Energy and Environmental Economics, Inc.

Meeting California's Long-term Greenhouse Gas Reduction Goals

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Study Overview

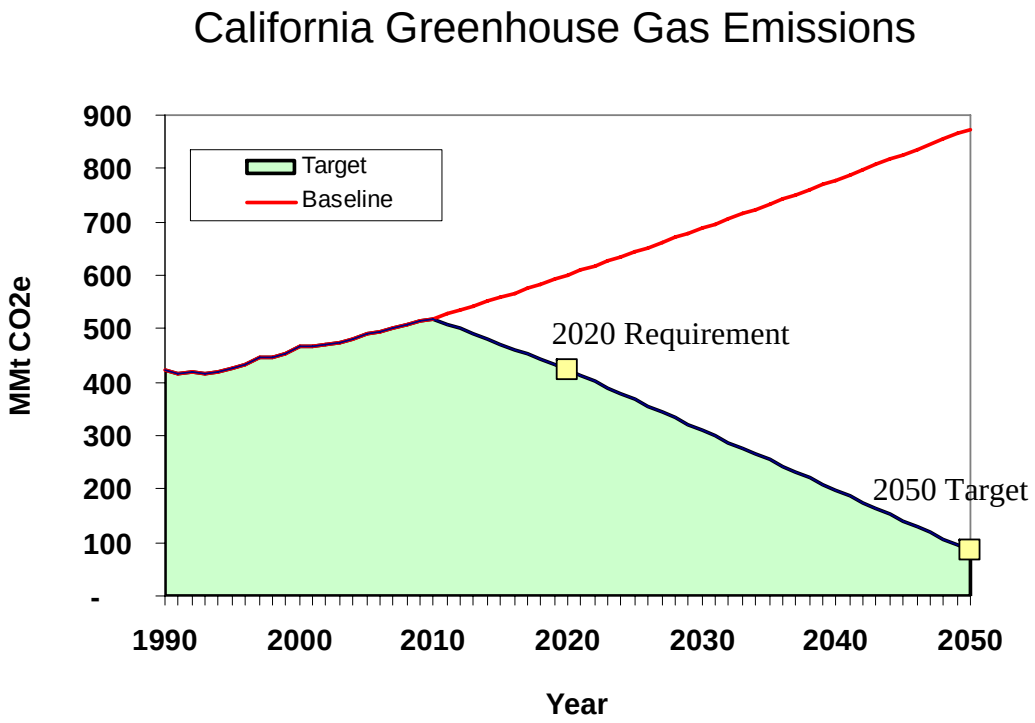
- Key question
  - What does California need to do to meet the 2050 GHG reduction goal?
  - Current California analyses focus on AB32 2020 goal
- Infrastructure modeling approach
  - Bottom-up, multi-sector, stock roll-over model
  - Integrated electricity grid dispatch algorithms
  - Calibrated to CA projections of population, GSP and AB32 Scoping Plan
- Independent study sponsored by Hydrogen Energy International (HEI)
  - HEI is seeking to develop a hydrogen-powered electricity generation facility with carbon capture and sequestration (CCS) in California

California Climate Policy Goals

- 2020 Goal set by Assembly Bill 32
  - Reduce statewide GHGs to 1990 levels by 2020
- 2050 Target set by Executive Order S-3-05
  - Reduce statewide GHGs 80% below 1990 levels by 2050

