Scenarios for meeting California's long-term greenhouse gas emissions reductions goals in the transportation sector

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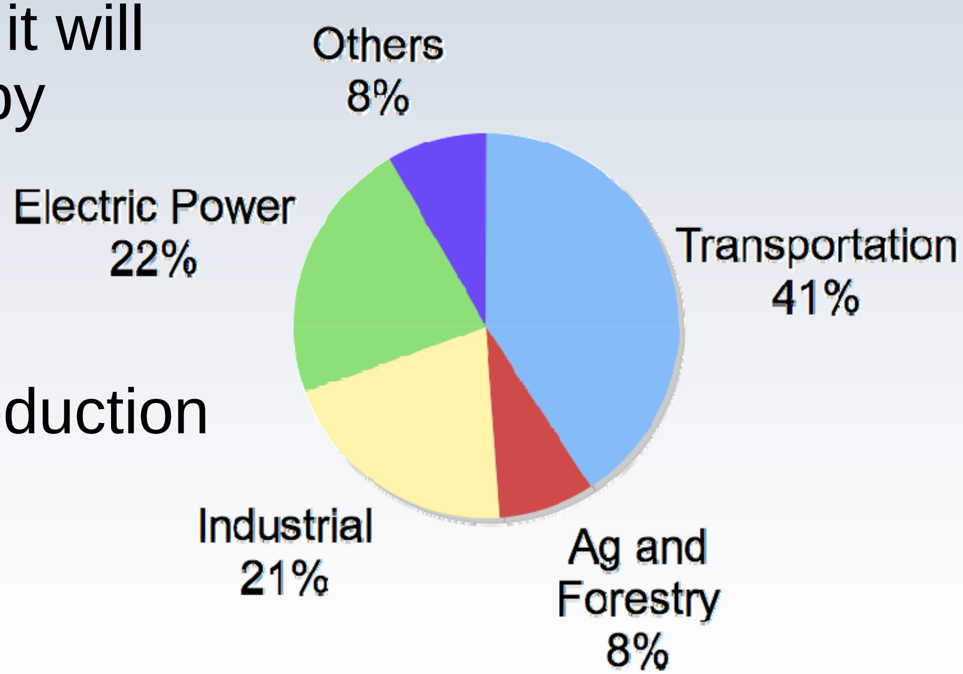
Transportation Focus

- Transportation sector is the largest emitter of GHGs in CA
- Not every sector will need to reduce emissions equally
- Transport is a difficult sector to address
- At 40% of 1990 emissions, it will need to reduce emissions by at least 50% even if all other sectors can reduce 100%
- Focus on achieving 80% reduction

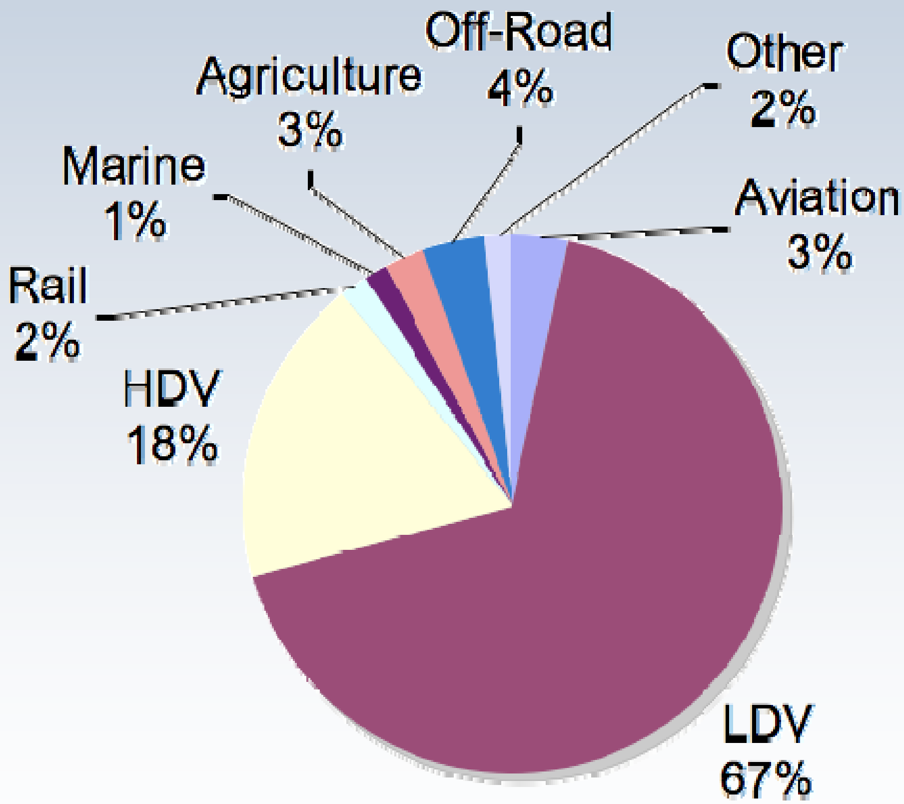


80in50 Project Goals

- Highlight and generate discussion about the options and challenges of deep reductions in transportation greenhouse gas emissions
- Provide snapshots of what 80% reduction in transport could look like
  - To see what role technology (efficiency and advanced vehicles and fuels) can play and how much reductions in transport activity will be needed
- Provide a simple tool for developing scenarios and calculating emissions
  - Long-term Evaluation of Vehicle Emission Reduction Strategies (LEVERS) model
  - To see the results and tradeoffs resulting from specific assumptions and understand sensitivity

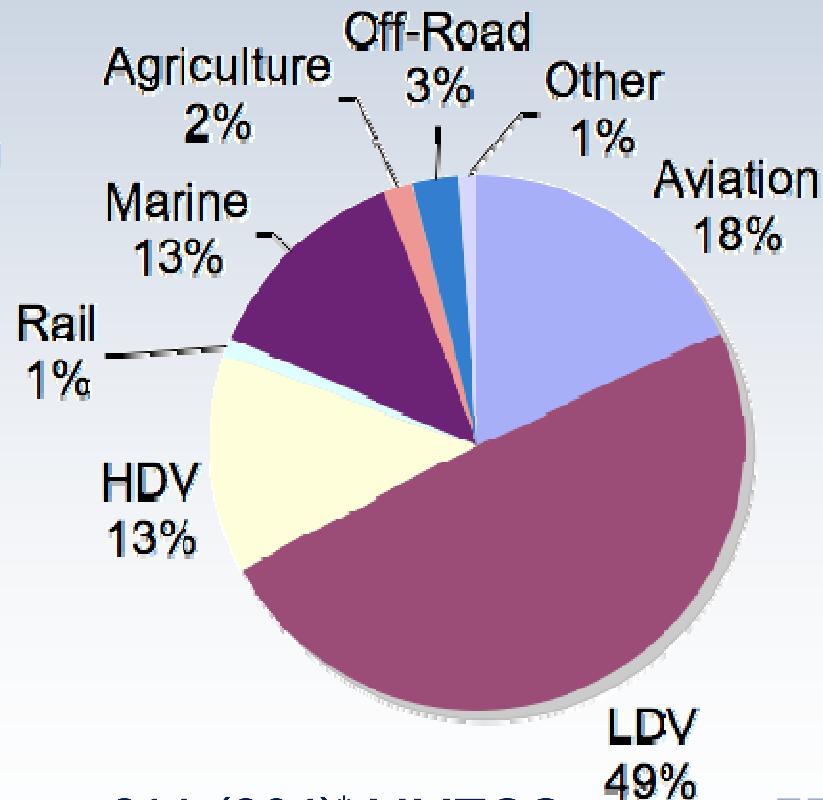
Transport Sector Emissions: 1990

“***In-State Emissions***”



152 (193)* $MMTCO_2e$

“***Overall Emissions***”
i.e. In-State and Out-Of-State Transport



211 (264)* $MMTCO_2e$

* Values not in parentheses are emissions from direct fuel combustion onboard the vehicle.
* Values in parentheses are lifecycle emissions, including fuel production, refining, and transportation.

