COCHIN-TIMES: Integration of Vehicle Consumer Choice in TIMES Model and its Implications for Climate Policy Analysis

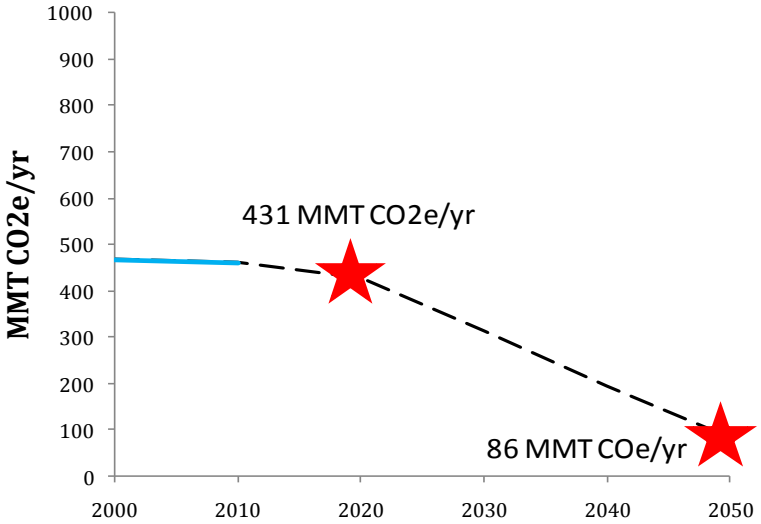
International BE_4 Workshop
University College London
April, 2015

Kalai Ramea, David Bunch*, Sonia Yeh, Chris Yang, Joan Ogden
*Graduate School of Management, University of California, Davis
Institute of Transportation Studies, University of California, Davis

ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

Background

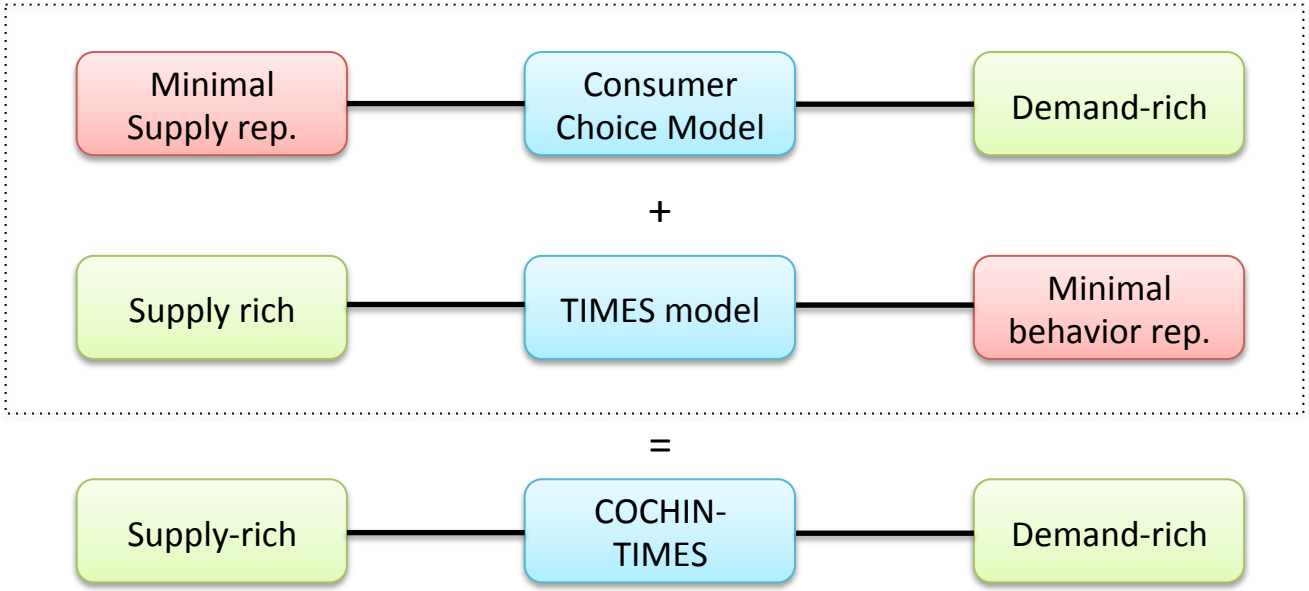
- Since 2007 California government has pursued public policy and regulations to mitigate GHG emissions



- Motivation: There is a need for improved models for analyzing policies for addressing climate change goals
- Consumer choice is very important in light-duty vehicle adoption—59% of energy use comes from LDVs in the transportation sector

Overview of Model Approach

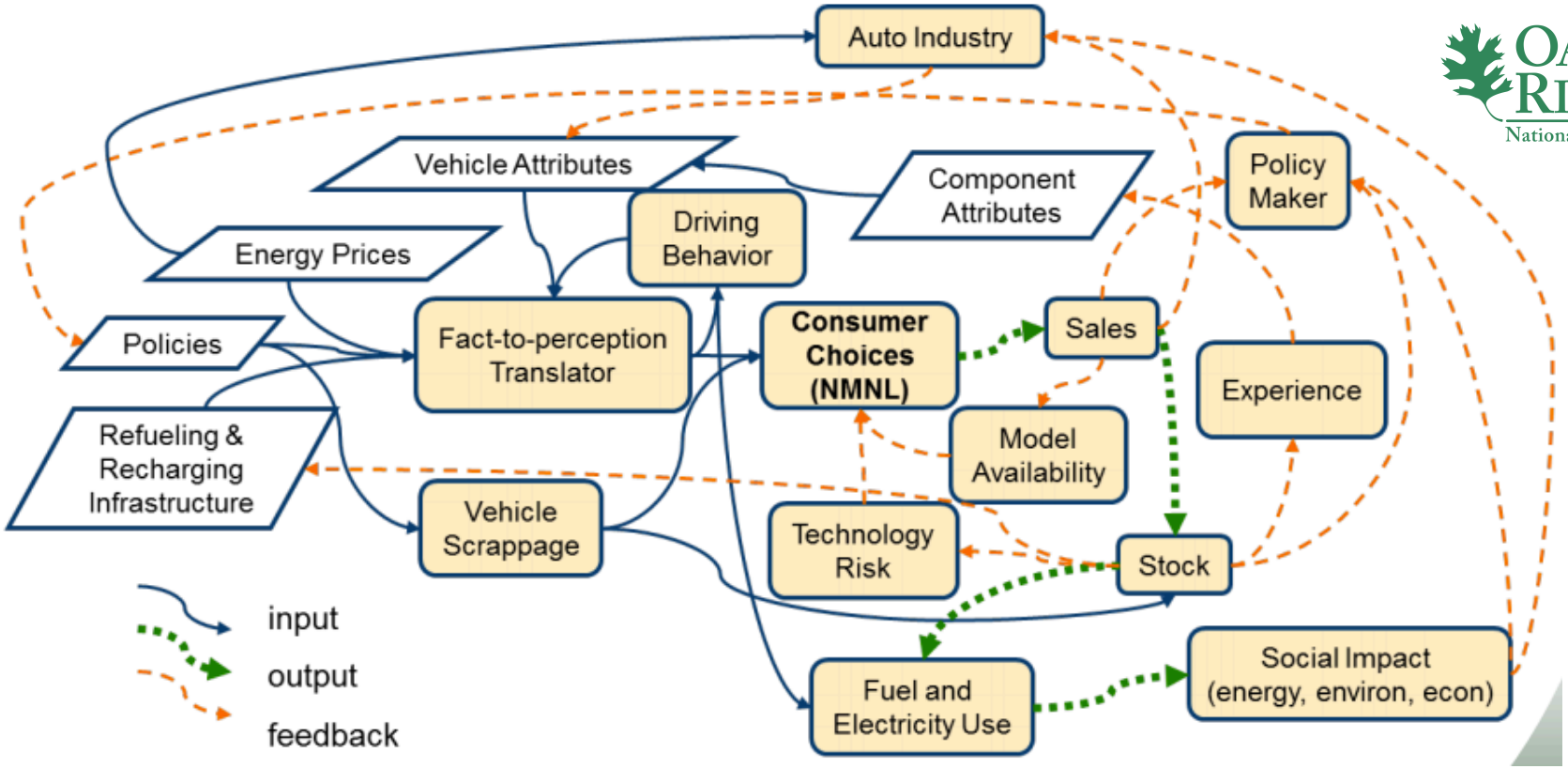
- Energy Systems Models
  - Technology rich on the supply side, but lack behavioral details
- Consumer Choice Models
  - Detail choices on the demand side but lack supply sector details
- Our focus: 'Marrying' these two types of models



COCHIN: **CO**nsumer **CH**oice **IN**tegration

MA^{3}T Consumer Choice Model

- MA^{3}T (Market Allocation of Advanced Automotive Technologies), nested multinomial logit model developed by Oak Ridge National Laboratory

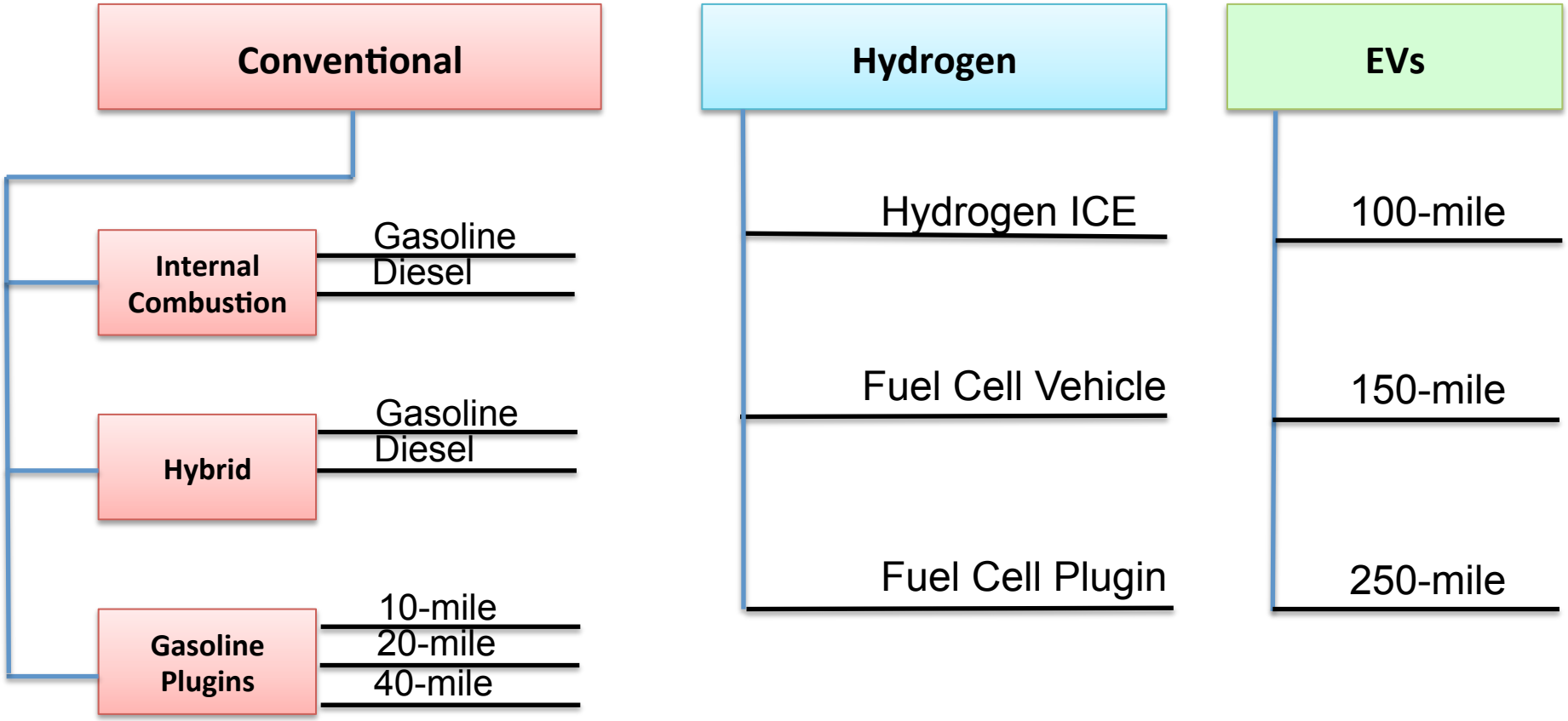


Consumer Group Divisions in the MA^{3}T Model (for every census region)

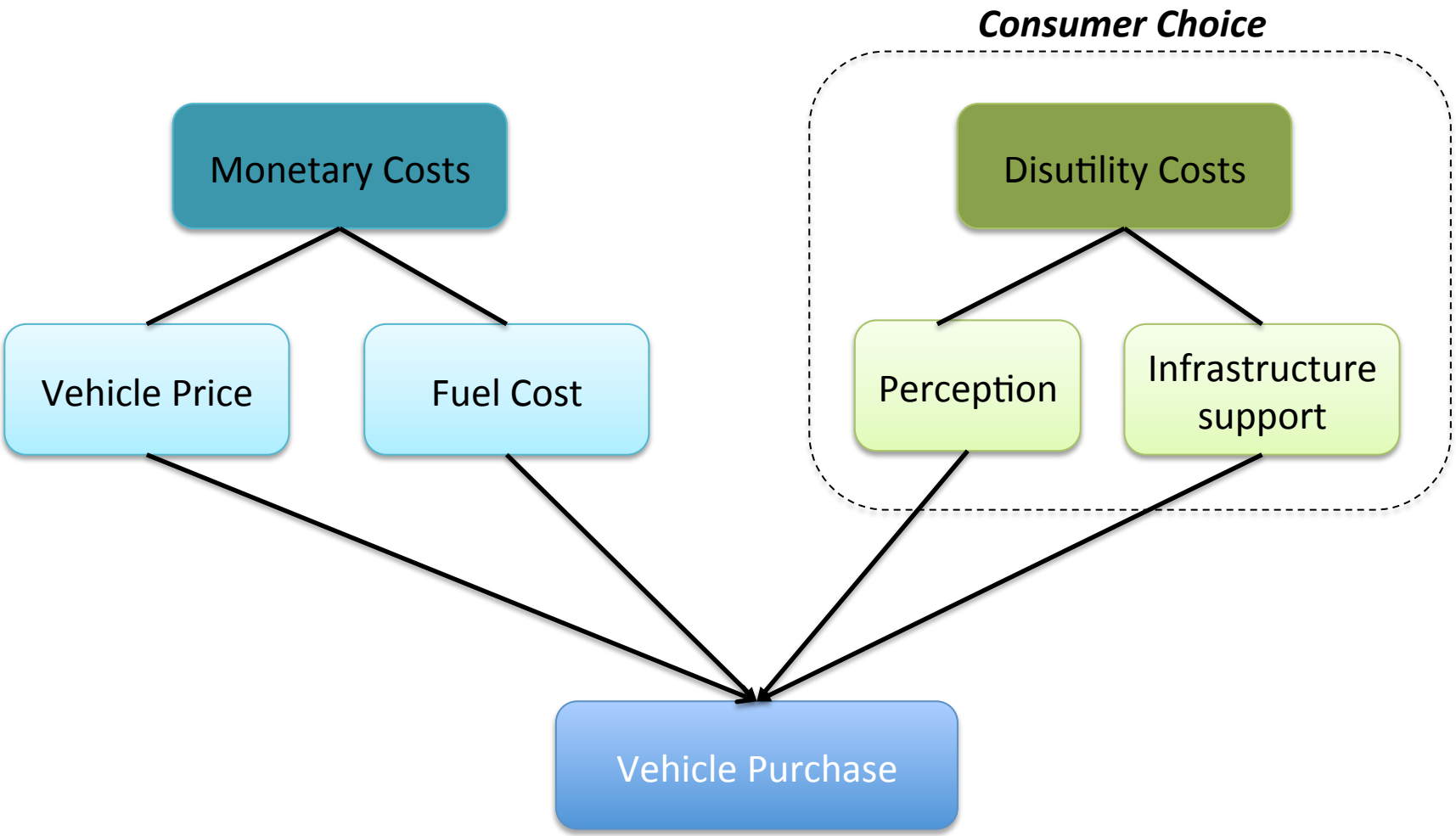
Settlement Type	Urban
	Suburban
	Rural
Risk Attitude	Early Adopter (8%)
	Early Majority (38%)
	Late Majority (54%)
Driving Behavior	Low Annual VMT (8656 miles)
	Medium Annual VMT (16068 miles)
	High Annual VMT (28288 miles)
Recharging Infrastructure	Home + Work
	Home + No Work
	No Home + Work
	No Home + No Work

