The Transition to Electric Drive in California
(and the Rest of the US)

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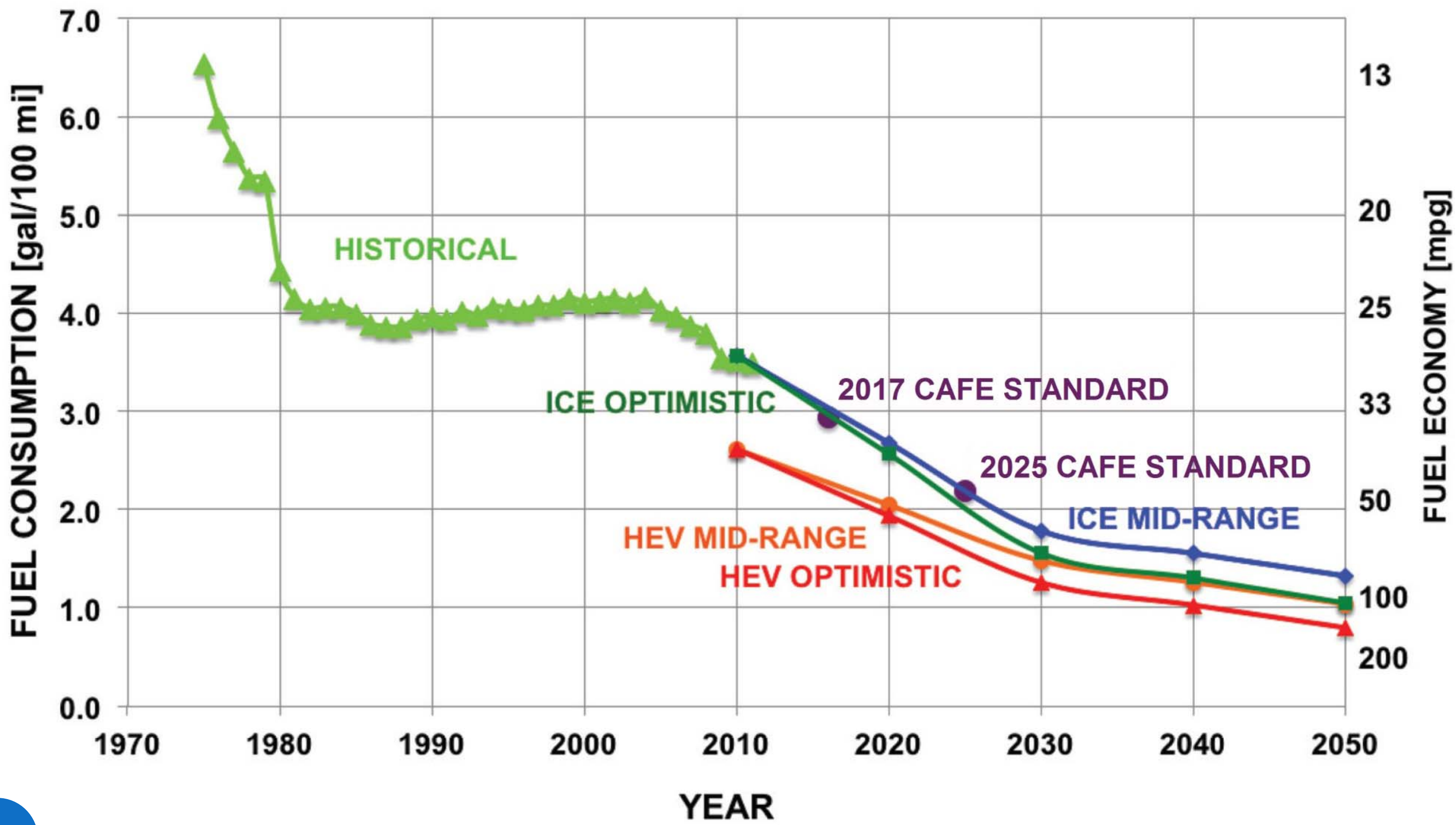
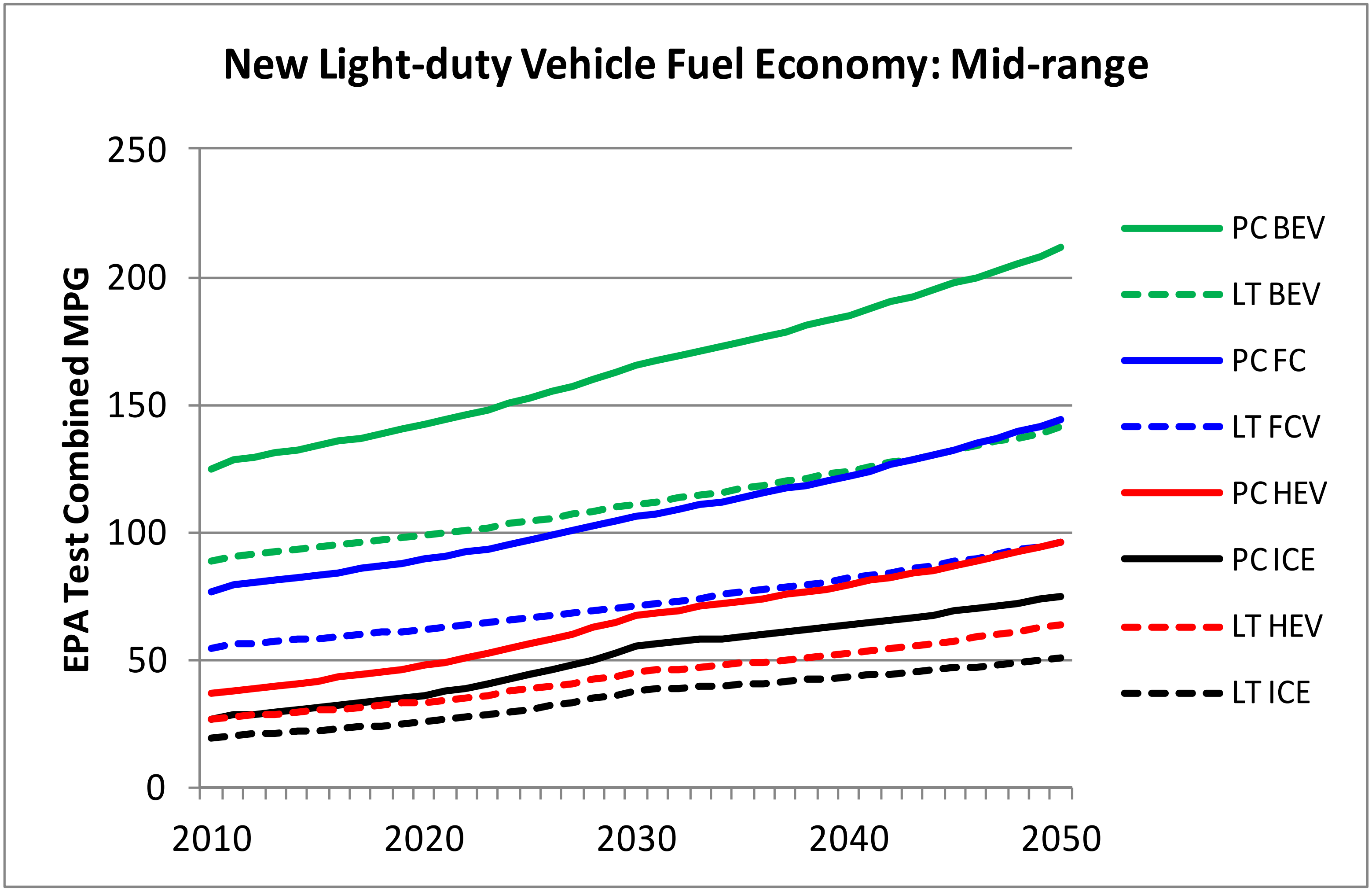
The purpose of our study for the ICCT was to quantify the costs and benefits of a transition to electric drive in California and work towards a new economic paradigm for energy transitions.

- How much is the transition likely to cost?
- How large are the benefits likely to be?
- How long will it take?
- What is the role of the ZEV mandates?
- How important is refueling/recharging infrastructure?
- How important are policies in the rest of the US/World?
- What about uncertainty?
- Used the model, technology and economic

A key premise of the NRC study was that fuel economy & GHG emissions standards would be tightened through 2050.



All technologies make major improvements.



How are these fuel economies achieved? Reduced load + improved drivetrain efficiency.

