Energy+Environmental Economics

California PATHWAYS: GHG Scenario Results

Updated Results April 6, 2015

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Agenda

+ **Overview of California PATHWAYS**
+ **Scenario results**
  - 2030 greenhouse gas emissions
  - Commonalities across scenarios
  - Forks in the road
  - Costs impacts of the energy transformation

About the California state agencies' PATHWAYS project

+ Purpose

- To evaluate the feasibility and cost of a range of greenhouse gas reduction scenarios in California

+ Project sponsors

- Collaboration between CARB, CAISO, CPUC, CEC
- Additional funding provided by the Energy Foundation

+ Team

- Energy & Environmental Economics with support from LBNL

PATHWAYS: modeling approach

- **PATHWAYS is a California-wide, economy-wide infrastructure-based GHG and cost analysis tool**
  - Adoption rates of technologies are defined by user, stock turn-over rates are based on lifetime of equipment
  - Energy & infrastructure costs are tracked
  - Not a macroeconomic model, costs & technologies are not endogenously defined, not an optimization model
- **"Bottom up" forecast of energy demand by end use, driven by:**
  - Population, residential & commercial square footage, space heating/cooling, water heating, lighting, etc.
- **Hourly electricity demand & supply detail simulates planning, system operations, and cost**

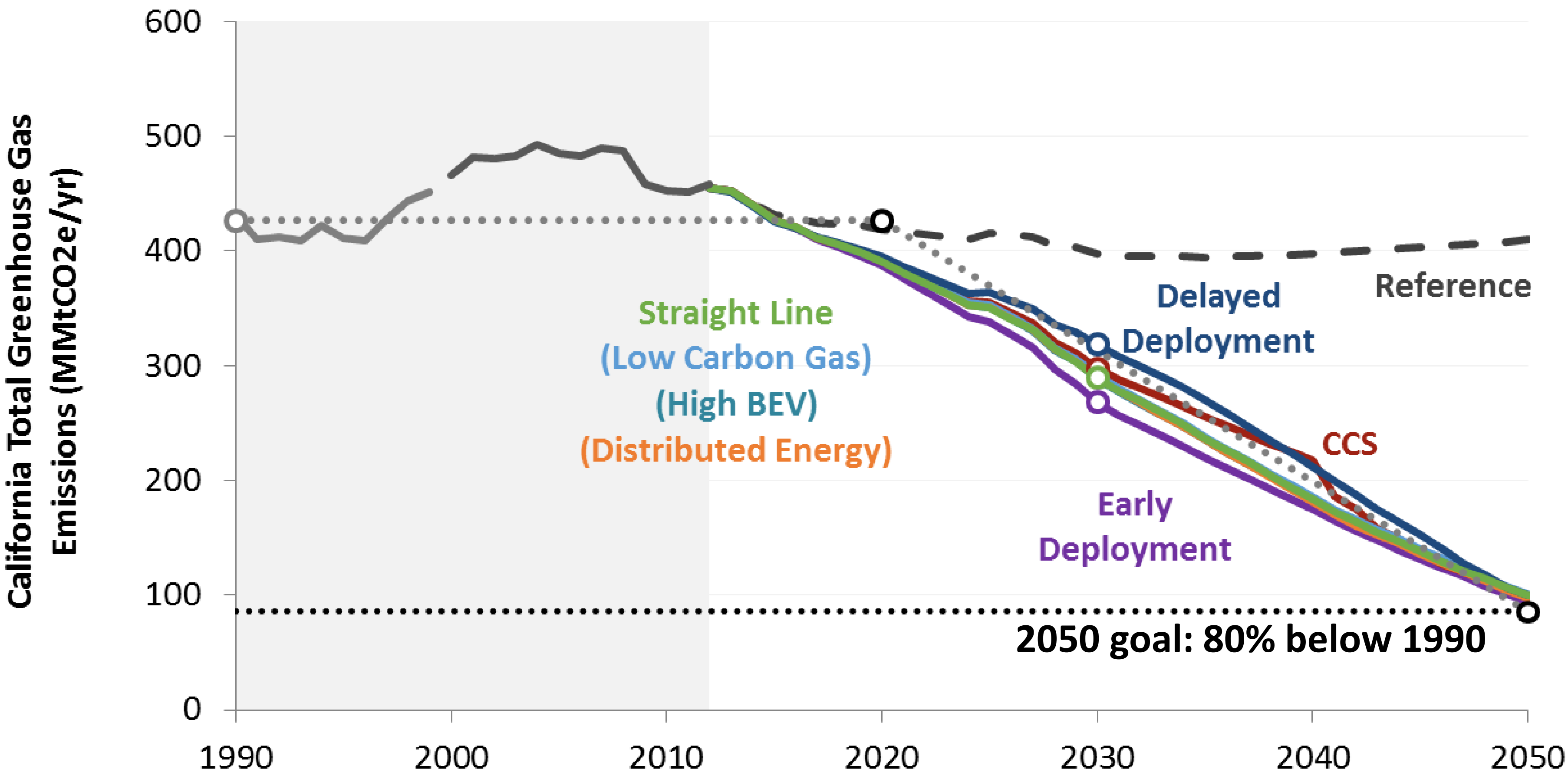
Key conclusions

- GHG reductions of 26 – 38% below 1990 levels (319 – 268 MMTCO2e) appears achievable in 2030 with significant increase in GHG reduction efforts, mitigation of key risks
- 2030 "straight line" scenario ranges from net savings of $4B to net cost of $11B (in real 2012$)
- Critical to success of long-term GHG goals:
  1. Significant increase in energy efficiency and conservation in buildings, vehicles & industry
  2. Fuel-switching away from fossil fuels in buildings & vehicles
  3. Sustained pace of low-carbon electricity development (~50% renewables in 2030 in CA)
  4. Decarbonize liquid or gas fossil fuels with sustainable biofuels and/or synthetic decarbonized fuels
  5. Reductions of non-energy GHGs (methane & F-gases)
     More data are needed on forestry & land-use GHG emissions

Key scenario assumptions

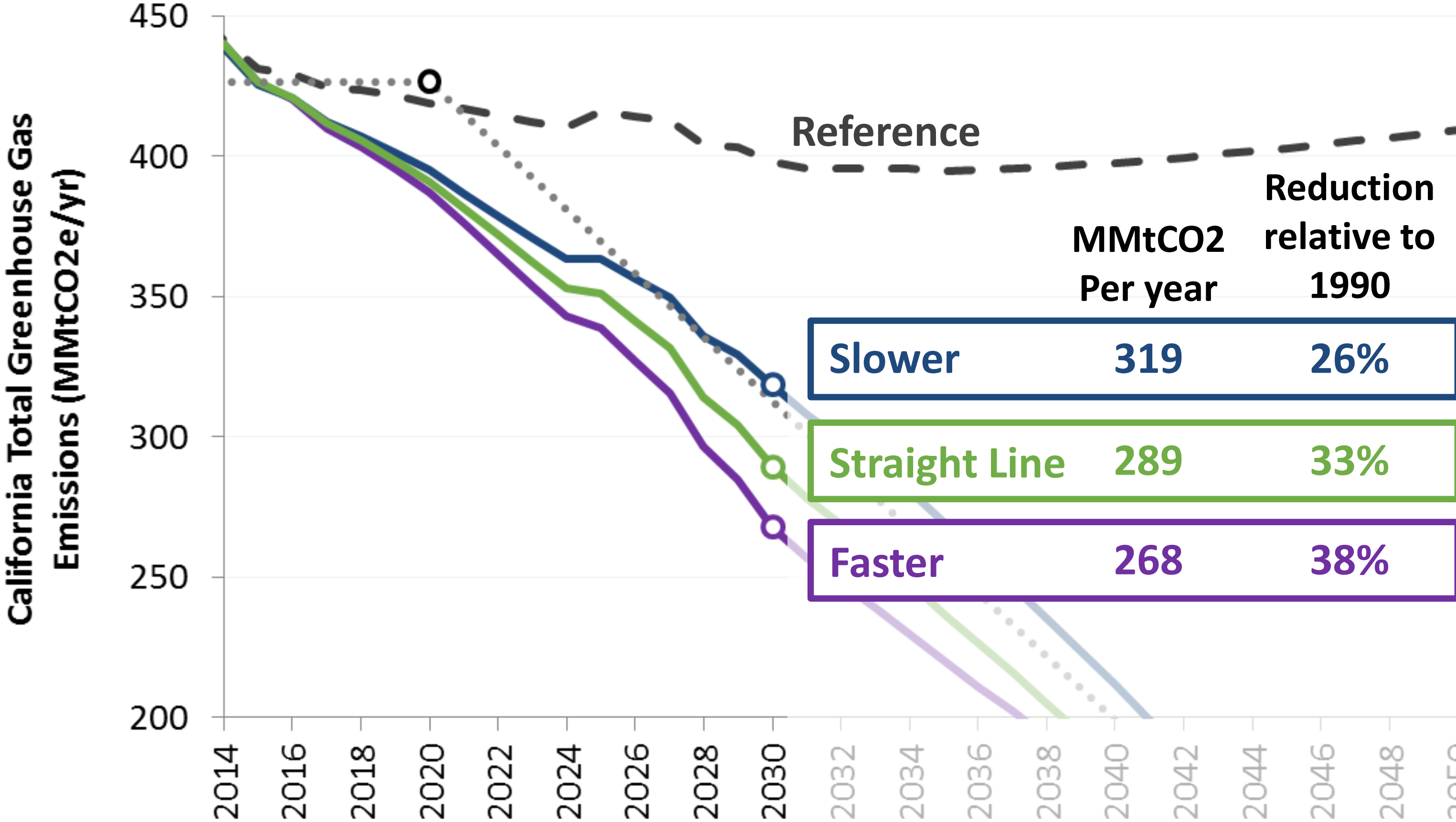
- Continuation of current lifestyle & growth of economic activity
- Technological conservativism, plus key emerging technologies
- Natural retirement of equipment (not early replacement)
- Biomass use is limited based on DOE estimate of sustainable supply
- Advanced biofuels are assumed to have net-zero carbon emissions
- Electricity planning and operational assumptions maintain hourly balance of electricity supply & demand

Multiple scenarios are on a consistent trajectory to meet 2050 GHG goal



A range of potential targets in 2030 are consistent with 2050 goals

Initial scenarios achieve a 26% – 38% reduction in GHGs by 2030, relative to 1990 GHG levels (34% - 45% below 2005 levels)

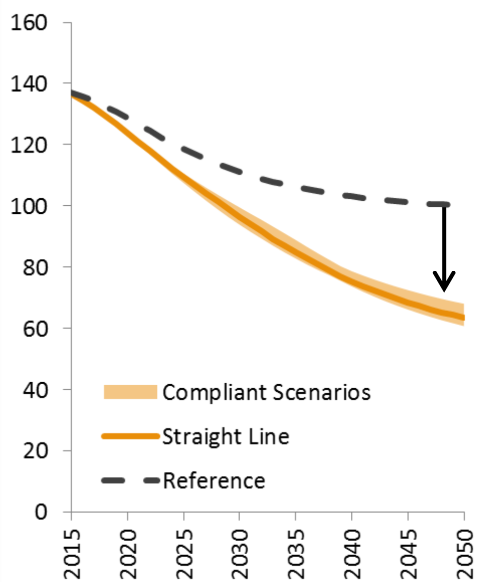


	MMtCO2 Per year	Reduction relative to 1990
Slower	319	26%
Straight Line	289	33%
Faster	268	38%

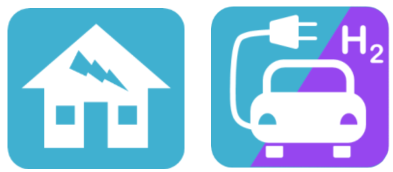
Decarbonizing CA's economy depends on four energy transitions

1. Efficiency and Conservation

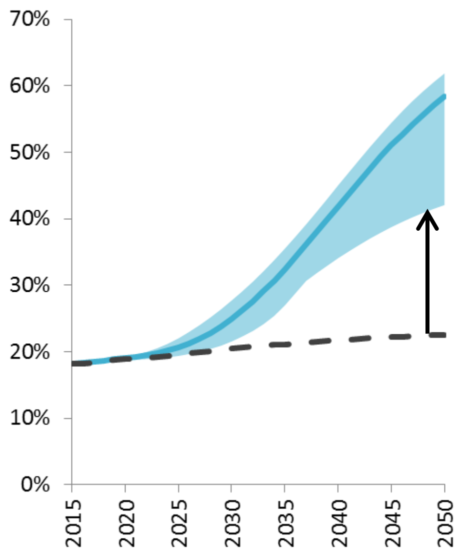
Energy use per capita (MMBtu/person)



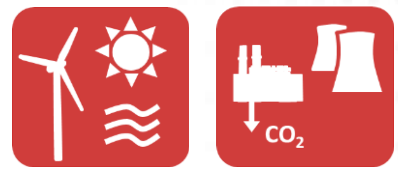
2. Fuel Switching



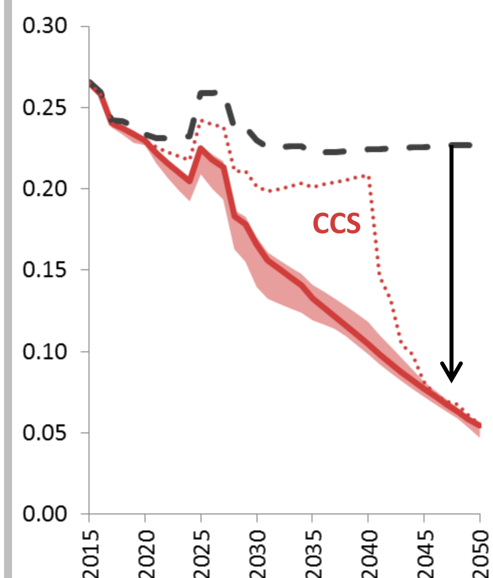
Share of electricity & H_2 in total final energy (%)



3. Decarbonize electricity

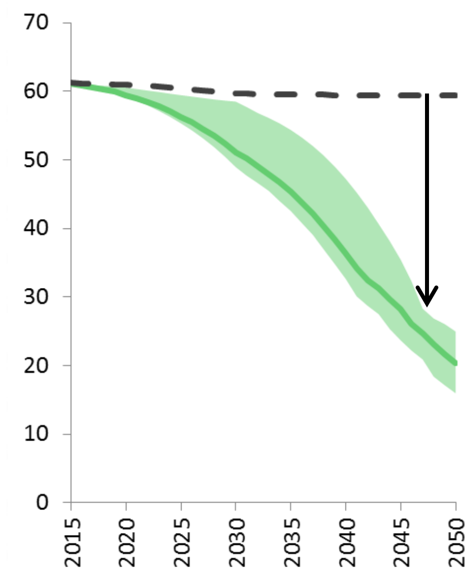


Emissions intensity (tCO2e/MWh)



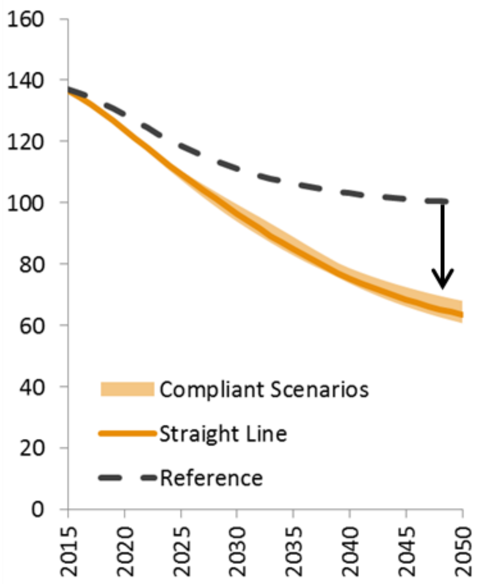
4. Decarbonize fuels (liquid & gas)

Emissions intensity (tCO2/EJ)



1. Doubling of current energy efficiency goals & reduced vehicle miles traveled

Energy use per capita (MMBtu/person)



+ Higher Efficiency in Buildings & Industry

- Approximate doubling of current plans for EE savings
- Largest EE savings assumed to come from commercial LED lighting, more efficient equipment & appliances

+ Higher Efficiency of Vehicles and Reduced Demand for Transportation Services

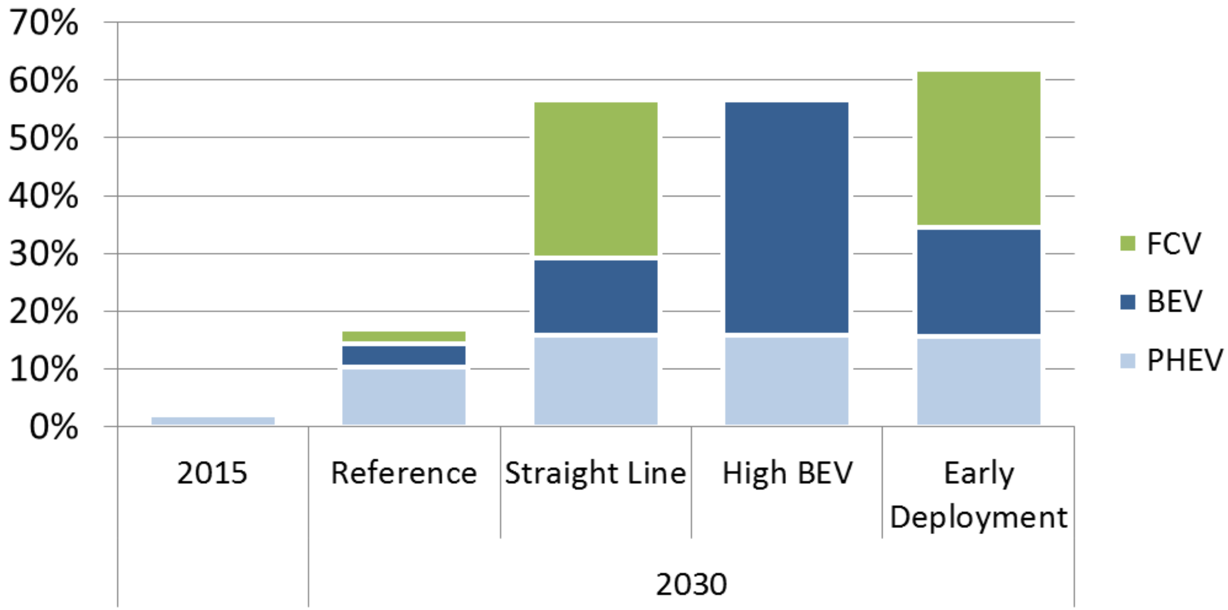
- 8% reduction in vehicles miles traveled through smart growth policies and demographic trends by 2030
- Sustained vehicle efficiency improvements
- Petroleum refining and oil & gas extraction energy use decline proportionally with demand for liquid fossil fuels

2. Greater reliance on electricity in buildings & zero emission vehicles

- Switching to electric space conditioning & water heating in buildings
- Electric processes in industry
- Rapid ramp up of battery electric and/or fuel cell vehicles

- 6-7 million ZEVs and PHEVs on the road by 2030

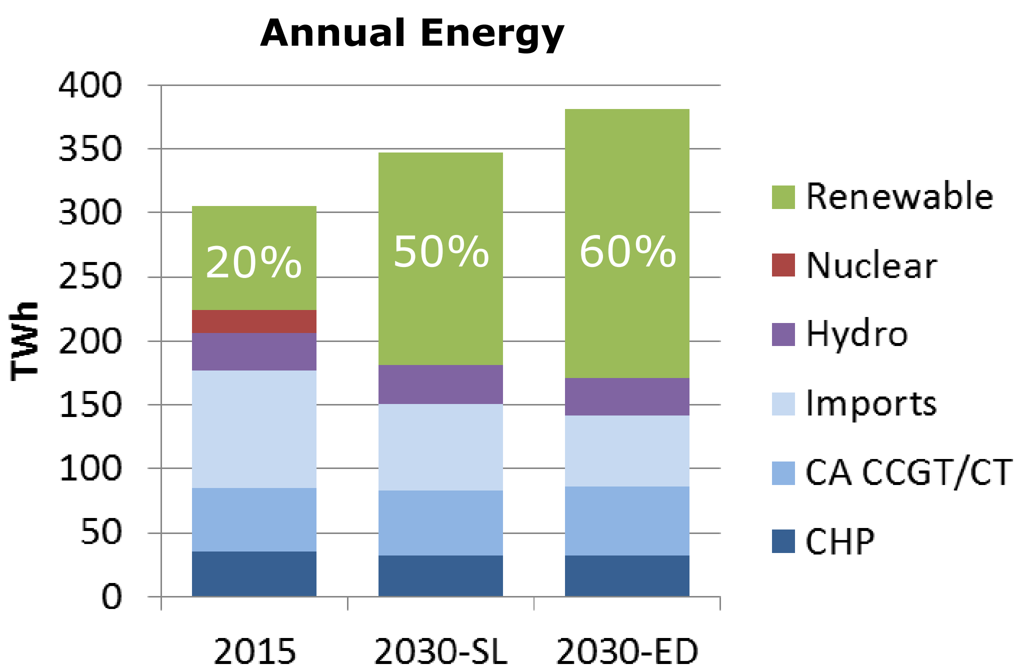
Share of New Vehicle Sales by Year and Technology

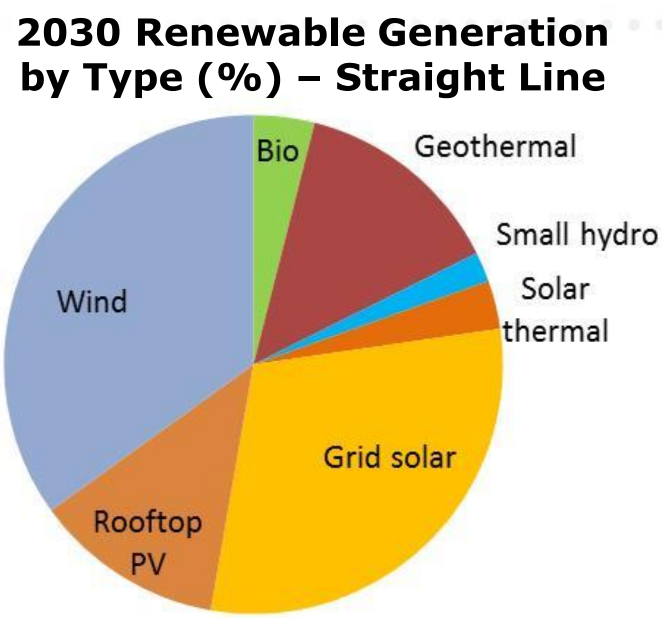


3. Renewables account for 50-60% of annual energy use by 2030

+ **Average renewable additions are ~2,400 MW/year (plus rooftop PV) through 2030, mostly solar and wind resources.**

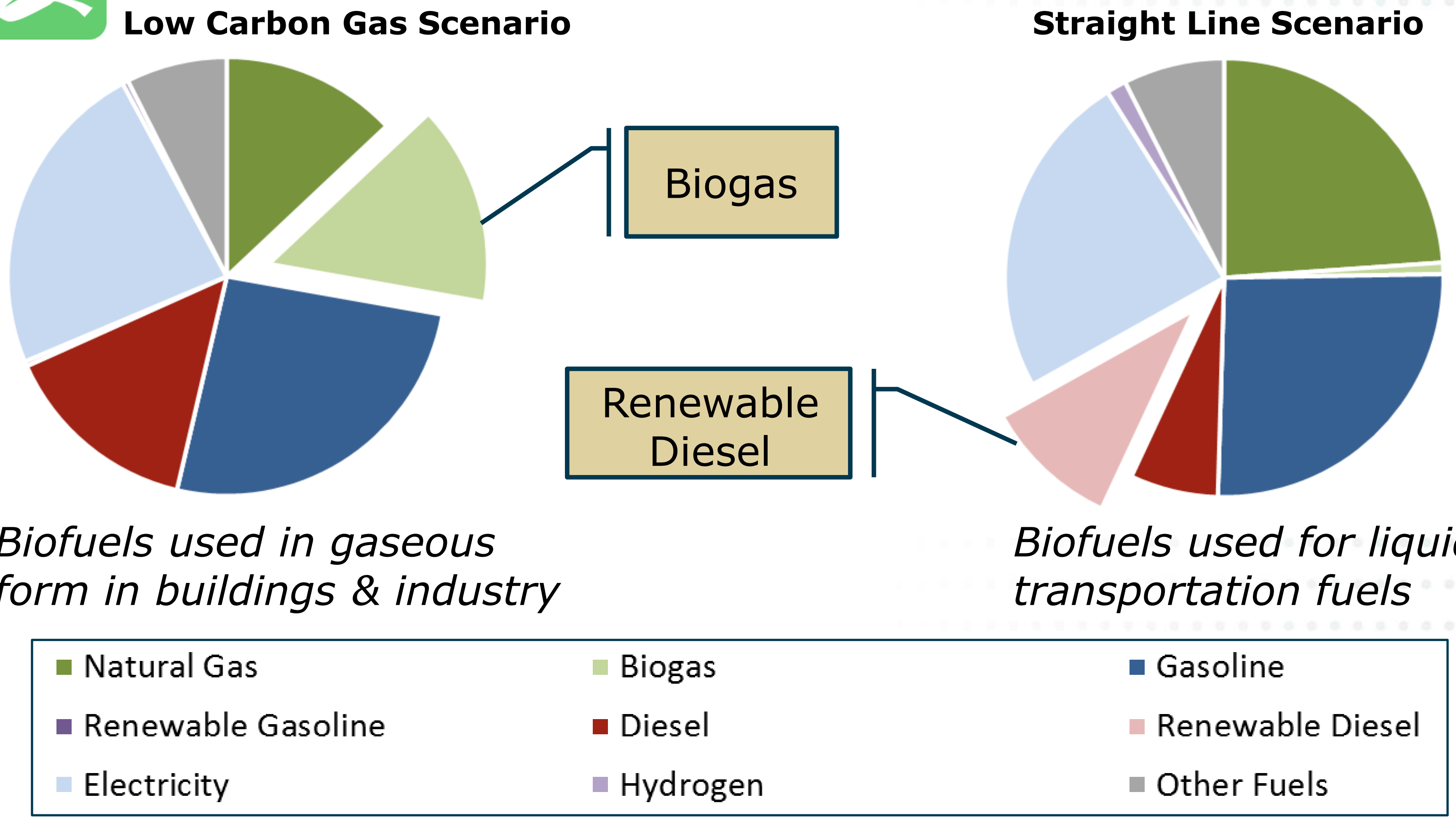
+ **Integration solutions are needed in all high renewables cases:**
  - regional coordination, renewable diversity, flexible loads, more flexible thermal fleet, curtailment energy storage, flexible fuel production for ZEVs





4. Limits to sustainable biomass: insufficient to replace both liquid and gaseous fuels

Share of Final Energy Demand by Fuel Type: 2030

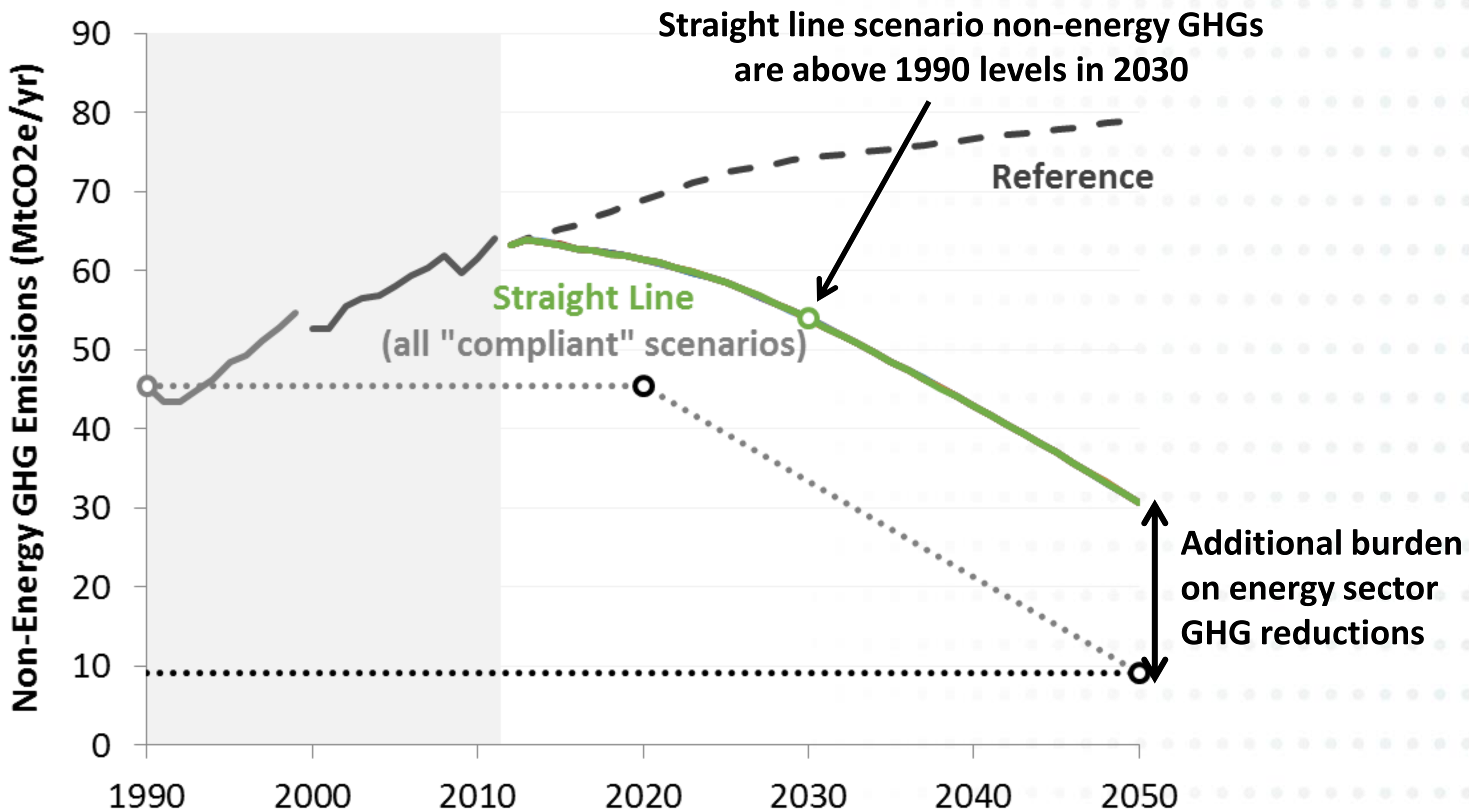


Biofuels used in gaseous form in buildings & industry

Biofuels used for liquid transportation fuels

5. Reduction in non-energy, non-CO_2 GHGs

Mitigation potential is high for F-gases, methane leaks and some types of waste & manure. Difficult to mitigate cement, enteric fermentation, other agricultural non-energy GHG emissions. Places higher burden on mitigating energy GHGs.