(+ public recharging infrastructure common to all)

Vehicle Technologies



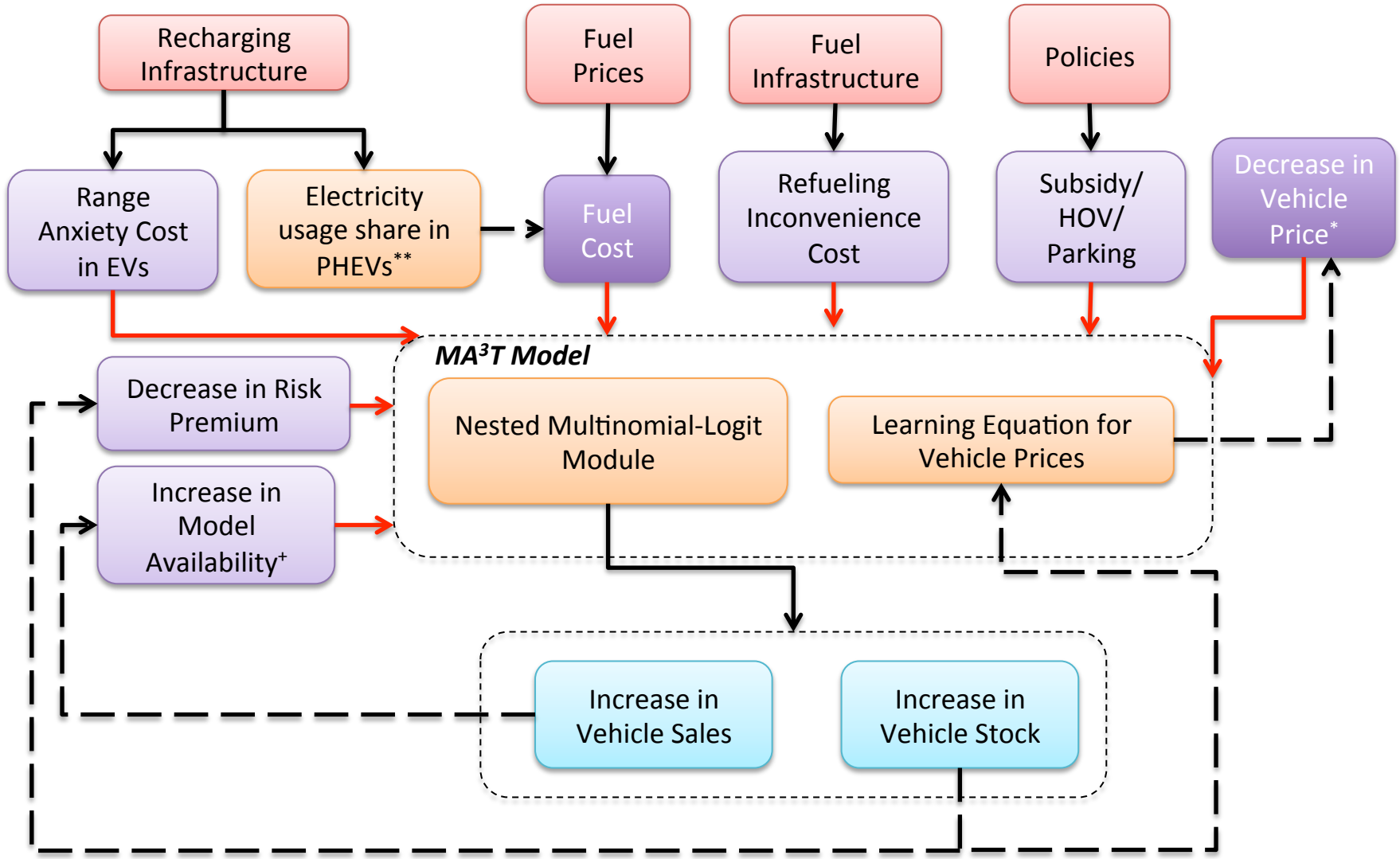
Vehicle Purchase Decision-Making



Disutility Cost Components

- Refueling Inconvenience Cost
  - Cost associated with the lack of access to refueling infrastructure (station availability)
  - Based on various spatial simulation and cluster analysis studies done on access time to find stations—multipliers are derived
- Range Anxiety Cost
  - Cost to capture the consumer's perception of anxiety associated with the limited range of EVs and infrastructure availability.
  - Based on a daily VMT distribution, model checks whether it meets the range for the day. If not, a $/day penalty is given, which differs across risk groups
- New Technology Risk Premium
  - The consumers' willingness to pay to avoid risk (or gain novelty) approaches zero as cumulative sales of the vehicle technologies increases over time
- Model Availability Cost
  - Make and model diversity is represented in the vehicle choice model as the log of the ratio of the actual number of makes and models available, to the "full diversity" number (conventional vehicles)

More details on formulation of these costs can be found in this National Research Council report: "Transitions to Alternative Vehicles and Fuels": http://www.nap.edu/catalog.php?record_id=18264



+ Increase in 'Model Availability' leads to decrease in model availability cost.

** Decrease in Vehicle Price until it reaches the 'Learned Out Cost'.*

*** Electricity usage share in PHEVs decrease when there is inadequate recharging infrastructure.*

Model Component | Model input | Model Output | Direct Costs | Disutility Costs

Model input | Feedback Loop

Steps to Introduce Consumer Choice in TIMES

Standard TIMES model

Social Planner

Vehicle Cost

Fuel Cost

Step 1: Creating heterogeneity in demand

Step 2: Adding disutility costs

Vehicle Cost

Fuel Cost

Disutility Cost

Step 3: Creating clones of each group and adding random error terms

All three costs + Random error terms

Eg. Creating clones to include MNL structure for any consumer group (simpler than COCHIN, which has NMNL structure)

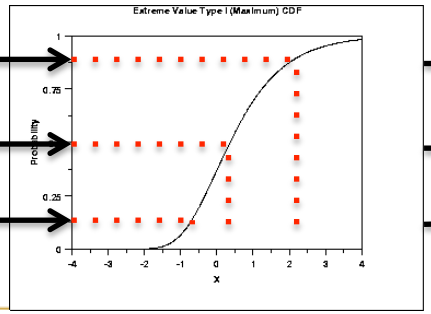
Vehicle & Fuel Costs

+

Disutility Costs

3 clones

Logistic Regression Curve

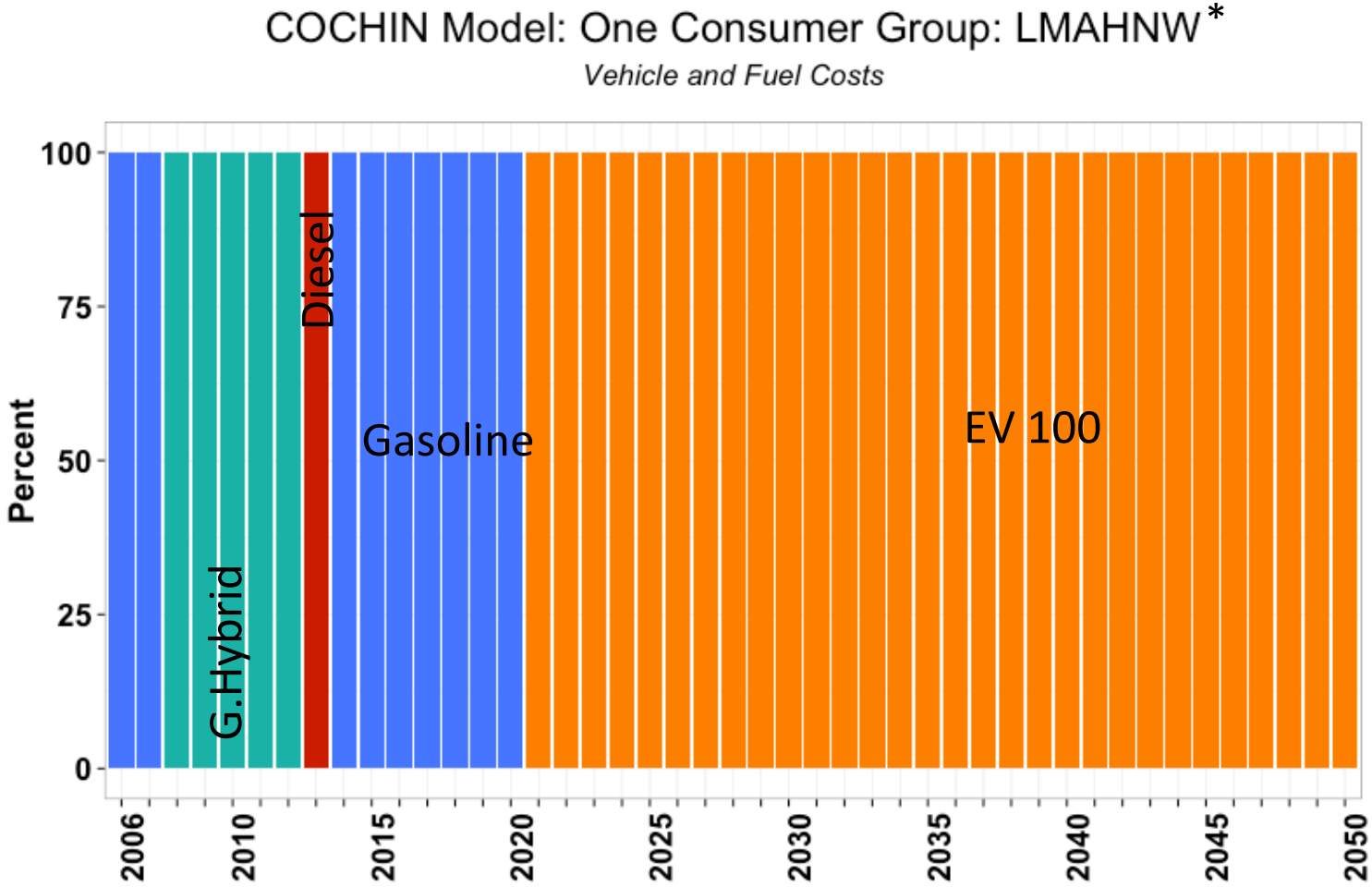


Total Cost = Vehicle Cost + Fuel Cost + Disutility Costs + (Error term/scale)

COCHIN: US Reference Case

- Timeline: 2005 to 2050, nationwide model, annual investment
- Represents both light-duty cars and trucks
- 12 light-duty car technologies and 12 light-duty truck technologies
- Has 36 consumer groups (risk attitudes, driving profiles, recharging infrastructure)
- Vehicle costs and efficiencies are included from Argonne National Laboratory's Autonomie model
- Fuel prices are taken from Annual Energy Outlook (2013)
- 52% of the population has access to home recharging infrastructure, 5% of the population reaches access to workplace recharging in 2050, about 15,000 public recharging station locations are installed by 2035.

