80in50 PATH ANALYSIS:

Getting to an 80% reduction in transport-related GHG emissions in California by 2050

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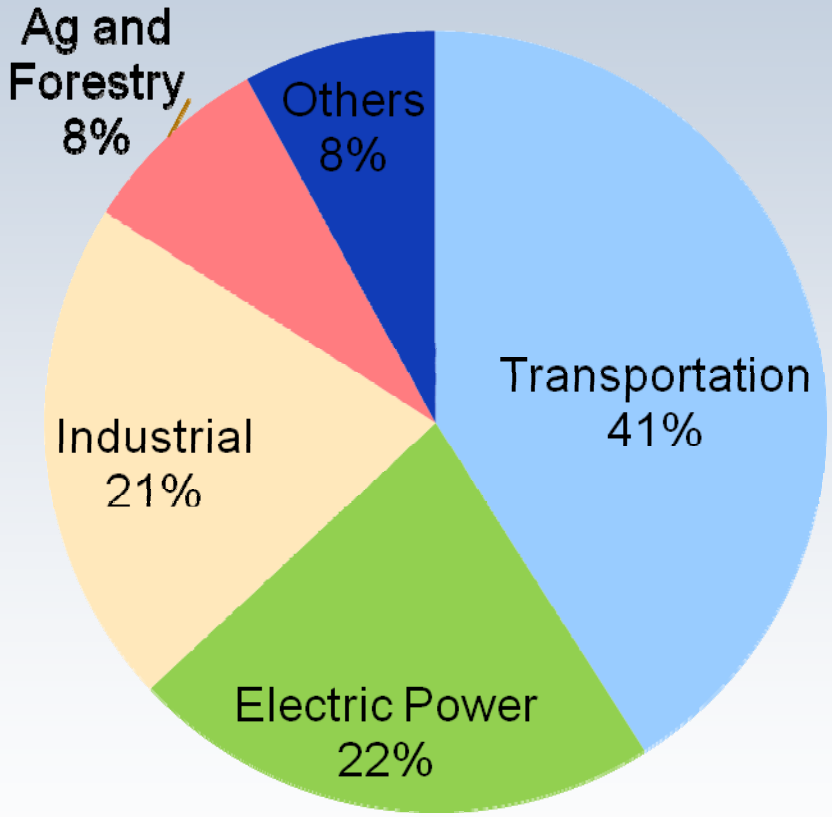
CALIFORNIA GHG EMISSIONS IN 2006

Focus: Transportation = 41% of CA GHG emissions

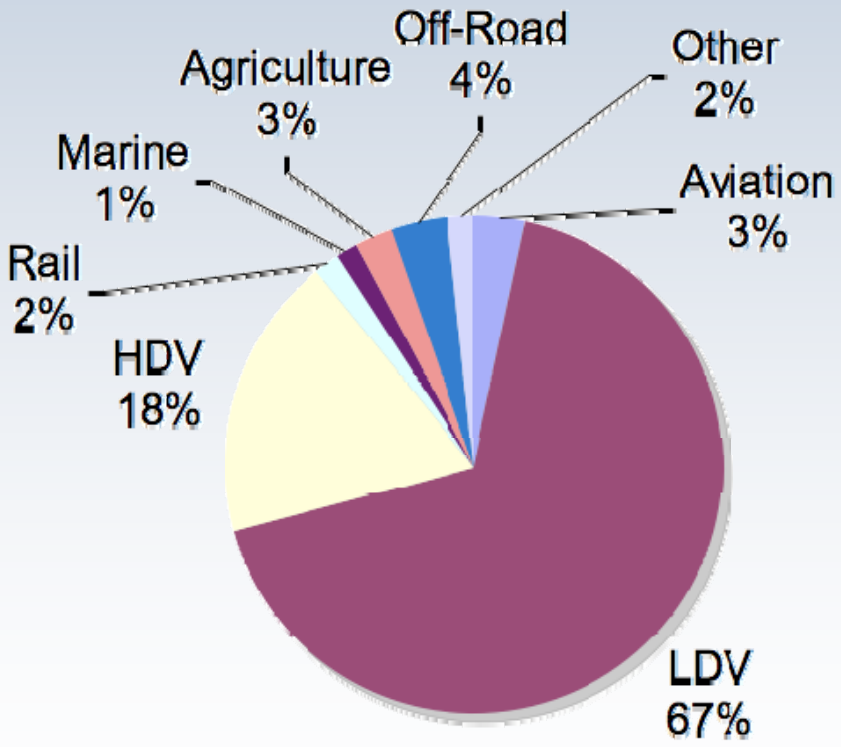


CalEPA (2006) *Climate Action Team Report to Governor Schwarzenegger and the California Legislature.*

CALIFORNIA TRANSPORTATION IN 1990

Focus: “In-State” Emissions, Light Duty Vehicles (LDVs)

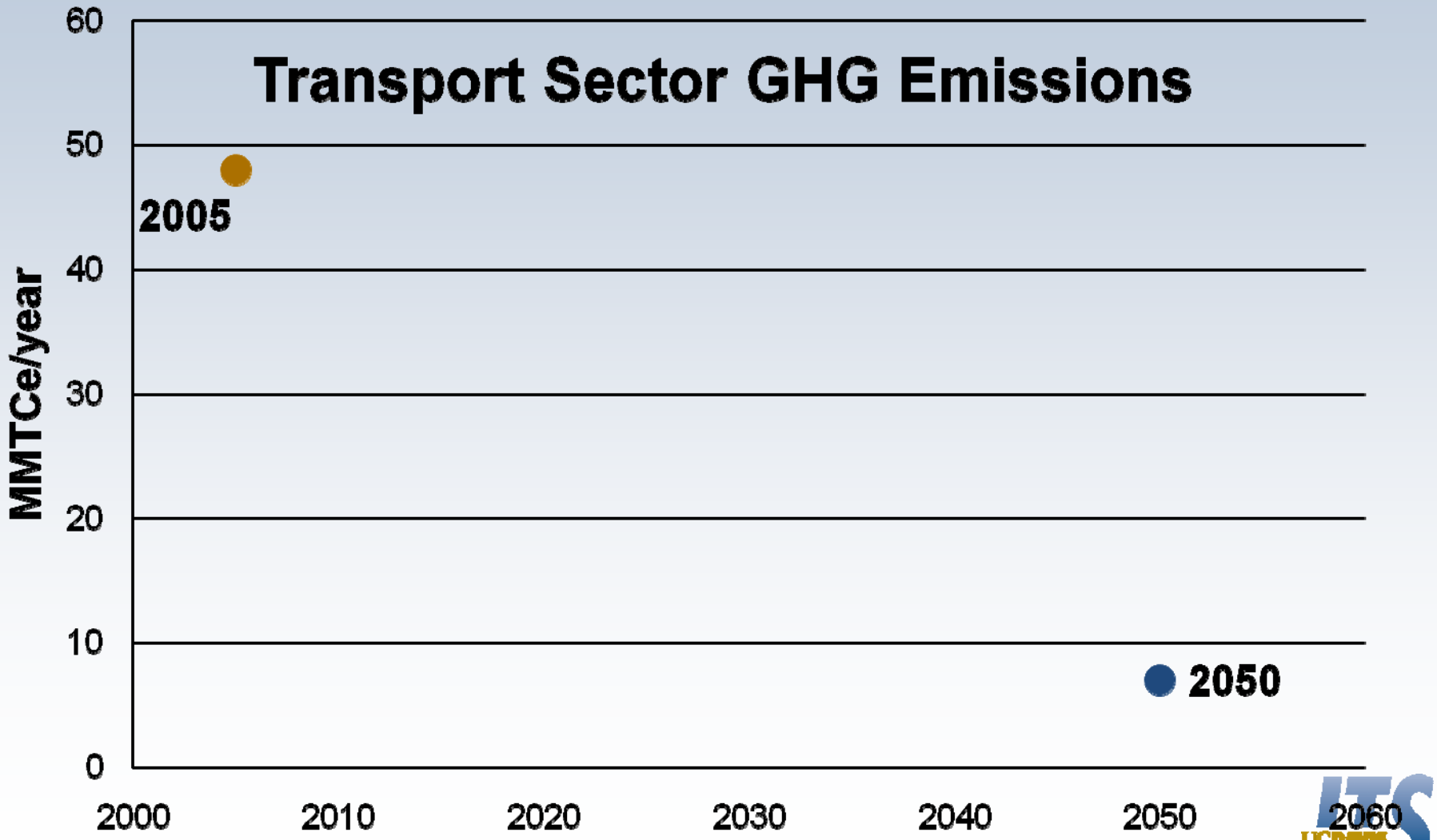
“***In-State Emissions***”



193 MMTCO$_2$e

RESEARCH QUESTION #1:

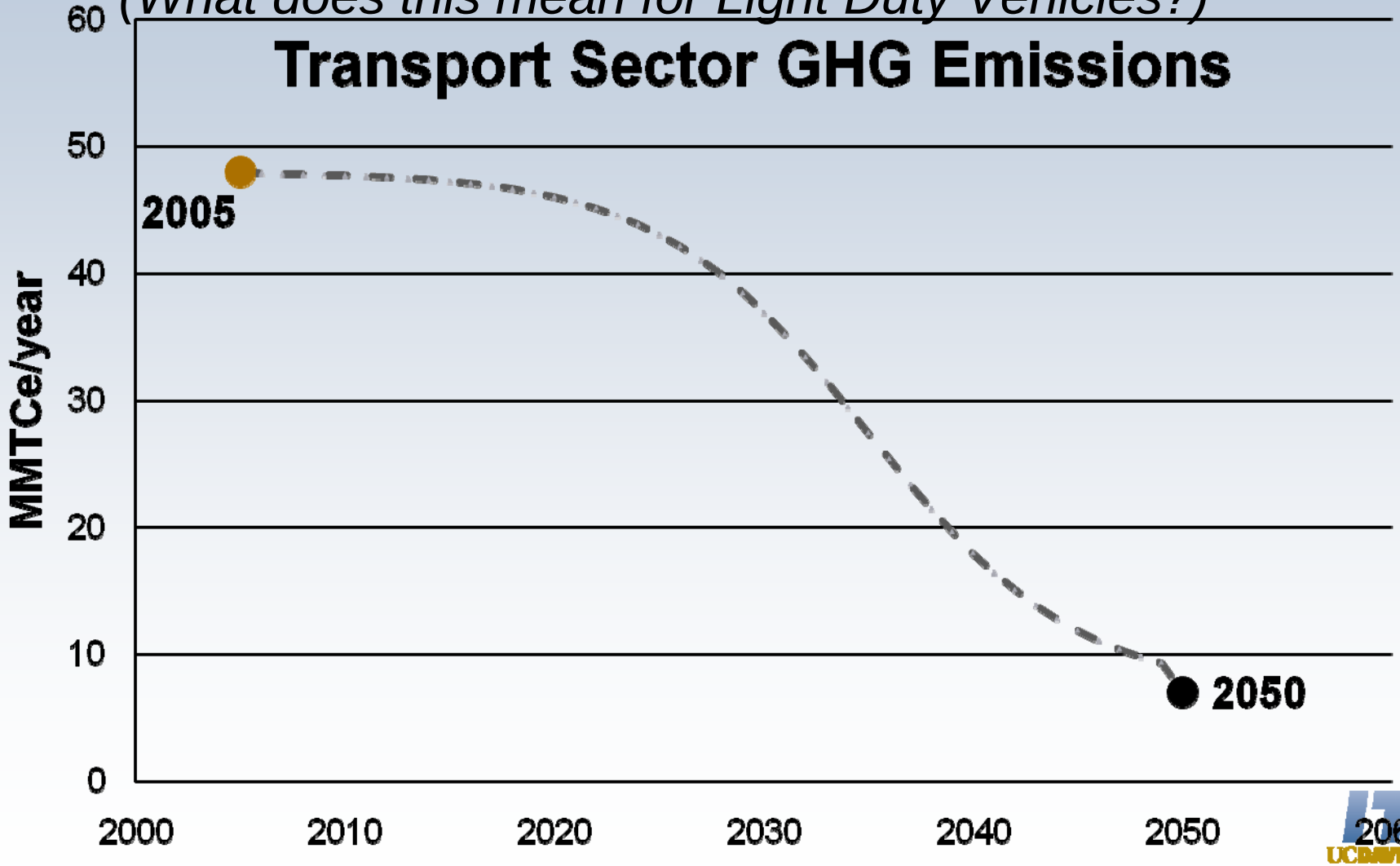
Can we get 80% reduction in GHG by 2050?



RESEARCH QUESTION #2

How do we get from here to there?

(What does this mean for Light Duty Vehicles?)



QUESTION 1#:

CAN WE REACH 80% REDUCTION IN TRANSPORT GHG EMISSIONS BY 2050?

The UCD 80in50 LEVERS model provides a platform for visioning a "snapshot" of CA transport sector in 2050

- *Includes ALL transportation sub-sectors (Light Duty Veh, Heavy Duty Veh , Bus, Rail, Aircraft, Marine, Agriculture, Off-Road & Construction)*

Inputs:
Population, Travel Activity, Vehicle Mix & Fuels Mix for each sub-sector

→

80in50 Model
visioning platform: CA transportation system in 2050

→

Outputs:
GHG Emissions
Energy Use

Transportation system, defined to meet the goal

Goal: 80% reduction from 1990 level by 2050

LEVERS model calculates emissions and energy use from input parameters

User sets inputs, constrained by feasibility, to achieve 2050 GHG target

Yang, C., McCollum, D., McCarthy, R., Leighty, W. (2009) Meeting an 80% reduction in greenhouse gas emissions from transportation by 2050: A case study in California, *Transportation Research Part D.*

CALIFORNIA TRANSPORTATION IN 2050

Kaya decomposition analysis

$$CO_2 \text{ emissions} = P \times T \times E \times C$$

P	T	E	C
Population California pop.	**Transport intensity** (e.g., VMT/capita)	**Energy Intensity** (e.g., MJ/mile)	**Carbon Intensity** (e.g. gCO_2-eq/MJ)

GHG Emissions can be reduced by:

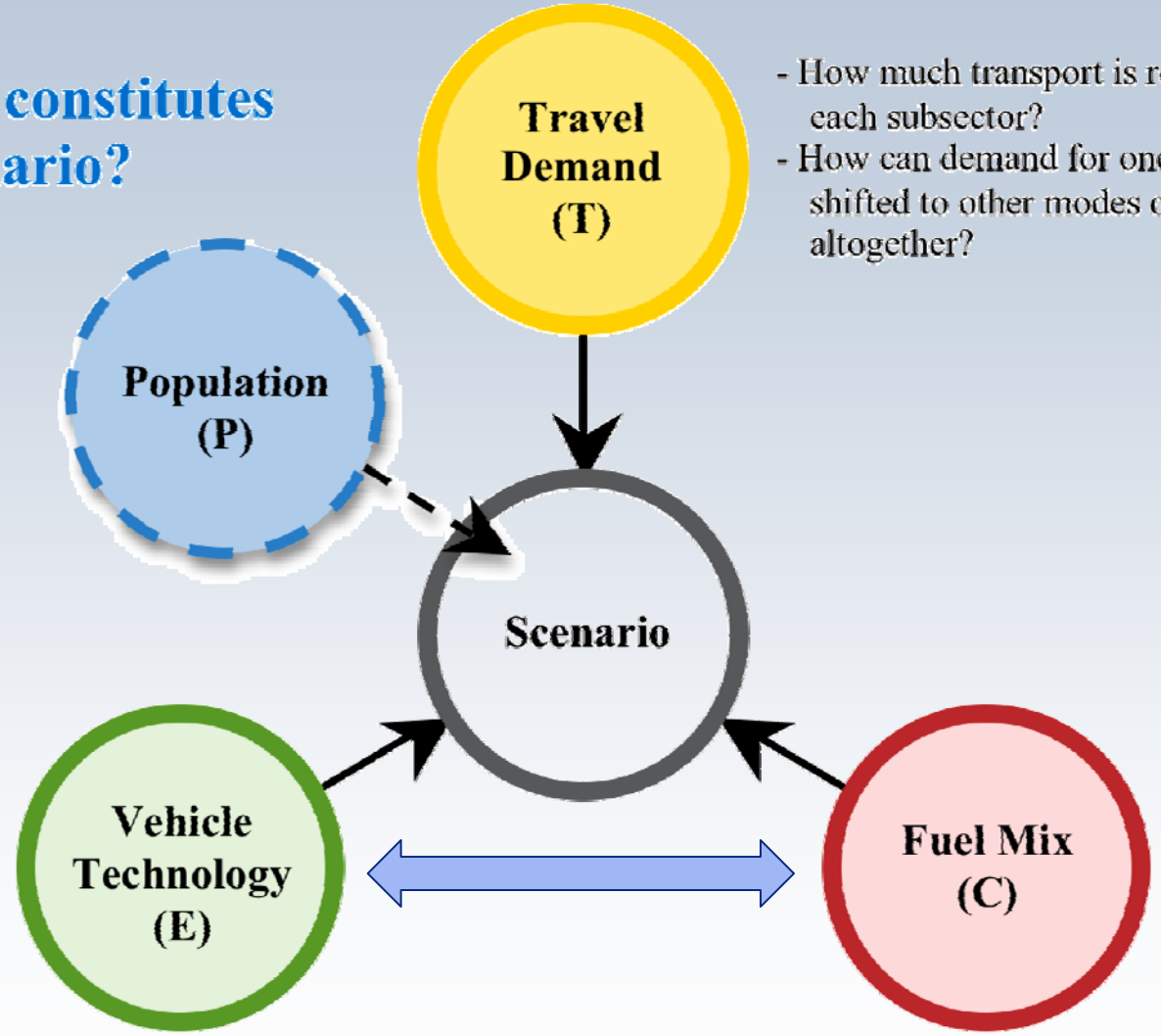
T: Decreasing Transport intensity (e.g., reduce VMT)

E: Decreasing Energy Intensity (e.g., improve fuel economy)

C: Decreasing Carbon intensity (e.g., lower-carbon fuels)

DEVELOPING SCENARIOS

What constitutes a scenario?



- How much transport is required in each subsector?
- How can demand for one mode be shifted to other modes or reduced altogether?

- What vehicle technologies are used?
- What is mix of technology penetration in each subsector?
- How efficient are vehicles?

- What fuels are used?
- What is the fuel mix in each subsector?
- How "green" are they (i.e. how are they produced)?

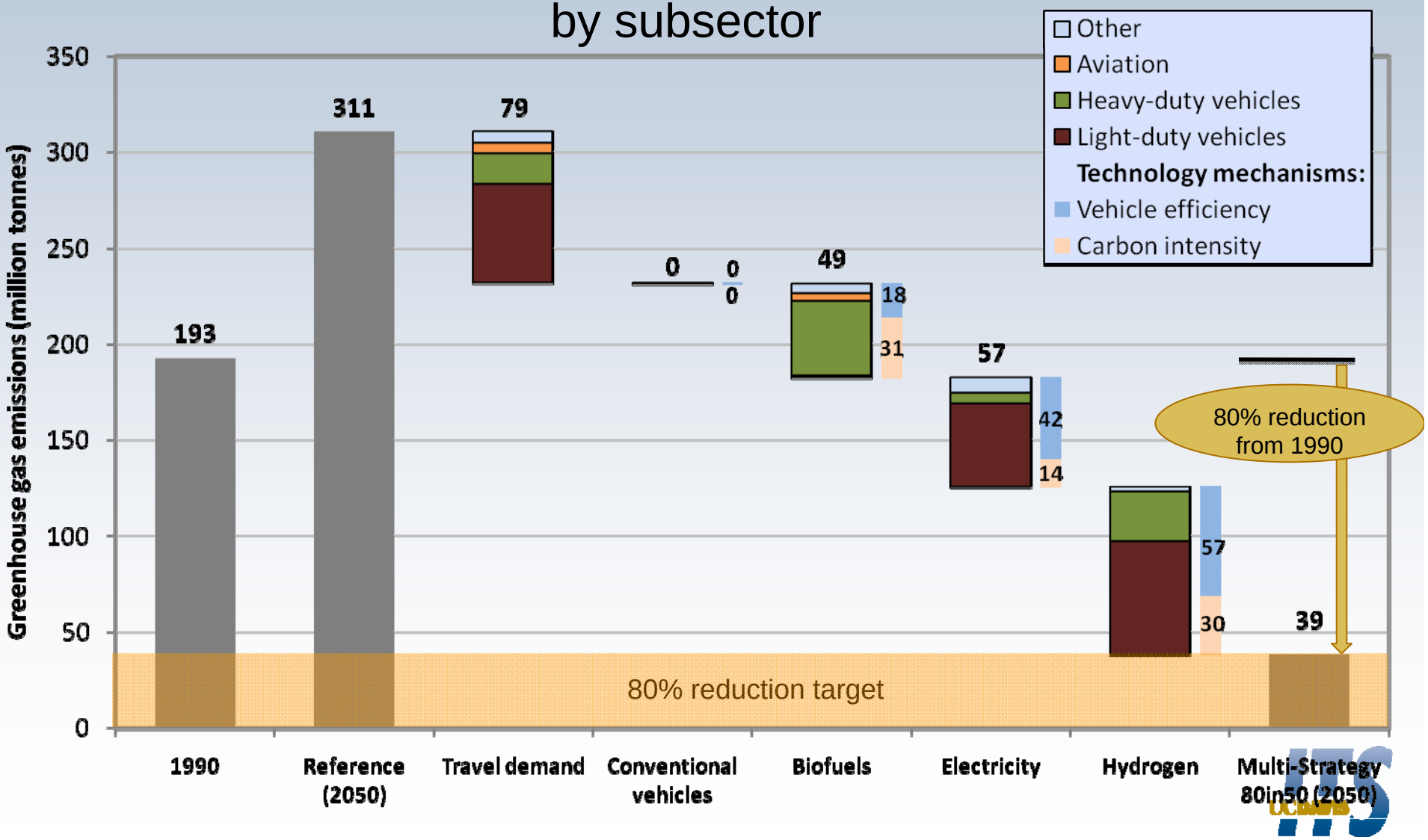
80in50 Scenarios

- ***Efficient Biofuels*** - 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*** - 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*** - *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.
- ***Multi-Strategy with WGA Biofuel Feedstock Supply Constraint*** – *Biofuel feedstock supply constraint means scarity of low-C biofuels.* A combination of actor-based changes, electric drive vehicles, and fuel decarbonization occurs (although each is less extreme than in the actor-based, electric drive and efficient biofuels scenarios).