Notes: Does not include land-use GHGs; Emissions inventory accounting protocol changed between 6th and 7th edition, resulting in higher estimate of historical non-energy GHG emissions.

Two forks in the road

Zero Emissions Vehicles

1. Fuel production for ZEVs impacts electric grid needs

New Infrastructure

- Flexible production of hydrogen fuels using **9,000 MW of grid electrolysis can balance 50% renewables, eliminating need for other storage** (straight line)
- Without flexible hydrogen fuel production, ~**5,000 MW of long-duration energy storage is needed at 50% renewables** in 2030 (high BEV scenario)

Biomass Utilization

2. Use of biofuels impacts need to electrify buildings

Building Electrification

- If biomass is used for liquid transportation fuels, **over 50% of new sales of space conditioning & water heating are electric** in 2030 (straight line)
- If biomass is used to produce biogas to replace over 50% of natural gas use in buildings & industry in 2030, **no electrification in buildings and industry is needed** (low carbon gas scenario)

WHAT ARE THE COST IMPACTS?

How does PATHWAYS measure costs?

Included:

+ **Incremental cost of energy infrastructure**
  - Transportation: light-, medium- & heavy duty vehicles
  - Building & end uses: lighting, hot water heaters, space heaters, air conditioners, washer/dryer, etc.
  - Industrial equipment: boilers, motors, etc.
  - Electricity production: revenue requirement of all electric assets
+ **Fuel & avoided fuel cost**
  - Electricity, hydrogen, gasoline, diesel, natural gas, biofuel

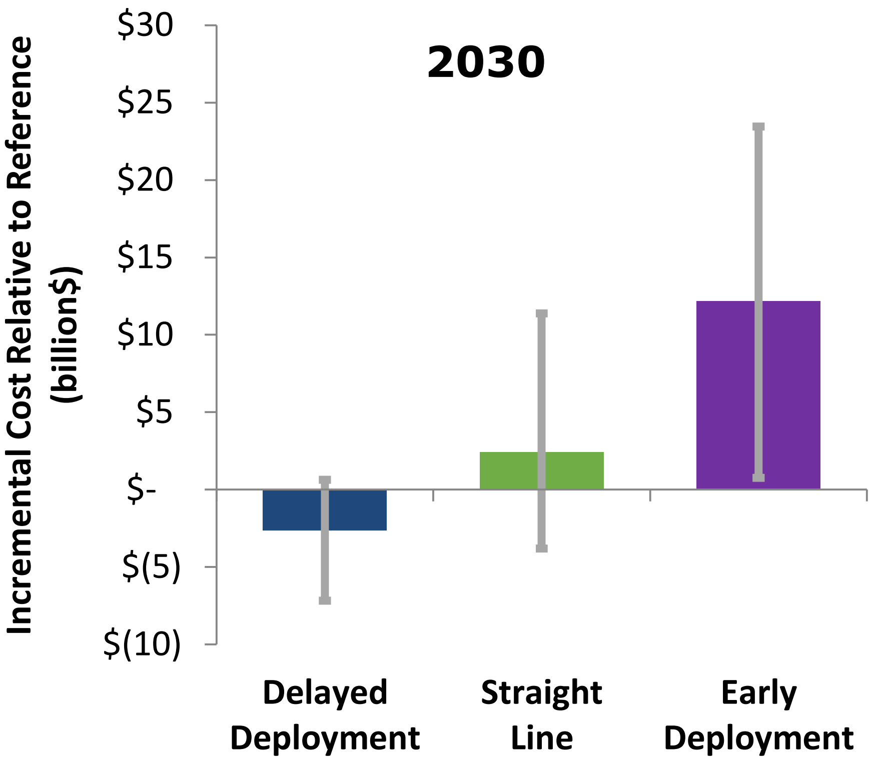
Excluded:

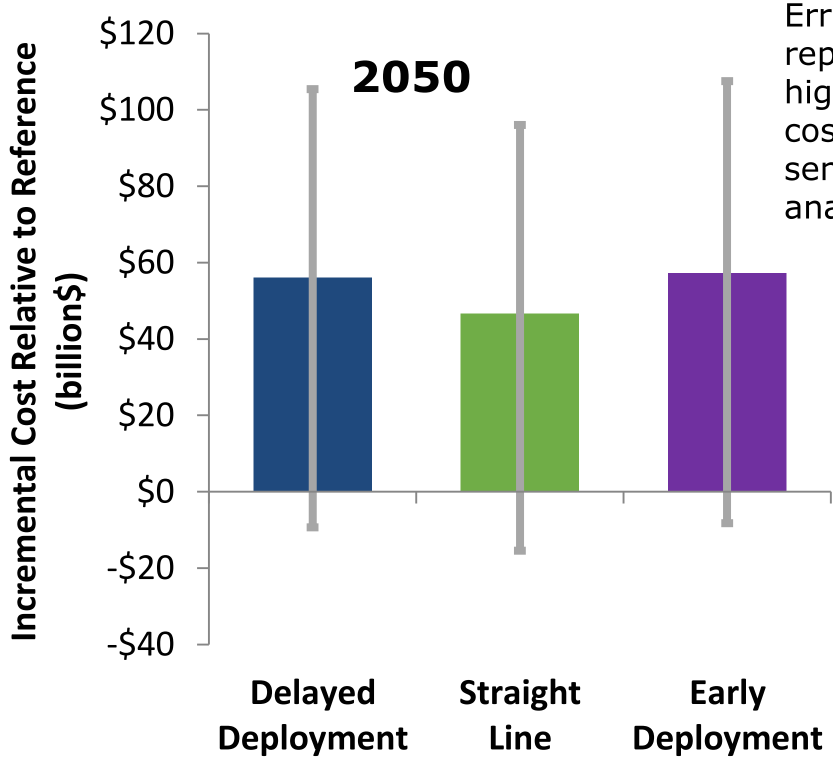
+ **Societal cost impacts**
  - Climate benefits of GHG mitigation
  - Health benefits of reduced criteria pollutants
+ **Structural/macroeconomic impacts**
  - Changes in the costs of goods and services, jobs, structural changes to economy

Note: All costs are reported in real, levelized 2012 dollars

Cost impacts of timing decisions

+ **2030 scenarios & sensitivities span savings of $8B to costs of $23B/year**
+ **2030 Straight Line scenario equivalent to $50/yr/capita total net cost**
+ **Delaying deployment of some high cost measures until post-2030 reduces cost in near-term, but may increase cost in long-run; Early deployment increases near-term costs (but reduces criteria pollutants)**

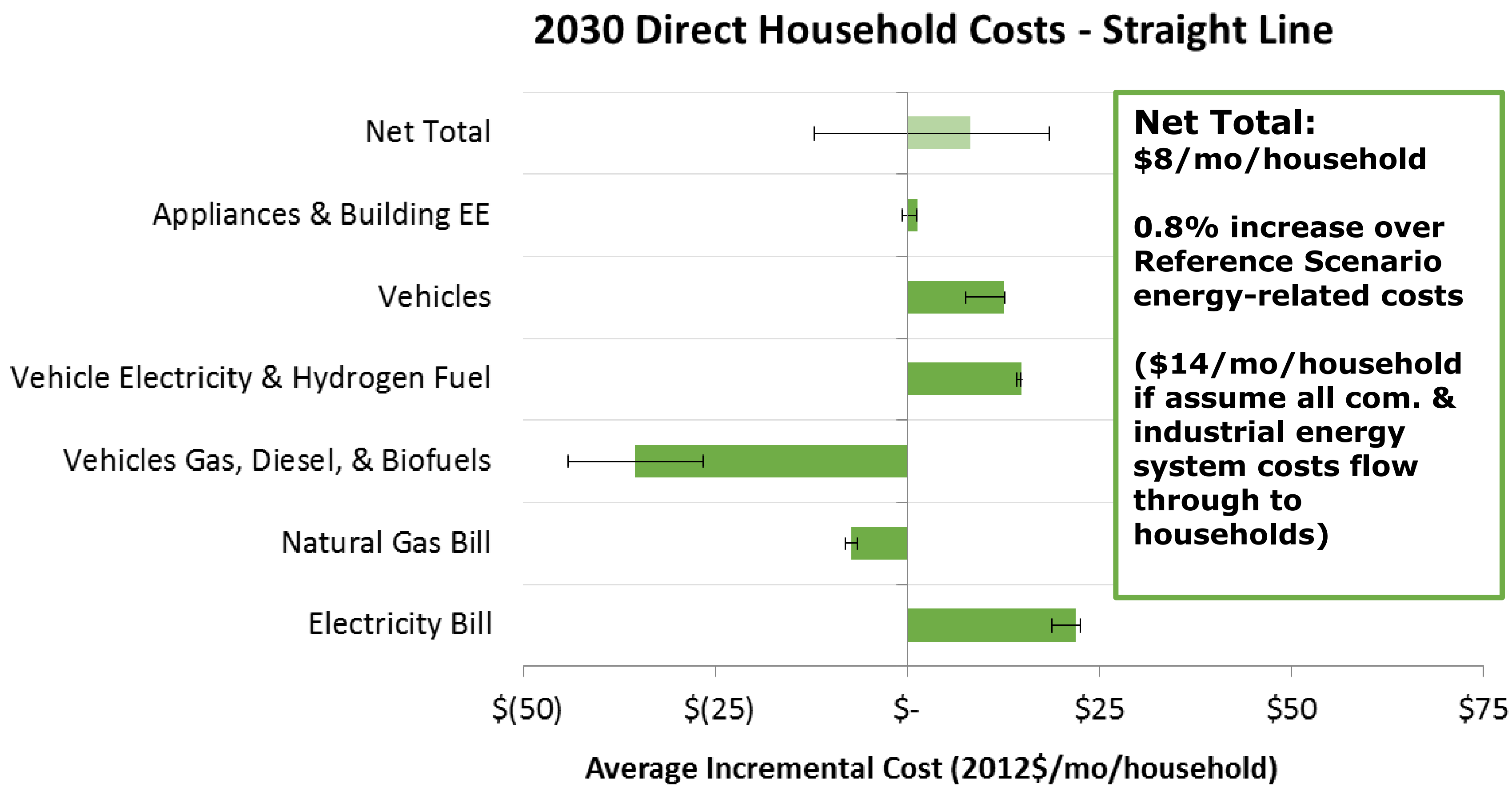




Error bars represent high & low cost sensitivity analysis

Average Household
Monthly Cost: 2030 Straight Line Scenario

- **Average household sees significant savings in gasoline/diesel costs, offset by increases in electric bill, car payments and cost of ZEV fuel (doesn't include changes to cost of goods & services)**



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)

Thank You!

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APPENDIX

PATHWAYS: Model framework

Energy Demand	Energy Supply	Model outputs
• Residential • Commercial • Industrial • Refining • Oil & gas extraction • Transportation • Agriculture • Water-related energy demand	• Electricity • Pipeline gas • Diesel + biofuels • Gasoline + biofuels • Refinery & process gas • Coke • Waste heat	• GHG emissions • Final energy demand • Energy system costs • Electricity dispatch metrics • Appliance, building, vehicle stock numbers

Key Scenario Assumptions

- **Continuation of current lifestyle & growth of economic activity**
- **Technological conservativism with key emerging technologies**
  - Use commercial, or near-commercial technologies with conservative cost and performance assumptions. Key emerging technologies in include: advanced biofuels, decarbonized gas, electrolysis, long-duration energy storage, and CCS.
- **Natural retirement of equipment (not early replacement)**
- **Limitations on use of biomass**
  - Based on DOE estimate of sustainable U.S.-based supply of biomass
  - Advanced biofuels are assumed to have net-zero carbon emissions
- **Electricity planning and operational heuristics**
  - Hourly demand derived from flexible end use loads; resources built to RPS requirement and planning reserve margin requirement; hourly supply simulated; import/export capability, & operational heuristics benchmarked to production simulation and historical data; all renewables are assumed to be balanced with in-state resources

Disclaimer on Using PATHWAYS Data

- **PATHWAYS was developed to provide a high-level assessment of economy-wide greenhouse gas emissions and costs; Although the model includes detailed data that went into the calculation of the GHGs and costs, this data should not be used outside the context of economy-wide GHG analysis. In particular:**
  - The tool does not calculate macroeconomic impacts or predict how technology or fuel prices may drive adoption of a particular technology or practice
  - The tool should not be used for electric generation resource adequacy calculations, or to calculate flexible electric generation resource capacity needs, including energy storage needs. PATHWAYS should not be used in place of an electricity resource planning tool.

WHAT IS AN ACHIEVABLE 2030 GHG GOAL?

Scenarios evaluate GHG reduction timing and energy pathways to 2030 and 2050

1. Reference	current GHG policies

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)

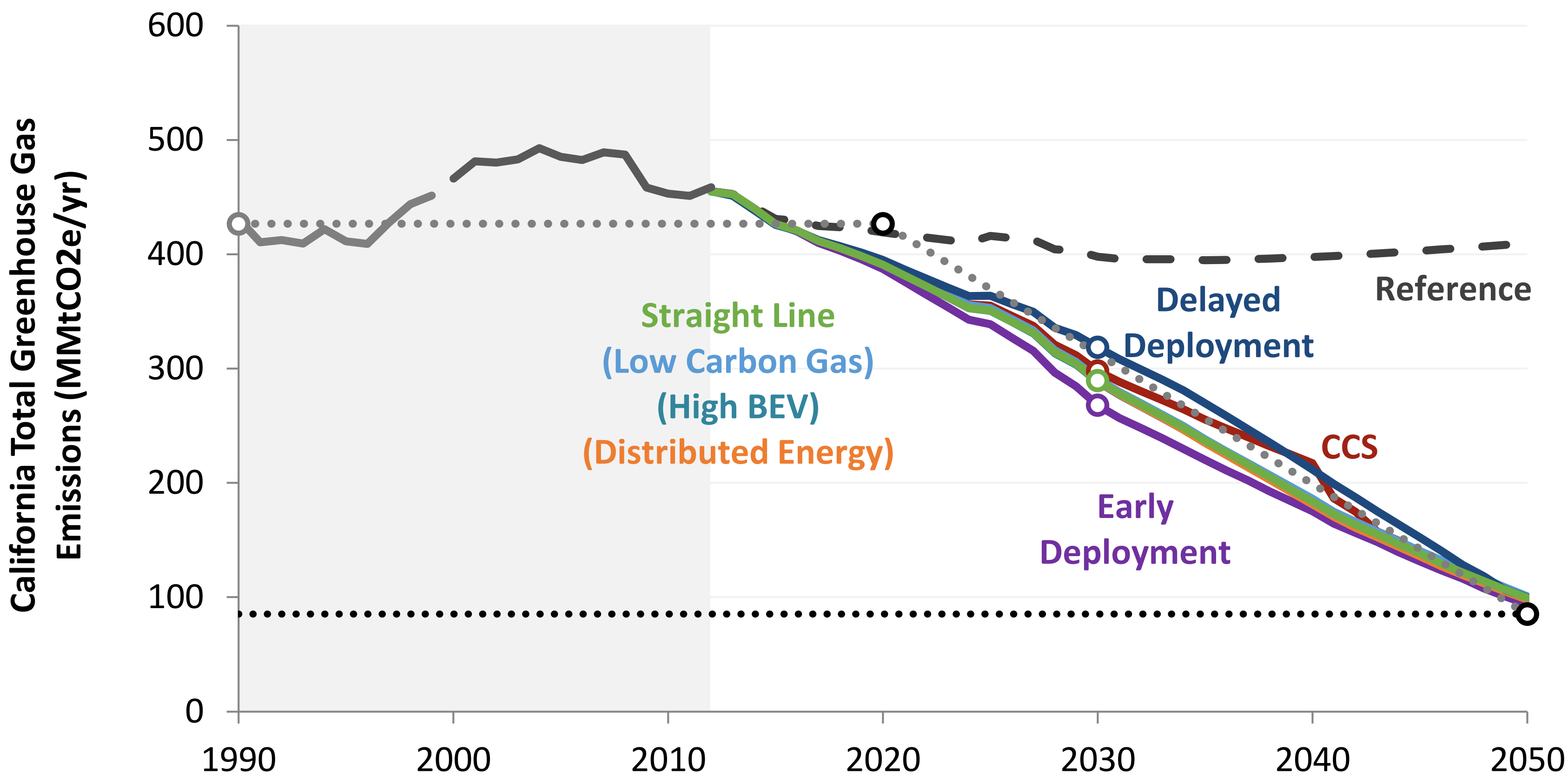
5. Low Carbon Gas	no building electrification, decarbonized pipeline gas
6. Distributed Energy	achieves zero-net energy building goals w/ DG PV and grid storage
7. CCS	phase-in of CCGTs with CCS post-2030
8. High BEV	no fuel cell vehicles, focus on BEVs

Summary of Timing Scenarios: Key Input Assumptions in 2030

	Slower Commercial Adoption Scenario	Straight Line Scenario	Early Deployment Scenario
Electricity	50% qualifying renewables in 2030	50% qualifying renewables in 2030	60% qualifying renewables in 2030
Biomass & Biofuels	Ramp up of renewable diesel is delayed until after 2030	Significant imported renewable diesel	Same as Straight Line Scenario
Electricity balancing services	Same as Straight Line Scenario	Mix of 2 to 8 hour battery storage, flexible loads and smart charging of EVs. Increasing reliance on grid electrolysis for H2 production after 2030.	Same as Straight Line Scenario plus additional pumped hydro in 2020 timeframe.
End-uses and fuel choices			
Buildings	Commercial electric heat pump adoption is postponed until 2030, then sees faster adoption post-2030. Residential buildings are unchanged from Straight Line scenario.	Significant energy efficiency though out, electric heat pump HVAC & water heating large part of new appliance sales starting in 2020, no early replacement of equipment.	Electric heat pumps for nearly all new sales of hot water & HVAC in South Coast region by 2030
Transportation	Postponed adoption of BEVs & FCVs until 2030, faster adoption post-2030. Faster adoption of LNG for HDVs & CNG buses through 2030.	Significant increase in H_2 fuel cell vehicles (FCV) and electric vehicles + biodiesel	CNG & LNG for all new MDVs and HDVs in South Coast, more rapid adoption of ZEVs than Straight Line Scenario
Industry	Delayed electrification of industrial end uses until post-2030.	Increase in energy efficiency, electrification	Same as Straight Line Scenario

Multiple scenarios are on a consistent trajectory to meet 2050 GHG goal

- Initial scenarios achieve a 26% – 38% reduction in GHGs by 2030, relative to 1990 GHG levels (34% - 45% below 2005 levels)



A range of potential targets in 2030 are consistent with 2050 goals

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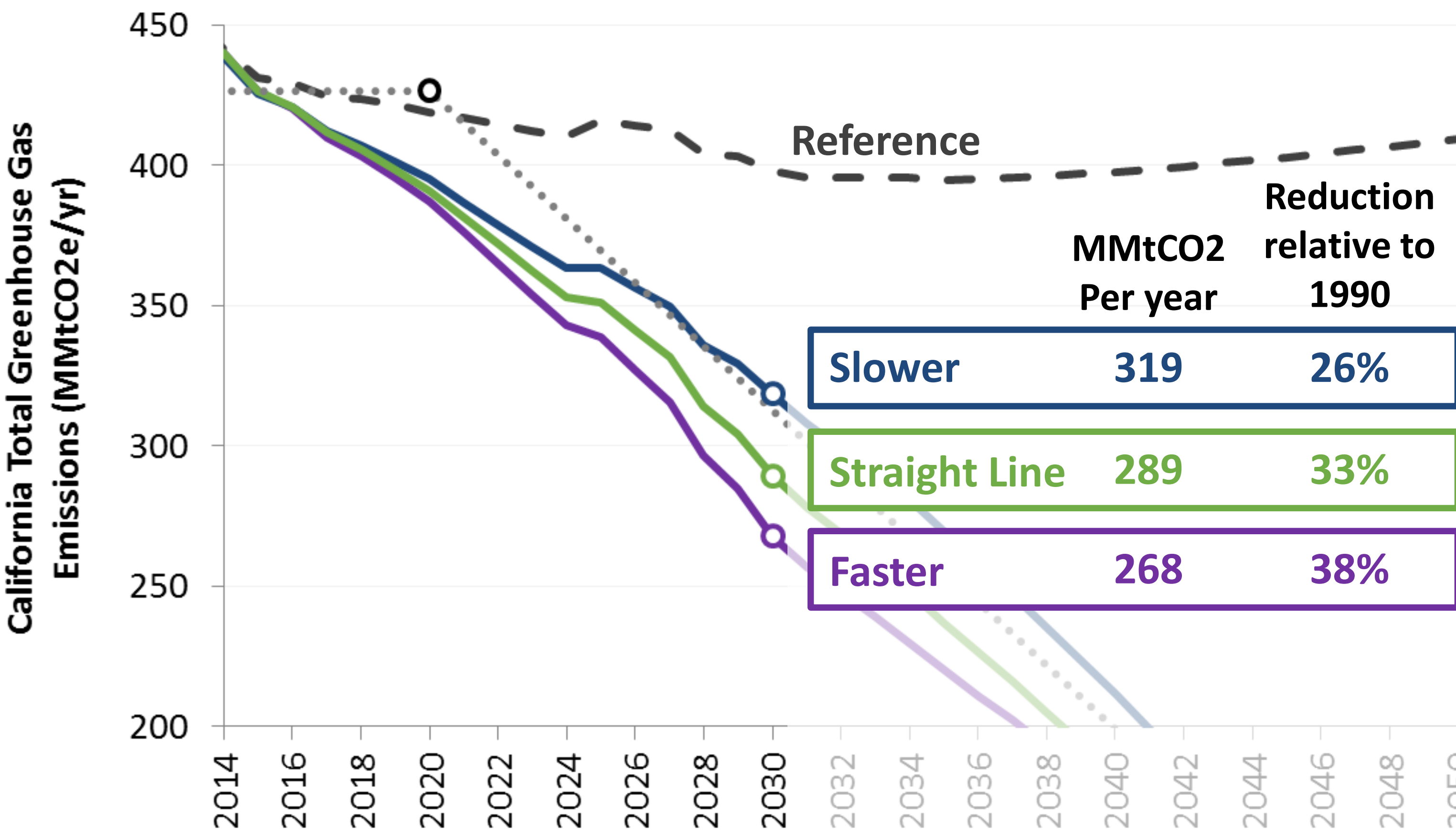
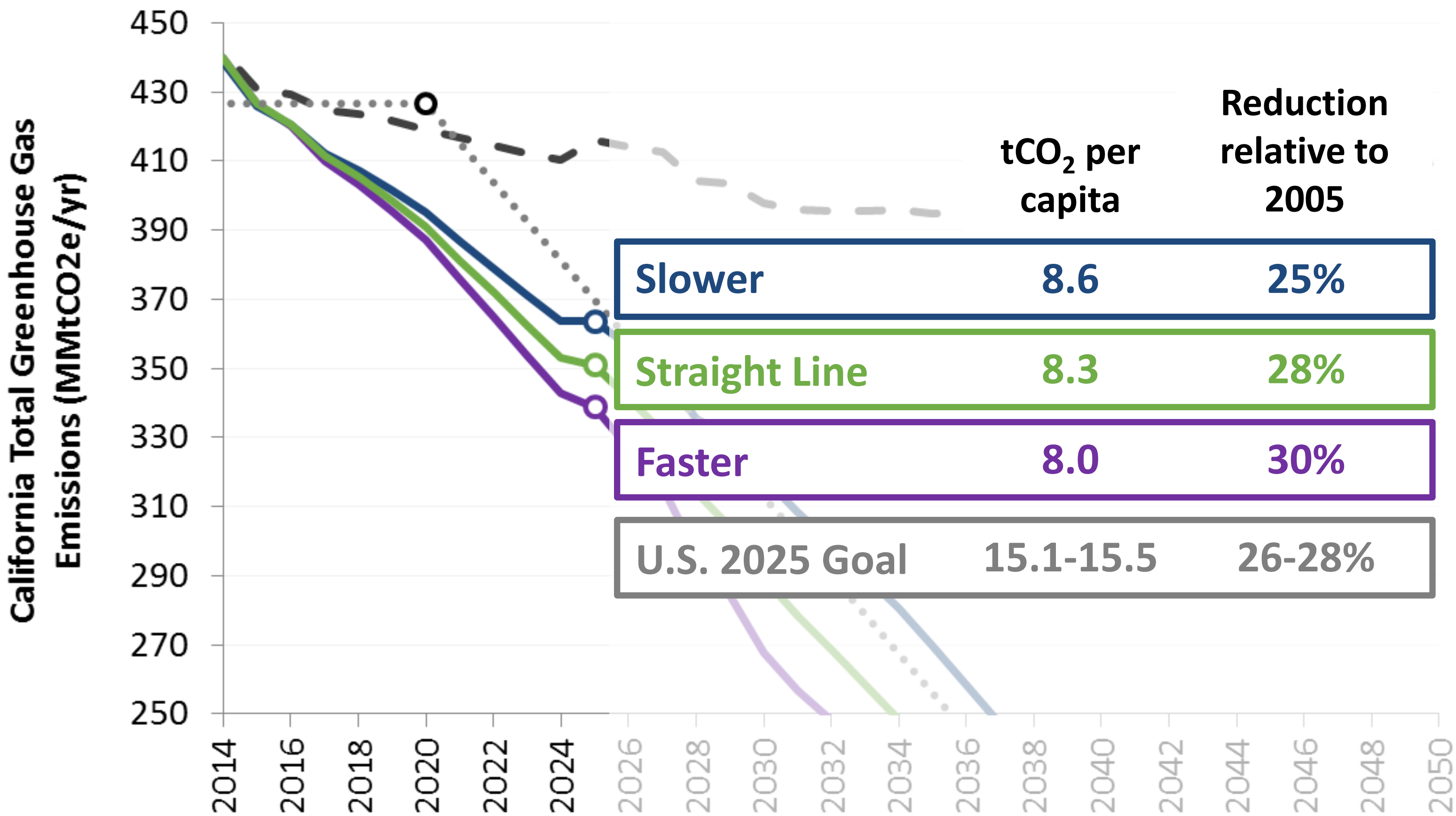


	MMtCO2 Per year	Reduction relative to 1990
Slower	319	26%
Straight Line	289	33%
Faster	268	38%

Comparison of CA 2025 results with U.S. administration 2025 goal

+ **CA scenarios in 2025 are similar to U.S. administration's 2025 goal on a percent reduction basis, although CA has lower per capita GHG emissions.**