TABLE 2.9 Details of the Potential Evolution of a Midsize Car, 2007-2050

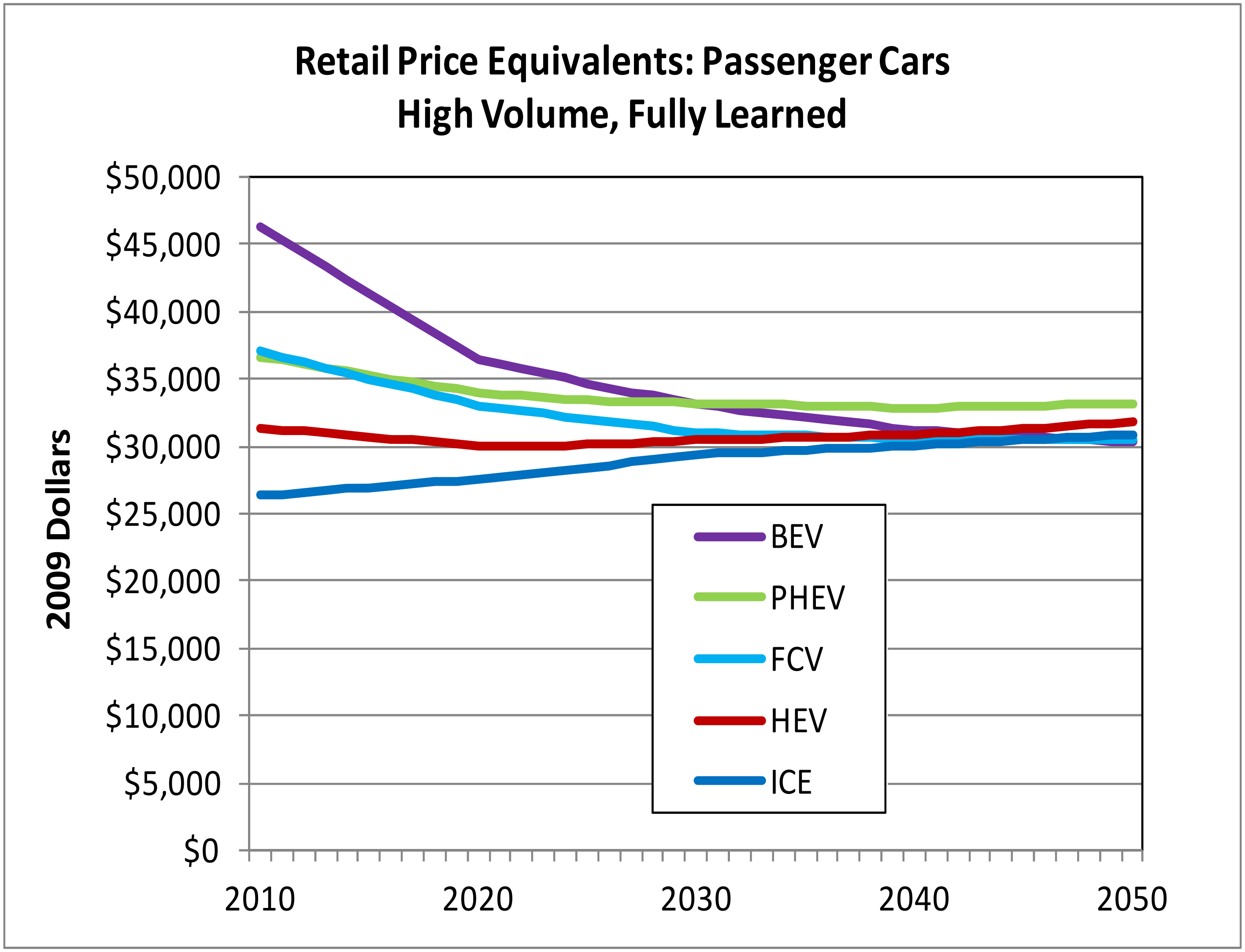
Conventional Drivetrain	Baseline	2030 Midrange	2030 Optimistic	2050 Midrange	2050 Optimistic
Engine type	Baseline	EGR DI turbo	EGR DI turbo	EGR DI turbo	EGR DI turbo
Engine power, kW	118	90	84	78	68
Transmission type	6-sp auto	8-sp auto	8-sp auto	8-sp auto	8-sp auto
Drivetrain improvements					
Brake energy recovered through alternator, %	—[a]	14.1	14.1	14.1	14.1
Reduction in transmission losses, %	n/a	26	30	37	43
Transmission efficiency, %	87.6	91	91	92	93
Reduction in torque converter losses, %	n/a	69	75	63	88
Torque converter efficiency, %	93.2	98	99	99	99
Reduction in pumping losses, %	n/a	74	76	80	83
Reduction in friction losses, %	n/a	39	44	53	60
Reduction in accessory losses, %	n/a	21	25	30	36
% increase in indicated efficiency	n/a	5.6	6.5	10.6	15.6
Indicated efficiency, %	36.3	38.4	38.7	40.2	42
Brake thermal efficiency, %	20.9	29.6	30.3	32.5	34.9
Load changes					
% reduction in CdA	n/a	15	24	29	37
CdA (m^2)	7.43	6.31	5.64	5.29	4.68
% reduction in Crr	n/a	23	31	37	43
Crr	0.0082	0.0063	0.0057	0.0052	0.0047
% reduction in curb weight	n/a	20	25	30	40
Curb weight, lb	3325	2660	2494	2328	1995
Fuel economy, test mpg	32.1	65.6[b]	74.9	88.5	111.6

NOTE: All conventional drivetrains have stop-start systems and advanced alternators that can capture energy to drive accessories.

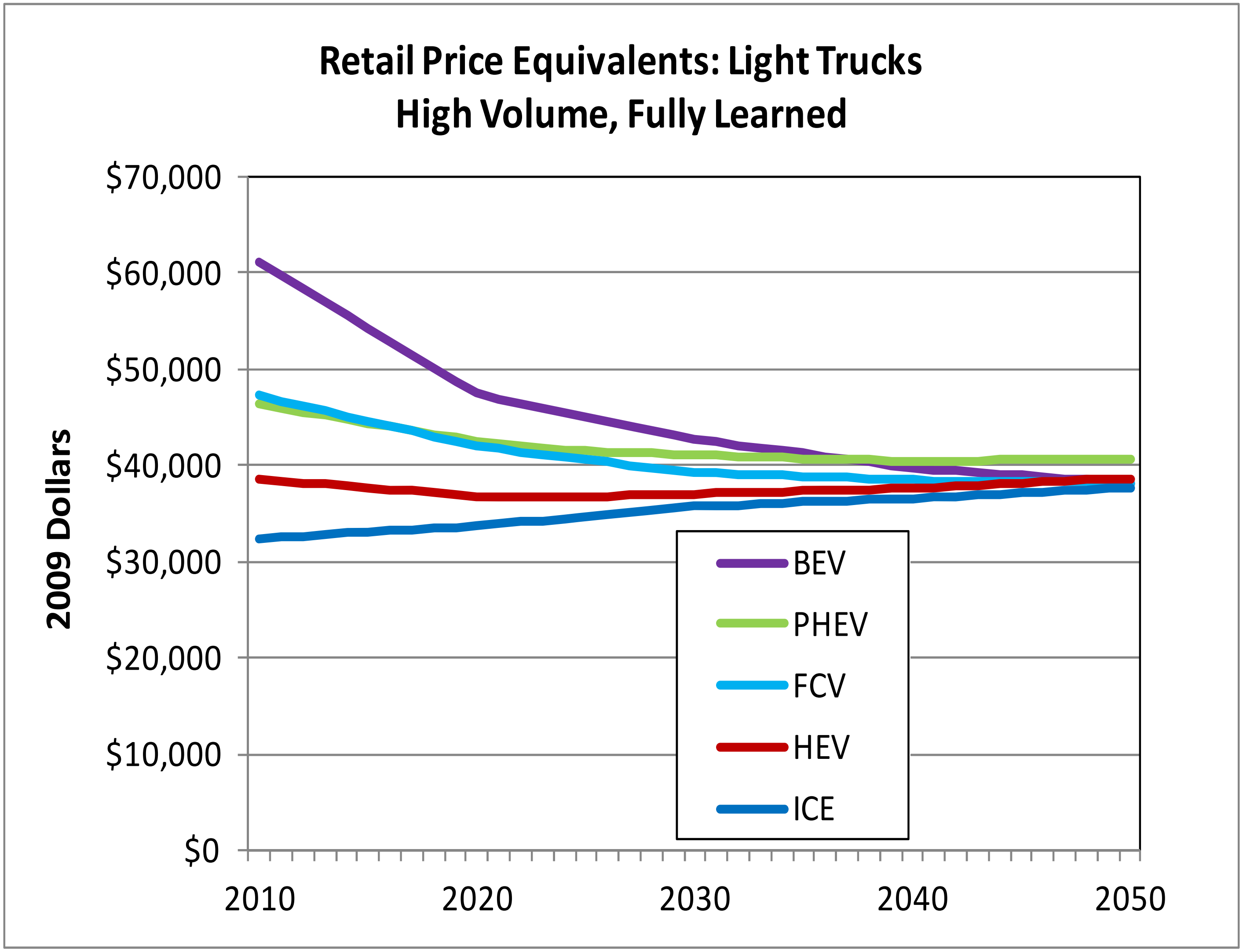
[a]Ricardo assumed stop start and smart alternator, with 14.1 percent of braking energy recovered, resulting in fuel economy = 34.9 mpg.

[b]Fuel economy with drivetrain changes only = 50.5 mpg.

By reducing power requirements, the standards help make e-drive vehicles **cheaper** than ICEs.



The retail price projections for light trucks are similar but ICEs remain the least expensive.



The NRC study assumed the cost of producing "drop-in" bio-fuel via pyrolysis and refining would decrease over time to $3-$4 per gallon.

