Energy+Environmental Economics

California PATHWAYS: A Tool to Examine Long-Term Greenhouse Gas Reduction Scenarios

California Air Resources Board
Scoping Plan Update Workshop
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Snuller Price, Senior Partner

Energy + Environmental Economics (E3)

- San Francisco-based consultancy with 40 professionals focusing on electricity sector economics, regulation, planning and technical energy analysis
- Broad client base includes utilities, regulators, government agencies, power producers, technology companies, and investors
- Our experience has placed us at the nexus of planning, policy and markets

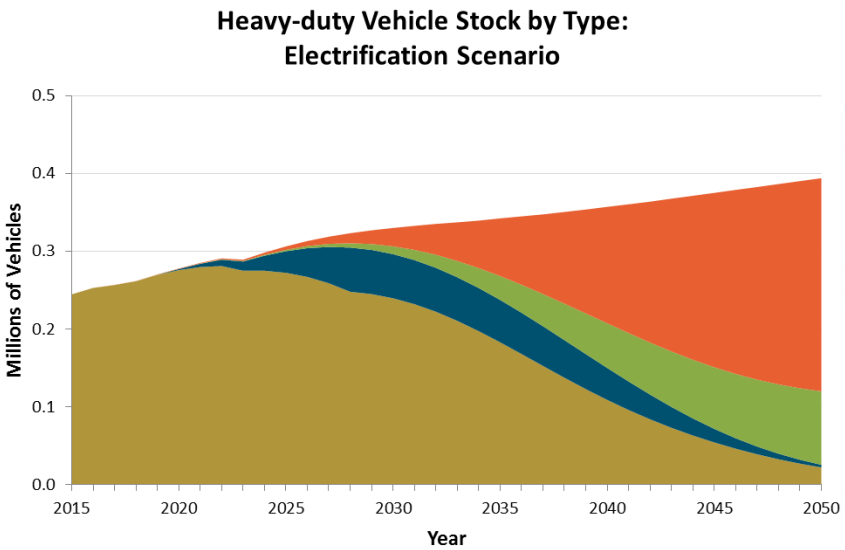
Topics

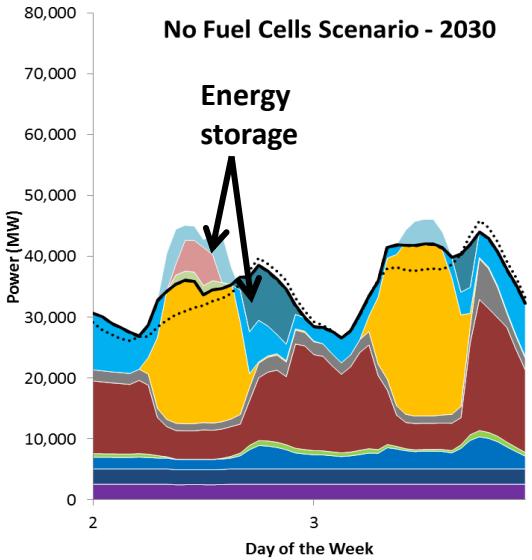
- **About the California PATHWAYS model**
- **Data inputs and data sources**
  - Examples: Translating a policy into technology adoption assumptions in the model
- **Examples of model outputs**
- **Key lessons learned so far**
- **Next steps**

ABOUT THE CALIFORNIA PATHWAYS MODEL

What is PATHWAYS?

- Bottom-up, user-defined, non-optimized scenarios test "what if" questions
- Economy-wide model captures interactions between sectors & path-dependencies
- Annual time steps for infrastructure-based accounting simulates realistic stock roll over
- Hourly treatment of electric sector
- Tracks capital investments and fuel costs over time





Allows for development of realistic & concrete GHG reduction roadmaps

What is PATHWAYS?

PATHWAYS does:

- Compare user-defined policy and market adoption scenarios

Included in model:

- Physical accounting of energy flows within all sectors of the economy
- Cost accounting, including energy infrastructure and fuel costs
- GHG accounting
- Physical representation of policy

PATHWAYS does not:

- Optimize for lowest cost solutions

Not included in model:

- Structural/macroeconomic impacts
  - Changes in the costs of goods and services, jobs, structural changes to economy
- Societal cost impacts
  - Climate benefits of GHG mitigation
- Criteria Pollutants

Basic Energy Modeling Framework

Demand Sectors

End-Use Energy Services Demand

How many miles do Californians drive per year (2010-2050)?

Stock Rollover

How many electric vehicles are on the road?

End-Use Energy Demand

How much fuel of each type is required to meet driving demand?

Supply Sectors

Electricity Supply

What is the % of renewables on the grid?

Pipeline Supply

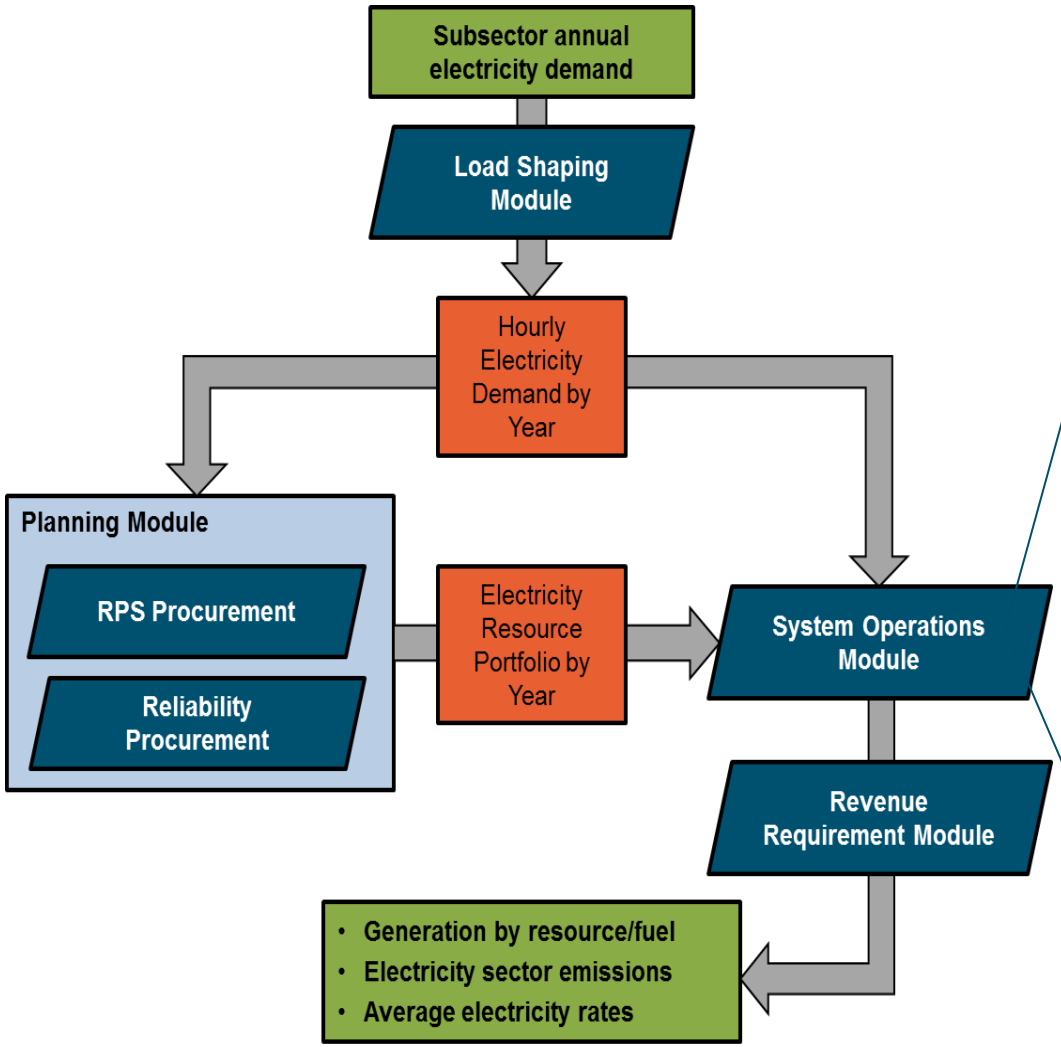
Other Fuels (Gasoline, Diesel, Hydrogen, etc.)

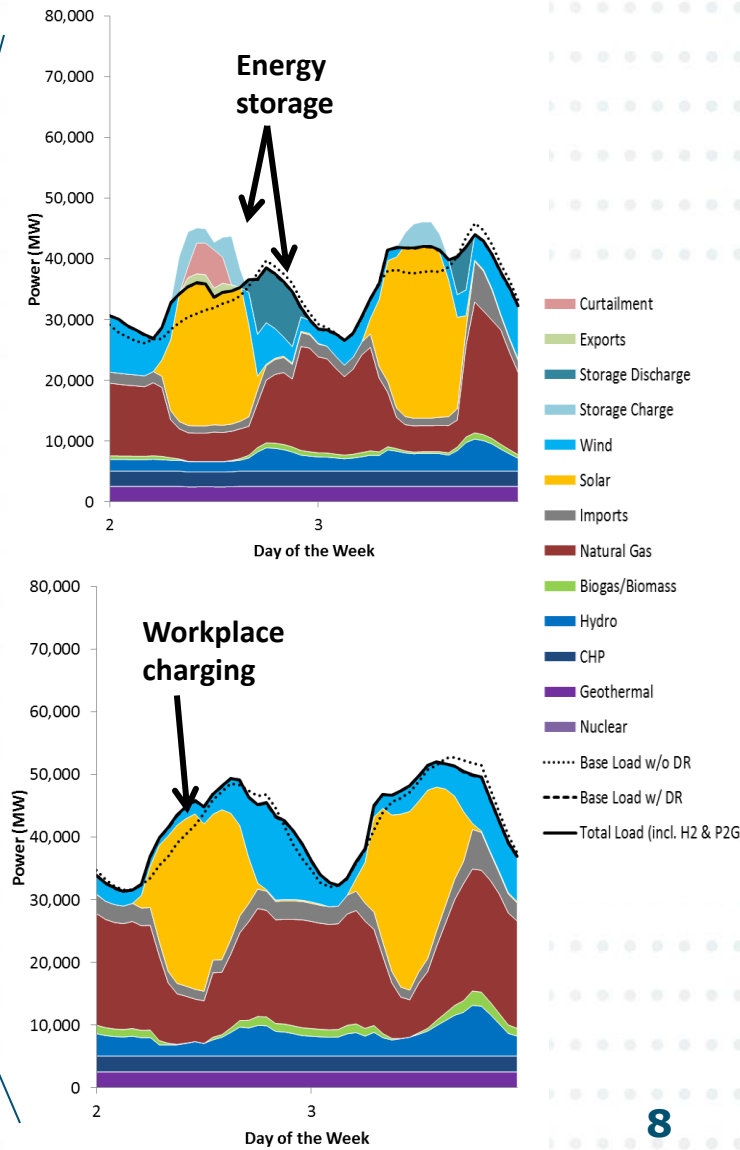
Model Outputs

How many GHG emissions are saved?

How much do EVs cost over the baseline internal combustion engine vehicle?