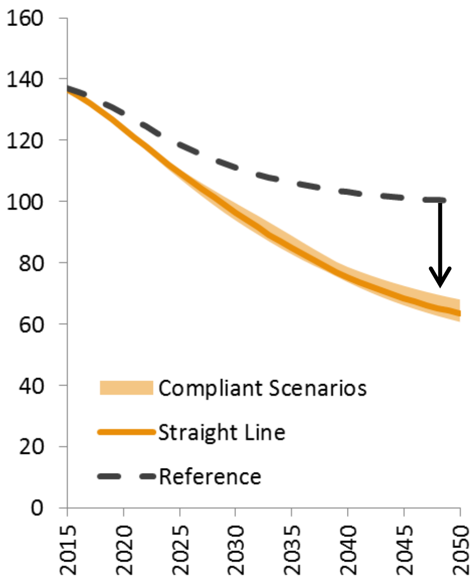
	tCO_2 per capita	Reduction relative to 2005
Slower	8.6	25%
Straight Line	8.3	28%
Faster	8.0	30%
U.S. 2025 Goal	15.1-15.5	26-28%

KEY COMMONALITIES ACROSS SCENARIOS

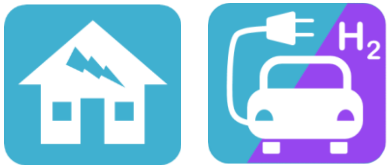
Decarbonizing CA’s economy depends on four energy transitions

1. Efficiency and Conservation

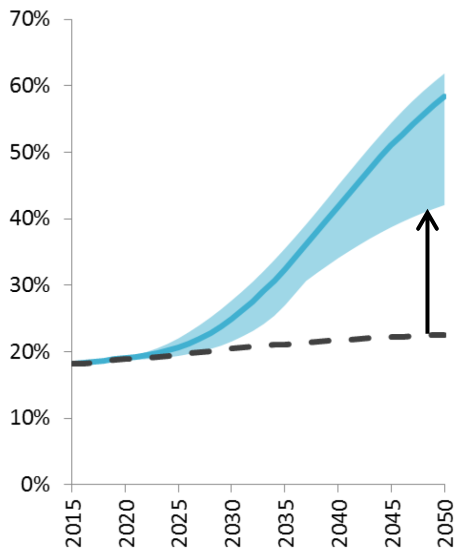
Energy use per capita (MMBtu/person)



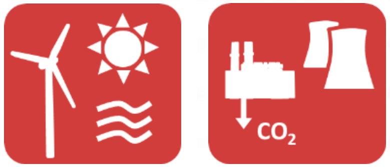
2. Fuel Switching



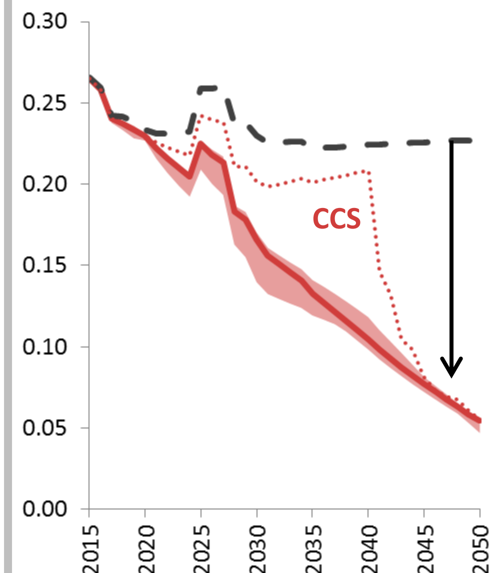
Share of electricity & H_2 in total final energy (%)



3. Decarbonize electricity

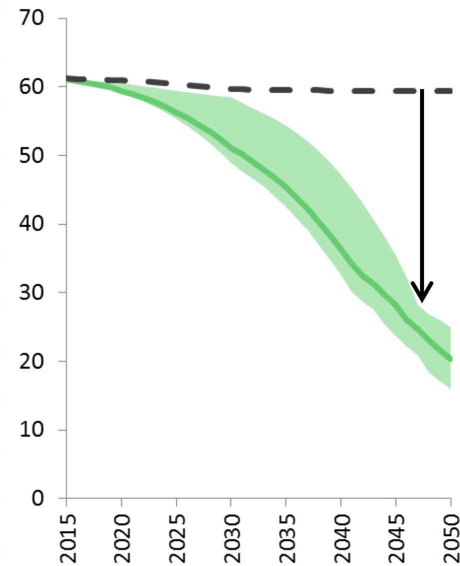


Emissions intensity (tCO2e/MWh)



4. Decarbonize fuels (liquid & gas)

Emissions intensity (tCO2/EJ)



Decarbonizing CA's economy depends on four energy transitions

1. Efficiency and Conservation

Energy use per capita (MMBtu/person)

Common strategies applied across all scenarios

2. Fuel Switching

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

Forks in the road:

1) Electrification vs. biogas in buildings
2) All-electric vehicles vs. fuel cell

3. Decarbonize electricity

Emissions intensity (tCO2e/MWh)

Common strategies applied across all scenarios (except CCS scenario)

4. Decarbonize fuels (liquid & gas)

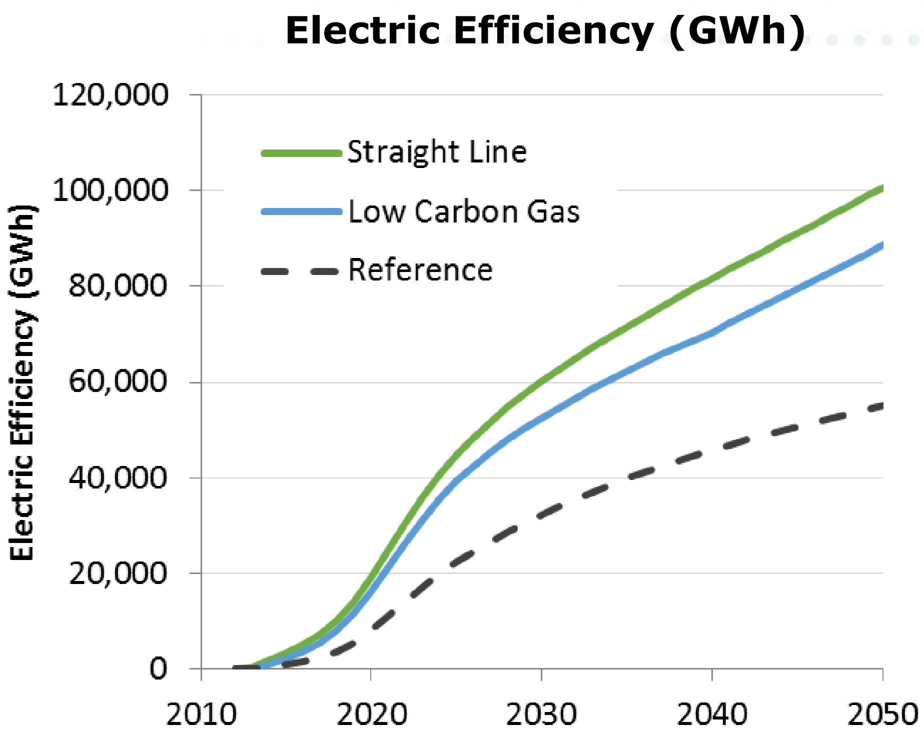
Emissions intensity (tCO2/EJ)

Forks in the road:

1) Liquid biofuels in vehicles vs. biogas & synthetic gas in buildings

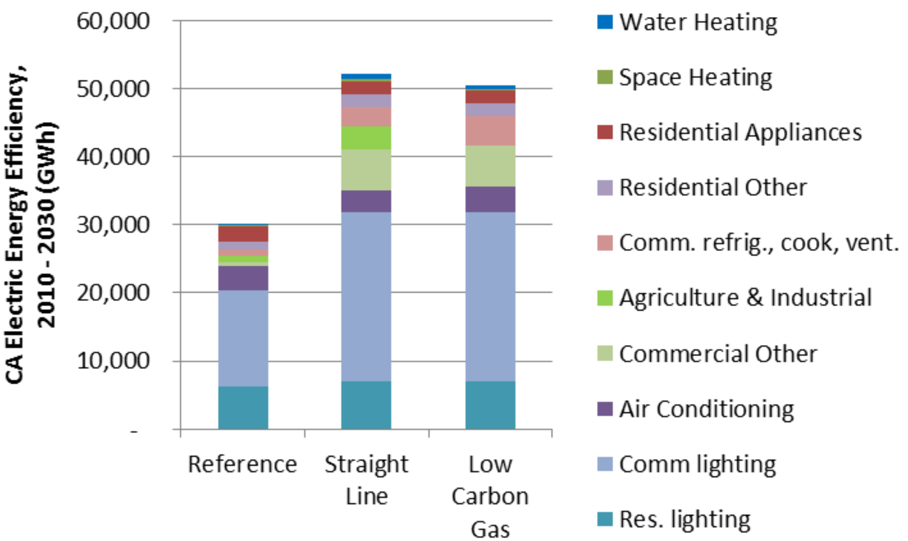
Energy Efficiency Electricity

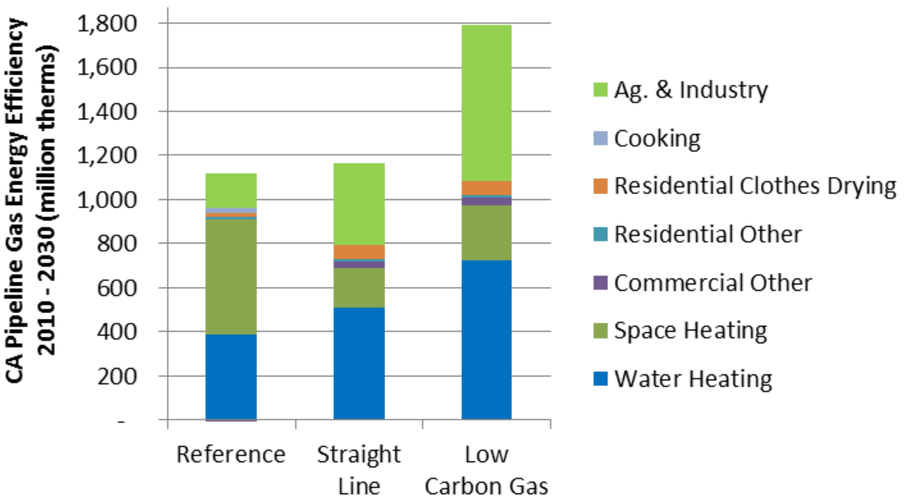
- **Electric energy efficiency** is nearly double in the straight line scenario compared to current policy, mostly due to LED lighting and more efficient appliances
- Fuel switching from natural gas appliances to high efficiency electric heat pumps (not shown at right) achieves additional EE in the Straight line scenario; increases electric loads
- Natural gas efficiency also increases through 2030; but in the straight line scenario it falls post-2030 due to fuel switching to electricity



Energy Efficiency by End Use

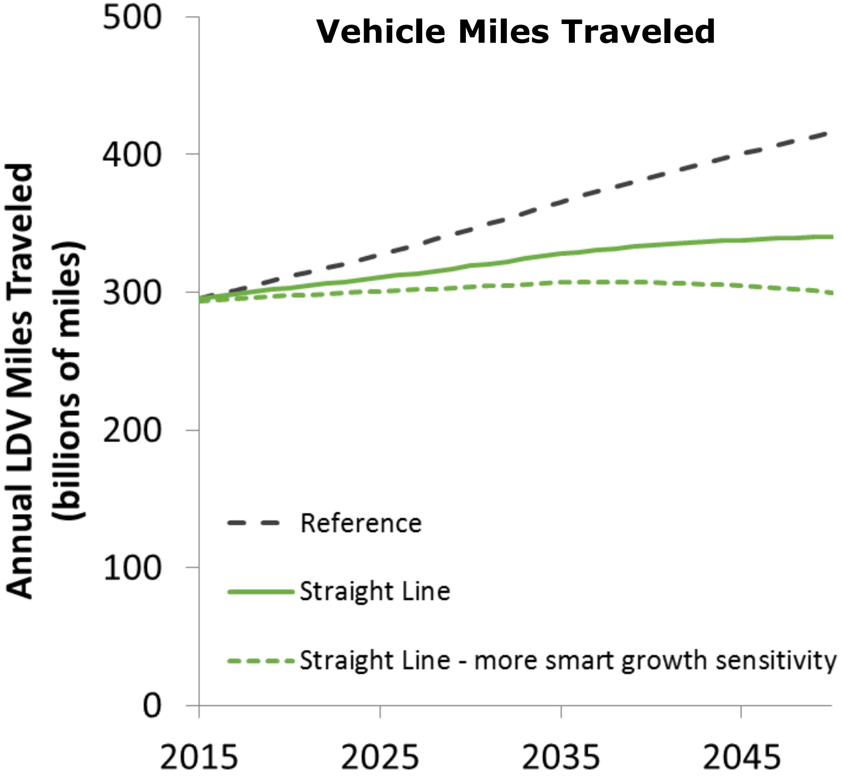
- Conventional energy efficiency savings are driven by residential & commercial lighting, HVAC and commercial plug-loads and appliances, additional efficiency from fuel-switching to heat pumps are not shown
- Natural gas efficiency is driven by water heating, space heating and agriculture and industrial measures

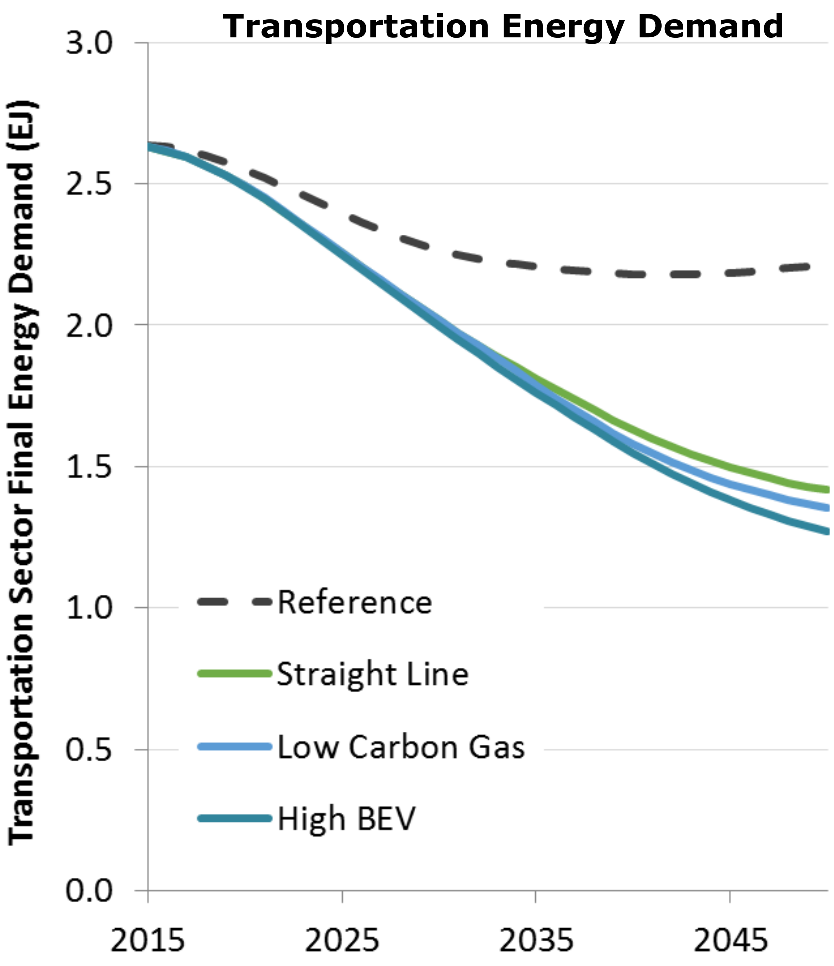




Energy Efficiency & Smart Growth in Transportation

+ **Significant reduction in vehicle-miles-traveled (VMT) & transportation energy demand in all compliant scenarios**

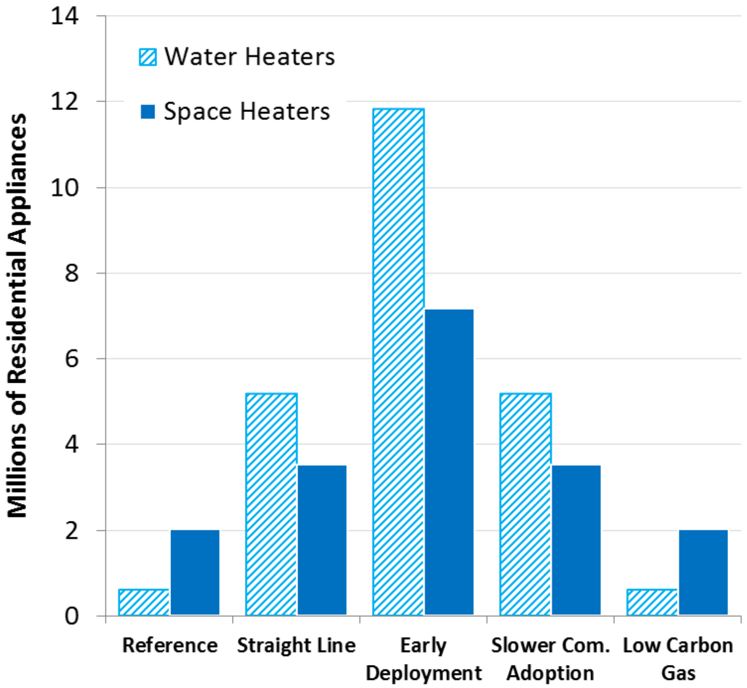




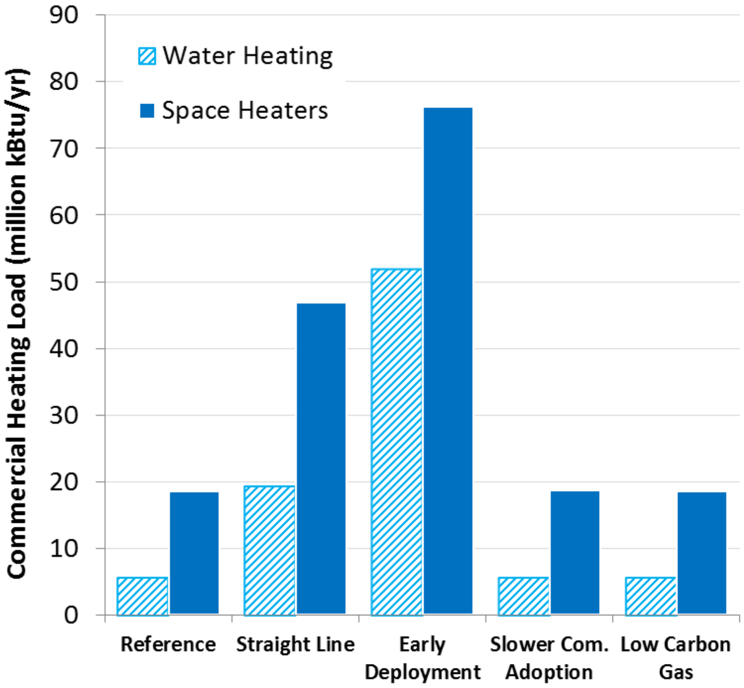
Increase in Building Electrification

+ Transition toward electric heat pumps in buildings in Compliant Scenarios begins in 2020
+ Early deployment scenario assumes *all* new building space heating and water heating in the South Coast is electric starting in 2020

Residential Electrification: 2030

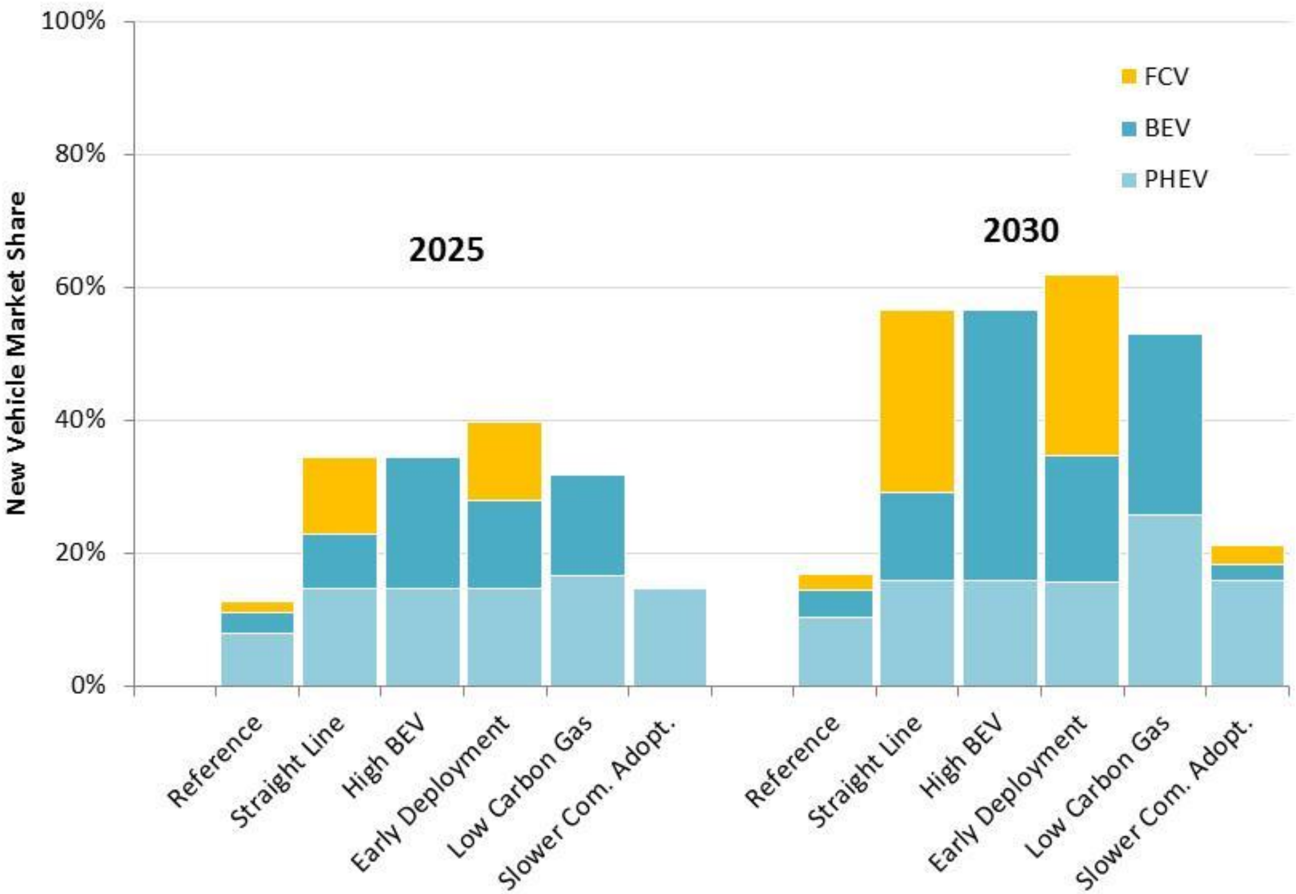


Commercial Electrification: 2030



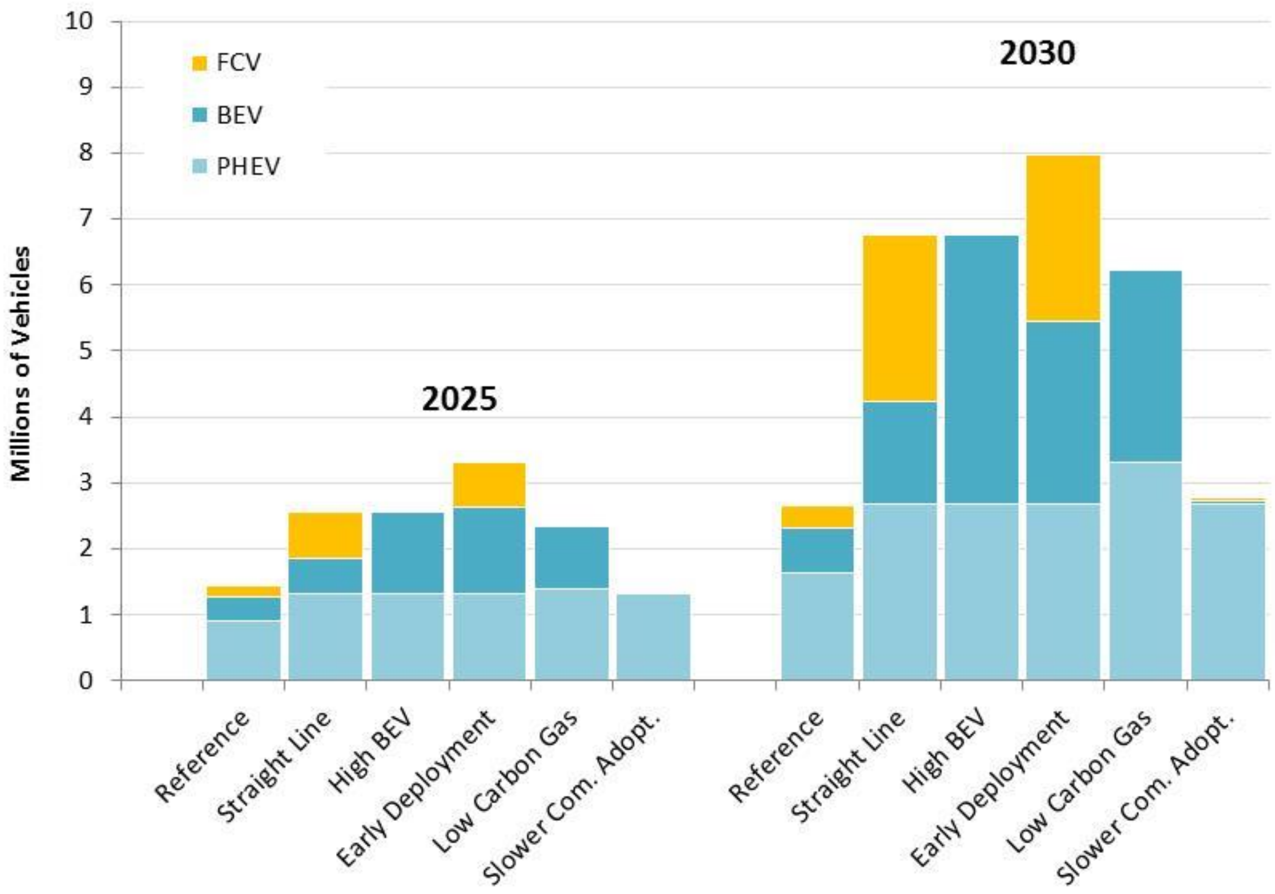
Light Duty Vehicles – ZEV & PHEV Market Share of New Sales (%) by Year

+ 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



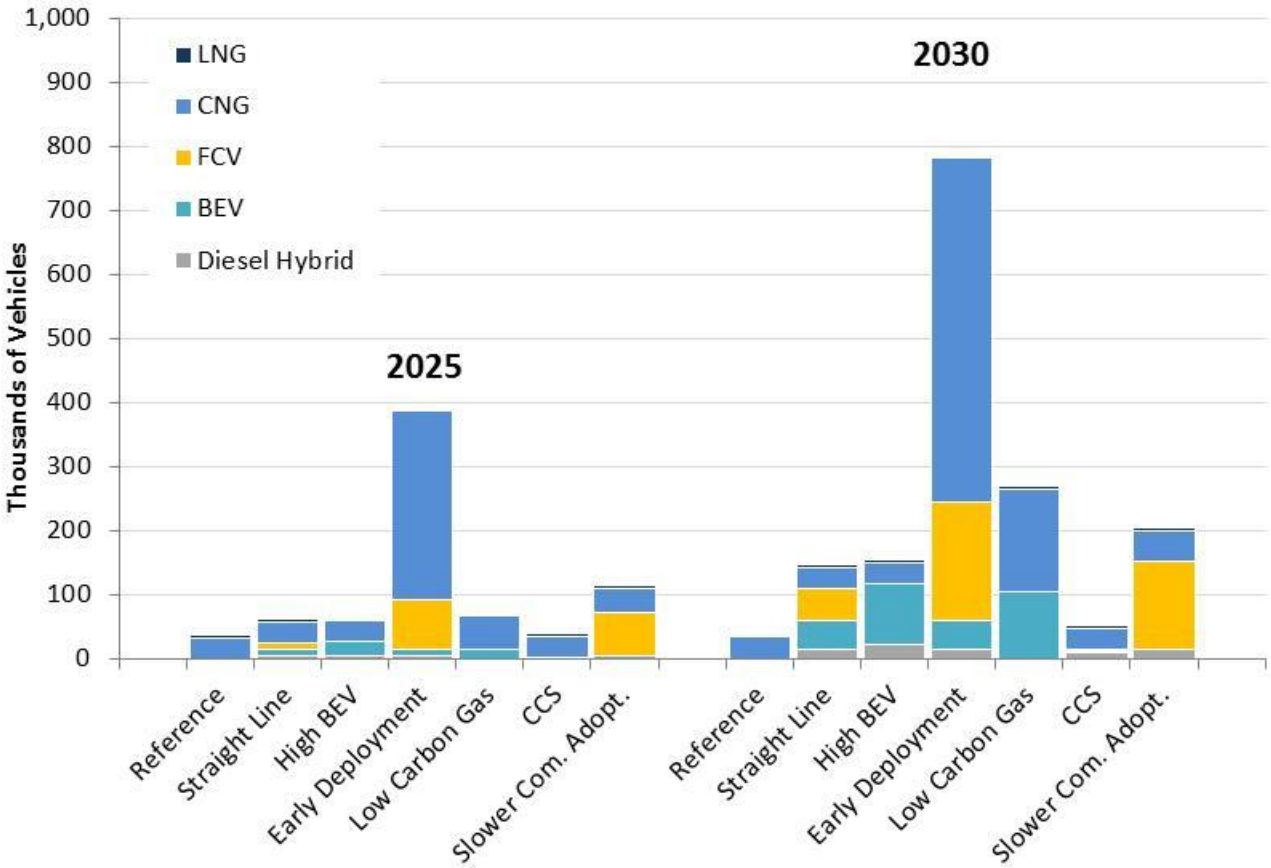
Light Duty Vehicles – Number (#) of ZEVs & PHEVs in Fleet by Year

+ Number of light duty fuel cell vehicles (FCV), battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) on the road in CA in 2025 and 2030



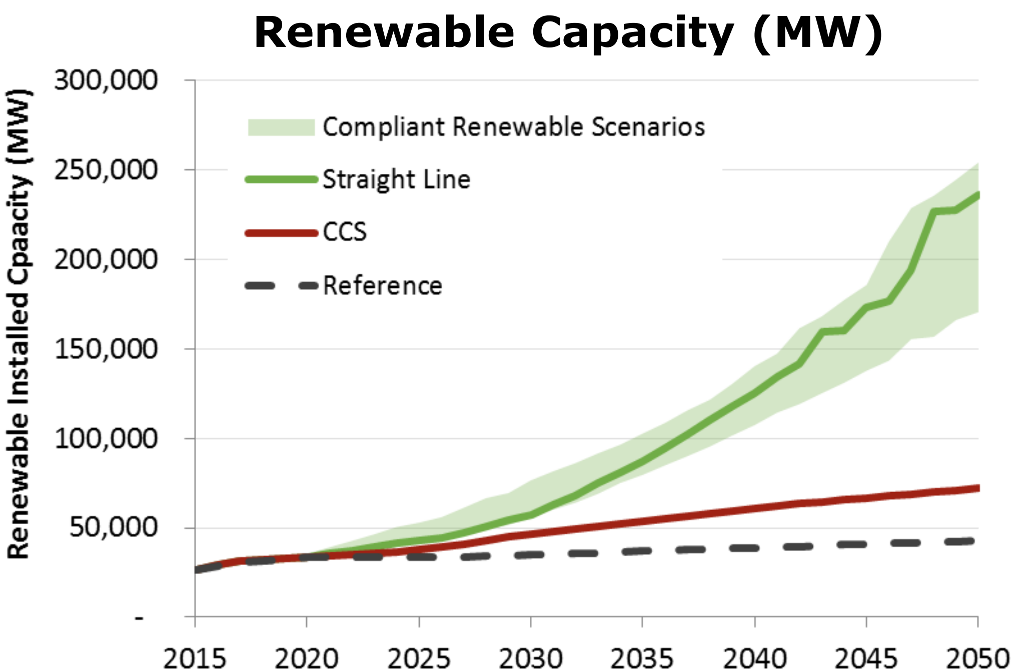
Heavy & Medium Duty Vehicles – # ZEVs & hybrids in Fleet by Year

+ Number of medium and heavy duty zero-emission vehicles



All scenarios except CCS rely on renewables to decarbonize electricity

+ **Straight line scenario targets 50% renewables in 2030**
  - 75 – 86 % renewables in 2050, except for CCS scenario
+ **Renewable capacity needs increase dramatically post-2030 due to higher electric loads and higher renewable goals**



Note: In-state and out-of-state renewable development is assumed, including new transmission to deliver renewable resources.