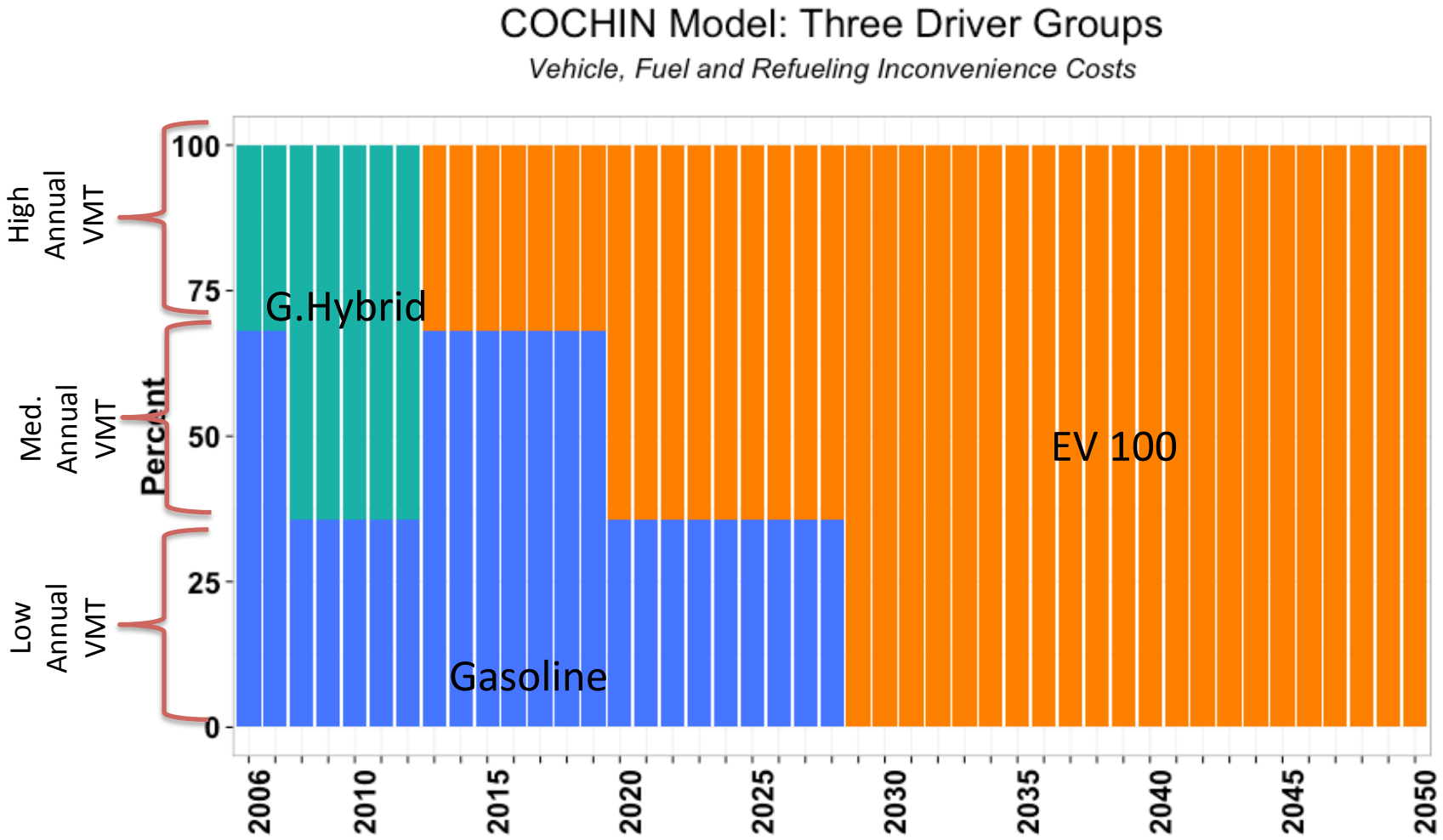
COCHIN: Annual Sales Share



- *LMAHNW: Late Majority, Average Driver, Home Recharging, No work recharging
- Exhibits “winner-takes-all” or “knife edge” phenomenon
- All the vehicles in the mix are light-duty cars. Trucks do not get invested at this point.

COCHIN: Annual Sales Share

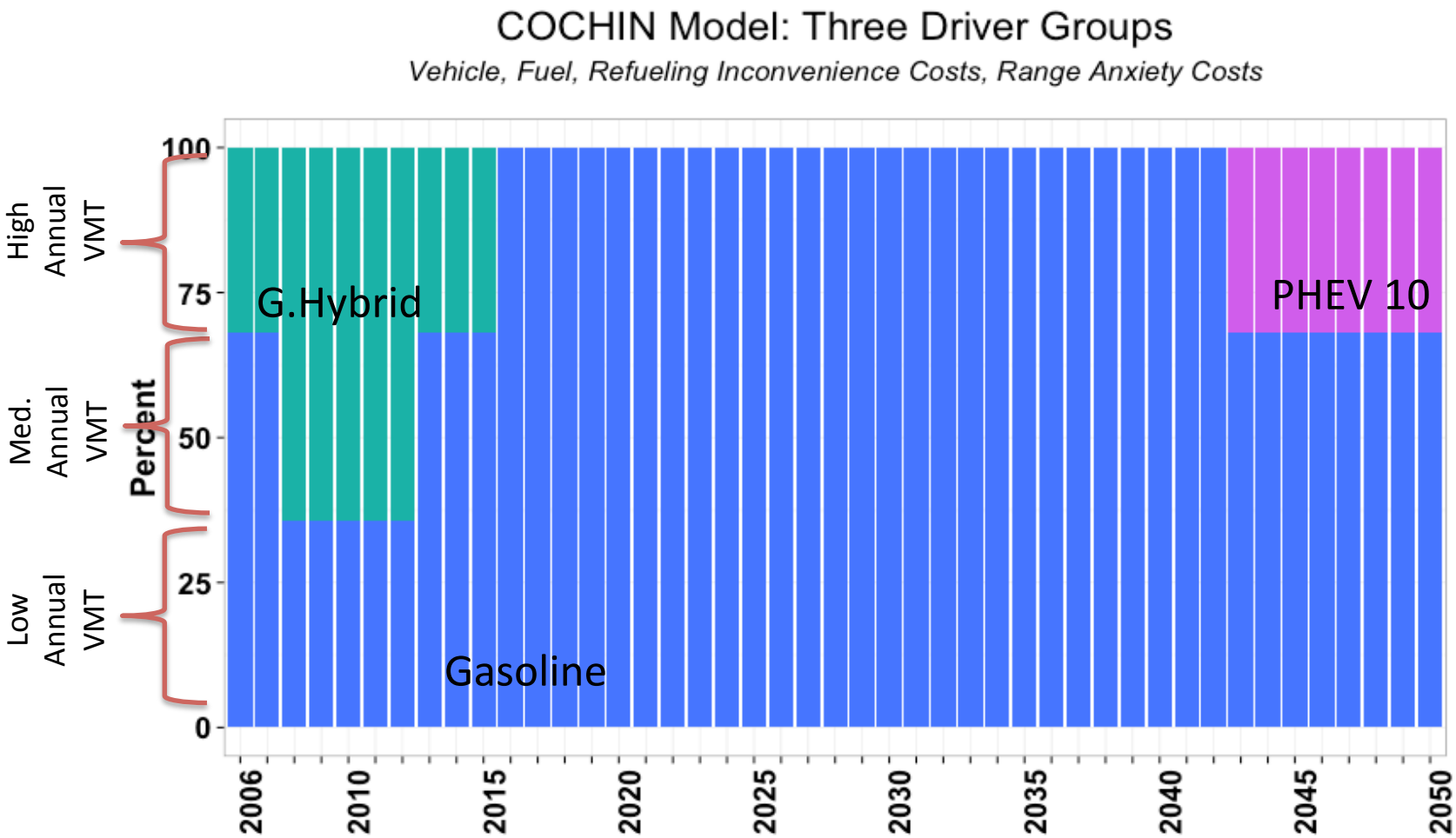
+ Refueling Inconvenience Cost



- Adding driver groups introduce variations in vehicle technology investments with high annual VMT drivers investing in more fuel efficient vehicles followed by lower VMT groups.

COCHIN: Annual Sales Share

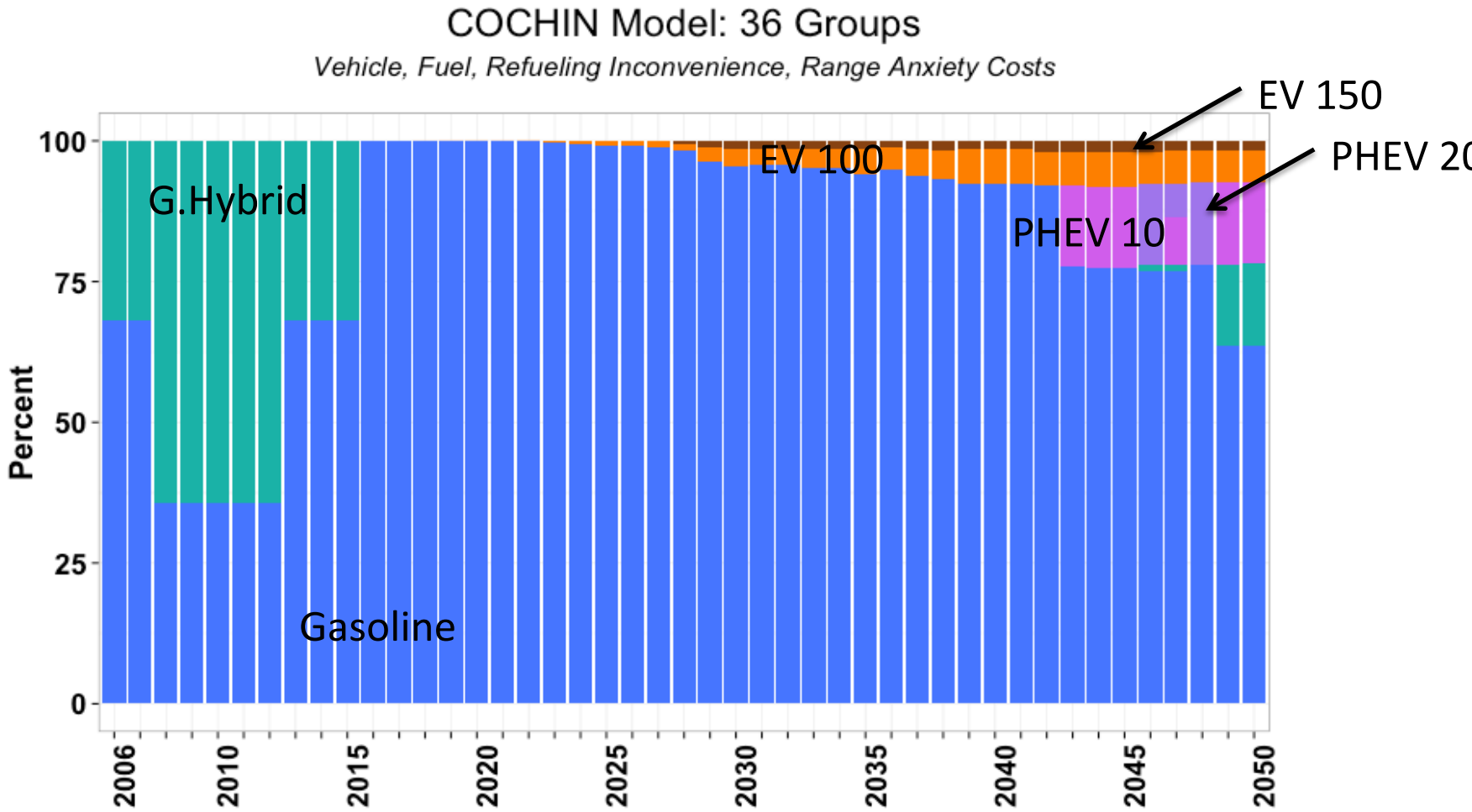
+ Range Anxiety Cost (WITH public recharging)



- Due to public recharging availability, high annual VMT drivers invest in plugins towards the end of the model time period.

COCHIN: Annual Sales Share

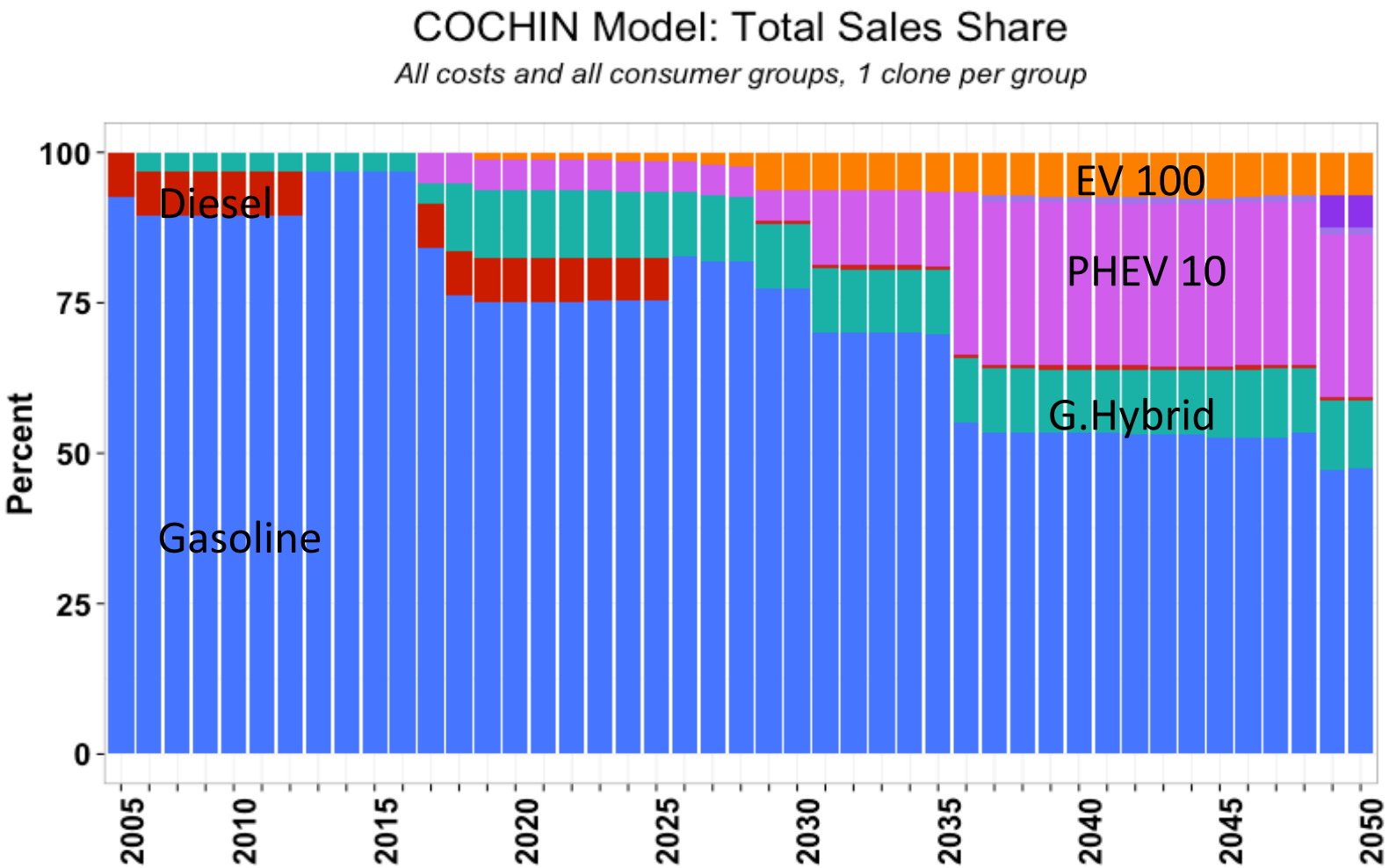
36 consumer groups: 3 driver groups, 4 recharging levels, 3 risk attitudes



- PHEV 10s are chosen by late majority frequent drivers, and PHEV 20s are chosen by early majority frequent drivers.