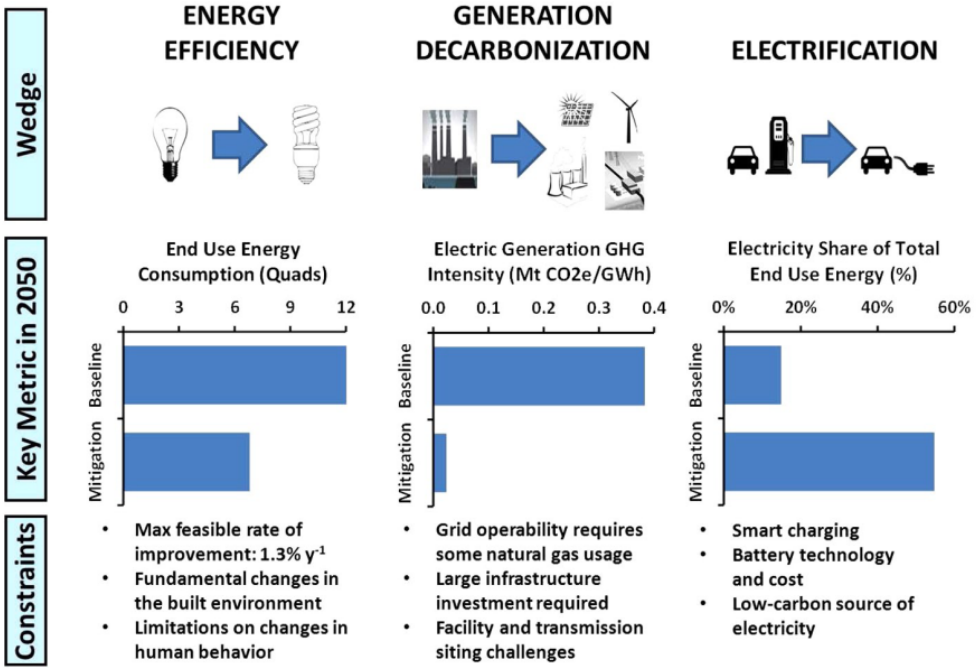
In-Depth Electricity Module Included in PATHWAYS





2012 Science Paper: "The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050"

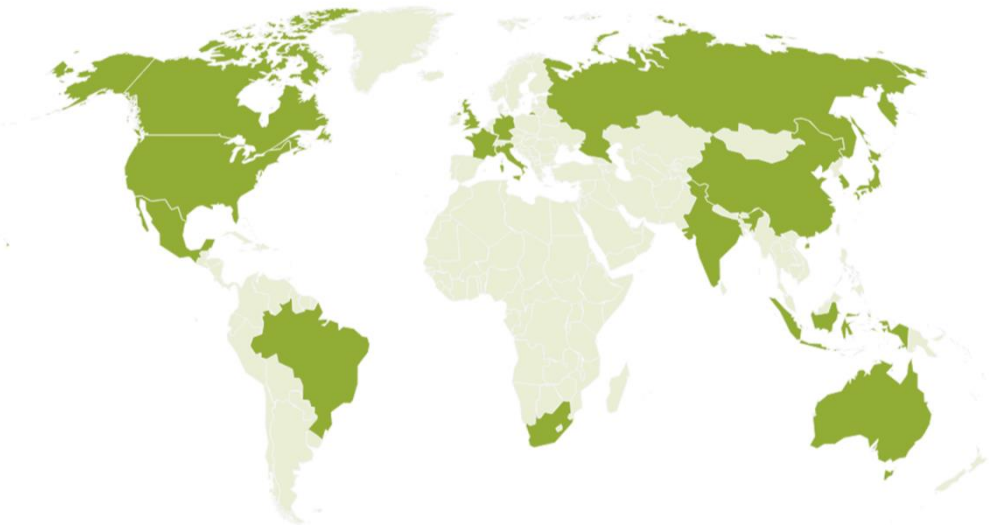
- **What is the impact of the electric generation mix on the cost and feasibility of a low-carbon future in CA?**
- **Compared renewables, nuclear, carbon capture and storage**
- **Demonstrated a feasible pathway to 2050 goal with focus on electrification**



"The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity," Williams et al, Science (2012)

2014: UN Deep Decarbonization Pathways Project

- **UN Deep Decarbonization Pathways Project**
  - 17 countries, >70% of current global GHG emissions
  - Scenarios to keep global warming below 2 degrees C
- **E3 was lead author of the U.S. country report**



2014-2015: The California PATHWAYS Project

+ Purpose

- To evaluate the feasibility and cost of a range of GHG reduction scenarios in California (prior to development of Governor's 2030 goals)

+ Project sponsors

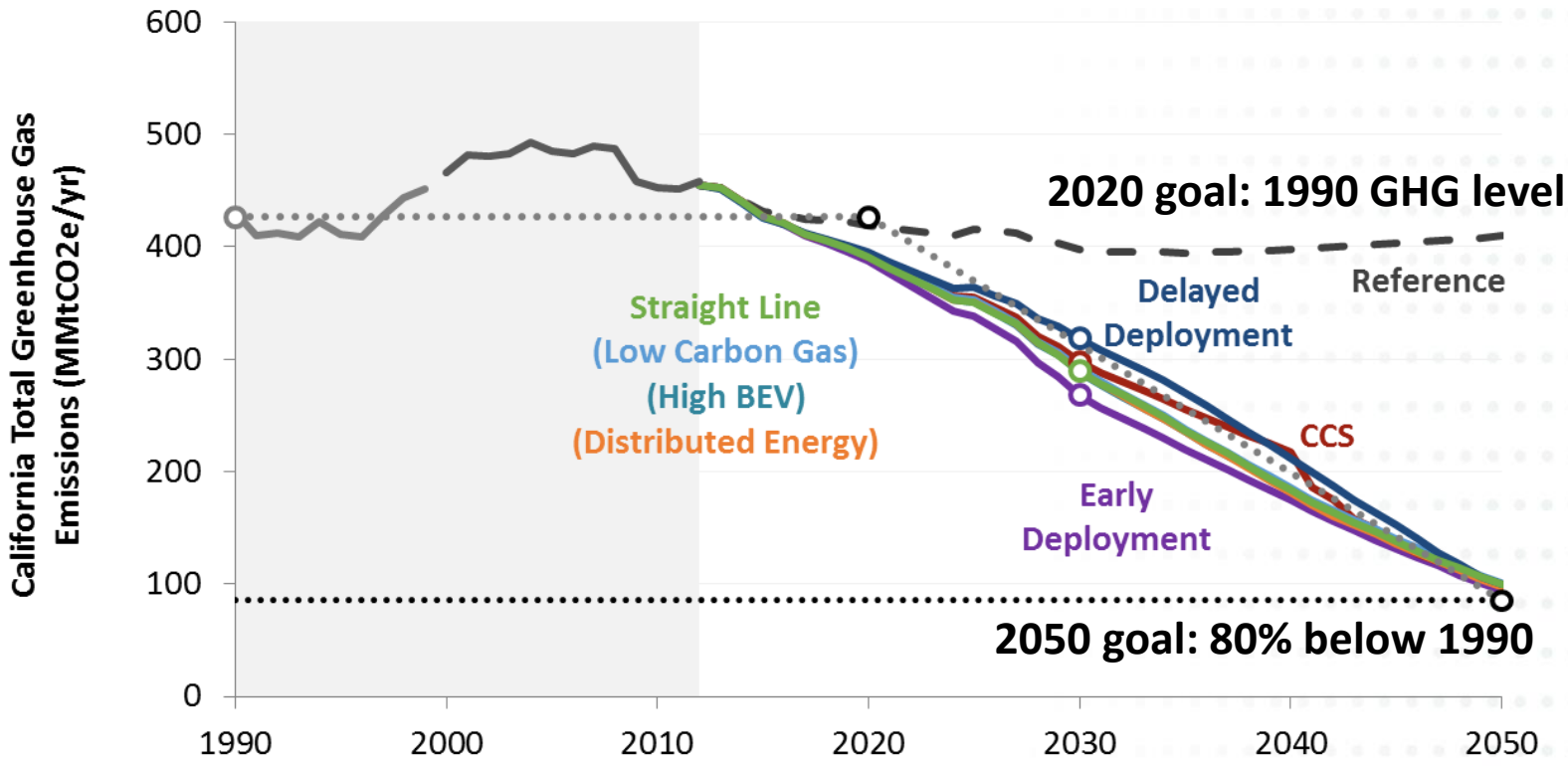
- California Air Resources Board, Energy Commission, Public Utilities Commission, Independent System Operator & the Governor's Office
- Additional funding provided by the Energy Foundation

+ Team

- Energy & Environmental Economics with support from LBNL

Study results: https://ethree.com/public_projects/energy_principals_study.php

We Modeled Several Scenarios That Reach California's 2050 GHG Goal



- **Current policies** (Reference scenario) are expected to achieve 2020 goal
- **Examined Scenarios** (E.g. Early Deployment, Straight Line scenarios) that achieve 2050 goals

Scenarios Evaluate GHG Reduction Timing and Energy Pathways to 2030 and 2050

1. Reference	current GHG policies, as of 2014

Timing Scenarios (achieve 80% below 1990 by 2050)

2. Straight Line	distinguished by high renewable energy, fuel cell and battery electric vehicles, energy efficiency and electrification
3. Early Deployment	similar to Straight Line scenario but with more focus on near-term air quality & GHG actions
4. Slower Commercial Adoption	delay some higher-cost measures in commercial and trucking until post-2030, accelerate adoption post-2030 to hit 2050 goal

Alternate Technology Scenarios (achieve 80% below 1990 by 2050)

5. Low Carbon Gas	no building electrification, decarbonized pipeline gas
6. Distributed Energy	achieves zero-net energy building goals w/ DG PV and grid storage
7. CCS	phase-in of CCGTs with CCS post-2030
8. High BEV	no fuel cell vehicles, focus on BEVs

DATA INPUTS AND DATA SOURCES

Model Inputs, Measures and Outputs

Illustration of influence between exogenous variables and calculated end use energy services demand

Raw Data Inputs

e.g. California population

e.g. Average number of people per household

Intermediate Calculations

e.g. Number of residential households

Measures (Scenario Input Assumptions)

e.g. Appliance efficiency changes

e.g. Changes in new construction

Calculated Outputs

e.g. Residential energy demand

Energy Demand by Sector and Subsector

Residential	Commercial	Transportation	Industrial	Agriculture
16 subsectors, including: • Water Heating • Air Conditioning • Cooking	**9** subsectors, including: • Refrigeration • Ventilation • Office Equipment	**9** modes of transport, including: • Cars, Trucks, Buses • Passenger Rail • Aviation	**7** subsectors, including: • Conventional boiler use • Machine drive • Process heating	**7** subsectors, including: • Lighting • Motors • Refrigeration

Petroleum refining	Oil & gas extraction	Energy use due to Water Demand	Non-Fuel, Non-Energy GHGs	Forestry, Land use change
• Sector-Level Energy Demand Only	• Sector-Level Energy Demand Only	• Energy use from procurement (including desalination, reclaimed water, conservation and groundwater), treatment, conveyance and wastewater-treatment of water	• Sector-Level GHGs Only, with reduction measures by GHG type consistent with CARB inventory categories (e.g. non-CO2 emissions from agriculture, methane from waste and manure, F-gases, etc.)	• Not currently explicitly modeled

Expansive Modeling of Supply Technologies and Fuels

Electricity	Combined Heat & Power	Pipeline Gas	Liquid fuels	Other fossil fuels
• Uranium • Hydro • Coal • Geothermal • Wind • Solar PV • Solar thermal • Natural Gas • Biomass • Biogas • Specified imports (various types) • Unspecified imports • Carbon capture & sequestration	• Waste heat	• Natural Gas • Hydrogen • Power to Gas • Biogas Note: Pipeline gas can be compressed (CNG) liquefied (LNG) or remain as a gas	• Diesel • Gasoline • Biodiesel • Bio-gasoline • Hydrogen • Kerosene-Jet Fuel	• Coke • Refinery and Process Gas • Fuel Oil • Kerosene • LPG