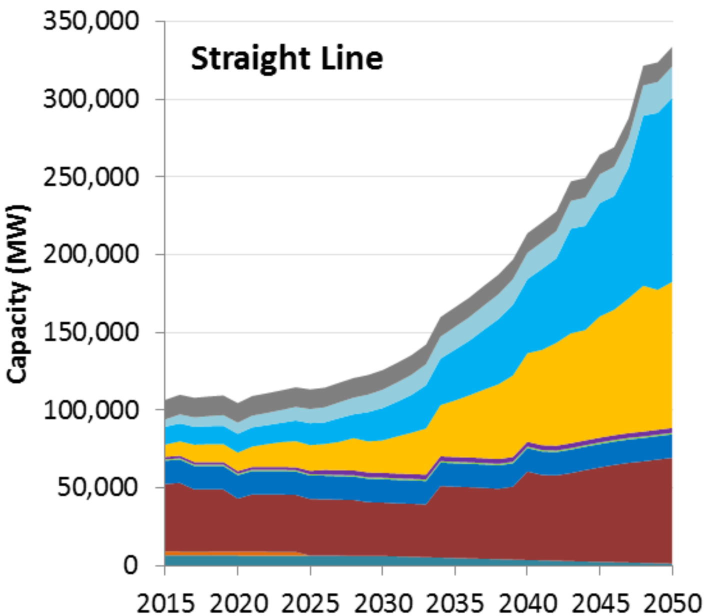
Integration solutions needed:

+ Hydro & thermal generation
+ Renewable diversity, regional coordination, renewable curtailment
+ Increased reliance on flexible loads, especially flexible fuel production (grid electrolysis) in scenarios with fuel cell vehicles
+ 4-8hr stationary storage is needed in high BEV scenario due to no flexible grid electrolysis

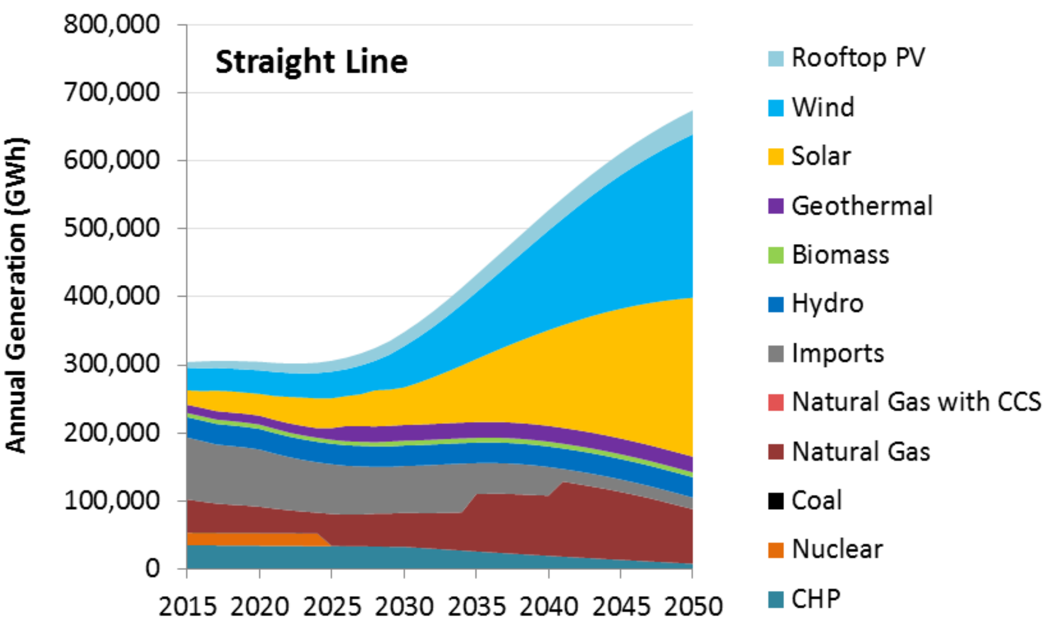
Electricity generation increases significantly due to fuel switching

- Low-carbon electricity is primarily provided by solar and wind resources, natural gas generation continues to provide energy when solar and wind are not available
- Electric loads increase significantly between 2030 – 2050 due to fuel switching in buildings, industry & transportation

Generating capacity by fuel type

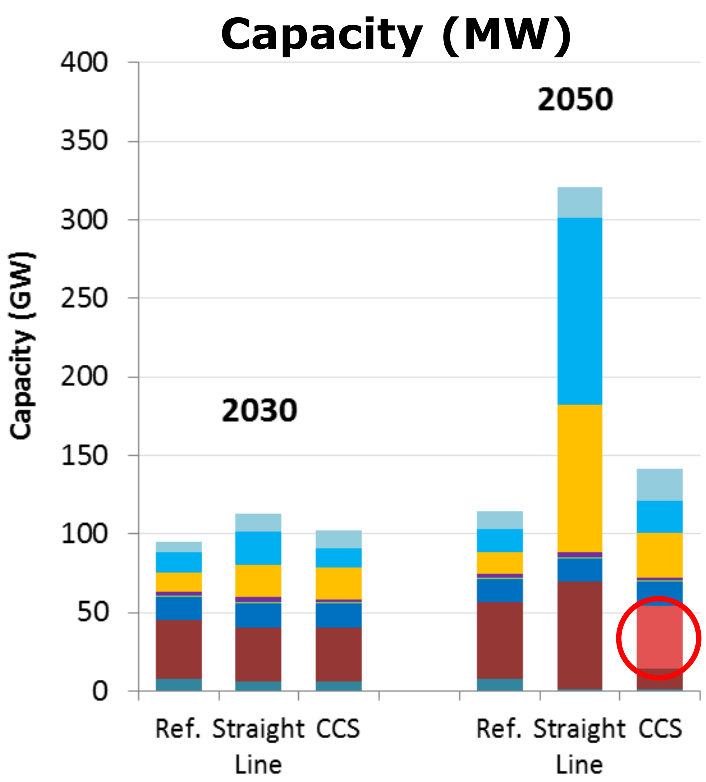


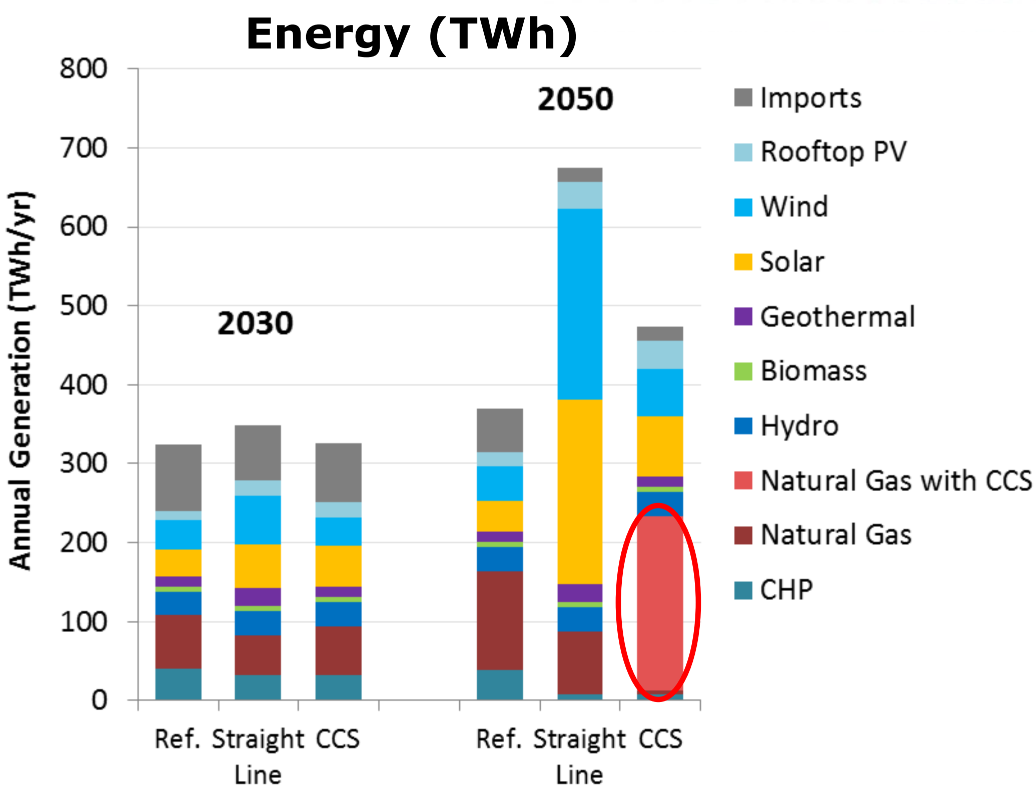
Annual Generation by fuel type



CCS Scenario

- Meets capacity needs post-2030 with dispatchable natural gas CCGT with CCS, limited new renewables
- Lower total demand because natural gas reformation with CCS replaces grid electrolysis to produce hydrogen

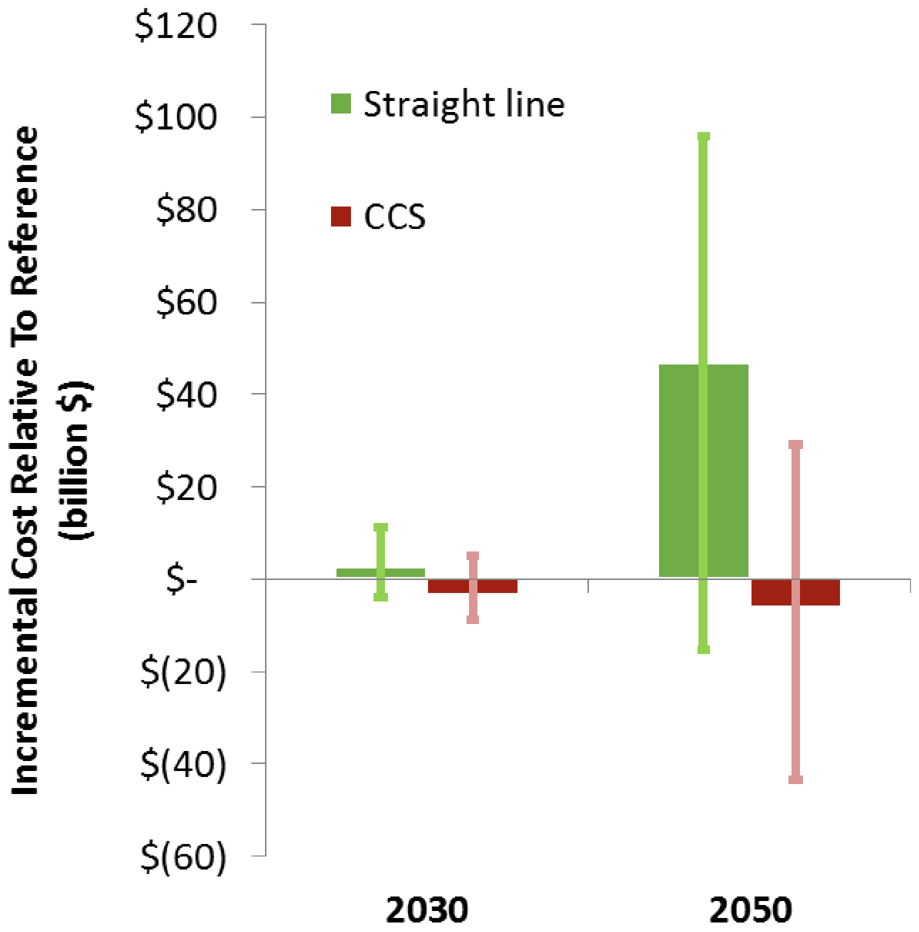




CCS Scenario

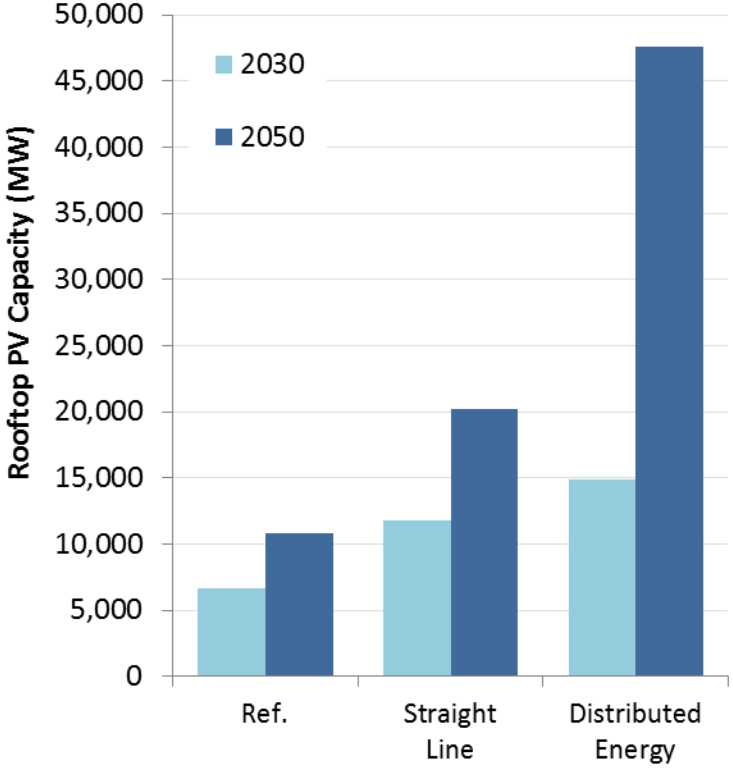
Key Results:

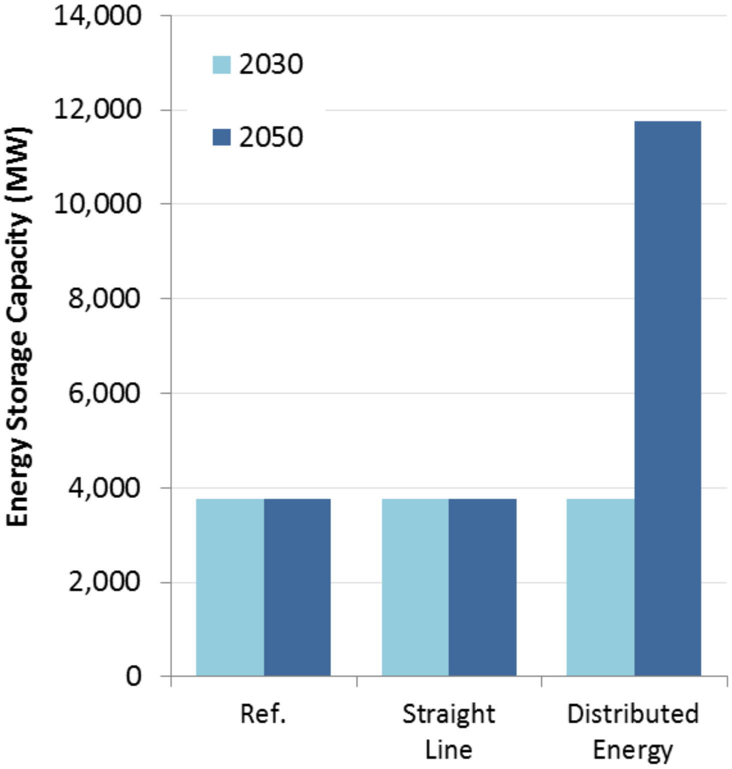
- CCS runs at high capacity factor, reducing capacity build of renewables
- CCS is higher risk strategy since technology is not yet commercialized but opportunity for cost savings



Distributed Energy Scenario

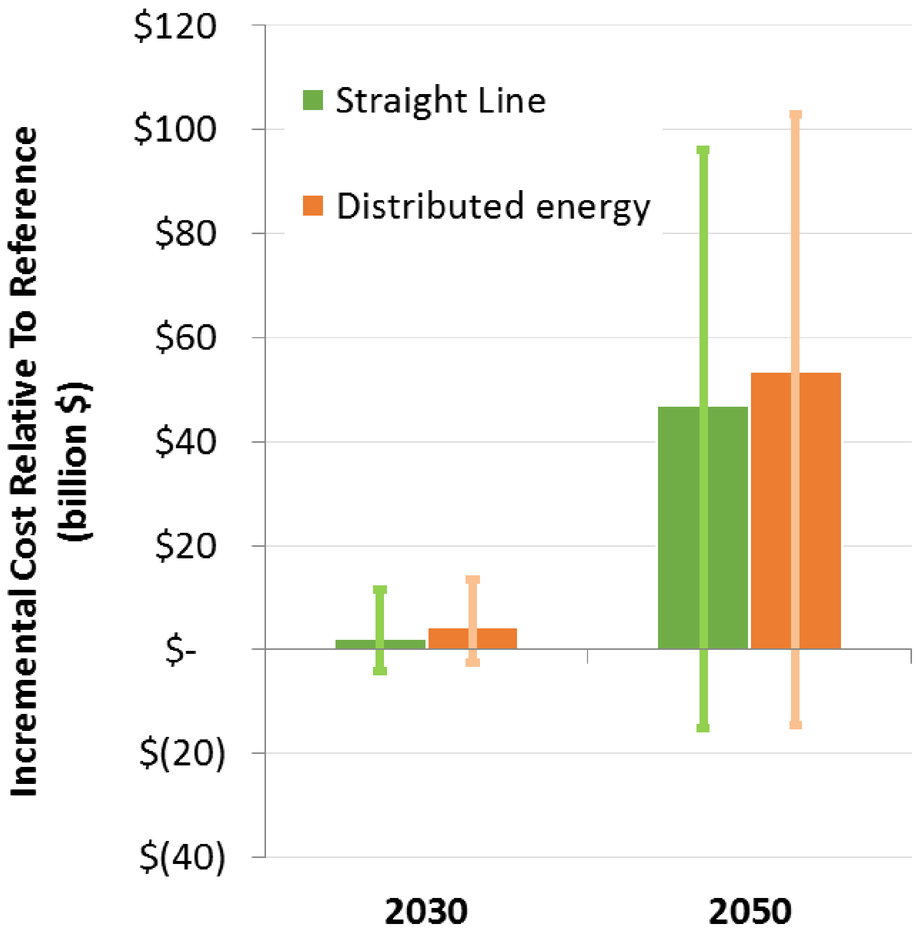
+ **Meets zero net energy goal (ZNE) by 2020 for new residential & ZNE by 2030 for all new commercial**





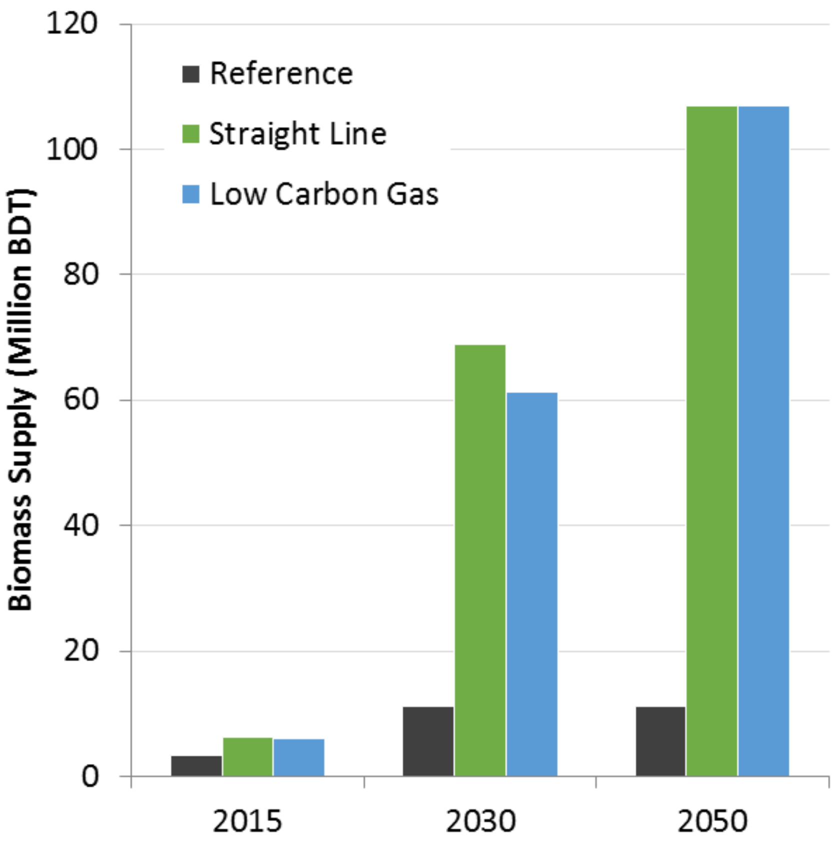
Distributed Energy Scenario

- Rooftop PV vs. ground-mounted PV is not a critical GHG policy decision
- High DG scenario is not very different than straight line scenario in terms of GHG and cost metrics
- Key questions in this scenario are who pays for the rooftop solar & cost uncertainty around upgrades to the grid.



