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Energy+Environmental Economics

+ California PATHWAYS

RETI 2.0 Plenary Group
Planning Goals Workshop
January 29th, 2016

Arne Olson

Agenda

- PATHWAYS Background
- What is PATHWAYS?
- Results from Energy Principals Pathways study
- Key takeaways for RETI 2.0

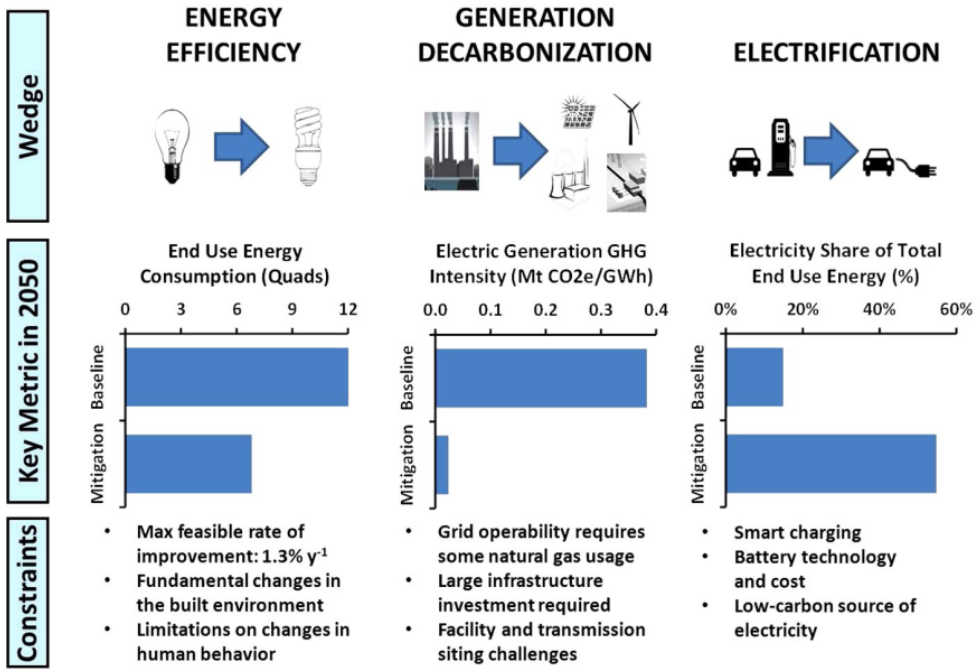
Energy + Environmental Economics (E3)

- 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

PATHWAYS BACKGROUND

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

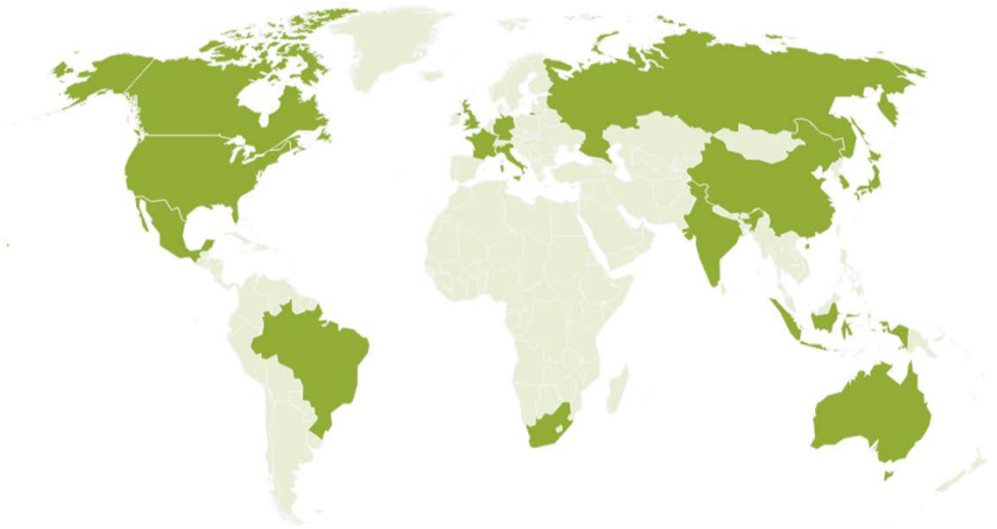
- What is the impact of the electric generation mix on the cost and feasibility of a low-carbon future in CA?
- Compared renewables, nuclear, carbon capture and storage
- Demonstrated a feasible pathway to 2050 goal with focus on electrification



"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**



ECONOMY

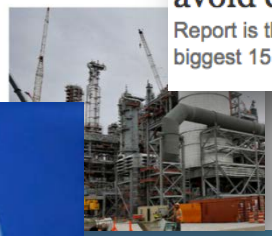
Blueprints for Taming the Climate Crisis

JULY 8, 2014

Here's what your future will look like if we are to have a shot at preventing devastating climate change.

Within about 15 years every new car sold in the United States will be electric. In fact, by

Eduardo Porter



UN issued with roadmap on how to avoid climate catastrophe

Report is the first of its kind to prescribe concrete actions that the biggest 15 economies must take to keep warming below 2C

UN: Avoiding climate disaster is tough but feasible

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Energy & Sustainability » Climatewire

Clean Energy to Stave Off Catastrophic Climate Change Possible by 2050, Barely

The world is not on track to keep global warming below 2 degrees Celsius but can still hold that line with tremendous effort

SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

deepdecarbonization.org

IDDRI
SciencesPo.

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

2016: AB 32 Scoping Plan Update

+ Overview

- Starting in 2016, E3 will be supporting the ARB with their update of the economic analysis in the Scoping Plan update
- E3 is updating the Energy Principles model with the latest data and updating new policy assumptions (e.g. SB 350)
- Revised model results will be translated into inputs to the macroeconomic analysis tool, REMI, to evaluate structural and job impacts

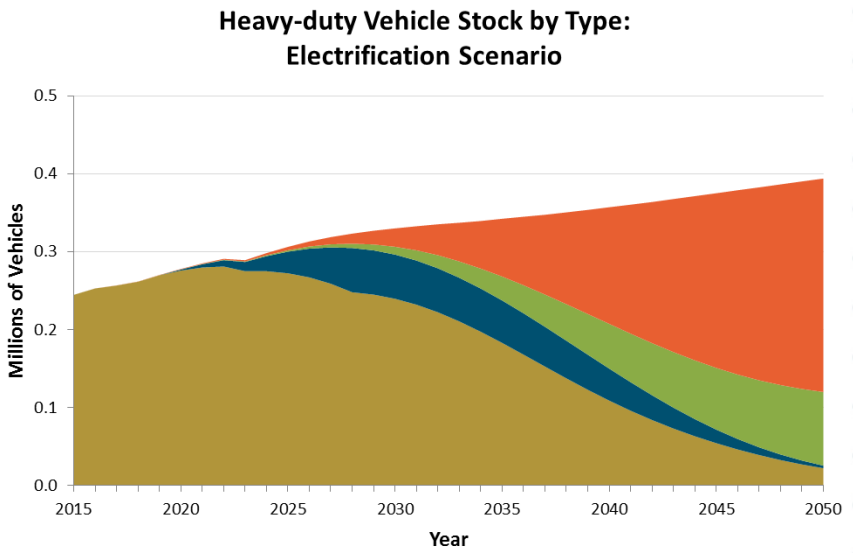
+ Logistics

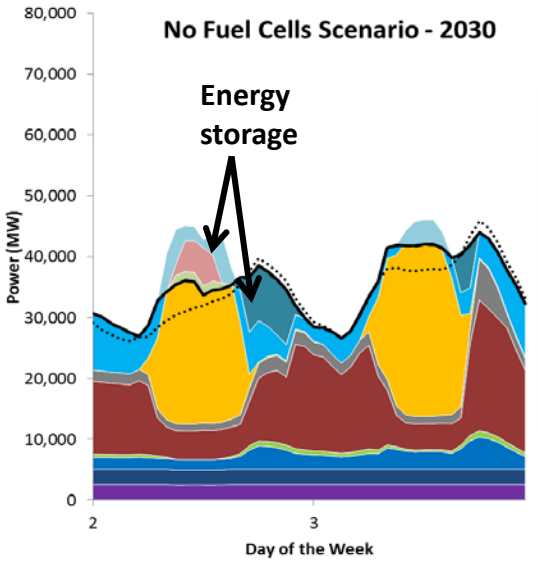
- Draft to be completed late Spring 2016
- More information: http://www.arb.ca.gov/cc/scopingplan/scopingplan.htm

WHAT IS PATHWAYS?

What is PATHWAYS?