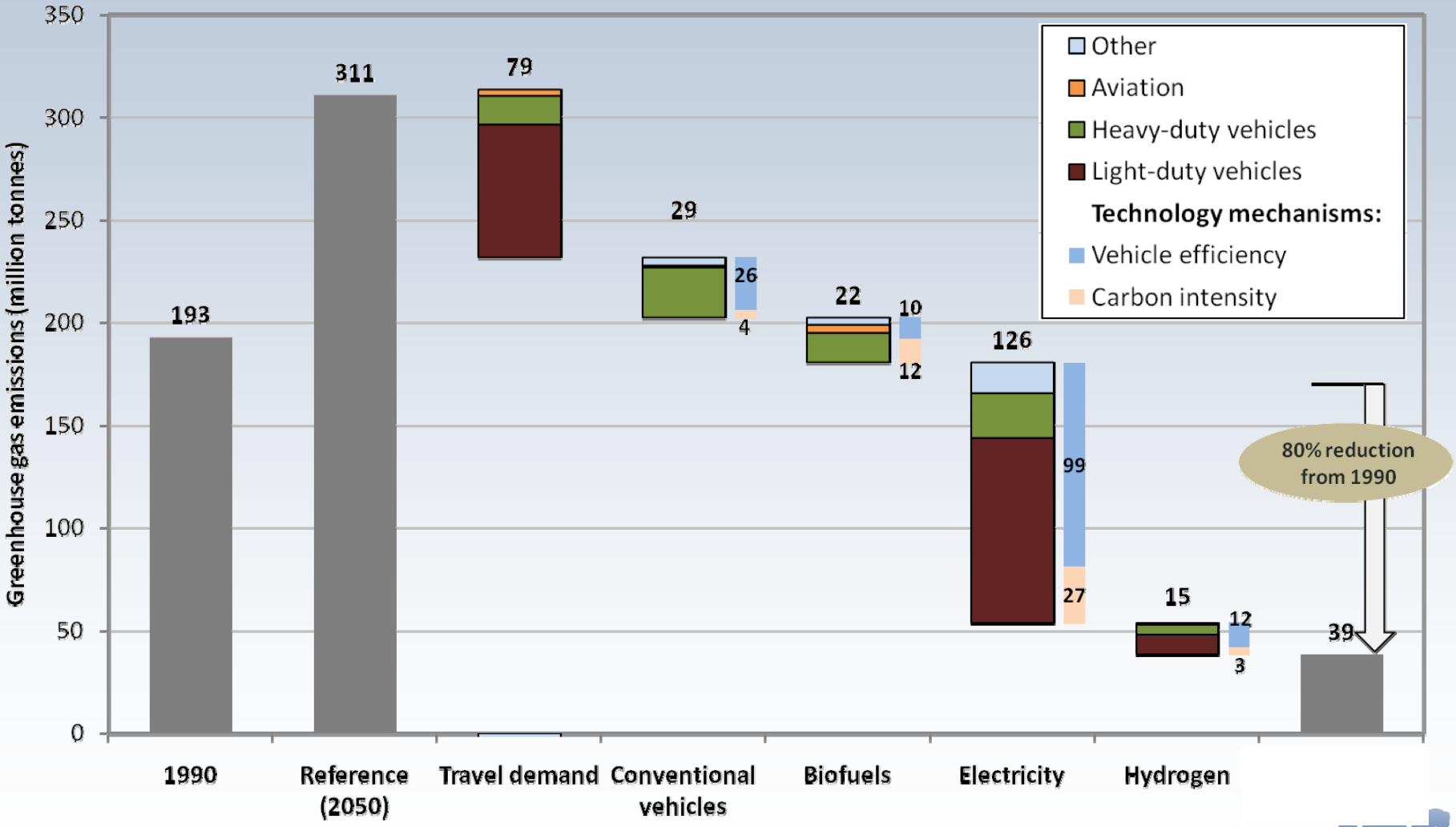
A SCENARIO FOR 80% GHG REDUCTION IN 2050

Multi-Strategy with WGA Biofuel Feedstock Supply Constraint

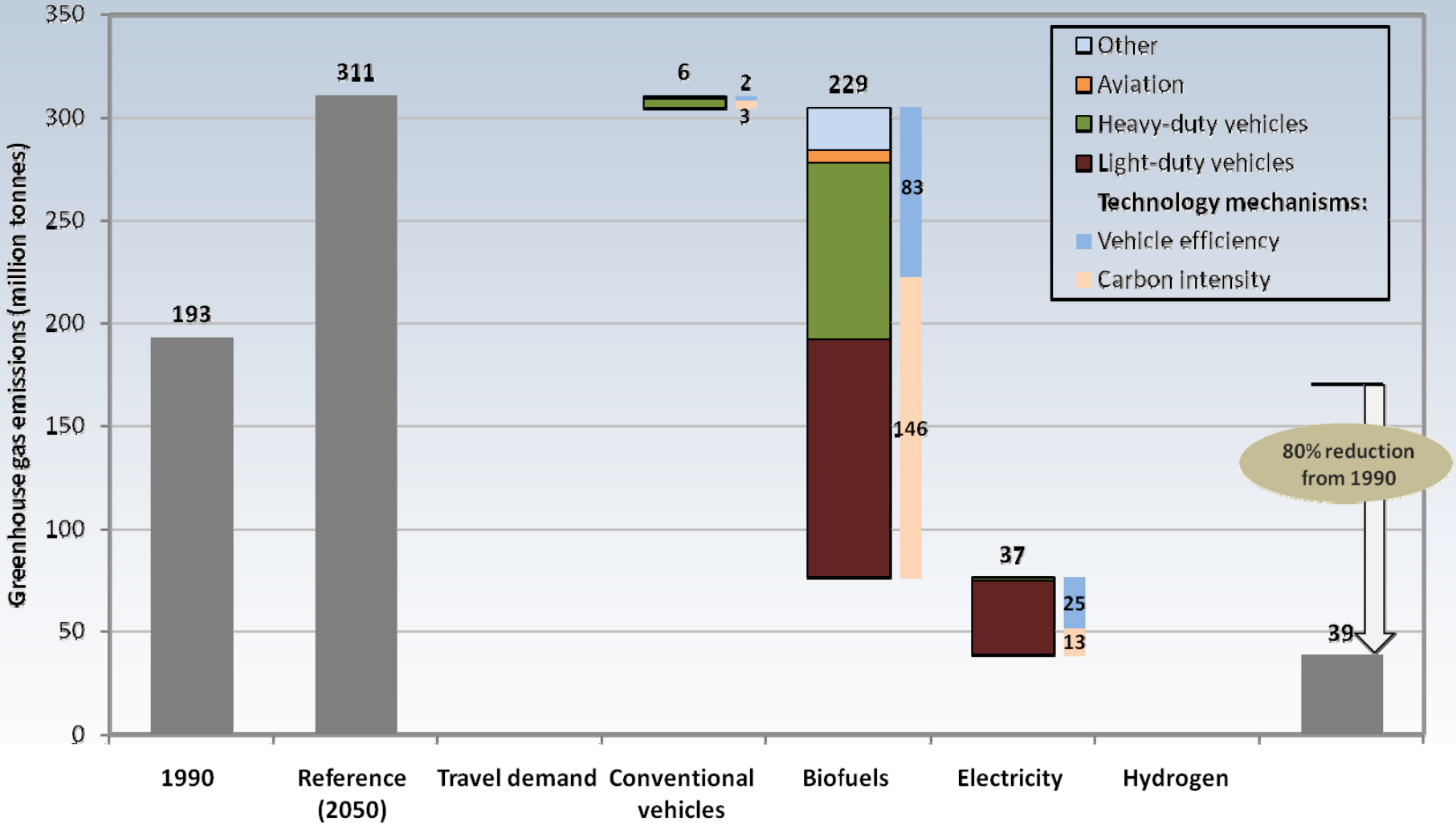
Reducing T,E,C contributes to emission reduction, varying by subsector



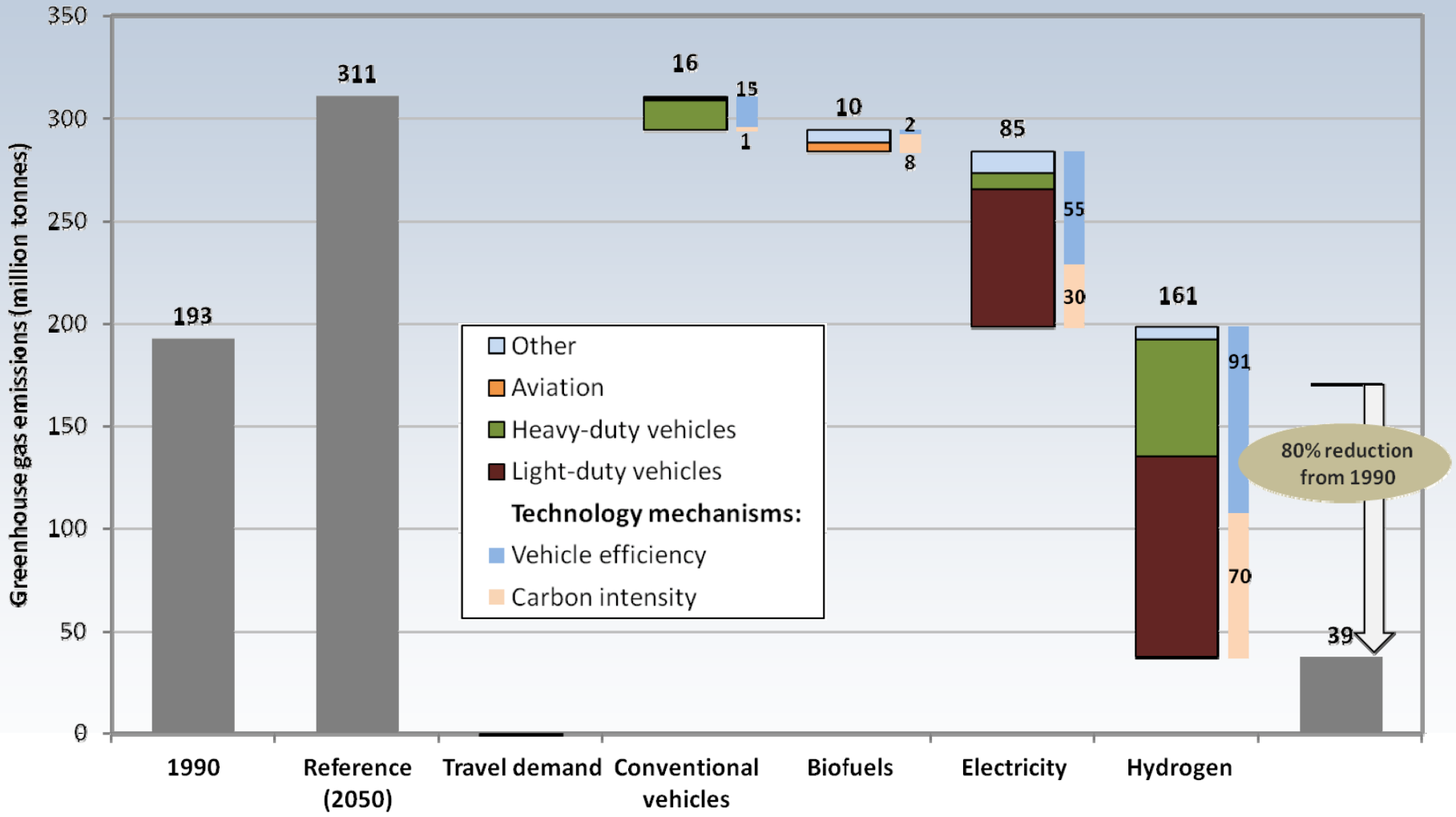
Actor-based 80in50



Efficient Biofuels 80in50



Electric-drive 80in50

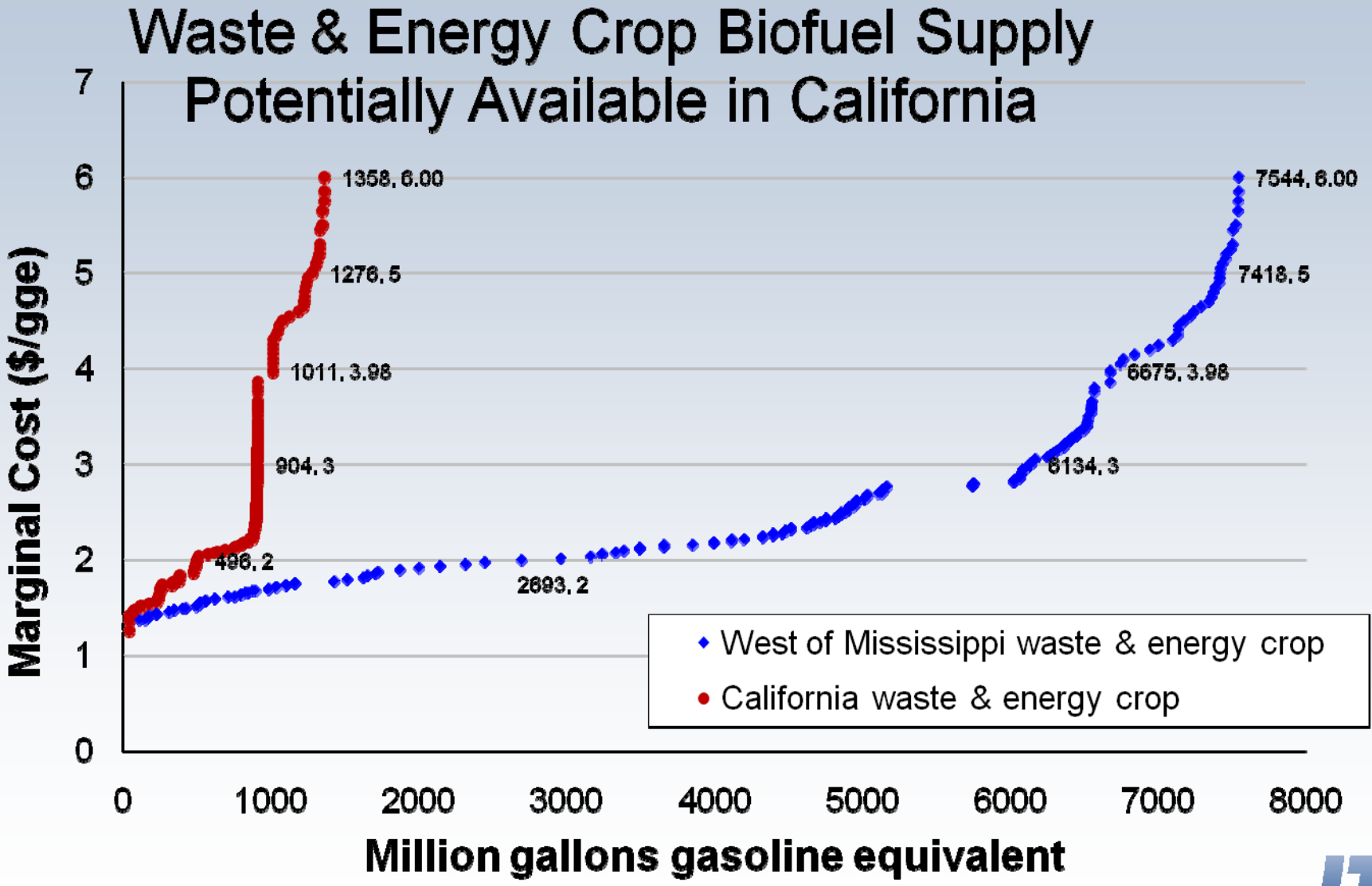


BIOFUEL SUPPLY IS A KEY FACTOR

- Availability of **low-carbon biofuels** in California influences mix of LDV technologies needed to meet 80% reduction goal
- Current gasoline use in CA ~ 15-16 Billion gal/y
- Projected transportation fuel use in 2050 (BAU) ~ 25 B gge/y
- Potential biofuel supply from entire US (long term) (75-120 B gge/y for 2nd generation biofuels)
  - CA share of US biofuels based on population ~ 12-18 B gge/y
- Significant uncertainty in well to wheels carbon emissions for biofuels from energy crops.
- This could constrain amount of low-C biofuel available in CA.

gge = gallons gasoline equivalent on an energy basis

BIOFUELS SUPPLY CONSTRAINT



Source: Parker, N., et al., *Strategic Assessment of Bioenergy Development in the West: Spatial Analysis and Supply Curve Development*. 2008, Western Governors' Association: Denver, CO.

BIOFUEL SUPPLY ASSUMPTIONS

SCENARIO	BIOFUEL DESCRIPTION	Biofuel Quantity used in all vehicles (B gge)	% Biofuel used in LDV	All Trans. Fuels Quantity (B gge)
Multi-Strategy w/WGA Biofuel Supply Constraint	75% instate, 25% outside CA (west of Mississippi) 53% Waste, 33% Energy Crop, 14% Food Crop 20.6 gCO2/MJ	3.6	3.6%	10.2
Actor-Based	30% Ethanol, 40% Biodiesel, 30% Bio-Butanol 17.7 gCO2/MJ	1.7	5.6%	7.8
Efficient Biofuels	30% Ethanol, 40% Biodiesel, 30% Bio-Butanol 17.7 gCO2/MJ	16.0	53%	17.8
Electric Vehicle Intensive	5% Ethanol, 85% Biodiesel, 10% Bio-Butanol 23.7 gCO2/MJ	0.8	0%	13.0

80in50 Scenario Results:

CA Transportation GHG Emissions in 2050

(% of 1990 level)

	Actor-Based	Multi-Strategy with WGA Biofuel Feedstock Supply Constraint	Efficient Biofuels	Electric Vehicle Intensive
LDV	5%	13%	15%	6%
HDV	60%	38%	25%	63%
Aircraft	27%	20%	38%	61%
Rail	72%	63%	35%	8%
Marine, Ag., Off-Road	48%	36%	48%	34%
All Transport	20%	20%	20%	20%

LDVs must meet more stringent goals than “All transport”

RESULTS FROM 80in50 LEVERS MODEL

1. **Consideration of all transportation sectors essential**
   - Variety of ways to meet 80% reduction goal in 2050
   - Combination of approaches required (no silver bullet)
   - LDV must meet more stringent GHG reduction goals than other sub-sectors (esp. aircraft, where liquid fuels are essential)
2. **Achieving 80% reduction in GHG by 2050**

requires (for LDVs):

- VMT/capita reduction
- Improved efficiency
- Shift toward cars from light trucks
- Electrification – FCV, BEV, PHEV
- Low-carbon fuel production

is constrained by:

- Population Growth
- Travel demand
- Vehicle efficiency
- Low-carbon biofuel supply
- Low-carbon primary energy source availability

QUESTION #2: HOW DO WE GET FROM HERE TO THERE?

Having defined range of scenarios that achieve 80% reduction goal, explore transition paths to 2050

Constraints:

New Vehicle Penetration Rates

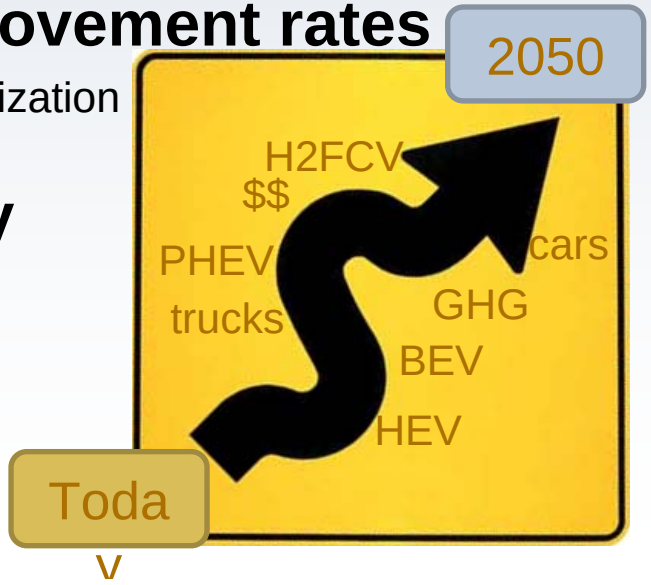
- R&D Commercialization
- Infrastructure build-out
- Consumer adoption
- Higher-C technologies squeezed out

Efficiency Improvement rates

- R&D Commercialization
- Policy push

Fuel C Intensity

- Infrastructure build-out
- Policy push



Results:

Vehicle share paths

- Market share
- Fleet share

GHG emissions paths

- Annual rate
- Cumulative total

Energy use paths

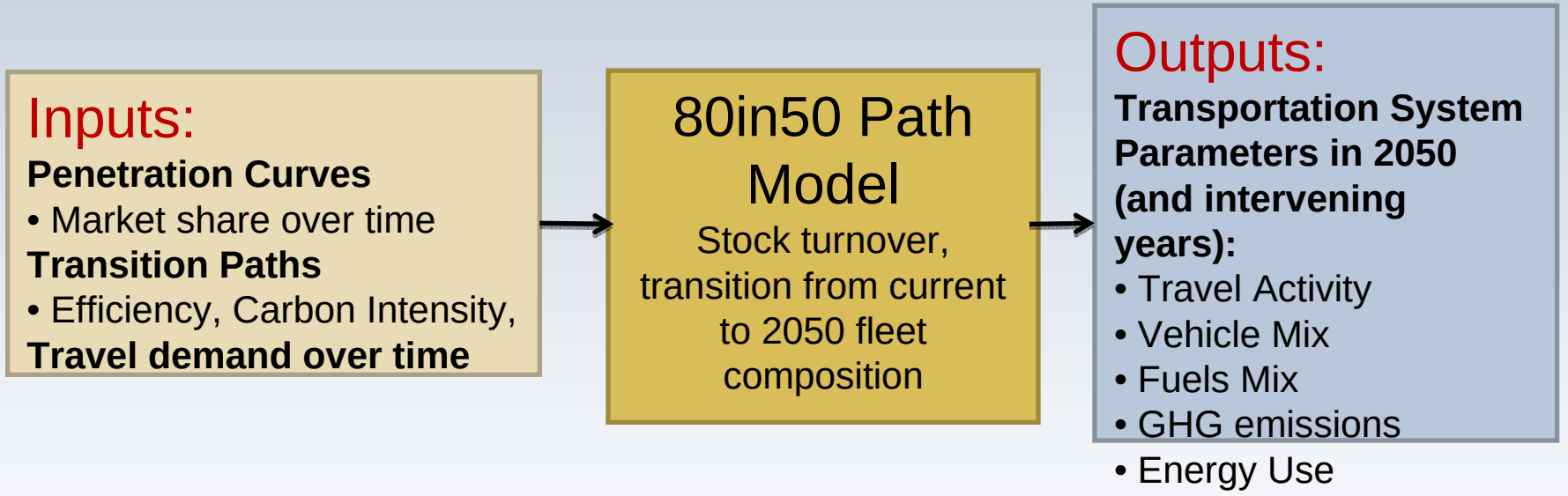
- Petroleum, biofuel, hydrogen, electricity
- Fuel carbon intensity

Future Work

- Transition Cost
- Optimization Criteria

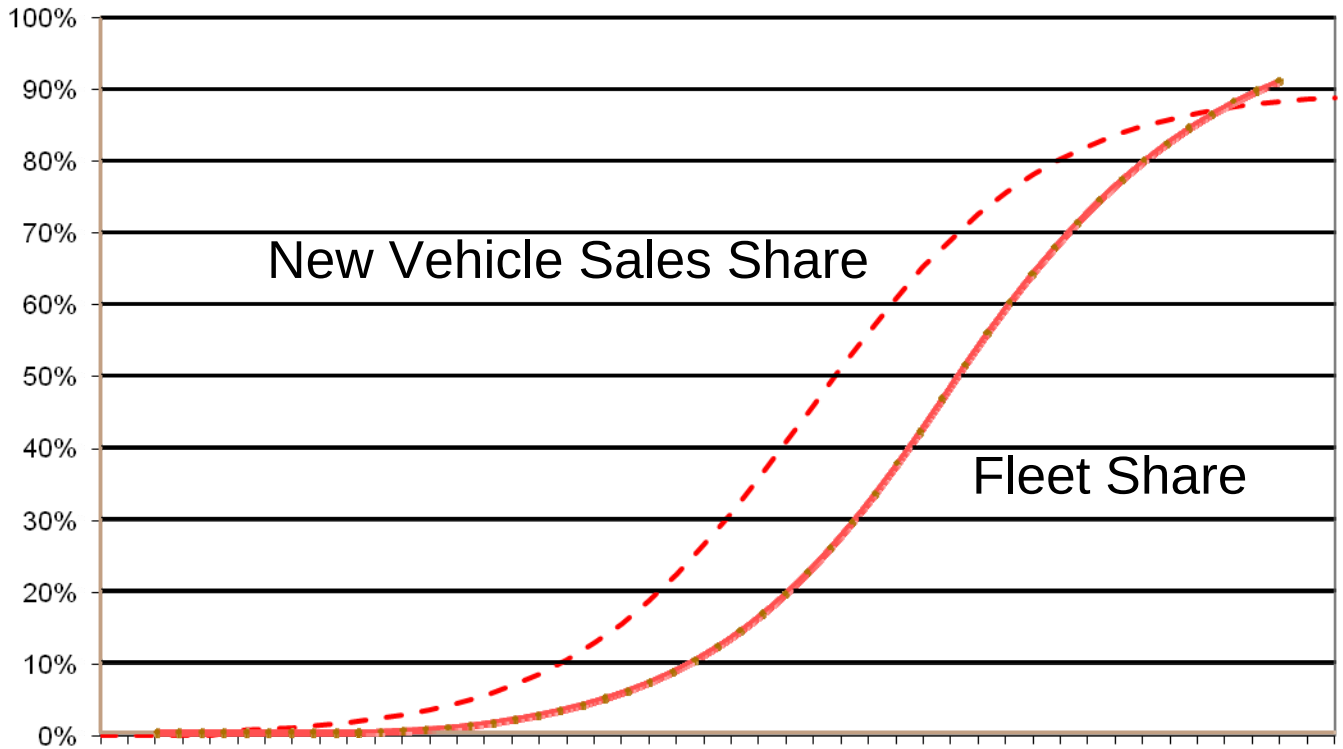
80in50 TRANSITION PATH ANALYSIS

The **80in50 PATH** model analyzes ***dynamic*** transition paths to the 2050 transportation system ***static*** scenarios produced with the 80in50 LEVERS model.



User can adjust transition path inputs, constrained by feasibility, so that output matches static “80in50” scenarios in 2050.