California is assumed to import biofuels from U.S. resource

- Compliant scenarios assume California imports population weighted share of U.S. sustainable biomass supply for biofuels
- Biomass supply is assumed to increase over time, up to 75% of U.S. estimated resource potential, based on DOE's "Billion Tons Study Update"

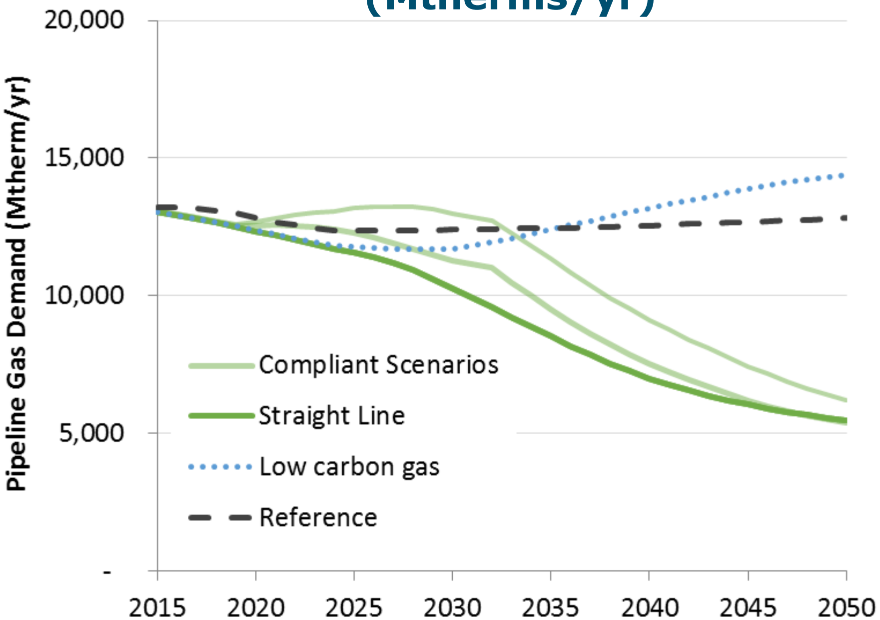


Pipeline gas demand & emissions intensity varies with future policy & technology options

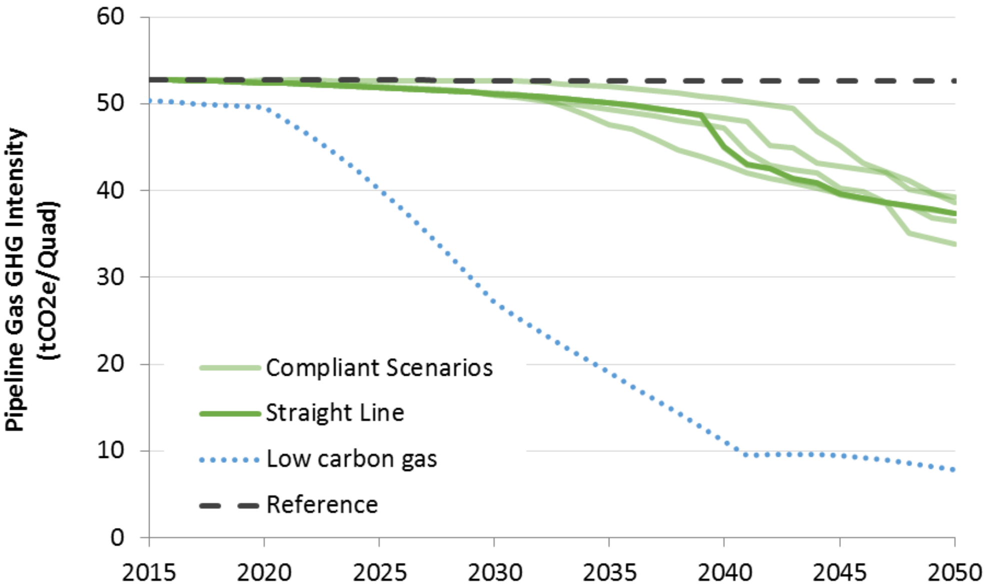
+ Bi-modal scenarios evaluated on pipeline gas:

- Enable a switch to low-carbon fuels and sustain gas distribution grid (i.e. through a renewable fuels standard for biogas and synthetic methane) or;
- Enable electrification and phase out gas distribution grid

Pipeline gas demand (Mtherms/yr)

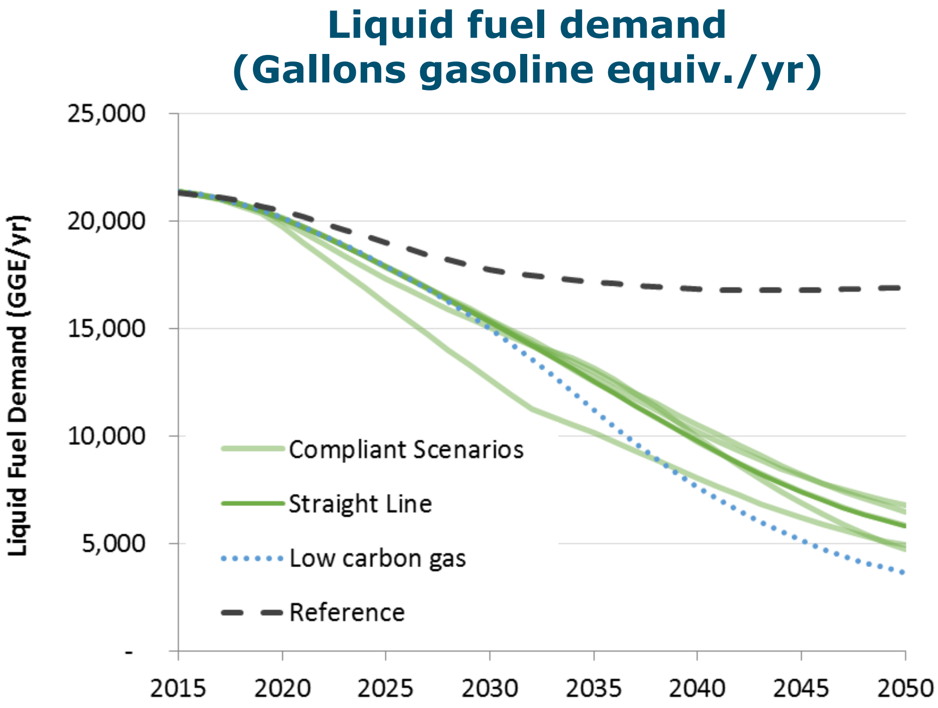


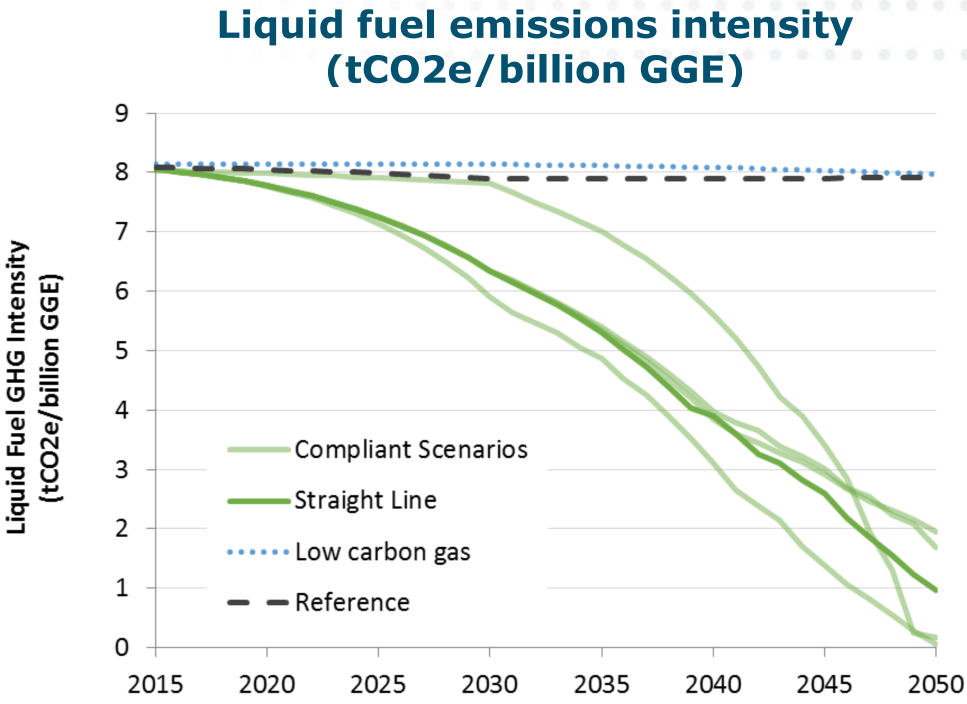
Pipeline gas emissions intensity (tCO2e/Quad)



Liquid fuel demand falls in all scenarios, but emissions intensity depends on policy choices

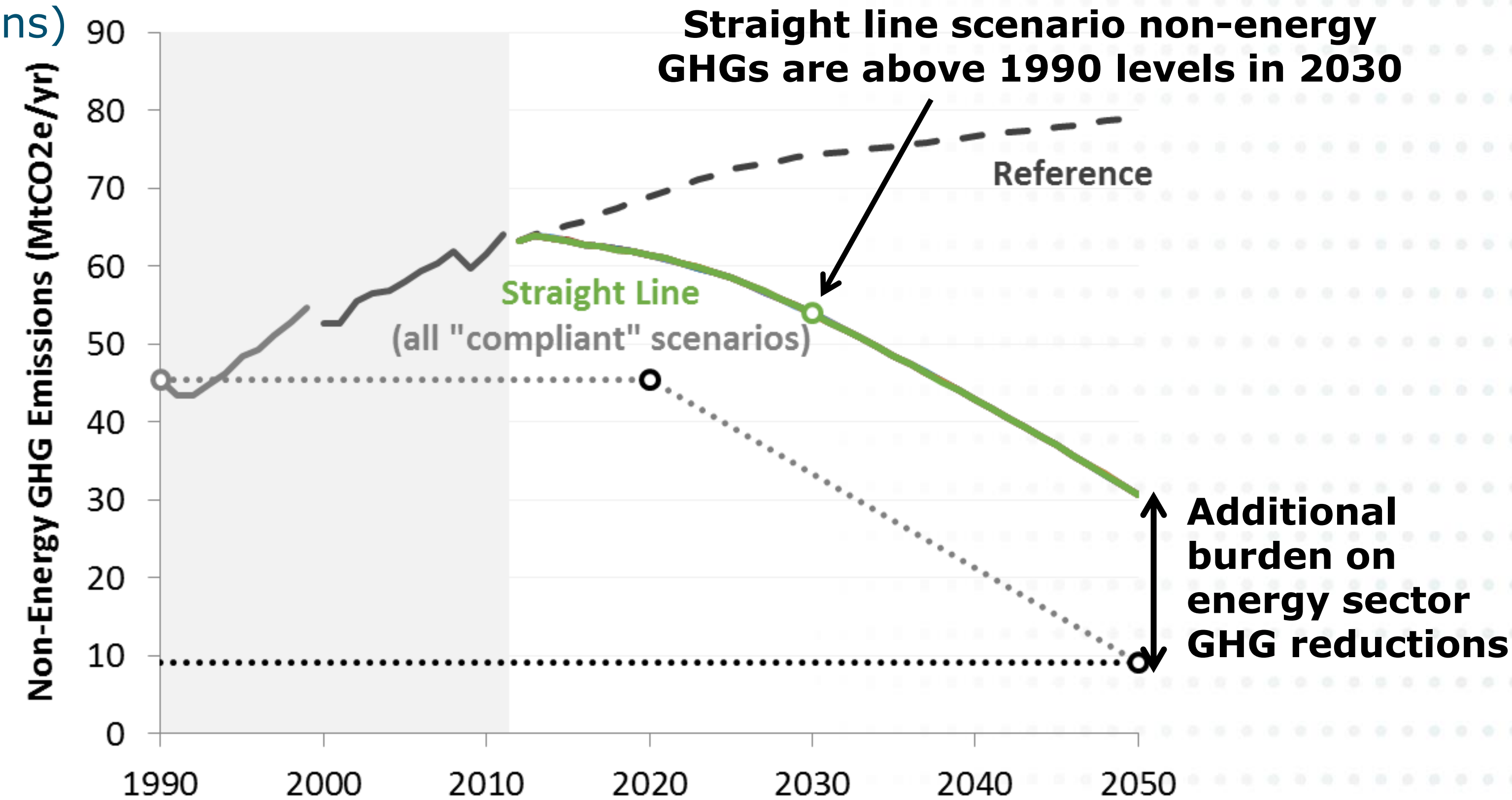
- Low-emissions and zero-emissions vehicles are needed in all scenarios, dramatically reducing demand for liquid fossil fuels
- If natural gas sector is decarbonized (low carbon gas scenario), then liquid fuel supply doesn't need low-carbon fuels through 2050, otherwise, large amounts of liquid biofuels are needed





Reduction in non-energy GHGs is essential, but mitigation measures are limited

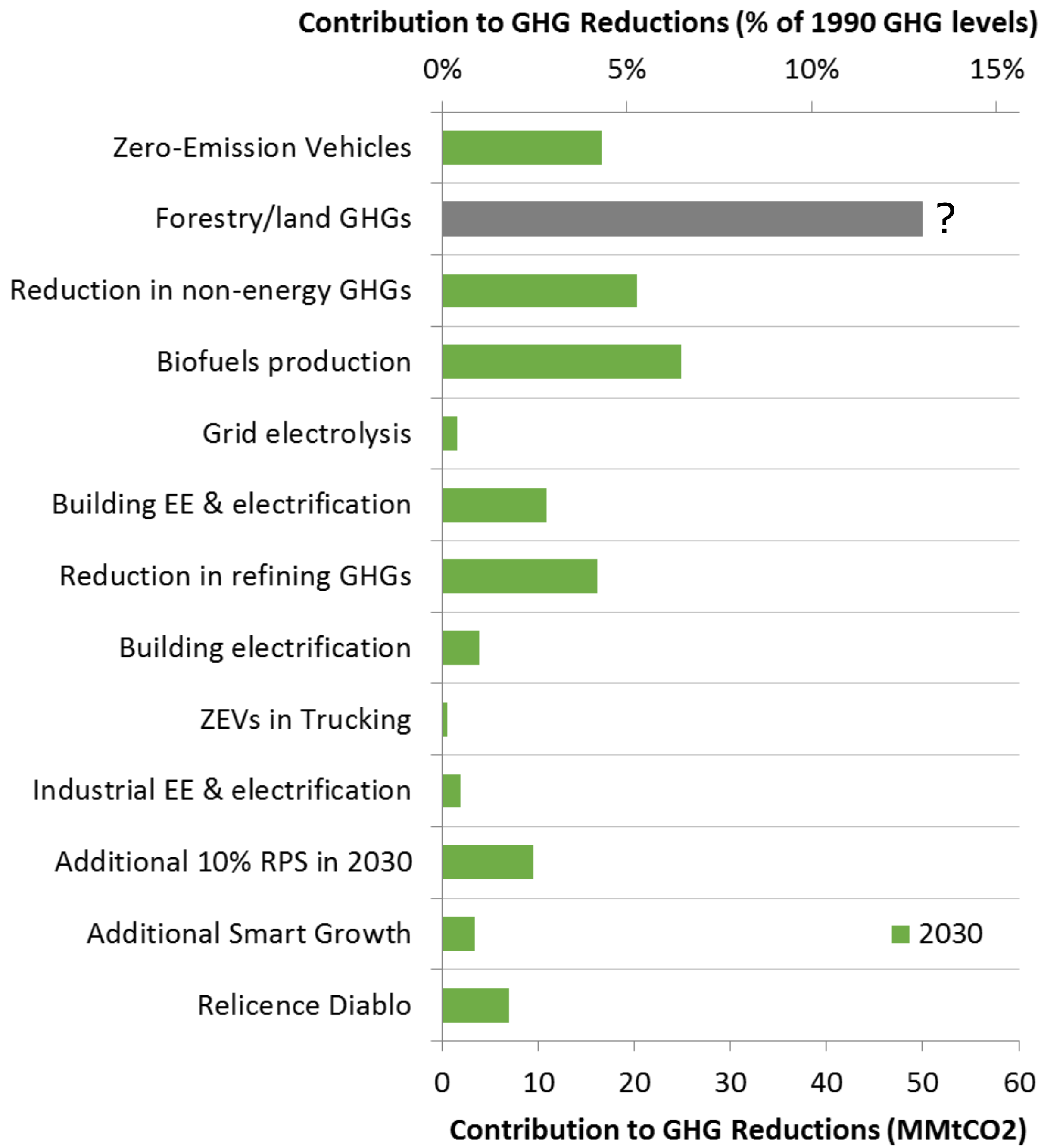
- Mitigation potential is high for F-gases, methane leaks and some types of waste & manure. Difficult to mitigate cement, enteric fermentation, other agricultural non-energy GHG emissions. (Does not include Forestry/lands GHGs due to data limitations)



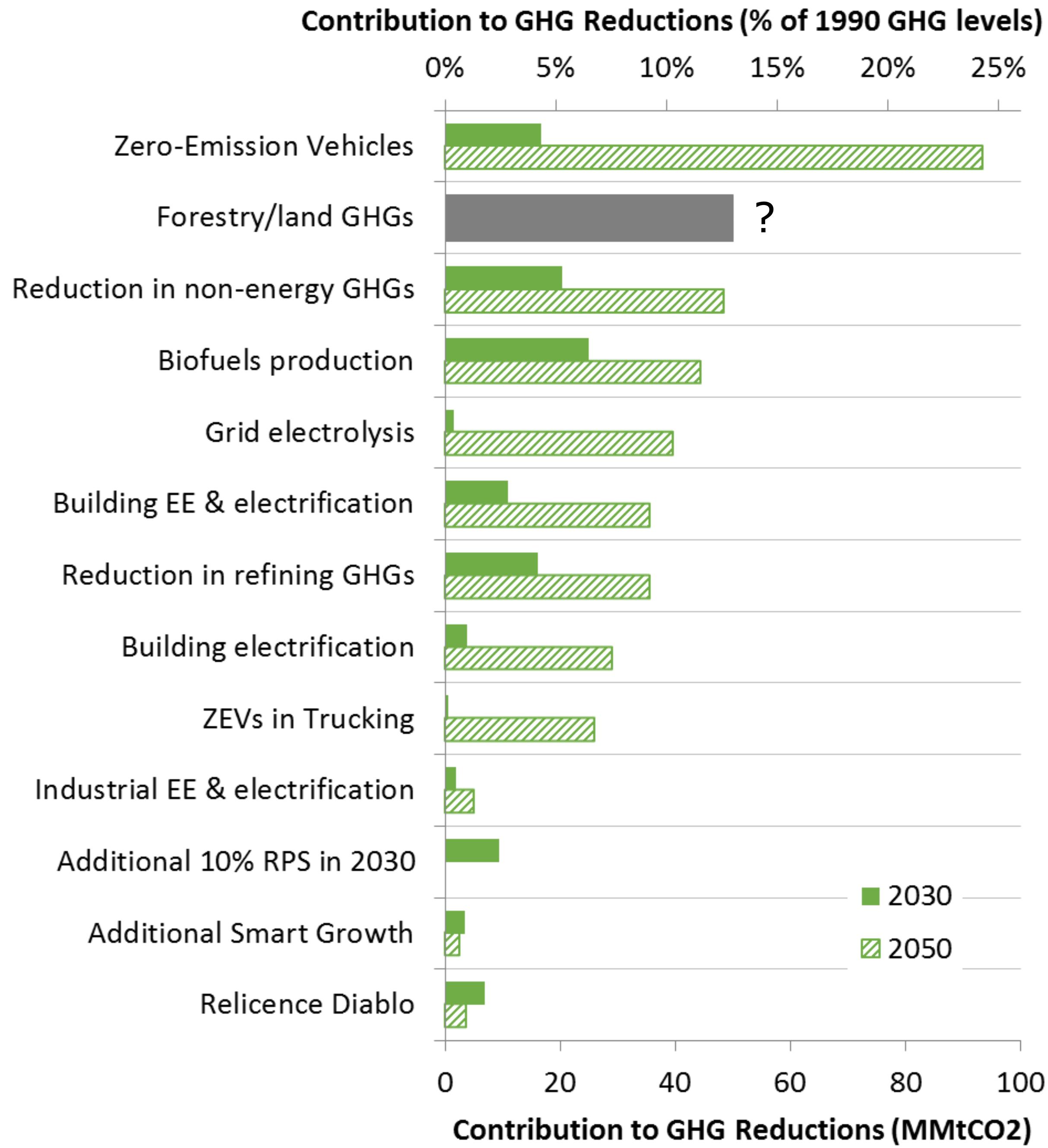
Note: Emissions inventory accounting protocol changed between 6th and 7th edition, resulting in higher estimate of historical non-energy GHG emissions.

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

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

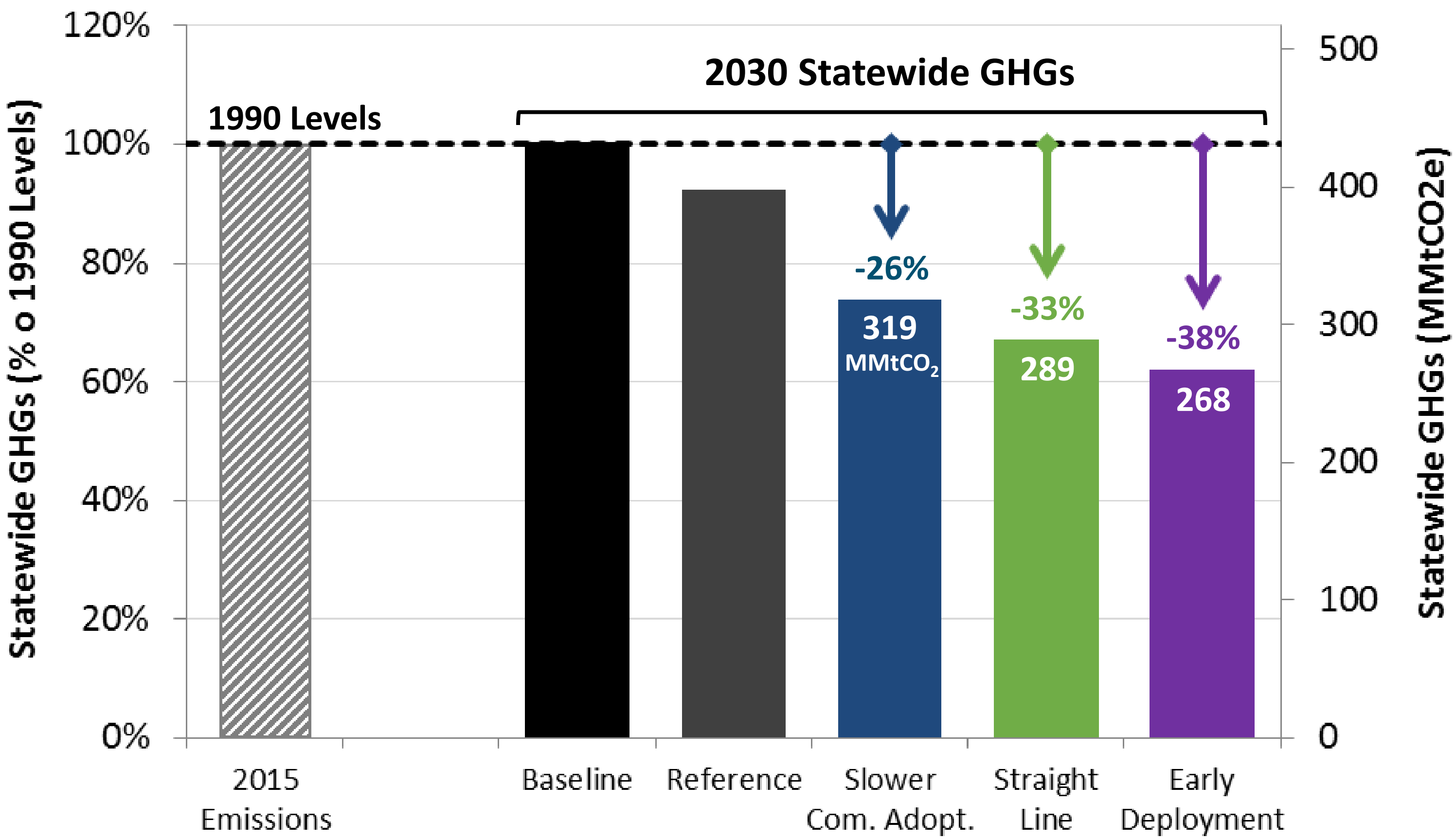


Sensitivities in 2050 show relative importance of carbon reduction strategies in long-term



2030 GHG Ranges Across Potential Strategies

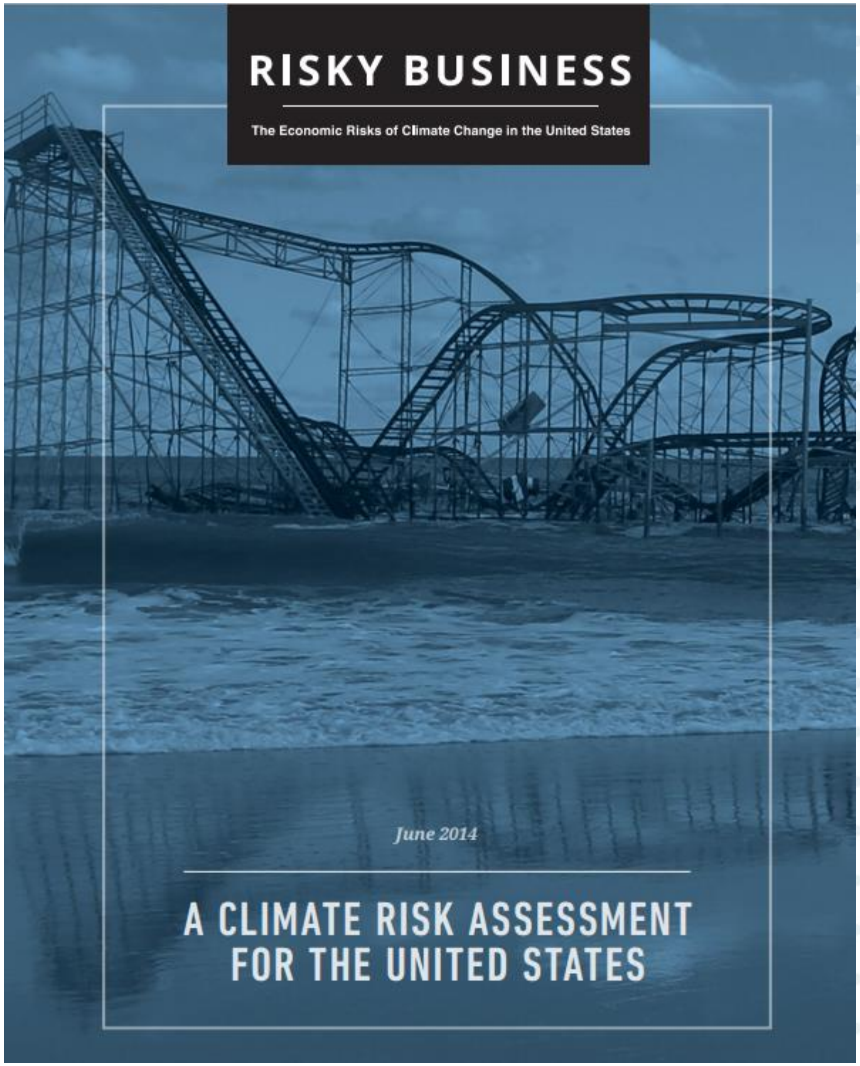
+ **GHGs in compliant strategies range from 26% - 38% below 1990 levels by 2030 (i.e. 34% - 45% below 2005 levels by 2030)**



WHAT ARE THE COST IMPACTS?

Other studies attempt to quantify the costs of climate change

- Other studies have shown that the costs and risks of climate change exceed expected investment cost in low-carbon solutions
- PATHWAYS does NOT evaluate whether carbon mitigation is cost-effective relative to the costs of climate change
- PATHWAYS evaluates trade-offs between carbon mitigation pathways & investment need in low-carbon solutions



Source: "Risky Business: The Economic Risks of Climate Change in the United States," June 2014.

How does PATHWAYS measure costs?

Included:

+ **Incremental cost of energy infrastructure**
  - Transportation: light-, medium- & heavy duty vehicles
  - Building & end uses: lighting, hot water heaters, space heaters, air conditioners, washer/dryer, etc.
  - Industrial equipment: boilers, motors, etc.
  - Electricity production: revenue requirement of all electric assets
+ **Fuel & avoided fuel cost**
  - Electricity, hydrogen, gasoline, diesel, natural gas, biofuel

Excluded:

+ **Societal cost impacts**
  - Climate benefits of GHG mitigation
  - Health benefits of reduced criteria pollutants
+ **Structural/macroeconomic impacts**
  - Changes in the costs of goods and services, jobs, structural changes to economy

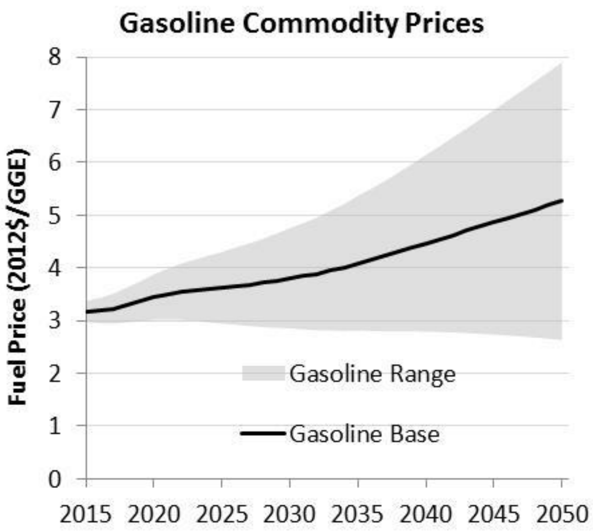
Note: All costs are reported in real, levelized 2012 dollars

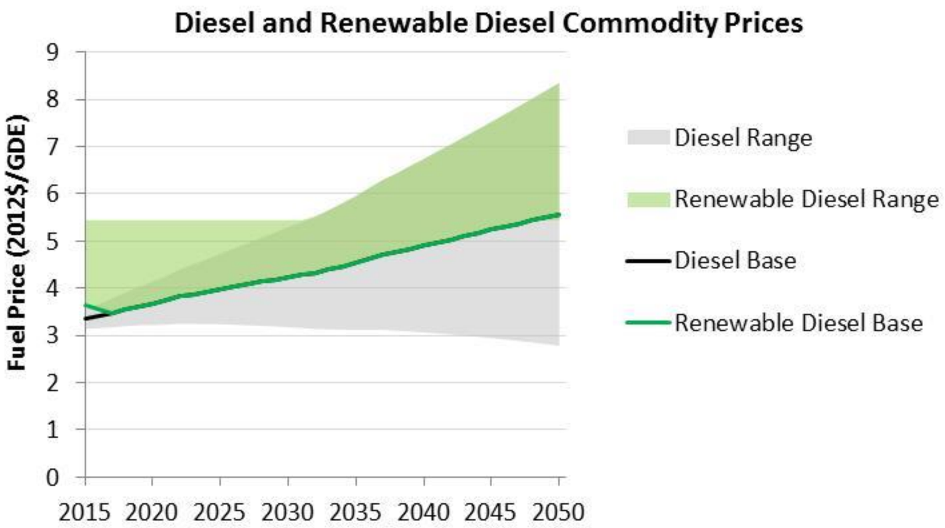
Cost sensitivities are asymmetric; focus on technology, fuels & financing costs

Key uncertainties	Low cost sensitivity	High cost sensitivity
Technologies		
• Solar PV	-50%	…
• Electric heat pumps	-20%	…
• LED lighting	-20%	…
• Grid electrolysis	-20%	…
• Wind power	-5%	…
• Fuel Cell Vehicles	-5%	…
• Battery Electric Vehicles & PHEVs	-5%	…
• Electric boilers	-5%	…
• Biofuels	…	High cost
Fossil fuel prices	+50%	-50%
Financing cost	5% (real)	10% (real)

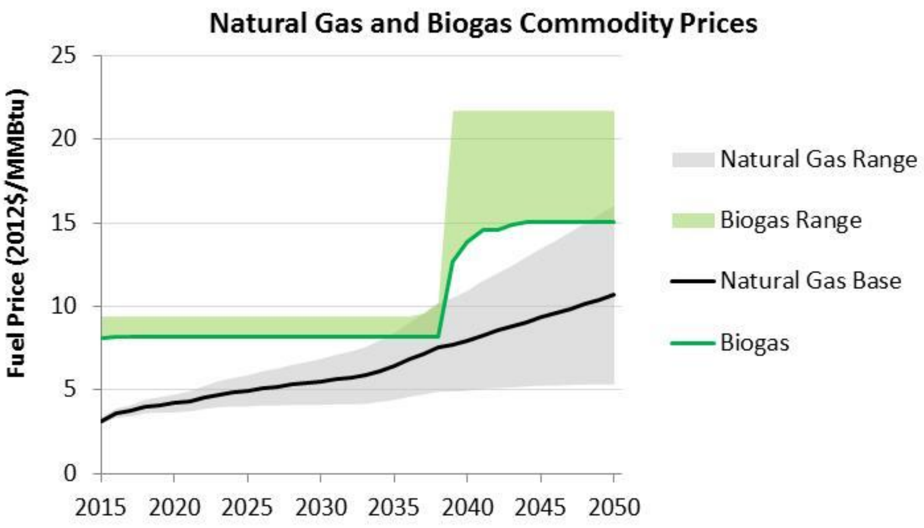
Technology costs are not modified in the high cost sensitivity because base cost assumptions are already conservative. All cost sensitivities modify both the Reference and Straight Line scenario assumptions.

