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Electrification and Decarbonization

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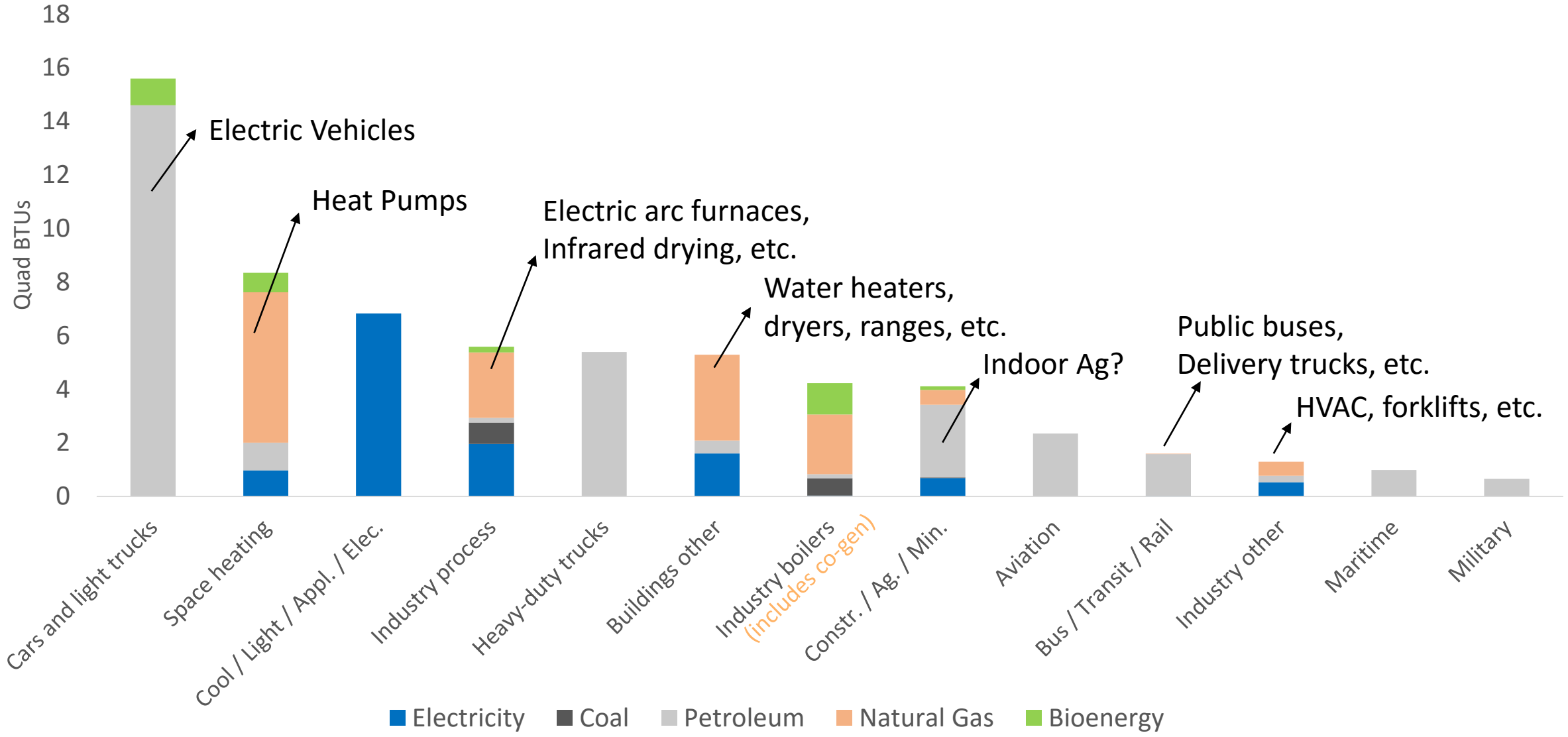
Reducing carbon emissions through electrification

- In many cases, replacing fossil fuels with electricity at the end-use results in lower overall carbon emissions
  - Leverage will only increase with tighter constraints on power sector CO2
- Key questions:
  - What are the potential drivers?
  - How much fossil use could be cost-effectively replaced by electricity even without a carbon price?
  - For the remainder, how does carbon pricing change the equation, i.e. how does electrification compare with other mitigation options?
  - In either case, how do we think about adoption and diffusion in the context of consumer behavior?