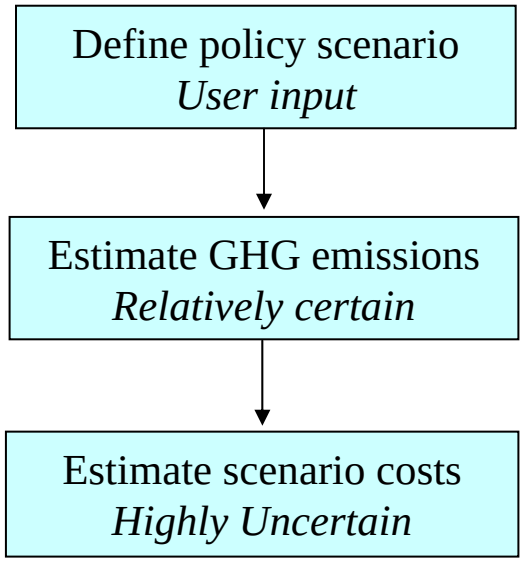
Baseline and Compliant Scenarios

- ‘Baseline’
  - Business-as-usual GHG projection
- ‘2050 Compliant’ Scenarios
  - High Renewables
  - High Nuclear
  - High CCS
  - Balanced



Modeling Overview

- Analysis Method

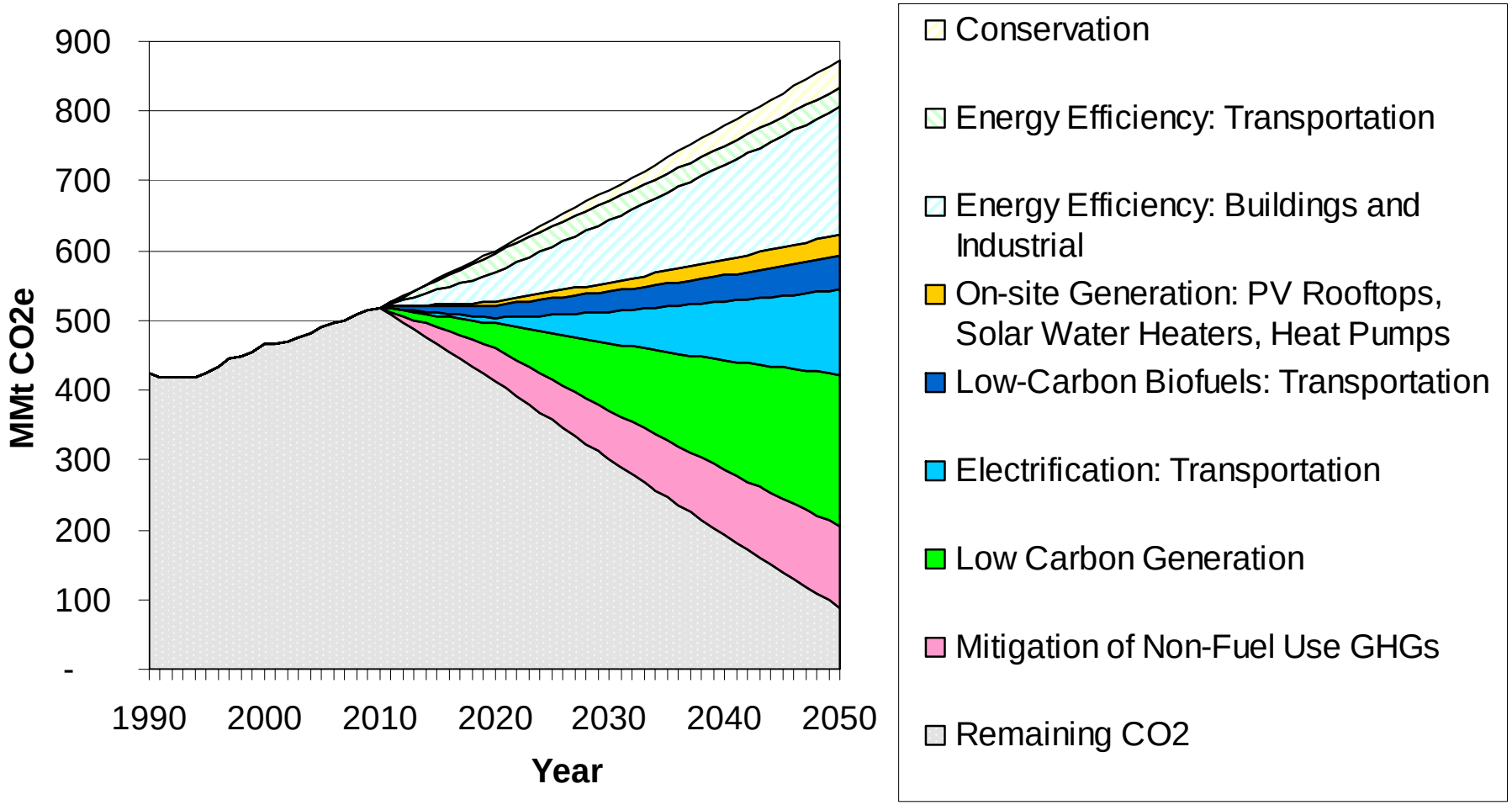


- Modeling Approach
  - Physical model of California infrastructure by sector (homes, commercial space, cars, trains, etc.)
  - Includes generation dispatch simulation to check grid operability
  - Inputs determine the built infrastructure which drives CO2 emissions and cost
  - Does not predict pathways based on assumed prices and economic behavior like an equilibrium model

Five Keys to Achieving 2050 Goal