Fuel price sensitivities



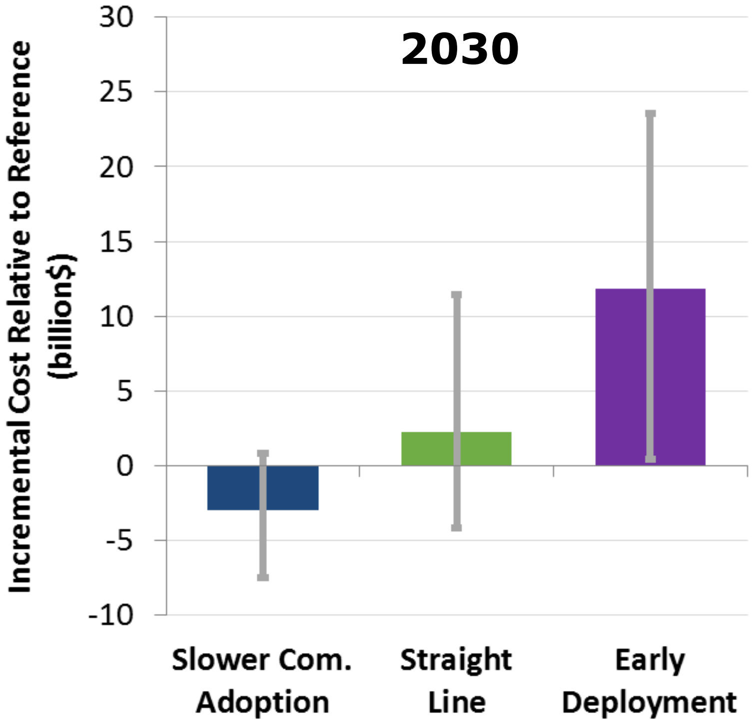


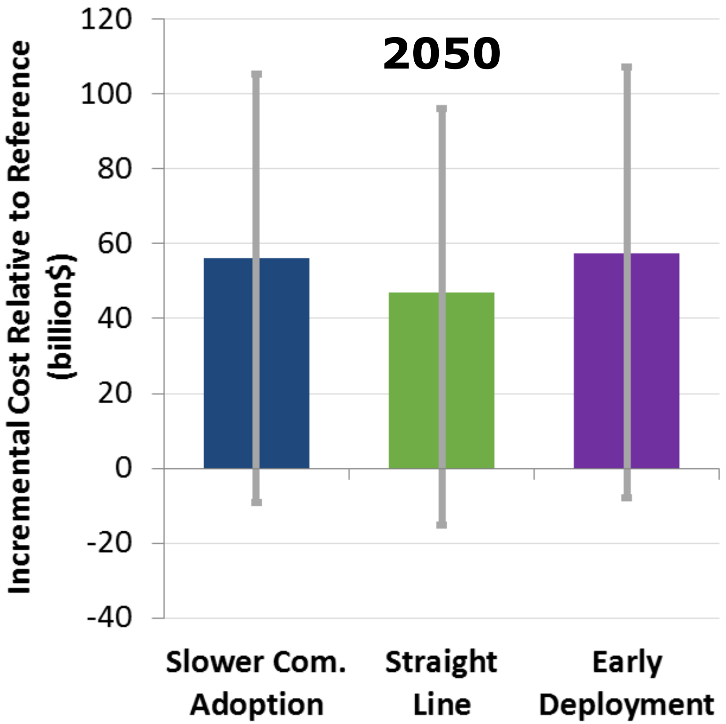
- Fossil and renewable fuel prices projections range from high to low, reflecting future price uncertainties



Cost impacts of timing decisions

- 2030 scenarios & sensitivities span savings of $8B to costs of $24B/year
- 2030 Straight Line scenario equivalent to $50/yr/capita total net cost
- Delaying deployment of some high cost measures until post-2030 reduces cost in near-term, but may increase cost in long-run; Early deployment increases near-term costs (but reduces criteria pollutants)

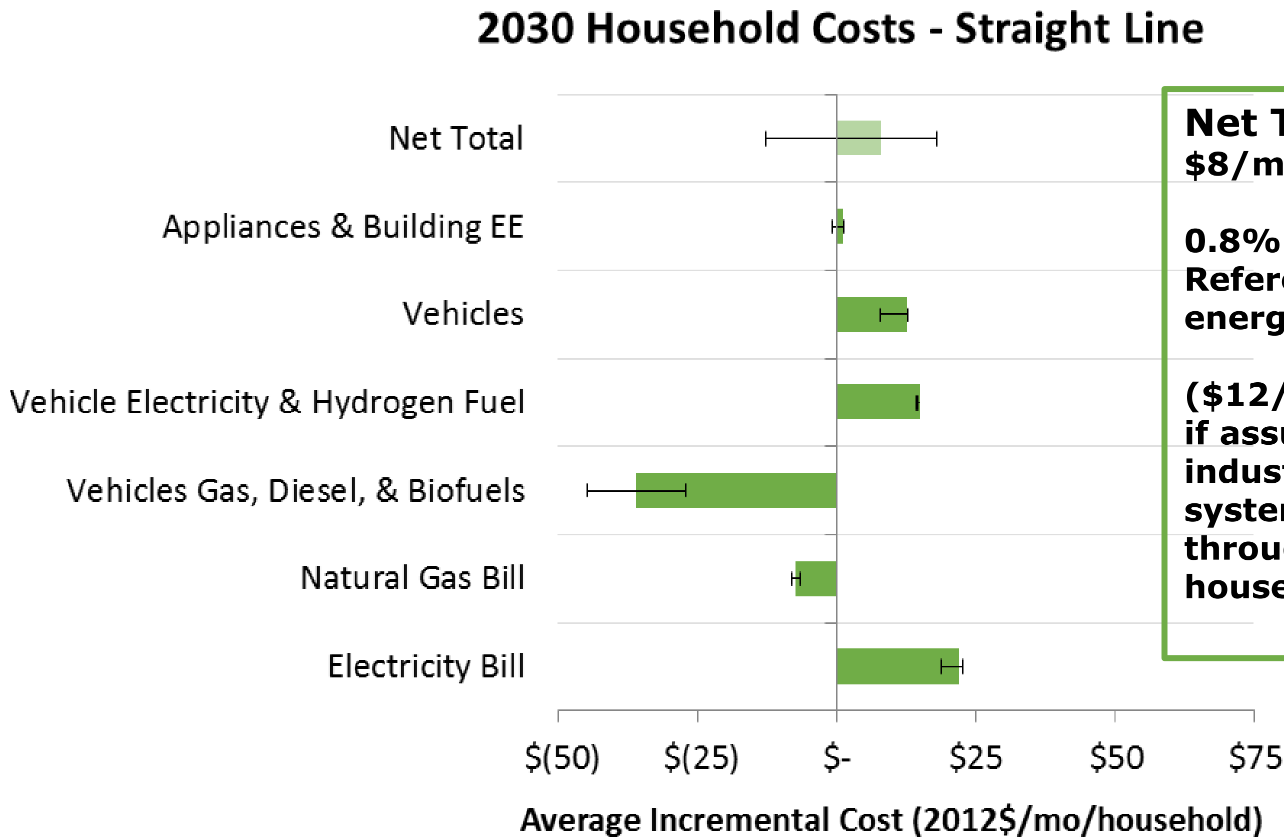




Error bars represent high & low cost sensitivity analysis

Average Household
Monthly Cost: 2030 Straight Line Scenario

- Average household sees significant savings in gasoline/diesel costs, offset by increases in electric bill, car payments and cost of ZEV fuel (doesn't include changes to cost of goods & services)



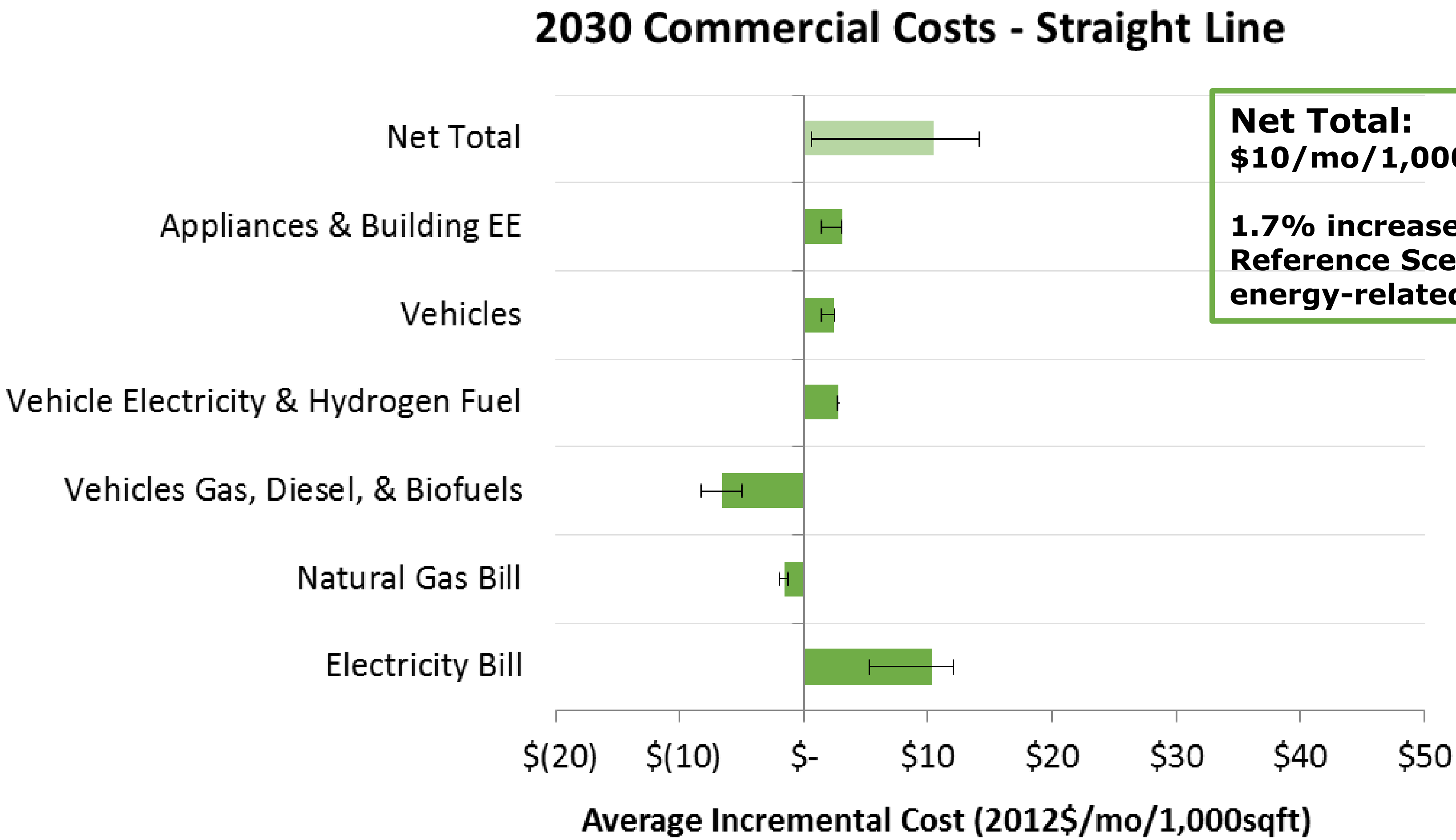
Net Total:
$8/mo/household

0.8% increase over Reference Scenario energy-related costs

($12/mo/household if assume all com. & industrial energy system costs flow through to households)

Average Commercial
Monthly $/sq ft: 2030 Straight Line Scenario

+ **Average commercial enterprise sees significant savings in gasoline/diesel costs, offset by increases in other costs.**

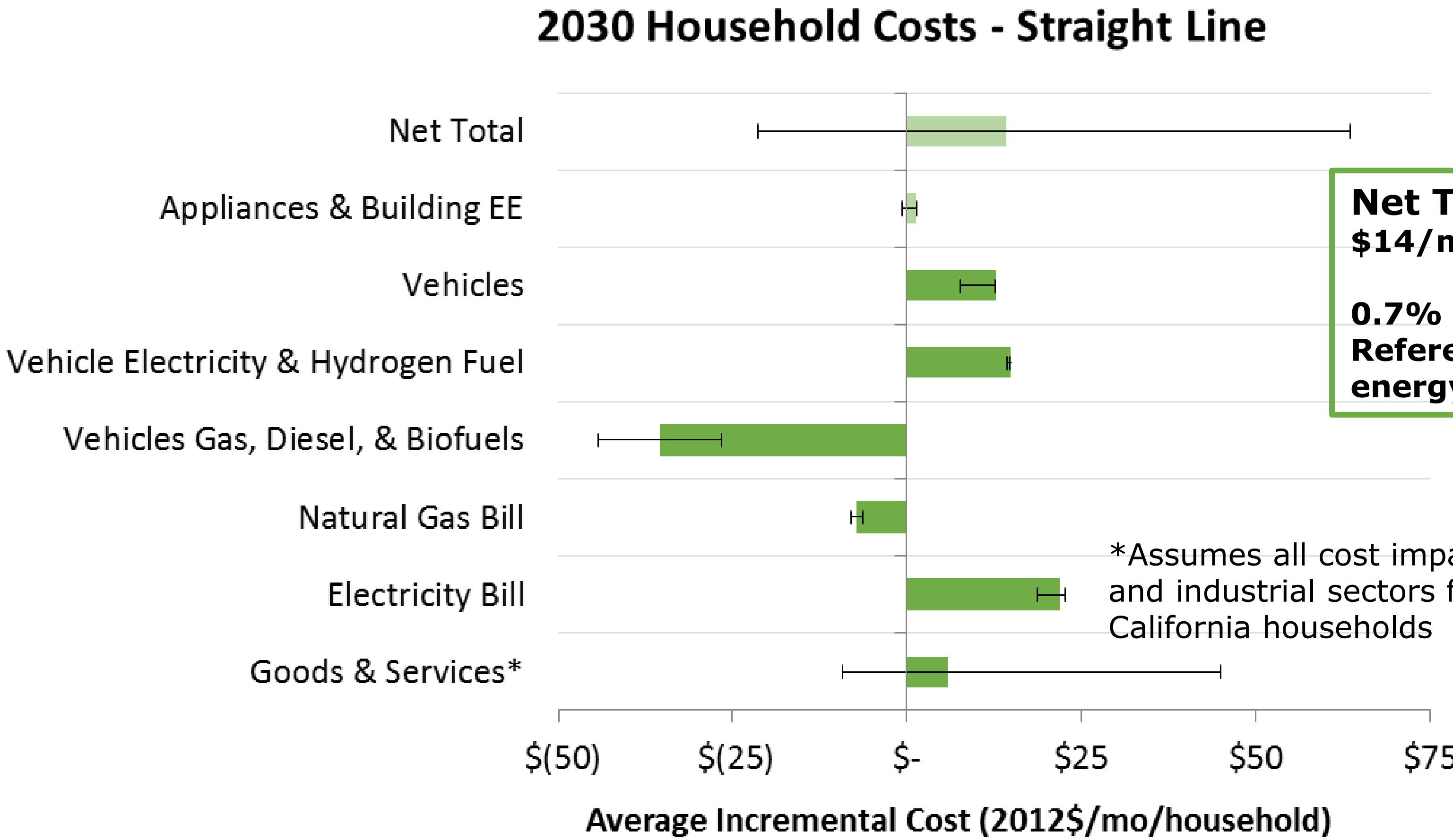


Net Total:
$10/mo/1,000 sf

1.7% increase over Reference Scenario energy-related costs

Total cost /Household (including change in goods and services costs)
Monthly Cost: 2030 Straight Line Scenario

+ **Total costs/# households: average household sees savings in gasoline/diesel costs, offset by increases in electric bill, ZEV costs and increases in the cost of goods & services**



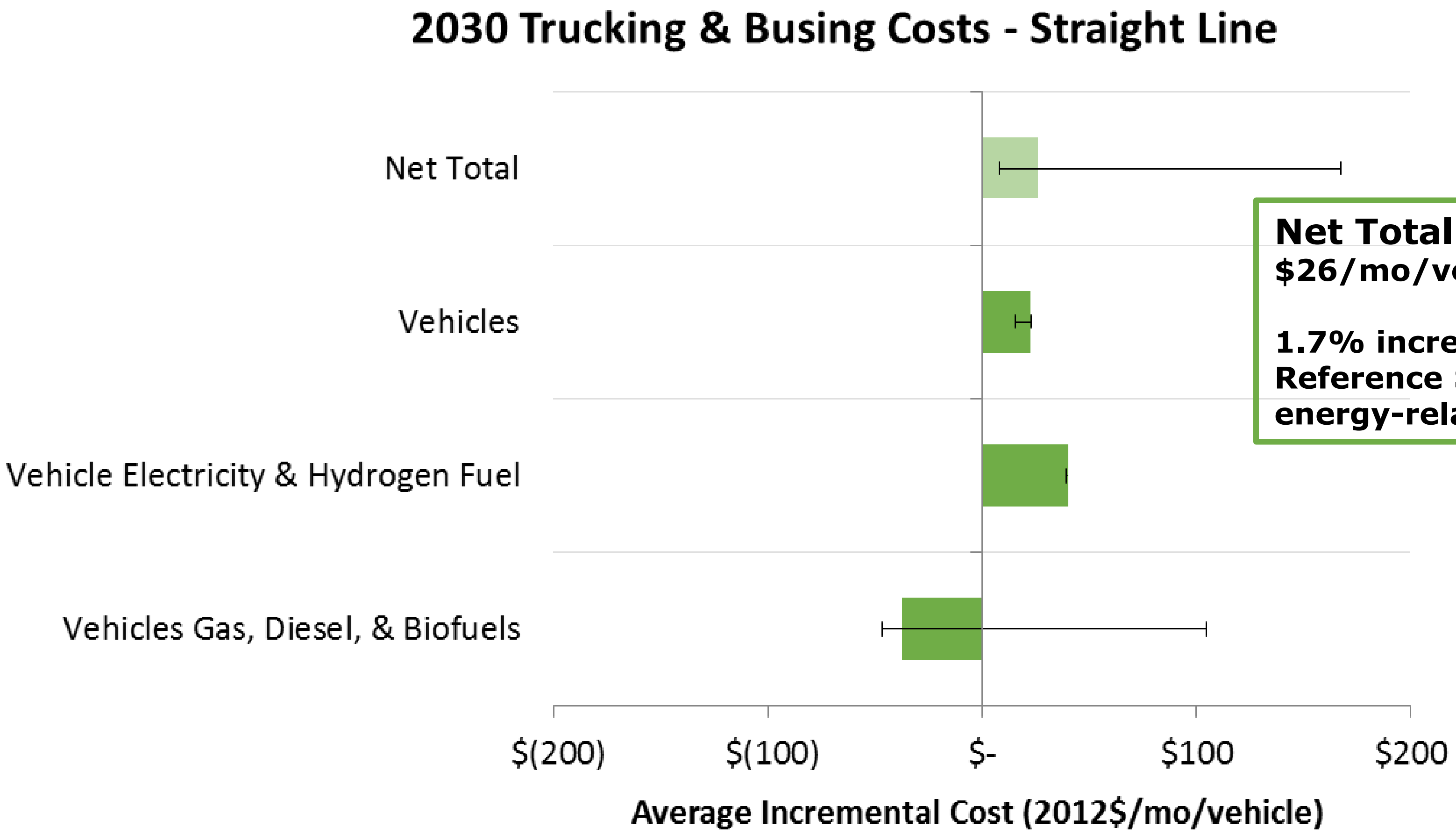
Net Total:
$14/mo/household

0.7% increase over Reference Scenario energy-related costs

*Assumes all cost impacts on commercial and industrial sectors flow through to California households

Average Trucking & Buses
Monthly $/vehicle: 2030 Straight Line Scenario

+ **Medium & heavy duty trucks & buses low-carbon alternatives are expected to be costly relative to current technologies.**

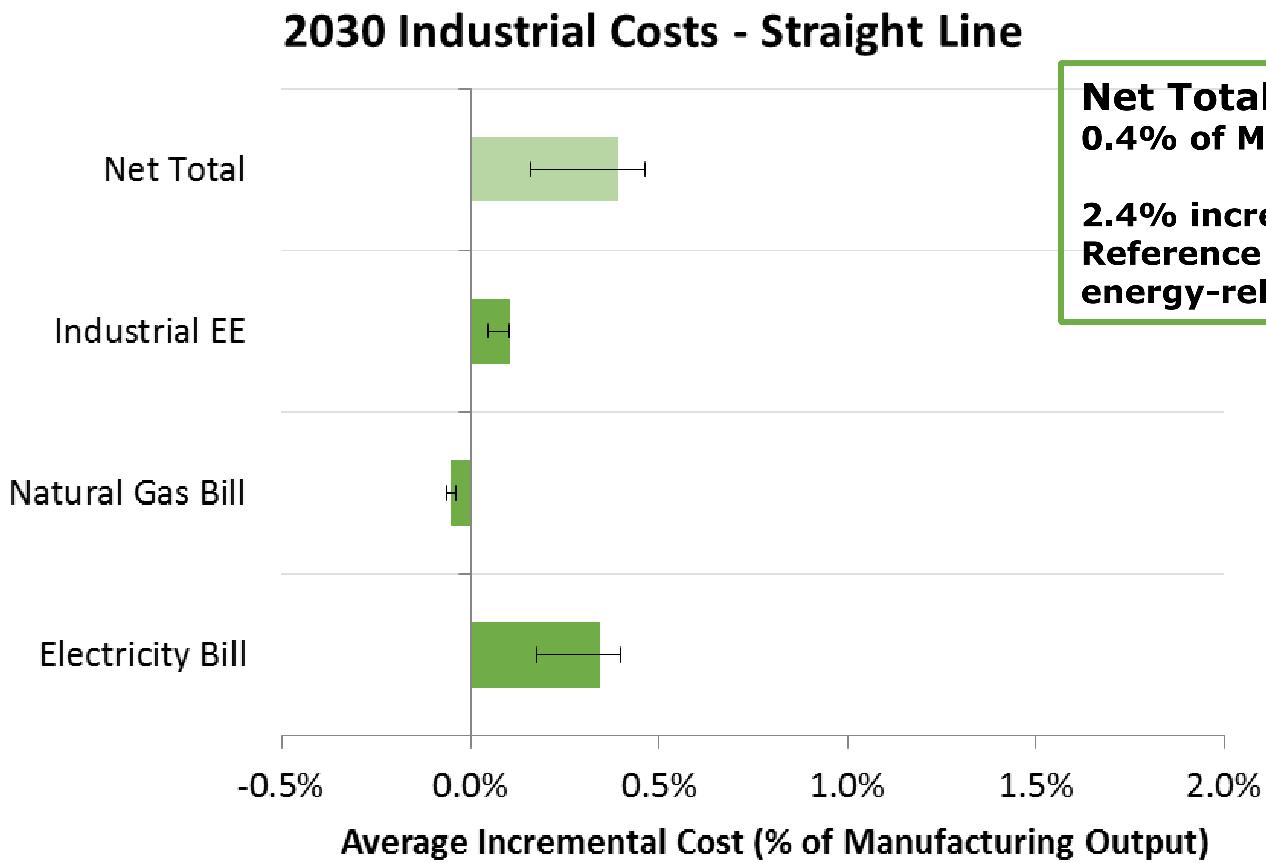


Net Total:
$26/mo/vehicle

1.7% increase over Reference Scenario energy-related costs

Average Industrial Cost
% of MFG output: 2030 Straight Line Scenario

- 2030 average industrial costs are relatively modest. Higher electricity bills are due largely to higher cost of electricity rather than electrification

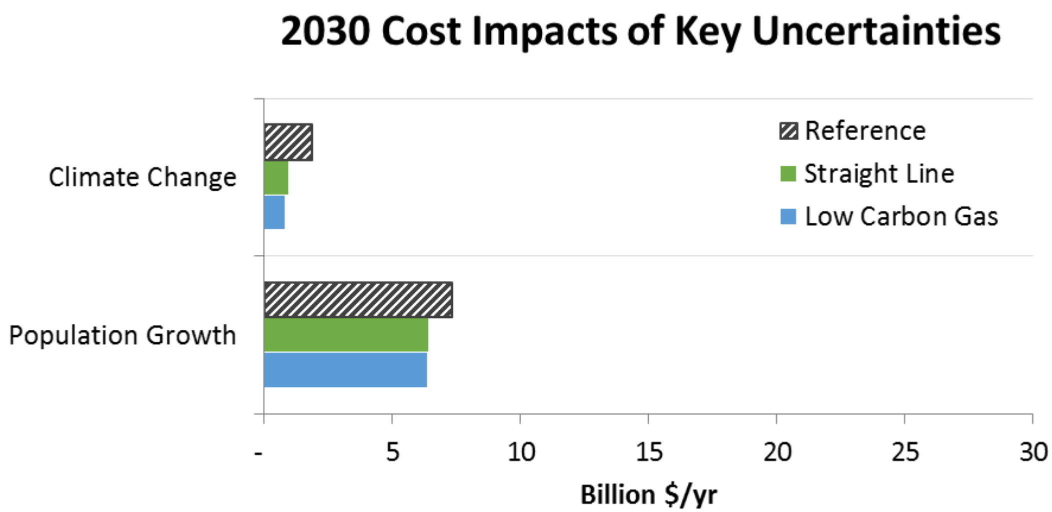


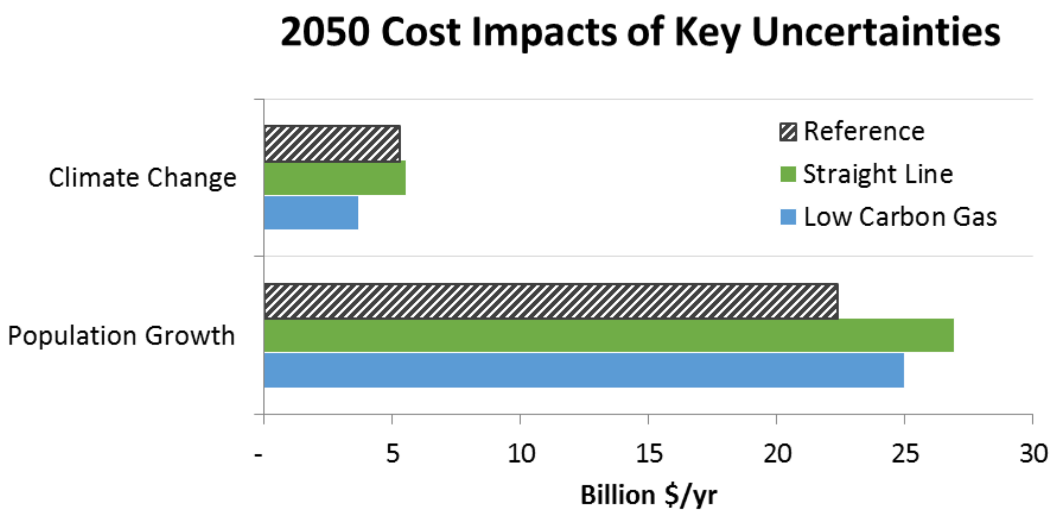
Net Total:
0.4% of MFG output

2.4% increase over Reference Scenario energy-related costs

Key Uncertainties Affecting Reference & All Scenarios

- Climate change (warmer summers, colder winters and less hydro availability) and unexpected increases population growth represent two uncertainties that would increase the cost of all future scenarios, including the Reference scenario
- These uncertainties have little impact on net costs or GHGs relative to Reference scenario, but large impact on total costs and GHGS



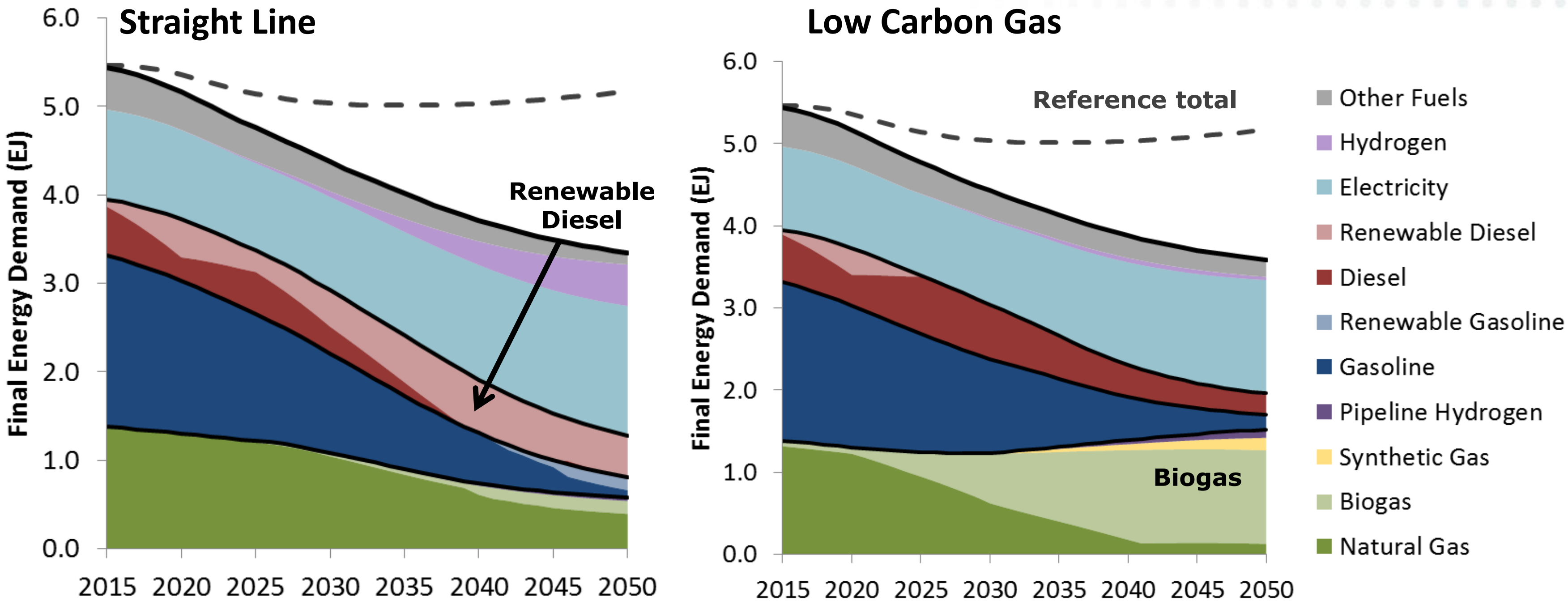


FORKS IN THE ROAD

How to use limited supply of biofuels?