Potential Drivers of Electrification

- Policy drivers (at federal, state, or local level)
  - Economy-wide carbon incentives
  - Sector-specific targets or mandates
  - Air quality regulations in non-attainment areas
- Non-policy drivers
  - Technological change (e.g., declining battery costs)
  - Fuel markets
  - New business models (e.g., autonomous vehicles, indoor agriculture)
  - Changing rate structures

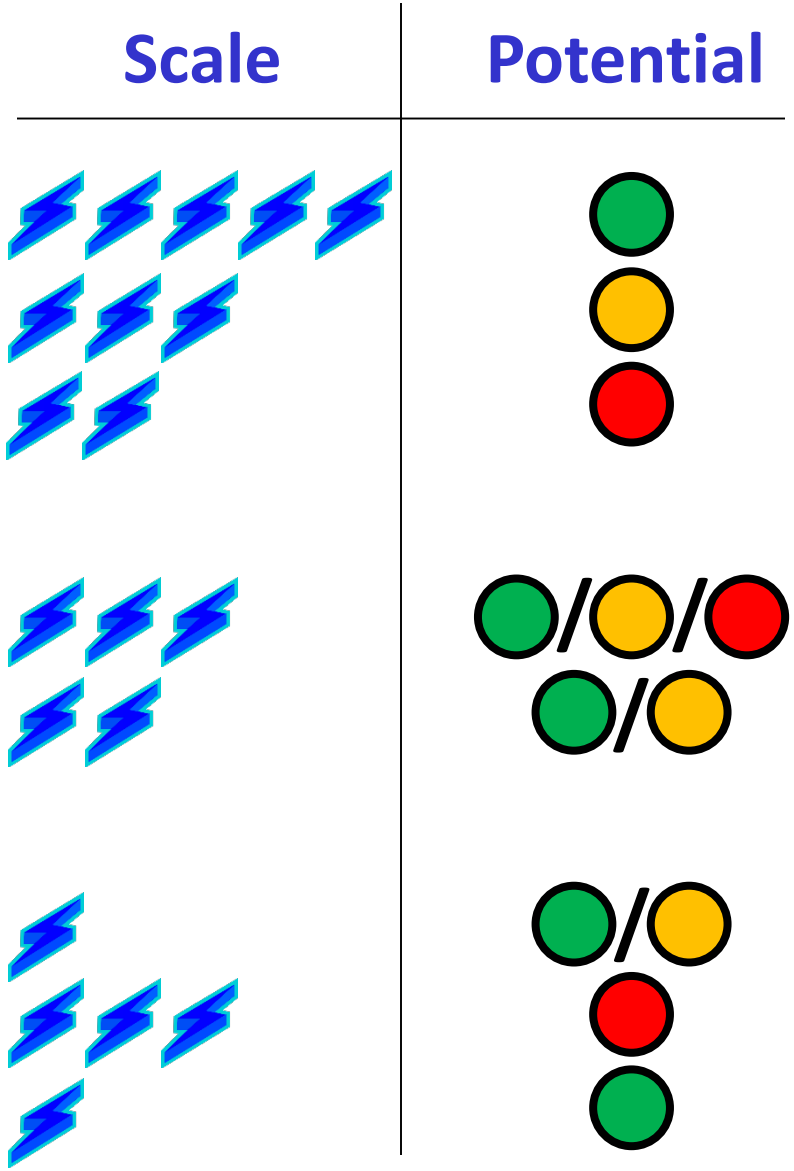
Final Energy by Sector / End-Use (2014)



** Excludes upstream and midstream energy use, e.g. power generation, oil & gas extraction, refining, and pipelines*

Electrification Prospects by Sector

- Transportation
  - Light duty vehicles
  - Heavy duty road vehicles
  - Other
- Buildings
  - Heat pumps for space heating
  - Water heaters / dryers / ranges
- Industry
  - Specialized / low-heat process
  - Boilers / high-heat process
  - Facility energy use



US-REGEN End-Use Model

Building Data
(RECS / CBECS)

Industrial Energy
(MECS)

Industrial Mix
(IMPLAN)

Hourly Temperature
(MERRA)

Vehicle/Driver Data
(NHTS)

Service Demands
(AEO)

Cost/Performance
(EPRI)

