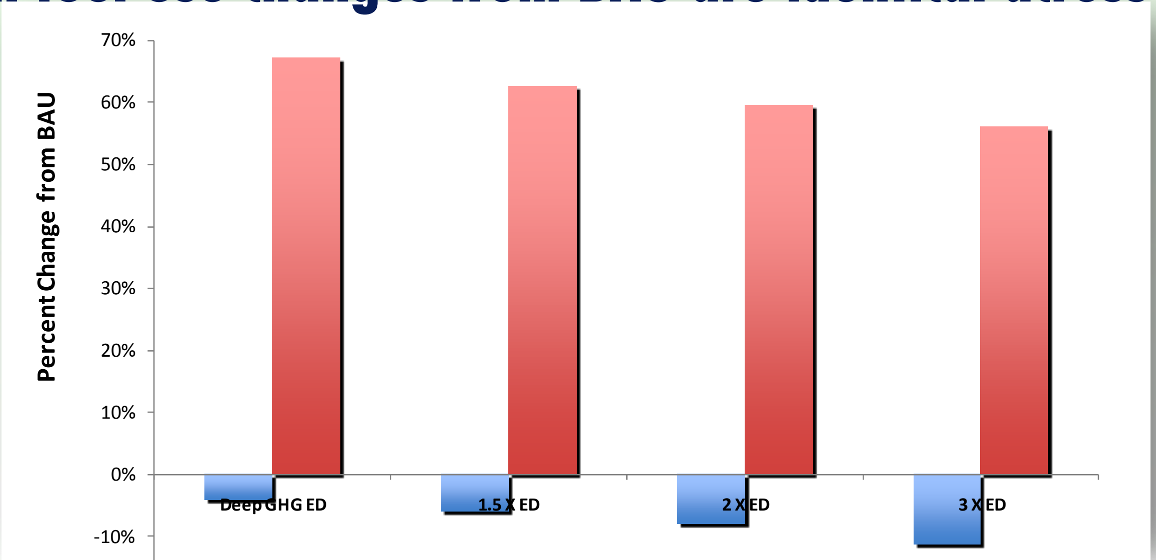


A portfolio approach is needed to deal with uncertainties in technology costs, market barriers and consumers' preferences

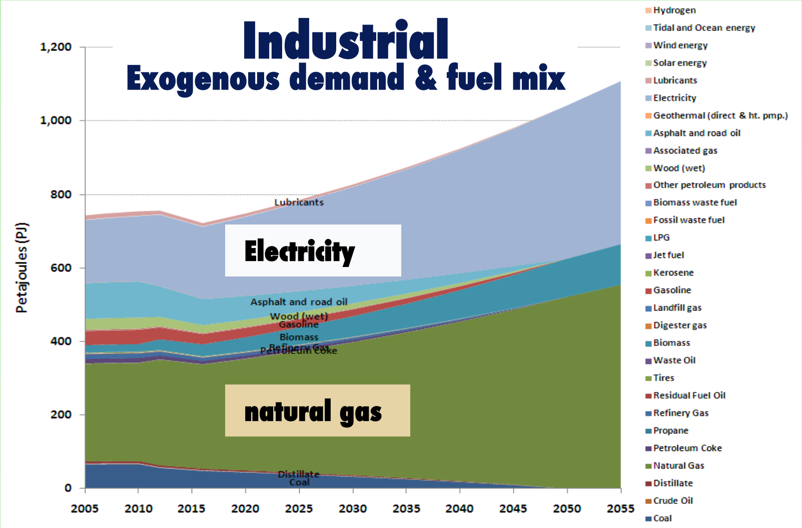
Tradeoffs between Travel Demand Reduction and Improvement in Vehicle Efficiency