TABLE 3.5 Estimates of Future Biofuel Availability

	Annual Plant Investment Rate (billion dollars per year)			
	1	4	7.2	10.4
Biofuel production (billion gge per year) by				
2022	0.9	3.7	6.7	9.7
2030	1.8	7.4	13.3	19.2
2050	4.3	17.3	31.2	45.0
Biomass required in 2050 (million dry tons per year)	68	270	488	703
Estimated land-use change (million acres)	5.5	22.2	40.1	57.8
Total investment to 2050 (billion dollars)	38	152	275	396
Average number of biorefineries built per year	2.7	10.8	19.5	28.2

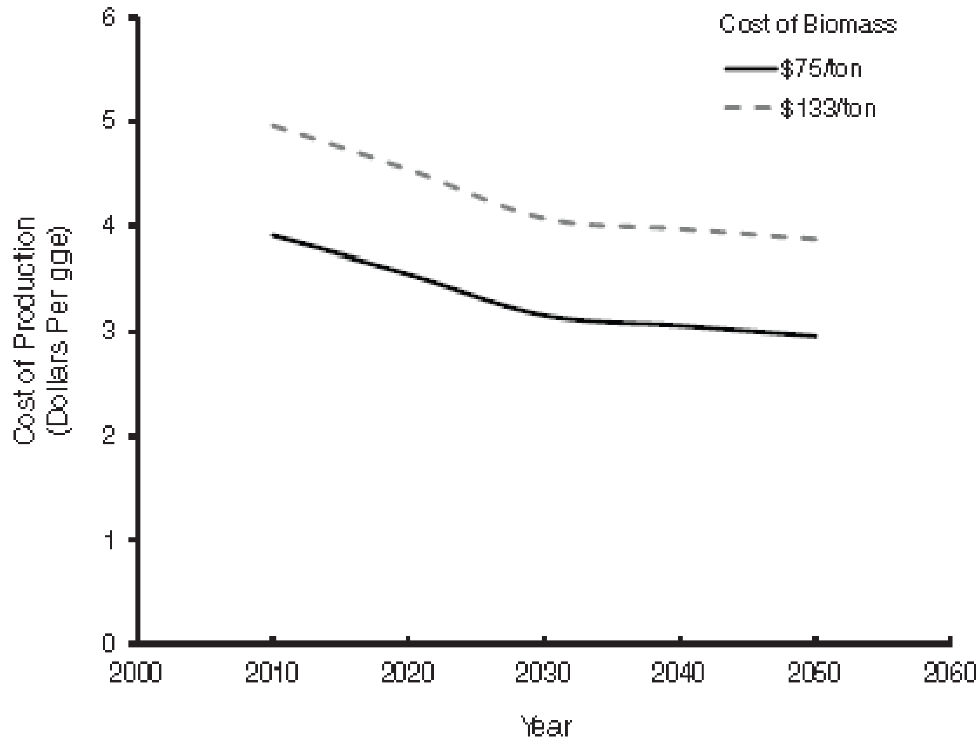
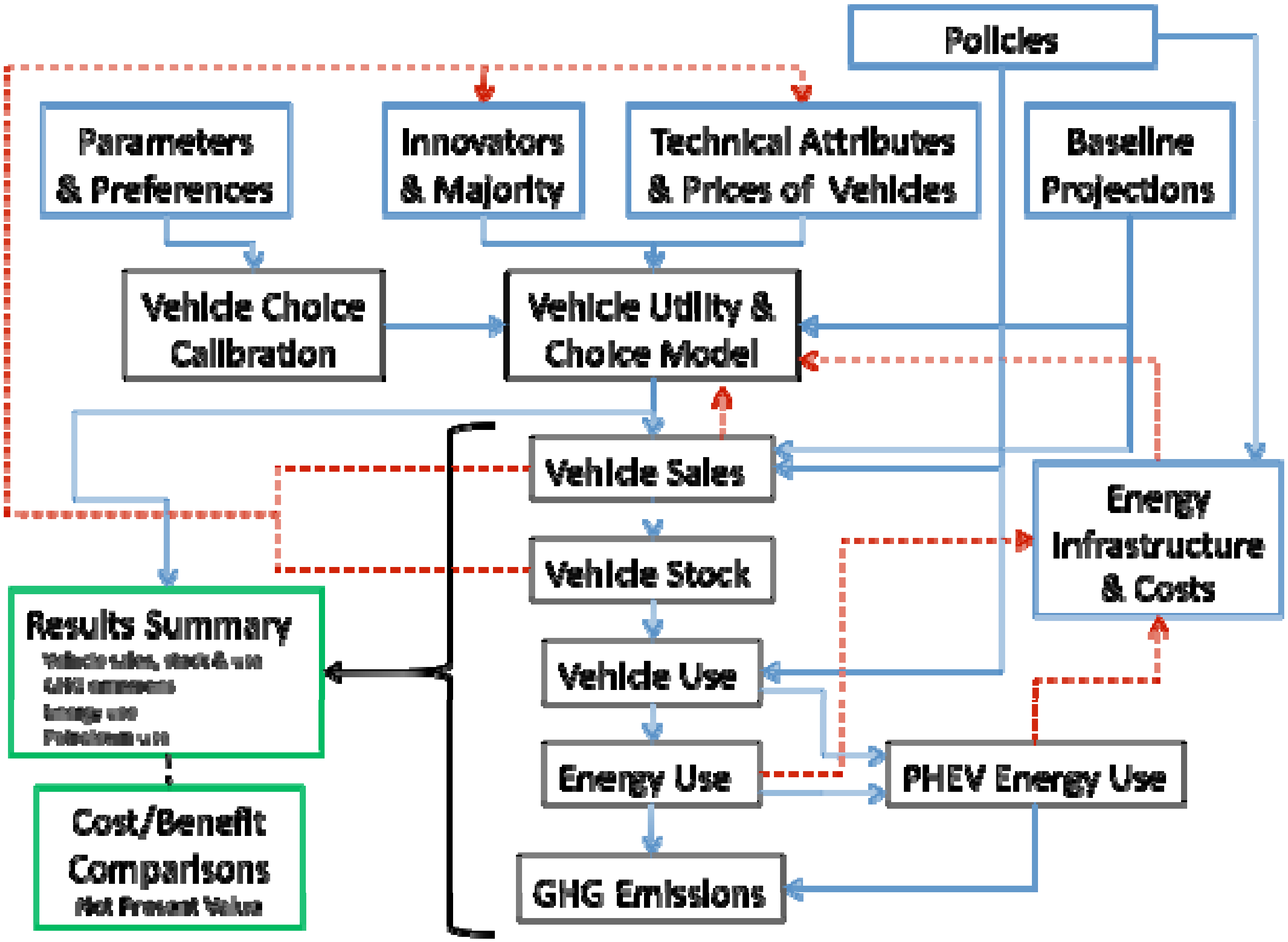


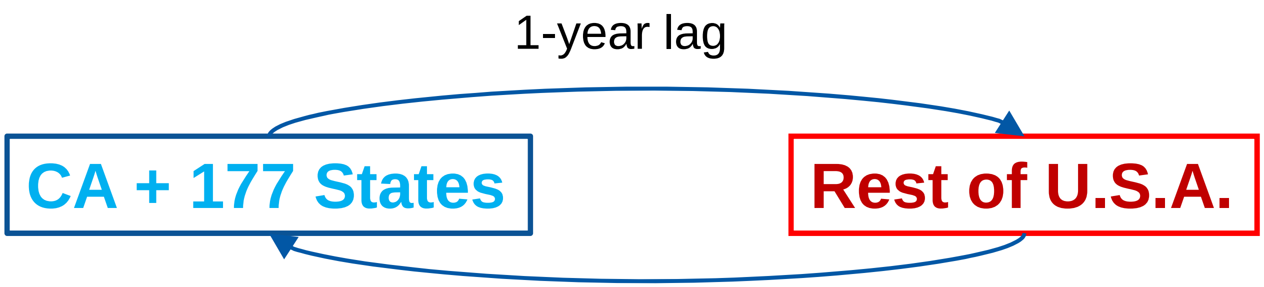
FIGURE 3.2 Sensitivity of biofuel cost to biomass cost.

How did we model this process? LAVE-Trans.
The Light-duty Alternative Vehicle Energy Transition Model.

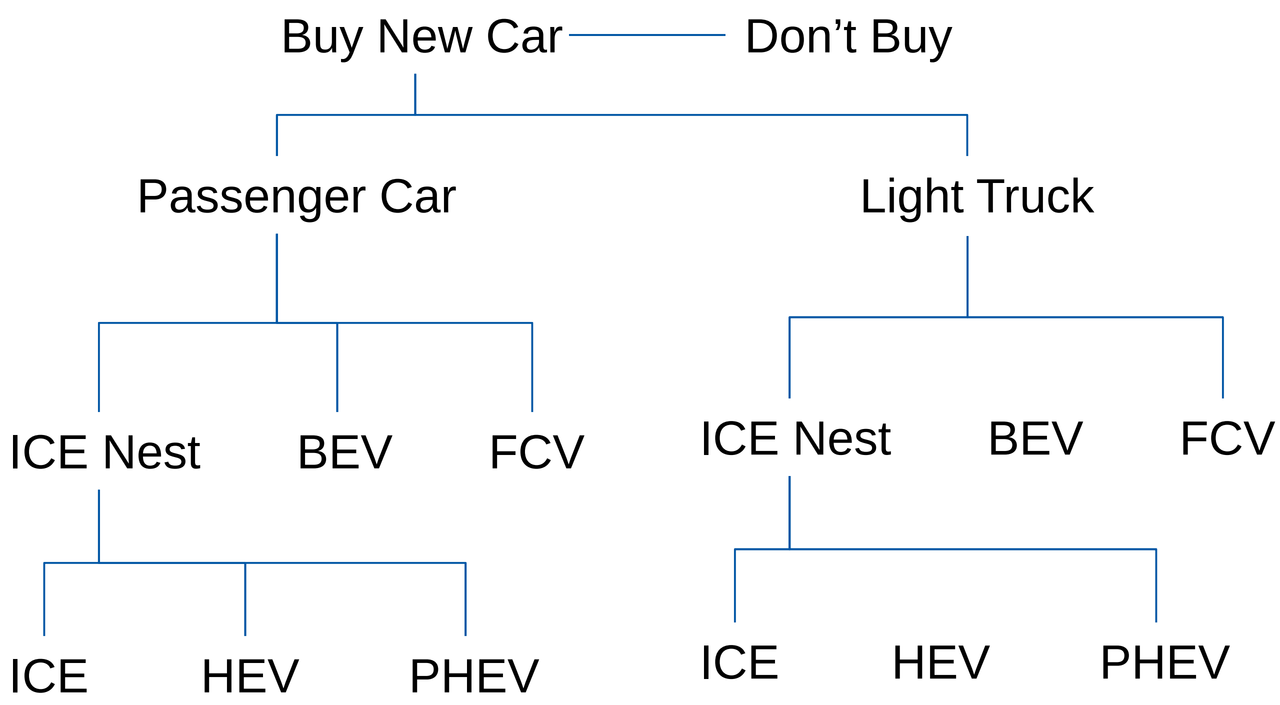


All feedback loops are recursive rather than simultaneous and are indicated by a dashed red line

The analysis for CA and 177 states links 2 LAVE models together.