Energy Prices

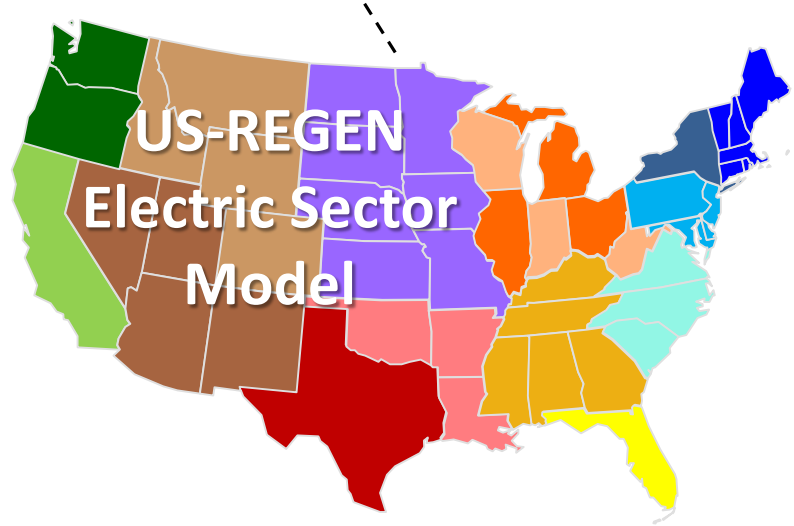
End-Use Simulation Model

Choice by region/vintage/sector/ class (e.g., climate zone/ consumer type)

Non-Electric Energy Use

Emissions/ Air Quality

Electricity Load Profile



Updated Electricity Prices

RECS = Residential Energy Consumption Survey (from EIA)
CBECS = Commercial Buildings Energy Consumption Survey (from EIA)
MECS = Manufacturing Energy Consumption Survey (from EIA)
IMPLAN = Impact Analysis for Planning (state- and industry-level economic data)
MERRA = Modern-Era Retrospective analysis for Research and Applications (gridded historical weather data from NASA)
NHTS = National Household Transportation Survey (US Department of Transportation)
AEO = Annual Energy Outlook (from EIA)