- **Biomass supply is limited**: assume CA imports population-share (12%) of U.S. total supply (61-69 million bone dry tons in 2030)
- **Current policy directs biomass into liquid fuels** (Straight Line scenario assumptions); Alternate pathway could direct biomass into biogas (Low carbon gas scenario assumptions); or a blend of different biofuels options (not tested here)

Final Energy Demand by Major Fuel Type



Biofuel pathways require different low-carbon strategies in buildings

Biomass Utilization

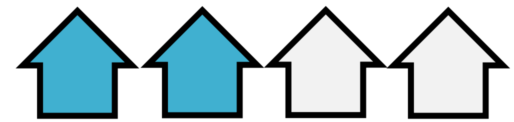
Building Electrification

Use renewable liquid fuels for transport.

Straight Line

By 2030:
Biomass serves 24% of liquid fuels; 60% of **new** water heaters, 50% of **new** residential space heaters are electric

Electrify new sales of water and space heating



OR

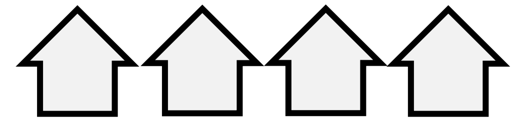
(new appliance sales)

Produce biogas for buildings & industry

Low Carbon Gas

By 2030:
Biogas serves 53% of natural gas demand; no building electrification

No building electrification



ZEV pathways require different electricity infrastructure

Zero Emissions Vehicles

New Infrastructure

Mix of fuels cell (FCVs) and battery electric vehicles (BEVs)

(new vehicle sales)

Straight Line

By 2030:
New sales are 29% PHEV/BEVs, 27% FCVs; Flexible electrolysis balances renewables (assuming 25% load factor)

Electric vehicle charging load: 7,000 MW

Flexible grid electrolysis: 9,000 MW

H_2 fueling stations

No new energy storage

OR

Focus on BEVs if FCVs don't materialize

High BEV

By 2030:
New sales are 57% PHEV/BEVs; Energy storage balances renewables

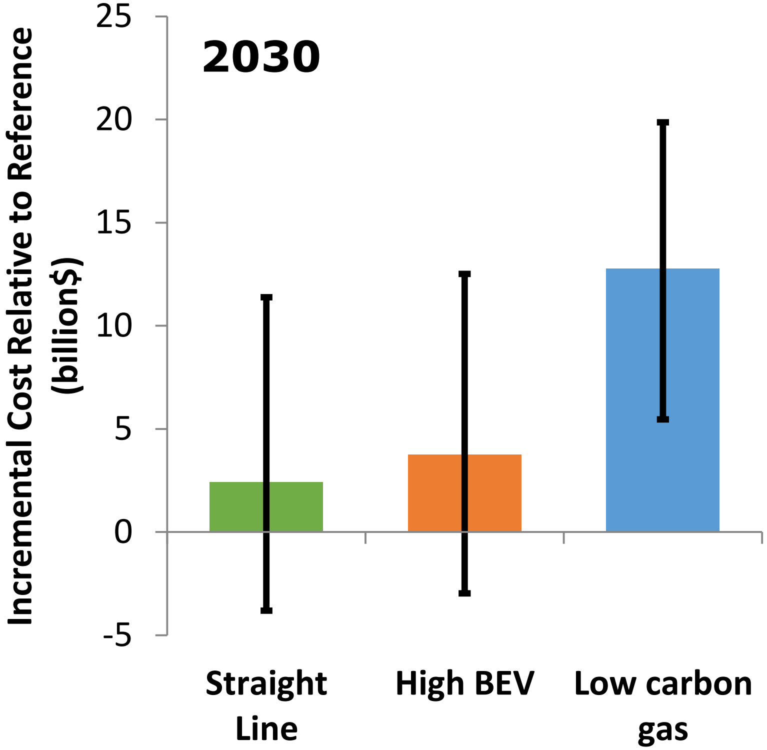
Electric vehicle charging load: 20,000 MW

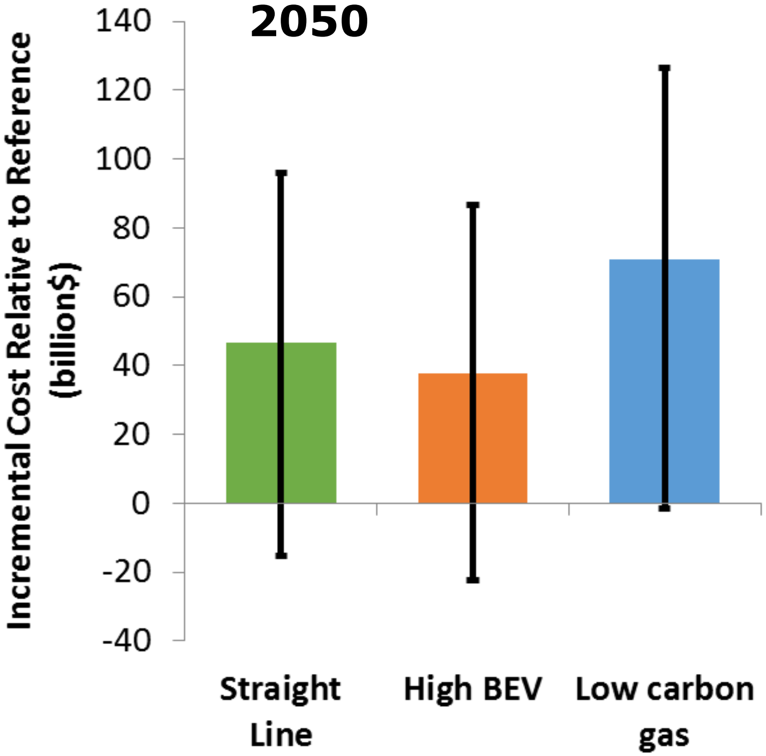
New 4-8 hr energy storage: 5,000 MW

No grid electrolysis
No H2 fueling stations

Cost implications of forks in the road

+ Low Carbon Gas scenario vs. Straight Line scenario costs are driven by assumptions about biofuel availability and cost (very uncertain)
+ Cost differences between Straight Line and High BEV scenario are minor and are driven by cost assumptions for FCVs vs. BEVs





Error bars represent high & low cost sensitivity analysis

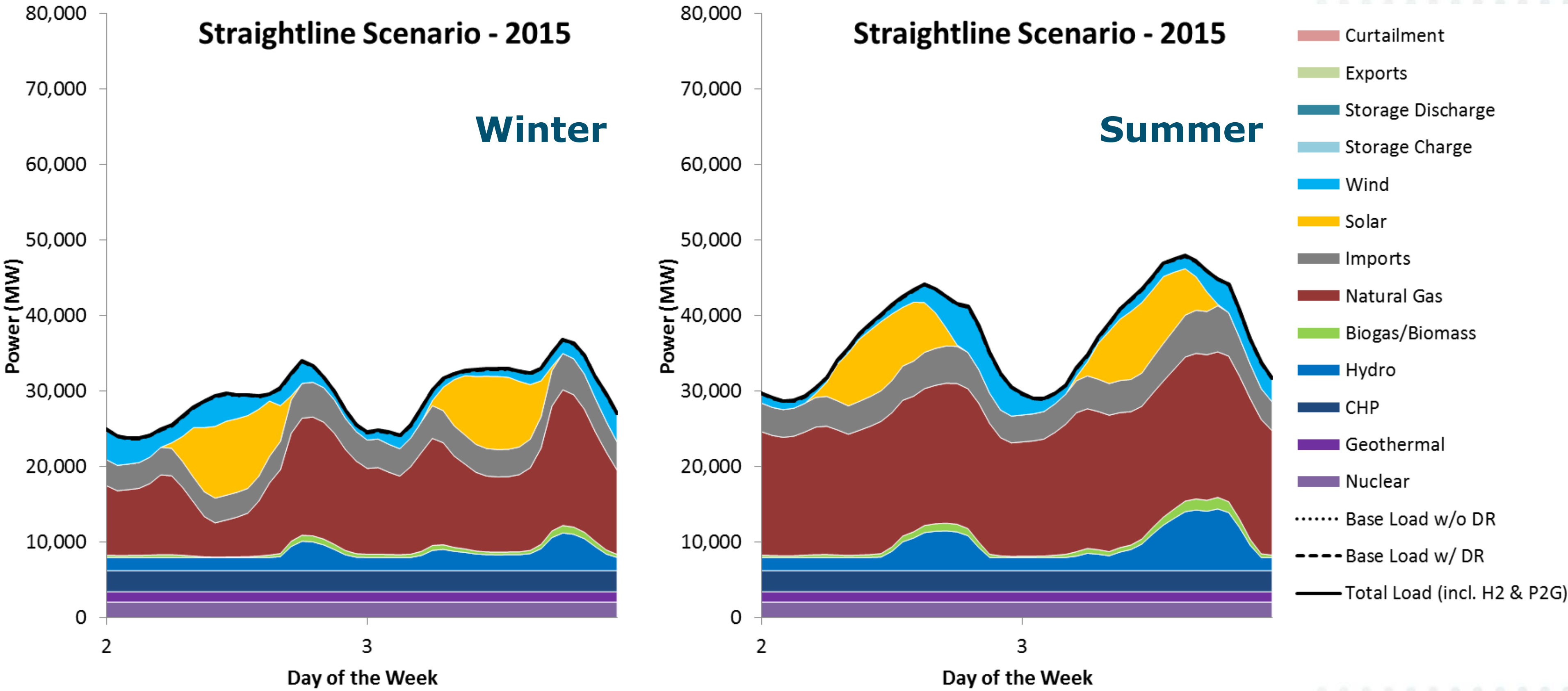
Technology commercialization risks vary by scenario

Technology Category	Technology Risk (combines importance and degree of commercialization)		
	Straight Line	High BEV	Low Carbon Gas
Availability of low-carbon, sustainably-sourced biomass	High	High	High
Hydrogen production using renewable electrolysis	High	n/a	High
Fuel cells in light-duty & heavy duty vehicles	High	n/a	High
Production of low-carbon, drop-in liquid biofuels	High	High	n/a
New long duration grid storage	n/a	High	n/a
Production of low-carbon biogas	n/a	n/a	High
Production of synthetic low-carbon gas	n/a	n/a	High
High efficiency heat pumps	Medium	Medium	n/a
Electrification of industrial end uses	Medium	Medium	n/a
Light duty & heavy duty electric vehicles	Medium	Medium	Medium
LED lighting	Low	Low	Low
Energy efficiency in vehicles	Low	Low	Low

ELECTRICITY SECTOR DETAILS

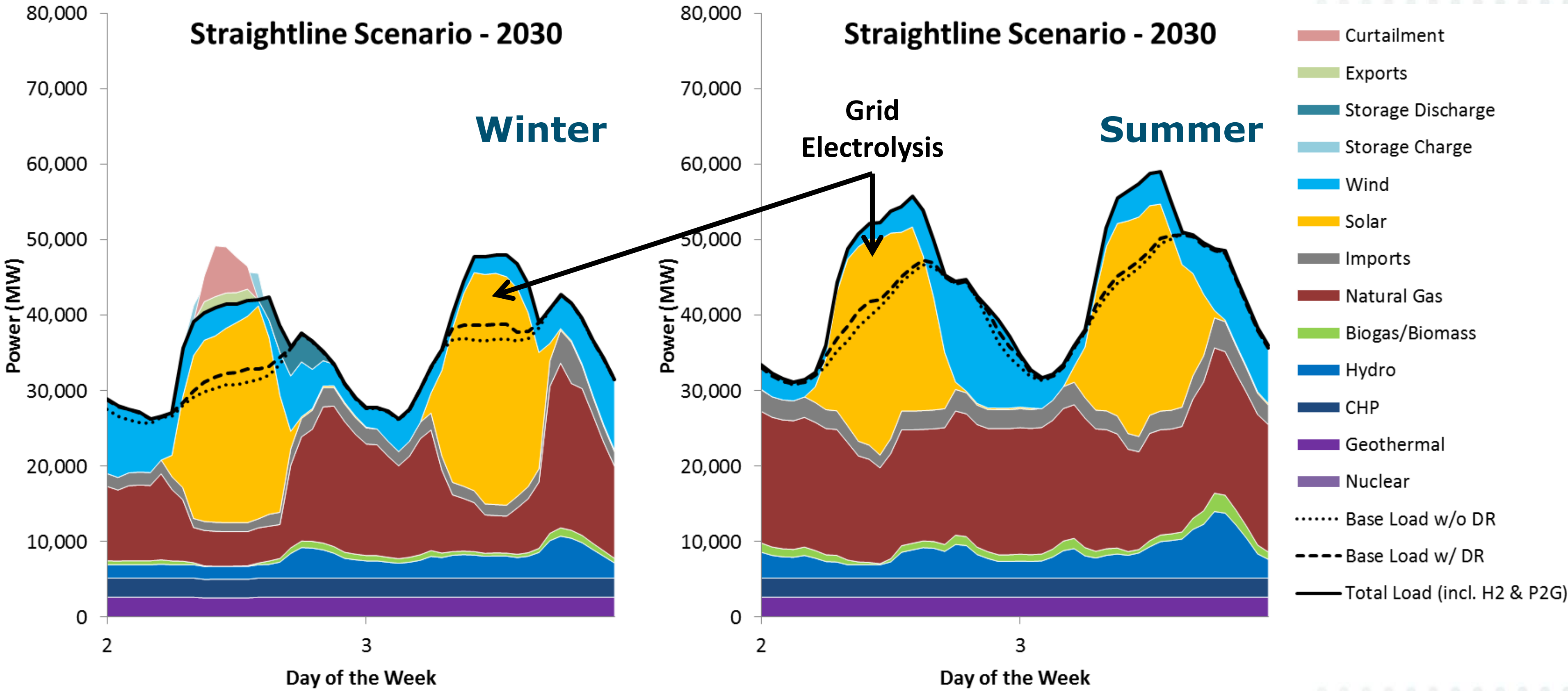
Electricity Balancing - 2015

+ **In near-term, renewables balanced largely by natural gas and hydro**



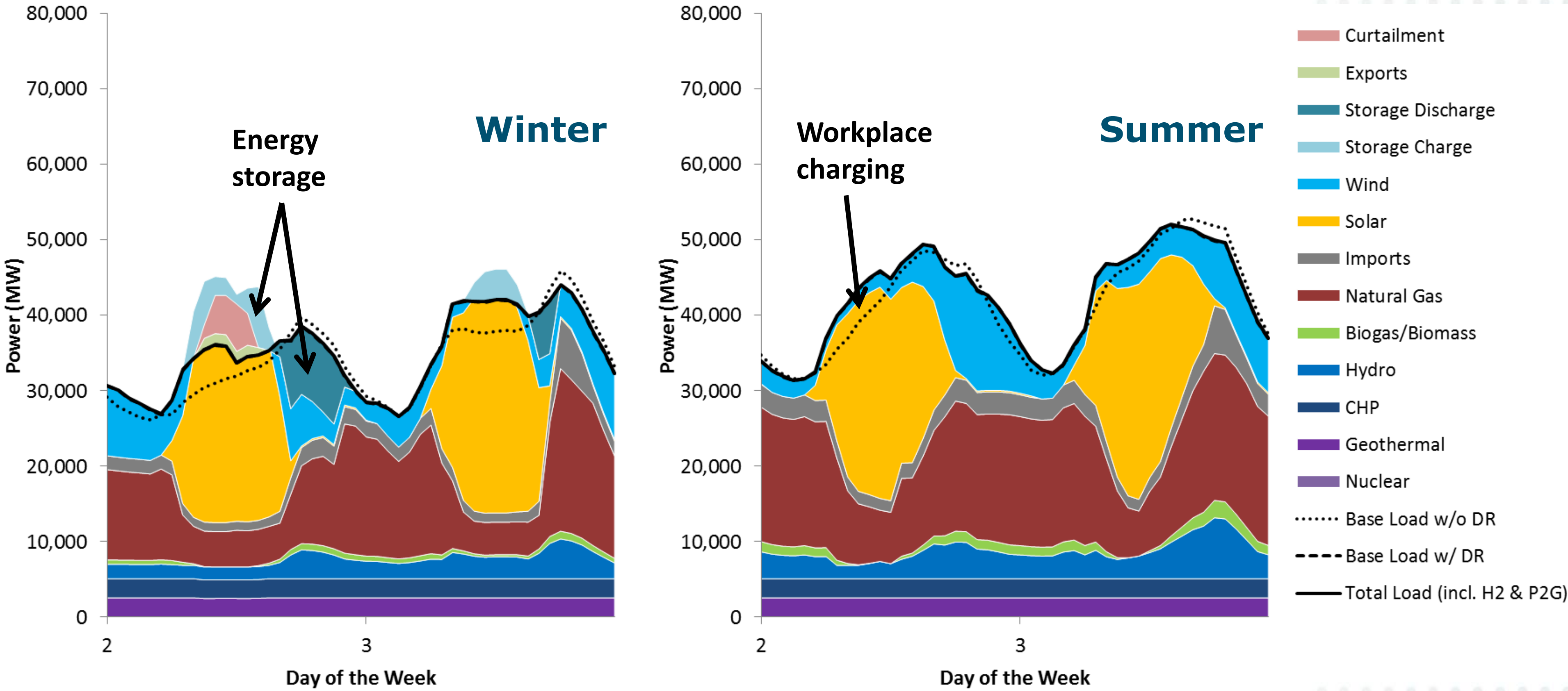
Electricity Balancing 2030 in Straight line Scenario

+ **Additional renewables built for and absorbed by flexible grid electrolysis to fuel FCVs**



Electricity Balancing 2030 in High BEV Scenario

+ **Lower loads, some balancing provided by workplace charging, additional balancing required from storage**

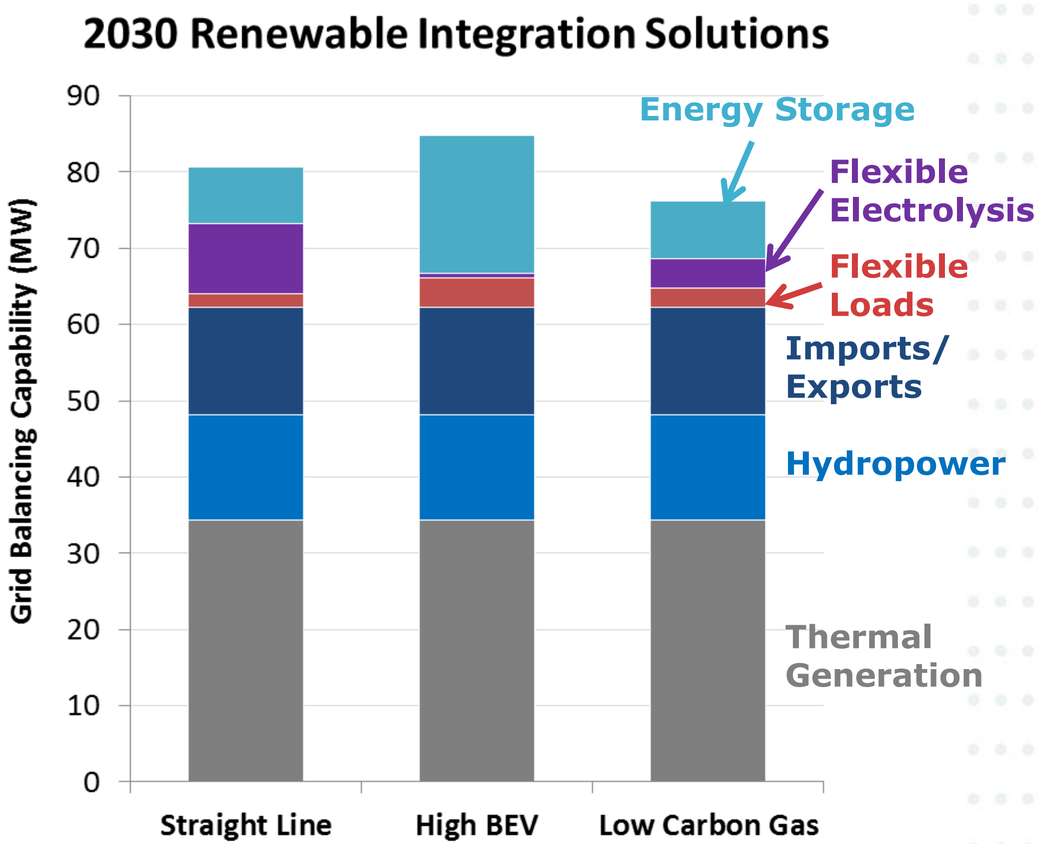


Integration solutions are needed in all high renewable scenarios

In all renewable scenarios:

+ Continued role for hydro & thermal generation
+ Renewable diversity, regional coordination, renewable curtailment
+ Increased reliance on flexible loads, especially flexible fuel production (grid electrolysis)

More 4-8hr stationary storage is needed in high BEV scenario due to no flexible grid electrolysis

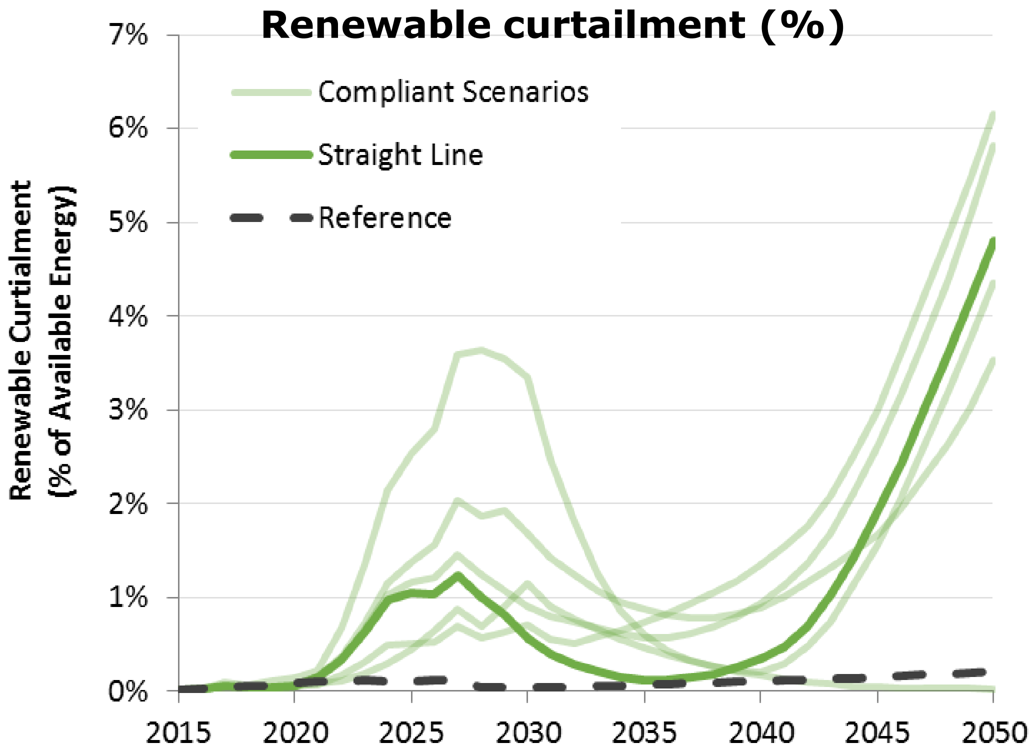


Renewable Curtailment (% of available renewable energy)	0.7%	0.8%	1.9%

*Storage balancing capability = charging + discharging capacity

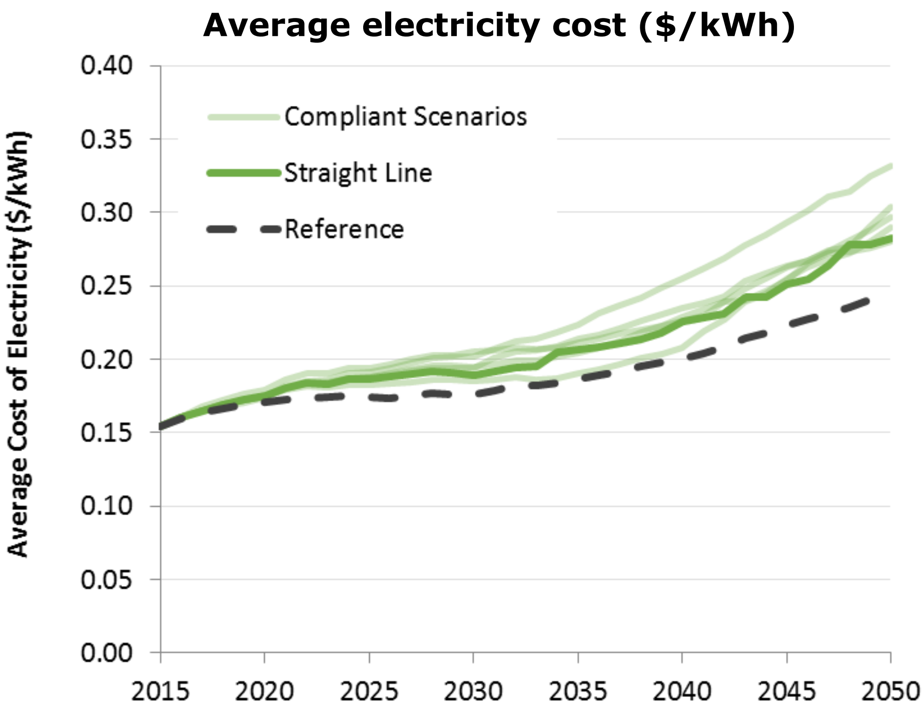
Renewable curtailment relatively low in all scenarios due to integration solutions