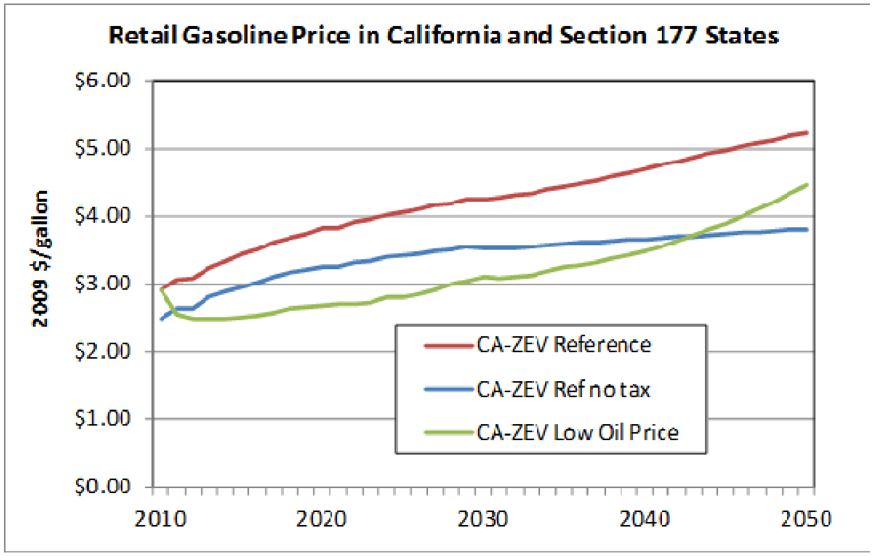
Choice Model Structure

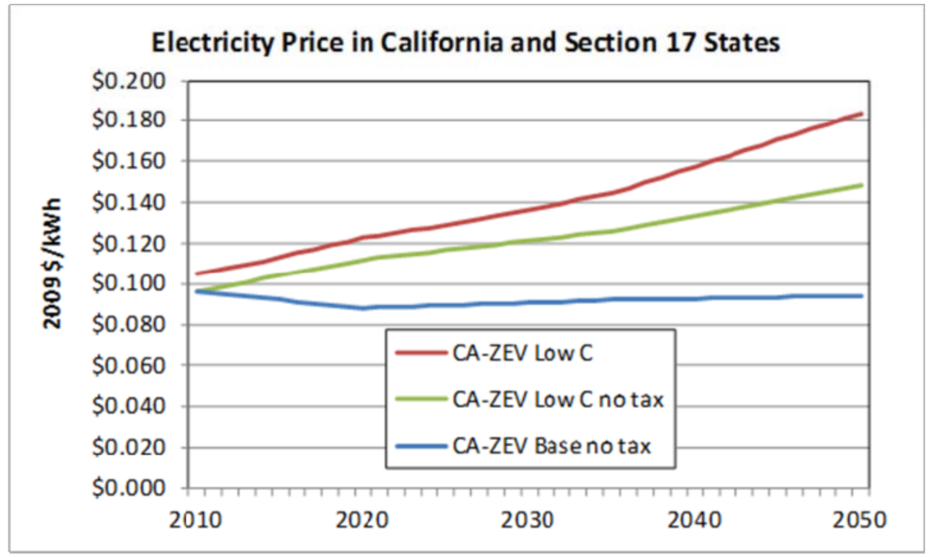


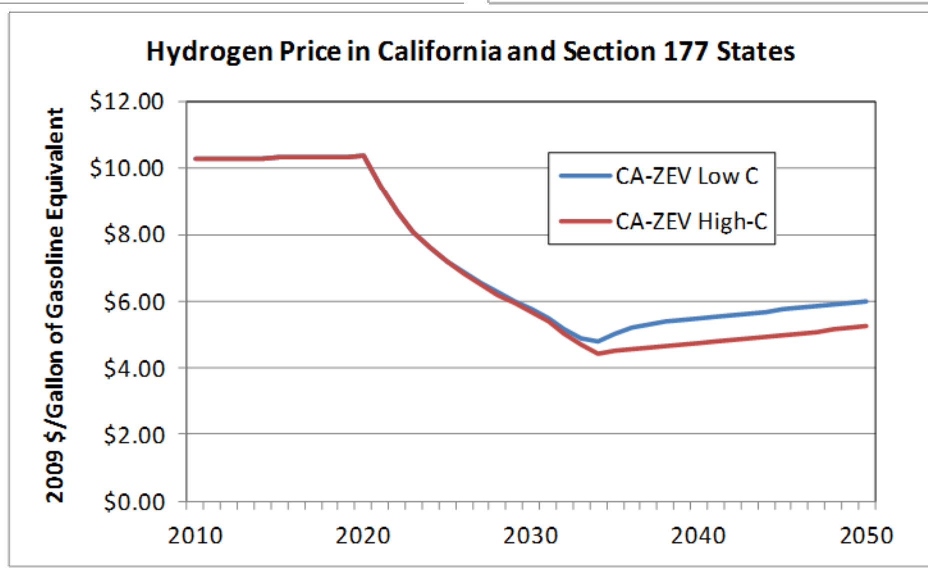
The LAVE model is highly generalized.

- 2 regions rather than geographically detailed.
- 2 market segments: innovators/early adopters v. majority.
- 2 types of vehicles: passenger cars and light trucks.
- Knowledge of market response is limited.
  - Innovators, early adopters, majority
  - Cost of limited fuel availability
  - Cost of short range/long recharge
  - Scale economies, learning-by-doing, risk aversion…
- The model provides a structured framework for integrating knowledge and assumptions rather than an accurate prediction of the future.

Like the NRC study, we took energy prices from the 2011 Annual Energy Outlook, and changed the motor fuel tax to an Indexed Highway User Fee on Energy.







Several important policies are assumed:

- Increasingly strict fuel economy/emissions standards.
- Policies to insure low carbon fuels.
- Existing vehicle subsidies end after 2015, but…
- Fuel economy/emissions standards induce vehicle pricing that reflects the social costs of oil and GHGs (like feebates).
- Highway user fee on energy indexed to average energy efficiency of all vehicles in use.
- **A scenario consists of the ZEV requirements plus any additional vehicle and infrastructure subsidies or mandates after 2015.**

Our ZEV sales requirements are from ARB estimates. For fuel cell vehicles they are much lower than CAFCP estimates. 68 hydrogen stations are assumed to be operating in California by 2015.

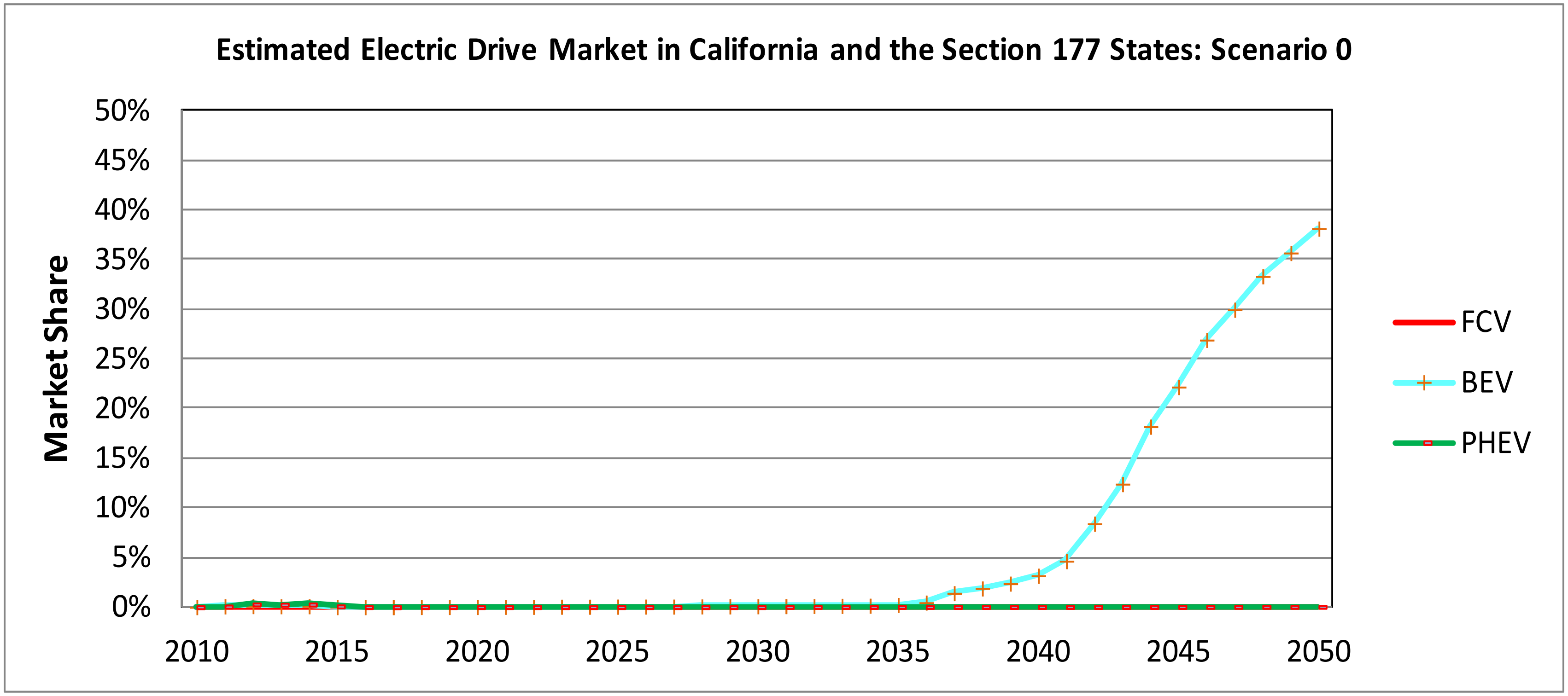
Station Deployment and Expected Vehicles Sales in California					
Year	Start of Year Station Total	Added Stations	CAFCP Number of Vehicles on the Road	CAFC Sales	Estimated Minimum ZEV Sales Requirement
2012	4	4	312	100	0
2013	8	9	430	118	0
2014	17	20	1389	959	0
2015	37	31	10000	8611	2134
2016	68	Market needs	20000	10000	2269
2017	*84*	Market needs	53000	33000	2297
2018	*100*	Market needs	*95000*	*42000*	2943
Sources: CAFCP, 2012, table 5; ICCT estimates.					
Numbers in italics have been approximated based on lower bounds given in CAFCP table 5.					

policies, rest of US policies, technology and energy prices.