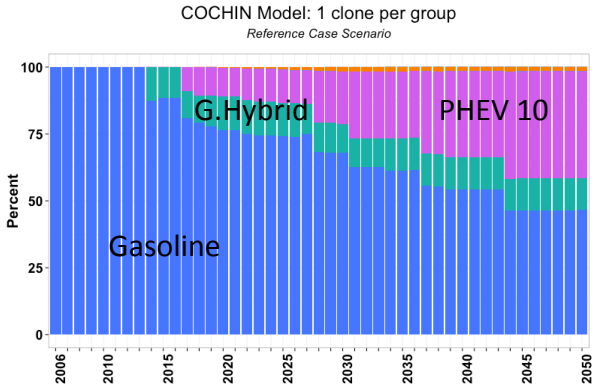
COCHIN: Annual Sales Share

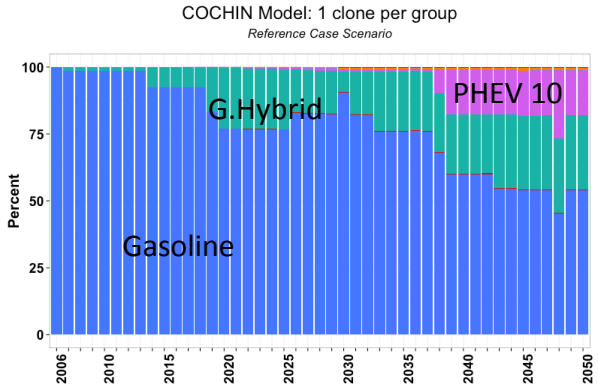
+ 1 clone per group

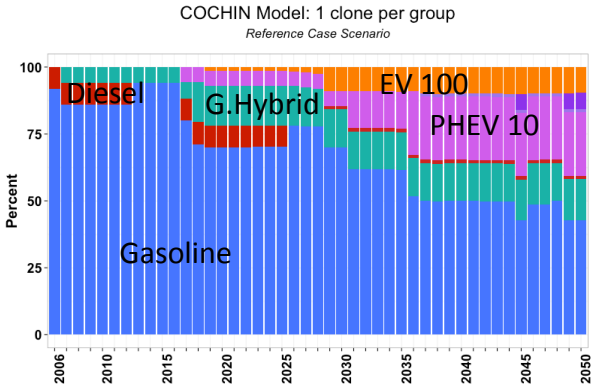


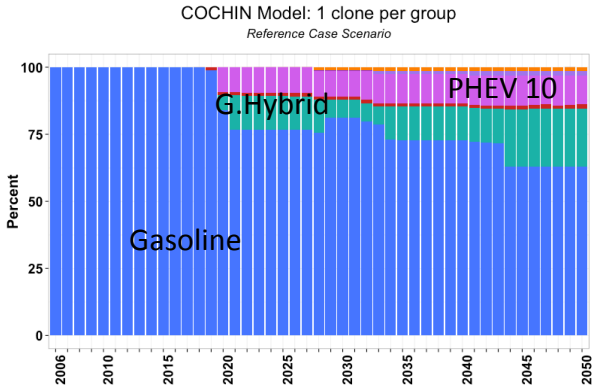
- Light-duty trucks enter the mix in the model results after adding the clones for every group.

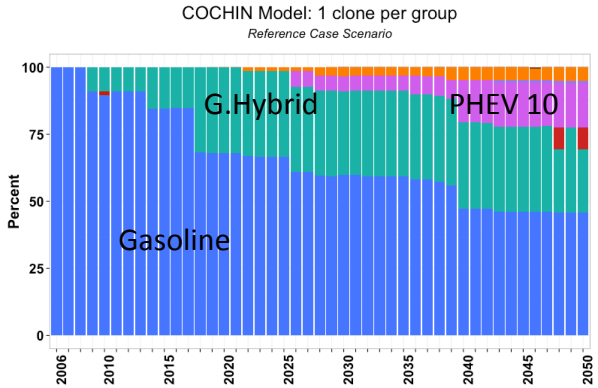
Random runs of COCHIN Model (1 clone per group)

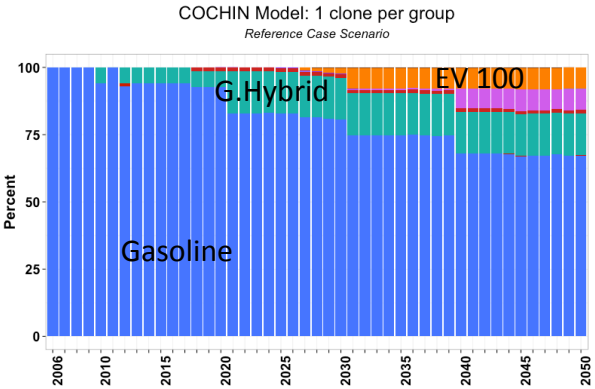


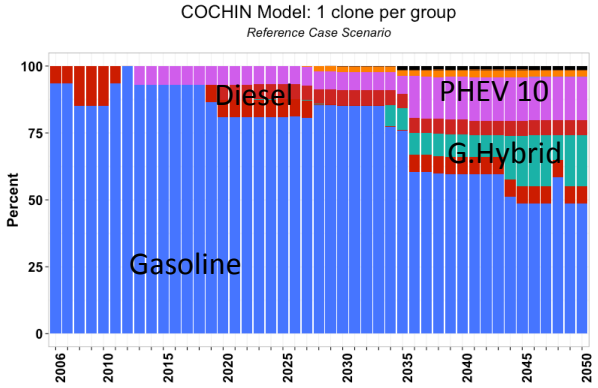


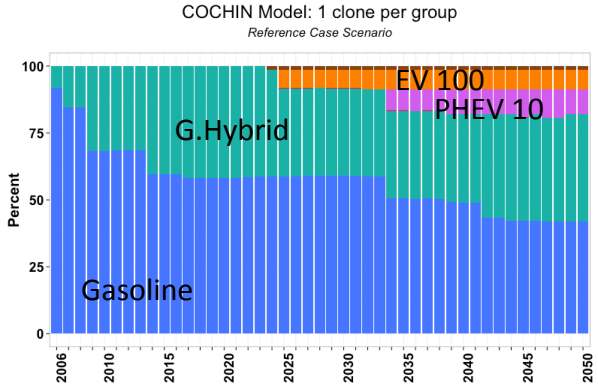


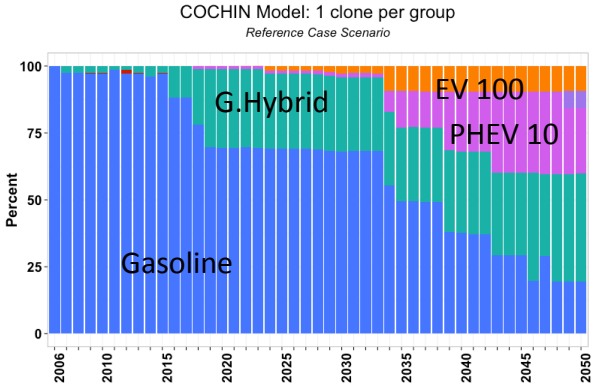






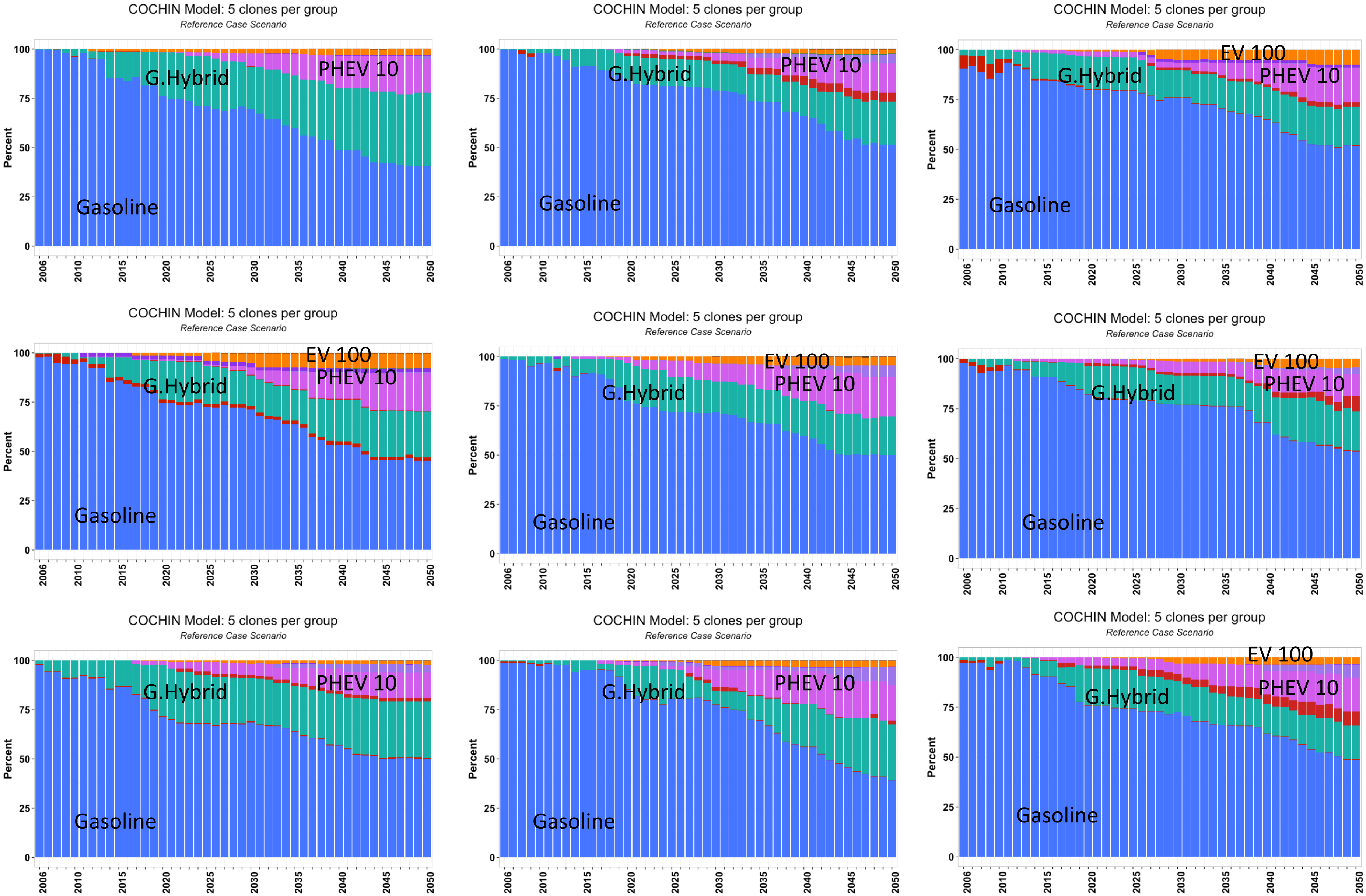






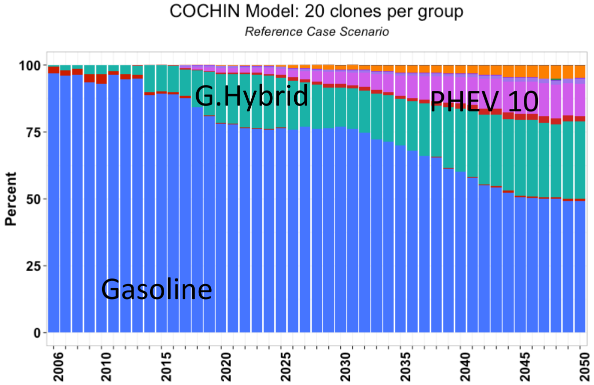
ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

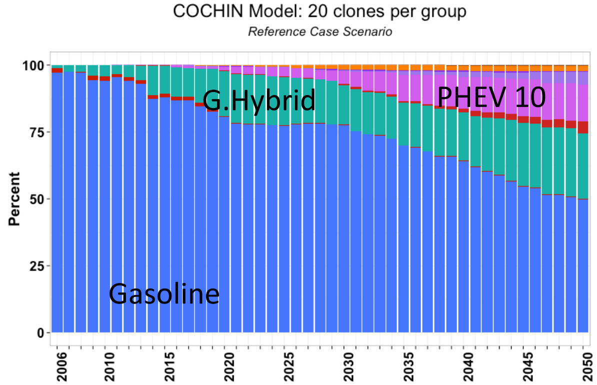
Random runs of COCHIN Model (5 clones per group)

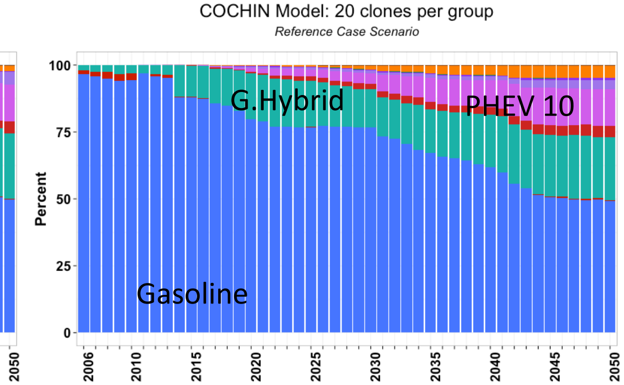


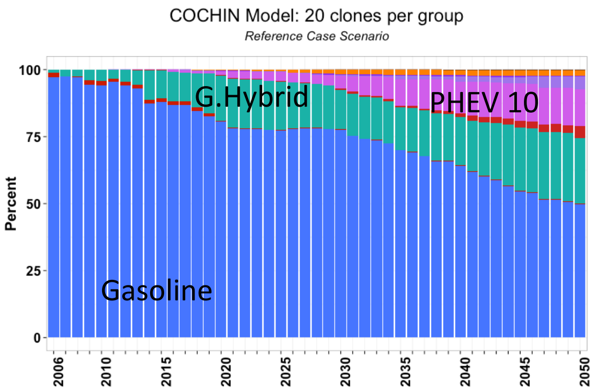
ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

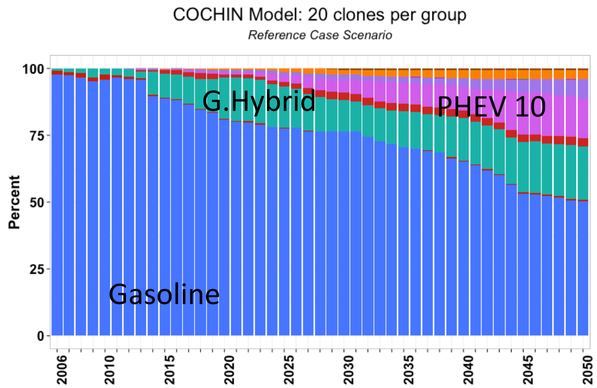
Random runs of COCHIN Model (20 clones per group)