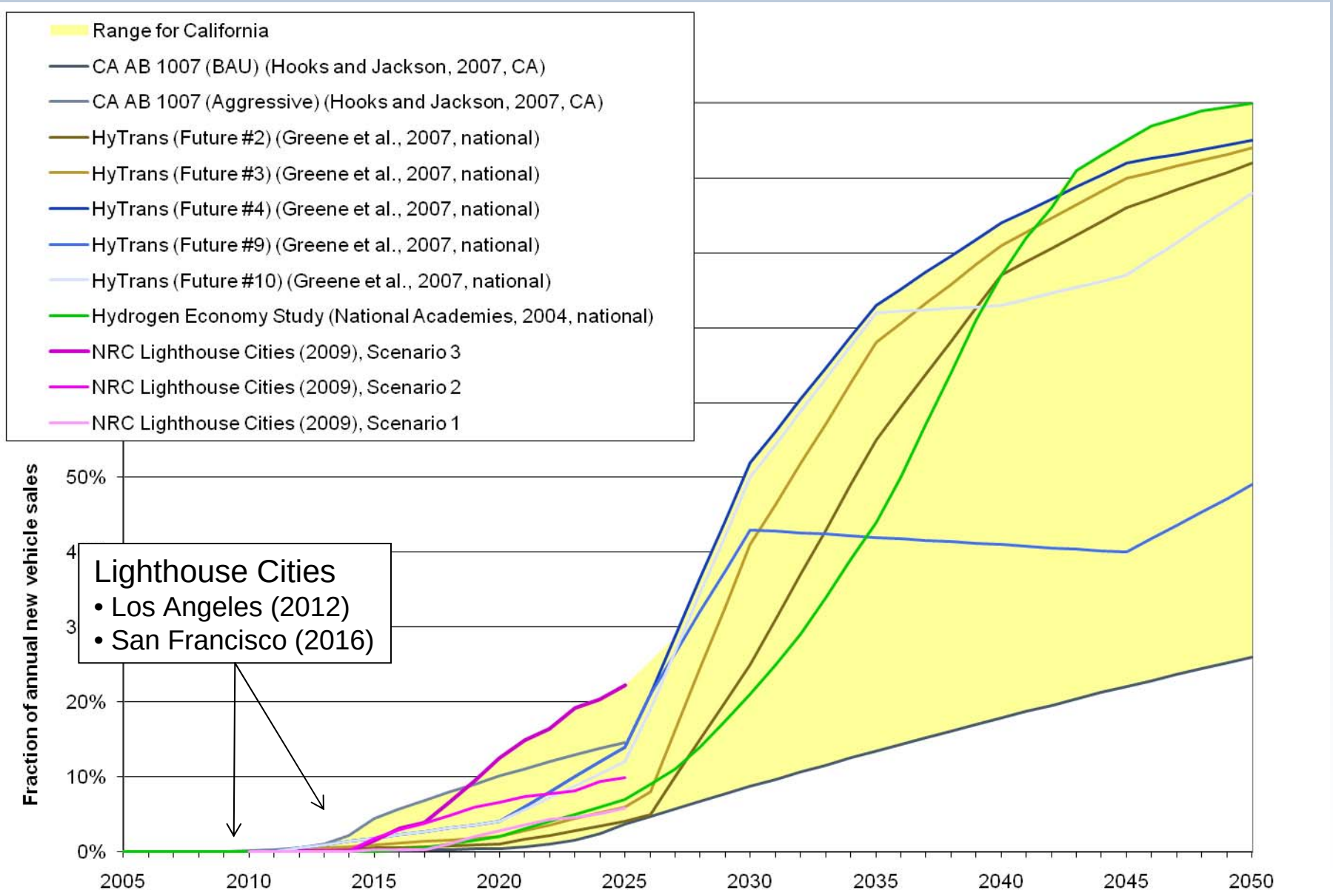
MODELING METHODS



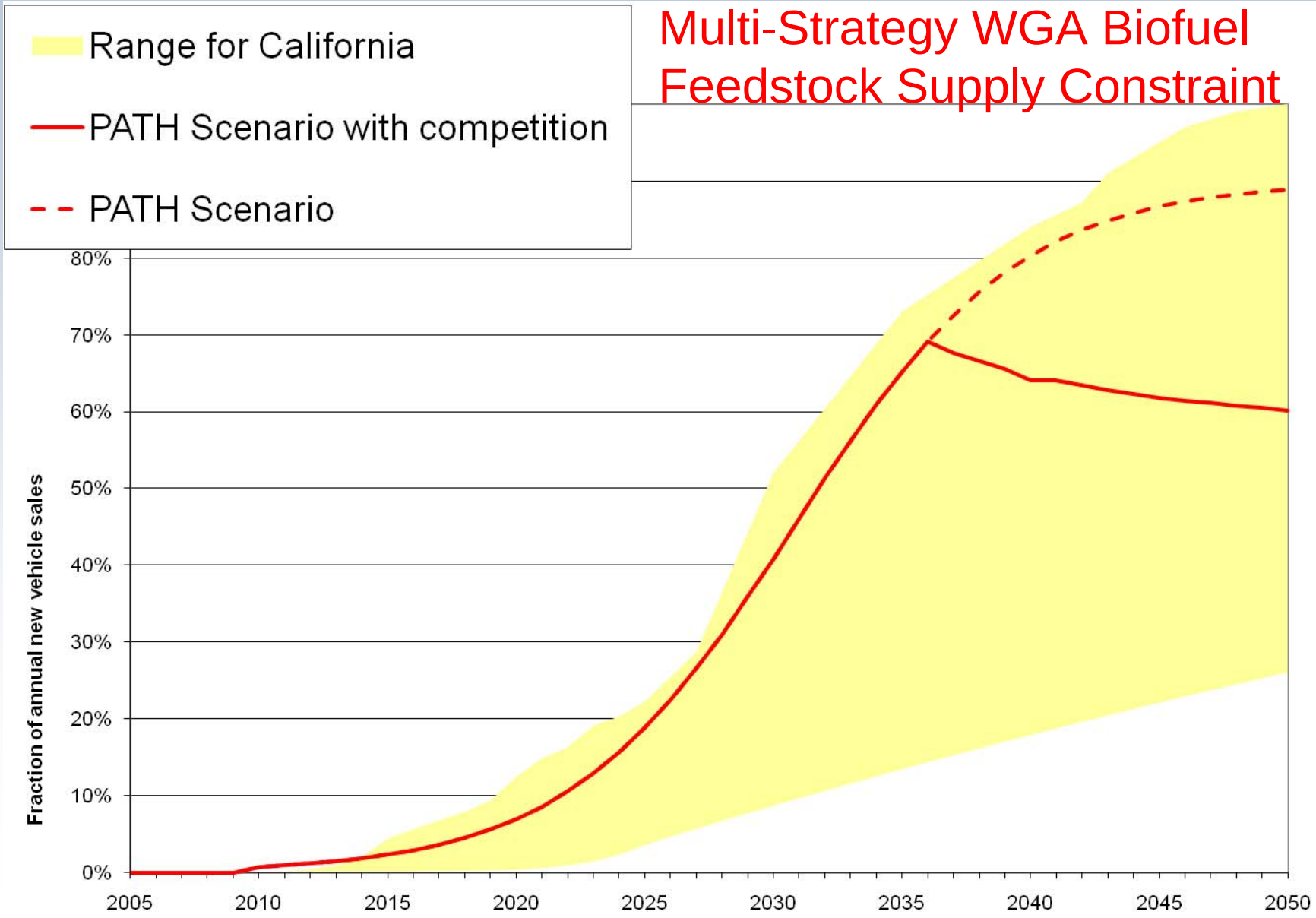
Adjust logistic function for *new vehicle sales share* to give required 2050 *fleet share*, subject to stock turnover dynamics and constraints on maximum market penetration rate (from literature review).

HYDROGEN FCV MARKET PENETRATION

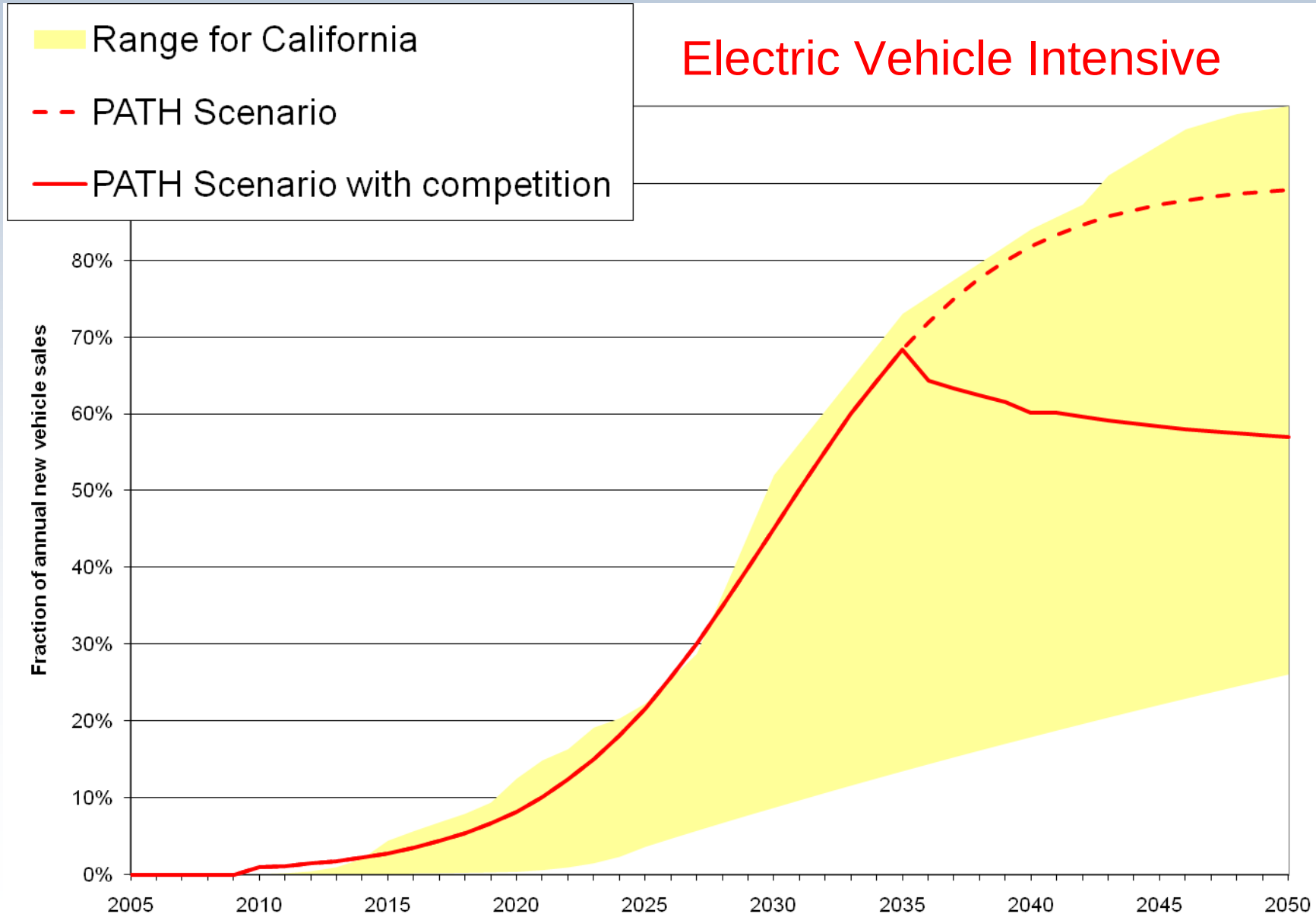
MAX RATE FROM LIT. REVIEW



HYDROGEN FCV MARKET PENETRATION



HYDROGEN FCV MARKET PENETRATION



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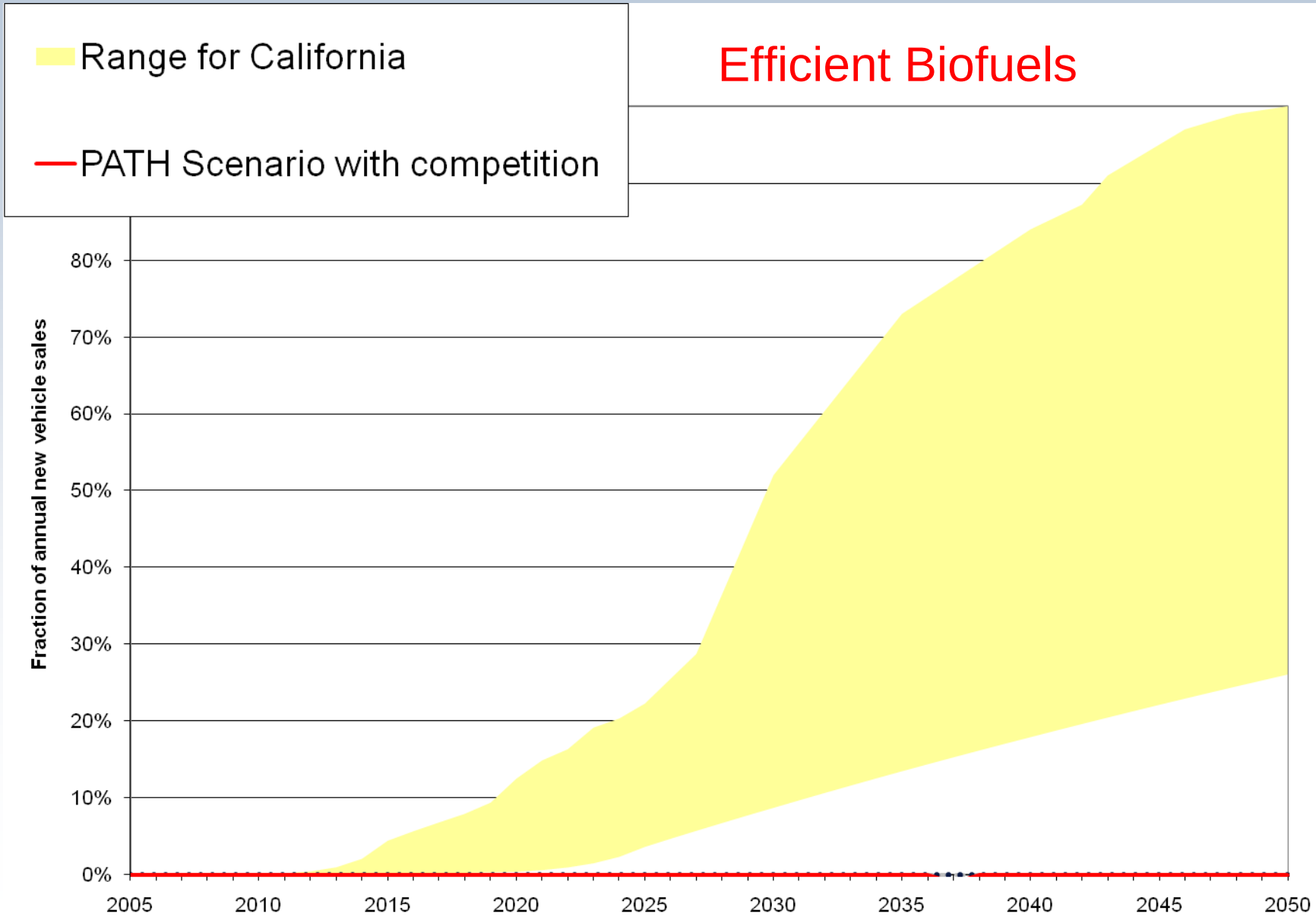

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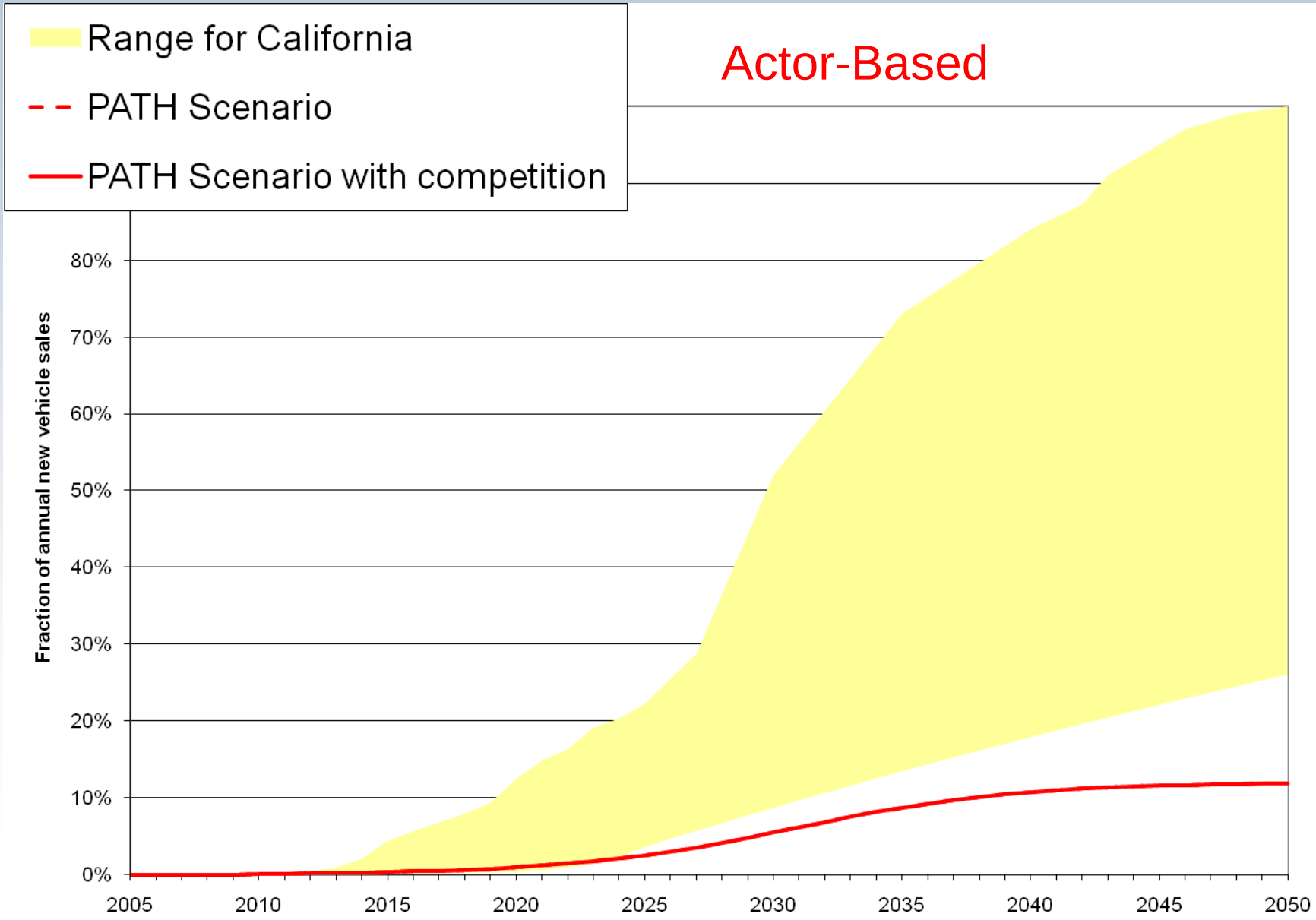
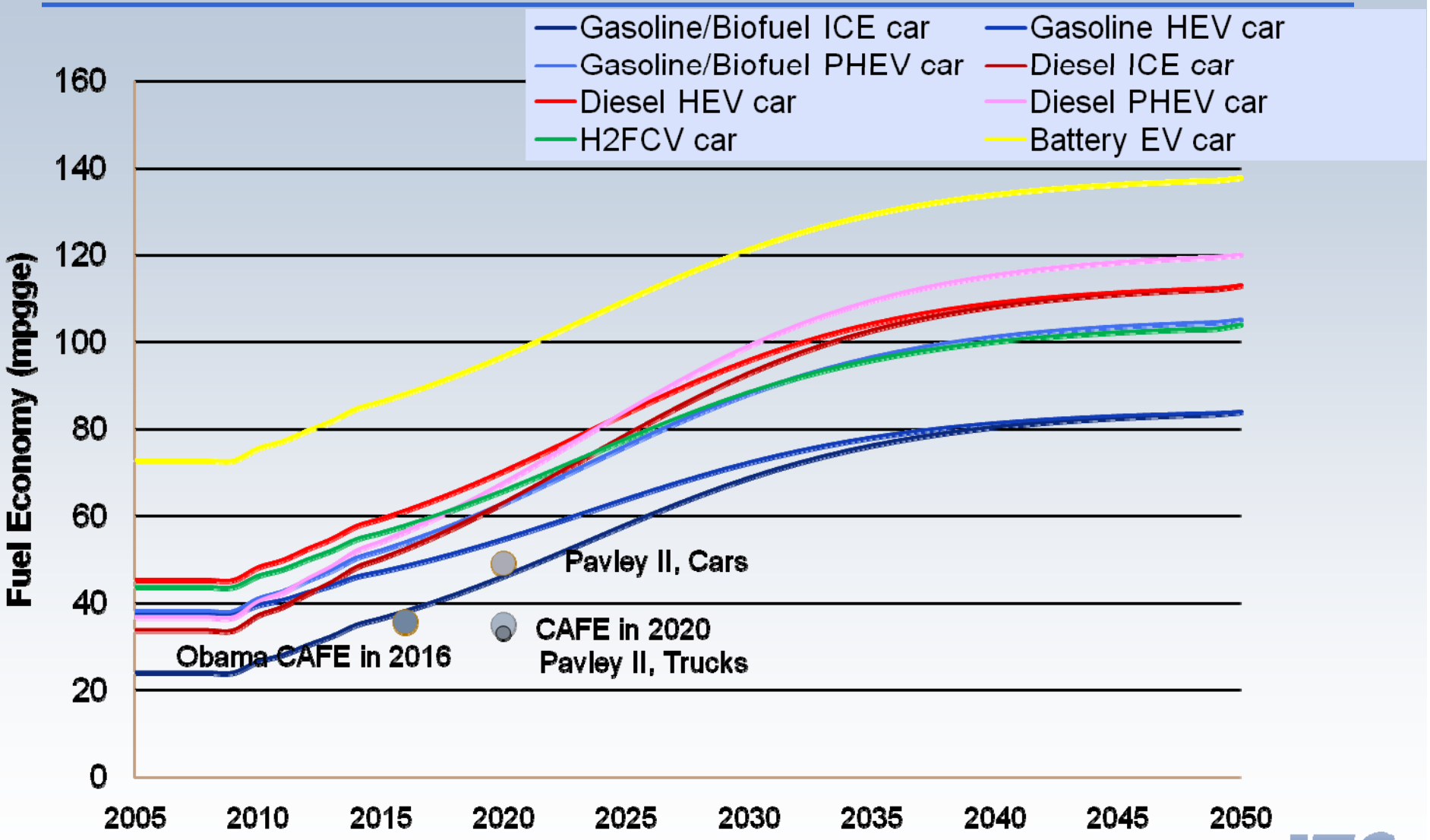


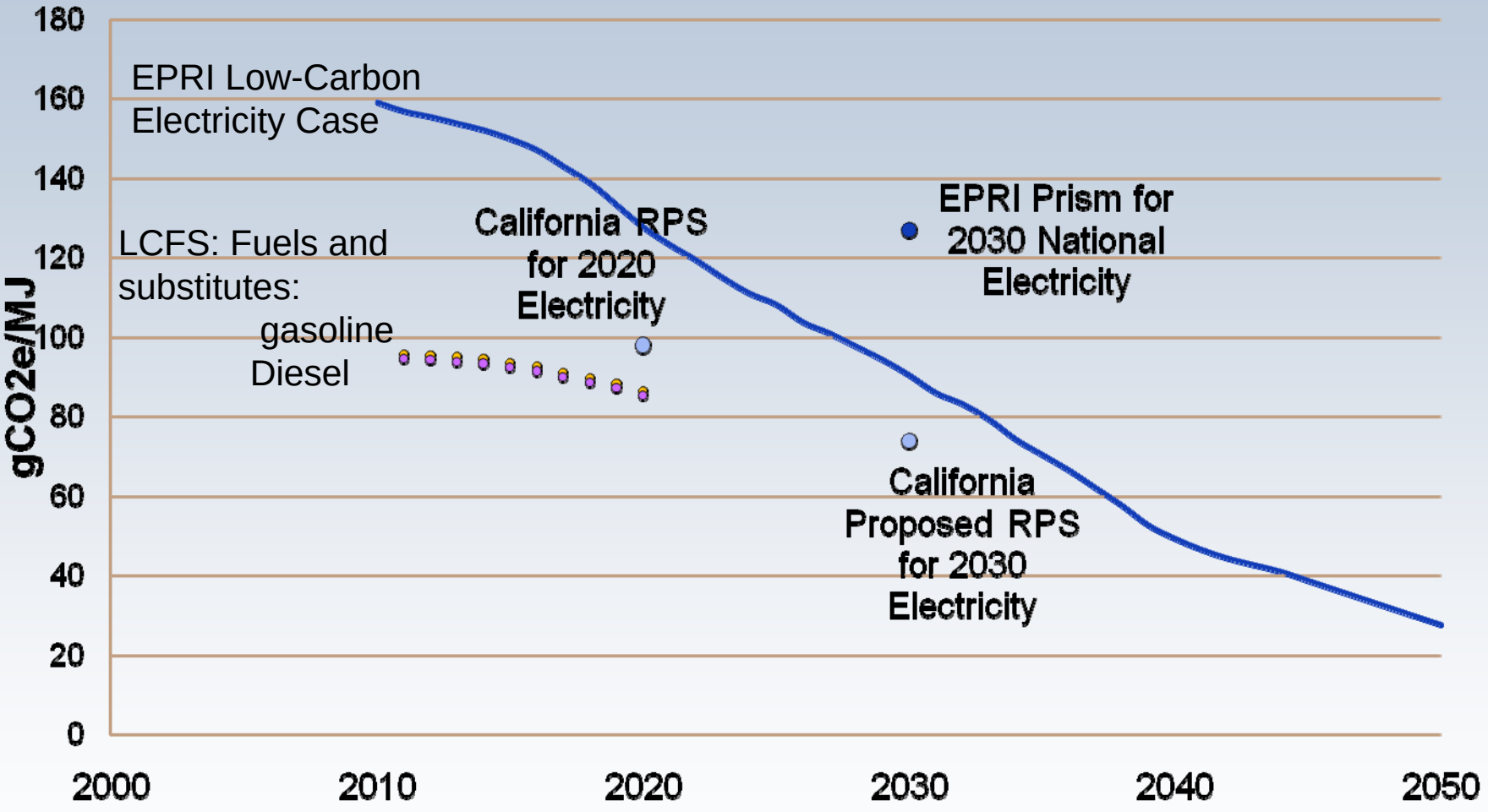
FUEL ECONOMY IMPROVEMENT (MAX. FEASIBLE)