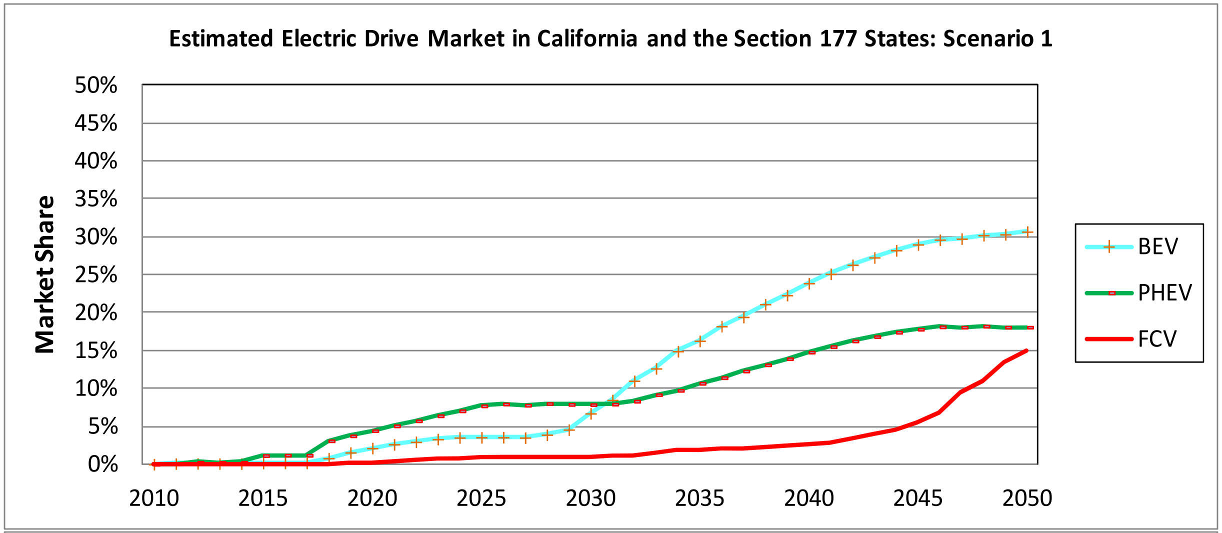
Benefits and costs are compared to a technologically and economically equivalent Base Case.

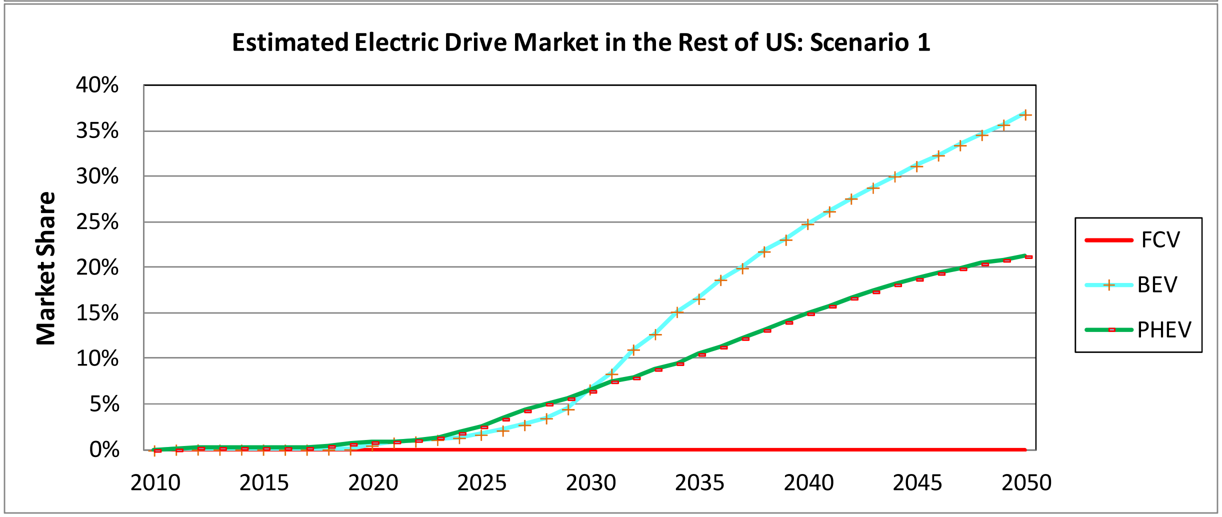
Scenarios	CA + S177 States' Policies	Rest of US Policies (with 3-year lag)	Rest of World Sales (Exogenous)	Vehicle Technology	Energy Prices
1	Infrastructure + Vehicle Subsidy	NO	NO	Expected	2011 AEO Reference
2	Infrastructure + Subsidy	Infrastructure + Subsidy	NO	Expected	2011 AEO Reference, High and Low
3	Infrastructure + Subsidy	NO	Introducing Rest of World Sales	Expected	2011 AEO Reference
4	Subsidy Only	Subsidy Only	NO	Expected	2011 AEO Reference
5	Infrastructure + Subsidy	NO	NO	Optimistic	2011 AEO Reference
6	Infrastructure + Subsidy	Infrastructure + Subsidy	NO	Optimistic	2011 AEO Reference

With no ZEV program and no vehicle subsidies after 2015, BEVs eventually capture a significant market share.



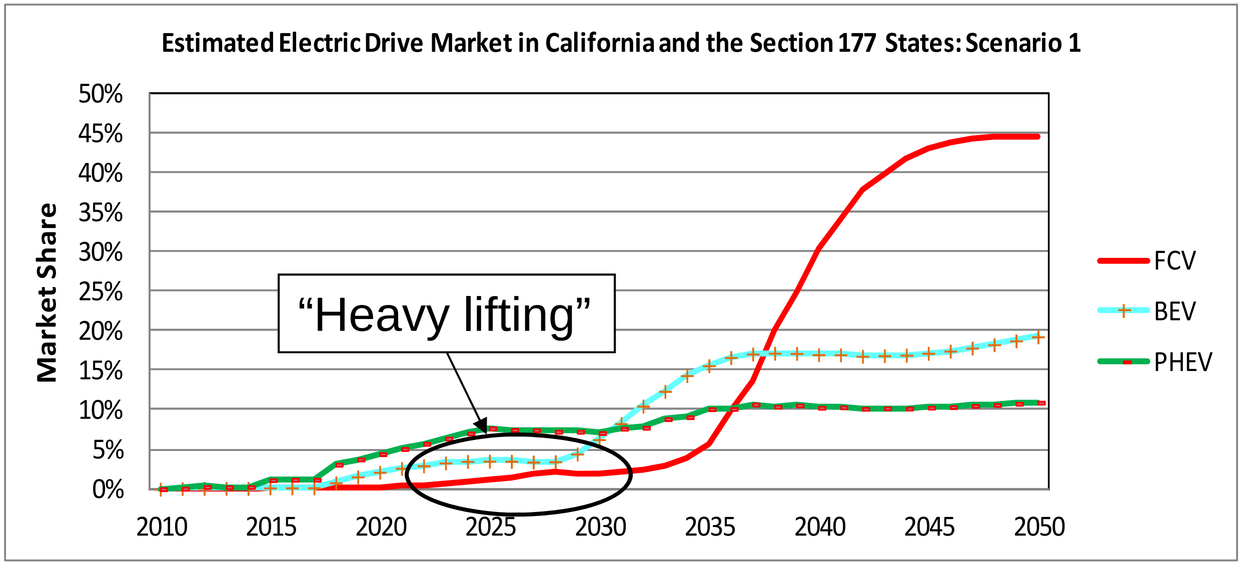
With ZEV mandates and H_2 infrastructure in California but ***no comparable rest of US policies after 2015***, plug-in vehicles are successful earlier and fuel cells break through after 2040. There are spillover benefits to the rest of the U.S.