Data Sources Planned for Use in California PATHWAYS Model

Sector	Component	Source
Residential and Commercial	Energy demand benchmarking	CEC California Energy Demand Forecast (to be updated from 2014 forecast)
	Technology costs and performance	National Energy Modeling System (data used in support of Annual Energy Outlook 2013)
	Residential appliance shares	California Residential Appliance Saturation Survey (KEMA, 2009)
	Commercial appliance shares	California Commercial End Use Survey (CEUS, 2006)
Transportation	Reference scenario data	EMFAC 2014
	Vehicle shares	CARB VISION model scenarios developed for the Mobile Source Strategy Discussion Draft
	Technology costs	National Academies Press, "Transitions to Alternative Vehicles and Fuels", and "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles"

Data Sources Planned for Use in California PATHWAYS Model

Sector	Component	Key Data Sources
Industrial, Refining and Oil and Gas Extraction	Electricity demand	CEC Energy Demand Forecast (to be updated from 2014 forecast)
	Other energy demand	CEC California Energy Demand forecast data. To be updated from CEC data used in support of the, "California Energy Balance Update and Decomposition Analysis for the Industry and Building Sectors", LBNL (2010).
	End-use energy shares by subsector	CPUC, Navigant Potential Study (2013)
Agriculture	Energy Demand	CEC California Energy Demand Forecast (to be updated from 2014 forecast)
	End-use energy shares by subsector	CPUC, Navigant Potential Study (2013)

Data Sources Planned for Use in California PATHWAYS Model

Sector	Component	Key Data Sources
Electricity Generation	Renewable generation costs and renewable portfolios	CPUC RPS Calculator (to be updated from 2014 version)
	Existing fossil generation fleet	TEPPC 2022 Common Case and WECC study data.
	Fossil fuel costs and financing cost assumptions	"Capital cost review of power generation technologies, recommendations for WECC's 10- and 20-year studies" (E3, March 2014)
	Hourly renewable generation shapes	• *Solar PV*: simulated using System Advisor Model (SAM), PV Watts; • *Concentrated solar power*: simulated using System Advisor Model (SAM); • *Wind*: Western Wind Dataset by 3TIER for the first Western Wind and Solar Integration Study performed by NREL

Data Sources Planned for Use in California PATHWAYS Model

Sector	Component	Key Data Sources
Biomass and biofuels	Resource potential and biomass costs	DOE "U.S. Billion Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry" report (2011)
	Biofuels conversion costs and efficiencies	Multiple sources in published literature, may be updated with more recent information.
Non-energy, non-CO_2 GHGs	Subsector GHG emissions	CARB's emissions inventory by IPCC category
	Emission reduction measures	CARB Draft Short Lived Climate Pollutant Strategy (current scenario data are based on results of literature review by E3 and LBNL)
Other	Fuel Price Projections	EIA Annual Energy Outlook (AEO), to be updated from 2013 AEO
	Population	California Department of Finance
	Hydrogen production	Department of Energy. H2A Analysis. 2014.

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TRANSLATING POLICY INTO PATHWAYS

Intro

- **PATHWAYS is a physical accounting model – policies are not directly modeled**
- **Policies must be translated into model assumptions about changes in technology deployment, technology cost or energy demand**
- **Three examples are shown below:**
  - SB 350: 50% Renewable Portfolio Standard (RPS) by 2030
  - SB 350: Doubling of Energy Efficiency savings (EE)
  - SB 375: Sustainable Communities and Climate Protection Act ("smart growth")

Renewable Portfolio Standard: Policy Translation Example

Translation

+ Policy → **+ PATHWAYS**

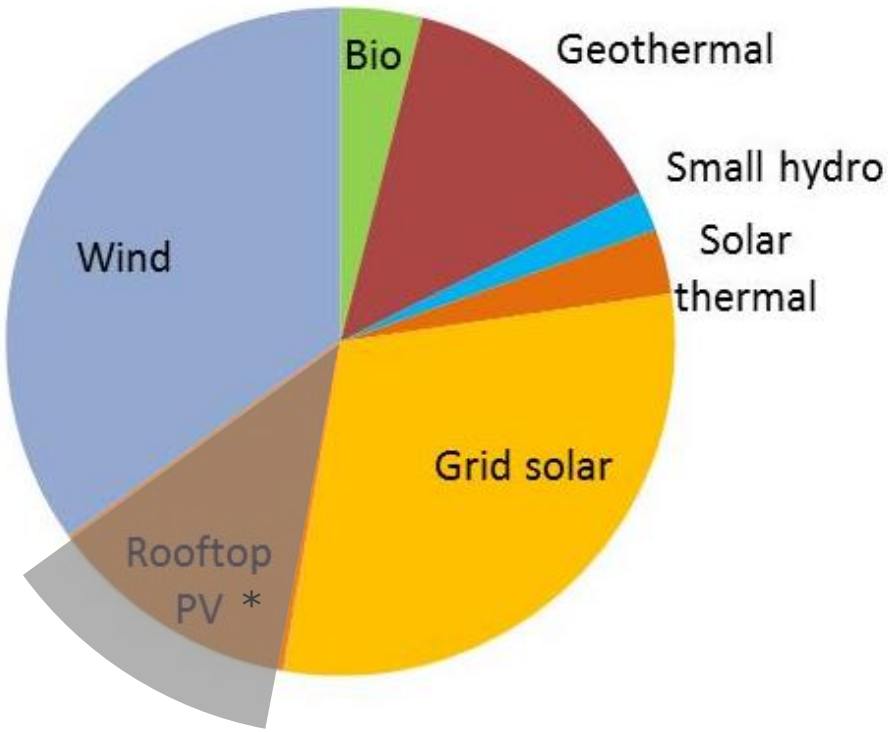
"the amount of electricity generated and sold to retail customers per year from eligible **renewable energy resources** be increased to **50%** by December 31, 2030"

SB 350

- Select % of retail sales to be met with qualifying renewable generation by specific year
- Select mix of renewable technologies (pre-packaged portfolios are available)
- Add renewable integration solutions if desired (e.g. energy storage)

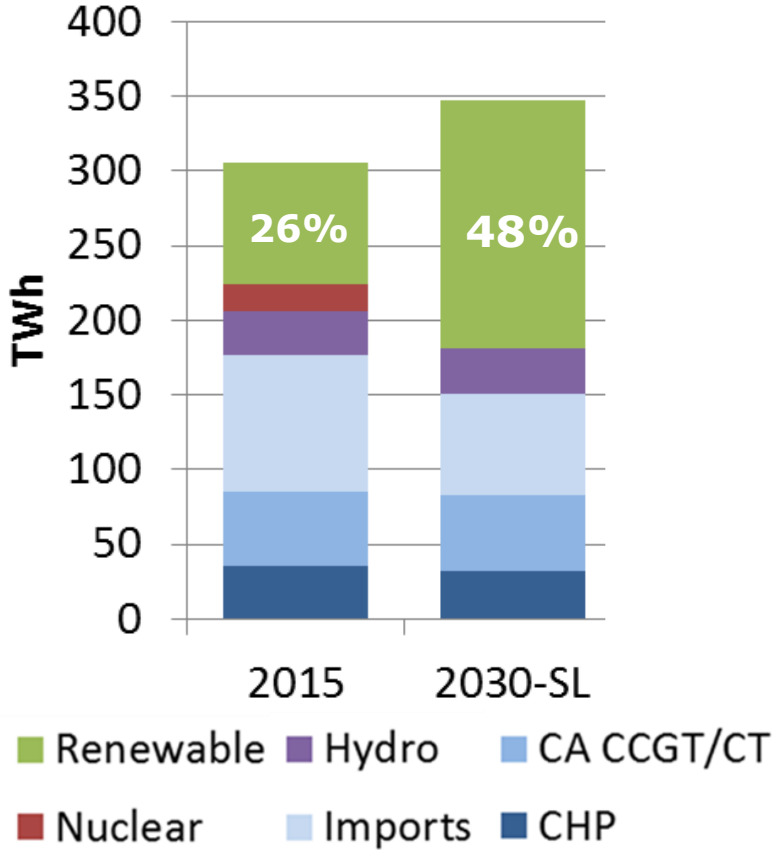
Example Results of RPS policy

2030 Renewable Generation by Type (%) – Straight Line



*Not included in RPS

2015 & 2030 Annual Generation – Straight Line



Energy Efficiency: Policy Translation Example

Translation

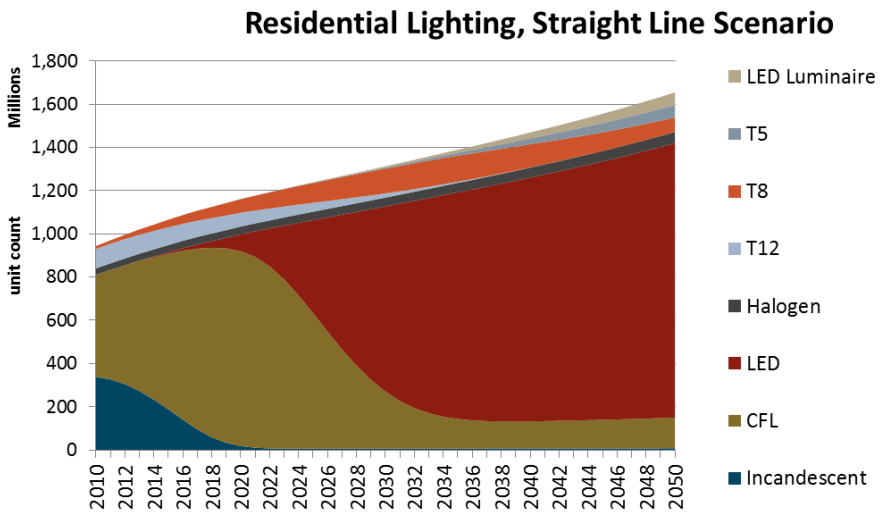
+ Policy → + PATHWAYS

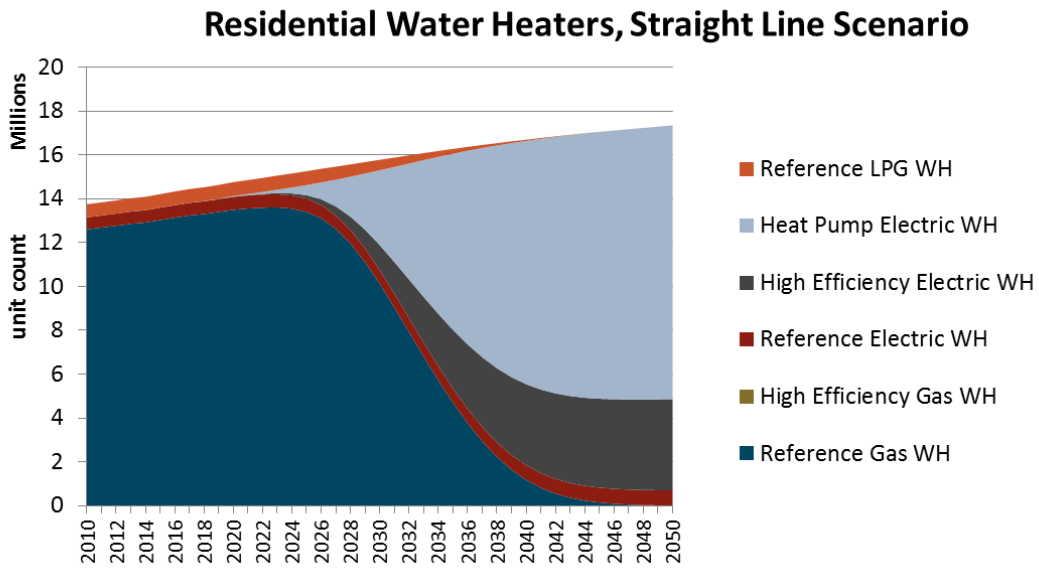
"establish annual targets for statewide energy efficiency savings and demand reduction that will **achieve a cumulative doubling of statewide energy efficiency savings** in electricity and natural gas final end uses of retail customers by January 1, 2030"

SB 350

+ **Select measure inputs for each end-use technology (e.g. residential water heaters)**
  - Start with existing technology – decide what new technology is going to replace it
  - Decide on % of new sales of new technology
  - Decide on adoption trajectory ("s-curve" or "linear" adoption)
  - Decide on a program start year and end year for technology adoption
  - Check resulting change in energy demand – was policy goal met?