Cars, On-road New Vehicle Fuel Economy



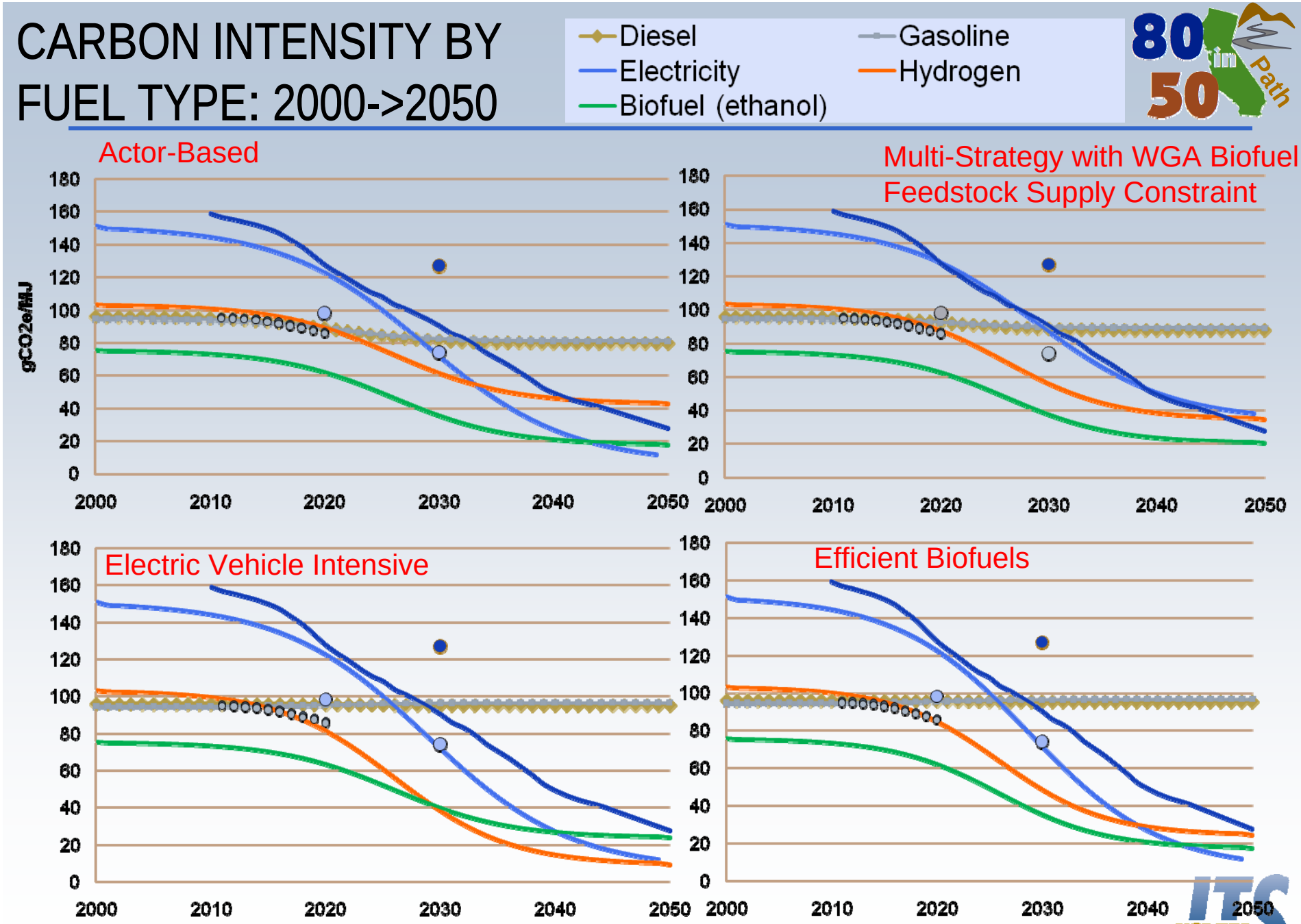
On-road is approximately 85% of EPA estimated fuel economy

CARBON INTENSITY BY FUEL TYPE : GOALS



Carbon intensity for RPS weigh points calculated assuming renewables replace highest-carbon alternatives

CARBON INTENSITY BY FUEL TYPE: 2000->2050



Carbon intensity for RPS waypoints calculated assuming renewables replace highest-carbon alternatives

PREVIEW:

LDV TRANSITION PATH ANALYSIS

TRENDS THAT REDUCE GHG EMISSIONS IN LDVs:

Increasing Vehicle Efficiency

- Continued ICE engineering applied to fuel economy
- Hybridization permeates the market
- Sales mix shifting to 75% cars, 25% light trucks

Increasing Vehicle Electrification

- HEV -> PHEV -> FCV and BEV

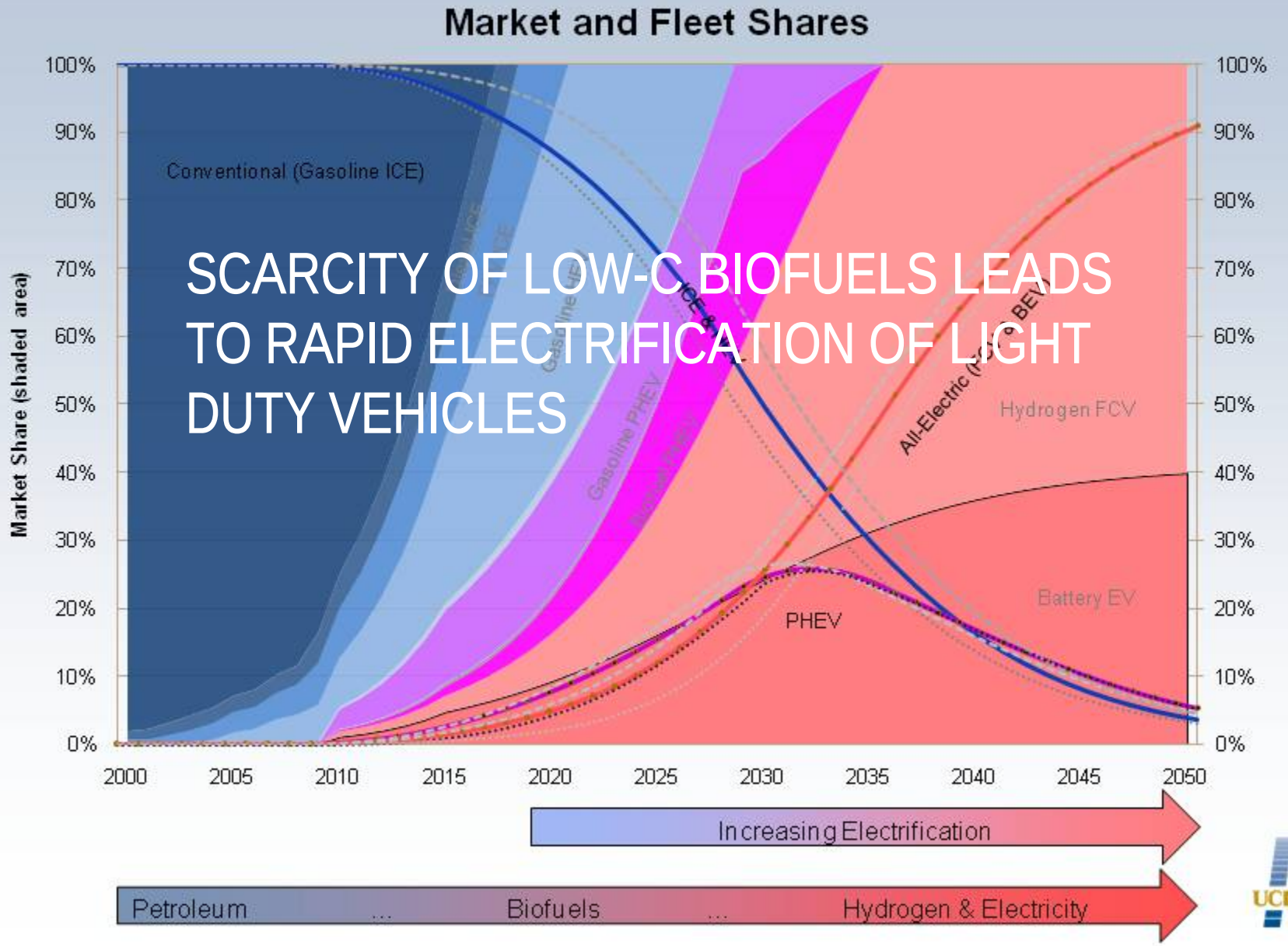
Fuel Mix shifts from petroleum to biofuels to hydrogen and electricity

The modeling uses the following sequencing rule:

- GHG emissions reduced over time as lower-carbon alternatives squeeze higher-carbon options out of the market.
- Technologies are “competing” in the race to meet 80% reduction by 2050; all must move quickly in order to meet intermediate targets as well.

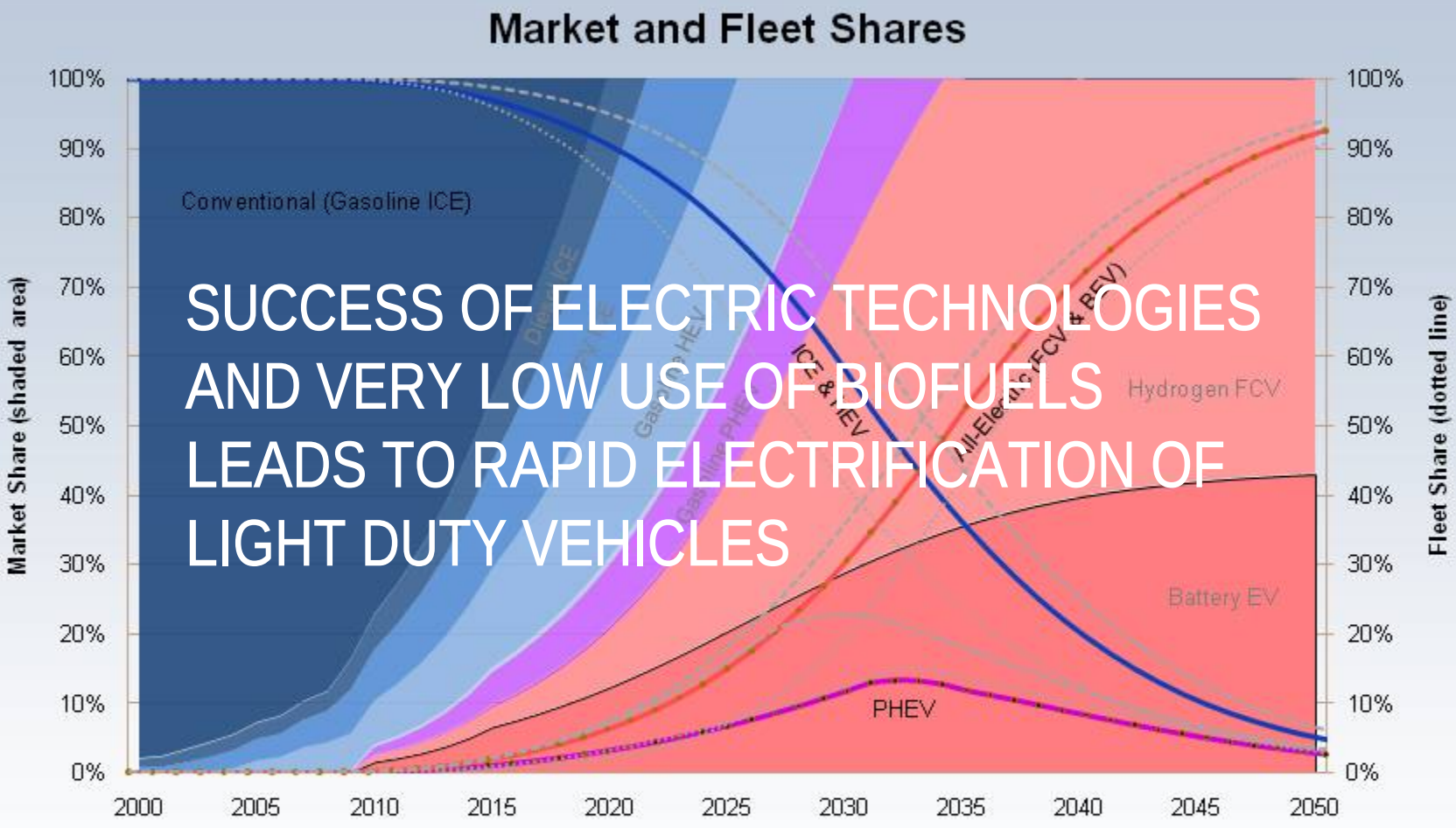
TRANSITION IN MARKET AND FLEET

Multi-Strategy with WGA Biofuel Feedstock Supply Constraint



TRANSITION IN MARKET AND FLEET

Electric Vehicle Intensive 80 in 50 Path



SUCCESS OF ELECTRIC TECHNOLOGIES AND VERY LOW USE OF BIOFUELS LEADS TO RAPID ELECTRIFICATION OF LIGHT DUTY VEHICLES

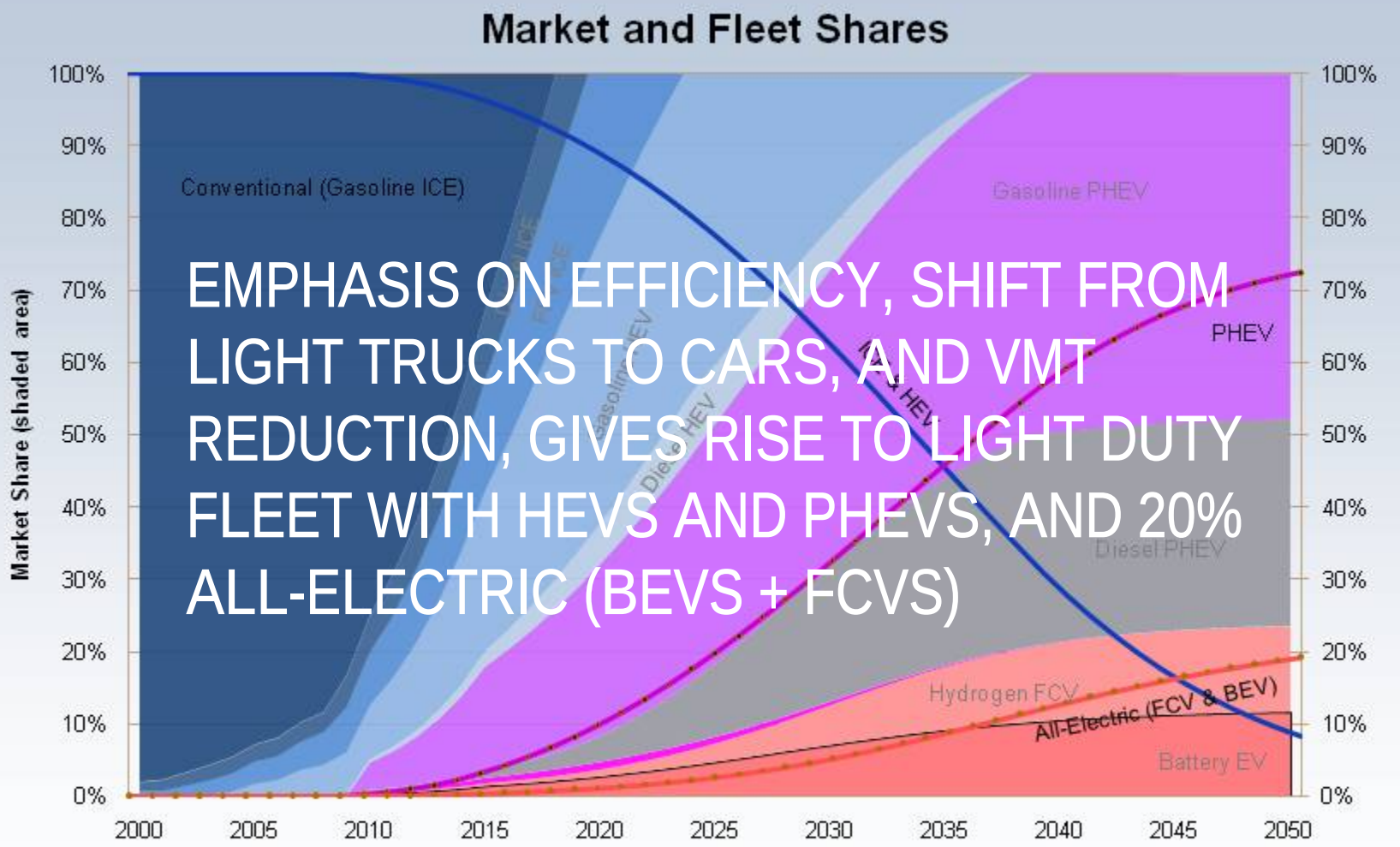
Increasing Electrification

Petroleum … Petroleum … Hydrogen & Electricity

ITS UCDAVIS

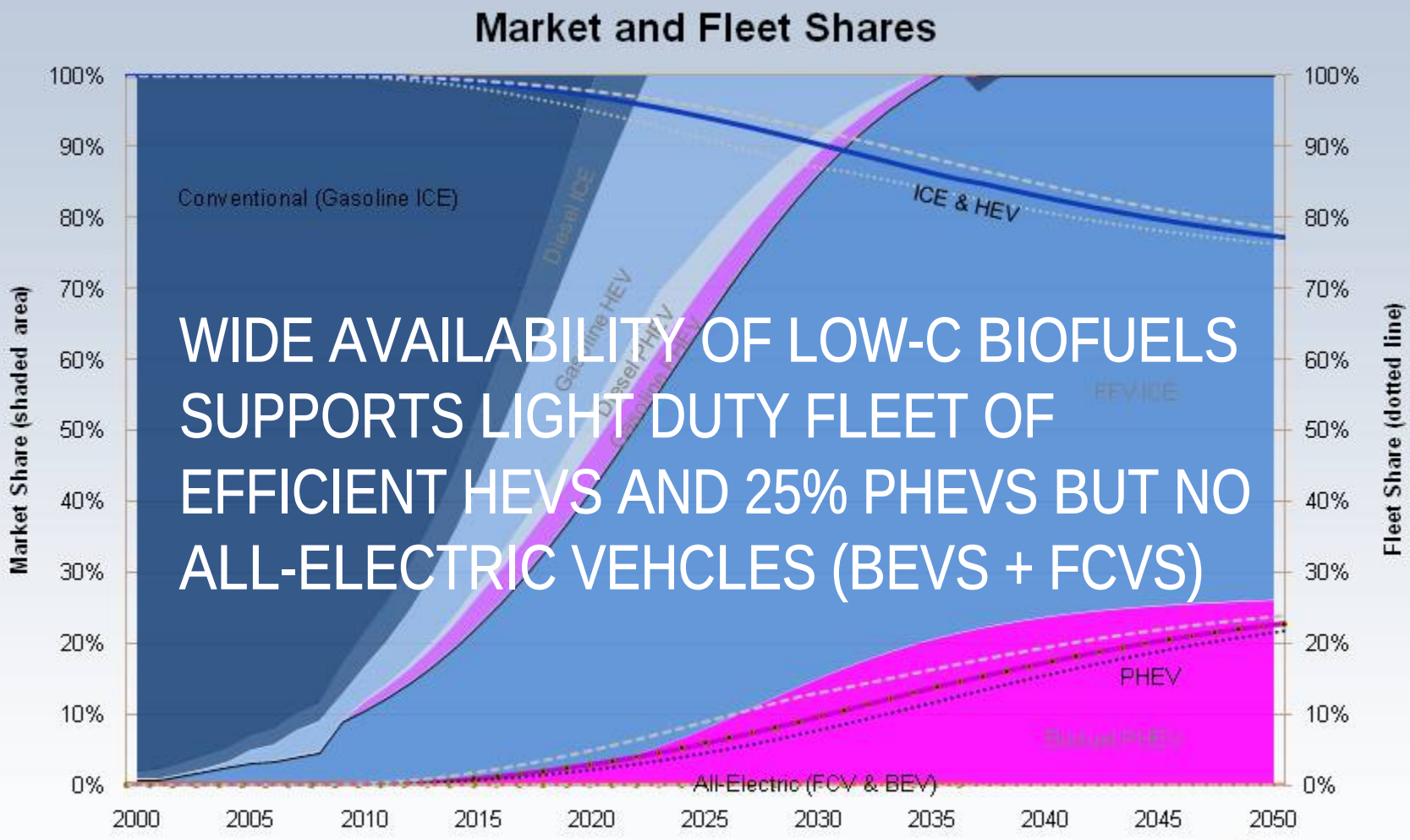
TRANSITION IN MARKET AND FLEET

Actor-Based



TRANSITION IN MARKET AND FLEET

Efficient Biofuels



WIDE AVAILABILITY OF LOW-C BIOFUELS SUPPORTS LIGHT DUTY FLEET OF EFFICIENT HEVS AND 25% PHEVS BUT NO ALL-ELECTRIC VEHCLES (BEVS + FCVS)

Slow Electrification

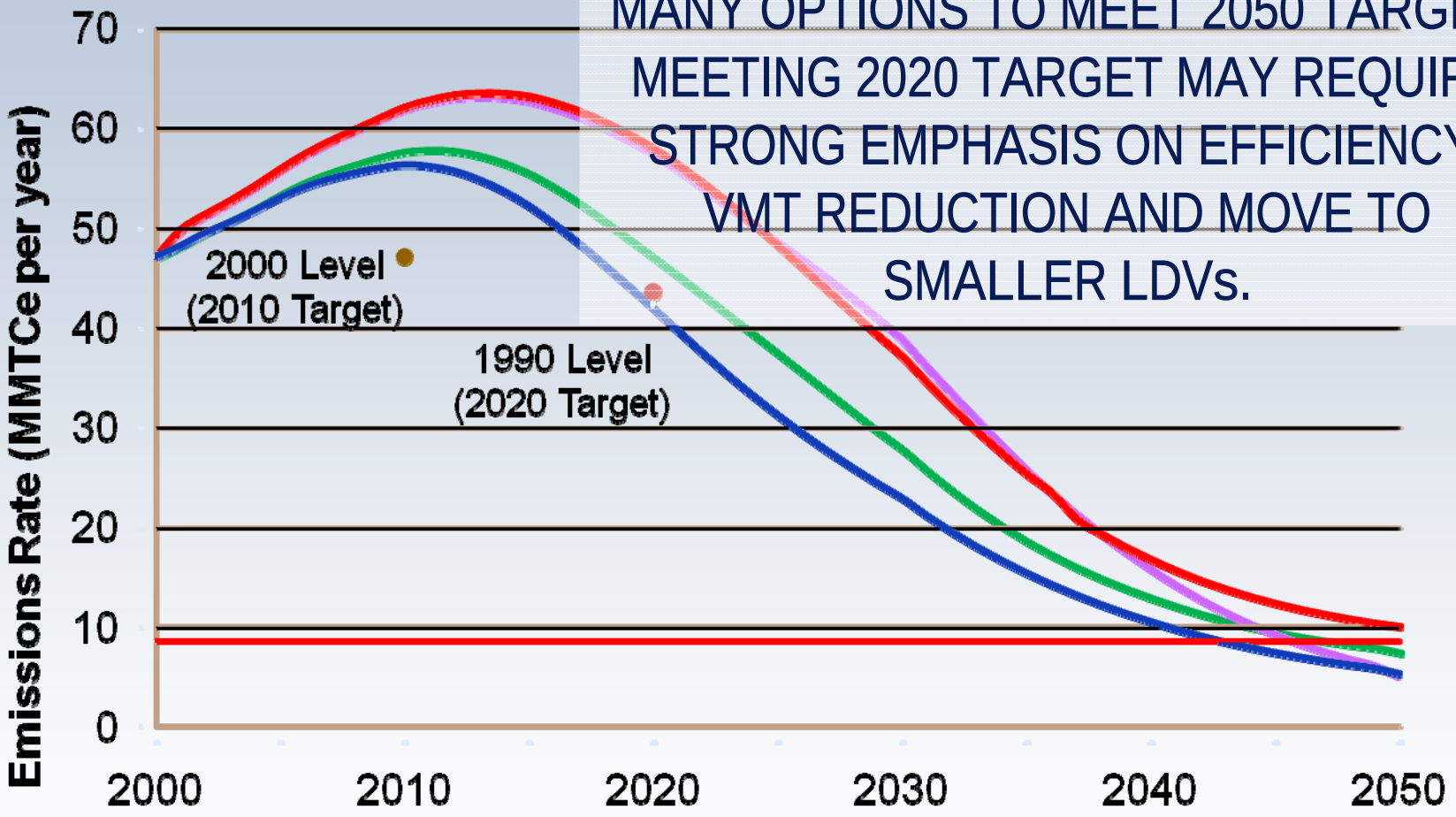
Petroleum ... Biofuels ... Biofuels

ITS UCDAVIS

GHG EMISSIONS FROM TRANSPORT SECTOR :

MEETING 2020 GOALS ENROUTE TO 2050

MANY OPTIONS TO MEET 2050 TARGET; MEETING 2020 TARGET MAY REQUIRE STRONG EMPHASIS ON EFFICIENCY, VMT REDUCTION AND MOVE TO SMALLER LDVs.