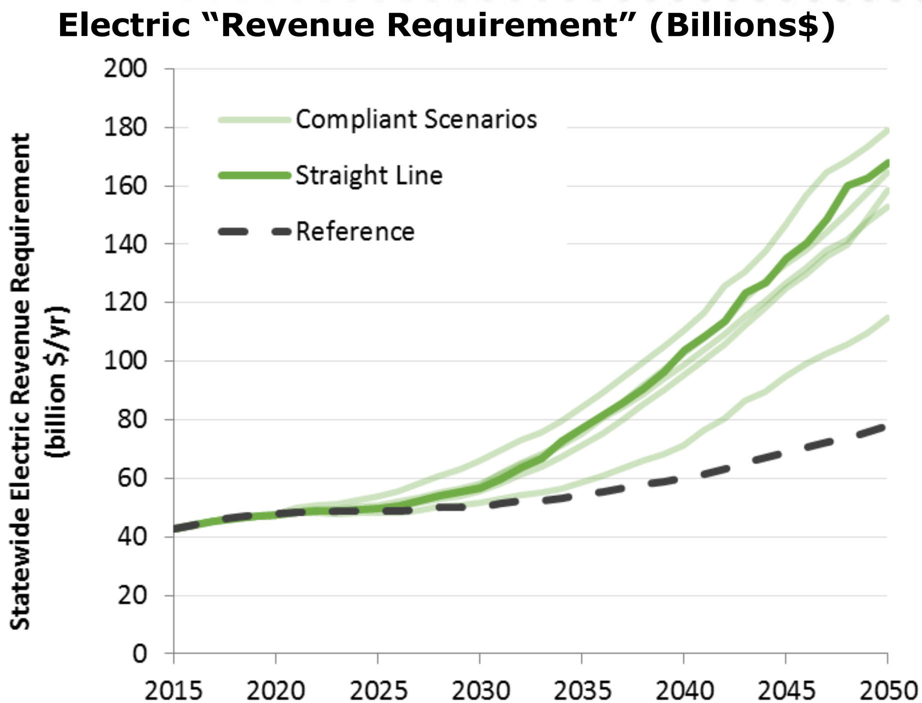
- Straight Line scenario assumes grid electrolysis (producing hydrogen for fuel cell vehicles) will provide grid balancing services. With no fuel cell vehicles or grid electrolysis, renewable curtailment and/or dedicated electricity energy storage needs increase substantially.
- **Important Note:** Storage 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



Electricity Costs by Scenario

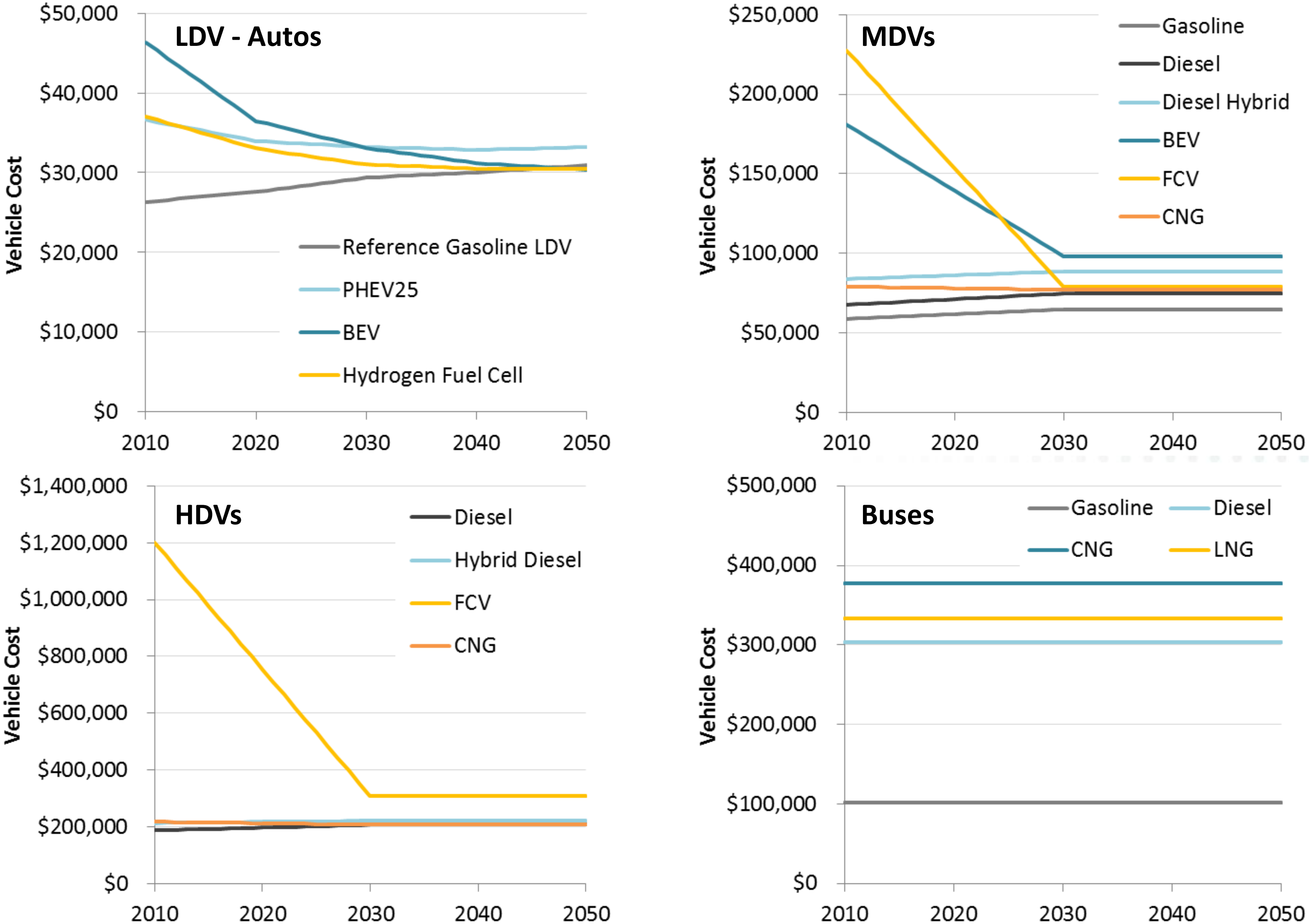
- Average cost of electricity generation (revenue requirement divided by total generation) increase in Compliant Scenarios relative to Reference scenario.
- Increases in reference case cost assumptions are driven by assumptions about "business-as-usual" escalation rates of existing generation, transmission & distribution costs.



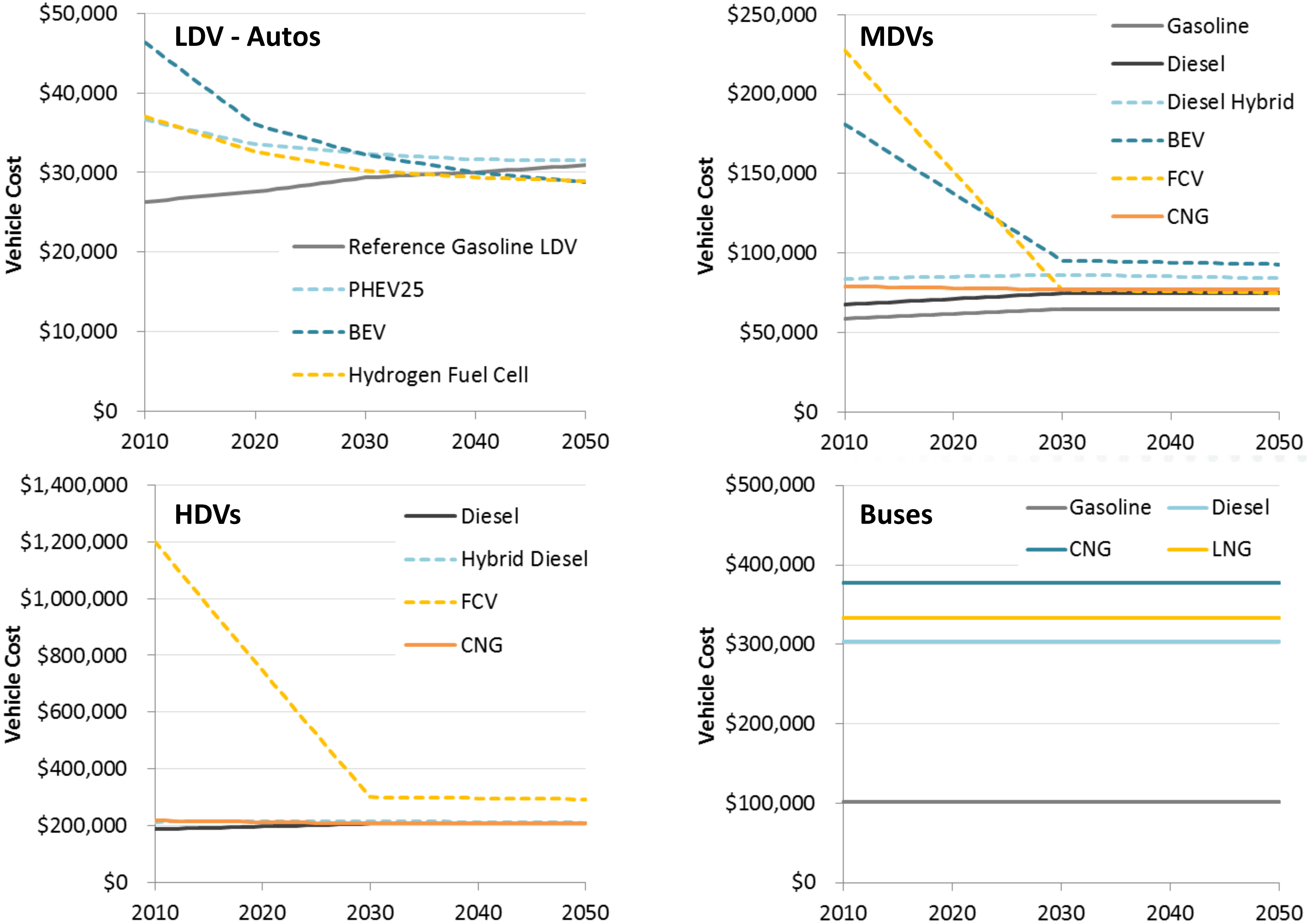


KEY INPUT ASSUMPTIONS

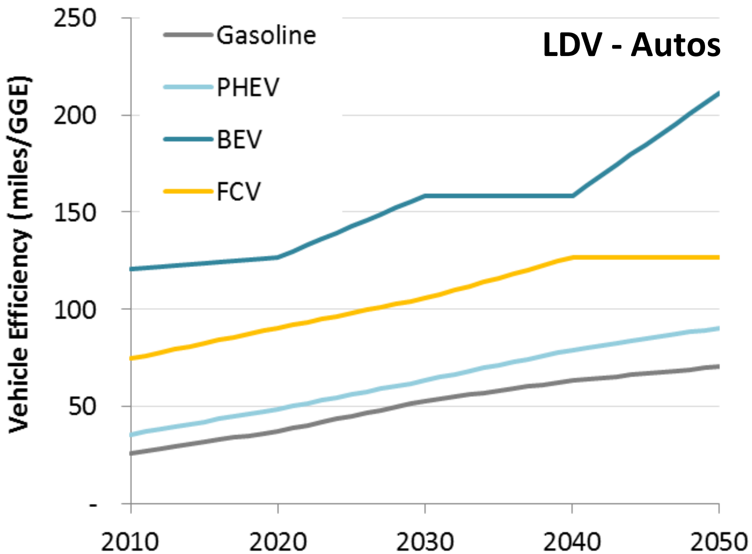
Vehicle Costs

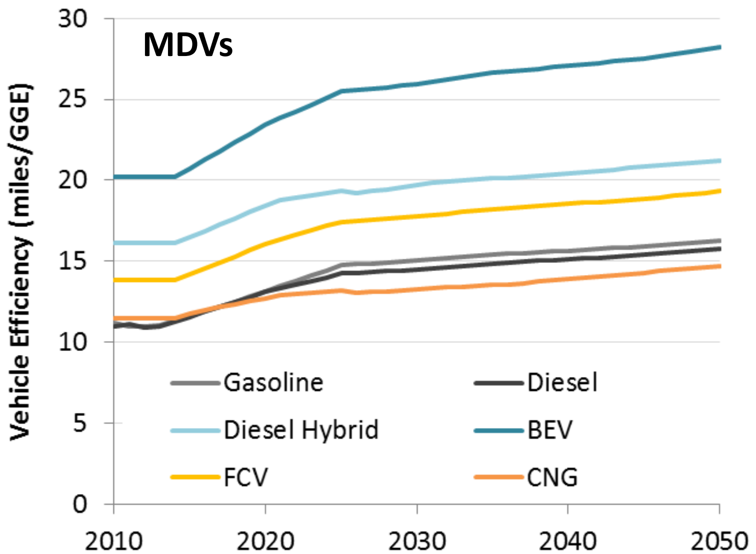


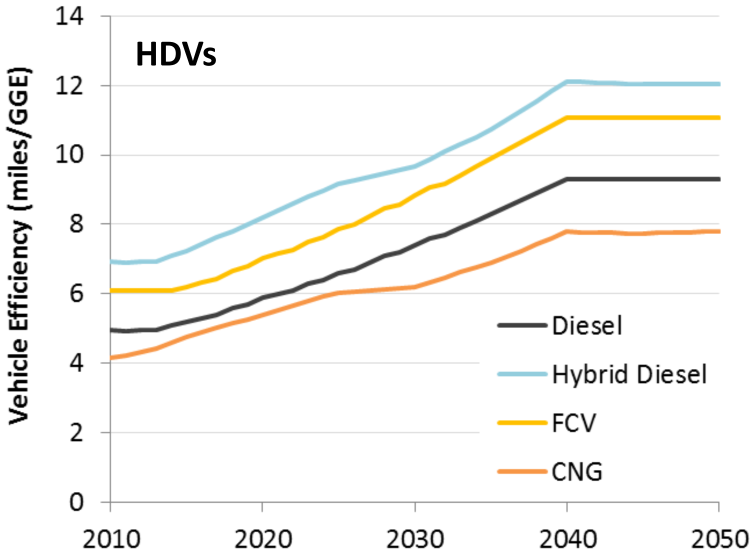
Vehicle Costs - Low Cost Sensitivity

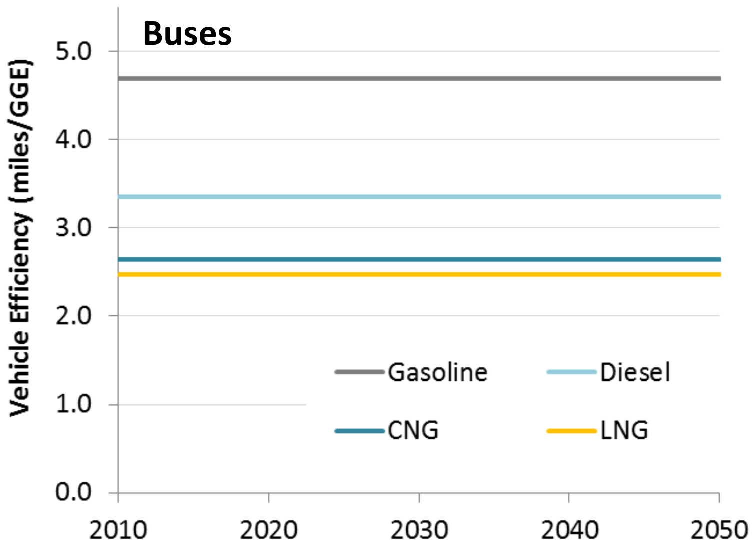


Vehicle Efficiency

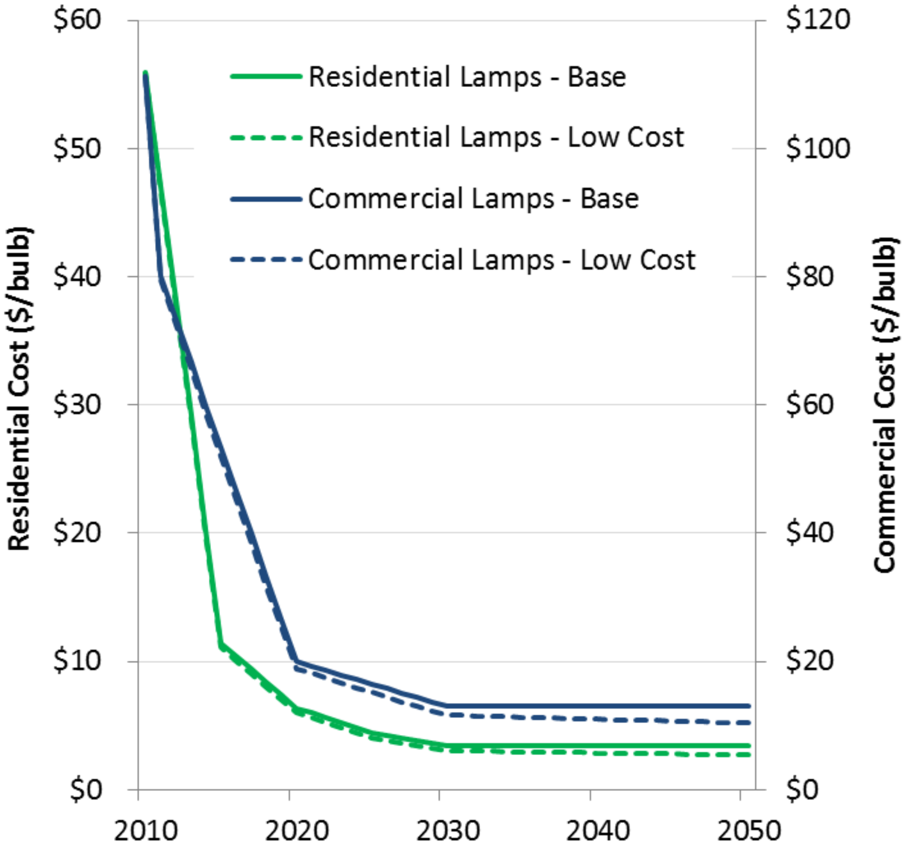


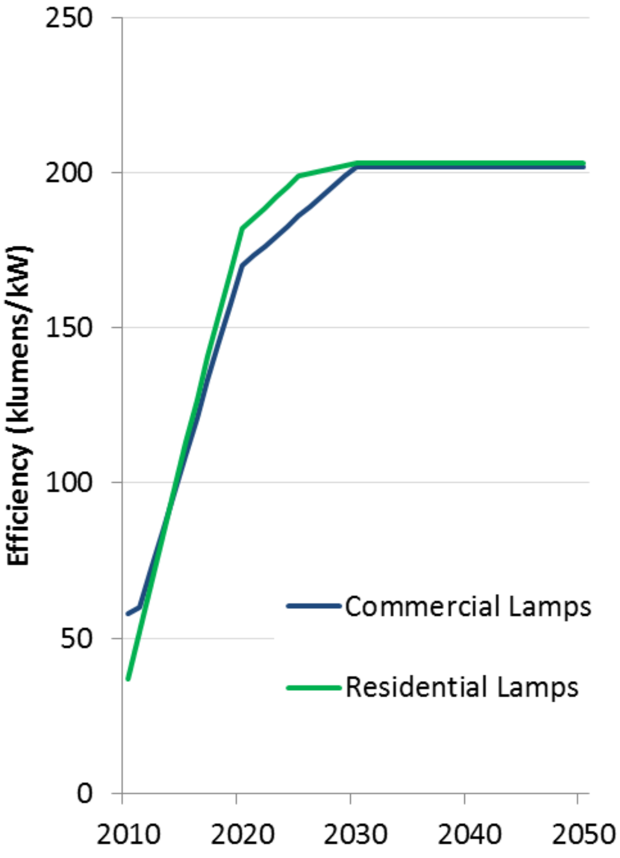




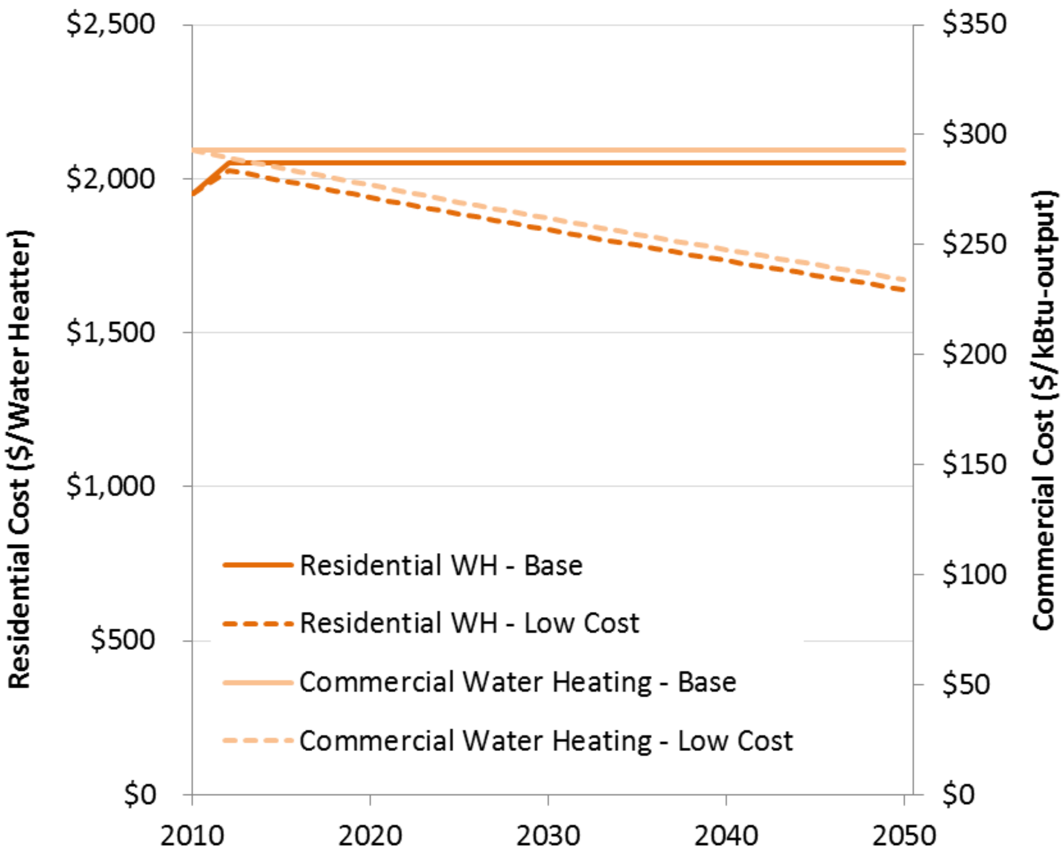


LEDs – Cost and Efficiency

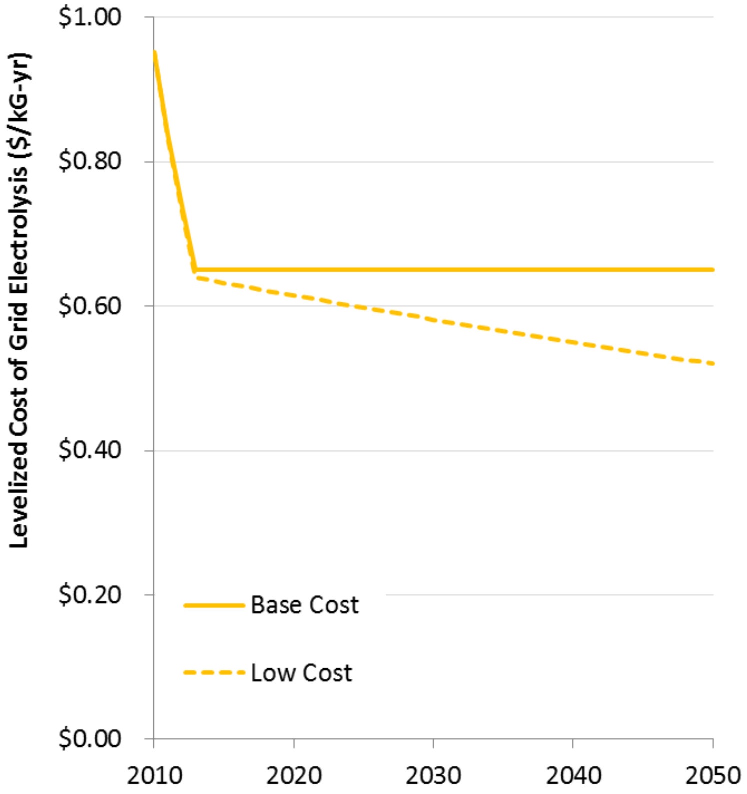


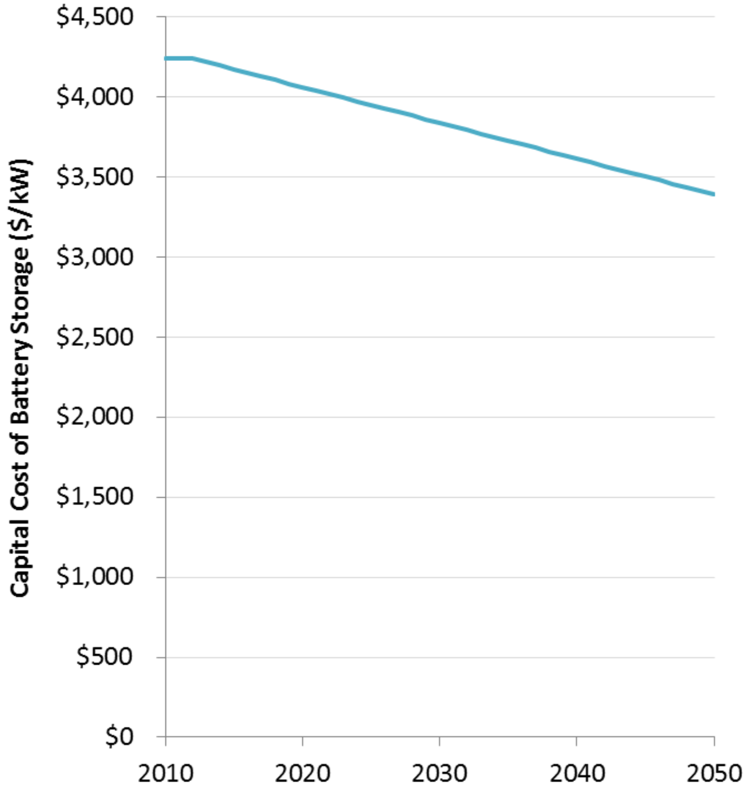


Heat Pump Water Heaters - Costs



Grid Electrolysis and Batteries - Costs





Base cost assumptions for new renewables

Renewable capital costs and trajectories through 2030 are based on Black & Veatch 2013 study of renewable capital costs used in CPUC RPS Calculator update, beyond 2030 B&V's learning curves are applied

All-in capital cost ($/kW – 2012$)		**2015**		**2030**		**2050**	**% reduction from 2015 by 2050**	**% reduction from 2050 cost in low cost sensitivity**
Biogas - Distributed	$	9,700	$	9,700	$	9,700	0%	0%
Biomass - Distributed	$	6,000	$	6,000	$	6,000	0%	0%
Biomass - Large	$	5,600	$	5,600	$	5,600	0%	0%
Geothermal	$	5,522	$	5,522	$	5,522	0%	0%
Hydro - Small	$	3,960	$	3,960	$	3,960	0%	0%
Solar Thermal - No Storage	$	5,908	$	5,217	$	4,297	-27%	-50%
Solar Thermal - Storage	$	8,074	$	7,034	$	5,584	-31%	-50%
Utility PV - Res Roof	$	5,255	$	4,445	$	3,785	-28%	-50%
Utility PV - Distributed	$	3,774	$	3,193	$	2,719	-28%	-50%
Utility PV - Fixed Tilt - 1MW	$	3,822	$	3,233	$	2,753	-28%	-50%
Utility PV - Fixed Tilt - 5MW	$	3,545	$	2,999	$	2,553	-28%	-50%
Utility PV - Fixed Tilt - 10MW	$	3,258	$	2,756	$	2,347	-28%	-50%
Utility PV - Fixed Tilt - 20MW+	$	3,134	$	2,651	$	2,257	-28%	-50%
Utility PV - Tracking - 1MW	$	4,000	$	3,527	$	3,088	-23%	-50%
Utility PV - Tracking - 5MW	$	3,752	$	3,308	$	2,896	-23%	-50%
Utility PV - Tracking - 10MW	$	3,485	$	3,072	$	2,690	-23%	-50%
Utility PV - Tracking - 20MW+	$	3,380	$	2,980	$	2,609	-23%	-50%
Wind	$	2,341	$	2,277	$	2,190	-6%	-5%
Wind - Distributed	$	2,890	$	2,809	$	2,703	-6%	-5%

Thank You!

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