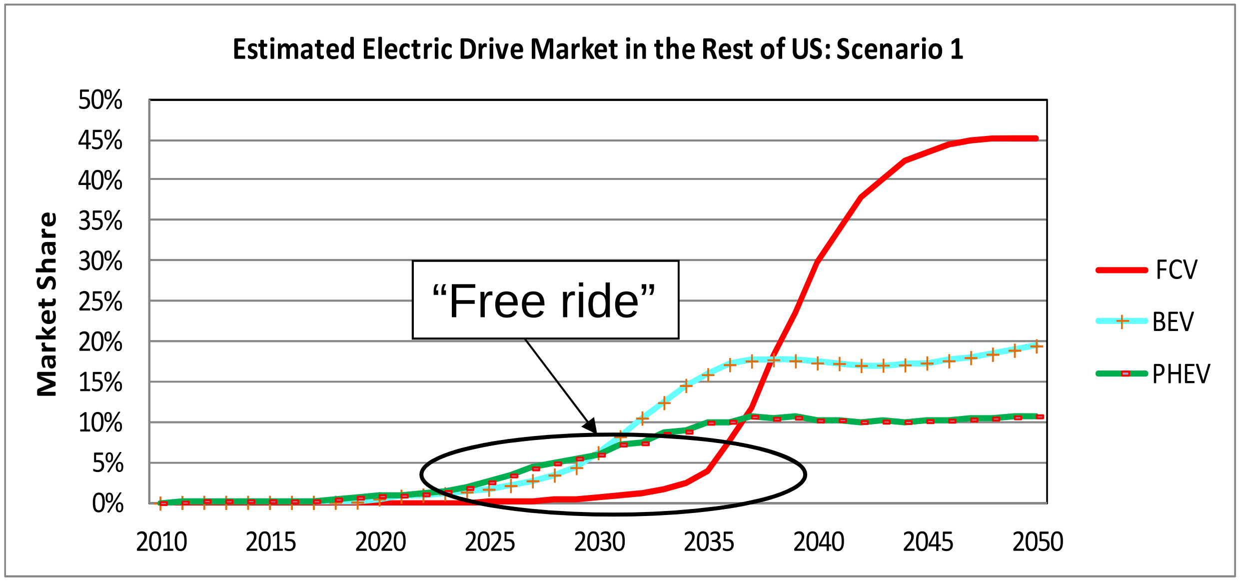




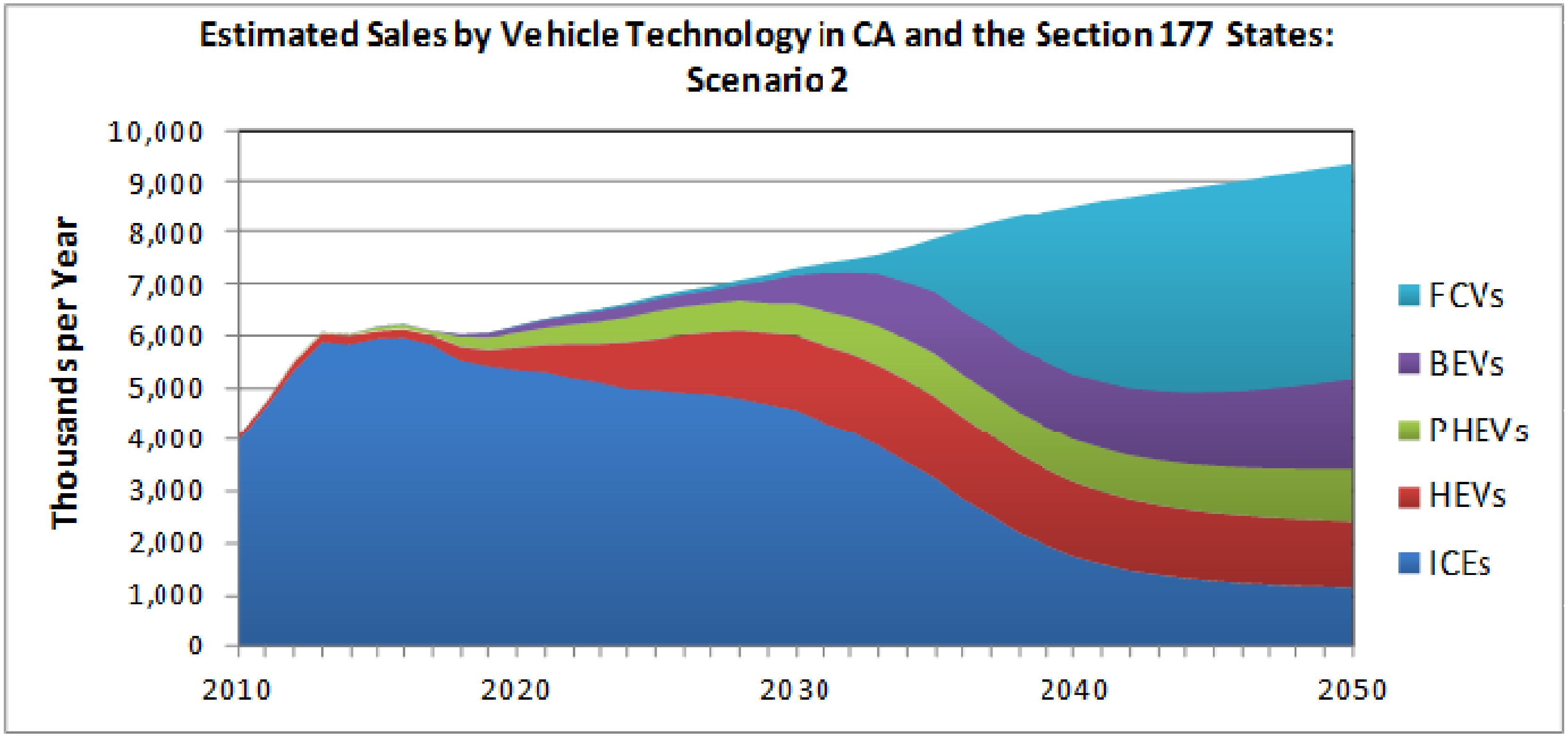
One tipping point is hydrogen infrastructure.

If the rest of US installs early H_2 infrastructure FCVs thrive.

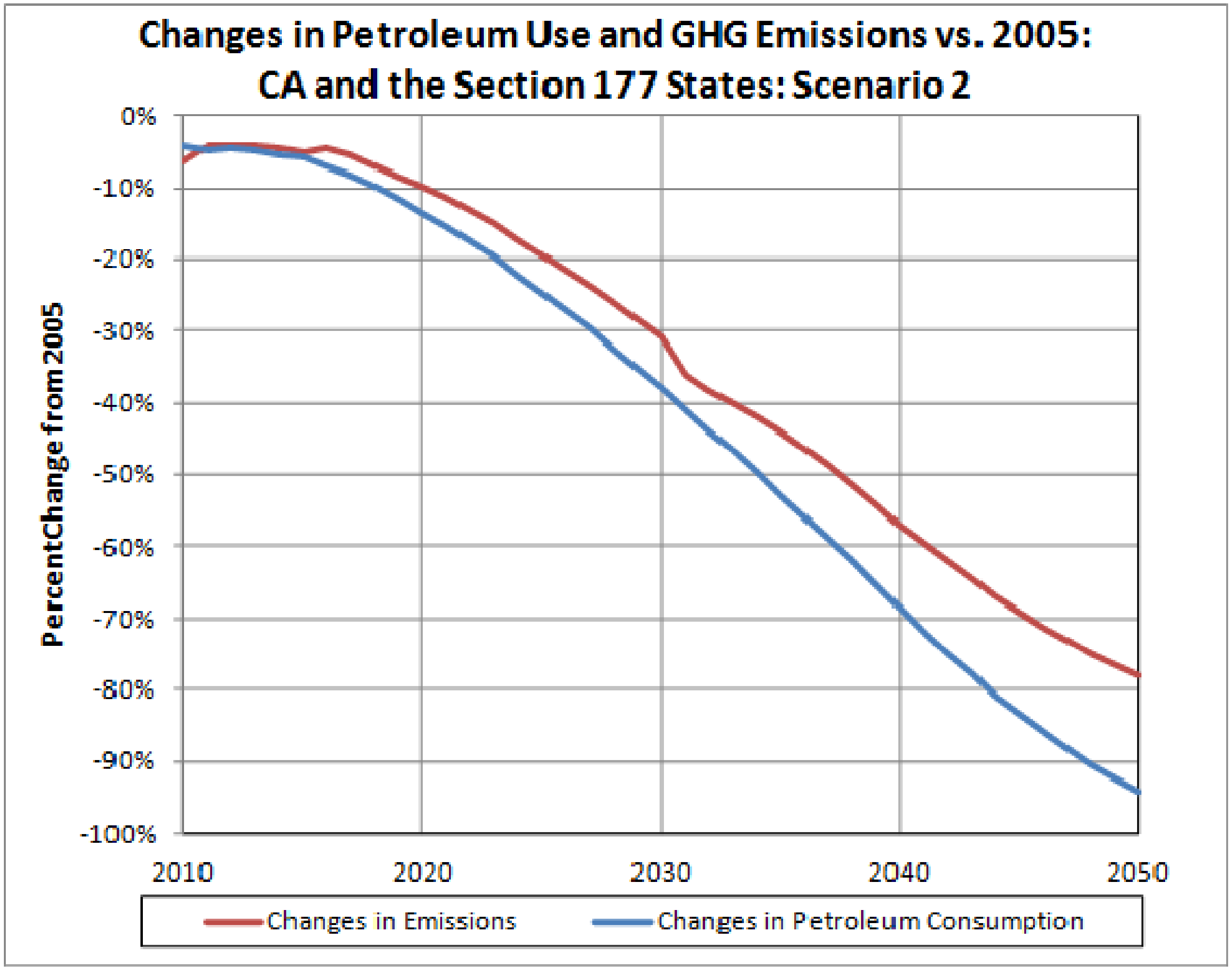




With comparable US policies lagging by 3 years there is an earlier, more complete transition.