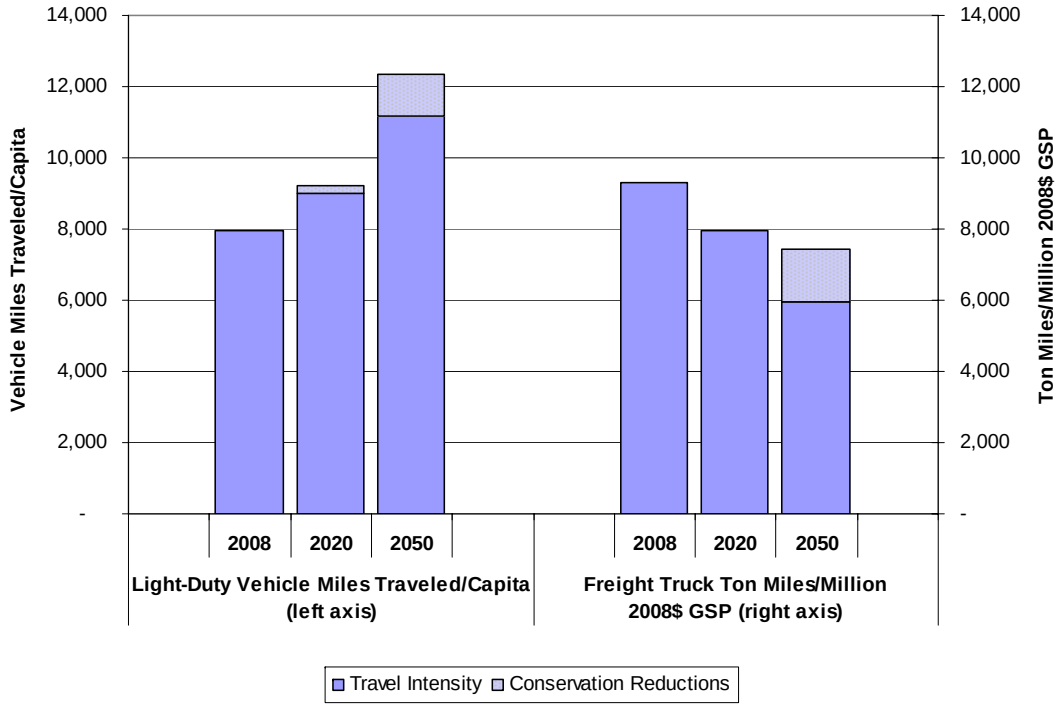
1. Conservation
   - "Smart growth" - homes are closer to jobs & people drive less
2. Energy efficiency & on-site generation
   - Efficiency increases the feasibility of meeting electricity and fuel demands with low-carbon energy
   - Efficiency is essential to keep costs from prohibitive levels
3. Electrification & low-carbon generation
   - All 2050 compliant scenarios require high electrification using low-carbon generation sources
4. Low-carbon bio-fuels
   - Biofuels become a premium fuel for those uses that are not readily electrifiable, particularly Heavy Duty Vehicles
5. Mitigation of non-fuel use GHGs (methane, refrigerant gases, etc.)