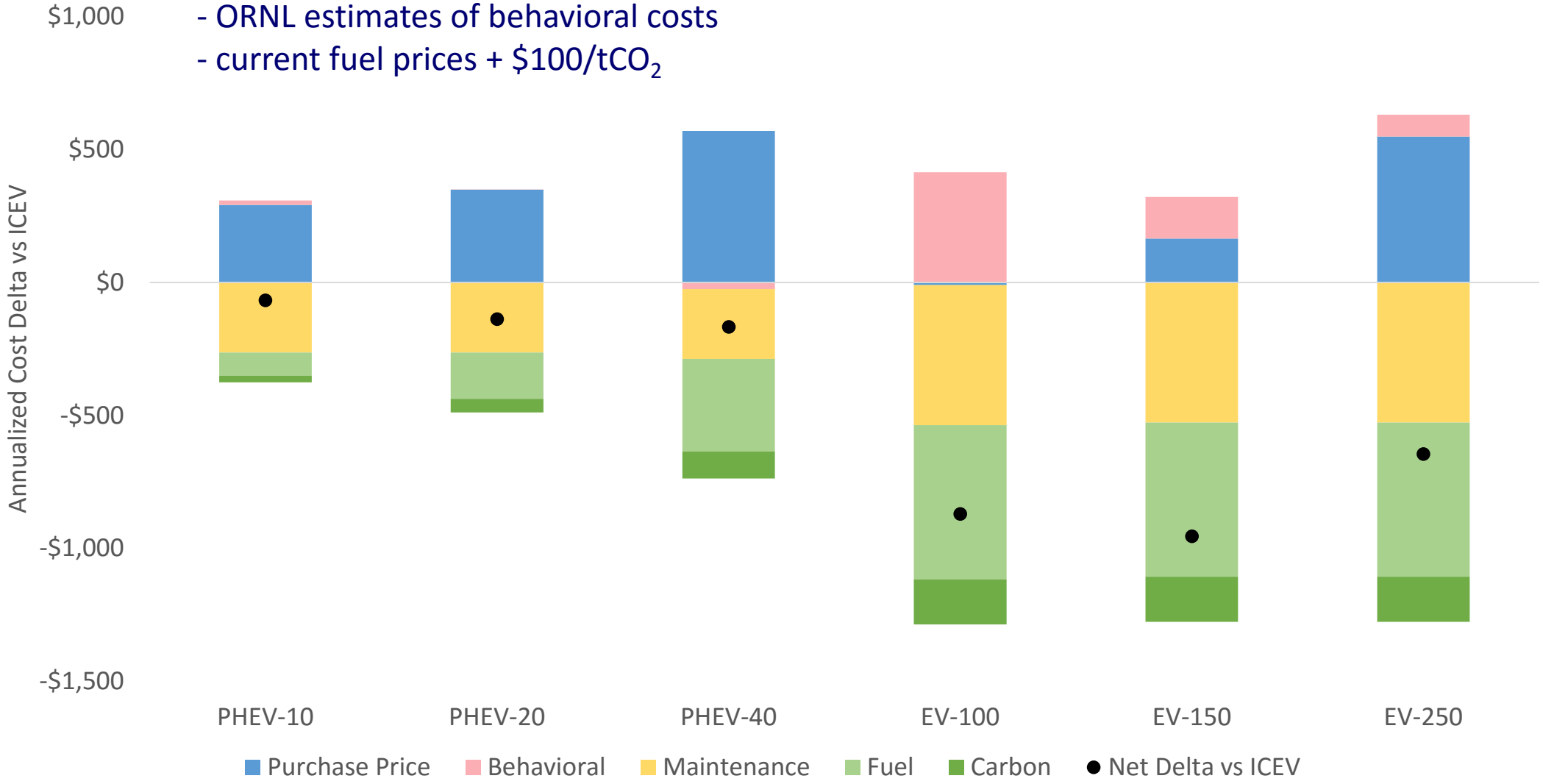
Light-Duty Vehicles

- Currently EVs and PHEVs have a very small market share but may be on the cusp of much more widespread deployment
  - Technology is moving fast, especially battery costs
  - Autonomous vehicle service could change the landscape dramatically
- Significant customer heterogeneity
  - Urban / Suburban / Rural
  - Low / Medium / High annual mileage
  - Single / multiple car households