Multi-Strategy with WGA Biofuel Feedstock Supply Constraint

Actor-Based

Efficient Biofuels

Electric Vehicle Intensive

RESULTS FROM THE 80in50 PATH MODEL

2050 GHG GOALS COULD BE REACHED IN VARIETY OF WAYS:

- Mix of light duty vehicle technologies and fuels to achieve 80% reduction in 2050 depends on many uncertain assumptions, incl. the amount of low carbon biofuel available.
- Unless low-C biofuels are very prevalent, some combination of FCVs and BEVs will be needed to meet goals.

MEETING BOTH THE 2020, 2050 GHG GOALS COULD BE FEASIBLE, PROVIDED:

- LDV efficiency is improved close to 100 mpg fleet average fuel economy apply tech. improvement to fuel economy (rather than performance) and shift in fleet composition to 75% cars (25% light trucks)
- Aggressive change in LDV vehicle sales mix to increase electrification
- Shift to lower-C fuels and aggressive decarbonization of all primary energy sources
- Decrease in travel demand by approximately 15%

RESULTS FROM THE 80in50 PATH MODEL

New LDV technologies must be introduced soon and progress rapidly (at close to the max. rates found in the literature) to achieve CA's 2050 GHG emission reduction goals.

A porfolio approach is needed, because of uncertainties and timelines for market penetration

ZEV TECHNOLOGIES ARE KEY FOR MEETING CALIFORNIA'S 2050 GOALS

- Some combination of FCV and BEV required; limited low-carbon biofuel supply used mostly for other sub-sectors (heavy duty, aviation), except in Biofuel efficiency case.

Thank You

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Supplementary Materials

Future Work

1.) Transition Costs – including VISION fuel costs, modified to include learning, and transition cost analysis (e.g., infrastructure + buydown cost for FCV)

2.) Monte Carlo to "narrow" the path

- Sensitivity analyses and side cases to improve understanding, insight

2.) Ranking alternative 80in50 scenario and transition paths

Possible Criteria:

- **Cumulative GHG emissions** – salient for climate change
- **Cost** – total social and disaggregated
- **Proximity to policy targets** – allow deviation, but with penalty
- **Degree of social change** – in travel and consumption behavior.

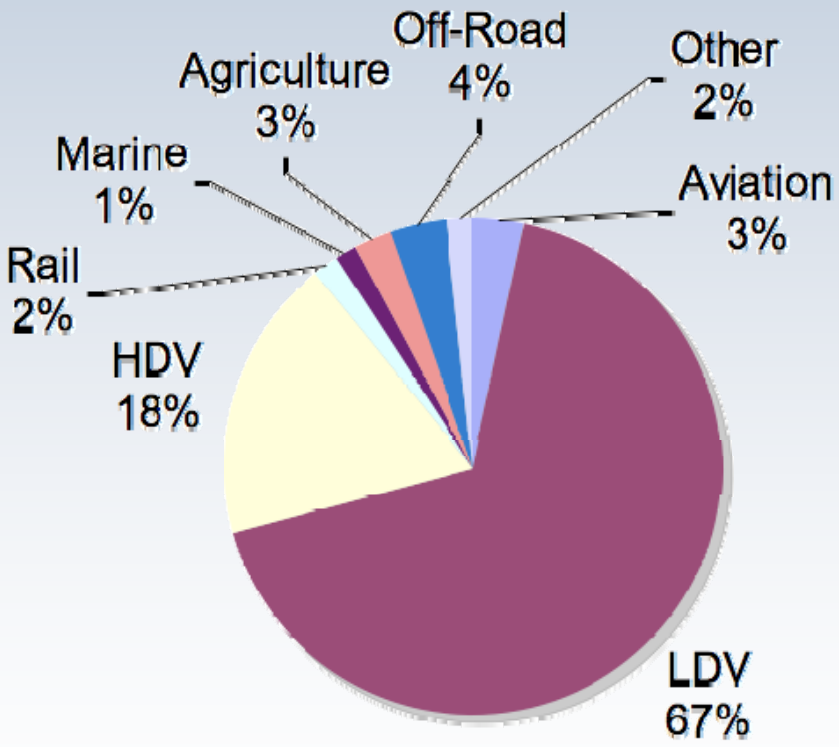
Optimization for scenario and path ranking

- Easiest to rank by cumulative GHG emissions or rank by cost for each scenario-pathway combination
- Valuation formula for combining several criteria
- "Optimized" transitional pathway for each 80in50 scenario maximizing the objective function.

CALIFORNIA TRANSPORTATION IN 1990

Focus: “In-State” Emissions, Light Duty Vehicles (LDVs)

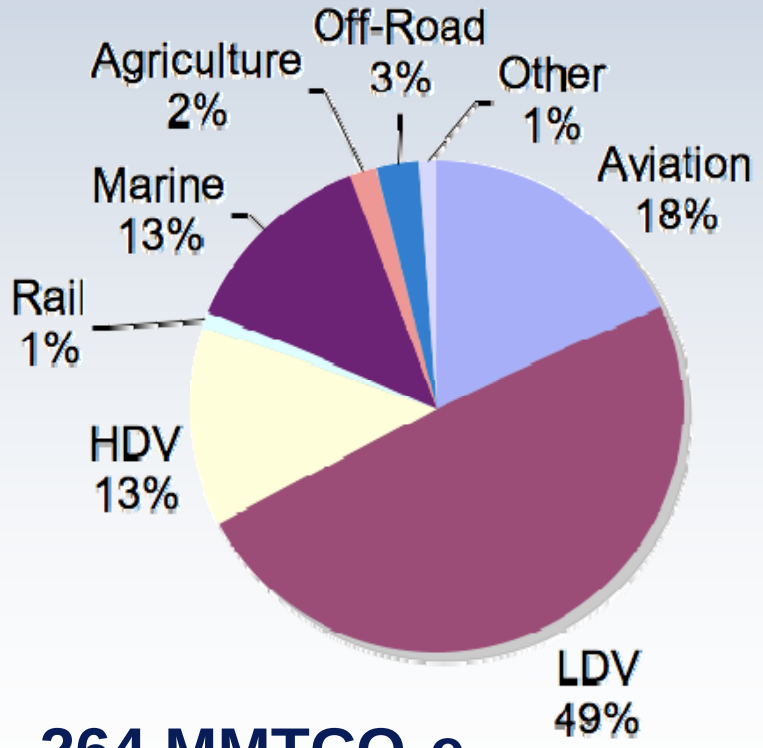
“*In-State Emissions*”



193 MMTCO$_2$e

“*Overall Emissions*”

(In-State + 50% trans-border)

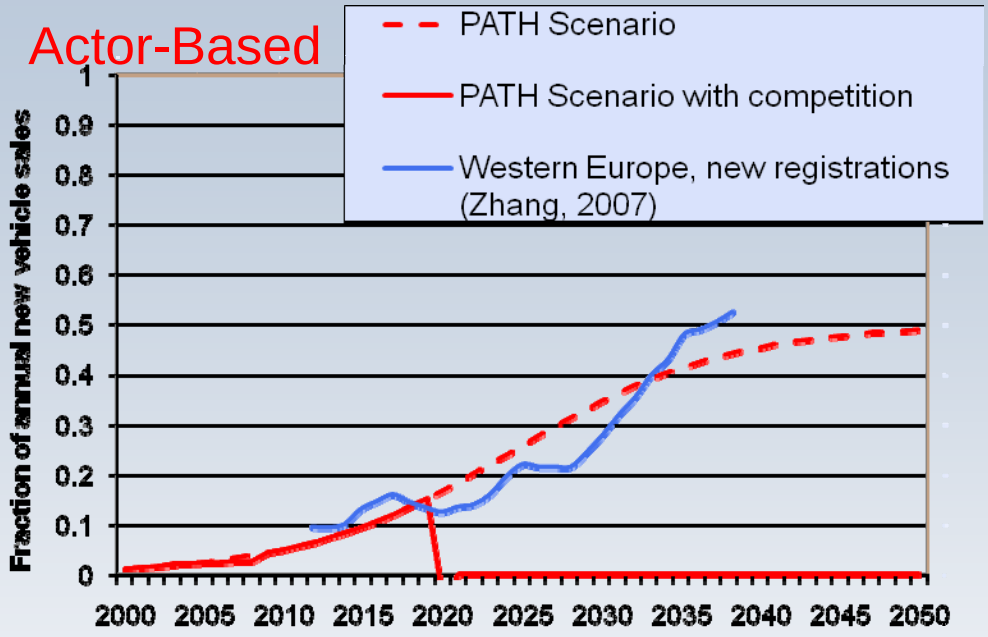


264 MMTCO$_2$e

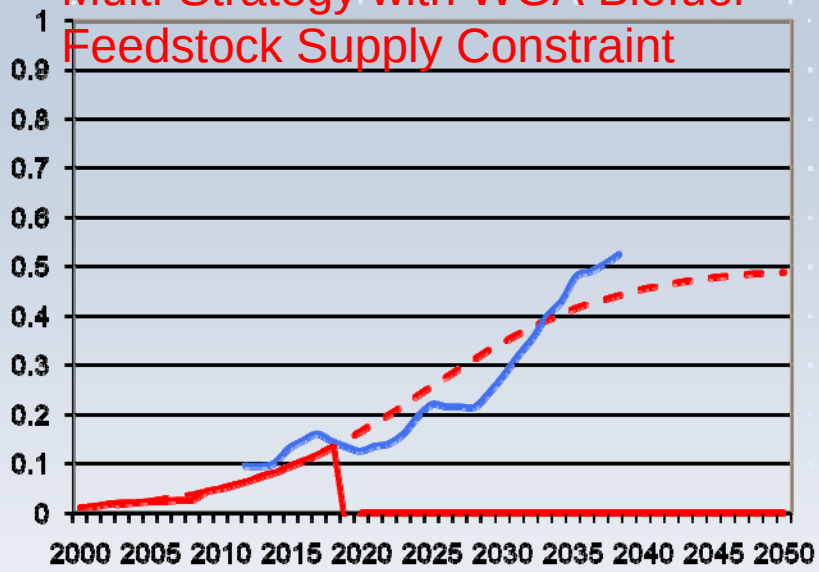
DIESEL MARKET PENETRATION

(Based On Western European Data)

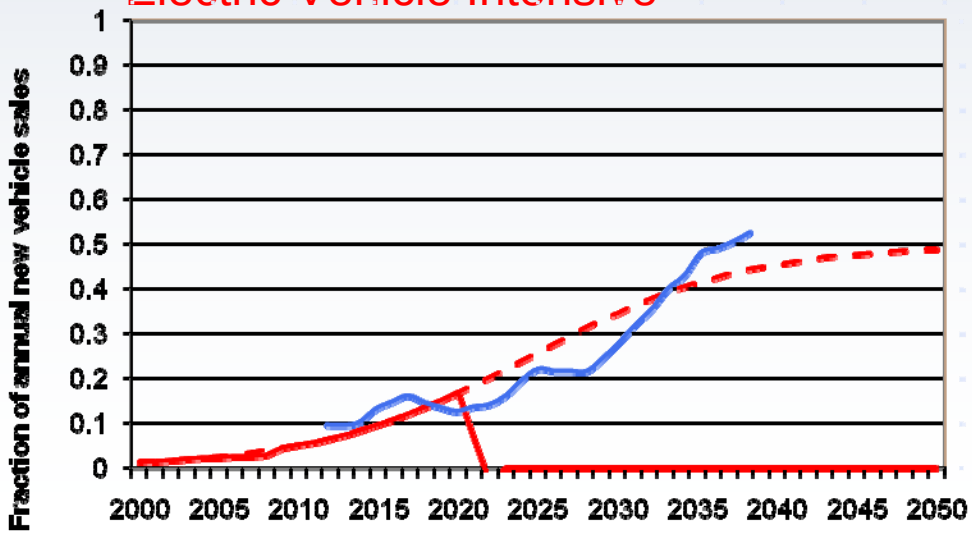
Actor-Based



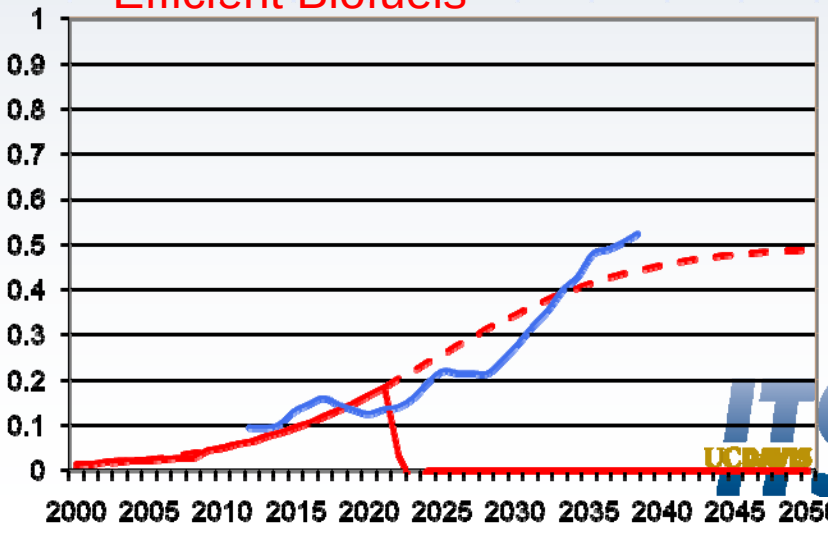
Multi-Strategy with WGA Biofuel Feedstock Supply Constraint



Electric Vehicle Intensive

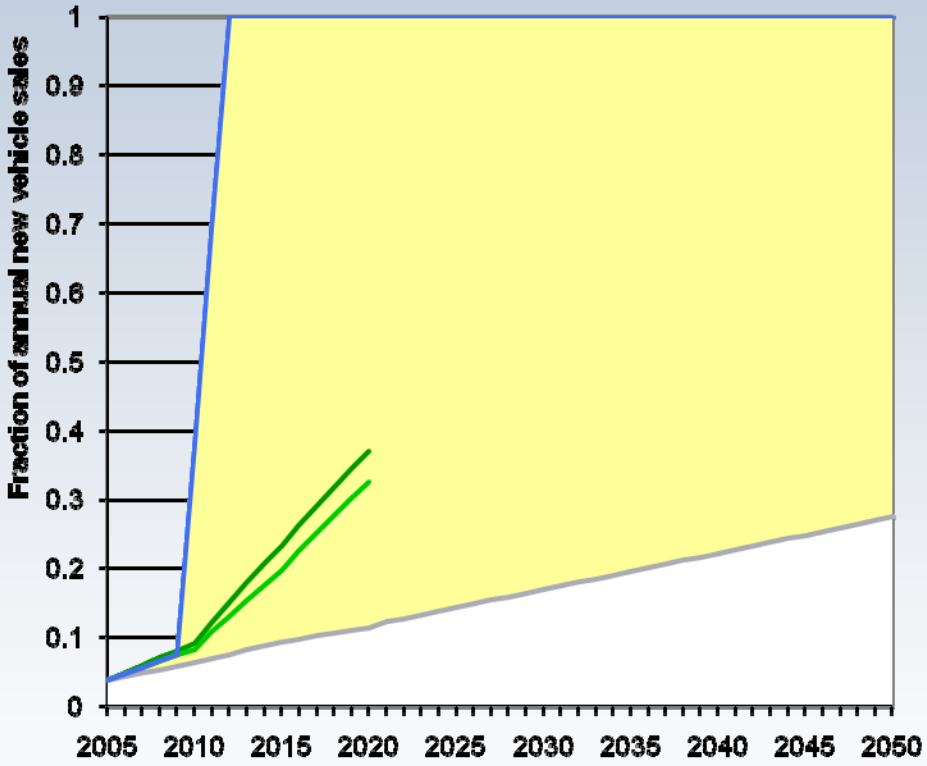


Efficient Biofuels



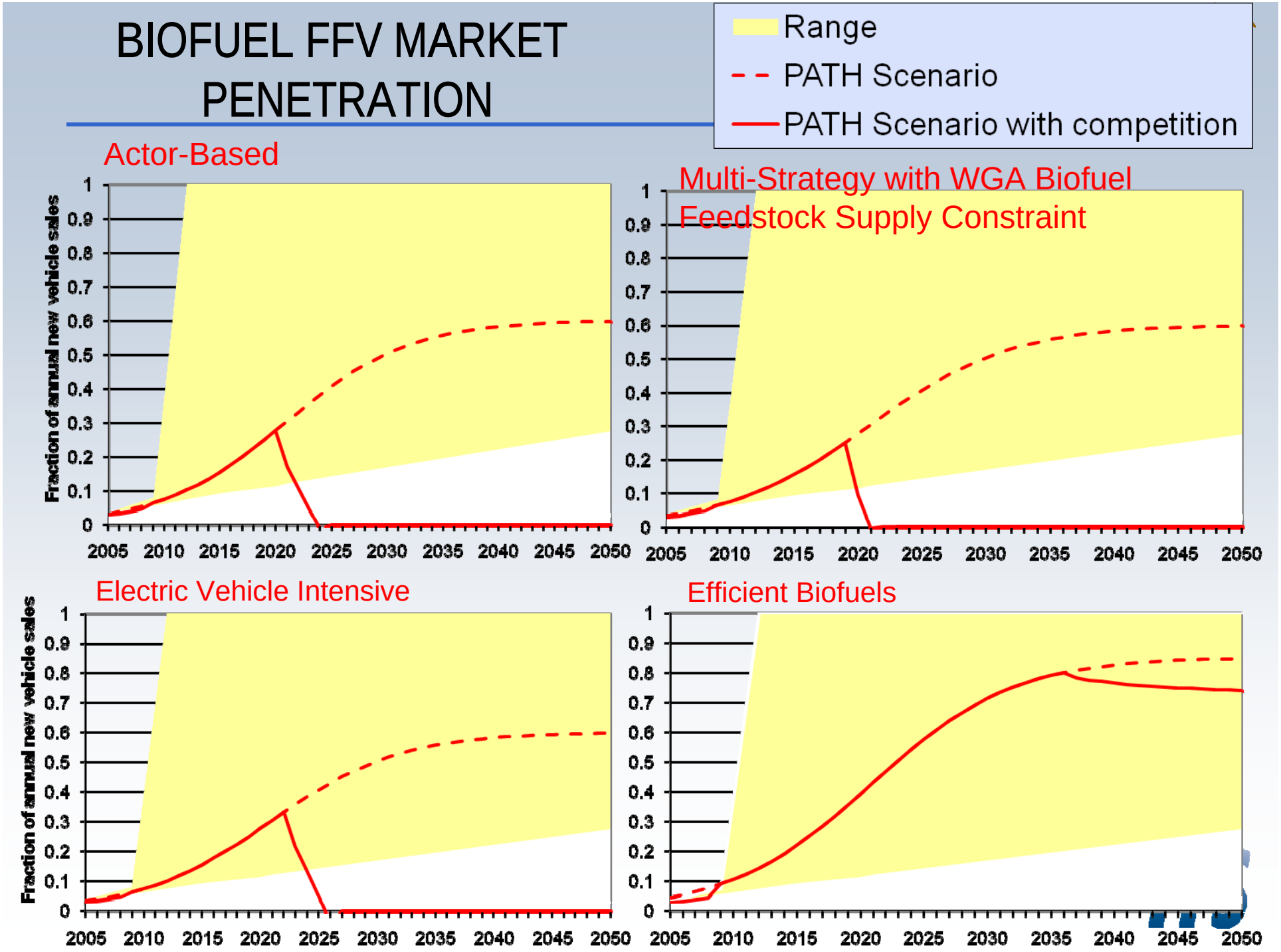
BIOFUEL FFV MARKET PENETRATION

MAX RATE FROM LIT. REVIEW

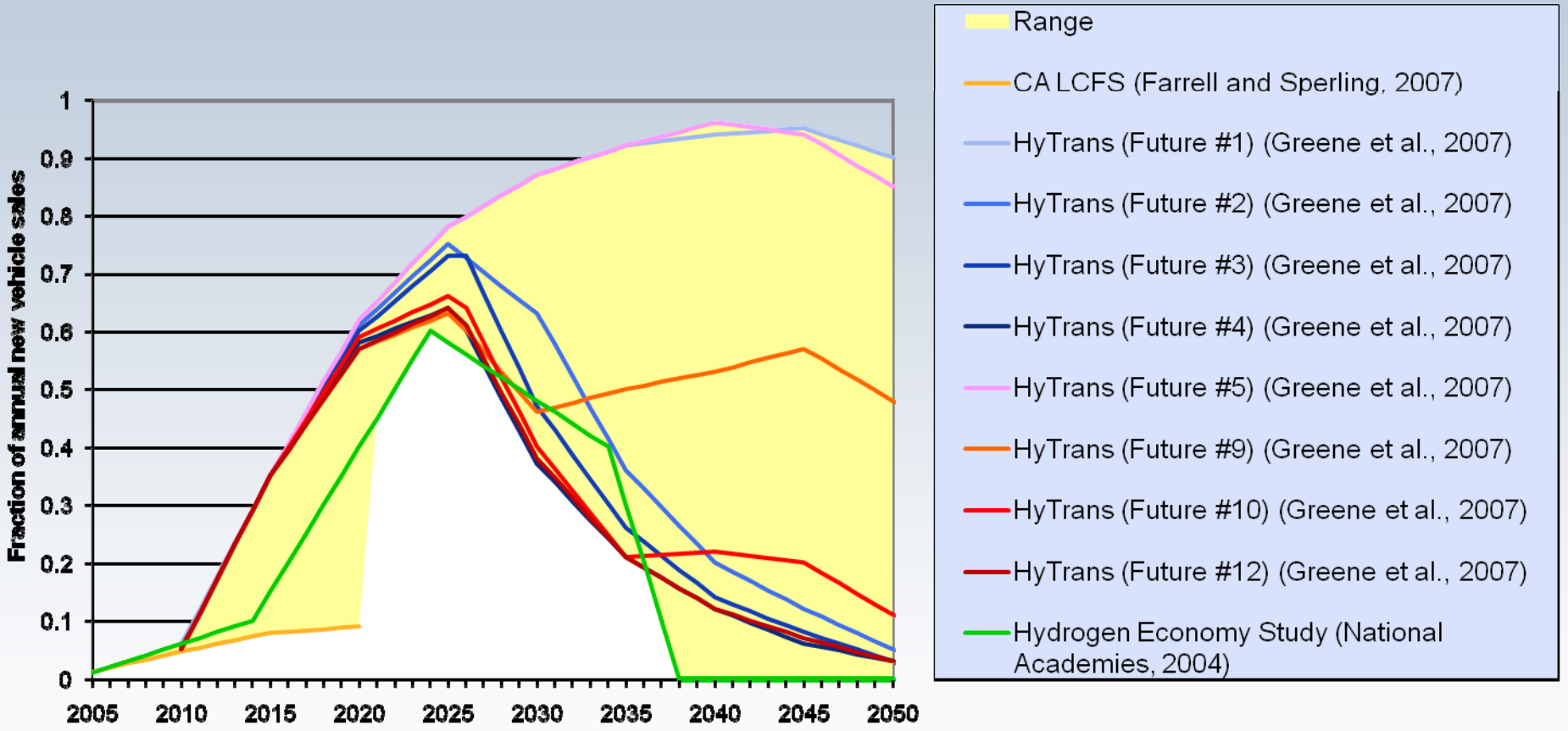


- Range
- CA LCFS (F10) (Farrell and Sperling, 2007)
- CA LCFS (G5,G10,G15,H10,H15) (Farrell and Sperling, 2007)
- CA LCFS (C5,D5,D10,F5,H5) (Farrell and Sperling, 2007)
- AB 1007 (all automakers) (Hooks and Jackson, 2007)

BIOFUEL FFV MARKET PENETRATION



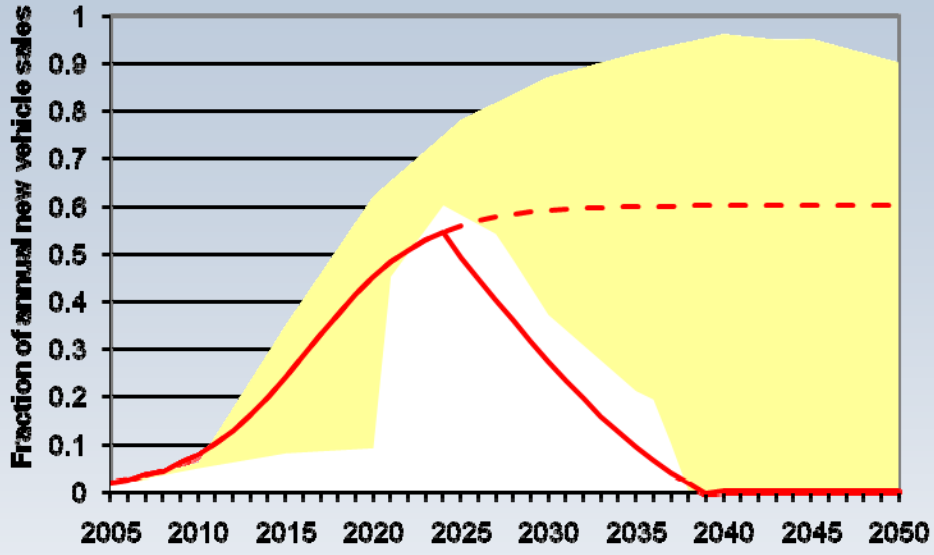
HEV MARKET PENETRATION:
MAX. RATE FROM LIT. REVIEW