Emission Analysis Framework

- Transportation variant of Kaya Identity

$$CO_{2,Transport} \equiv (Population)\left(\frac{Transport}{Person}\right)\left(\frac{Energy}{Transport}\right)\left(\frac{Carbon}{Energy}\right)$$

$$P \times T \times E \times C$$

Population California pop.

Transport intensity (e.g., VMT/capita)

Energy Intensity (e.g., MJ/mile)

Carbon Intensity (e.g. gCO_2-eq/MJ)

- Decomposes emissions into major driving forces of interest
- Terms are treated independently
- Each transport sector, sub-sector and individual technology options are characterized in terms of these Kaya components

Kaya Parameters

Social or Activity Parameters (P and T)

- ***P** - Population*
- ***T** - Transport Intensity*
  - Level of transport activity ***per capita***
    - e.g. VMT/capita, PMT/capita, freight ton miles/capita
  - Reduction options
    - Conservation, increasing cost of travel or fuel
    - Land use patterns, smart growth to reduce travel distances and vehicle trips
    - Carpooling, ridesharing
    - Shifting to non-motorized travel

Kaya Parameters

Technology Parameters (E and C)

- **E** - Energy Intensity
  - Energy required per unit of transport activity
    - e.g. MJ per mile, BTU per passenger mile, BTU per ton-mile
  - Reduction options
    - Mode shift - change to lower energy intensive modes
    - Increasing passenger occupancy in vehicles
    - Increasing vehicle efficiency
- **C** - Carbon Intensity
  - Carbon per unit energy - e.g. grams CO_2e/MJ
  - Reduction options
    - Fuel switching to lower carbon content fuels or feedstocks
    - Change in fuel production methods (e.g. CCS or higher efficiency)

Scenario Modeling using LEVERS

- Literature review to determine 1990 and potential 2050 Kaya parameters (T, E and C) for each transport subsector
  - Light duty, heavy duty, aviation, rail, marine, agriculture, off-road
- **L**ong-term **E**valuation of **V**ehicle **E**mission **R**eduction **S**trategies
  - Excel based modeling tool to organize parameters into scenarios and calculate GHG reduction

LDVs					
Gasoline ICEs	P	T	E	C	GHG
Biofuel ICEs	P	T	E	C	GHG
Diesel ICEs	P	T	E	C	GHG
Gasoline PHEVs	P	T	E	C	GHG
Biofuel PHEVs	P	T	E	C	GHG
Diesel PHEVs	P	T	E	C	GHG
H2FCVs	P	T	E	C	GHG
Battery EVs	P	T	E	C	GHG

→

Total LDVs	P	T	E	C	GHG

Total HDVs	P	T	E	C	GHG
Total Aviation	P	T	E	C	GHG
Total Rail	P	T	E	C	GHG
Total Marine	P	T	E	C	GHG
Total Agriculture	P	T	E	C	GHG
Total Off-road	P	T	E	C	GHG

→

Total Transport	P	T	E	C	GHG

- Develop scenarios of possible 2050 transport mixes
  - Investigate scenario sensitivity and tradeoffs between sectors, parameters, and among technologies

Why Scenarios?

- **Simplicity**
  - Predicting the future is complicated and we don't want to try
  - Instead, we focus on "what if" and "is this possible"
- **Transparency**
  - The model is very simple (multiplication)
  - Allows anyone to see the results of different assumptions and starts the dialog and debate about the assumptions
- **Diversity**
  - We want to explore a wide space of what the future could look like
  - We want to see how much GHG reduction we can achieve with technology and how much can come from activity
- We want to investigate what could be possible, to start the dialogue about what can and should be done

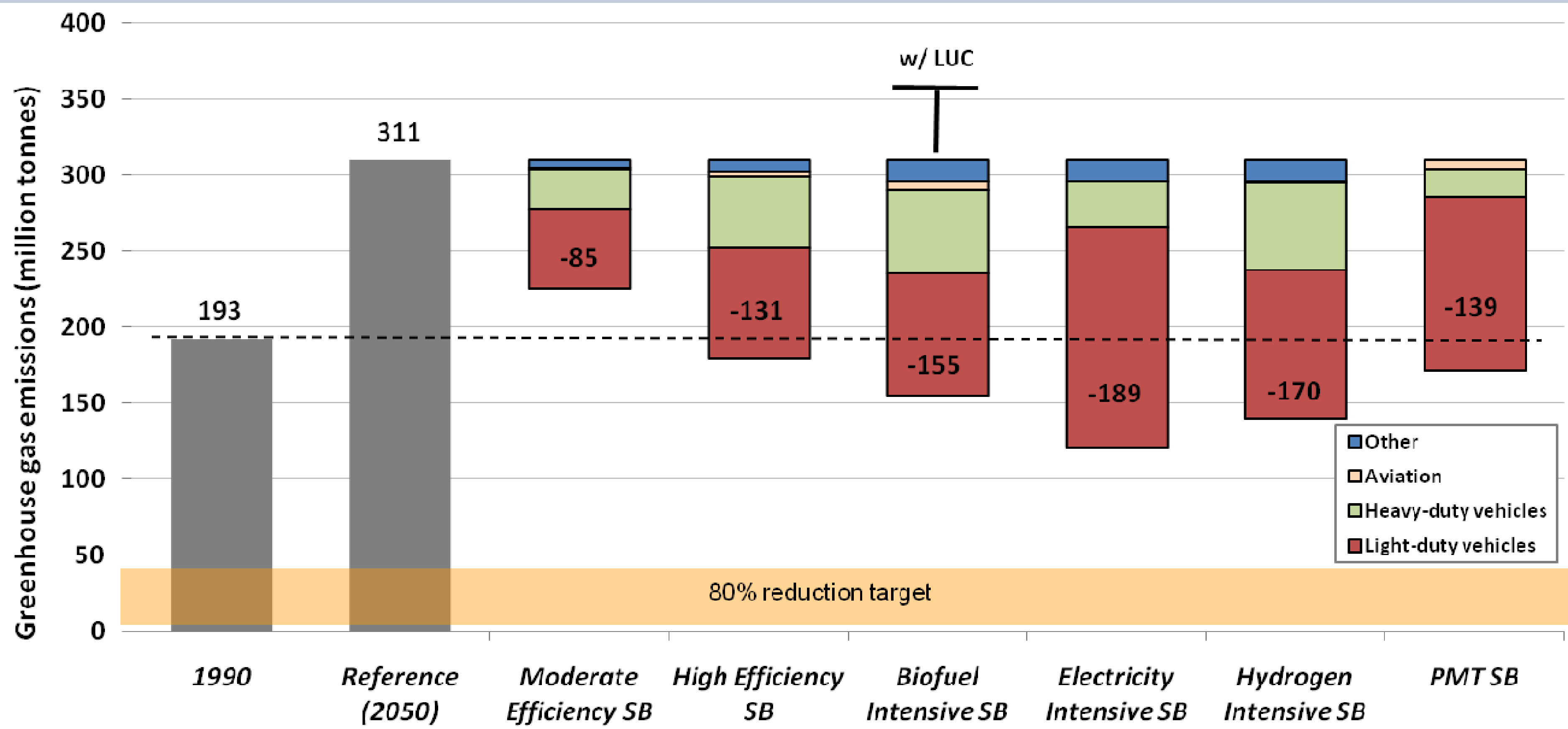
Scenarios to explore

- *Reference Scenario*
- *"Silver Bullet" Scenarios*
  - Goal is to explore whether any one technology or option can do it alone
  - Individual "option" scenarios - H_2, electric, biofuels, efficiency (no alt fuels), transport demand and VMT reduction
- *80% Reduction (80in50) Scenarios*
  - To present some snapshots for diverse suites of options that can meet the target
  - One will be presented here and there are more from our students on our poster outside