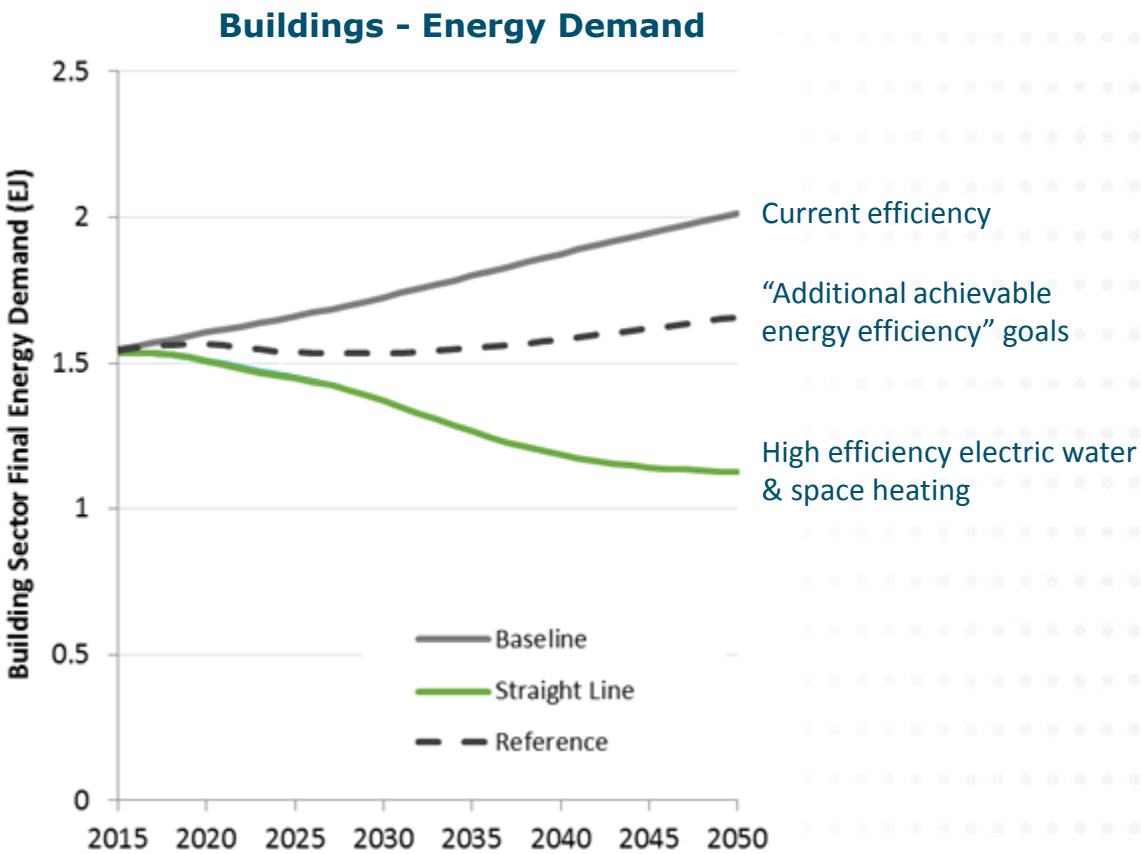
Example Results of Energy Efficiency Policy





Measuring Impacts of Energy Efficiency With Energy Demand in Buildings

- **Electric energy efficiency** targets are modeled compared to a current policy (Reference)



2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Sustainable Communities SB 375: Policy Translation Example

Translation

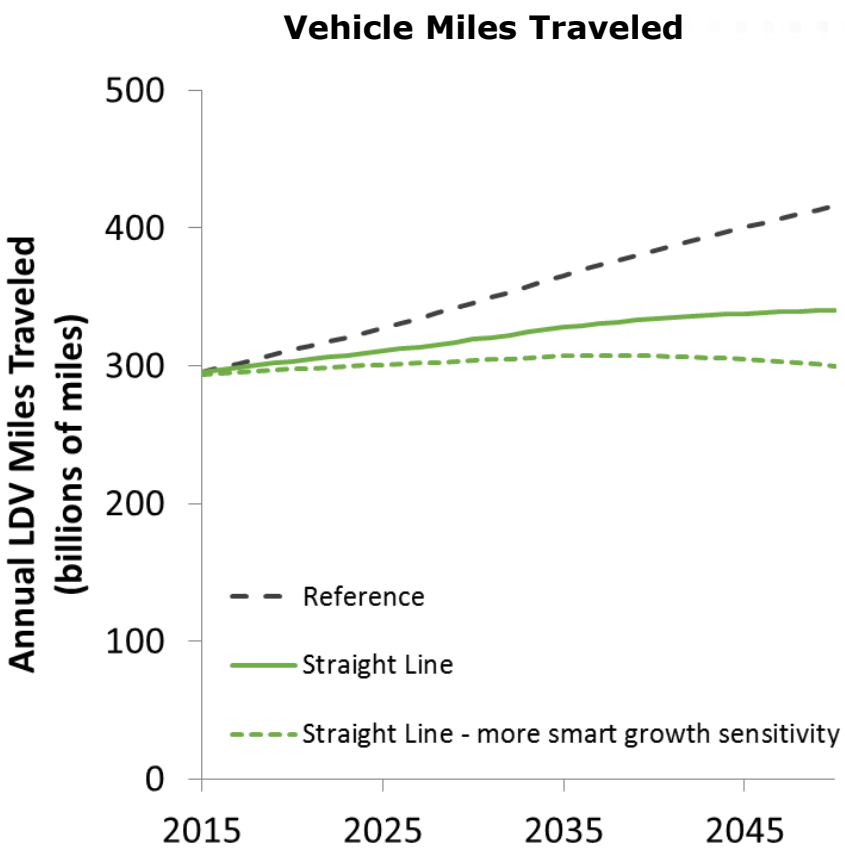
+ Policy → + PATHWAYS

"Adopt a sustainable communities strategy, as part of its regional transportation plan, as specified, designed to achieve certain goals for the reduction of greenhouse gas emissions from automobiles and light trucks in a region"

SB 375

+ **Reduction in vehicle miles traveled relative to baseline**
  - % reduction in light-duty vehicle miles traveled by a specific year relative to the Reference scenario assumptions
+ **Change in new construction mix for residential housing stock relative to baseline**
  - Start with existing housing stock type (e.g. single family home) – decide what new type is going to replace it (e.g. multi-family)
  - Decide on % of new construction of new housing type
  - Decide on adoption trajectory ("s-curve" or "linear" adoption)
  - Decide on a program start year and end year for technology adoption

"Smart Growth" Assumptions Reduce VMT and Energy Demand in Transportation Sector

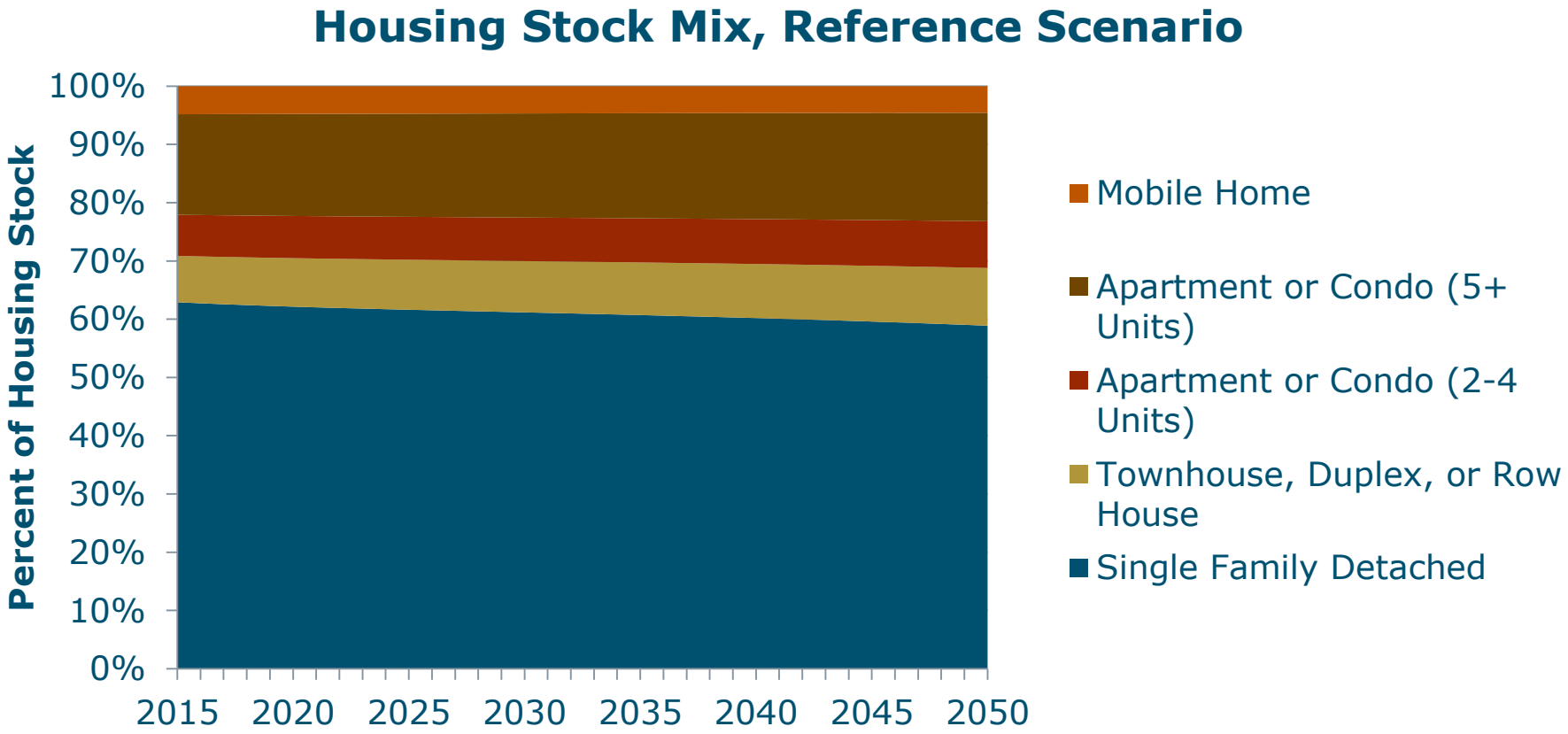


2015 Energy Principles outputs, subject to change in CARB Scoping Plan

+ Note that vehicle miles traveled assumptions will be updated with EMFAC 2014 data

"Smart Growth" Assumptions Shift Housing Stock Mix

+ **Long lifetime of houses result in slow shifts between housing types over time**