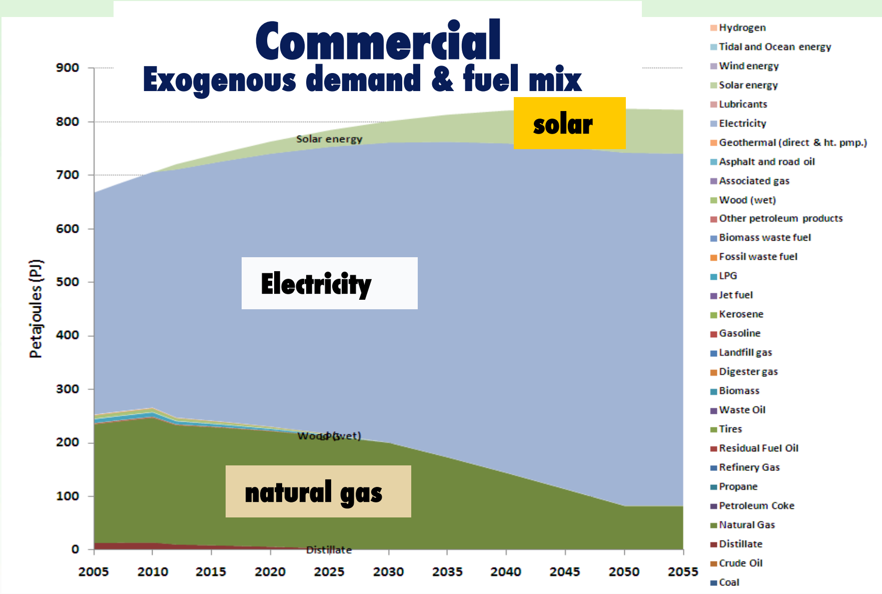
- **Interactions between mitigation wedges: VMT reduction and vehicle efficiency**
  - **Higher price response (higher ED) leads to lower improvement in vehicle efficiency**
    - **Requires less improvements to meet the GHG constraint**
    - **(relatively) cheaper to reduce VMT than to improve vehicle efficiency**
    - **Payback period becomes longer due to lower VMT**
  - **Total fuel use changes from BAU are identical across scenarios**

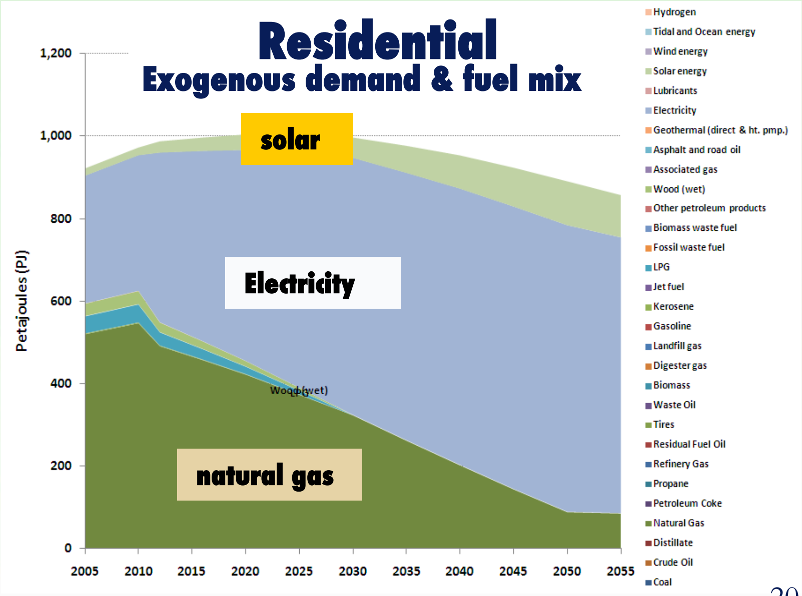


California End Use Demands by Sector in 80% Deep GHG Reduction Scenario

- Based on previous studies, current model version exogenously assume:
  - Increasing electrification of the end uses
  - Increasing use of natural gas in the industrial sector
  - Greater efficiency improvement
  - Moderate demand reduction







Apply MARKAL/TIMES Tool to Create Visions for Sustainable Low-Carbon Future

- Develop a portfolio of scenarios to explore how to make the transition to a low-carbon future specifically focusing on 2020-2050
- Better understand the best use of resources (e.g. biomass, renewable energy) across power and heat generation and modes of transportation (light-duty vehicles, heavy-duty vehicles, transit, freight, ships and aviation)
- Transportation
  - Electric vehicle time-of-day charging
  - Modal switching (e.g., from cars to mass transit)
  - Combine urban planning and VMT with supply side modeling to look at low VMT/low Carbon futures
  - Investment needs for Infrastructure:
    - Improve spatial modeling and identify Investment needs for Infrastructure
- Examine other sustainability constraints, e.g. materials, water, land
- Design and refine policy instruments for fuels, vehicles, VMT/LU, and energy efficiency

More Work is Needed to Improve Transportation End Use Modeling

- **Modal shift of transportation demands**
  - **VMT reduction in response to high fuel prices needs/ should be transformed into other travel demands (e.g. bus) or residential electricity demands**
    - **Cross-price elasticity?**
- **Urban planning and VMT reduction**
  - **Use a supply curve to represent costs of land use planning for VMT reduction?**

Conclusions

- (Economic) modeling effort is needed to help California better understand how to achieve 80% reduction goals by 2050.
  - Electric sector needs to be almost decarbonized to meet the electricity demand from all end-use sectors
  - Industrial sector will still rely on some natural gas
  - Transport sector expands the use of bio-derived diesel, gasoline, jet fuel, and RFO, as well as electricity and hydrogen.
- Need to improve the modeling of end-use sectors
  - Better understand consumer's decisions in making technology choices
  - Policy incentives needed **to encourage consumers to adopt low-C technology**