How do we get there?



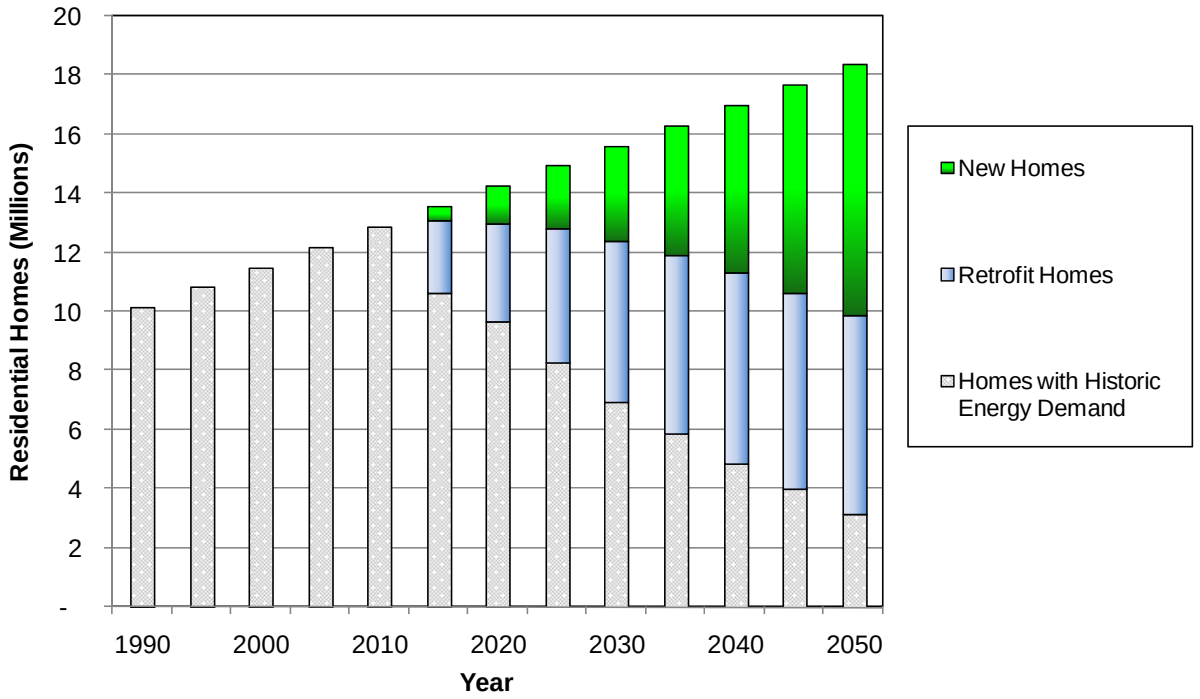
Conservation

- 10% reduction in business-as-usual vehicle miles traveled and freight truck ton miles traveled by 2050
- Similar assumptions in airplane transportation and other transportation sectors