  - Attitude / Access to electric charging / ride service
- Model trade-offs including economic and non-economic factors

Electric Vehicle Cost Delta vs Conventional Vehicle

- EPRI assumptions about vehicle costs for 2030 (no incentives)
- ORNL estimates of behavioral costs
- current fuel prices + $100/tCO$_2$

Median consumer type



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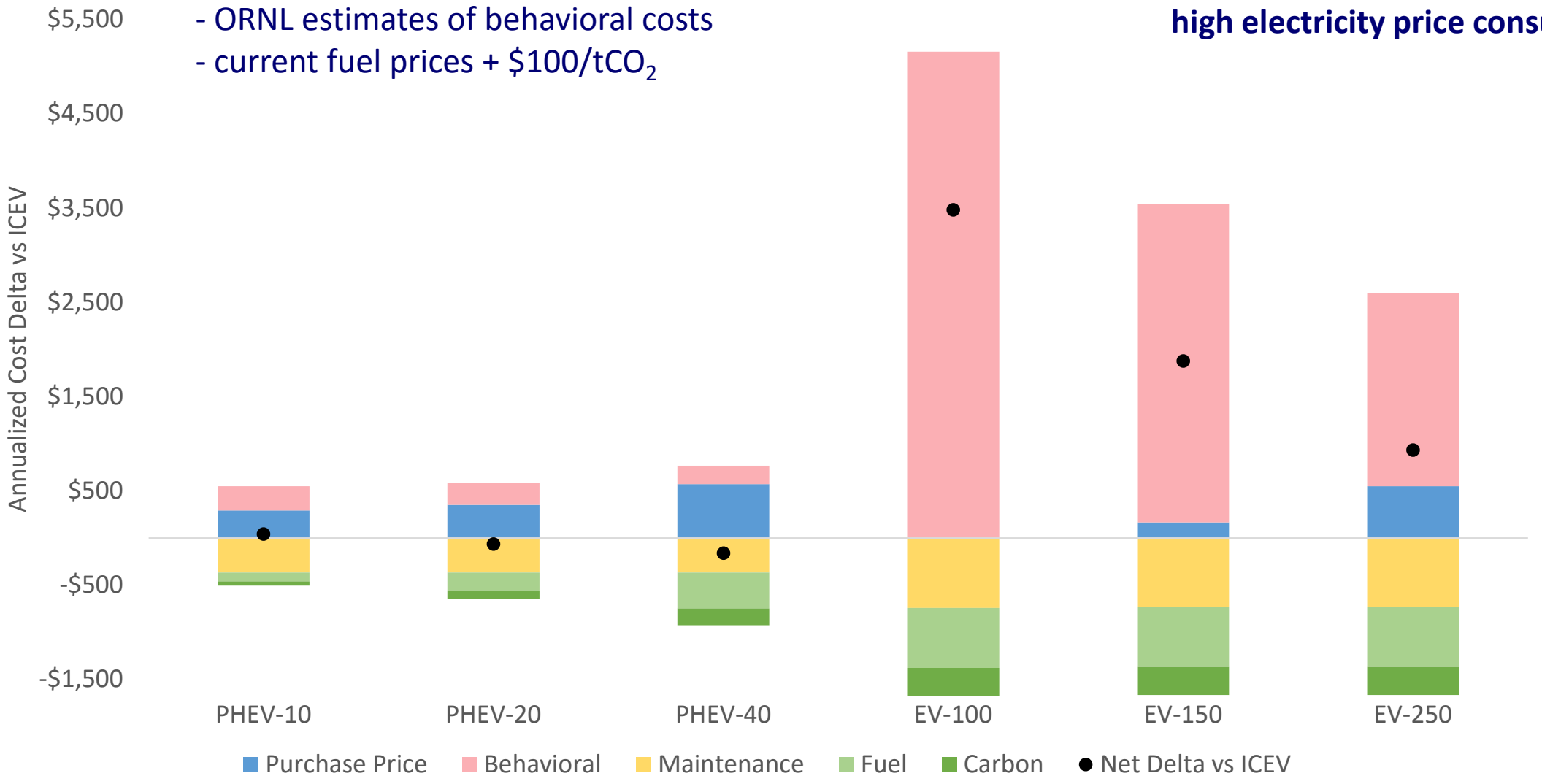
Electric vehicles may not work for all consumer types