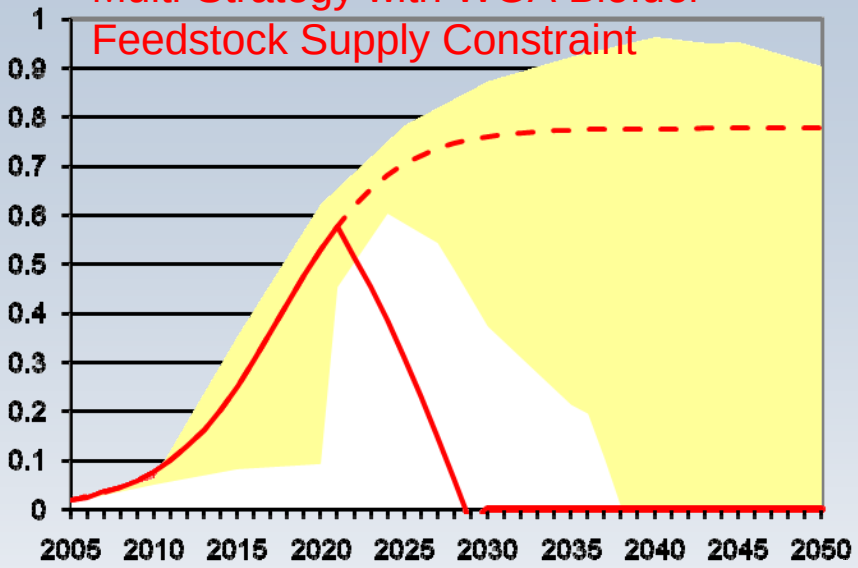
HEV MARKET PENETRATION

Range
PATH Scenario
PATH Scenario with competition

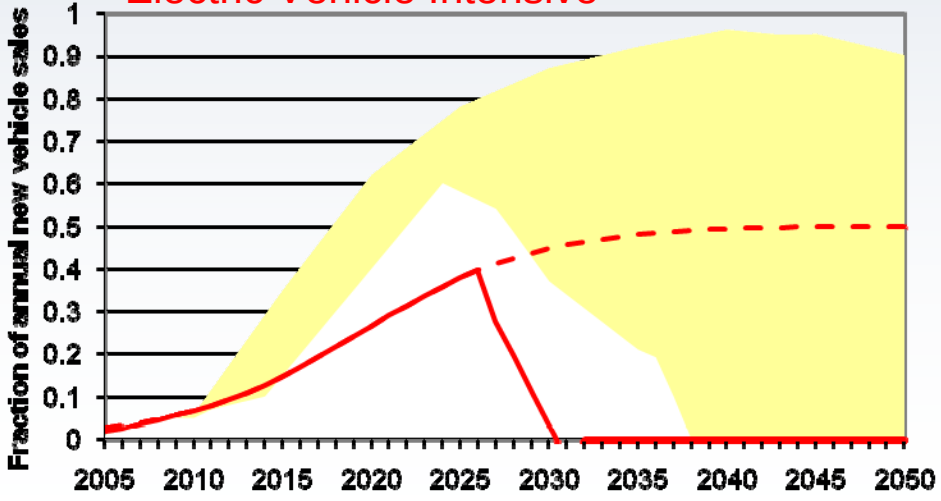
Actor-Based



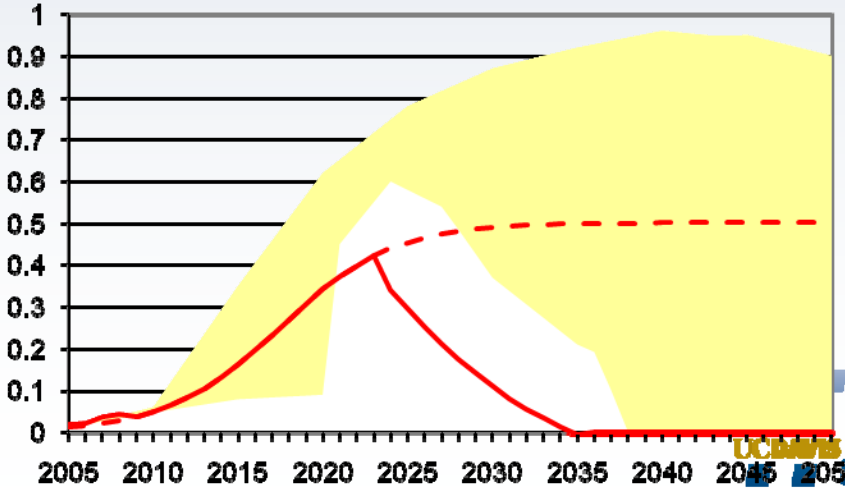
Multi-Strategy with WGA Biofuel Feedstock Supply Constraint



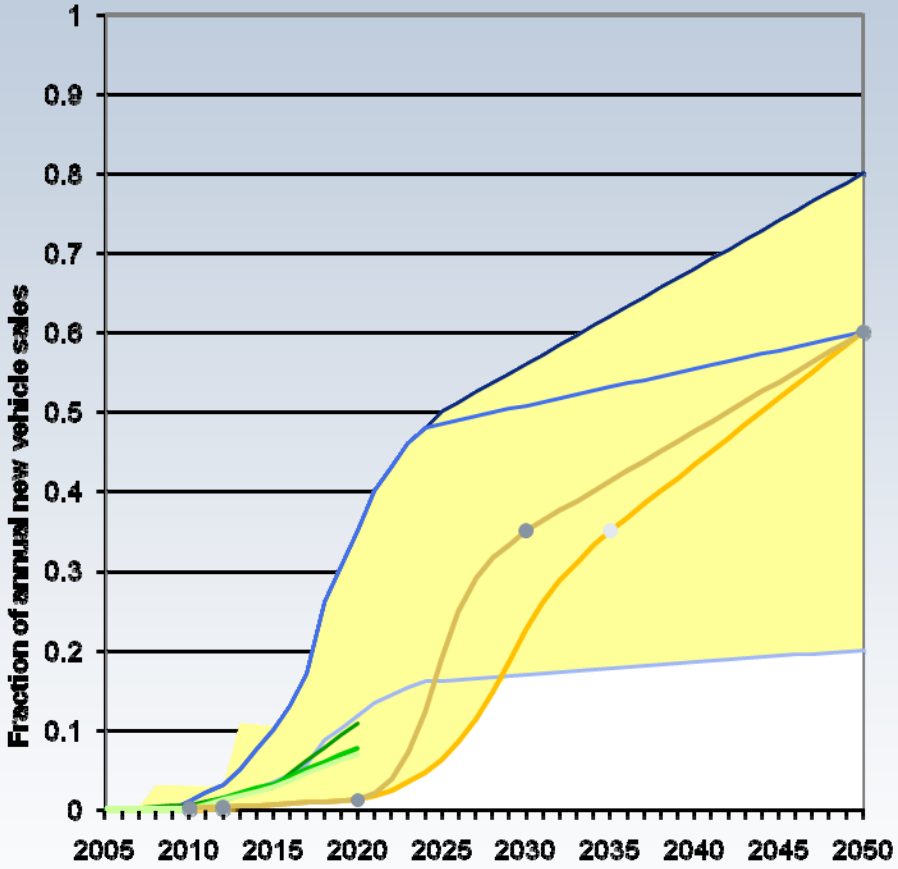
Electric Vehicle Intensive

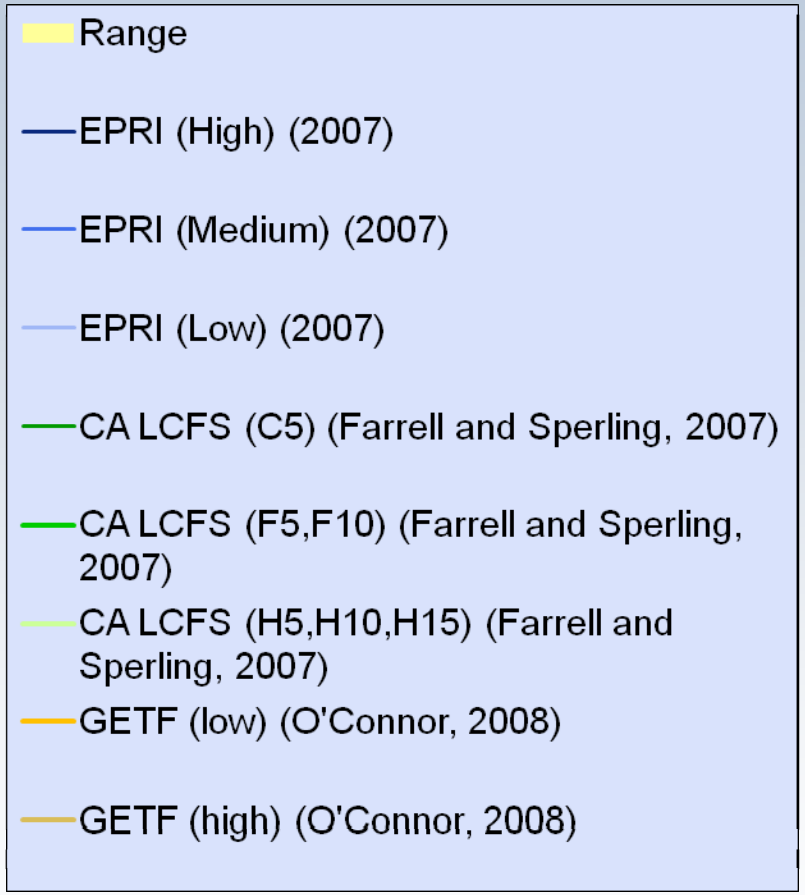


Efficient Biofuels

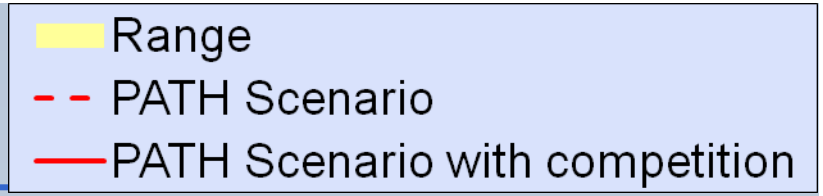


PHEV MARKET PENETRATION:
MAX RATE FROM LIT. REVIEW

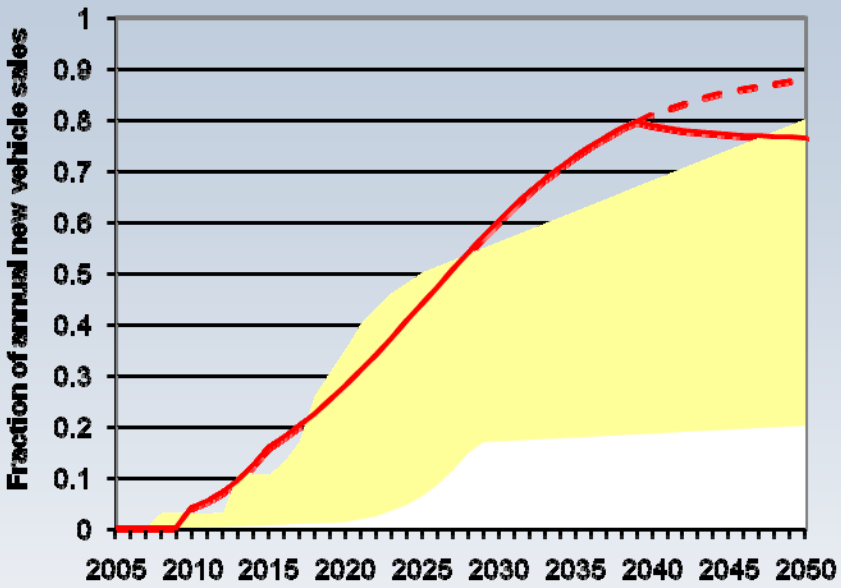




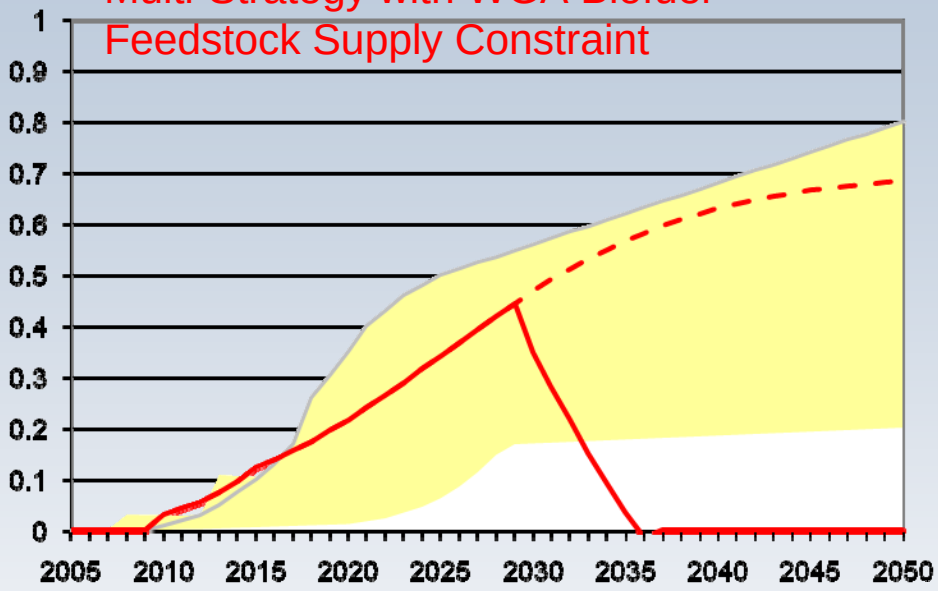
PHEV MARKET PENETRATION



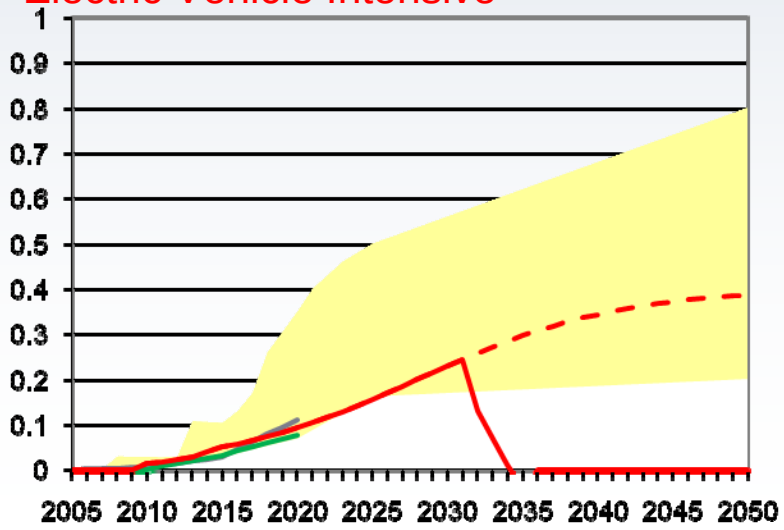
Actor-Based



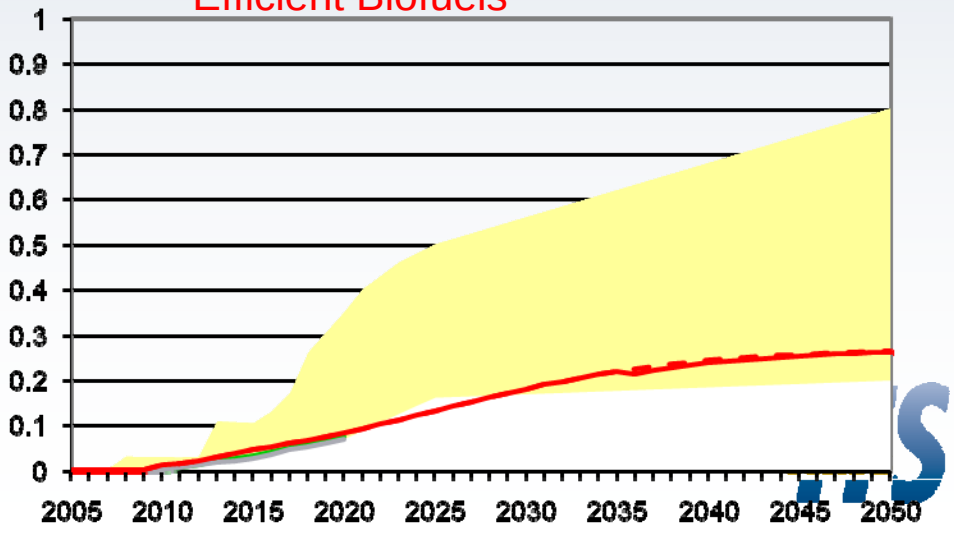
Multi-Strategy with WGA Biofuel Feedstock Supply Constraint



Electric Vehicle Intensive



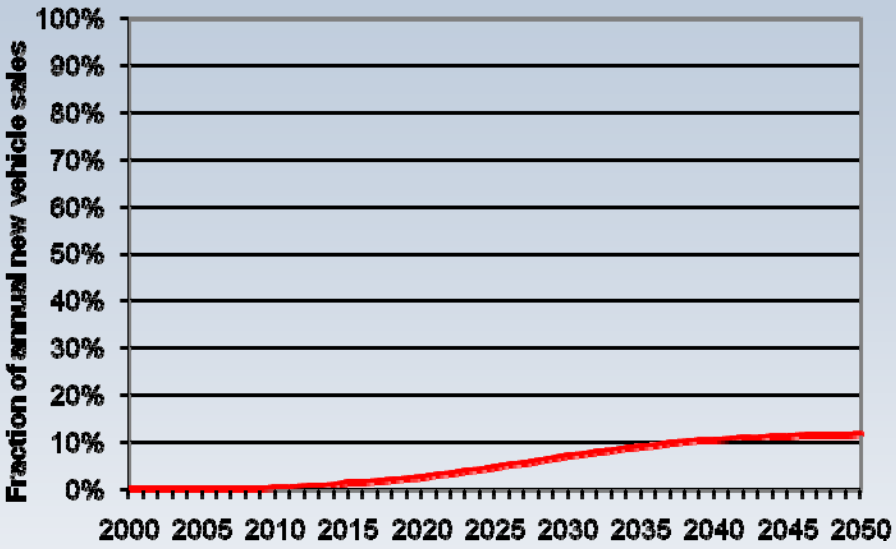
Efficient Biofuels



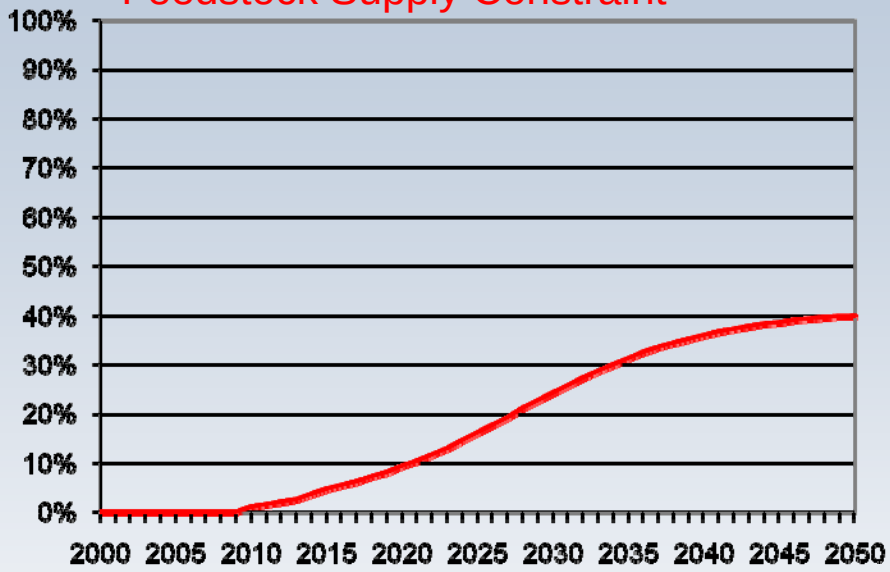
BEV MARKET PENETRATIONS

—PATH Scenario with competition

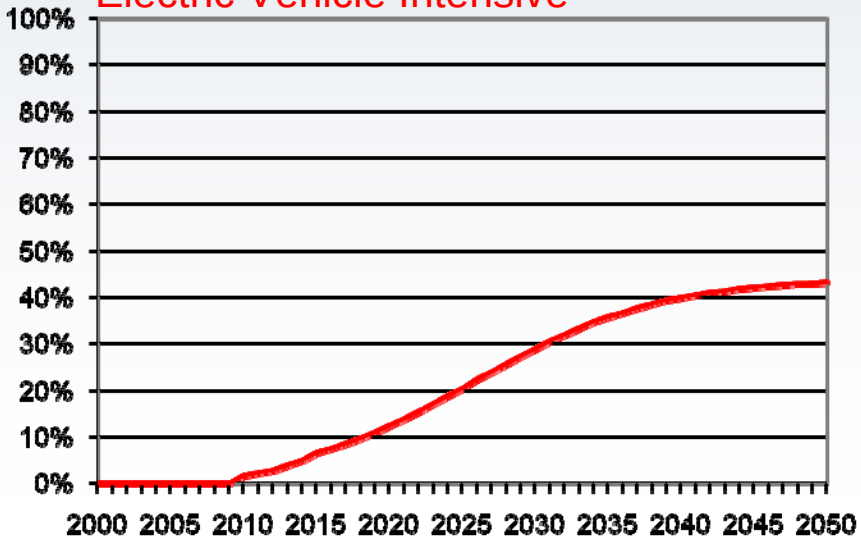
Actor-Based



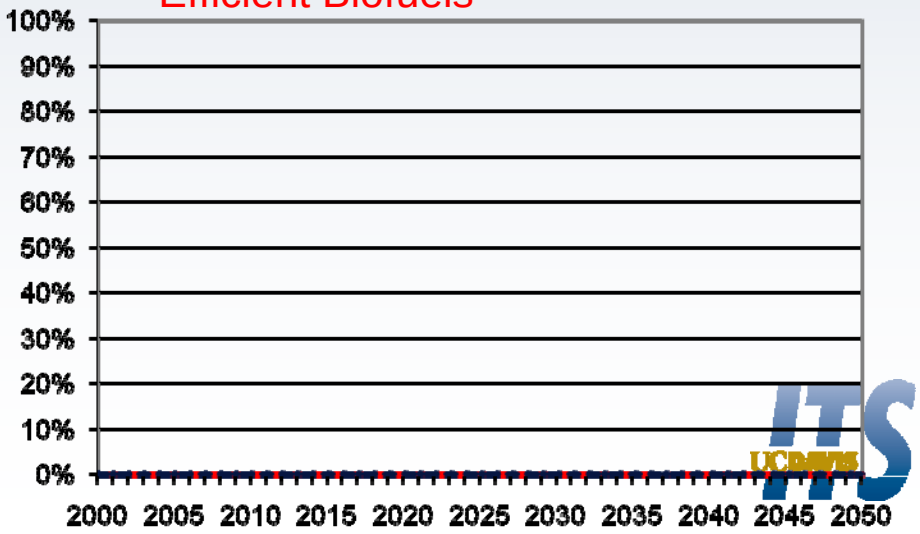
Multi-Strategy with WGA Biofuel Feedstock Supply Constraint



Electric Vehicle Intensive

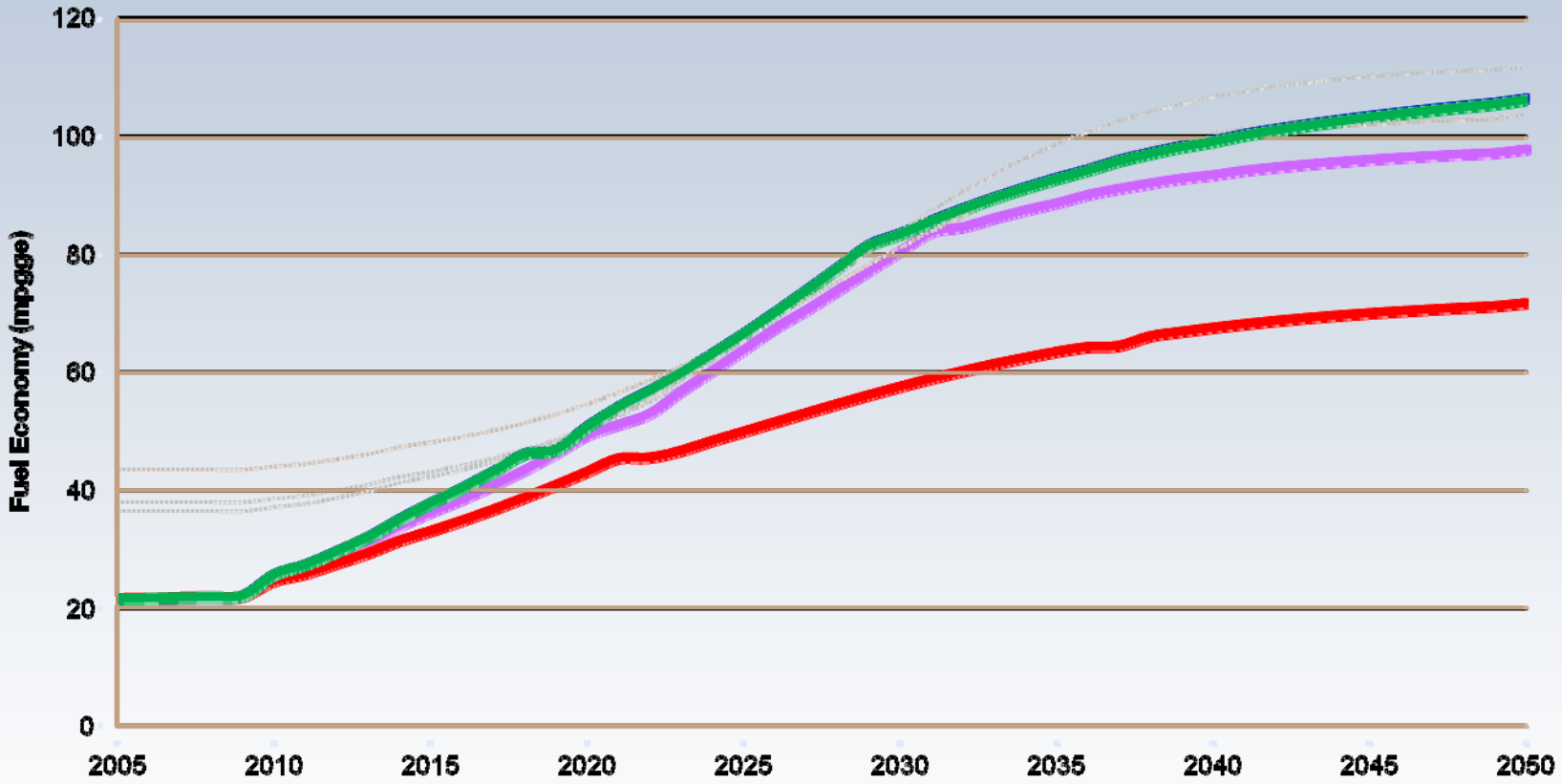


Efficient Biofuels



FUEL ECONOMY IMPROVEMENT:
2005 TO 2050 SCENARIO (MAX. FEASIBLE)