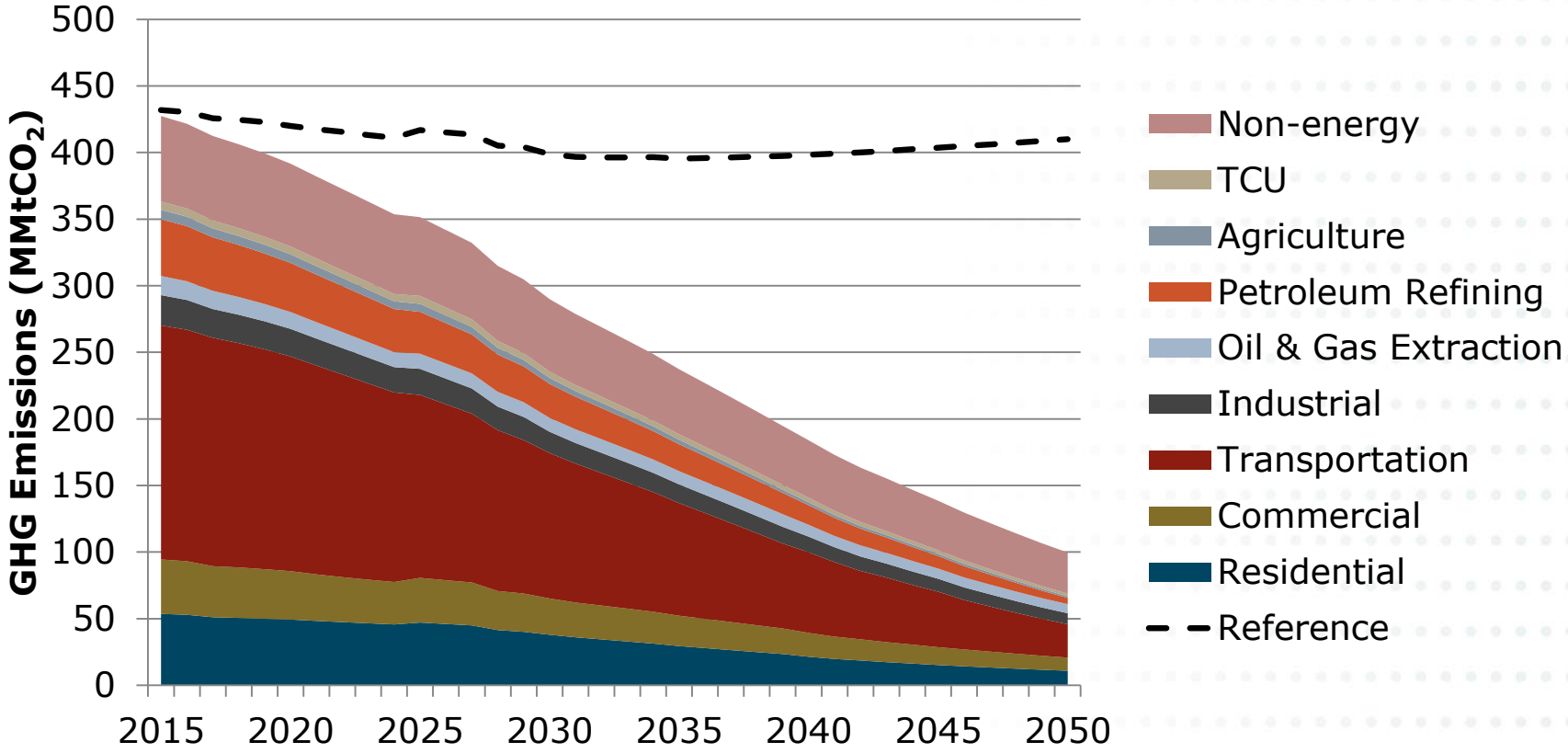
EXAMPLES OF MODEL OUTPUTS

Categories of Model Outputs

- **All outputs are tracked by sector, fuel and year**
- **Greenhouse gas emissions**
- **Energy demand**
- **Energy supply**
  - Electricity generation, gas supply, biofuel mix
- **Technology stocks & sales**
  - Household appliances, vehicles
- **Cost**
  - Direct costs and savings by sector
    - Household, commercial, industrial, trucking, busing, etc.
    - Direct and indirect accounting of costs
  - Total capital costs
  - Total energy costs
  - Electricity and natural gas rates

Greenhouse Gas Emissions

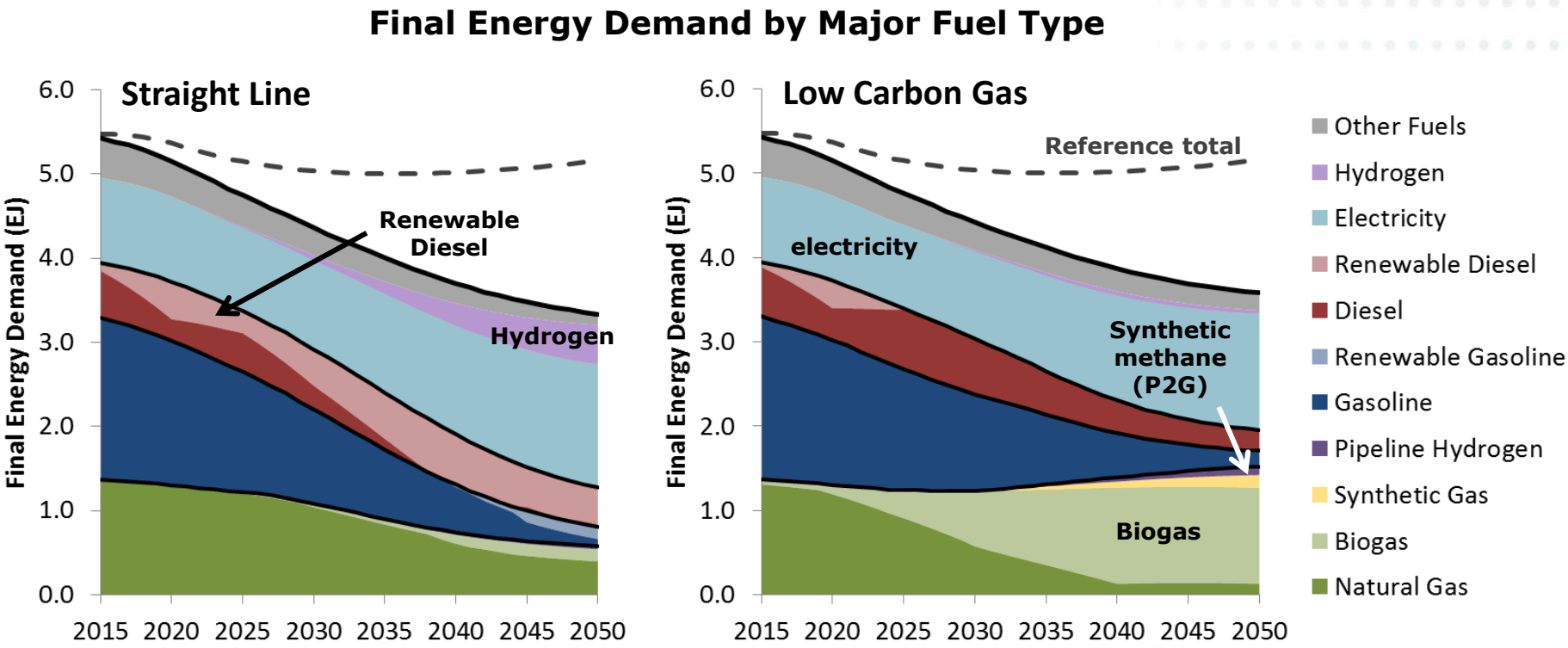
+ **GHG emissions by sector over time for Straight Line Scenario compared to the Reference Scenario**



2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Final Energy Demand by Fuel Type

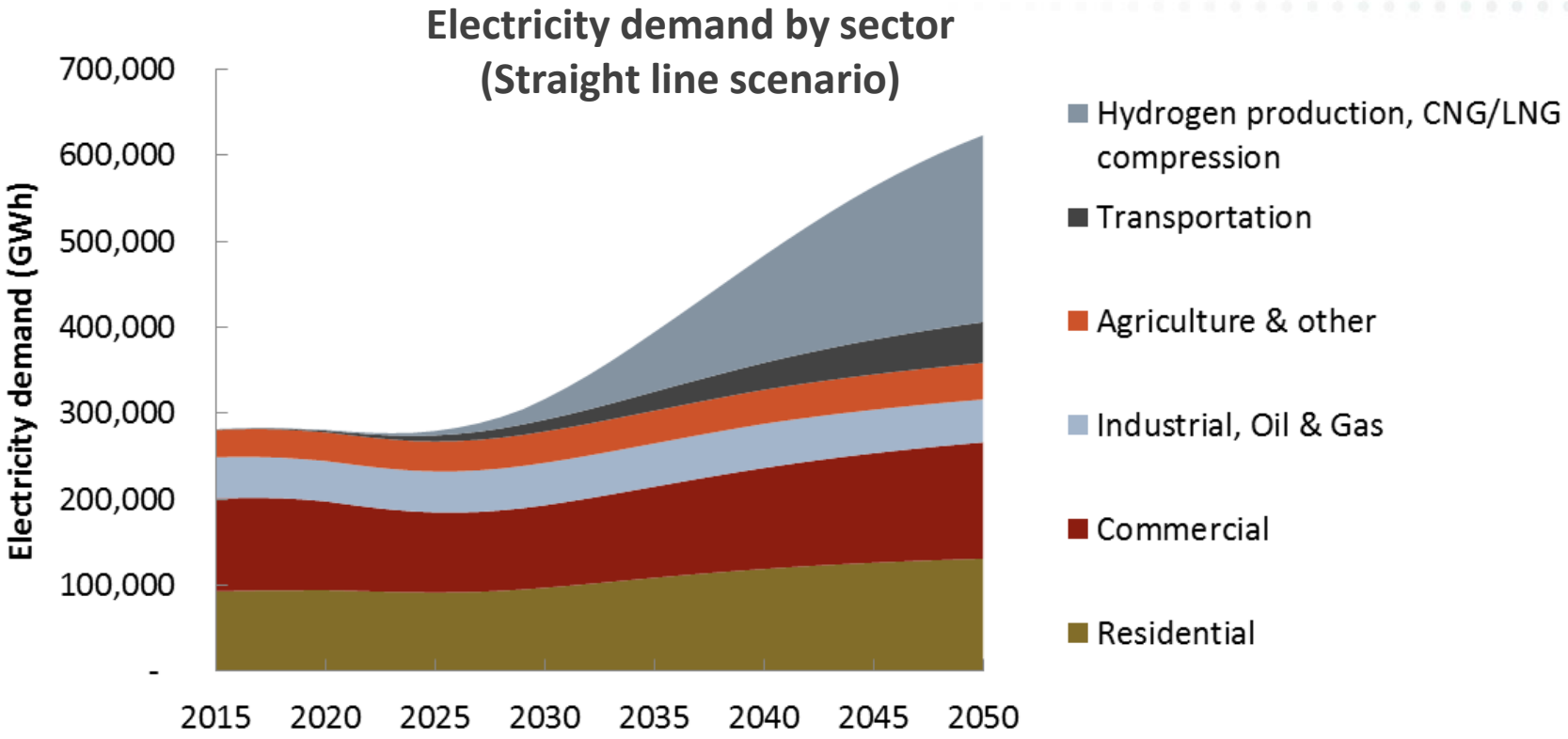
+ **Different scenarios include different fuel mixes over time**



2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Electricity Demand by Sector