- EPRI assumptions about vehicle costs for 2030 (no incentives)
- ORNL estimates of behavioral costs
- current fuel prices + $100/tCO$_2$

Rural, high mileage, late majority, high electricity price consumer type



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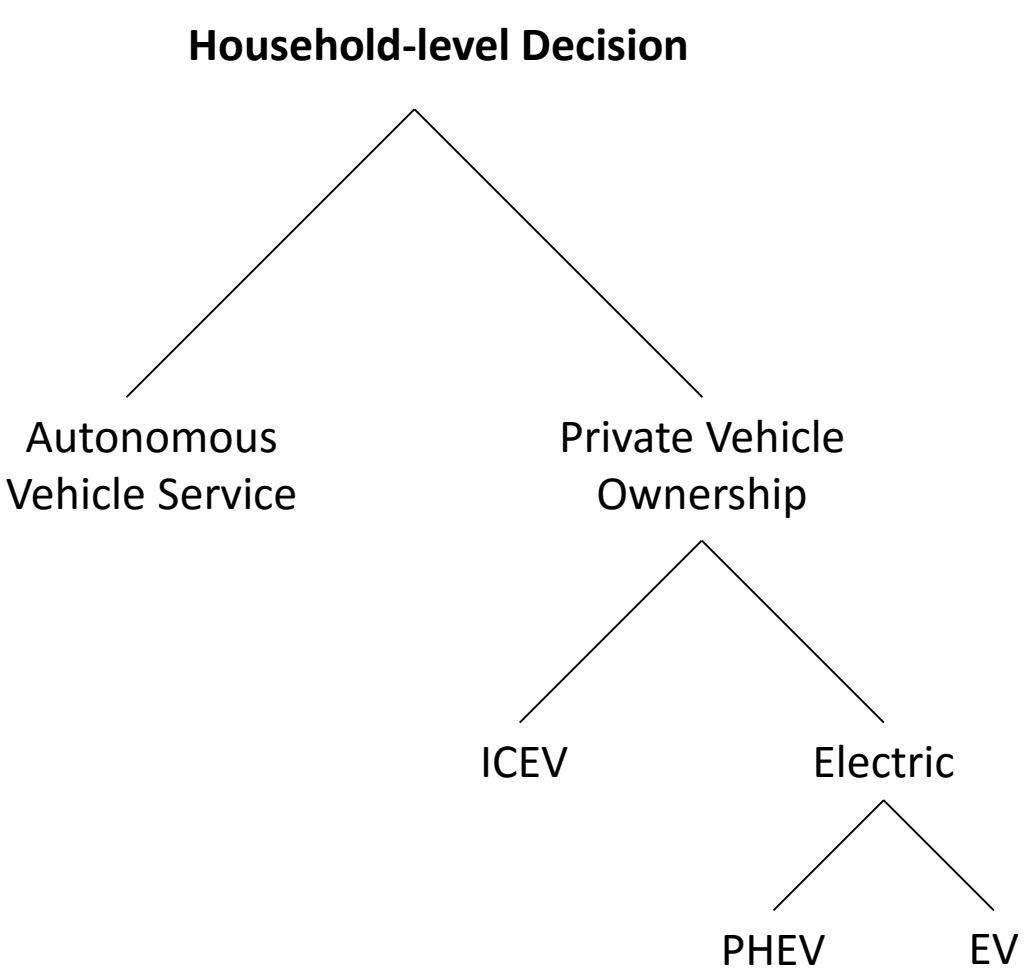
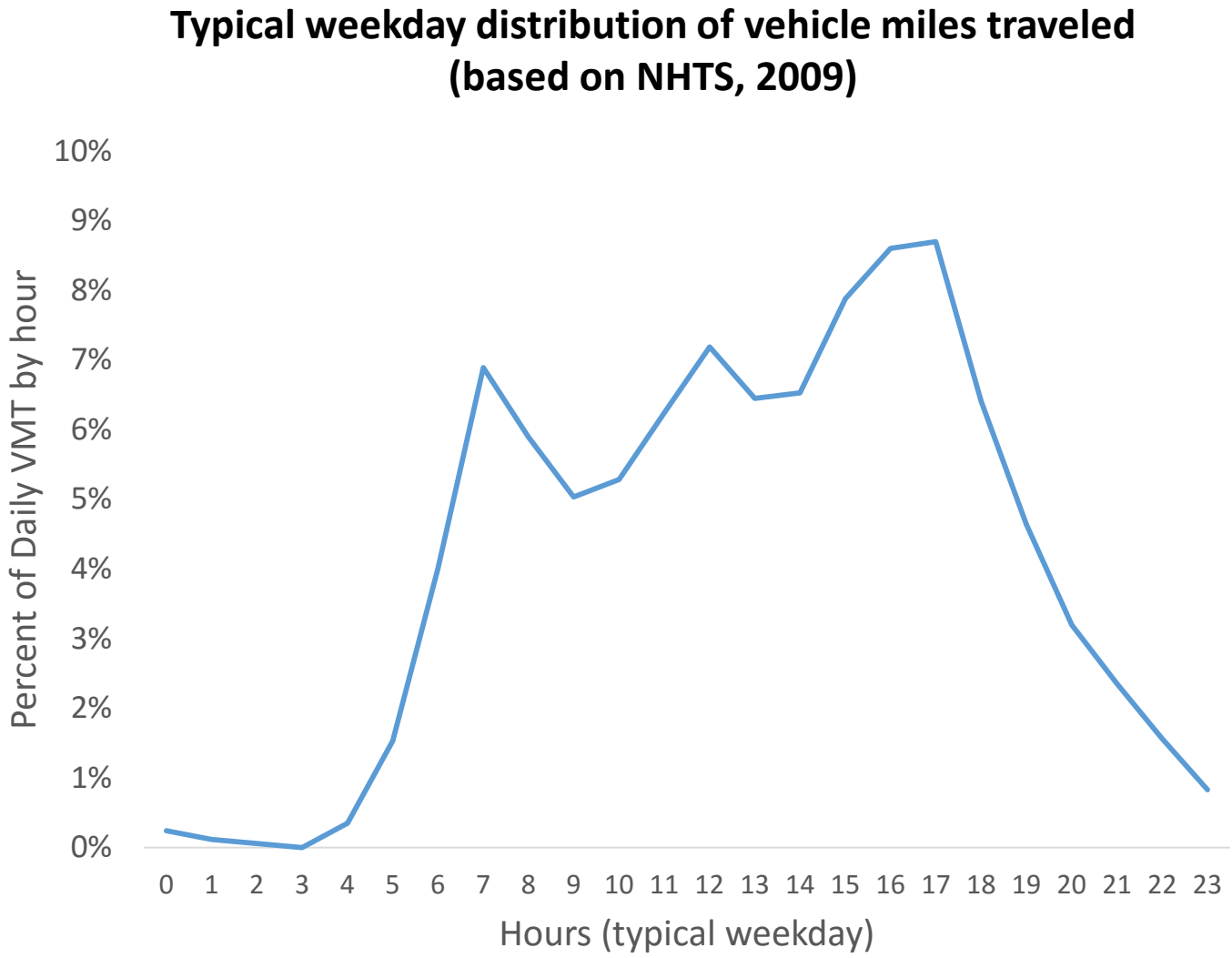
Modeling Autonomous Vehicles