- Bottom-up, user-defined, 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
- PATHWAYS is not a computable general equilibrium model





Allows for development of realistic & concrete GHG reduction roadmaps

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

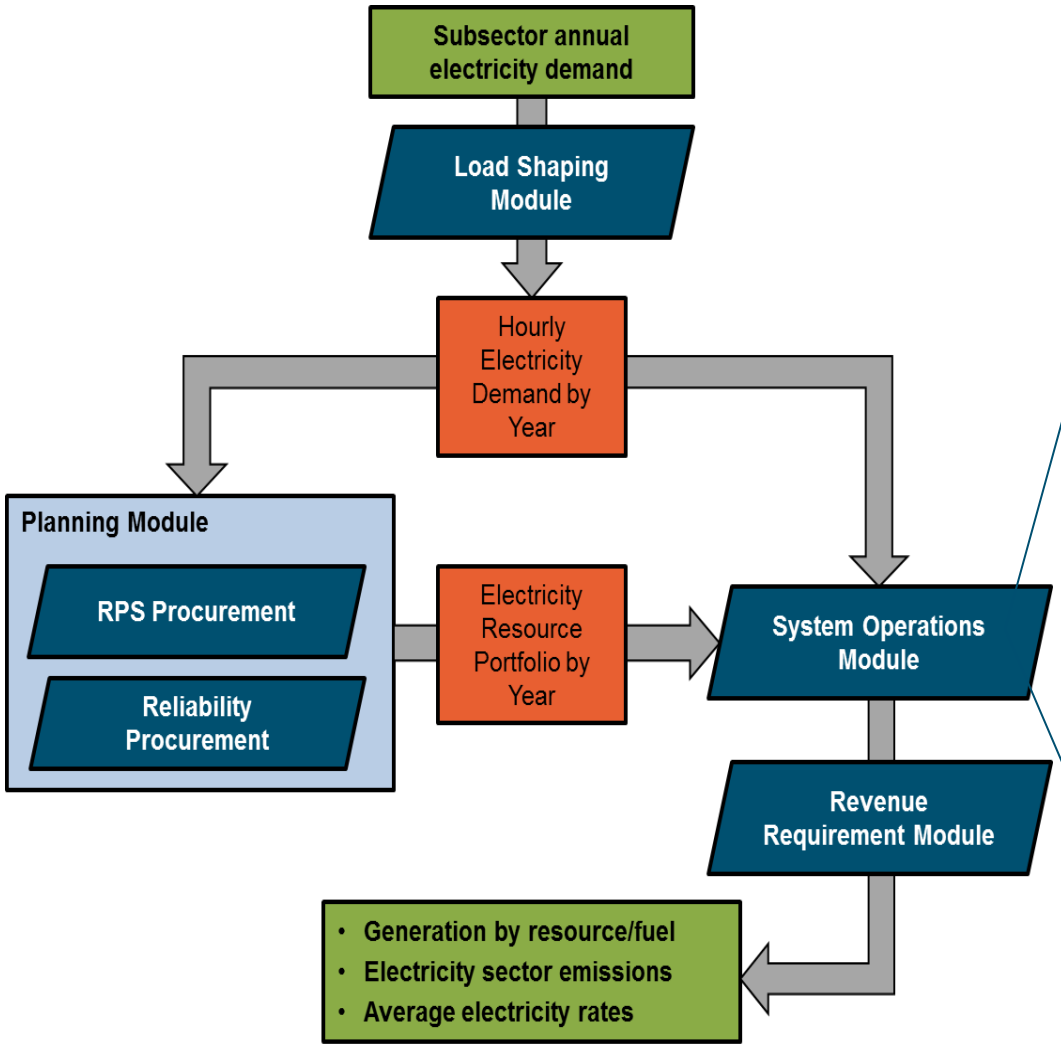
Other Fuels (Gasoline, Diesel, Hydrogen, etc.)

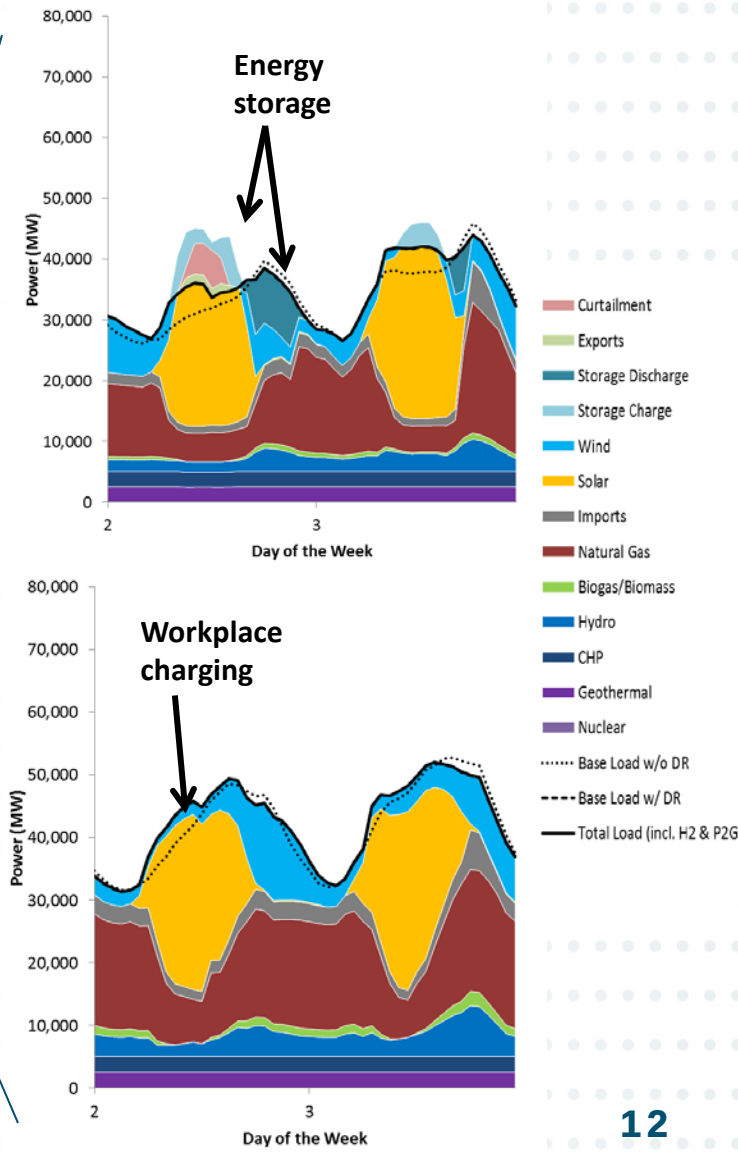
Model Outputs

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





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

RESULTS FROM 2015 ENERGY PRINCIPALS PATHWAYS STUDY

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

1. Reference	current GHG policies, as of 2014

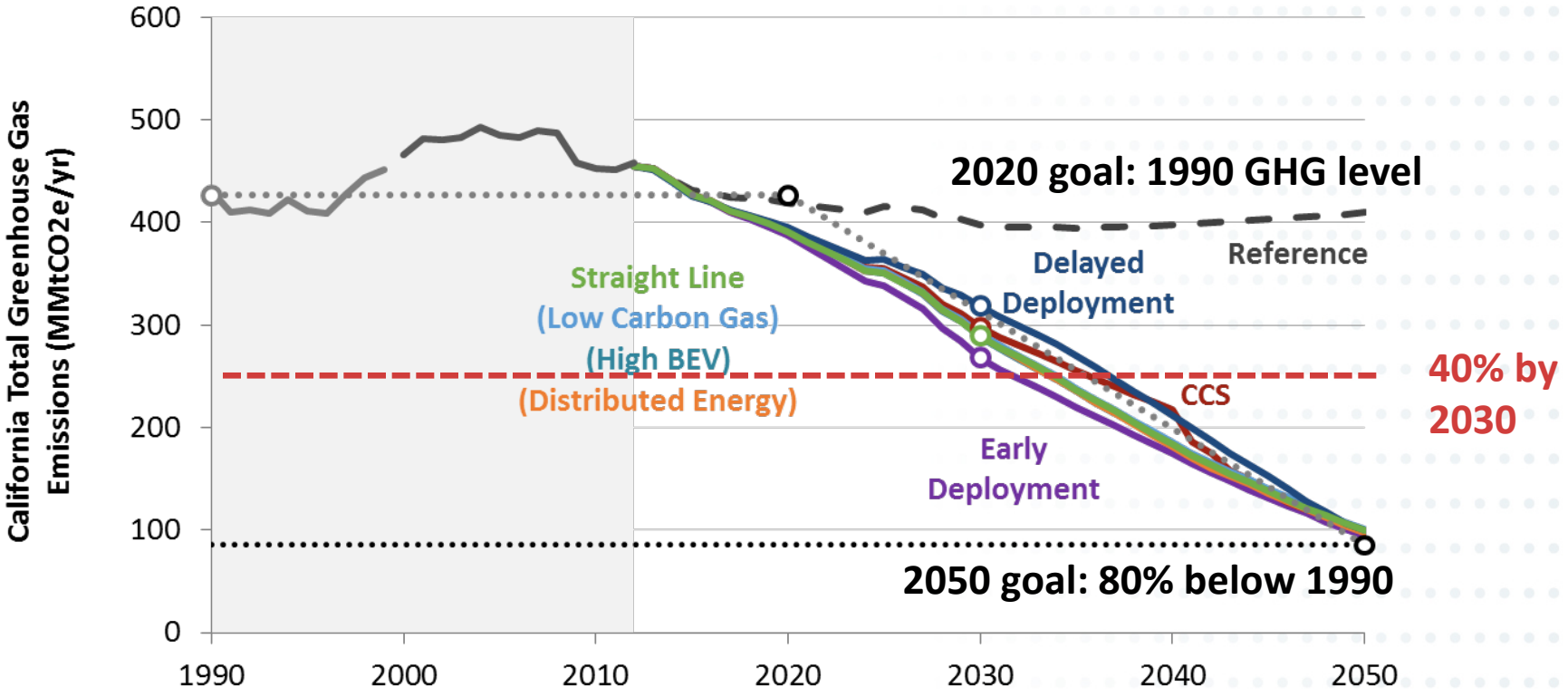
Timing Scenarios (achieve 80% below 1990 by 2050)