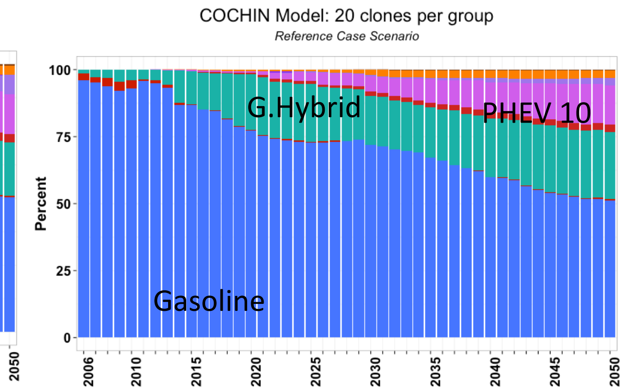


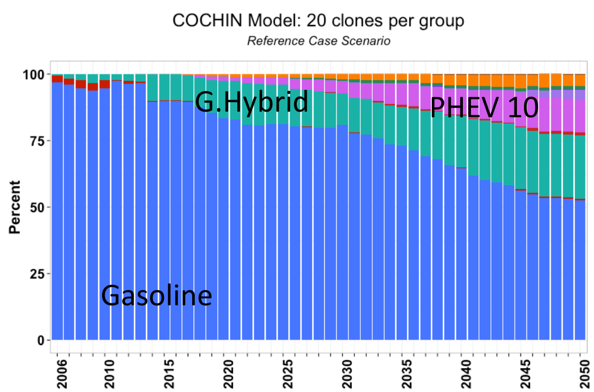


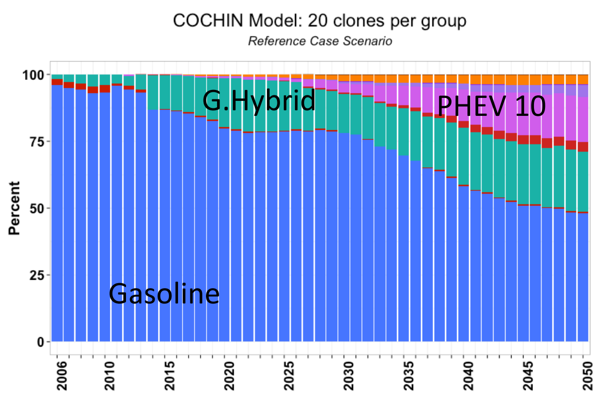


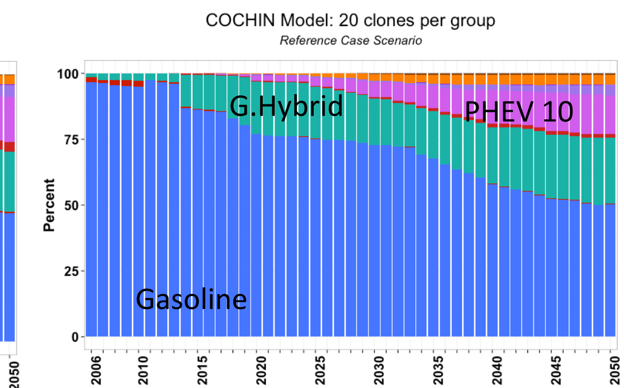












ITS UCDAVIS
INSTITUTE OF TRANSPORTATION STUDIES

COCHIN Vs. MA^{3}T: Annual Sales Share

G.Hybrid: Gasoline Hybrid

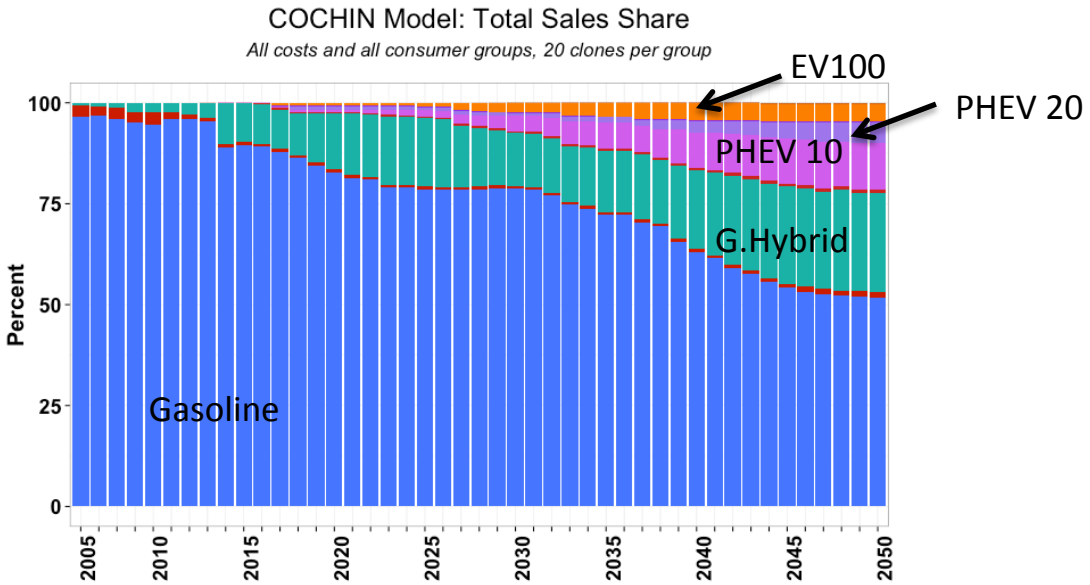
PHEV 10: Plugin 10-mile range

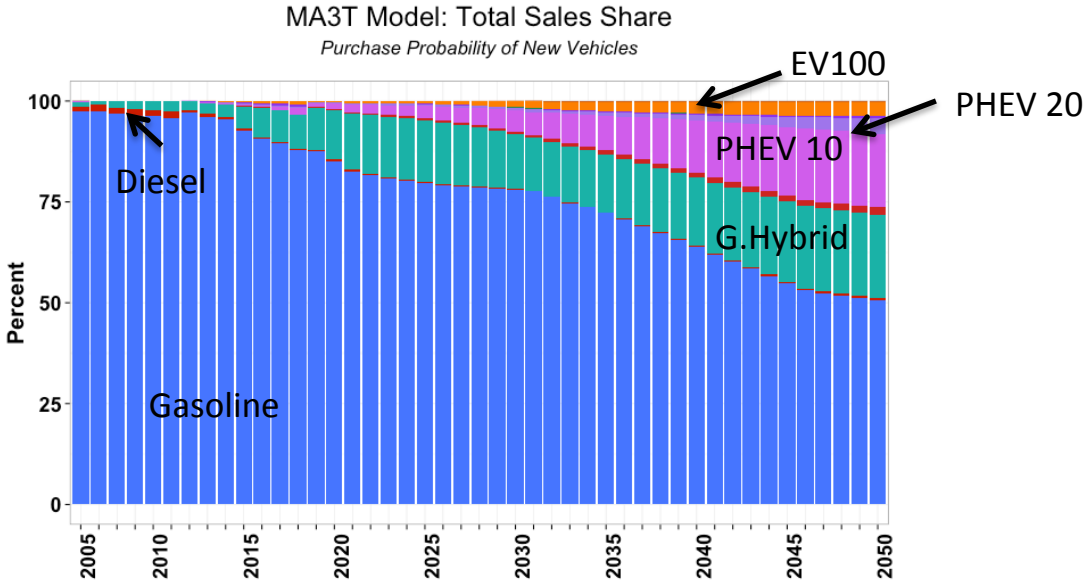
PHEV 20: Plugin 20-mile range

EV 100: Battery electric vehicle 100 mile range

FCV: Fuel cell vehicle

FP: Fuel cell plugin





ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

COCHIN Vs. MA^{3}T: Annual Sales Numbers

Total LDV sales numbers are taken from AEO 2014 Sales Numbers

G.Hybrid: Gasoline Hybrid

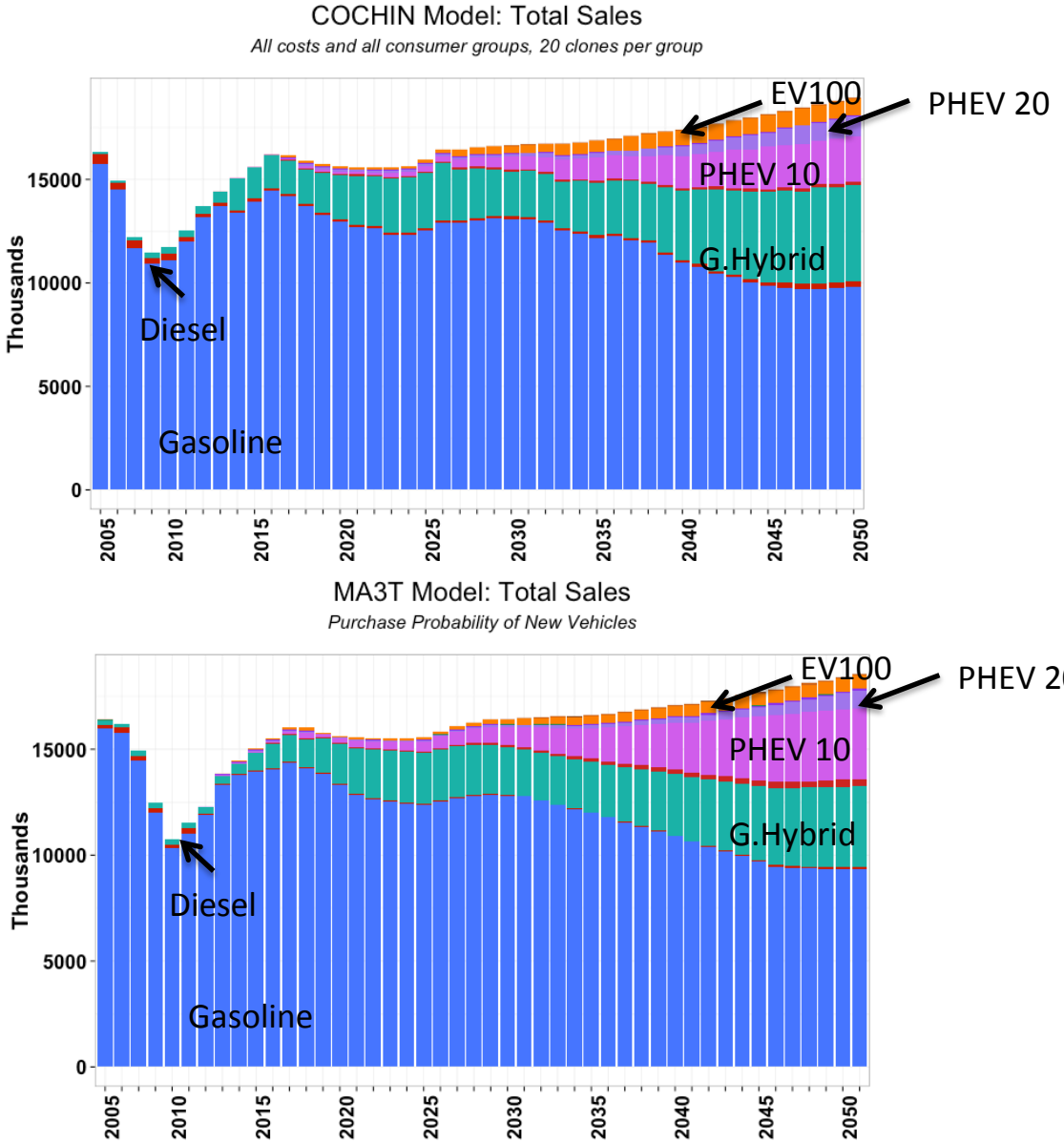
PHEV 10: Plugin 10-mile range

PHEV 20: Plugin 20-mile range

EV 100: Battery electric vehicle 100 mile range

FCV: Fuel cell vehicle

FP: Fuel cell plugin



ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

Summary and Work in Progress

- COCHIN 1.0
  - LDV-only model mimics consumer choice behavior similar to MA^{3}T model
  - Demand heterogeneity, disutility costs and random error distribution added as 'costs' to introduce nested-logit structure
  - Results can be reproduced for various scenarios
  - Model approach itself has a broad application—can be applied to any region, any sector (provided we have the data)
- COCHIN 2.0
  - Improves limitations of MA^{3}T—multiple levels of public recharging infrastructure (for example, co-existence of Level II and fast charging), better representation of spatiality
  - Incorporates endogeneity on station availability, risk premium and model diversity calculations
  - Need to perform sensitivity analysis and generate policy scenarios
- Currently COCHIN methodology is being integrated in the full CA-TIMES model
  - Policy analysis such as carbon cap, infrastructure investment, vehicle subsidies, etc.

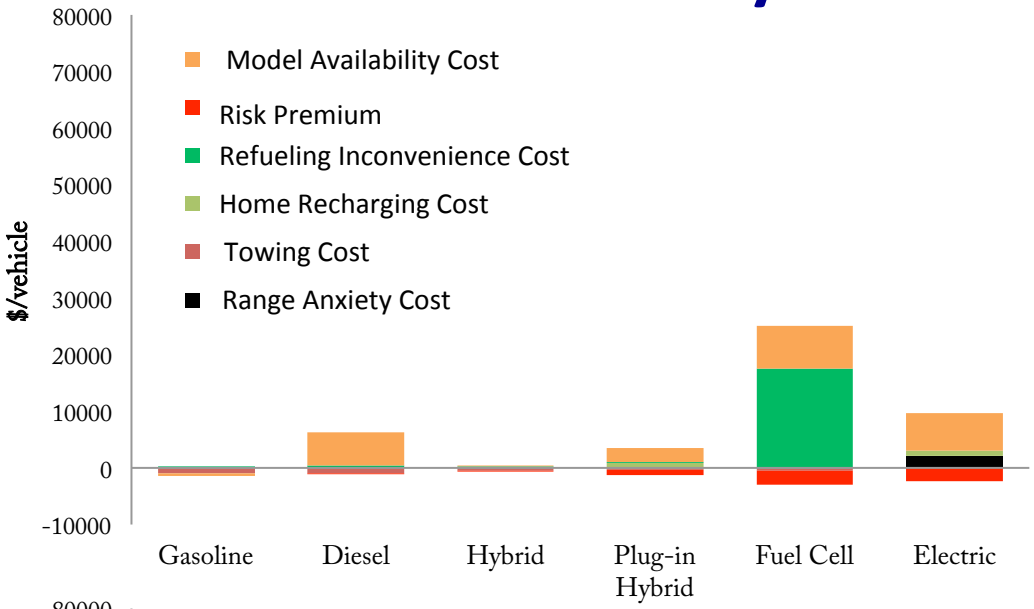
Working paper on the economic theory behind COCHIN-TIMES can be found at this link: http://gsm.ucdavis.edu/faculty/david-s-bunch
under " Research Articles".