Silver Bullet Scenarios

Scenario Name	Scenario Summary
Reference scenario	Doubling of population, modest increase (21%) in transport intensity, slight efficiency improvement (35%) and similar carbon intensity relative to 1990.
Moderate efficiency SB	No breakthrough technological advances, but applies all advances in conventional technologies towards improving vehicle efficiency to achieve doubling of average vehicle efficiency from 1990. Same carbon intensity as *Reference*, except for some electrified rail.
High efficiency SB	Significant breakthroughs in conventional technologies to achieve nearly triple (265%) vehicle efficiency from 1990. Same carbon intensity as *Reference*, except for some electrified rail.
Biofuel-intensive SB	Low-carbon biofuels (16.3 gCO2e/MJ) are the primary fuels used in conventional vehicles (low efficiency) in all transport subsectors, providing 59% of all transport miles. Biofuels are limited to 15-20% of future US supply .
Electricity-intensive SB	Electric vehicles (BEVs and PHEVs) and very low-carbon electricity are applied across many subsectors except marine and aviation, providing 77% of all transport miles. Electricity carbon intensity (6.5 gCO2e/MJ) is 94% below the 1990 value.
Hydrogen-intensive SB	Applies FCV and low-carbon hydrogen fuels (9.5 gCO2e/MJ) aggressively across most subsectors, except aviation, and provides 58% of all transport miles. Fleet market share of on-road H2 vehicles is limited to 60% in 2050 per (Greene et al., 2007, NRC, 2008). Assumes that the obstacles to use of hydrogen in heavy-duty trucks are overcome.
PMT SB	25-50% reductions in passenger travel demand for LDVs and aviation relative to Reference scenario, through better land use, smart growth, transit and high-speed rail (Ewing et al., 2007). No alternative fuels; same carbon intensity as *Reference*. Improved energy intensities due to increased vehicle load factors.

Silver Bullet Scenarios



* In *Biofuel Intensive SB* scenario, biofuels provides 60% of fuel in California (15-20% of total US supply).
* Significant uncertainties surrounding indirect land use change (LUC) impacts from biofuels production lead to the large variability in potential GHG changes from 1990 levels.

SB Scenario Input Assumptions

		Petroleum	Biofuels	Hydrogen	Electricity	Transport Intensity (1990= 100%)	Energy Intensity (1990= 100%)	Carbon Intensity (1990= 100%)
Reference Scenario	LDV	94%	6%	0%	0%	121%	53%	100%
	HDV	100%	0%	0%	0%	109%	133%	106%
	Aviation	100%	0%	0%	0%	238%	84%	105%
	Rail	91%	0%	0%	9%	146%	86%	95%
	Marine/Ag/Off-road	100%	0%	0%	0%	143%	51%	106%
	All sectors combined	95%	5%	0%	0%	123%	65%	102%
	Fuel Demand [Billion GGE]	27.5	1.0	0.0	0.0			
	Carbon intensity [gCO2e/MJ]	95-96	16.3	-	21.7			
Moderate Efficiency SB	LDV	94%	6%	0%	0%	121%	36%	100%
	HDV	100%	0%	0%	0%	109%	100%	106%
	Aviation	100%	0%	0%	0%	238%	63%	105%
	Rail	91%	0%	0%	9%	146%	64%	95%
	Marine/Ag/Off-road	100%	0%	0%	0%	143%	44%	106%
	All sectors combined	95%	5%	0%	0%	123%	47%	102%
	Fuel Demand [Billion GGE]	19.9	0.7	0.0	0.0			
	Carbon intensity [gCO2e/MJ]	95-96	16.3	-	21.7			
High Efficiency SB	LDV	94%	6%	0%	0%	121%	30%	100%
	HDV	100%	0%	0%	0%	109%	68%	106%
	Aviation	100%	0%	0%	0%	238%	52%	105%
	Rail	91%	0%	0%	9%	146%	54%	95%
	Marine/Ag/Off-road	100%	0%	0%	0%	143%	38%	106%
	All sectors combined	95%	5%	0%	0%	123%	37%	102%
	Fuel Demand [Billion GGE]	15.7	0.6	0.0	0.0			
	Carbon intensity [gCO2e/MJ]	95-96	16.3	-	21.7			
Biofuel-intensive SB	LDV	40%	60%	0%	0%	121%	53%	53%
	HDV	51%	49%	0%	0%	109%	115%	55%
	Aviation	40%	60%	0%	0%	238%	84%	53%
	Rail	30%	63%	0%	7%	146%	86%	43%
	Marine/Ag/Off-road	40%	60%	0%	0%	143%	51%	53%
	All sectors combined	40%	60%	0%	0%	123%	62%	53%
	Fuel Demand [Billion GGE]	11.0	16.4	0.0	0.0			
	Carbon intensity [gCO2e/MJ]	95-96	16.3	-	21.7			

SB Scenario Input Assumptions

		Petroleum	Biofuels	Hydrogen	Electricity	Transport Intensity (1990= 100%)	Energy Intensity (1990= 100%)	Carbon Intensity (1990= 100%)
Electricity-intensive SB	LDV	15%	1%	0%	84%	121%	30%	27%
	HDV	65%	0%	0%	35%	109%	99%	92%
	Aviation	100%	0%	0%	0%	238%	84%	105%
	Rail	0%	0%	0%	100%	146%	52%	7%
	Marine/Ag/Off-road	55%	0%	0%	45%	143%	49%	71%
	All sectors combined	21%	1%	0%	78%	123%	43%	55%
	Fuel Demand [Billion GGE]	9.4	0.1	0.0	9.5			
	Carbon intensity [gCO2e/MJ]	95-96	16.3	-	6.5			
Hydrogen-intensive SB	LDV	24%	1%	75%	0%	121%	31%	48%
	HDV	14%	0%	86%	0%	109%	61%	33%
	Aviation	95%	0%	5%	0%	238%	84%	101%
	Rail	0%	0%	93%	7%	146%	54%	10%
	Marine/Ag/Off-road	53%	0%	47%	0%	143%	51%	67%
	All sectors combined	25%	1%	73%	0%	123%	39%	49%
	Fuel Demand [Billion GGE]	7.0	0.2	9.8	0.0			
	Carbon intensity [gCO2e/MJ]	95-96	16.3	9.526	6.5			
PMT SB	LDV	94%	6%	0%	0%	61%	35%	100%
	HDV	100%	0%	0%	0%	265%	47%	106%
	Aviation	100%	0%	0%	0%	133%	58%	105%
	Rail	56%	0%	0%	44%	632%	65%	71%
	Marine/Ag/Off-road	100%	0%	0%	0%	117%	54%	106%
	All sectors combined	90%	3%	0%	7%	88%	53%	99%
	Fuel Demand [Billion GGE]	15.5	0.3	0.0	0.7			
	Carbon intensity [gCO2e/MJ]	95-96	16.3	-	21.7			