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

How do PATHWAYS scenarios measure up to GHG goals?



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

Decarbonizing CA's economy depends on four energy transitions

1. Efficiency and Conservation

By 2030:

- 8% reduction in vehicle miles traveled (smart growth)
- Continued vehicle fuel economy improvements
- Approximate doubling of current building efficiency savings goals

2. Fuel Switching

By 2030:

- 6-9 million light duty zero emission vehicles
- Trucking & freight strategy, i.e. CNG, hybrid, elec.
- 10% - 40% electric space heating & 5% - 70% electric water heating, depends on use of biogas

3. Decarbonize electricity

By 2030:

- 50 – 60% renewable electricity
- Renewable integration solutions

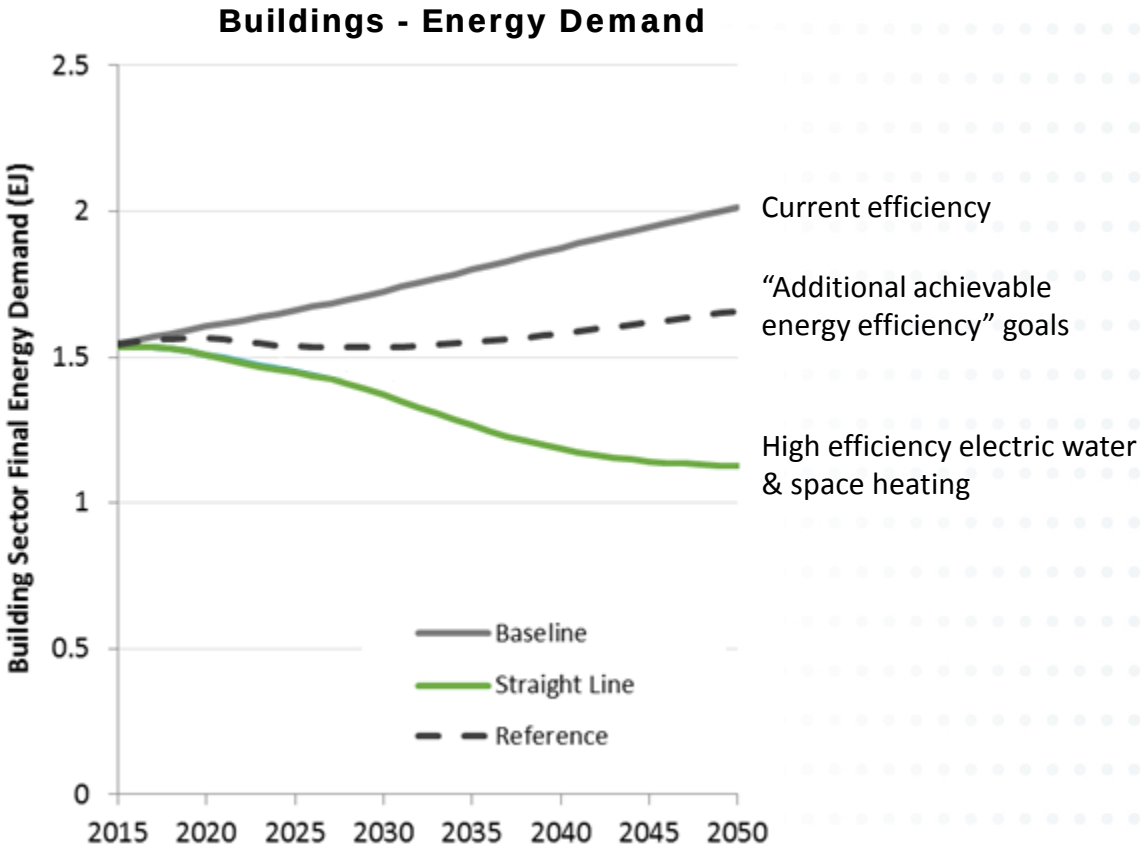
4. Decarbonize fuels (liquid & gas)

By 2030:

- 29 – 55% reduction in petroleum use in vehicles, relative to 2015
- Biofuels: Nearly all diesel use replaced with net-zero emissions biofuels, OR Nearly 50% biogas in the gas distribution pipeline

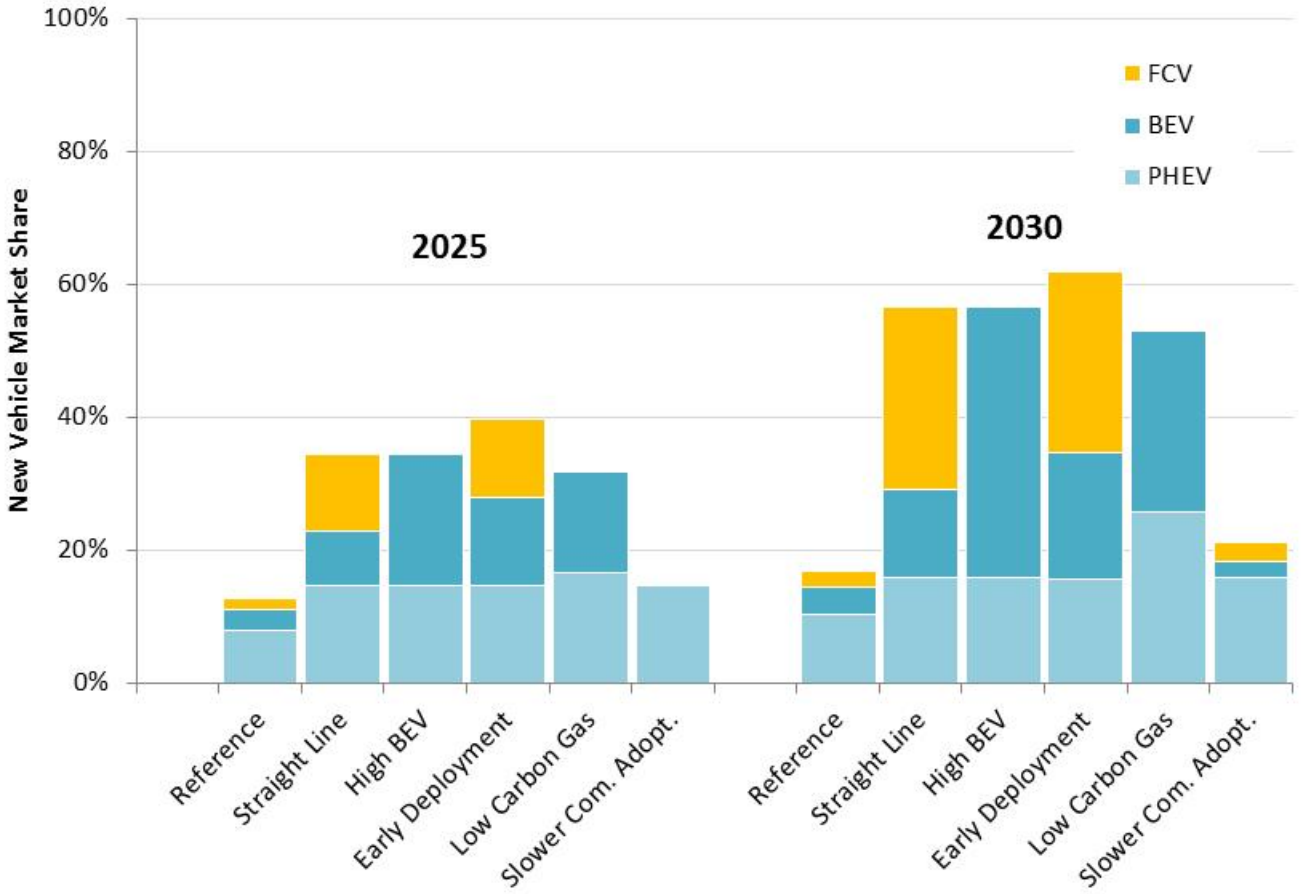
Higher energy efficiency in buildings

+ **Electric energy efficiency** is nearly double in the straight line scenario compared to current policy (Reference), mostly due to LED lighting and more efficient appliances