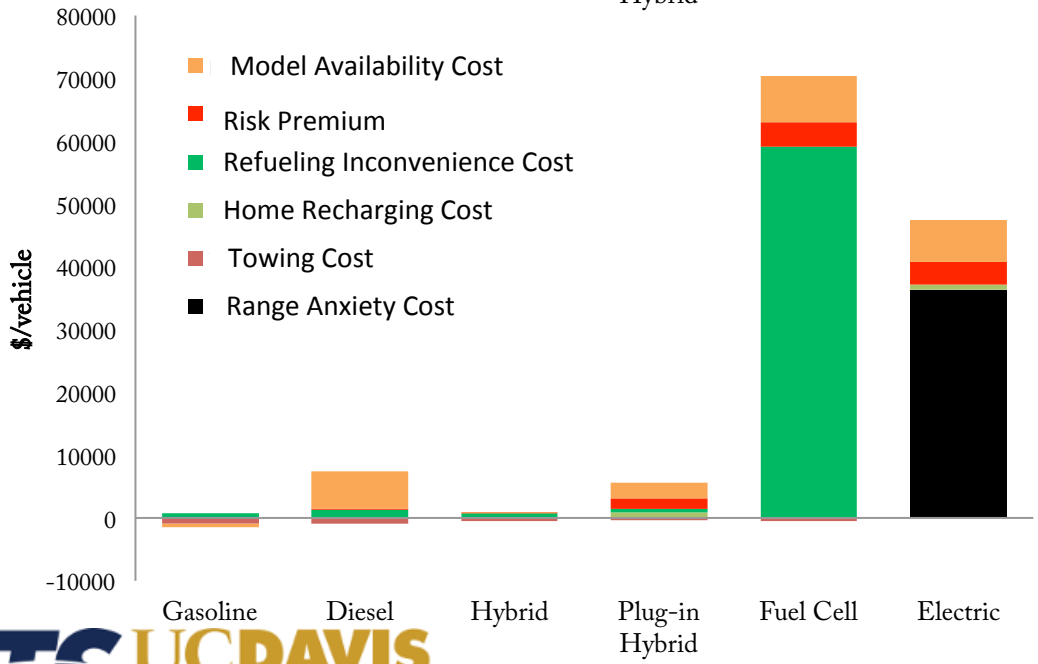
QUESTIONS?

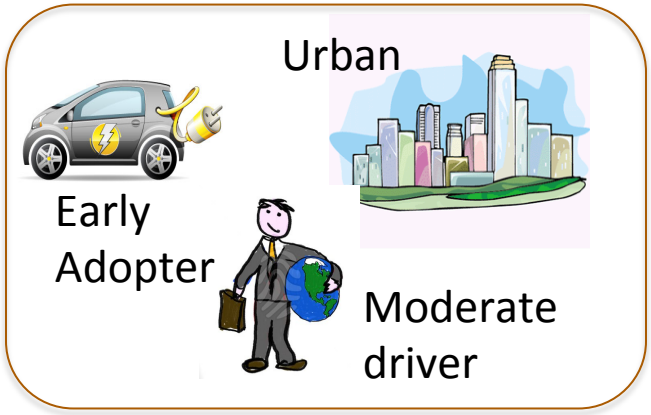
Email: kramea@ucdavis.edu

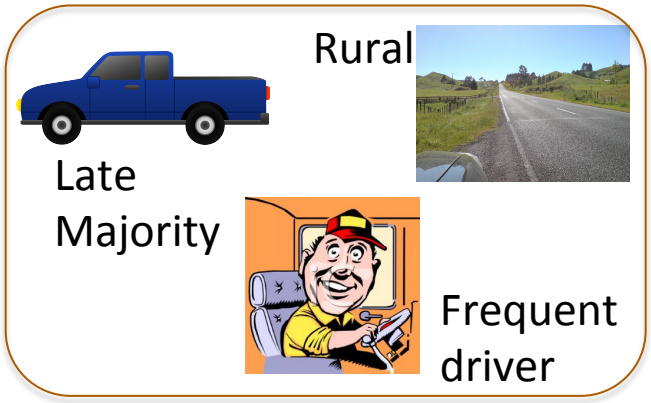
ADDITIONAL SLIDES

Disutility Cost Components

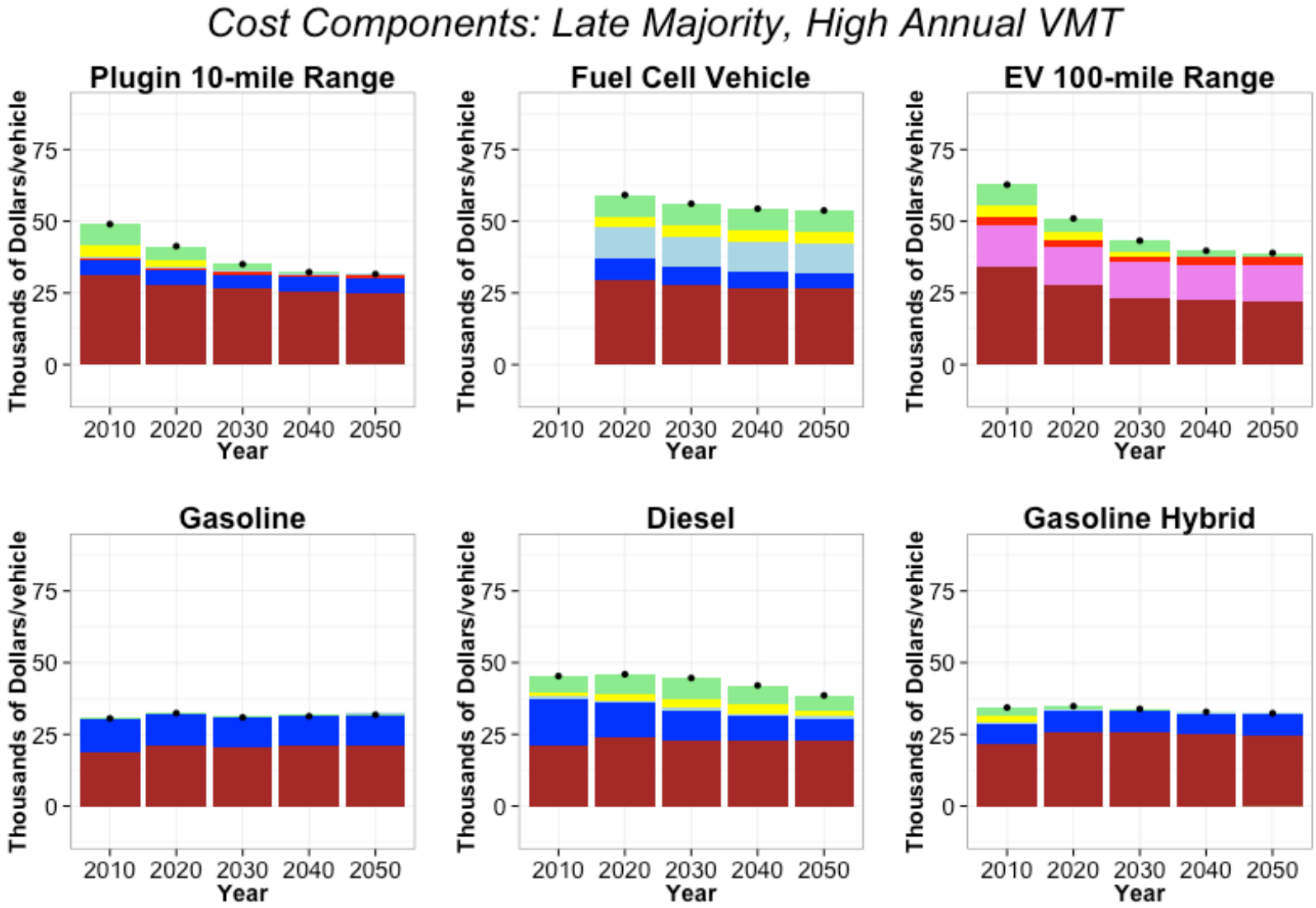








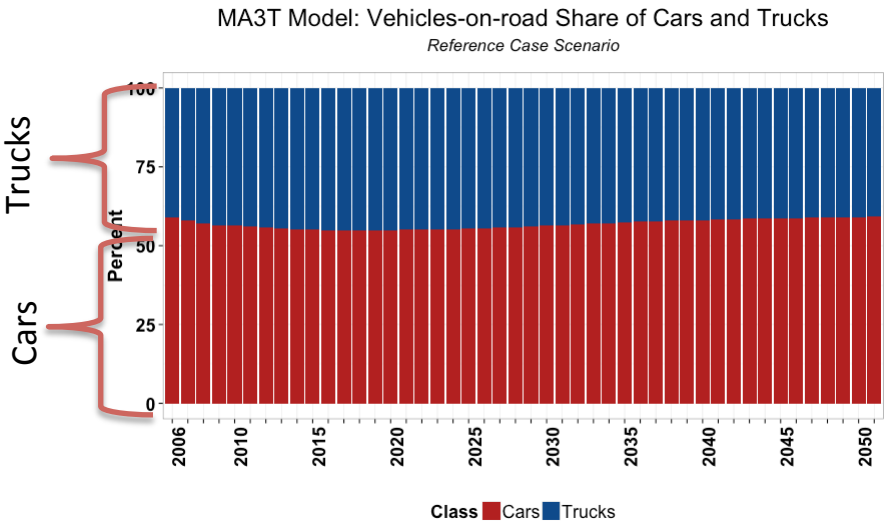
Has access to both home and work recharging

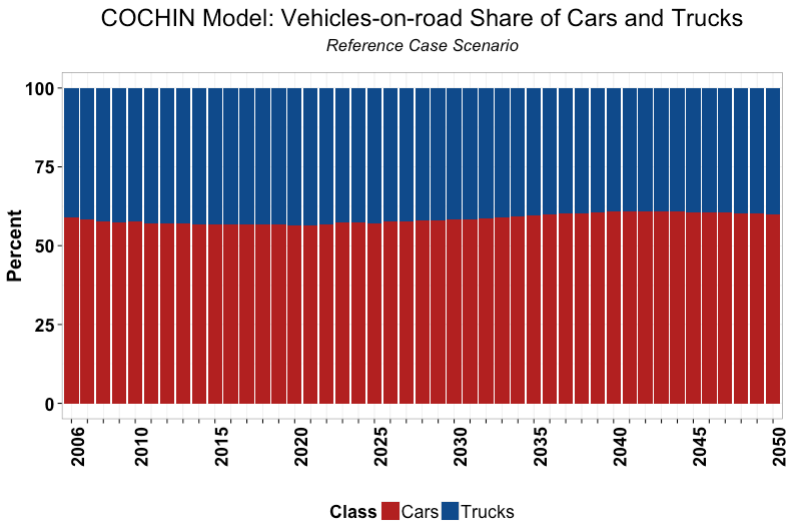


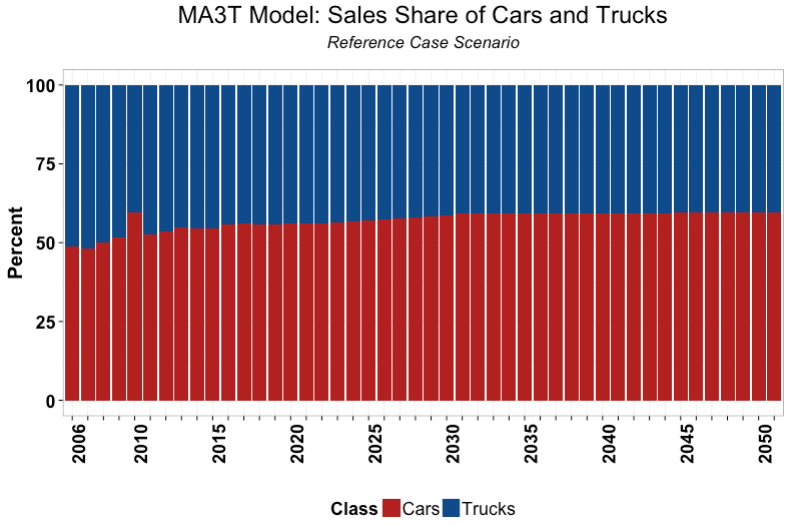
Consistency between TIMES and MA^{3}T

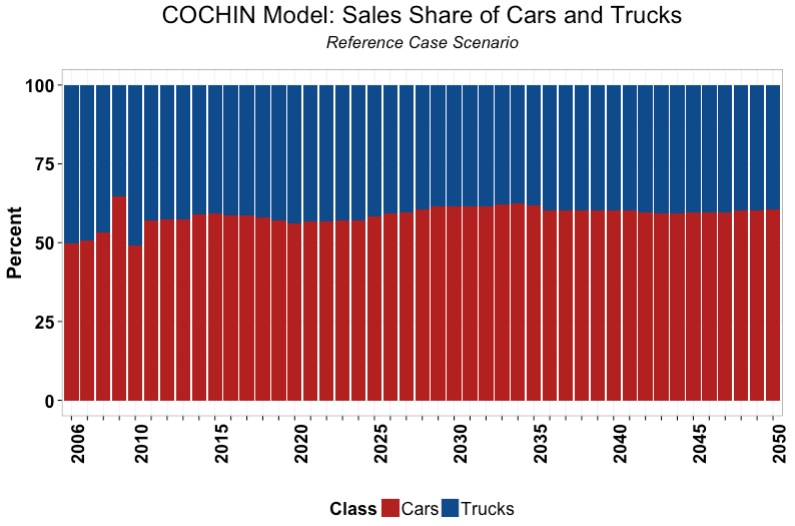
- Household VMT is essentially taken as a "given", it is not part of the choice process
- The only thing that differentiates competing vehicle technologies from one another is the "negative utility" associated with their *costs*
- Both TIMES and MA^{3}T models view the consumer's planning horizon "as if" the vehicle were purchased new and driven for the entire life of the vehicle (i.e., there is no explicit modeling of the used vehicle market)
- In both approaches, the vehicle is (generally) assumed to have a technical lifetime (*L* years)
- Both models are "essentially" based on cost minimization
- The approaches recognize two basic types of costs: a fixed costs based on acquisition of the vehicle, and variable costs based on distance traveled

Share of Cars and Trucks: MA3T and COCHIN (20 clones)