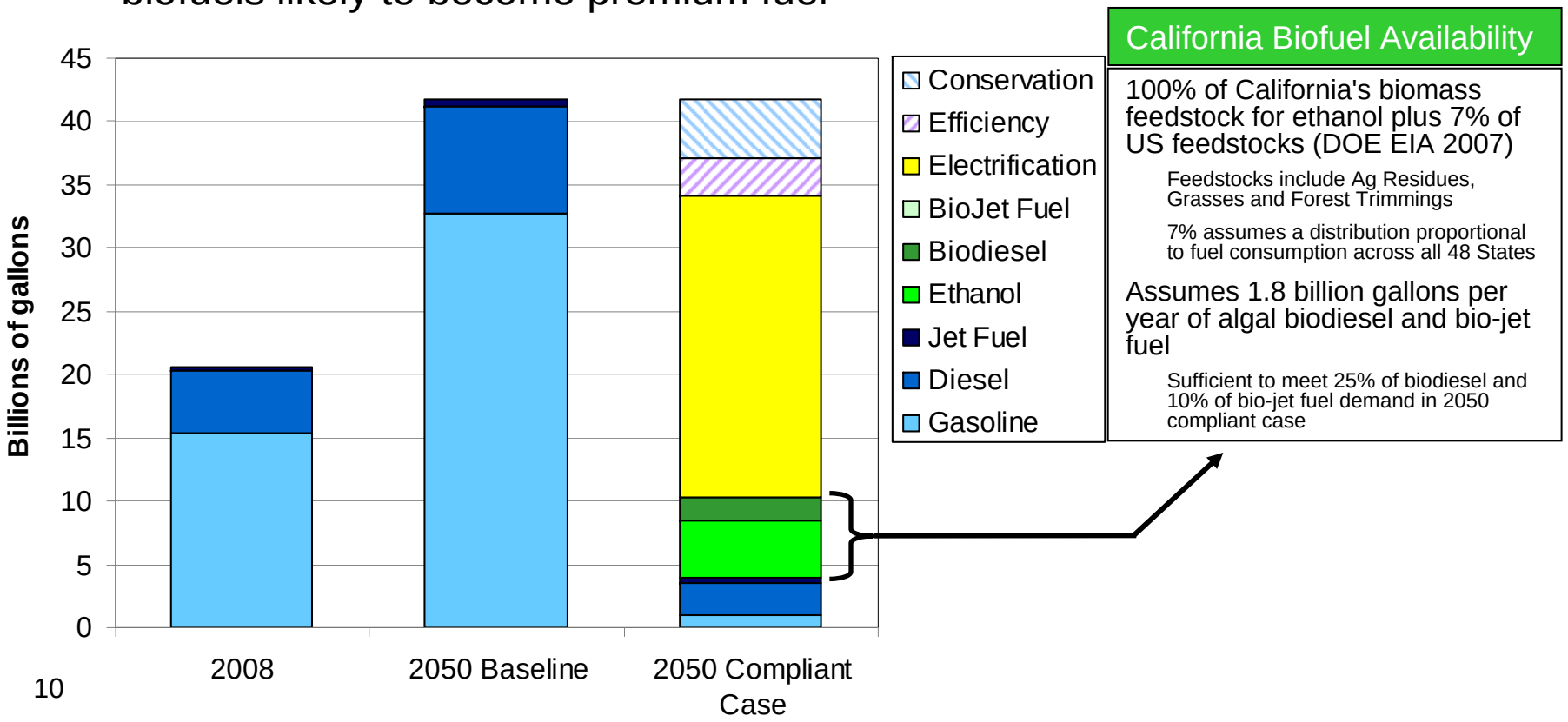
Energy Efficiency & On-Site Generation

- Transition to zero net energy homes by 2020
- Retrofits reduce consumption in existing homes
- Similar levels of effort in commercial sector buildings