Light Duty Vehicles – ZEV & PHEV Market Share of New Sales (%) by Year

- Light duty fuel cell vehicles (FCV), battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) as % of new vehicle sales in 2025 and 2030

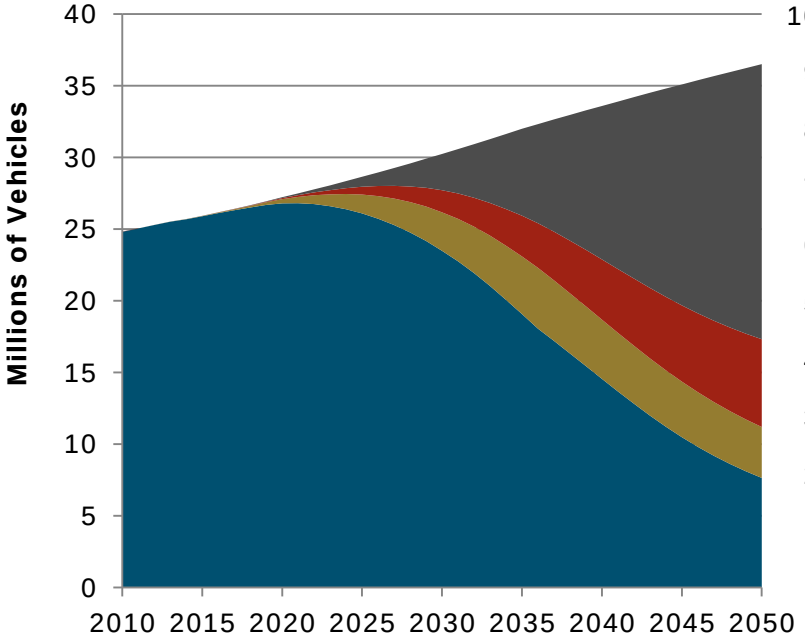


2015 Energy Principles outputs, subject to change in CARB Scoping Plan

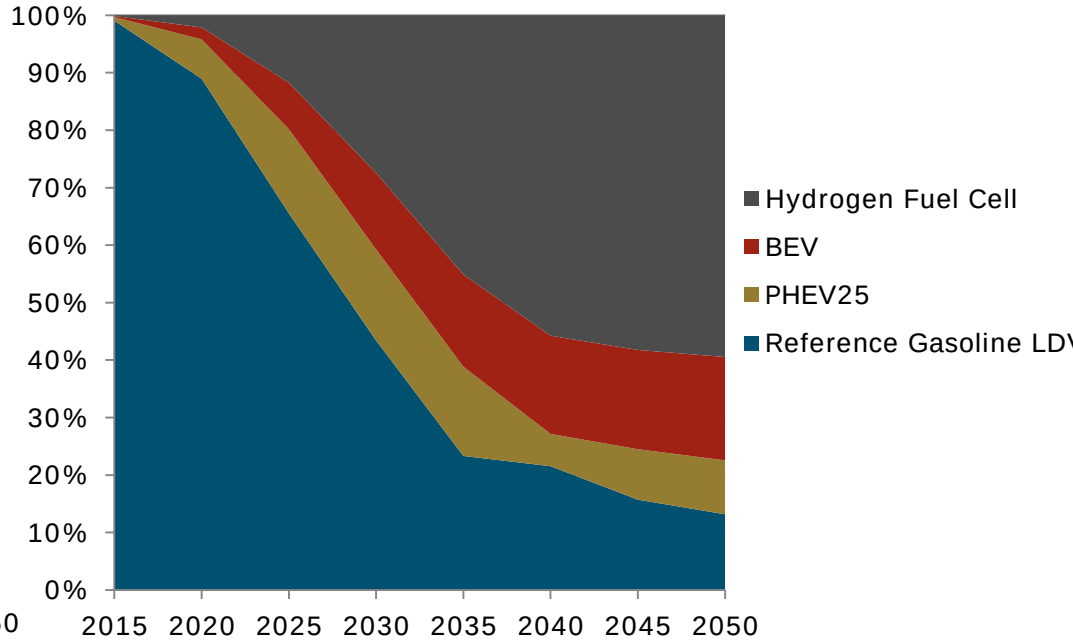
Light Duty Vehicle Fleet

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

Light Duty Vehicle Stock, Straight Line Scenario

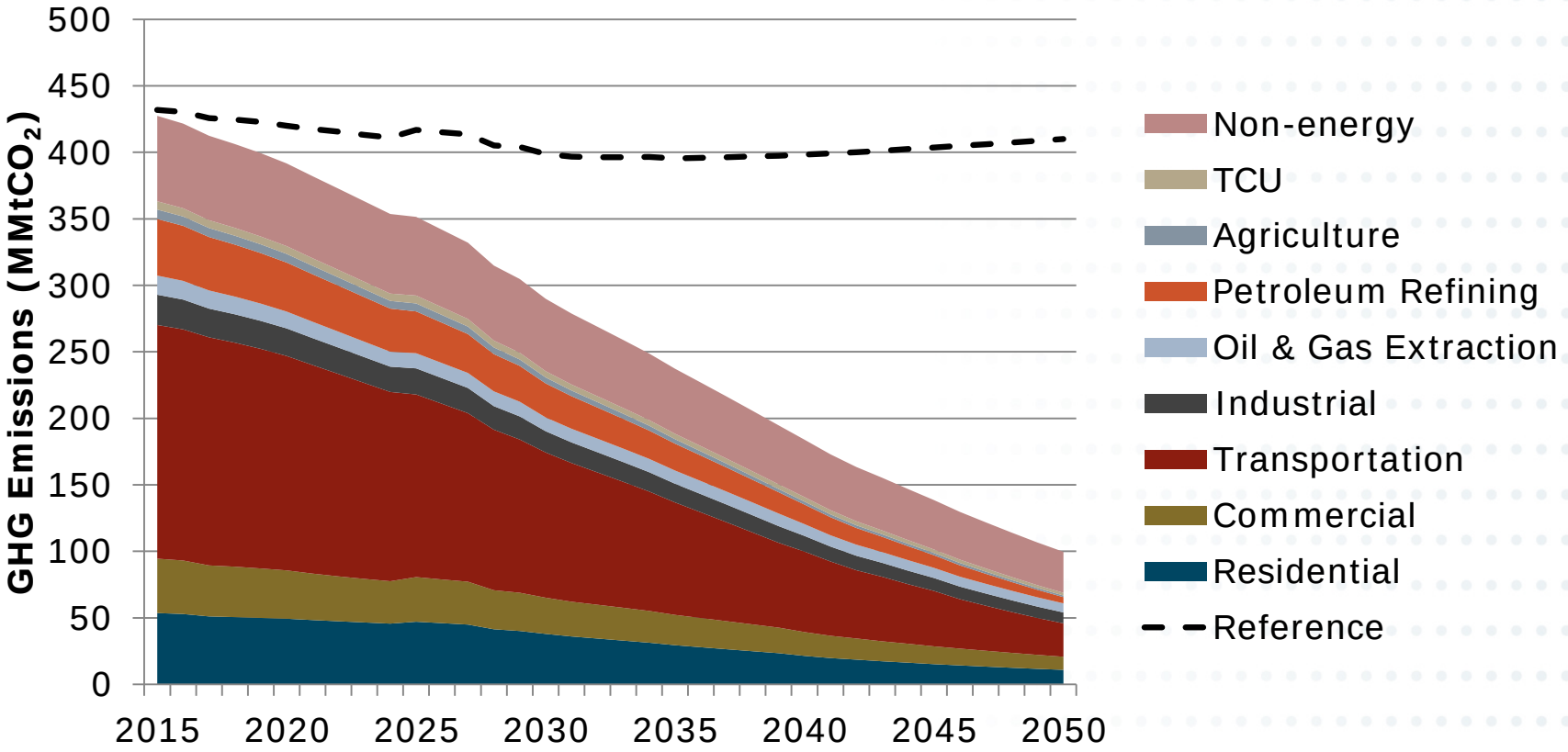


Light Duty Vehicle Sales, Straight Line Scenario



Greenhouse Gas Emissions

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

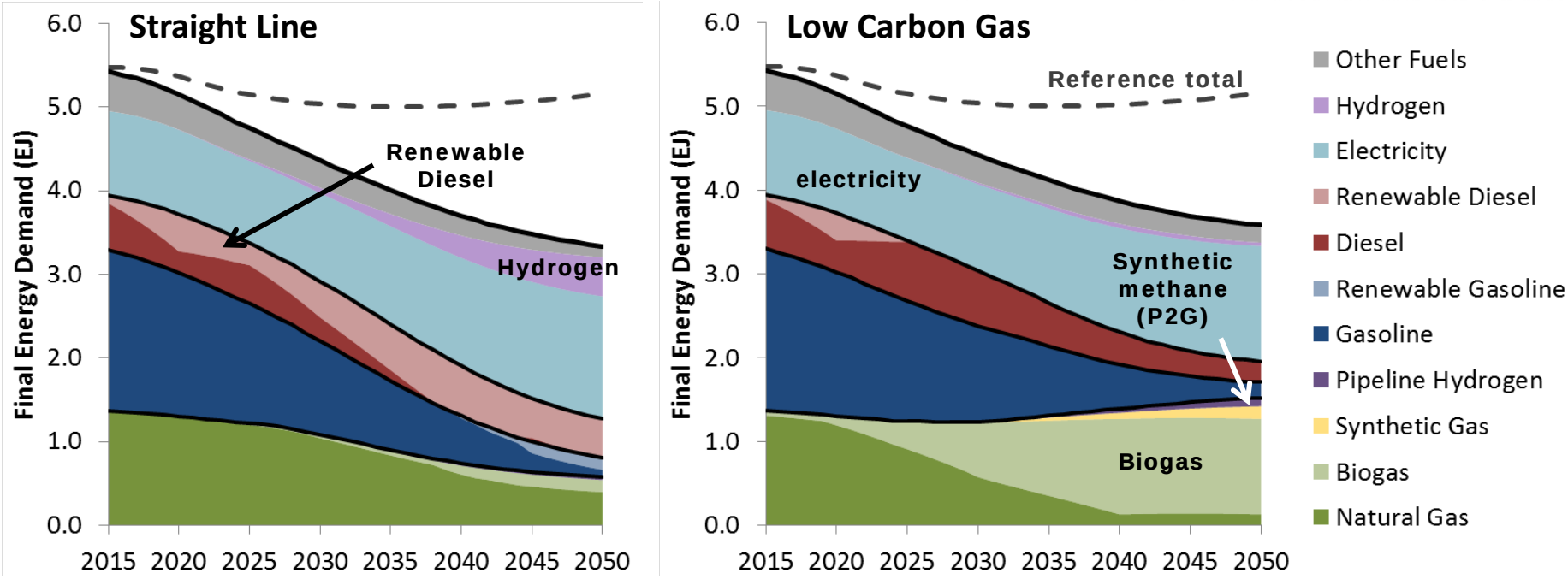


OBSERVATIONS FROM PATHWAY STUDIES

A key question is how to make best use of limited biofuels