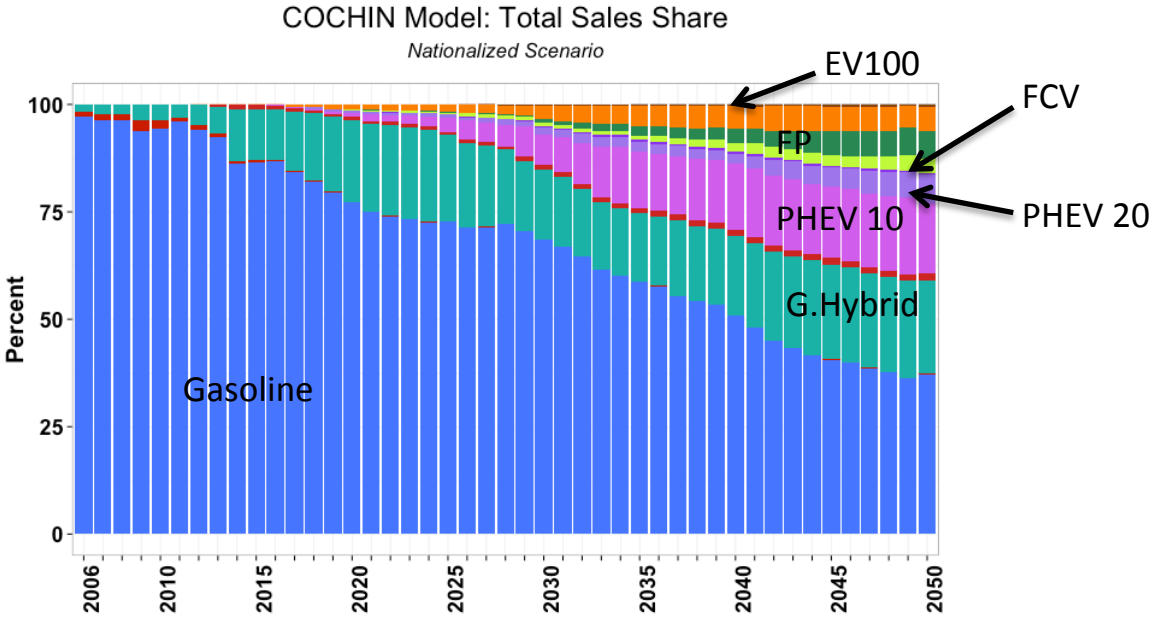


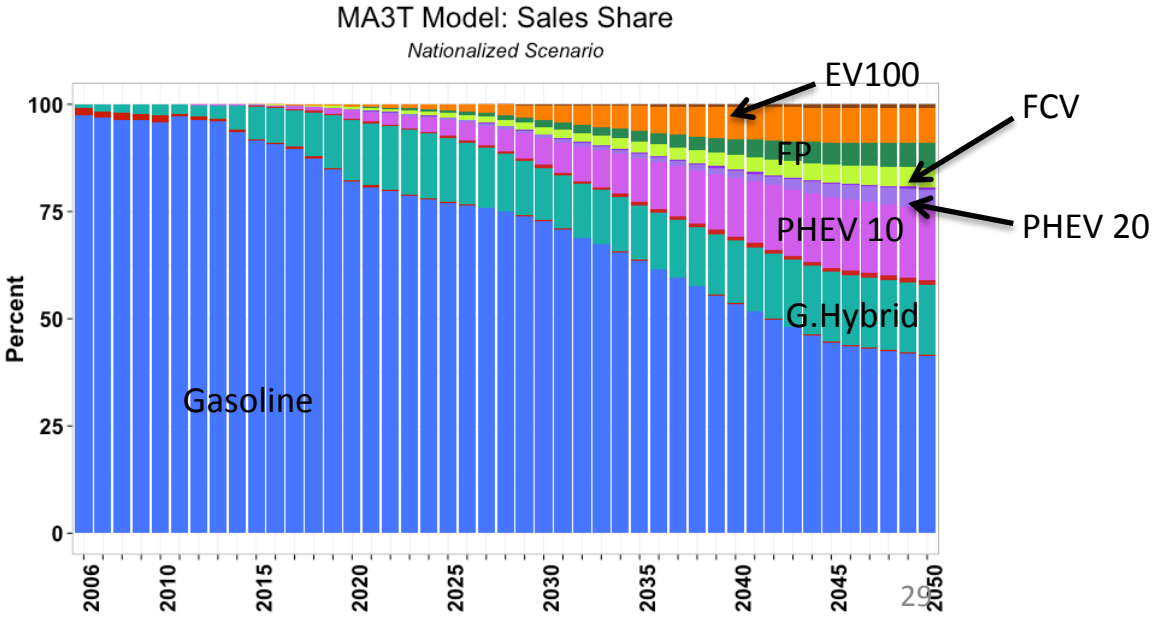


Infrastructure Scenario: MA3T vs. COCHIN (20 clones)

Illustrative infrastructure scenario:

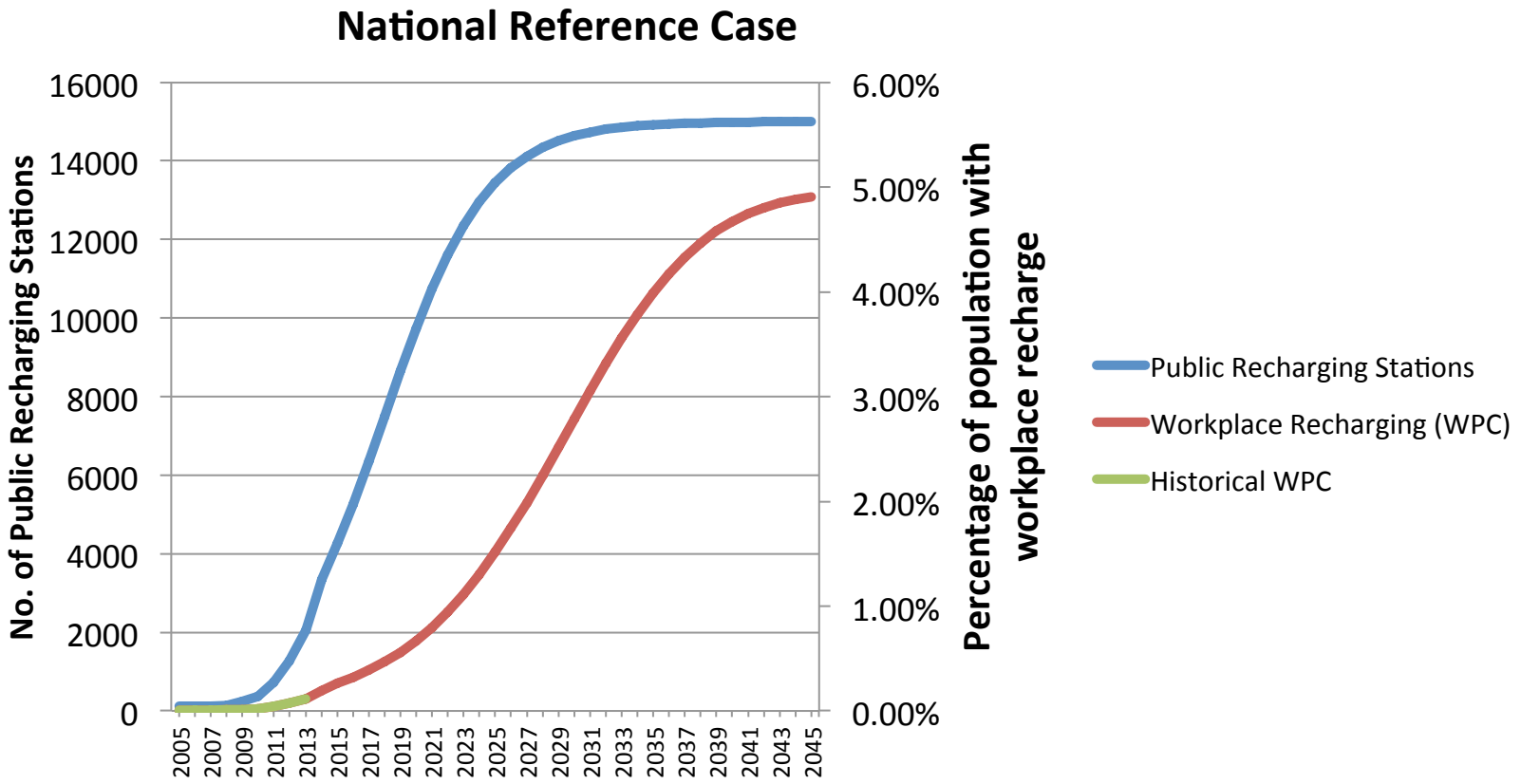
- Public recharging reaches 35,000 stations by 2025.
- Hydrogen infrastructure reaches 3000 stations by 2035
- Workplace recharging reaches 18% population in 2050 (ref. case: 5%)