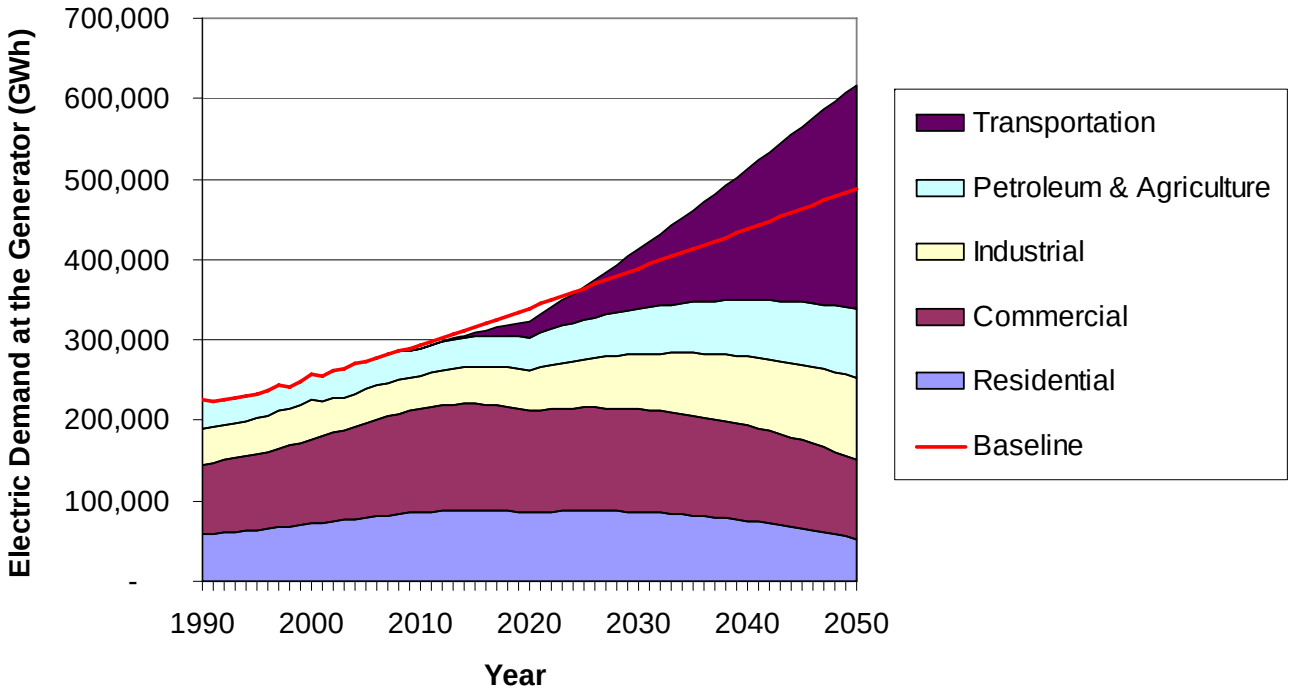
Low-Carbon Biofuels

- Eliminate consumption of gasoline by 2050 replacing it with some mix of low-carbon electricity and low-carbon fuels
- Aggressive biofuel assumptions don't meet all transportation energy needs – biofuels likely to become premium fuel



Electrification & Low-Carbon Generation

- Electricity demand could nearly double between today and 2050
- Increase in demand driven by electric vehicles
- Nearly all electricity must be from low-carbon generation by 2050



2050 Generation Mix by Scenario

- Low carbon electricity requires large investments and sustained commitment
  - Every case adds the equivalent of one new, large (2,000 MW) power plant every 2 years to 2050, renewables require higher build-out due to lower capacity factors
  - Roughly doubles transmission circuit miles in California

Share of electric generation and storage

2050 Compliant Case	*Renewable Energy*	*Nuclear Energy*	*Generation w/ CCS*	*Other*	*Energy Storage*
High Renewable	74%	6%	0%	20%	12,000 MW
High Nuclear	35%	55%	0%	10%	4,000 MW
High CCS	36%	7%	47%	10%	8,000 MW
Balanced	34%	19%	39%	8%	6,000 MW