- **Sustainable biomass supply is limited**, insufficient supply to displace both natural gas & diesel consumption (assuming CA's share of U.S. resource)
- **If biofuel supply is limited, greater electrification and/or carbon neutral fuels produced using low-carbon electricity is needed**

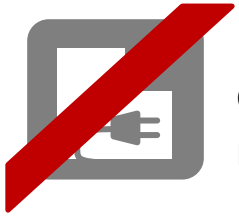
Final Energy Demand by Major Fuel Type



There are some forks in the road that may require decisions by government

Zero Emissions Vehicles

Fuel cell vehicles, flexible grid electrolysis



No additional energy storage needed

Battery electric vehicles

Significant energy storage needs

Buildings Strategy

Biogas replaces natural gas in buildings

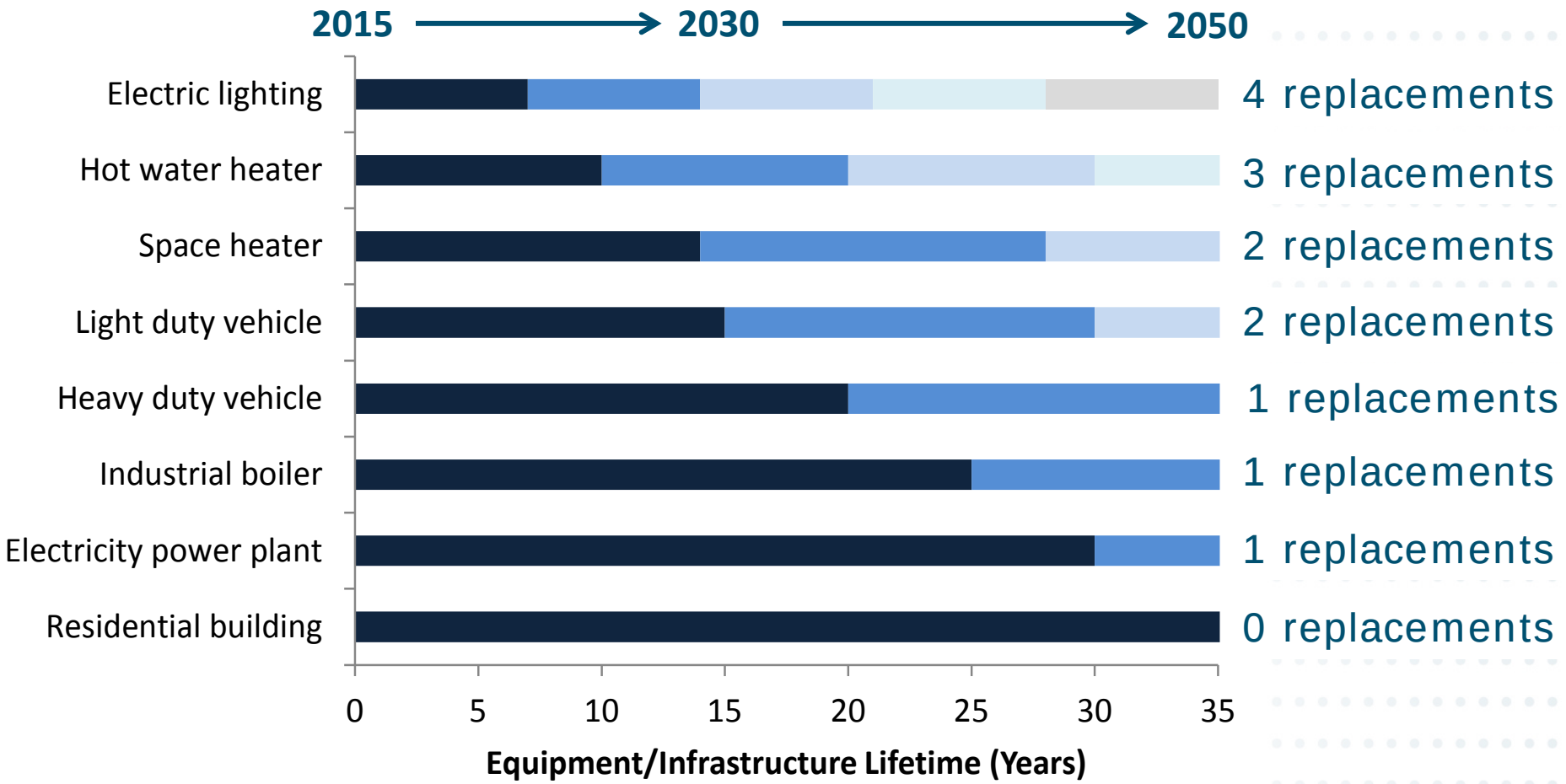
No building electrification needed

Electrification of buildings

No gas pipeline

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.