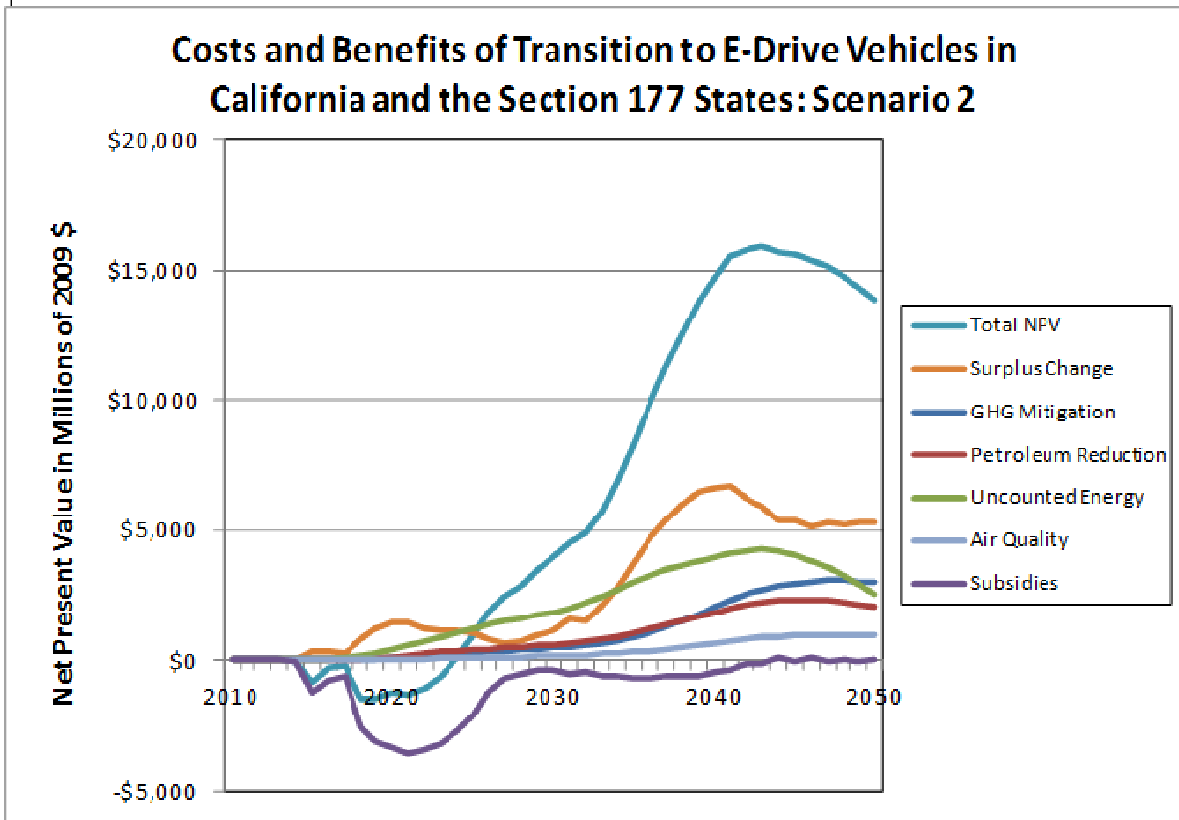


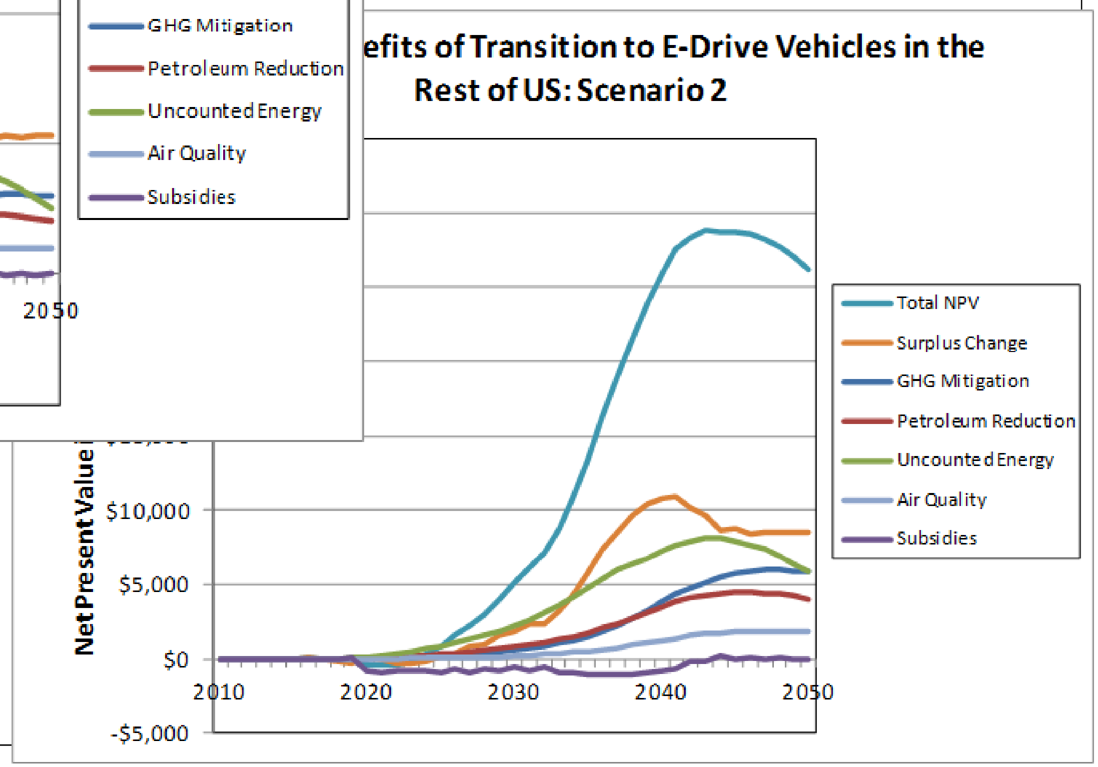
Petroleum use is nearly eliminated (with 4.6B gallons of drop-in biofuels) and CO_2 emissions are almost 80% lower in 2050.



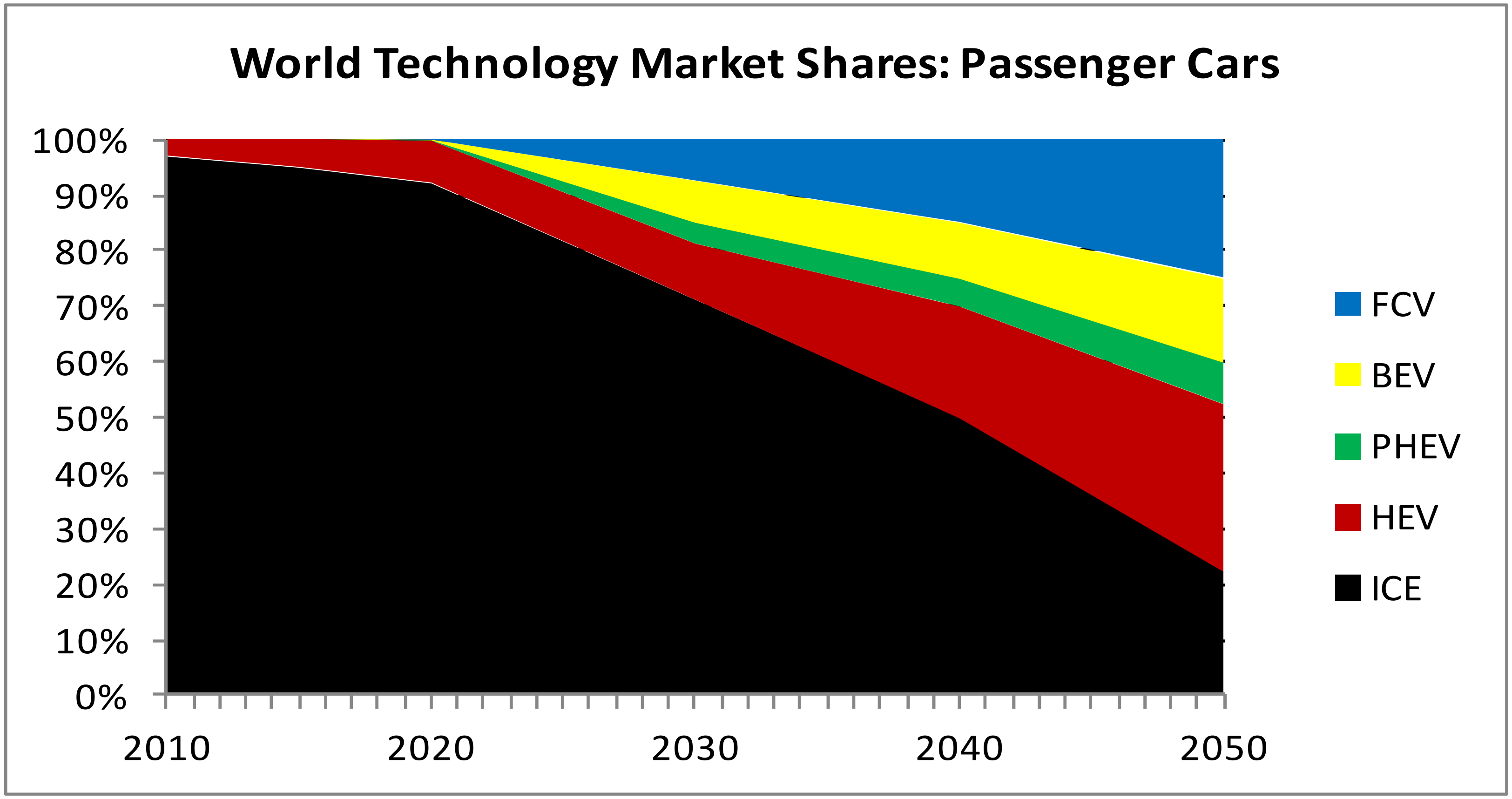
Benefits exceed costs by about an order of magnitude (technological success assumed).