Electricity Sector Findings

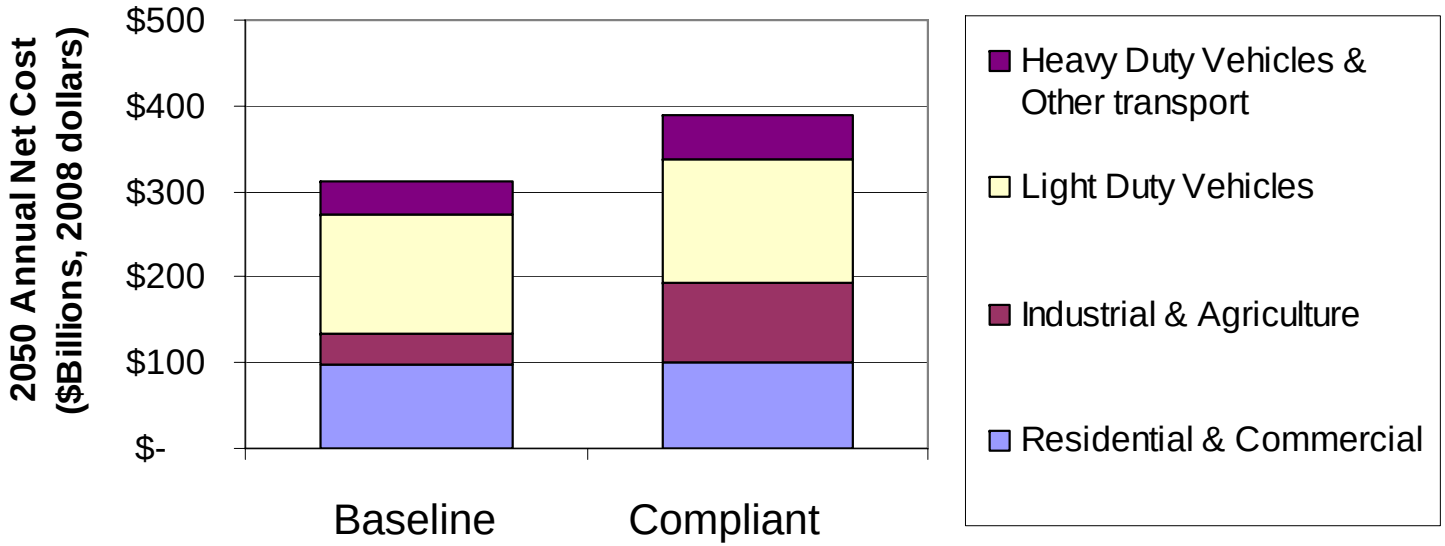
2050 Compliant Case	*Challenges*	*Required Technology Breakthroughs/ Commercialization*	*Benefits*
High Renewables	Maintaining grid operability & reliability Access to remote renewable resources requires large new transmission lines, lots of land area	Energy storage Solar thermal	Minimal security or safety concerns Many proven technologies
High Nuclear	Nuclear waste Excess baseload generation Safety and proliferation concerns	National strategy for safe nuclear waste disposal	Proven technology
High CCS	Testing and long-term verification of sequestration sites	Large-scale demonstration and commercialization of CCS	Grid reliability with low-carbon dispatchable and baseload CCS Potential international benefits of CCS, especially in India and China
Balanced	Requires development of multiple technologies simultaneously	All of the above	Grid reliability with balanced mix of generation types Diversified approach reduces risk of any particular technology

Research & Development Implications

- **Battery storage technologies for electric vehicles**
  - Batteries must be cheaper, last longer and have higher energy density
  - ‘Smart charging’ of vehicles improves grid utilization, economics
- **Low-carbon baseload and dispatchable generation**
  - Coal or gas with CCS, solar thermal with energy storage
  - Energy storage for electric grid
    - Multiple technology pathways are possible (pumped-hydro, compressed air, batteries, solar with thermal storage)
    - Challenges are scalability, cost and environmental impact
- **Low-carbon biofuels**
  - Cellulosic ethanol and algal biofuels from zero-net carbon biomass
  - Manufacturing capability must scale to billion of gallon per year