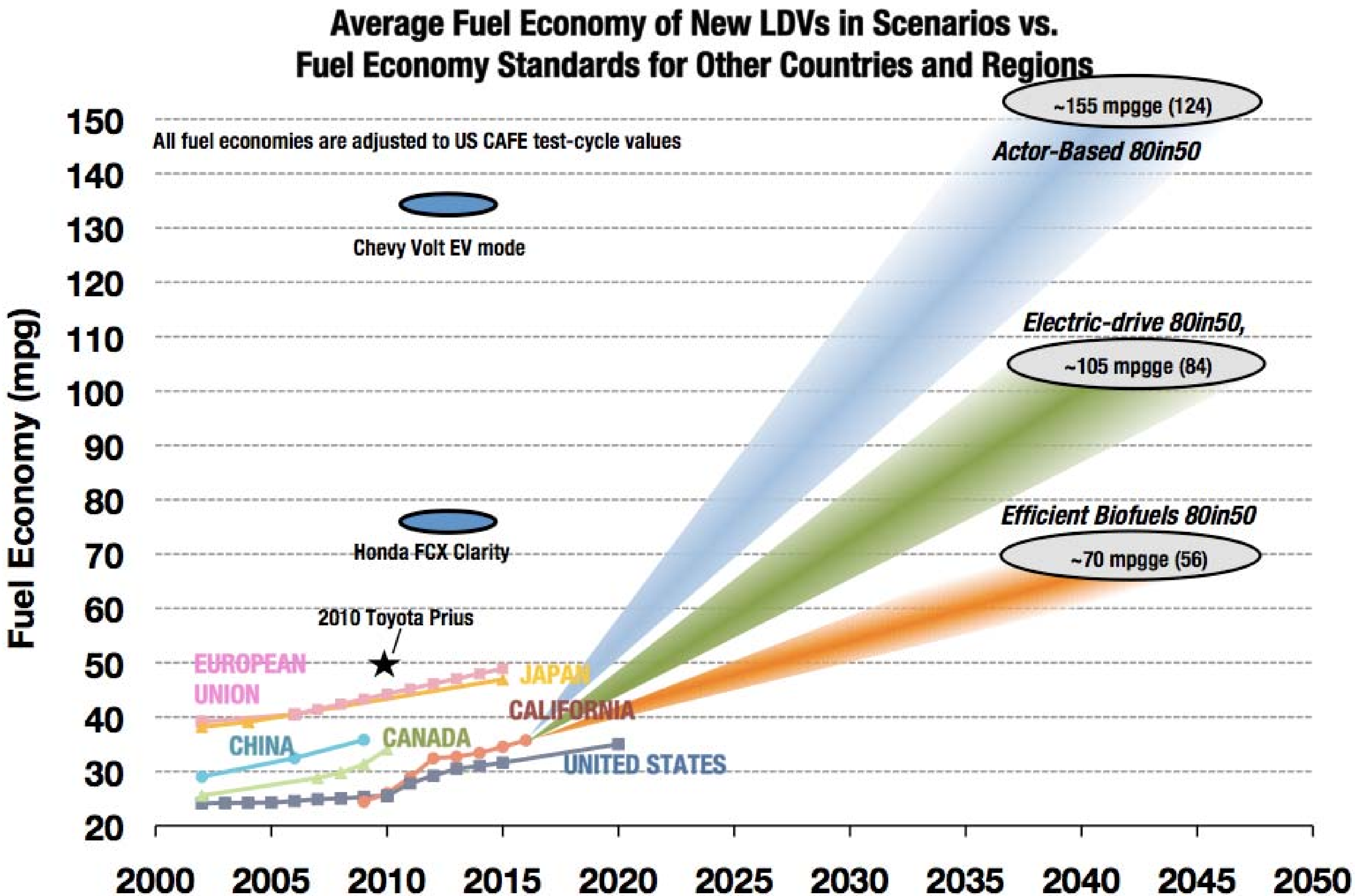
80in50 Scenarios

- ***Efficient Biofuels 80in50*** - Advanced technologies are developed for biofuel production. *Reference* travel demand. Low-carbon biofuels are the primary fuel in efficient vehicles (2x vehicle efficiency) across all sectors. Petroleum accounts for only 3% of fuel used.
- ***Electric-drive 80in50*** - Advanced technologies for electric drive vehicles and very low-carbon electricity and hydrogen are developed. *Reference* travel demand. Higher efficiency (3x) electric drive vehicles (EVs, PHEVs and FCVs) used in most sectors, except marine aviation and off-road where biofuels are used. Petroleum accounts for only 10% of fuel used.
- ***Actor-based 80in50*** - *High prices reduce travel demand and lead to smaller, high efficiency vehicles*. Reduced travel demand, very high efficiency vehicles, increased carpooling and use of transit. Fuels are not as decarbonized as in other scenarios. Biofuels used in aviation and marine. Petroleum still accounts for 35% of fuel used.

80in50 Scenario Summary

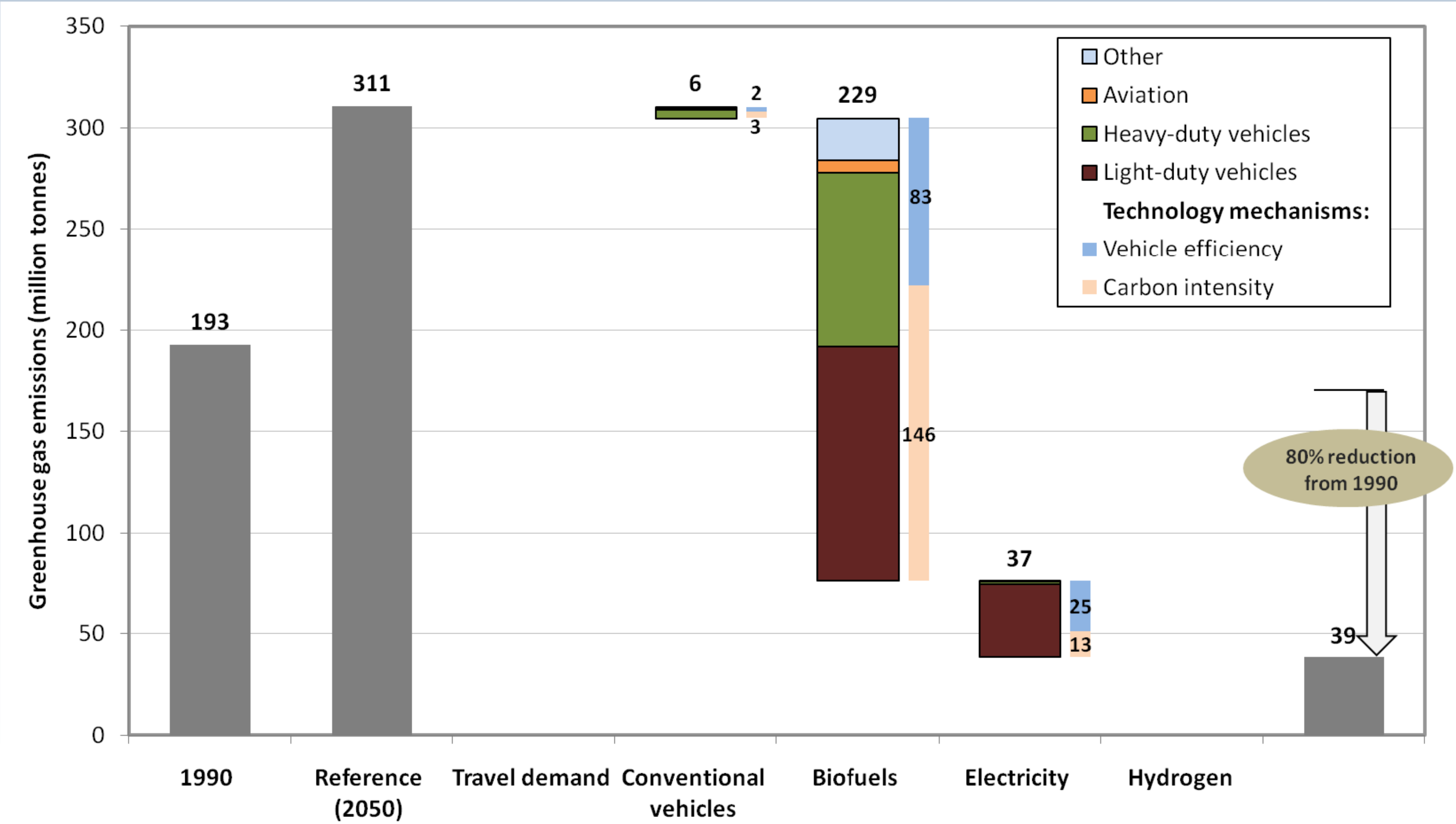
		Petroleum	Biofuels	Hydrogen	Electricity	Transport Intensity (1990= 100%)	Energy Intensity (1990= 100%)	Carbon Intensity (1990= 100%)
Efficient Biofuels 80in50	LDV	0%	83%	0%	17%	121%	33%	18%
	HDV	0%	95%	0%	5%	109%	77%	15%
	Aviation	25%	75%	0%	0%	238%	63%	40%
	Rail	0%	93%	0%	7%	146%	69%	18%
	Marine/Ag/Off-road	23%	77%	0%	0%	143%	44%	36%
	All sectors combined	1%	83%	0%	15%	123%	41%	20%
	Fuel Demand [Billion GGE]	0.5	16.2	0.0	1.3			
	Carbon intensity [gCO2e/MJ]	95-96	17.7	-	6.5			
Electric-drive 80in50	LDV	8%	0%	50%	42%	121%	22%	25%
	HDV	0%	0%	74%	26%	109%	52%	24%
	Aviation	50%	50%	0%	0%	238%	63%	63%
	Rail	0%	0%	0%	100%	146%	42%	7%
	Marine/Ag/Off-road	4%	32%	37%	27%	143%	44%	31%
	All sectors combined	8%	2%	48%	41%	123%	29%	28%
	Fuel Demand [Billion GGE]	1.2	1.0	7.1	3.7			
	Carbon intensity [gCO2e/MJ]	95-96	23.7	24.3	6.5			
Actor-based 80in50	LDV	20%	5%	10%	64%	75%	10%	33%
	HDV	25%	10%	10%	55%	222%	25%	60%
	Aviation	30%	70%	0%	0%	189%	44%	45%
	Rail	12%	3%	0%	85%	510%	45%	18%
	Marine/Ag/Off-road	44%	20%	9%	27%	113%	35%	62%
	All sectors combined	21%	8%	9%	62%	96%	23%	46%
	Fuel Demand [Billion GGE]	2.7	1.3	0.6	3.2			
	Carbon intensity [gCO2e/MJ]	95-96	17.7	48.4	6.5			