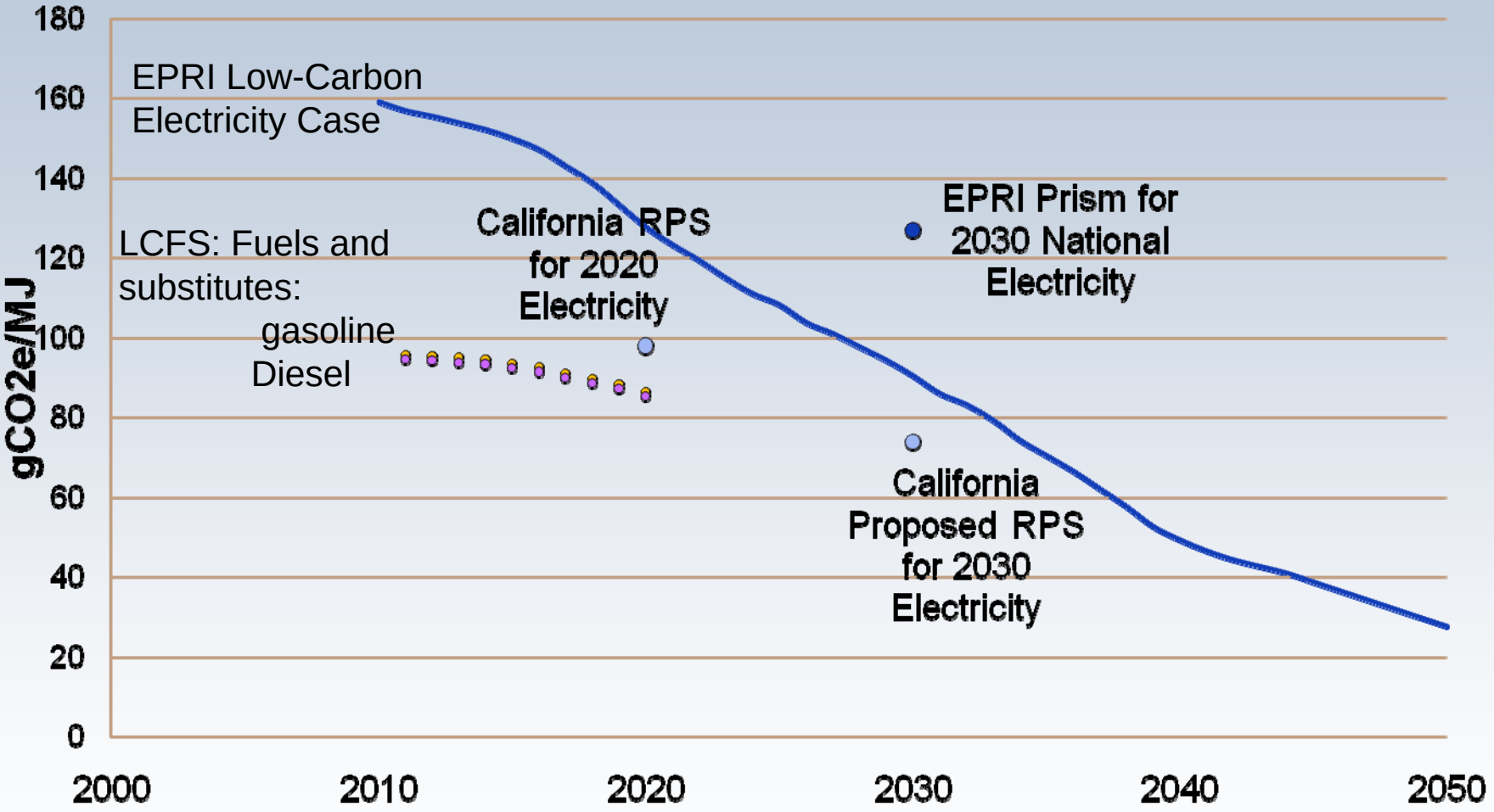
Sales-weighted Average On-road New Vehicle Fuel Economy (cars and trucks)



Multi-Strategy with WGA Biofuel Feedstock Supply Constraint
Actor-Based
Efficient Biofuels
Electric Vehicle Intensive

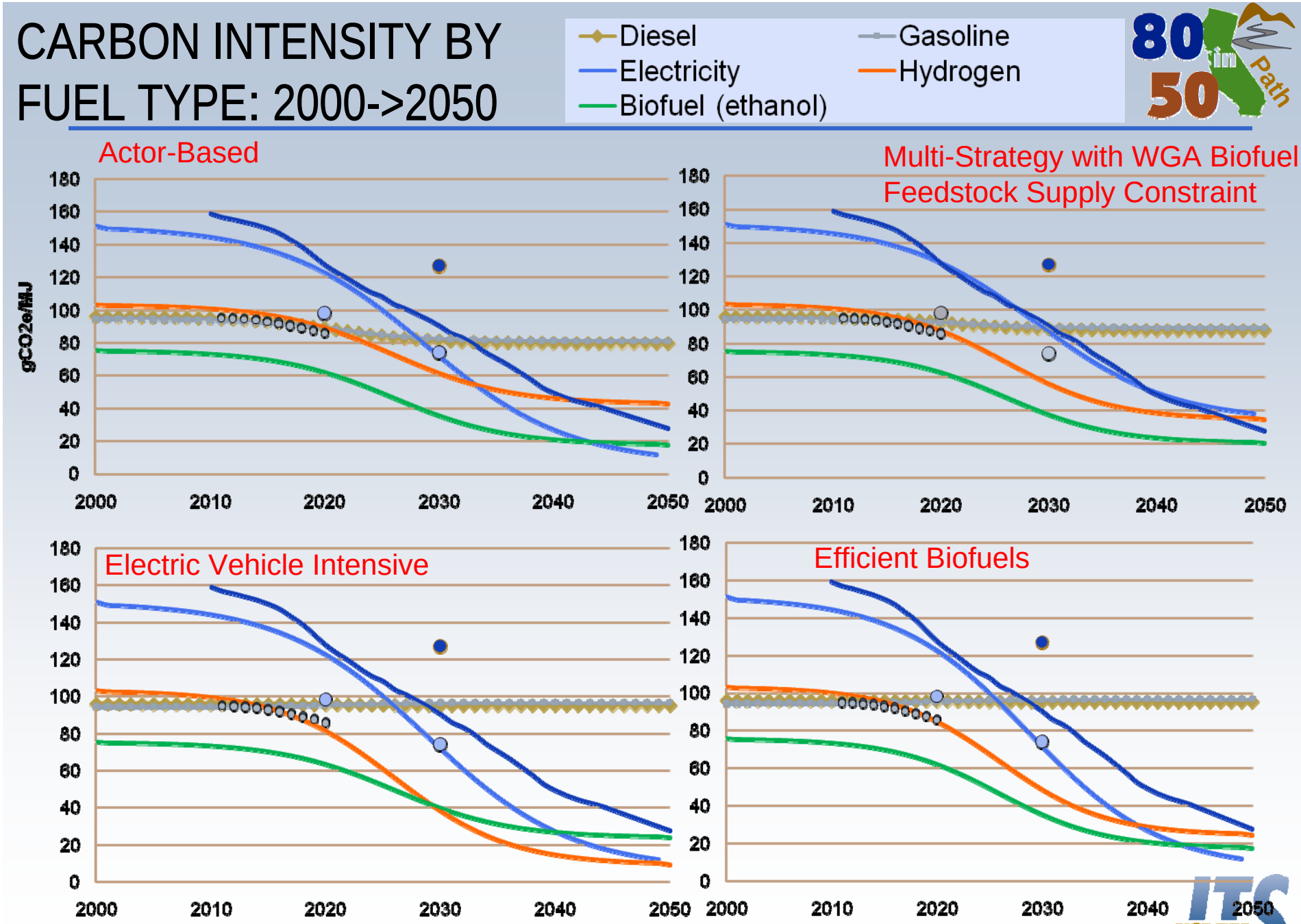
On-road is approximately 85% of EPA estimated fuel economy

CARBON INTENSITY BY FUEL TYPE : WAYPOINTS



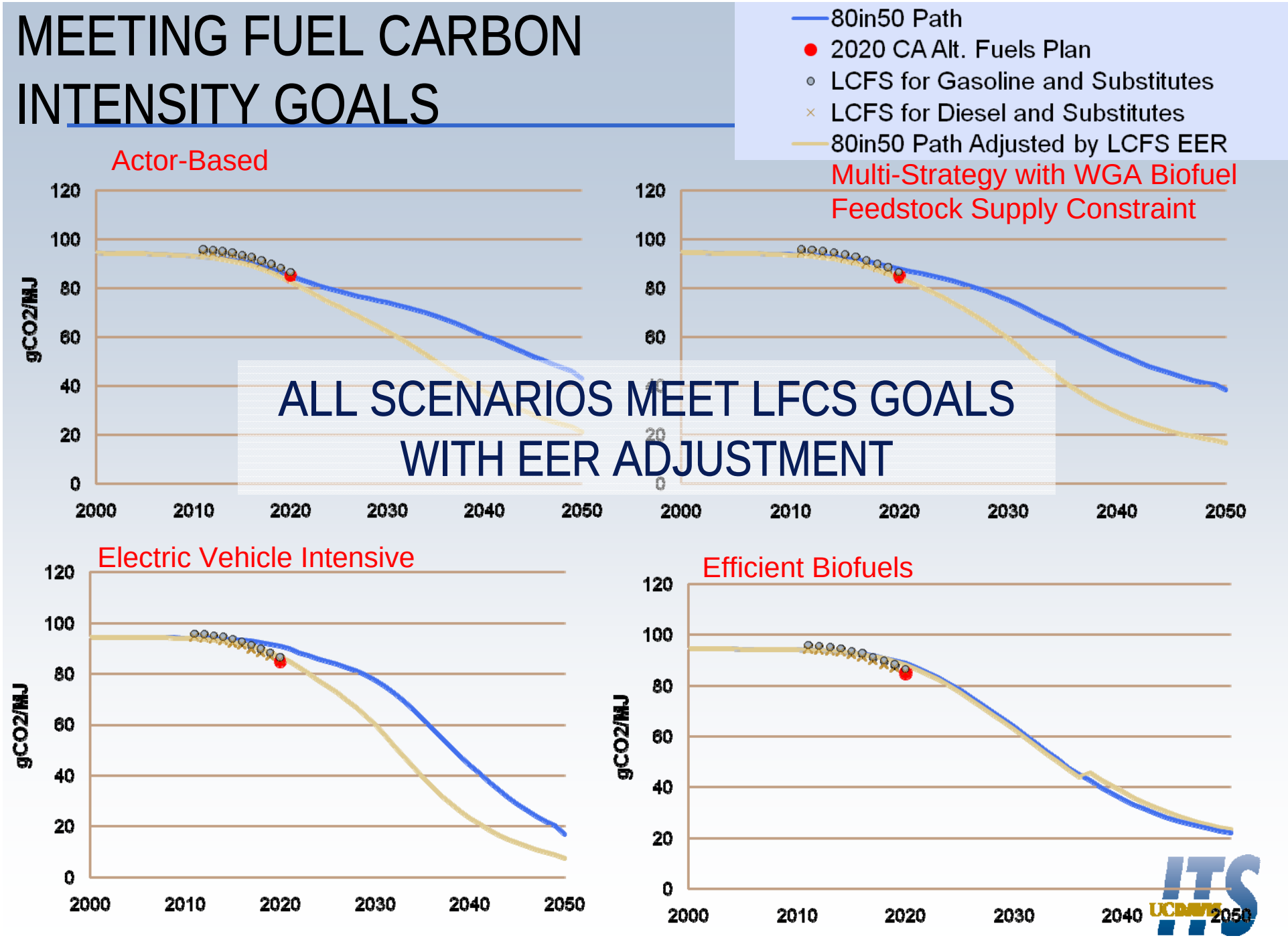
Carbon intensity for RPS weigh points calculated assuming renewables replace highest-carbon alternatives

CARBON INTENSITY BY FUEL TYPE: 2000->2050

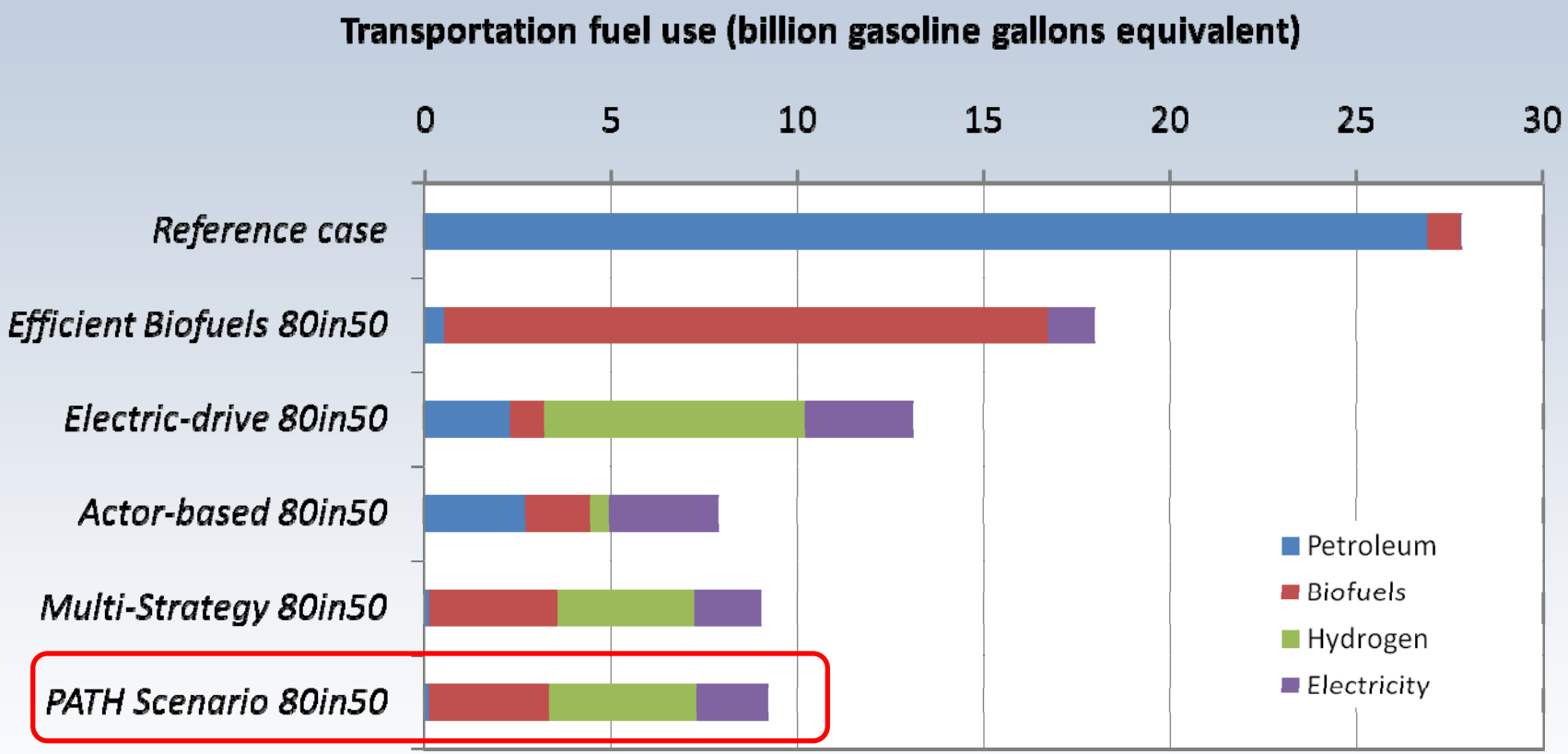


Carbon intensity for RPS waypoints calculated assuming renewables replace highest-carbon alternatives

MEETING FUEL CARBON INTENSITY GOALS

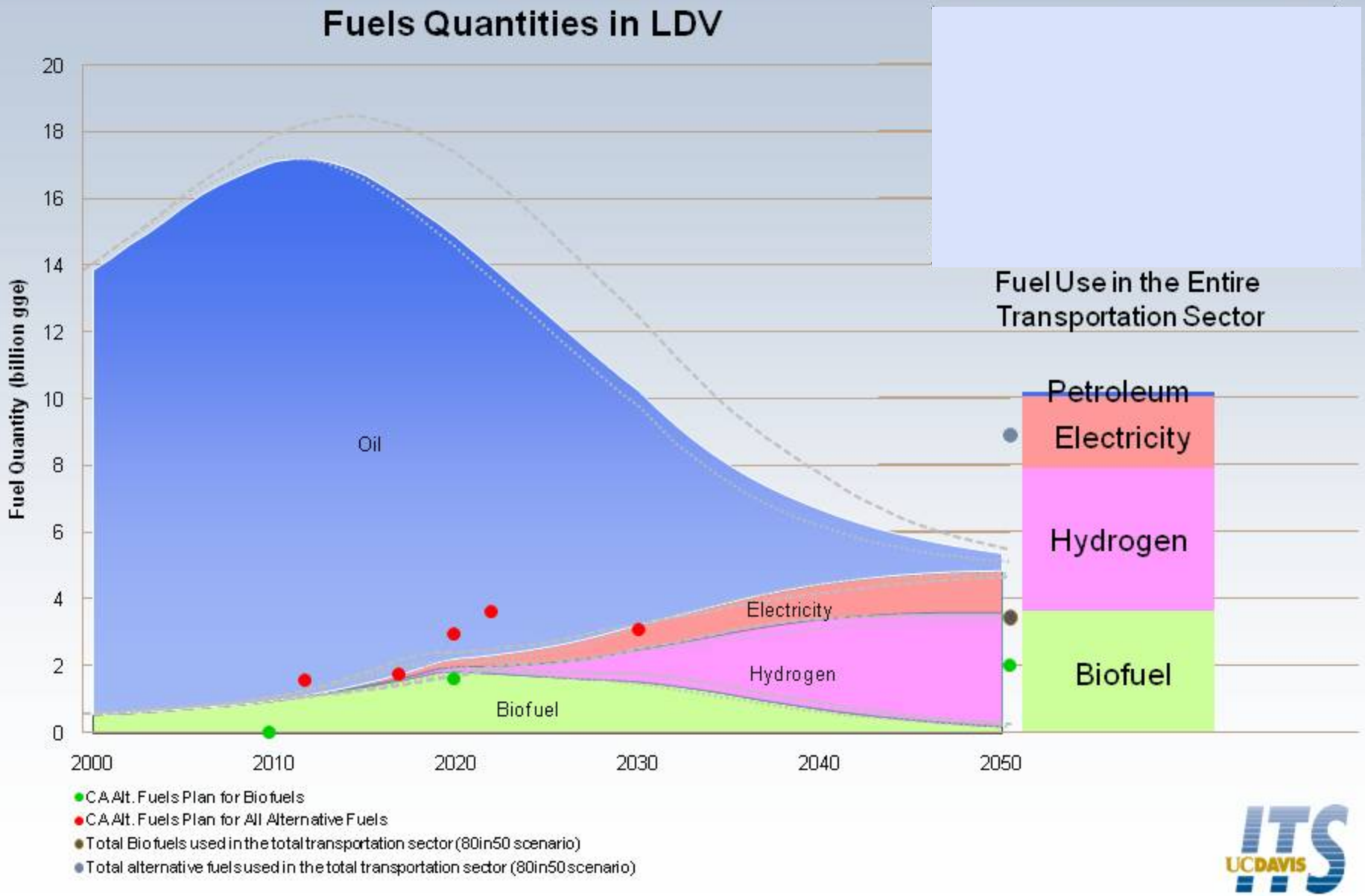


The PATH Scenario for 2050: comparison with other 80in50 Scenarios



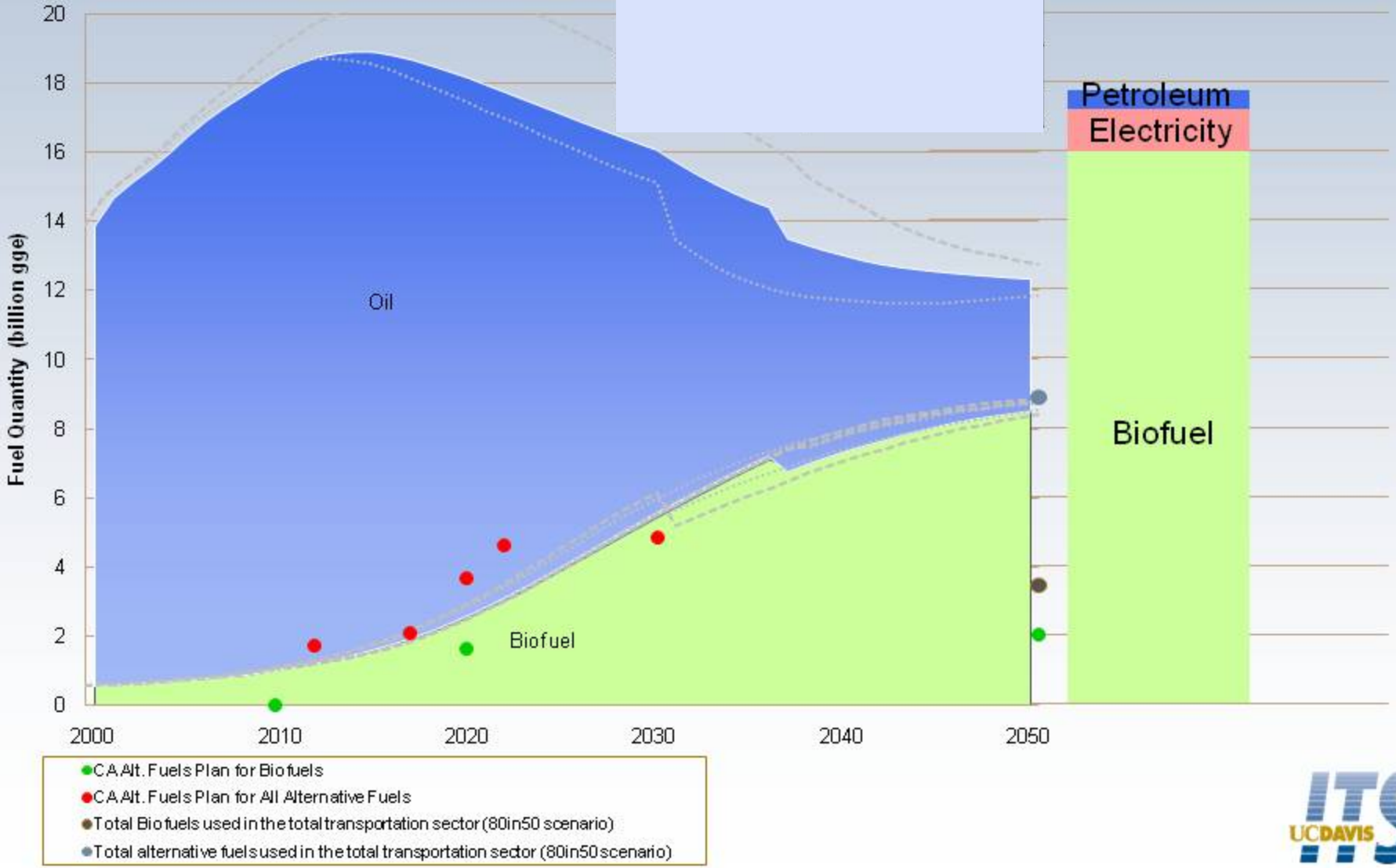
FUEL QUANTITIES FOR LDV AND THE ENTIRE TRANS. SECTOR