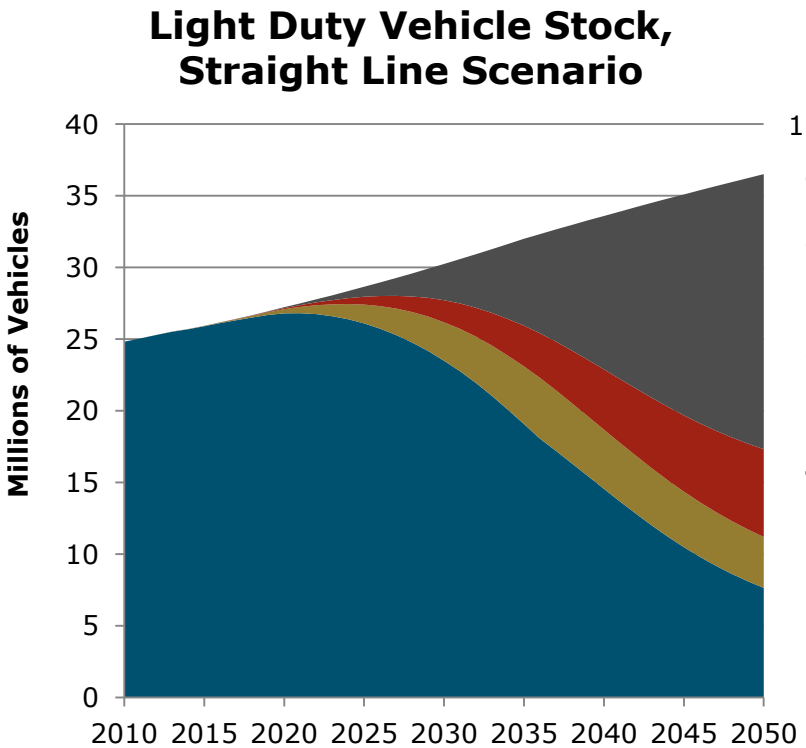
- **Energy efficiency offsets impact of electrification through 2030**
- **Beyond 2030 new loads offer potential for flexibility to help integrate solar and wind generation**

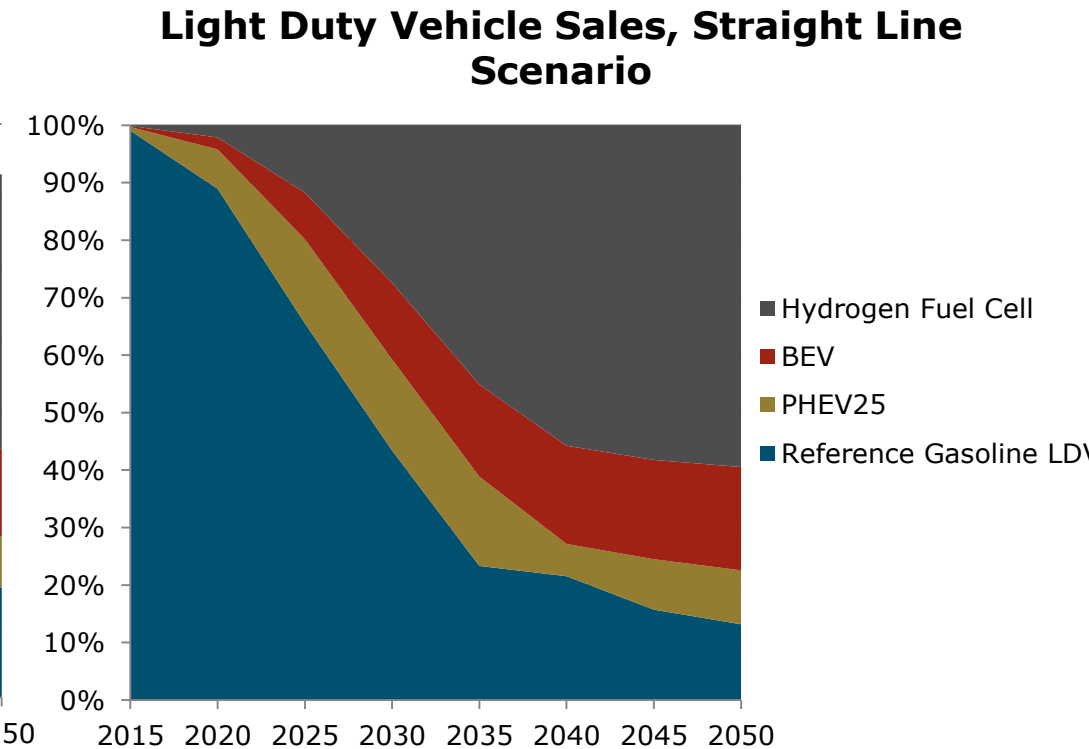


2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Light Duty Vehicle Fleet

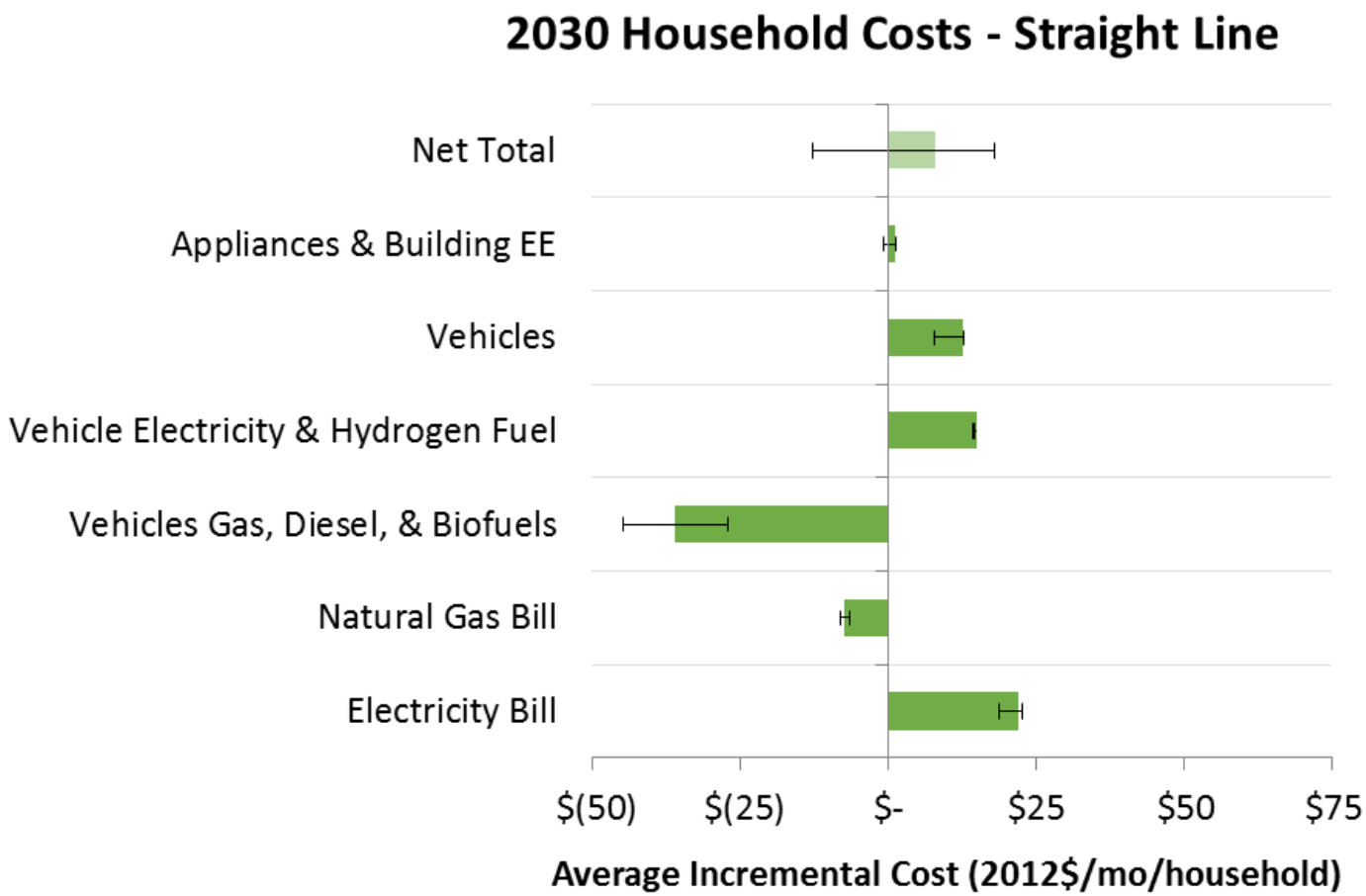
- Light duty vehicles stock and sales share by vehicle type in the Straight Line Scenario





2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Average Household Monthly Costs