80in50 LDV Scenarios

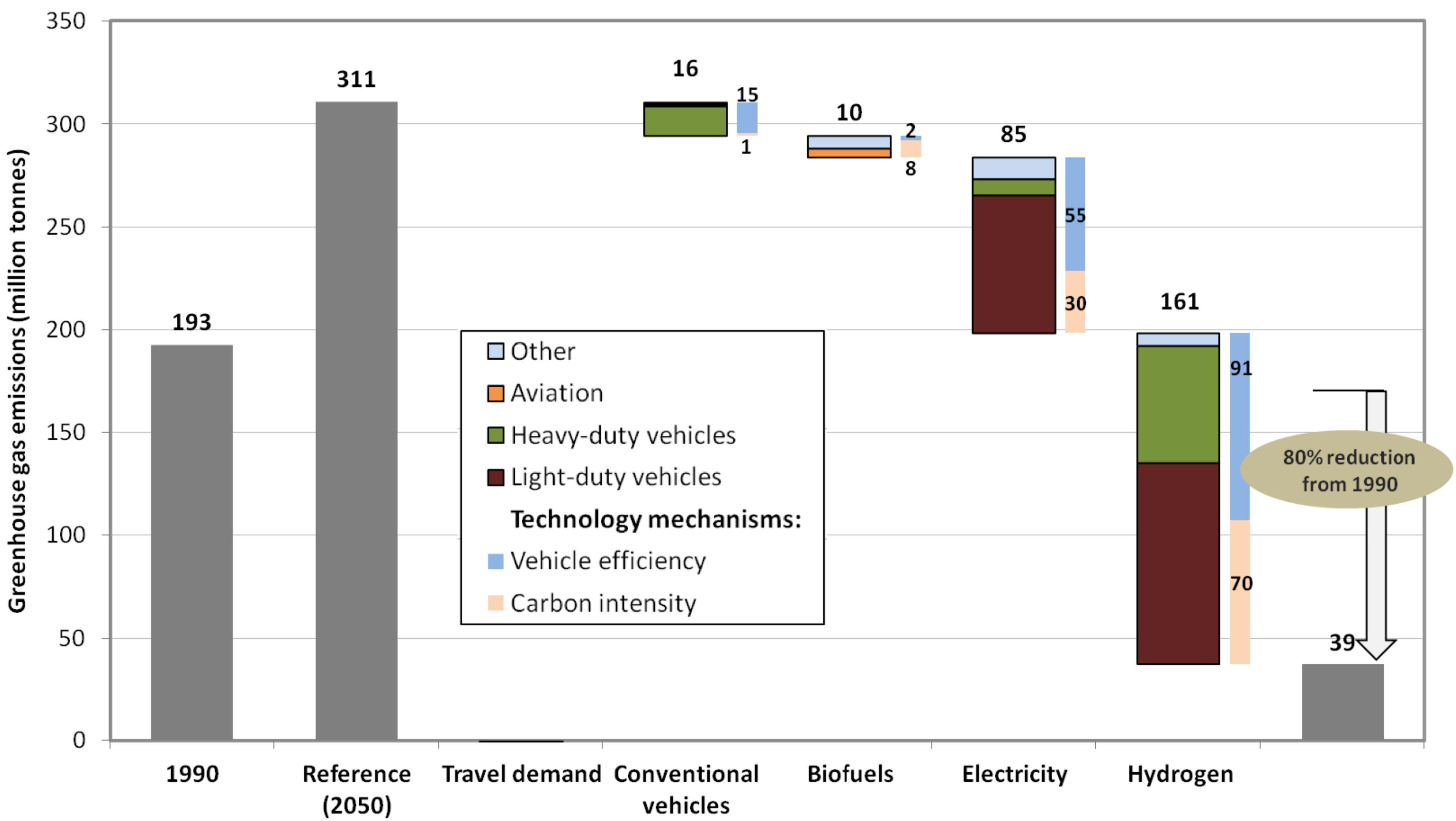


* All country level data comes from the International Council on Clean Transportation, *Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: A Global Update, December* 2008
* Timing of required new vehicle fuel economies for scenarios is approximate since it depends on fleet turnover. On-road fuel economies are assumed to be ~80% of test cycle values.
* Fuel economy of Chevy Volt is based on its classification as an EV. An exclusive EPA testing cycle for PHEVs has not yet been developed.