Multi-Strategy with WGA Biofuel Feedstock Supply Constraint



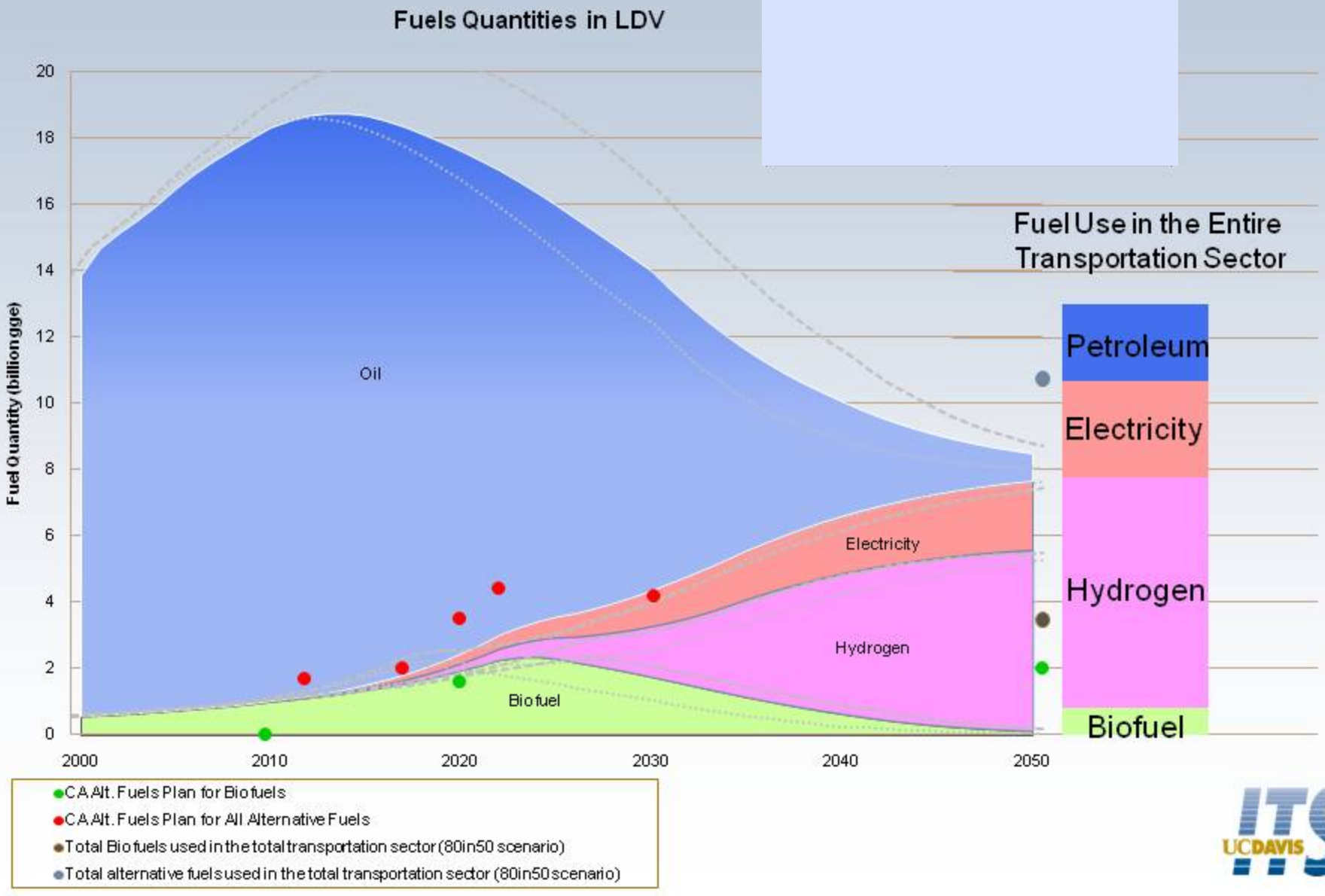
FUEL QUANTITIES FOR LDV AND THE ENTIRE TRANS. SECTOR

Efficient Biofuels



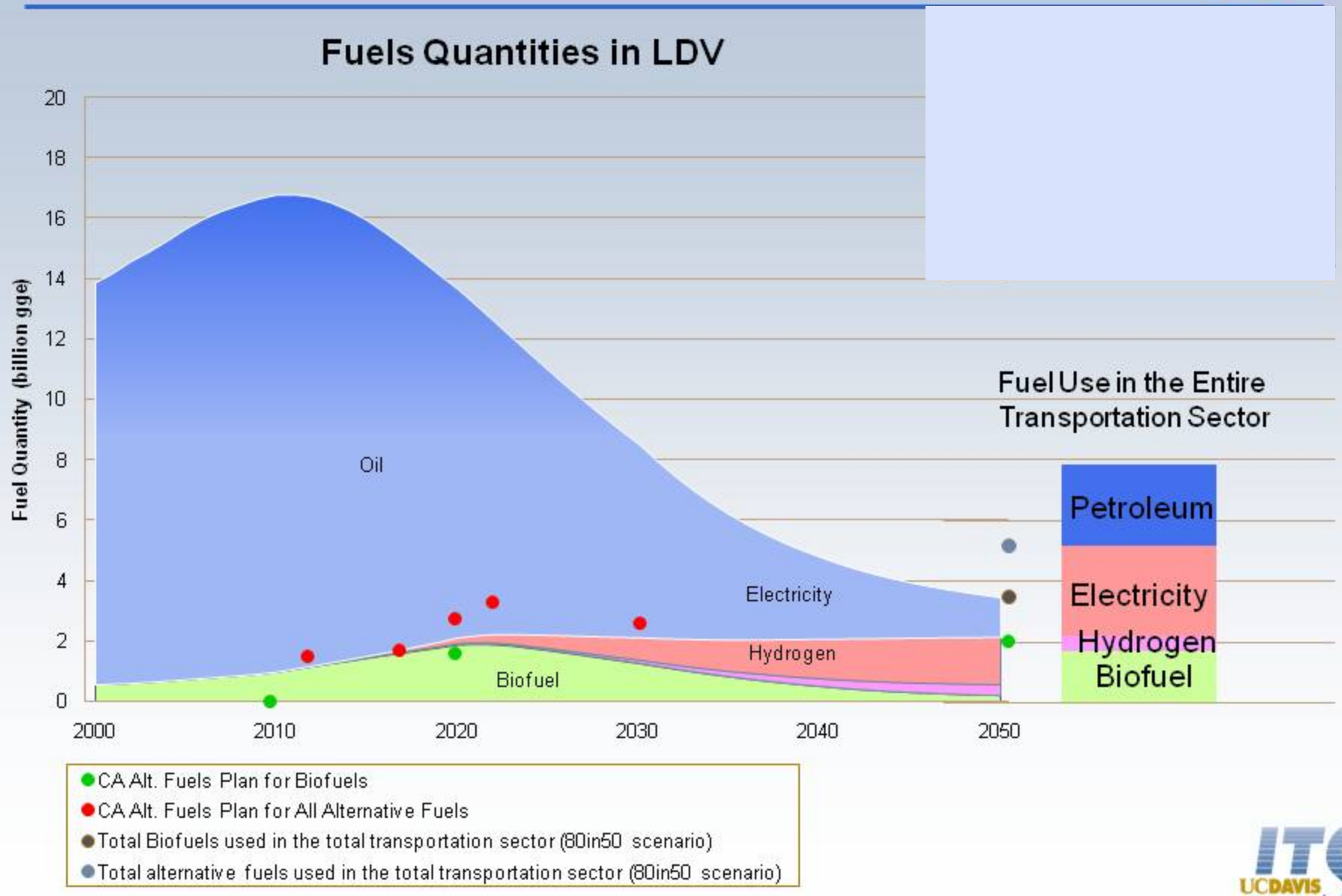
FUEL QUANTITIES FOR LDV AND THE ENTIRE TRANS. SECTOR

Electric Vehicle Intensive



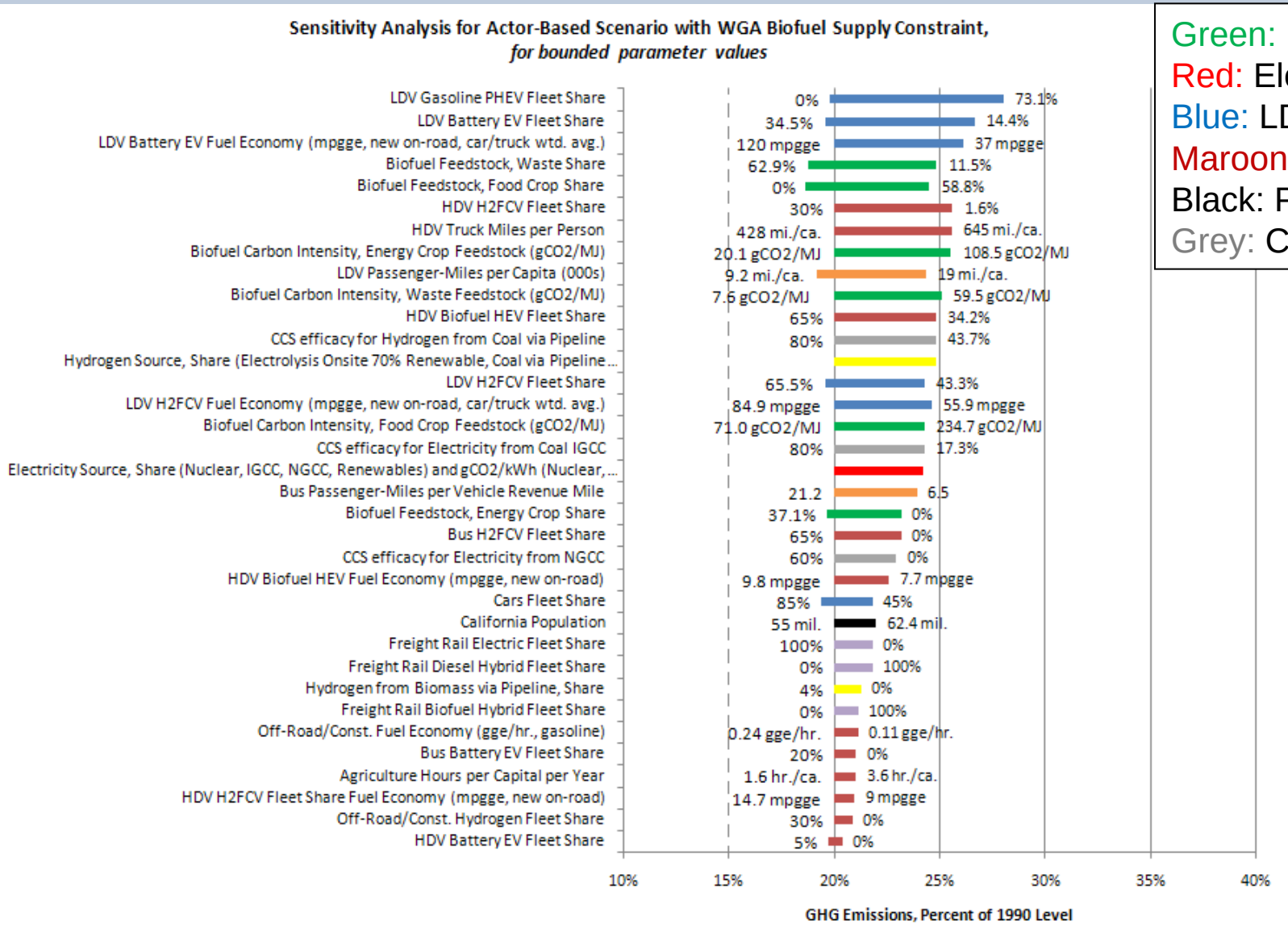
FUEL QUANTITIES FOR LDV AND THE ENTIRE TRANS. SECTOR

Actor-Based



SENSITIVITY OF THE 80in50 LEVERS MODEL

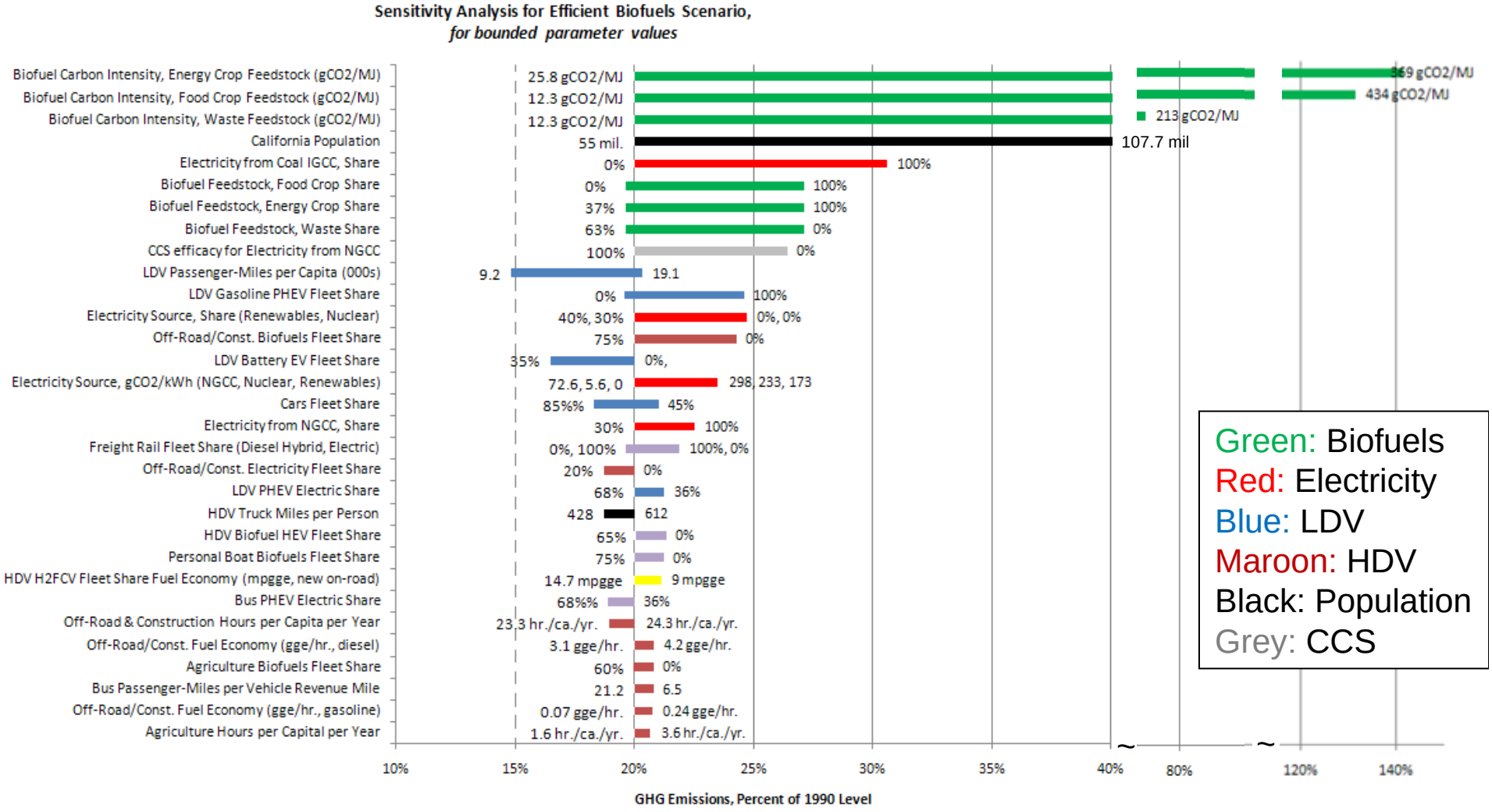
Sensitivity Analysis: Multi-Strategy w/ WGA Biofuel Supply Constraint



Green: Biofuels
Red: Electricity
Blue: LDV
Maroon: HDV
Black: Population
Grey: CCS

SENSITIVITY OF THE 80in50 LEVERS MODEL

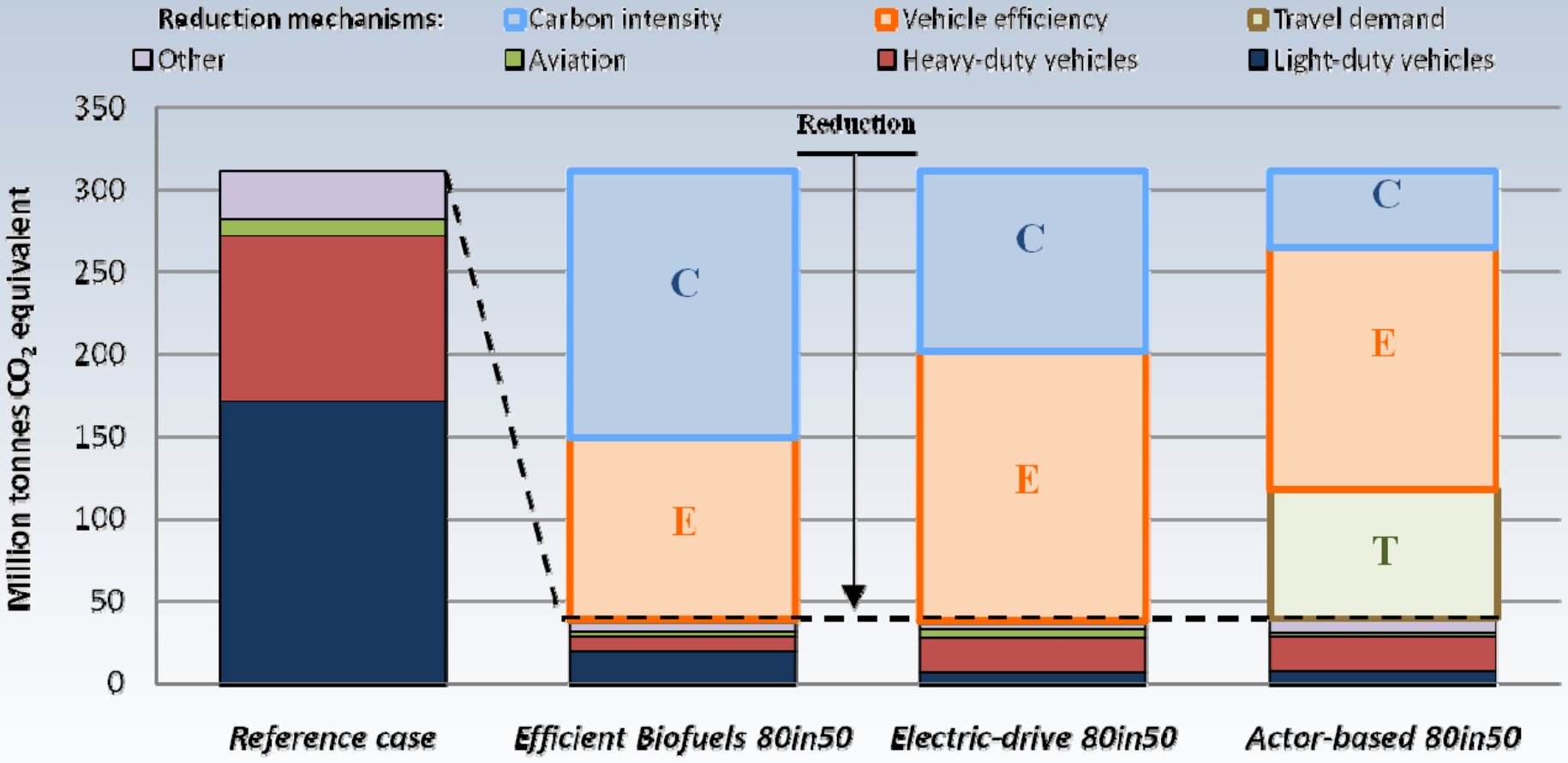
Sensitivity Analysis: Efficient Biofuels Scenario



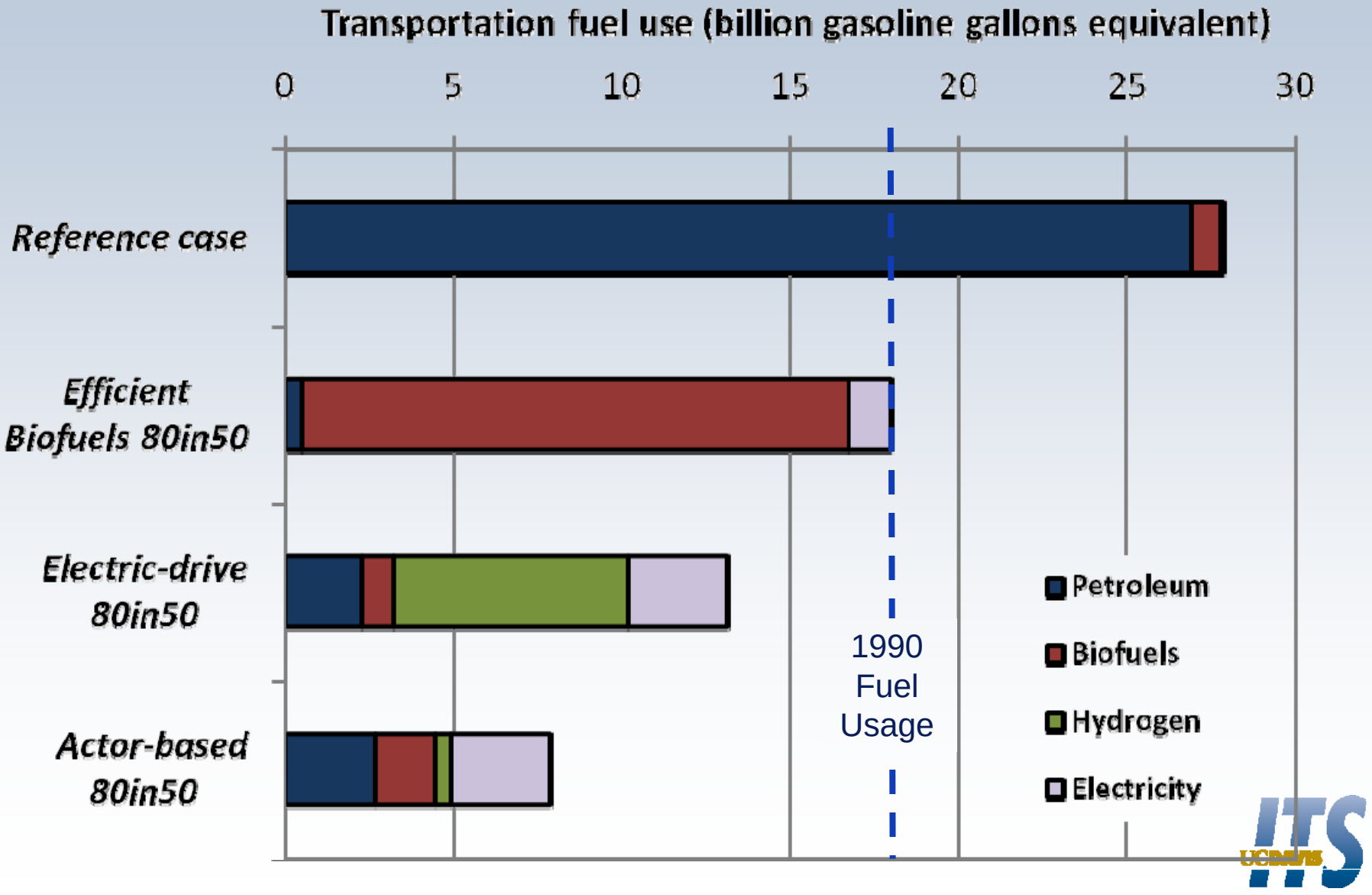
80in50 Scenarios

		% of miles traveled by fuel type				Relative Kaya Parameter Value	
		Petroleum	Biofuels	Hydrogen	Electricity	Energy Intensity (1990=100%)	Carbon Intensity (1990=100%)
Efficient Biofuels 80in50	LDV	0%	83%	0%	17%	33%	18%
	HDV	0%	95%	0%	5%	60%	15%
	Aviation	25%	75%	0%	0%	50%	40%
	Rail	0%	93%	0%	7%	69%	18%
	Marine/Ag/Off-road	23%	77%	0%	0%	45%	36%
	All subsectors combined	2%	83%	0%	15%	42%	20%
	Total # of miles	*1,083.8*	*billion*				
Electric-drive 80in50	LDV	0%	0%	60%	40%	21%	9%
	HDV	21%	0%	56%	23%	47%	47%
	Aviation	50%	50%	0%	0%	50%	63%
	Rail	0%	0%	0%	100%	42%	7%
	Marine/Ag/Off-road	4%	32%	37%	27%	45%	26%
	All subsectors combined	3%	3%	55%	39%	31%	26%
	Total # of miles	*1,082.9*	*billion*				
Actor-based 80in50	LDV	20%	5%	10%	64%	10%	32%
	HDV	25%	13%	9%	53%	48%	56%
	Aviation	30%	70%	0%	0%	42%	46%
	Rail	11%	3%	0%	87%	44%	17%
	Marine/Ag/Off-road	42%	21%	9%	27%	36%	59%
	All subsectors combined	21%	9%	8%	62%	24%	45%
	Total # of miles	*843.4*	*billion*				

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