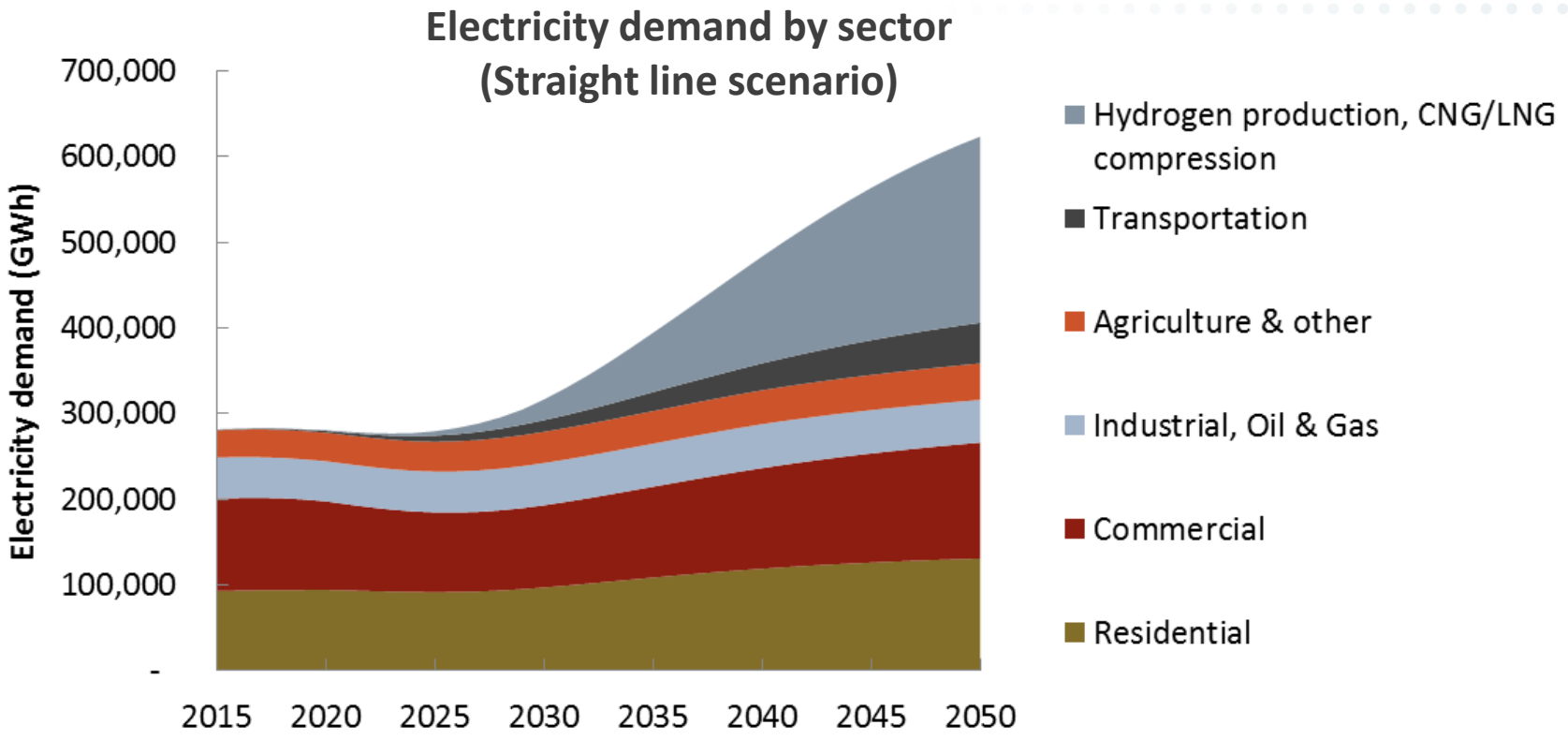
Additional Observations

- **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

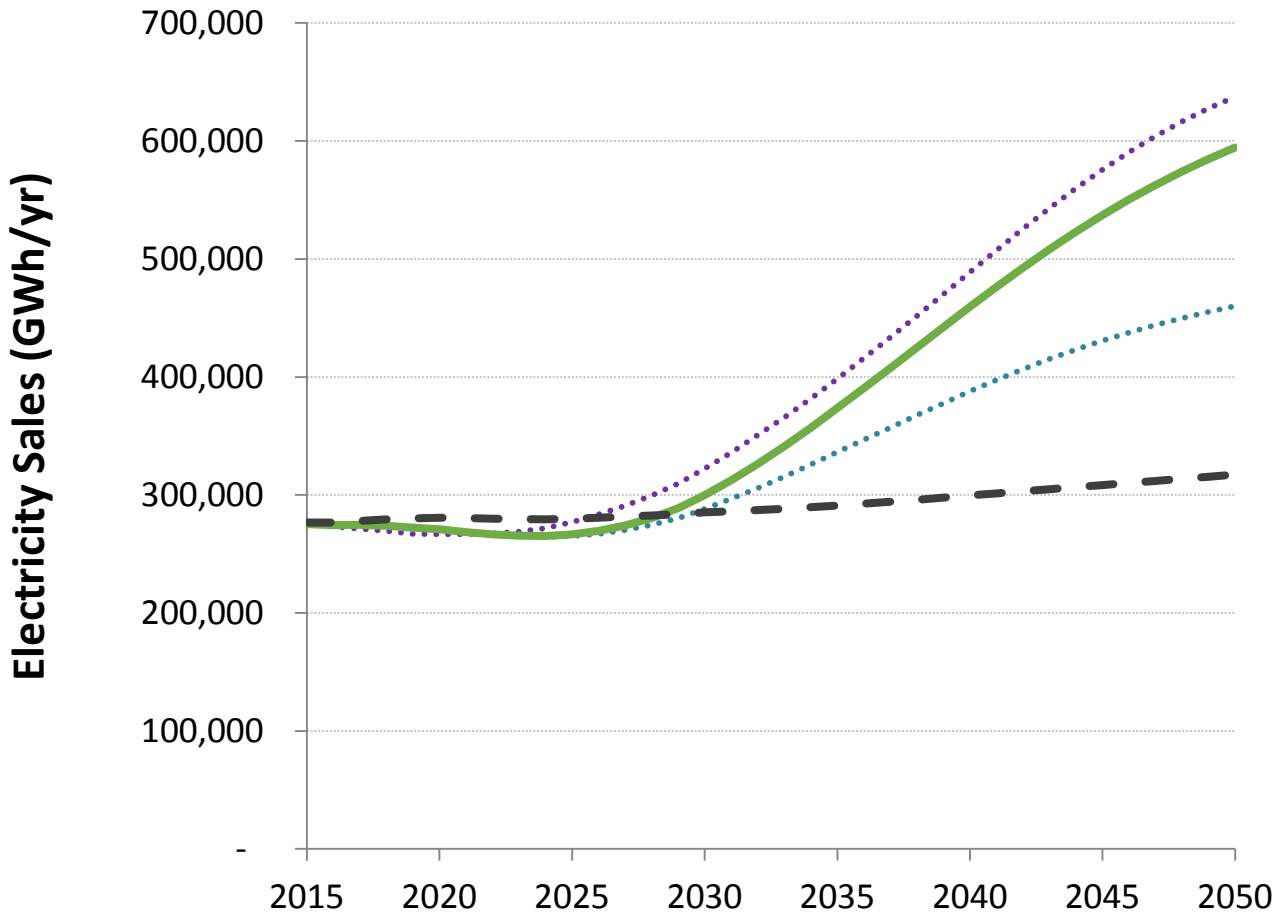
KEY TAKEAWAYS FOR RETI 2.0

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



Electricity Sales by Scenario

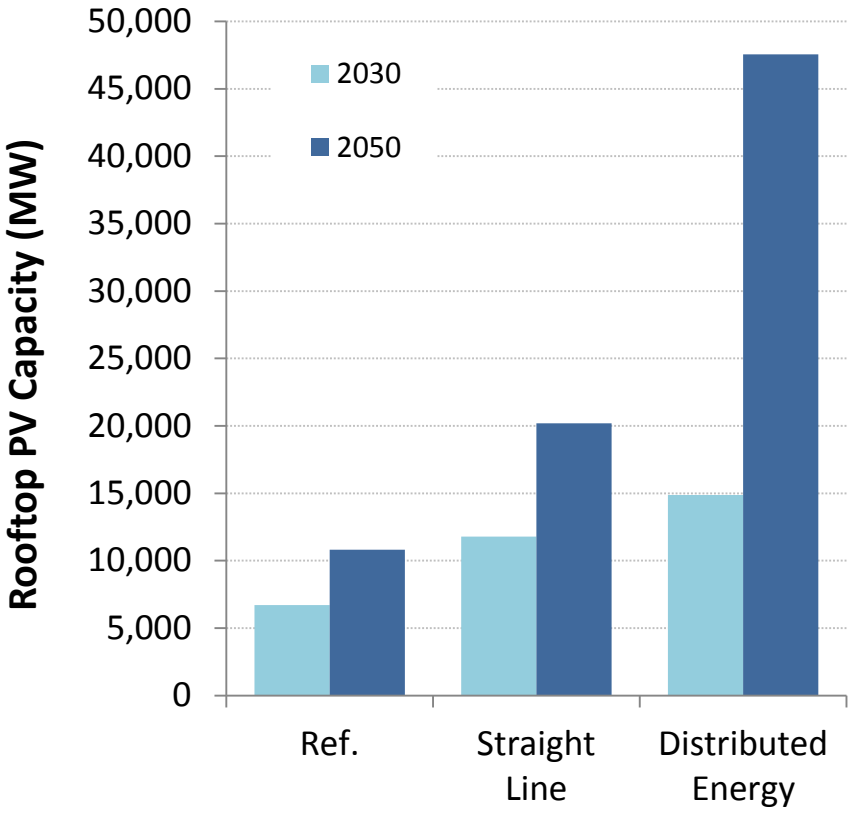


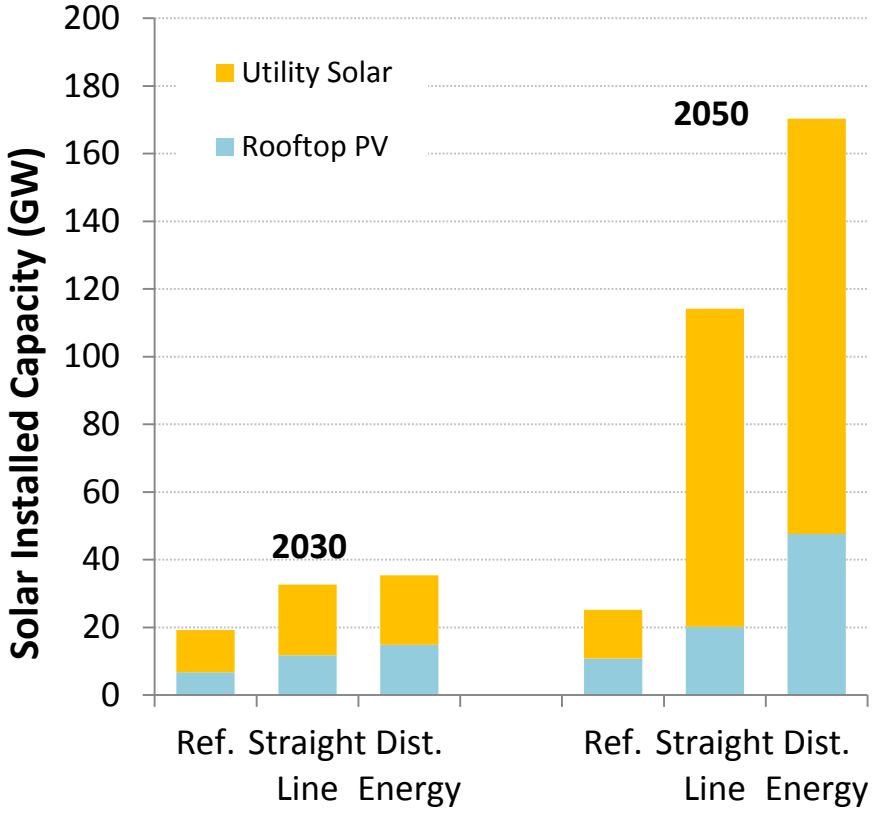