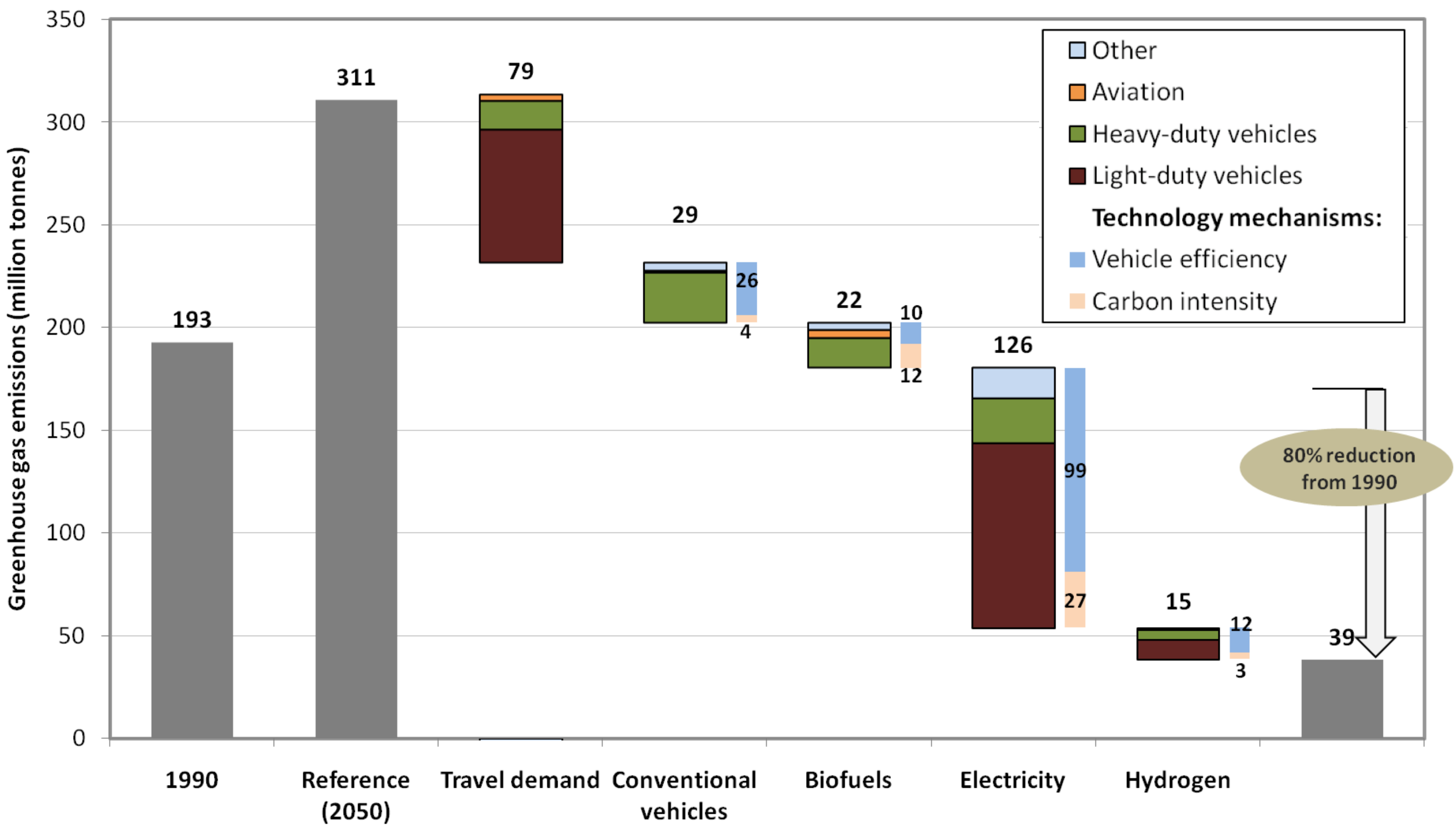
Efficient Biofuels 80in50



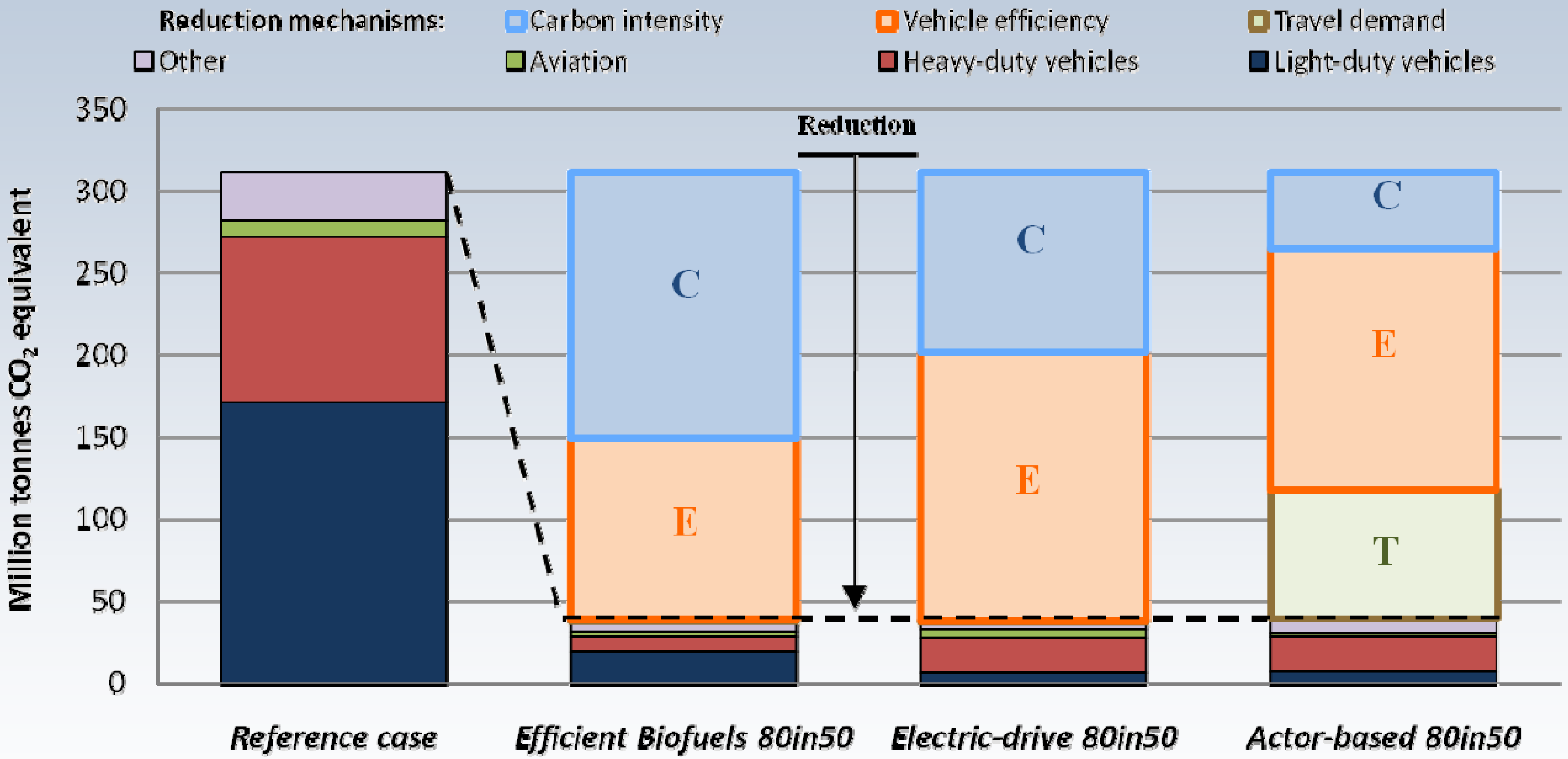
Electric-drive 80in50



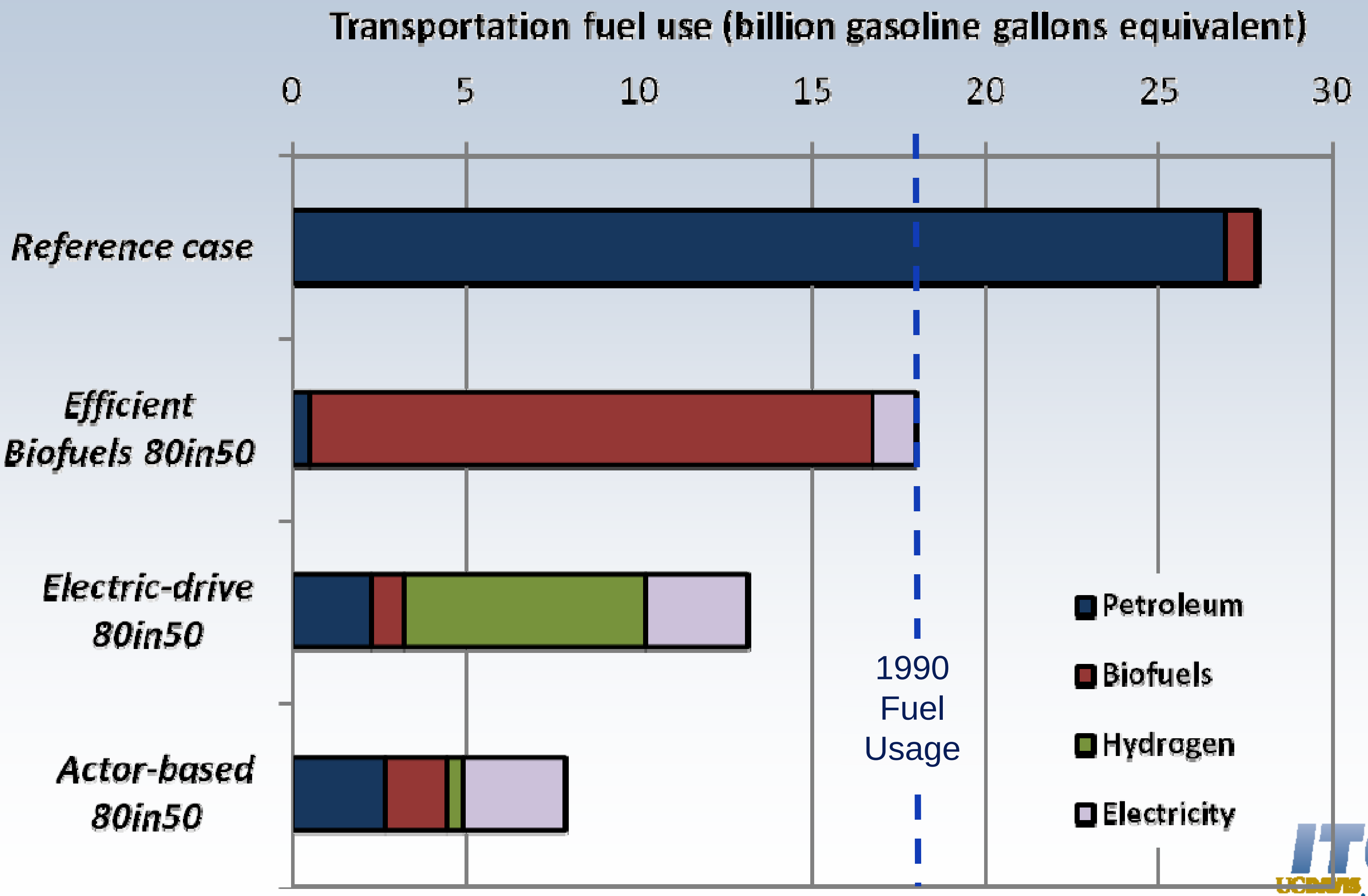
Actor-based 80in50



80in50 Scenario Comparison

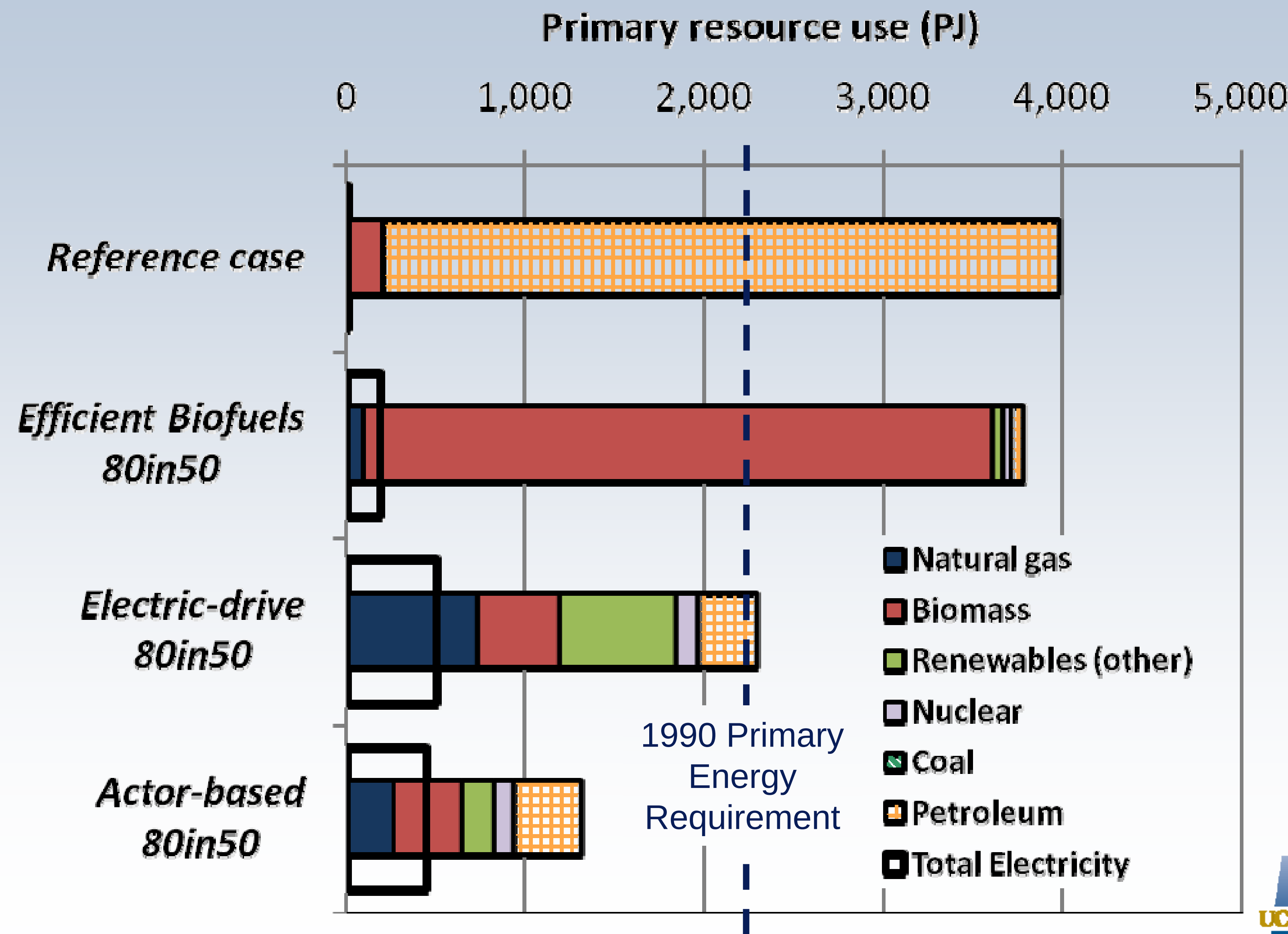


Fuels Usage



Transportation fuel use (billion gasoline gallons equivalent)
0
5
10
15
20
25
30
Reference case
Efficient Biofuels 80in50
Electric-drive 80in50
Actor-based 80in50
1990 Fuel Usage
Petroleum
Biofuels
Hydrogen
Electricity

Primary Energy Resource Use



Conclusions

- There is significant potential for greatly improved vehicle efficiency (reduced *E*) and use of low carbon fuels (reduced C) for use in all of the transport subsectors.
- Not all vehicle technology and fuel options can be applied to all transportation subsectors because of specific requirements for characteristics such as power, weight, volume or vehicle range.
- Biofuels (low-carbon liquid fuels) are most applicable across all transport subsectors, but are likely to be limited by biomass resource availability and land use change (LUC) impacts, which may reduce their GHG benefits.
- Hydrogen and electricity can be made from a wide range of domestic resources, and resource constraints are unlikely to limit their adoption; however, they are limited by their technological applicability to key transport subsectors (especially aviation, marine and off-road).