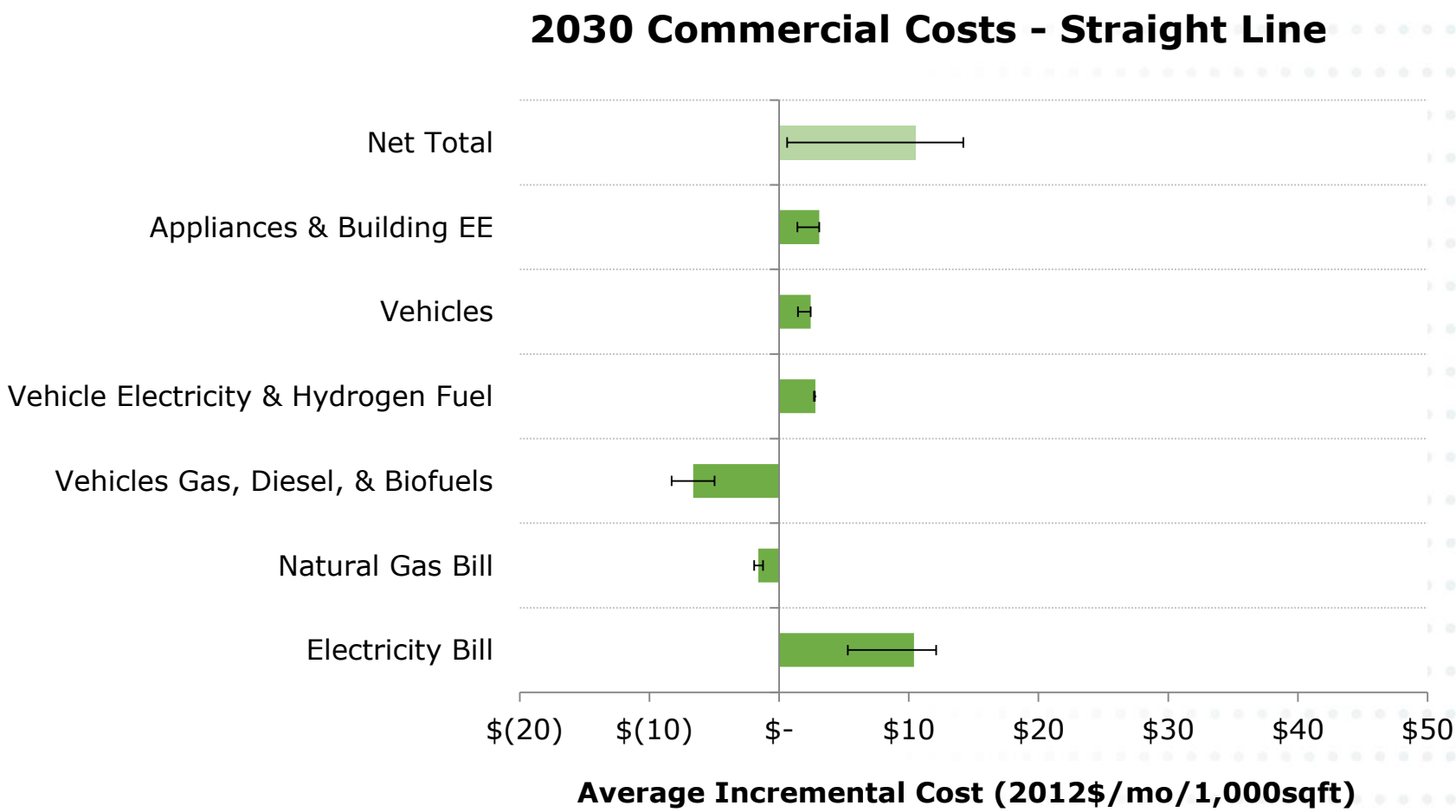


Net Total:
$8/mo/household

0.8% increase over Reference Scenario energy-related costs

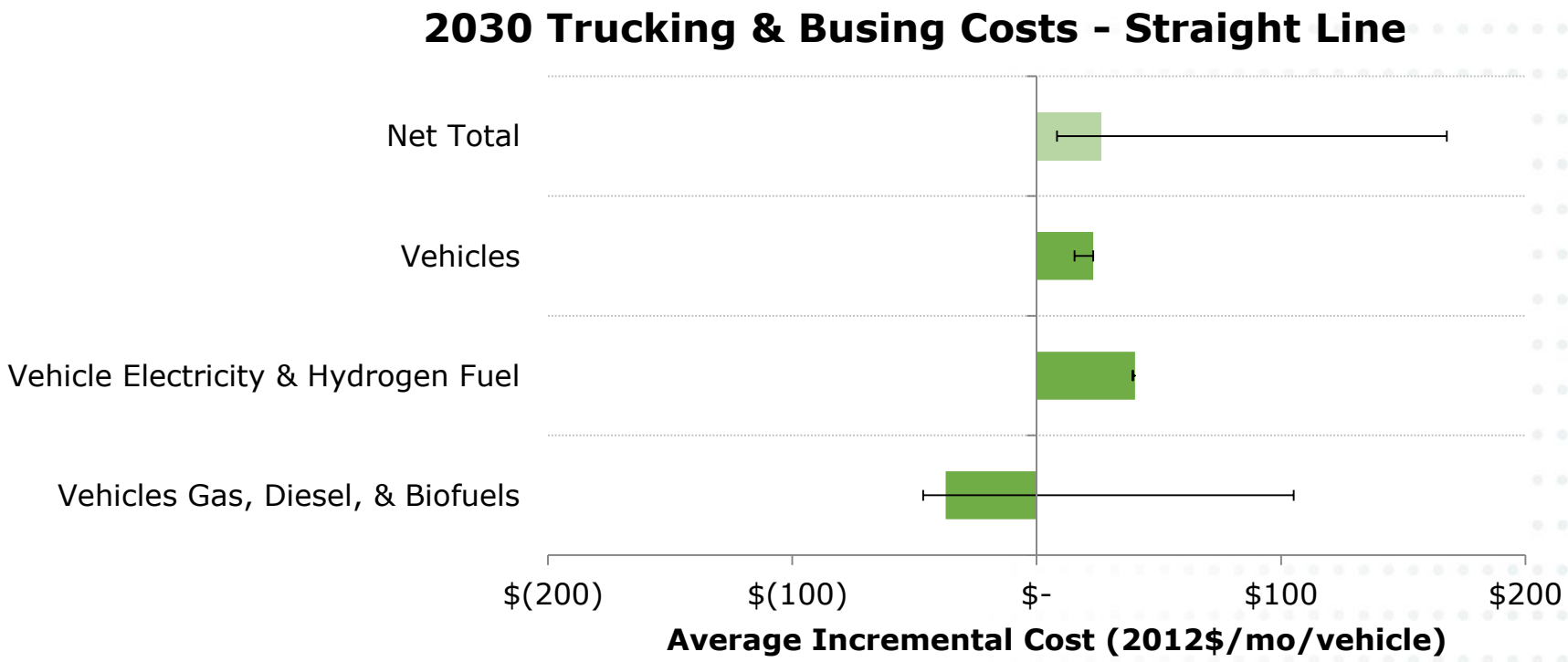
($14/mo/household if assume all com. & industrial energy system costs flow through to households)

Average Commercial Monthly Costs



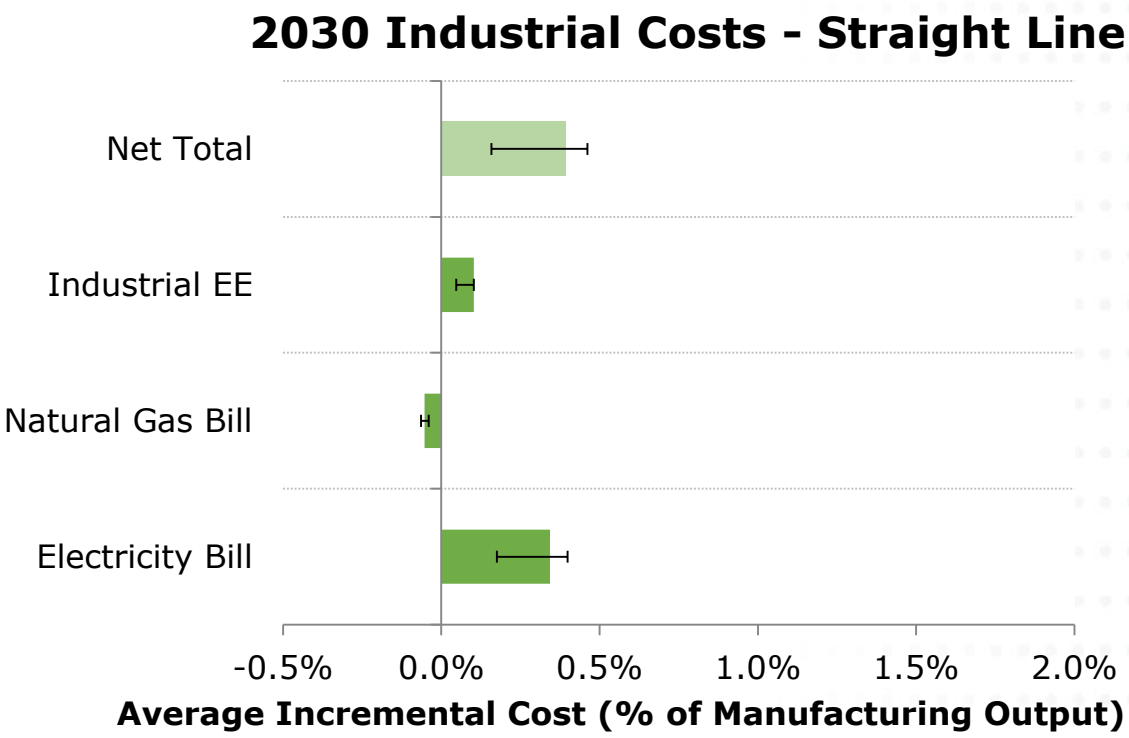
2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Average Trucking and Busing Monthly Costs



2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Average Incremental Industrial Costs