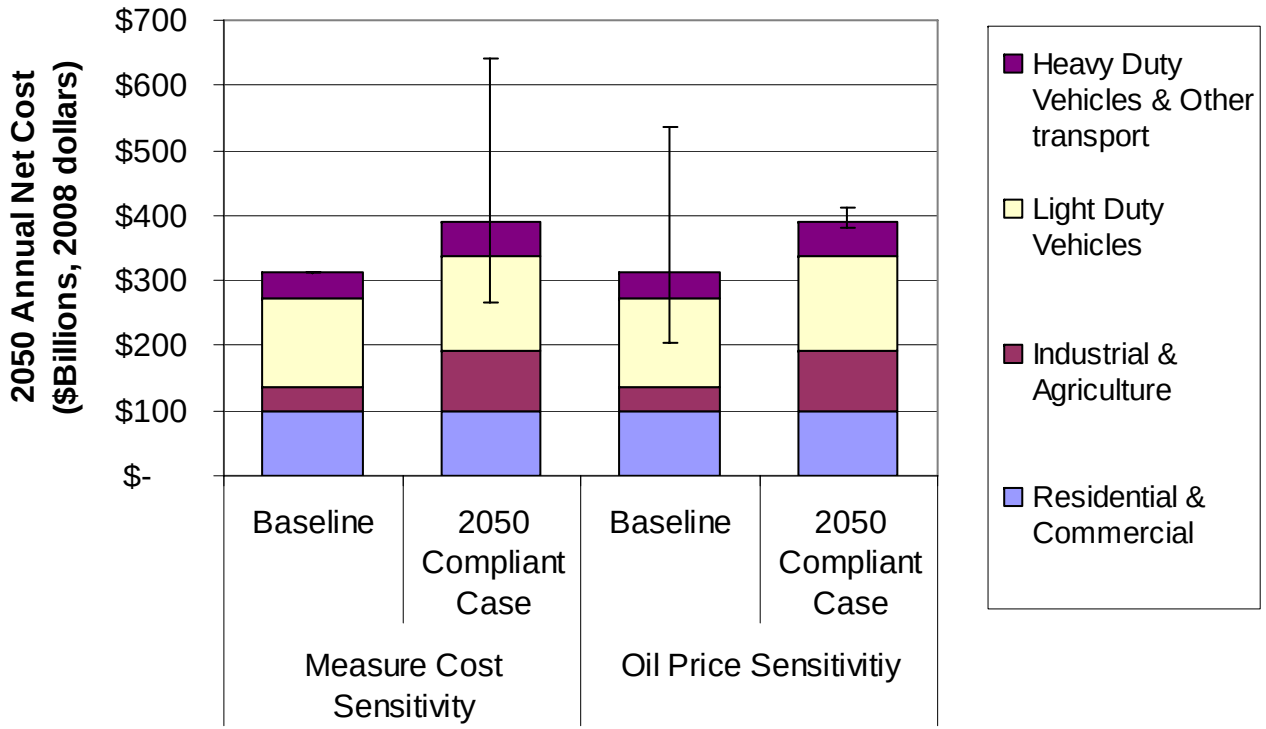
Costs

- Long-term costs are extremely uncertain, particularly given some of the technologies do not exist, or have not been commercialized
- Our cost estimates of achieving 2050 GHG goals are higher than Baseline case, but may not be prohibitive
- Net cost of the Balanced case is 25% higher, or $80 billion more per year in 2050 than Baseline case, or $1,400 per capita per year



Cost Sensitivity

- Measure costs in the 2050 Compliant Case are very uncertain: tested from 0.5x to 2x
- Oil prices are key driver of cost in Baseline case: tested using low to high EIA forecasts
  - Reduced dependence on oil in the 2050 Compliant Case reduces exposure to oil price uncertainty



Key Findings

- AB32 puts California on the right path, but alone is not sufficient to reach the 2050 goal
  - CARB Scoping Plan has correct CO2 trajectory, level of investment, and avoids stranded investments in 2050
- Low-carbon electricity is key to deep GHG reductions
- In the next 10 years we need to develop the technology necessary to sustain reductions beyond 2020
  - Critical breakthroughs will include energy efficiency, battery storage technology, biofuels, CCS and solar thermal
  - Investing early brings costs down in the long run and helps avoid stranded assets
- The costs are uncertain, but do not appear prohibitive

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Thank you

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