Conclusions

- Slowing the growth in travel demand (i.e., reducing transport intensity, T) can help reduce the extent to which technological advances will be required to reduce the amount of carbon emitted per mile of travel (ExC).
- Three distinct 80in50 scenarios are presented that meet the 80% reduction goal in different ways, and they show that meeting the goal is a challenging prospect and requires very extensive penetration of advanced technologies and low carbon fuels.
- Meeting the *80in50* goal with Overall transportation emissions is even more challenging

ZEV and *80in50* goals

- Are existing technology development roadmaps and policy incentives sufficient to achieve these long-term goals?
- Does ZEV appropriately incentivize R&D in these long-term solutions?
- How is ZEV complementary with existing policies - performance standards for vehicle efficiency/GHG and fuel carbon?
- Are ZEV-like policies needed in other transport sectors?

Thanks for listening!

We would appreciate your questions or feedback

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Extra Slides

Efficiency Improvements

- Efficiency improvements can come about by
  - Improving drivetrain efficiency
  - Reducing energy dissipation (aerodynamics, weight, rolling resistance, slower speed)

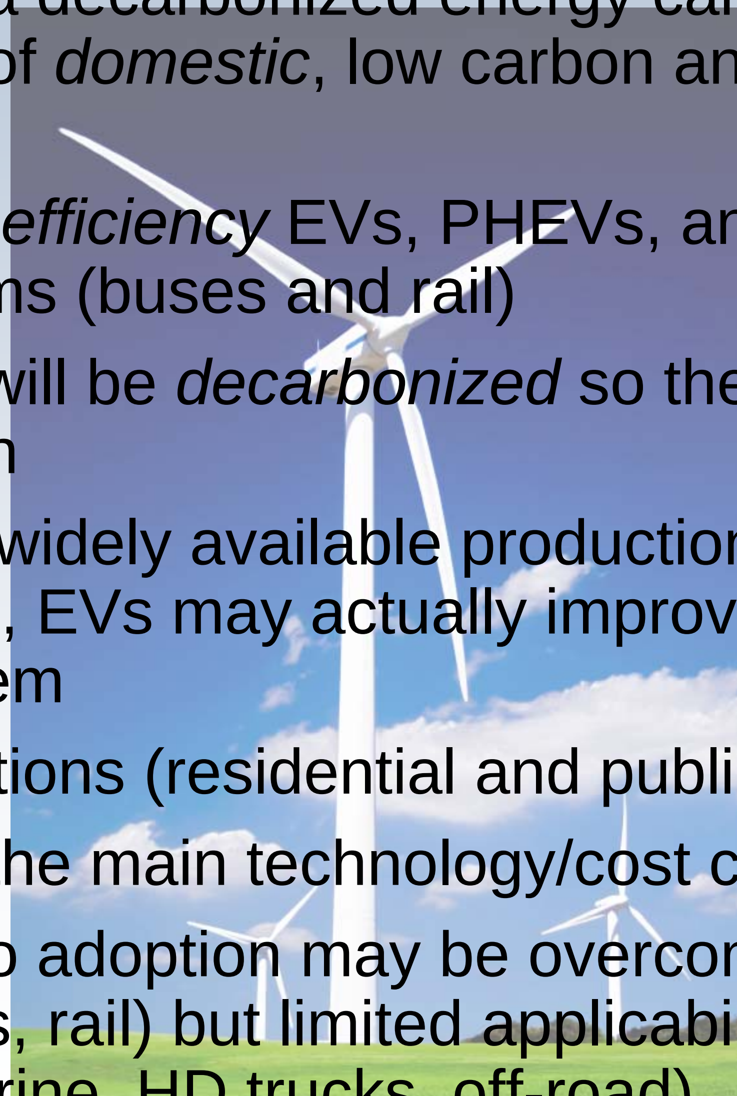
$$E_{fuel} = \frac{E_{road}}{\eta_{drivetrain}} = \frac{d[C_R M_v g + \frac{1}{2}\rho_a C_D A_v V^2]}{\eta_{drivetrain}}$$

- Efficiency can be a low cost method for GHG reduction
  - Negative costs
- Policies include CAFE standards and Pavley (CA)
- Can be applied across all sectors, though there may be sectors that are less efficient to begin with (e.g. LDVs)
- Takes time to impact emissions (fleet turnover)

Biofuels

- Biofuels are *potentially* a low-carbon fuel
- Can be “drop in” fuel or require some changes
- Developing infrastructure could take time
- There are many important inputs/factors that influence life-cycle environmental impacts
  - Competition with food production
  - Water usage
- Land use change - clearing land for agricultural production of biofuels releases LOTS of carbon and other GHGs
- Resource constraints: is there enough biomass?
  - 1990 California total fuel usage 17.8 billion gge
  - Waste biomass in California ➔ 2.3 billion gge
  - US Supply: 1.3 billion tons ➔ 85-100 billion gge
    - 20% of this is 17-20 billion gge

Electricity



- Electricity is a decarbonized energy carrier made from a wide variety of *domestic*, low carbon and renewable resources
- Used in *high efficiency* EVs, PHEVs, and some non-battery transport forms (buses and rail)
- Electric grid will be *decarbonized* so there is synergy for transportation
- Existing and widely available production and distribution infrastructure, EVs may actually improve operation of existing system
- Charging stations (residential and public) may be needed
- Batteries as the main technology/cost challenge
- Challenges to adoption may be overcome in some sectors (LDVs, buses, rail) but limited applicability in other sectors (aviation, marine, HD trucks, off-road)

Hydrogen and Fuel Cells

- H_2 is a decarbonized energy carrier made from a wide variety of domestic, low carbon and renewable resources
- FCVs have *high efficiency*
- Life-cycle emissions will depend upon pathway (H_2 production, delivery and refueling)
- H_2 can be used in several types of vehicles (LDVs, some HDVs, rail), but may have limited applicability in others (aviation, marine)
- Cost of fuel cells and H_2 storage (range) are important technical/cost challenges
- H_2 infrastructure is another critical challenge (LDV infrastructure may be hardest) which may impact rate of adoption (slow fleet introduction)

Travel Demand Reduction

- VMT can be reduced in LDV sector by a number of approaches
  - Better land use planning, higher density, smart growth
  - Carpooling, ride sharing, mode-shifting (transit)
  - Telecommuting
- Passenger aviation miles can switch to more efficient high speed rail mode
- Freight travel (rail, marine, truck and aviation) demand depends upon the demand for materials, goods and services and where they are produced

Transport Sector Potentials

- LDVs – Advanced vehicles (FCVs, PHEVs, BEVs, FFVs) and fuels (H2, biofuels, and electricity), improved efficiency through light-weighting and aerodynamics. Reduced VMT through mode switching and better planning.
- HDVs – Advanced vehicles and fuels, though stringent requirements for long-haul trucking limit the use of some options (BEVs and FCVs)
- Rail – Perhaps most suited to electrification (passenger and freight). High speed rail may eliminate some air travel in CA (LA ←→ SF)

Transport Sector Potentials (2)

- Air – perhaps the most limited in terms of alternative propulsion options, efficiency improvements in conventional technologies and liquid fuels, H_2?
- Marine – Multiple options for alternative propulsion (diesel, combined cycle, electric, fuel cell), alternative fuels infrastructure may be an issue for international shipping
- Ag and Offroad – Alternative propulsion and fuel technologies can be applied