New loads from hydrogen production are dependent on fuel cell vehicles.

A high BEV (and low FCEV) scenario has much lower electric load growth.

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

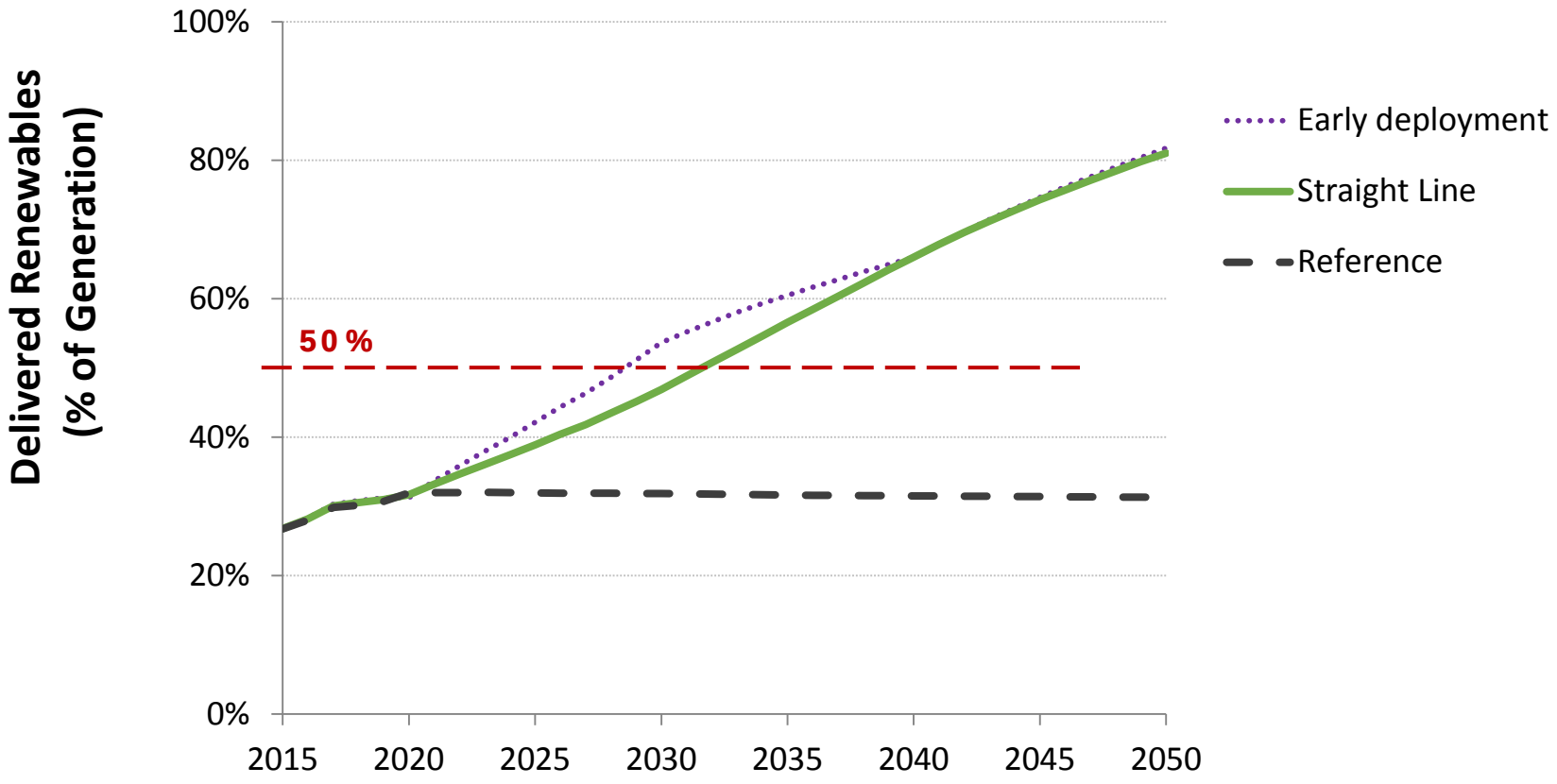
Solar PV Adoption





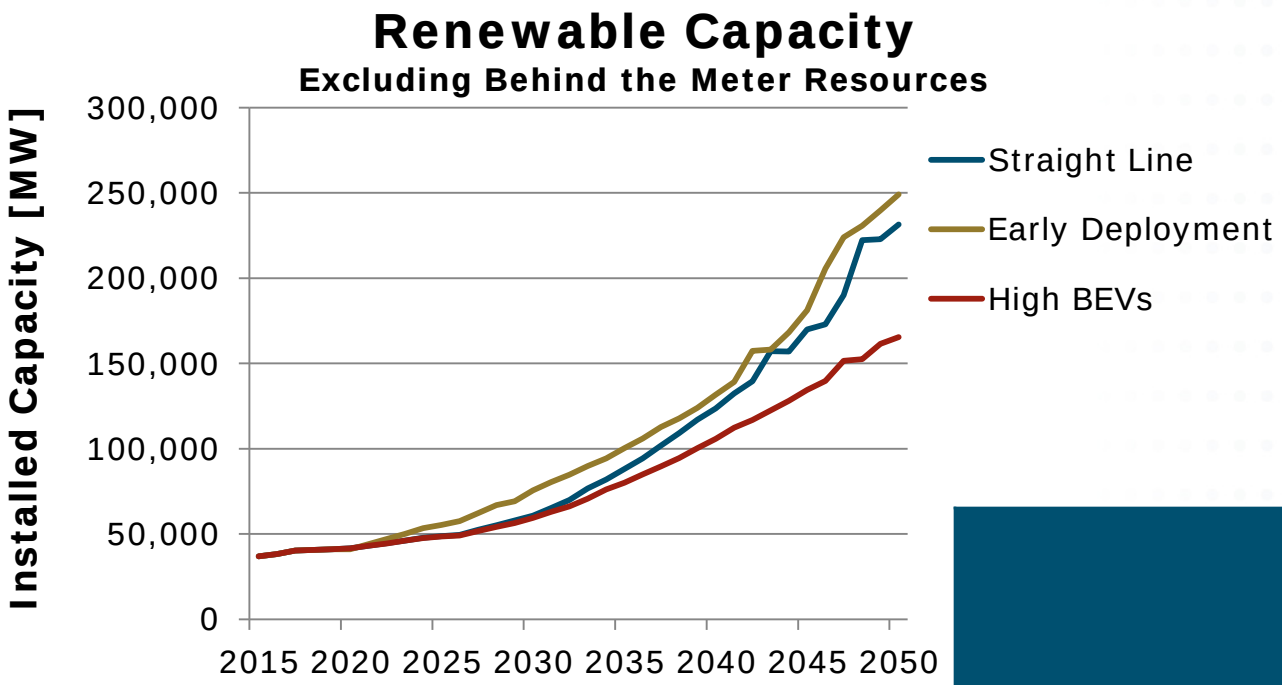
2015 Energy Principles outputs, subject to change in CARB Scoping Plan