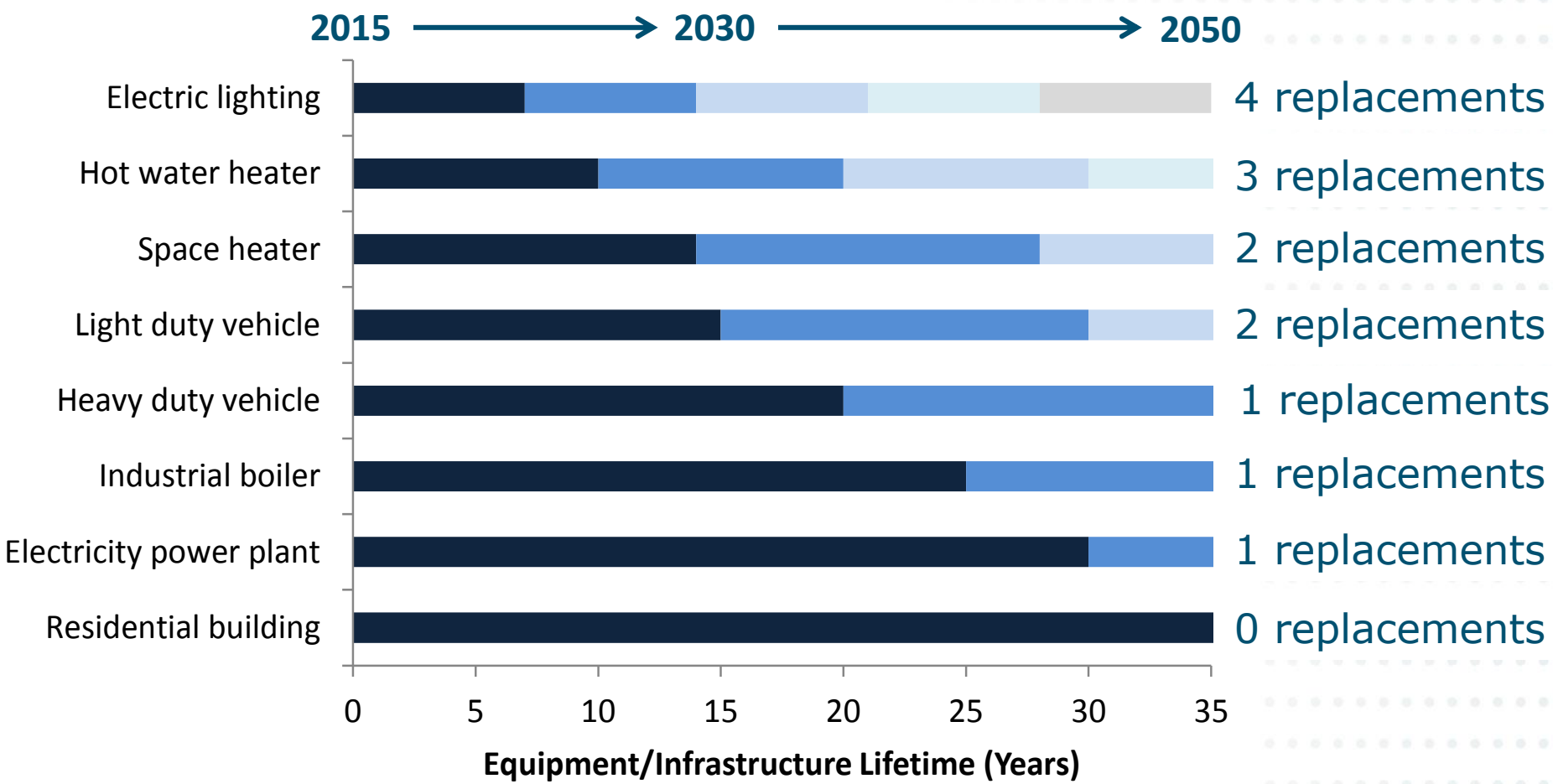


2015 Energy Principles outputs, subject to change in CARB Scoping Plan

KEY LESSONS LEARNED IN PRIOR WORK

Timing for Action is Limited

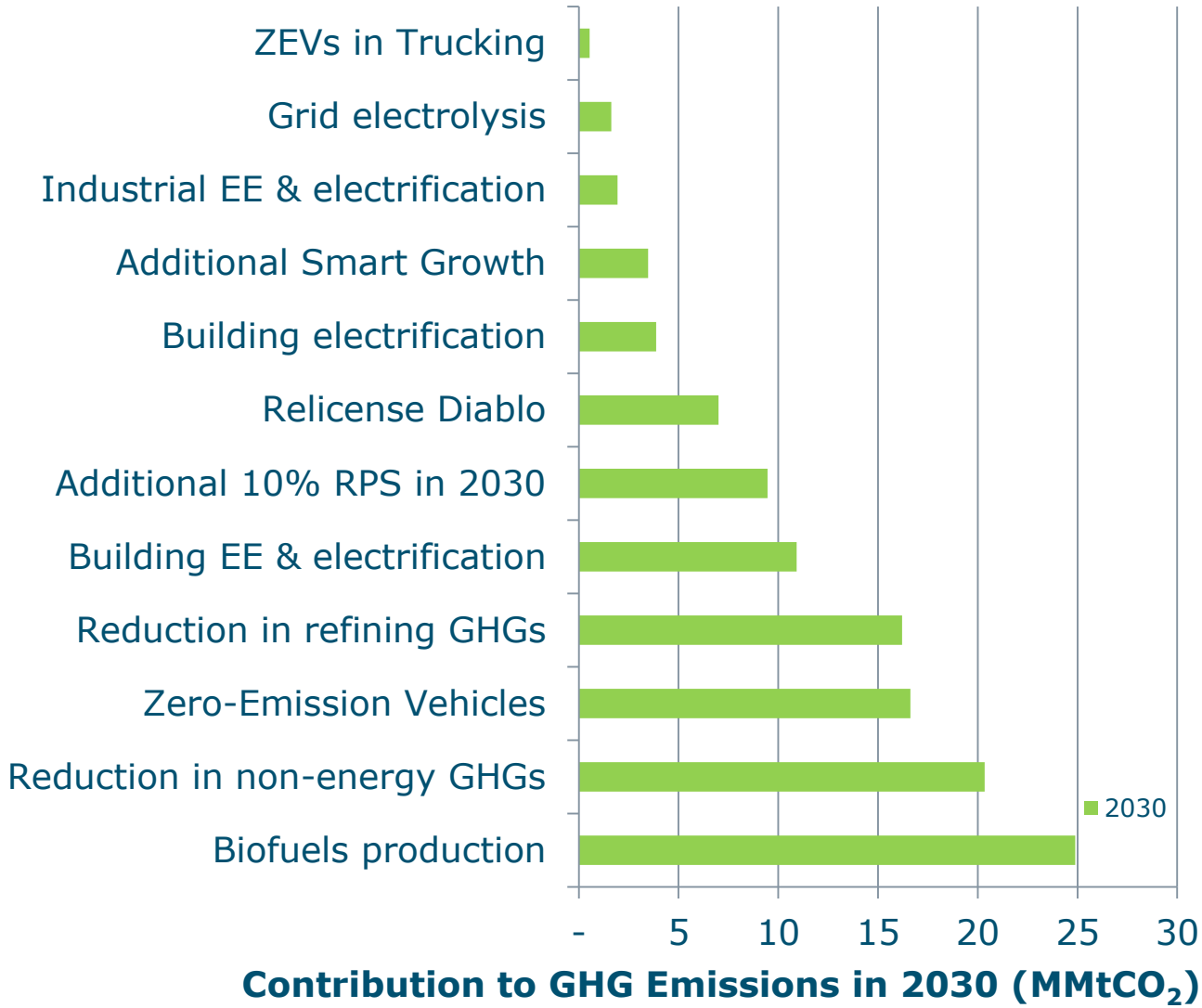
- A car purchased today, is likely to replaced at most 2 times before 2050.
  A residential building constructed today, is likely to still be standing in 2050.



2015 Energy Principles outputs, subject to change in CARB Scoping Plan

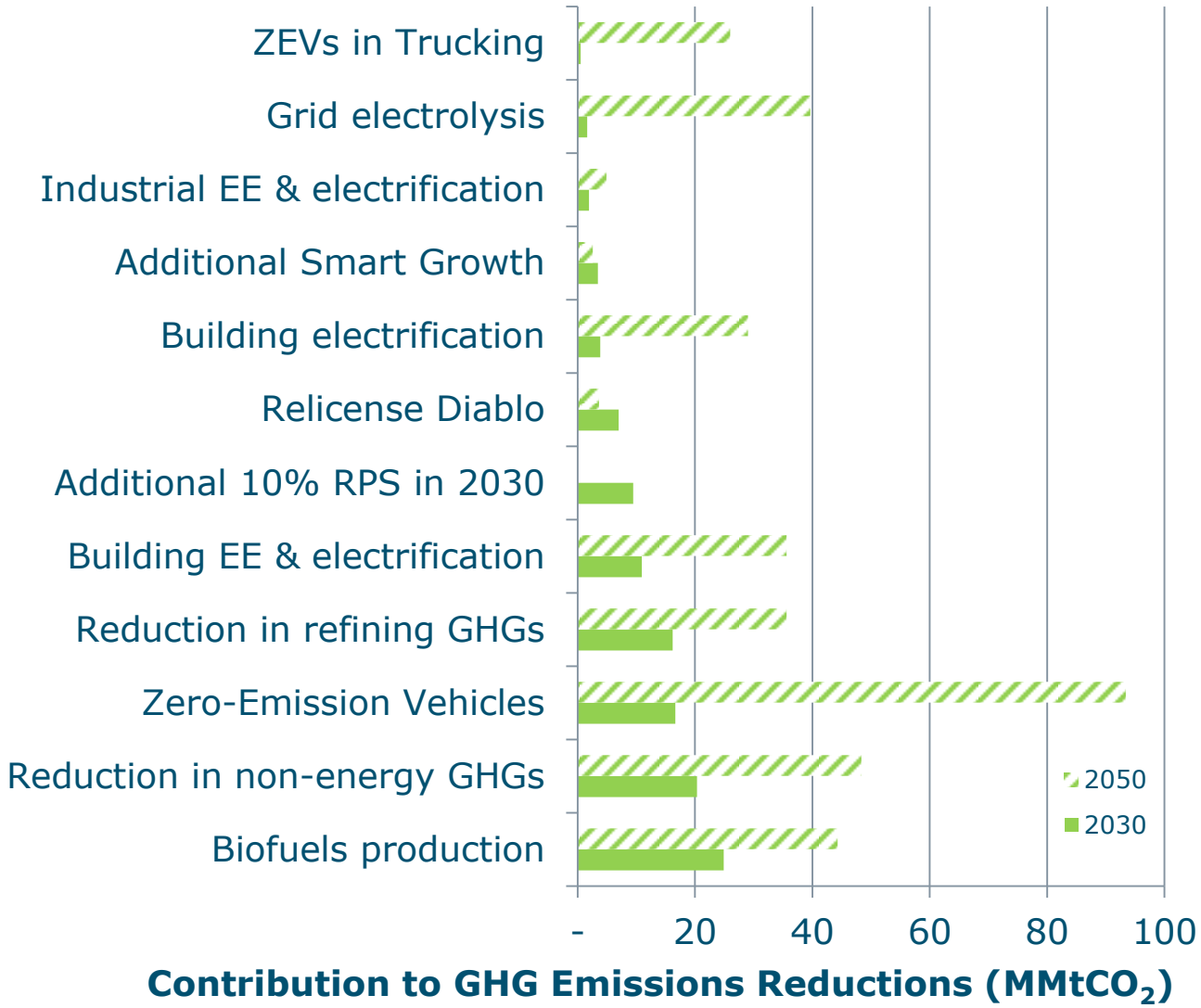
Sensitivities in Straight Line scenario reveal consequences of failure or achievement in 2030

- **Ex: ZEVs in 2030 contribute ~16 MMTCO2 reductions, given electricity portfolio**



2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Sensitivities in 2050 show relative importance of carbon reduction strategies in long-term

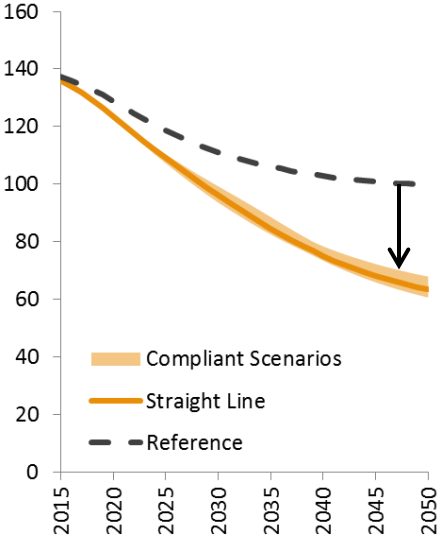


2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Success Requires Action in Four Areas

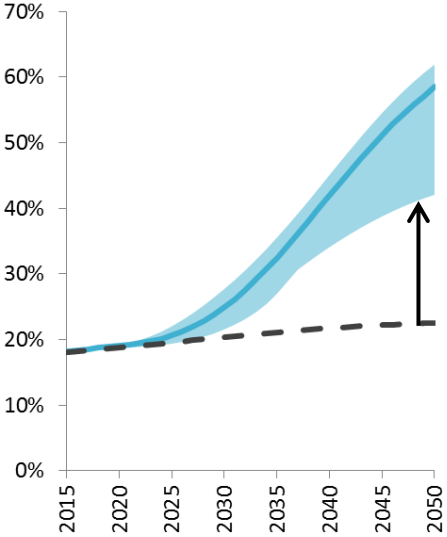
1. Efficiency and Conservation

Energy use per capita (MMBtu/person)

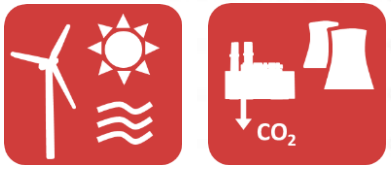


2. Fuel Switching

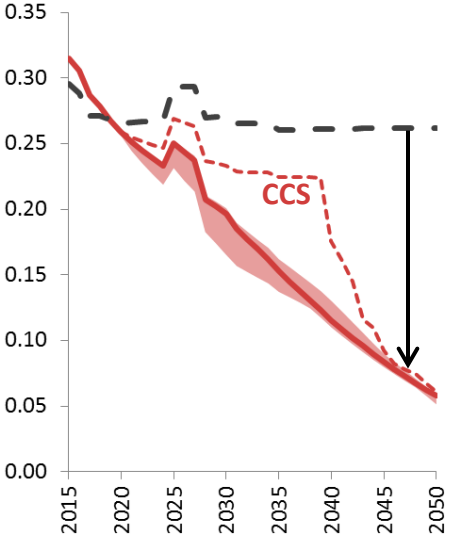
Share of electricity & H_2 in total final energy (%)



3. Decarbonize electricity

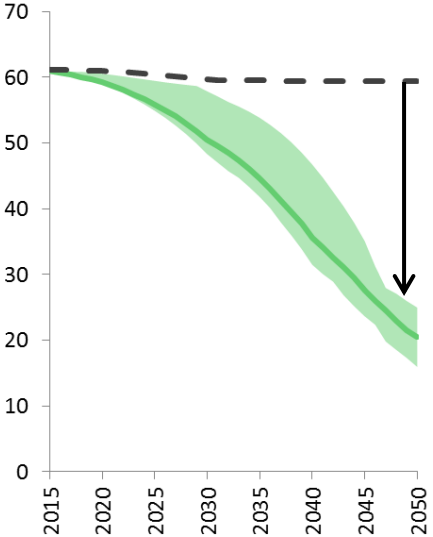


Emissions intensity (tCO2e/MWh)



4. Decarbonize fuels (liquid & gas)

Emissions intensity (tCO2/EJ)



2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Key Carbon Reduction Strategy Observations from Prior Work

- **Electricity decarbonization** – electricity policy must drive CA to near complete decarbonization by 2050
- **Renewable Fuel Standards** – policy must encourage development of fuels produced from electricity and should direct biomass toward its most highly valued uses
- **Transportation** – the majority of new light duty auto sales should be electric, fuel cell, or plug-in hybrid vehicles by 2030
- **Energy efficiency and electrification** – building energy efficiency programs must unlock deeper savings
- **Be proactive on distributional cost impacts** – key to sustaining a long term policy effort

NEXT STEPS

Next Steps

- E3 is working with ARB to update the CA PATHWAYS Reference scenario and to develop new Scoping Plan scenarios
- Revised model results will be translated into inputs to the macroeconomic analysis tool (REMI) to evaluate structural and jobs impacts
- Outputs from REMI are planned to feed-back into additional PATHWAYS model runs

For More Information

- **See:** https://ethree.com/public_projects/energy_principals_study.php
  - Model Documentation Technical Appendix
  - Model User's Guide
  - Analytica California PATHWAYS model v.3.2.1. (Note that the model will be updated for the Scoping Plan Update analysis)
  - PowerPoint of Energy Principals Scenario Results and supporting spreadsheets of inputs and outputs
- Williams et al, "The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity", *Science* 6 January 2011. https://www.sciencemag.org/content/335/6064/53.figures-only

Energy+Environmental Economics

Thank You!

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