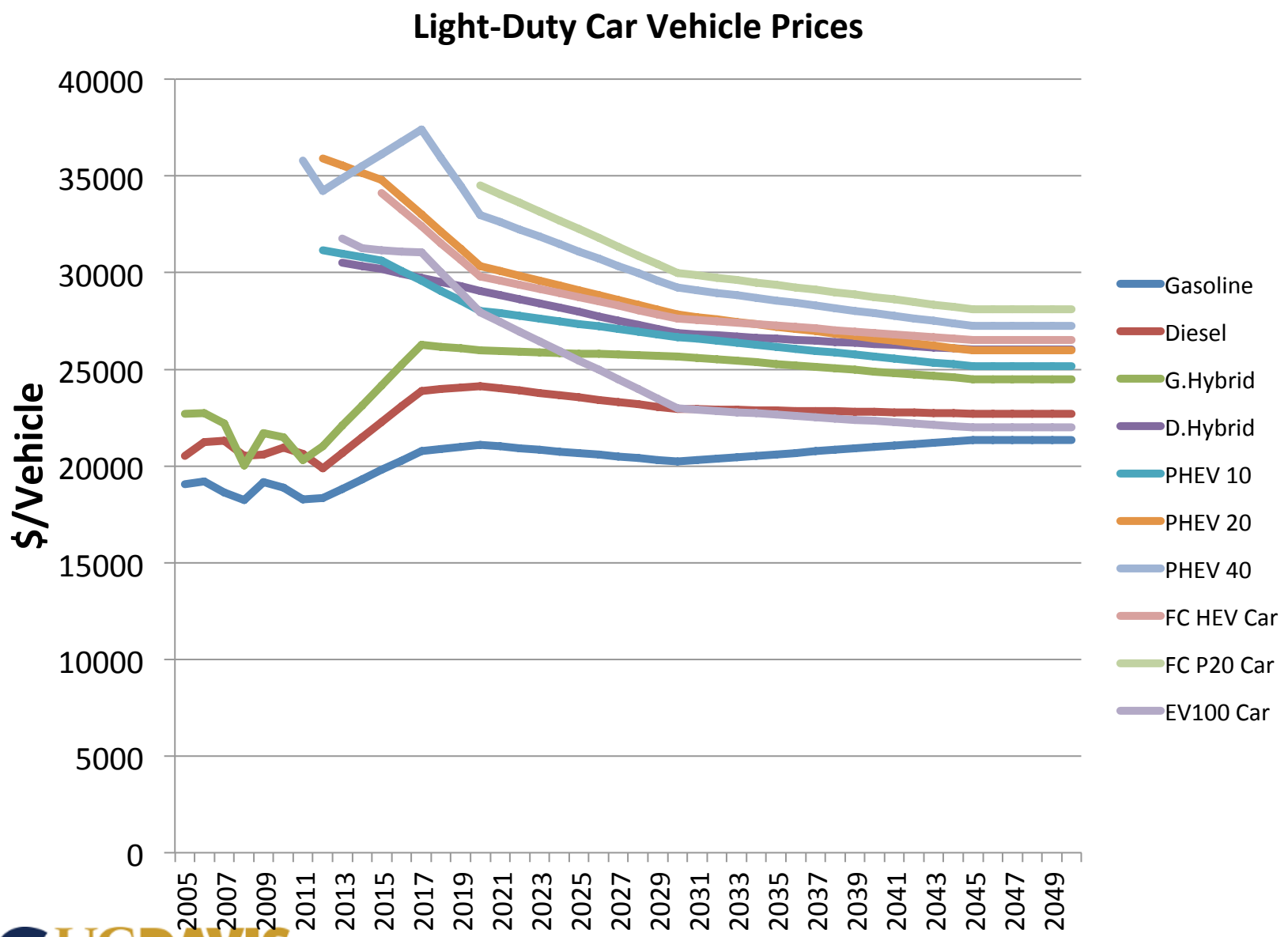


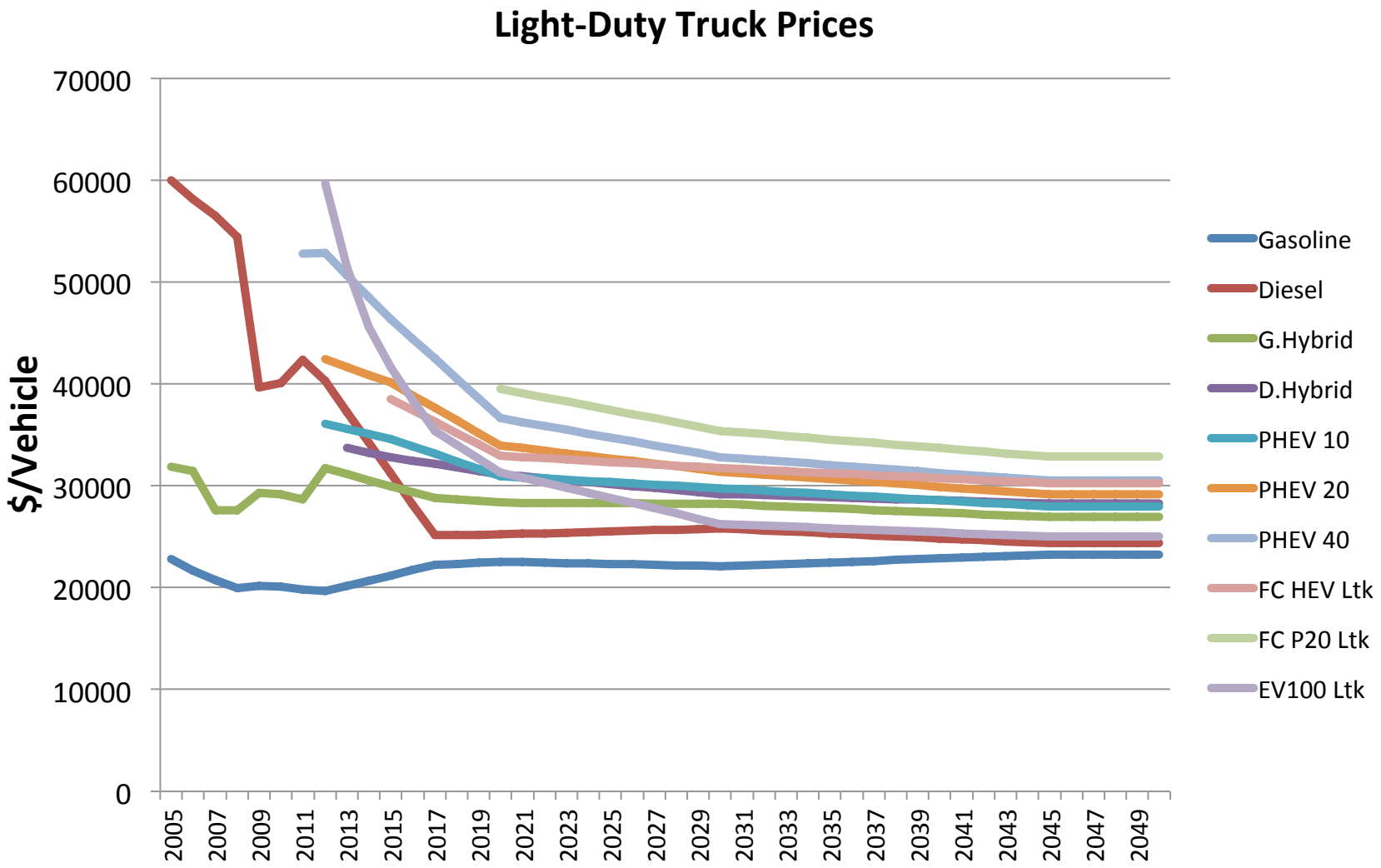
ITS UCDAVIS INSTITUTE OF TR

National Reference Case Infrastructure Growth Curves

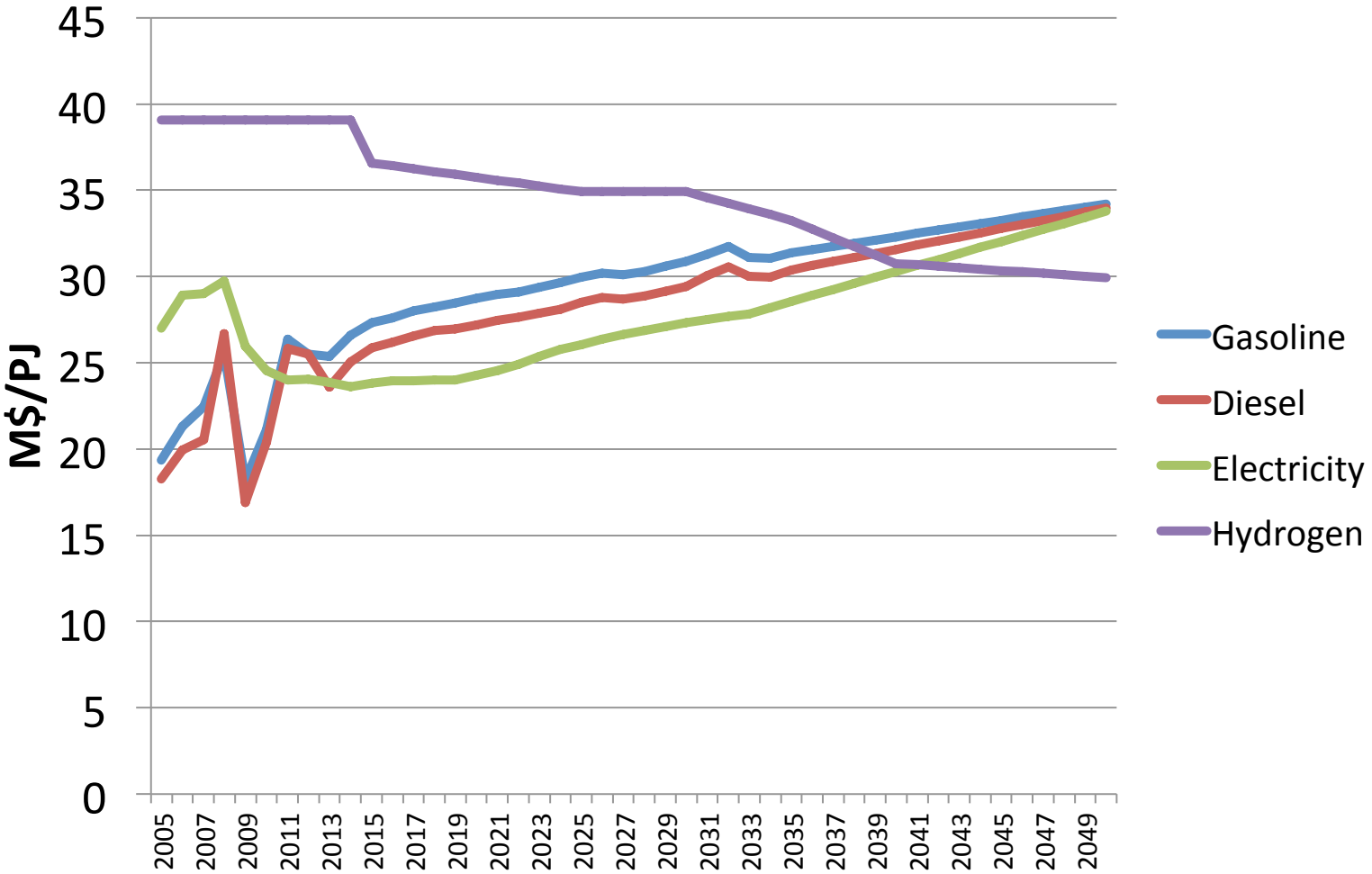


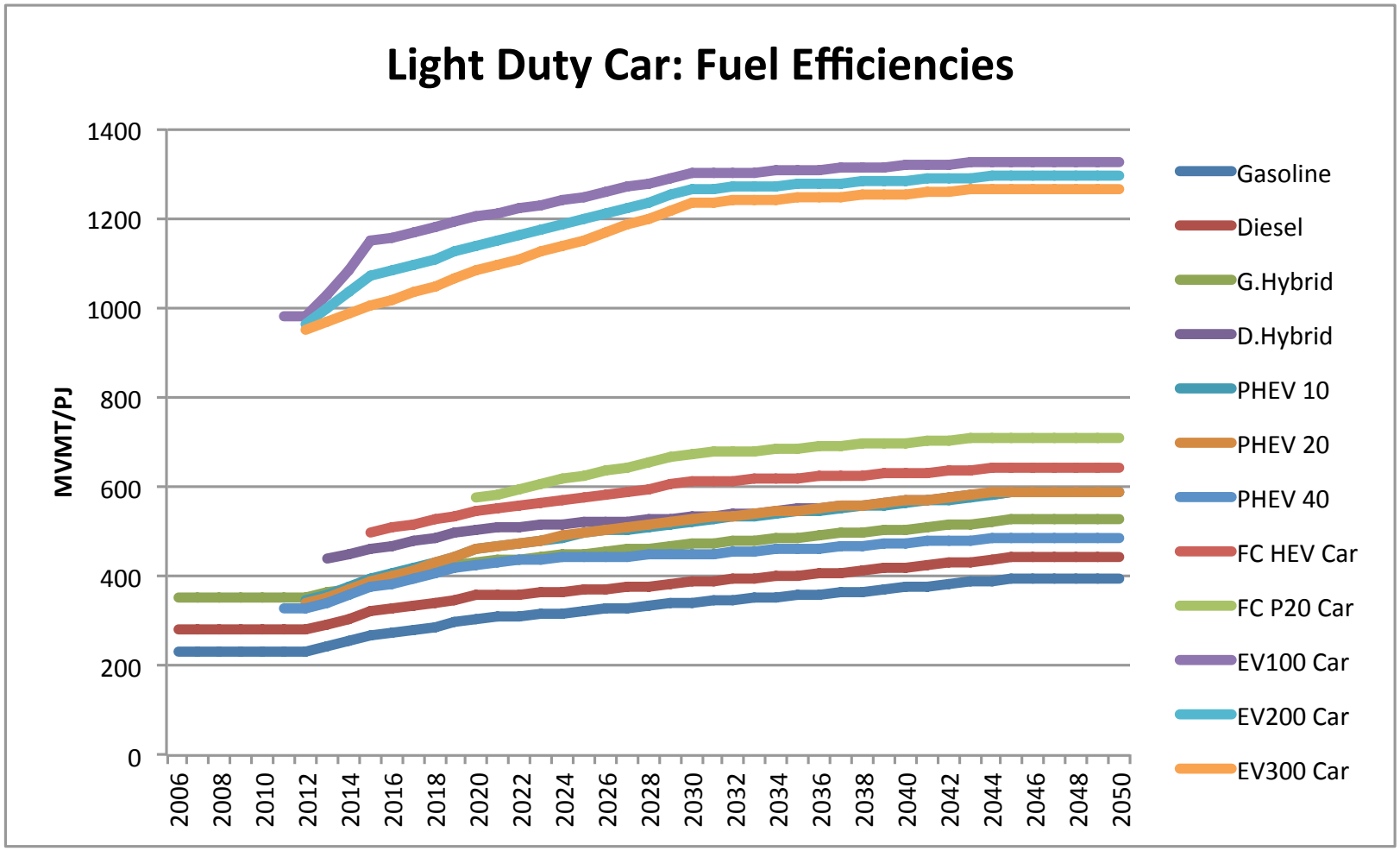
- All public and workplace recharging stations are LEVEL II stations (6kW power)
- Each public recharging station is assumed to have an average of 3 recharge points

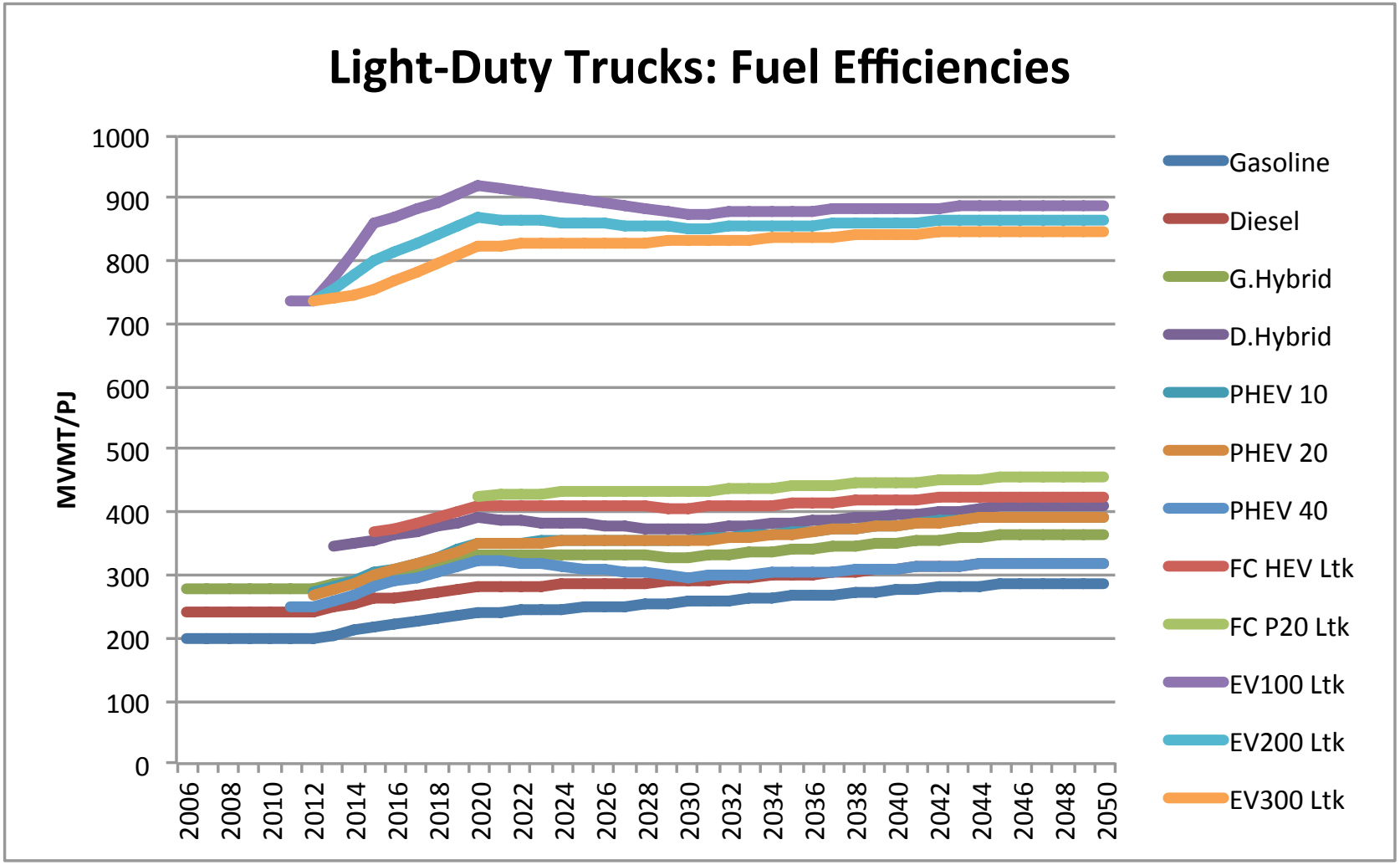

Light-Duty Car Vehicle Prices
$/Vehicle
40000
35000
30000
25000
20000
15000
10000
5000
0
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Gasoline
Diesel
G.Hybrid
D.Hybrid
PHEV 10
PHEV 20
PHEV 40
FC HEV Car
FC P20 Car
EV100 Car


Light-Duty Truck Prices
$/Vehicle
70000
60000
50000
40000
30000
20000
10000
0
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Gasoline
Diesel
G.Hybrid
D.Hybrid
PHEV 10
PHEV 20
PHEV 40
FC HEV Ltk
FC P20 Ltk
EV100 Ltk

Fuel Prices


M$/PJ
45
40
35
30
25
20
15
10
5
0
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
Gasoline
Diesel
Electricity
Hydrogen


Light Duty Car: Fuel Efficiencies
MVMT/PJ
1400
1200
1000
800
600
400
200
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050
Gasoline
Diesel
G.Hybrid
D.Hybrid
PHEV 10
PHEV 20
PHEV 40
FC HEV Car
FC P20 Car
EV100 Car
EV200 Car
EV300 Car


Light-Duty Trucks: Fuel Efficiencies
MVMT/PJ
1000
900
800
700
600
500
400
300
200
100
0
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050
Gasoline
Diesel
G.Hybrid
D.Hybrid
PHEV 10
PHEV 20
PHEV 40
FC HEV Ltk
FC P20 Ltk
EV100 Ltk
EV200 Ltk
EV300 Ltk