(Co-benefits, co-benefits…)

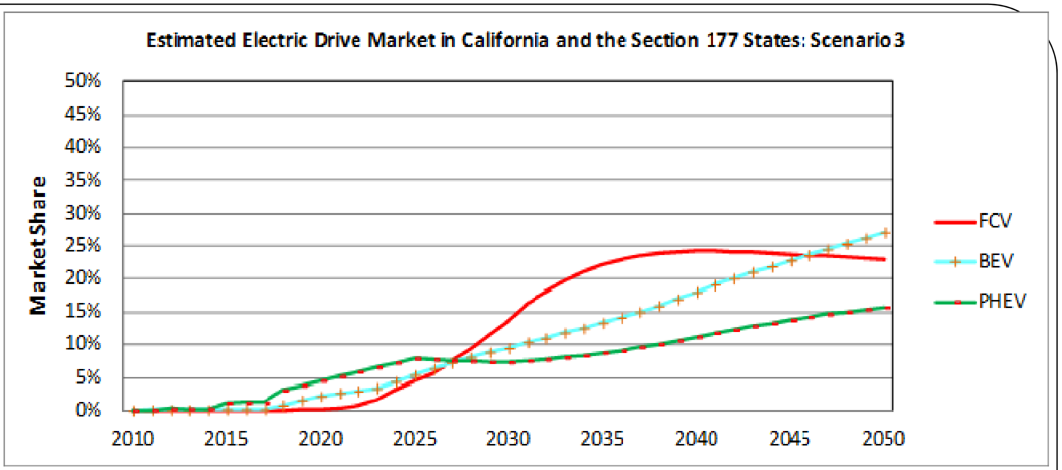


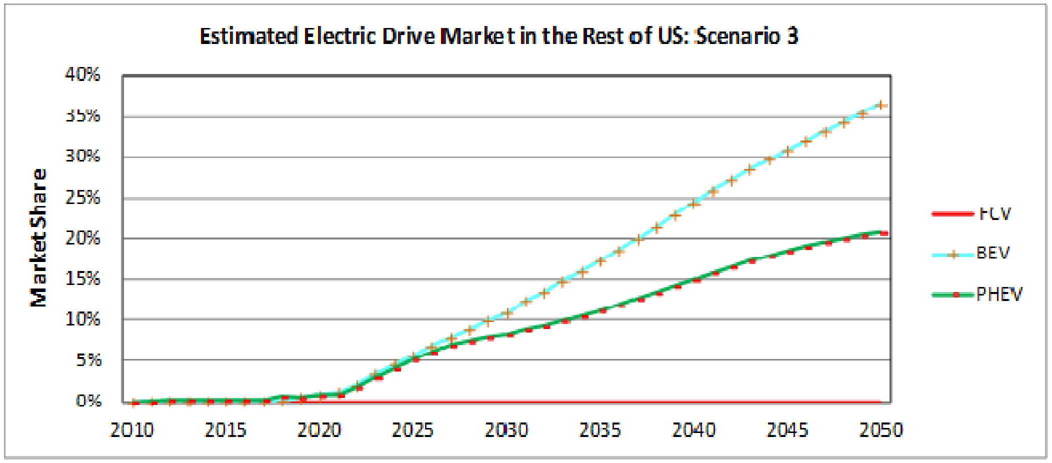


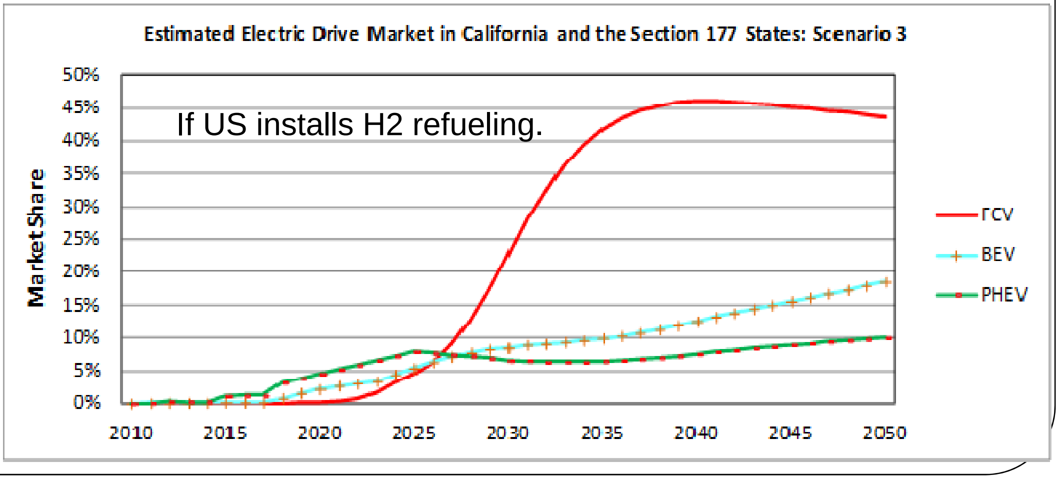
But the automobile market is global and the EU, Japan, South Korea, China and others are also promoting electric drive.



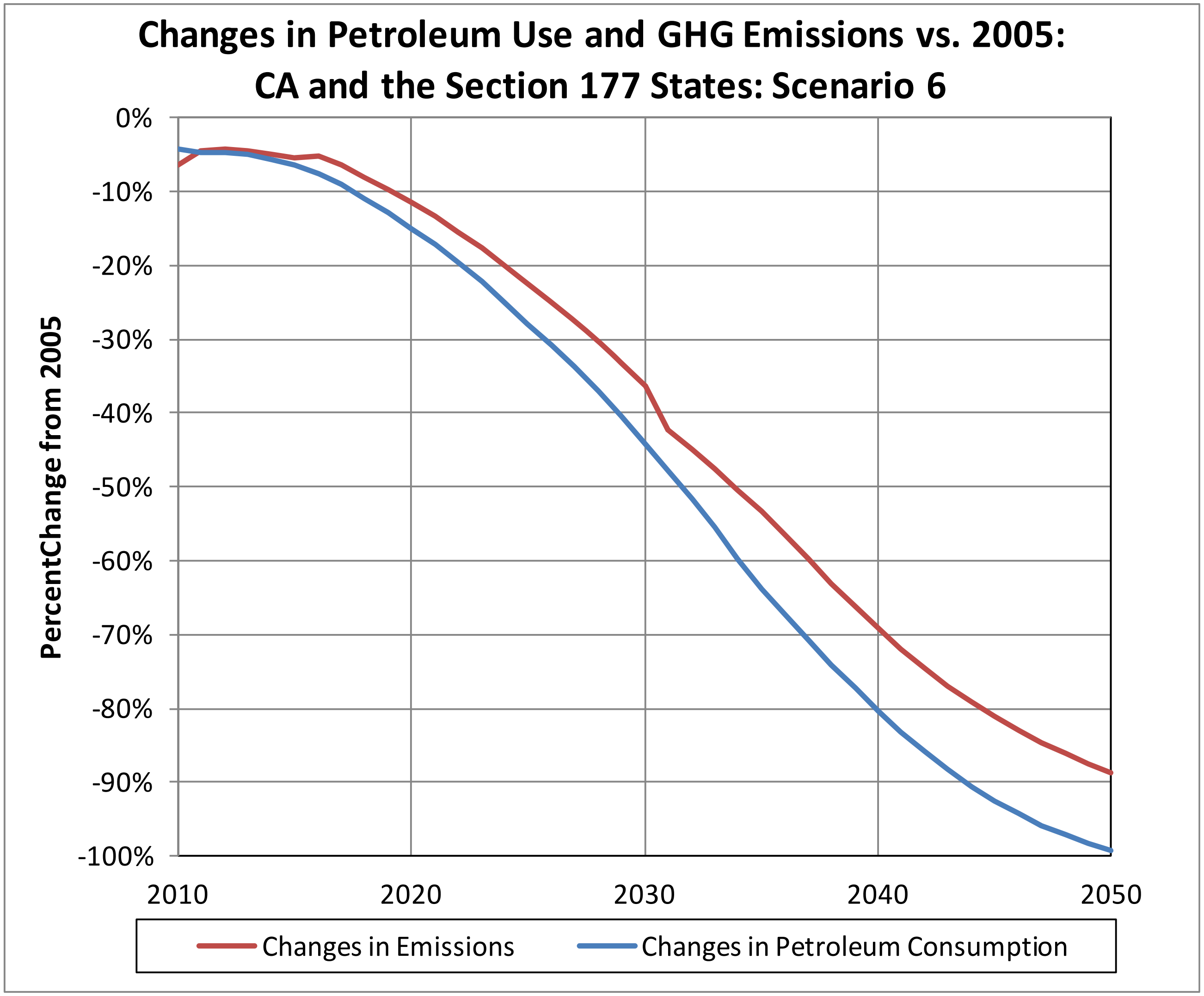
A rest-of-the-world transition to electric drive helps the CA & Section 177 states transition almost as much as a rest-of-US transition.







Scenario 4: No H_2 infrastructure no H_2 vehicles.
Scenario 5: Better technology, better transitions, little H_2.
Scenario 6: Better technology, better transitions.



The modeling results suggest some potentially important inferences.

- Net benefits of transition appear to exceed excess costs by approximately an order of magnitude, but
  - NPV < 0 for about a decade.
  - Subsidies may be needed for an extended period (to 2025 or 2030).
  - Temporarily, must do more than “internalize the external costs”.
- There are “tipping points” in vehicle deployment.
- “Network external benefits” create large positive feedbacks.
- Mandates (ZEV) or subsidies seem to be essential.
- Early hydrogen infrastructure is critical for FCEVs.
- FCEV market potential appears to be > BEV > PHEV.

Additional modeling results will be forthcoming in about two months. **The following results are preliminary.**

- Timing of policy action given NRC technology projections:
  - Waiting reduces subsidy costs but,
  - Reduces benefits even more → smaller NPV
- Intensity of policy actions given NRC projections:
  - Increasing ZEV requirements yields larger NPV
  - Reducing ZEV requirements yields smaller NPV
- Simulating deep uncertainty:
  - Ultimate vehicle costs +/- 10%
  - Uncertainty in all market parameters
  - Probability of NPV < 0 less than 1 in 10?
- But, there is a lot we don't yet understand.

THANK YOU.

Baker Center Report: *Analyzing the Transition to Electric Drive in California*
http://bakercenter.utk.edu/wp-content/uploads/2013/06/Transition-to-Electric-Drive-2013-report.FINAL_.pdf

NRC Report: *Transitions to Alternative Vehicles and Fuels*
http://www.nap.edu/catalog.php?record_id=18264

"Transition from Petro-Mobility to Electro-Mobility", in Stolten and Scherer, eds.,
Transition to Renewable Energy Systems, Wiley-VCH, Weinheim, Germany.

Analyzing the Transition to Electric Drive Vehicles in the U.S., D.L. Greene, C. Liu and S. Park,
forthcoming, *Futures*.