Renewable Penetration



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

Renewable Capacity Growth



	Renewable Capacity in 2030* [MW]	Renewable Generation in 2030* [GWh]
Straight Line	60,754	176,139
Early Deployment	75,613	213,049
High BEV	59,317	170,039

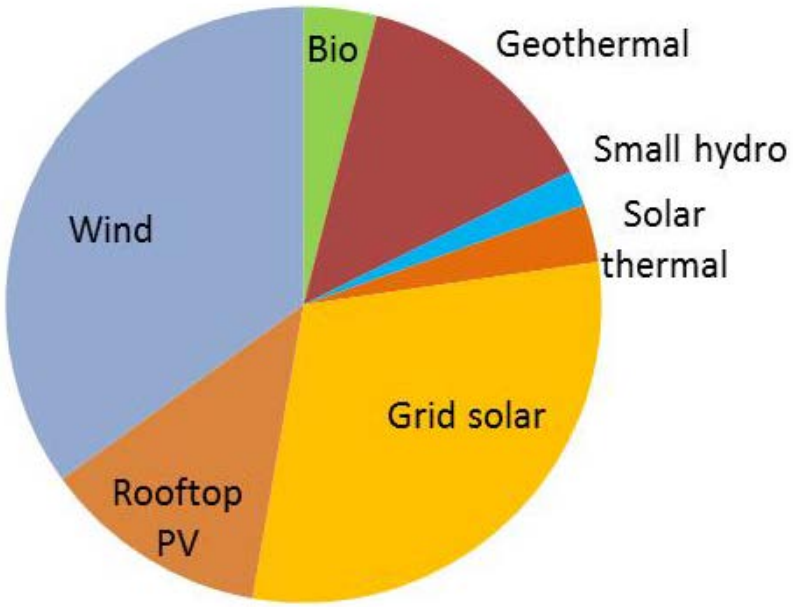
*Not including behind the meter renewables

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

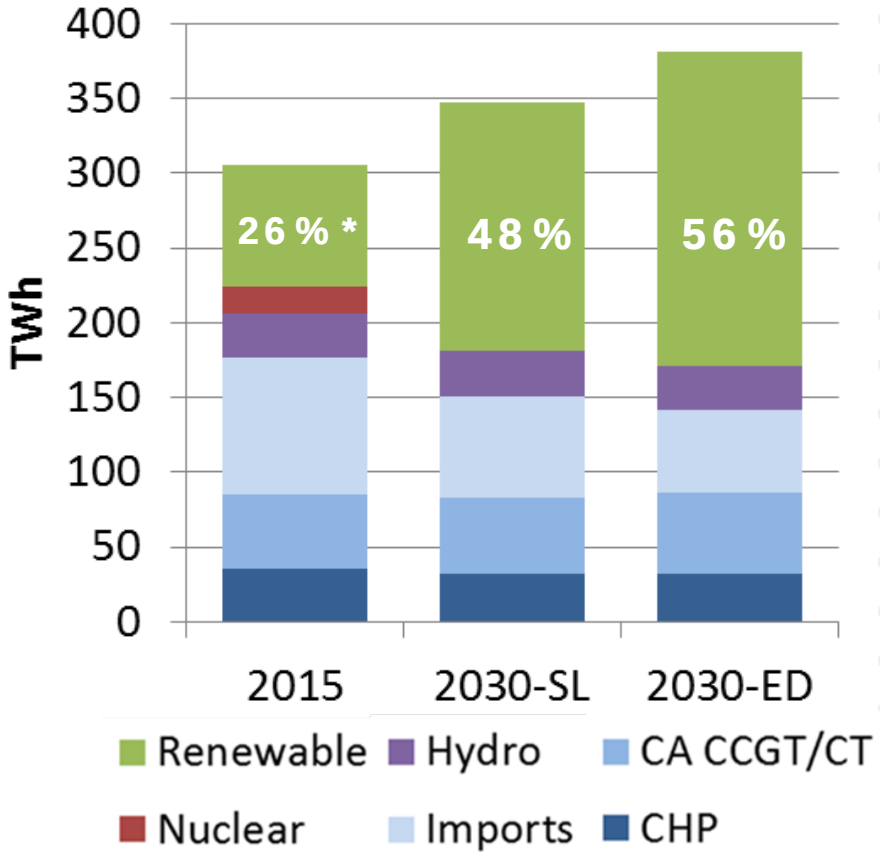
Renewables are 50-60% of annual generation by 2030

- Average grid scale renewable additions are ~2,400 MW/year (mostly solar, wind) plus total 11,800 MW rooftop PV by 2030

2030 Renewable Generation by Type (%) – Straight Line



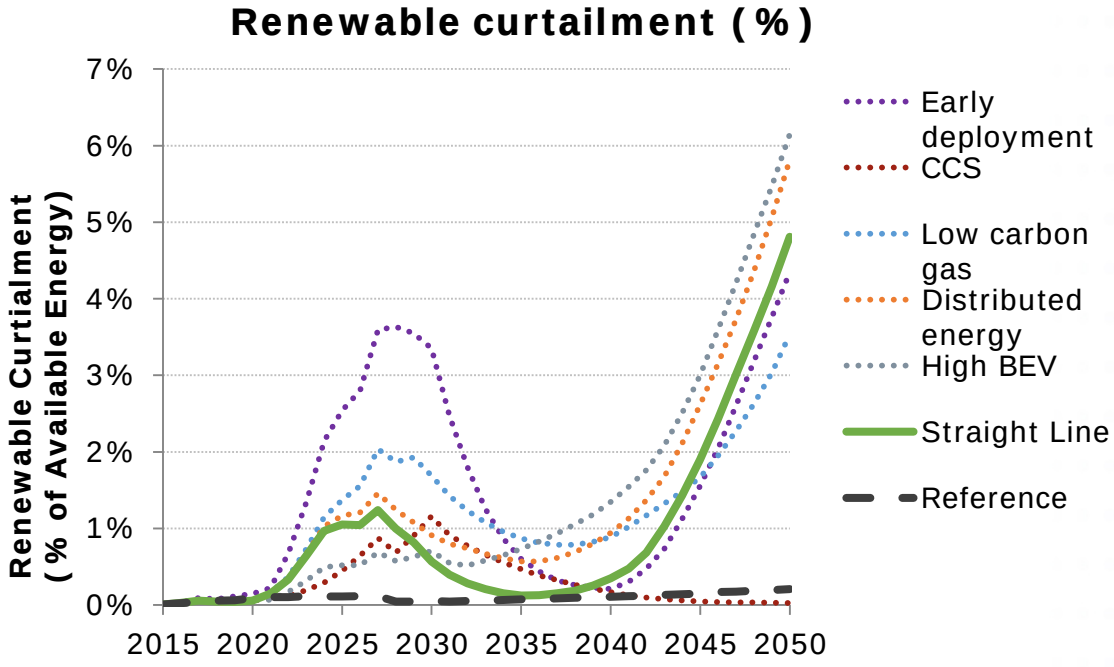
2015 & 2030 Annual Generation



* Estimated, not actual value

Integration solutions needed to avoid curtailment may come from new, flexible demands

- Curvature is due to 2025 nuclear retirement and end of imported coal electricity in late 20s
- Straight Line scenario assumes grid electrolysis (producing hydrogen for fuel cell vehicles) will provide grid balancing services. With no fuel cell vehicles or grid electrolysis, renewable curtailment and/or dedicated electricity energy storage needs increase substantially.
- **Important Note:** Storage needed for integration and system-wide renewable curtailment are highly sensitive to input assumptions in PATHWAYS. Additional integration studies would be needed to precisely determine adequate storage capacity for each PATHWAYS scenario



PATHWAYS Straight-line scenario: Renewable Curtailment [GWh]

2030	2050
833	5778

Energy+Environmental Economics

Thank You!

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