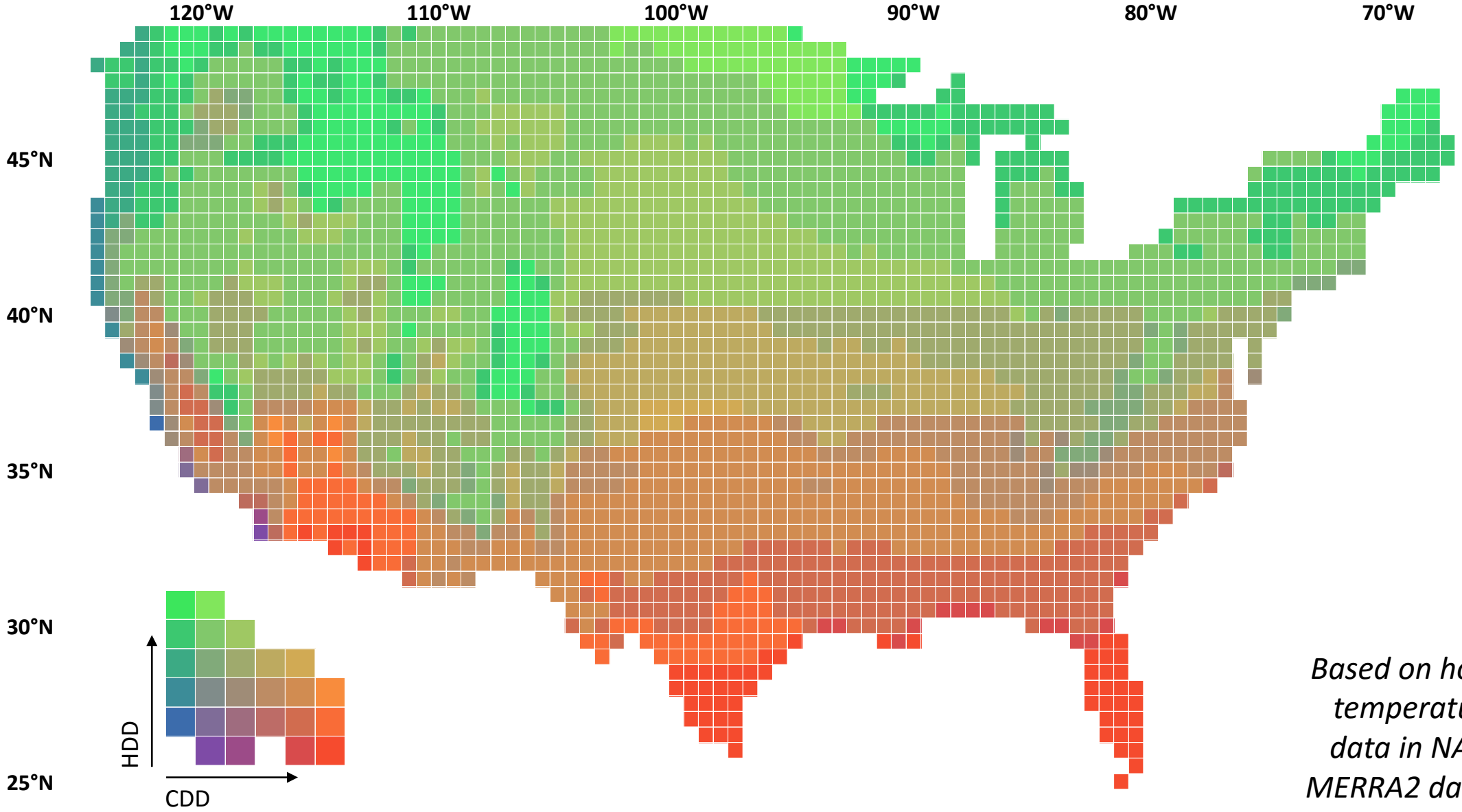




Electric Heating in Buildings

- Currently about 1/3 of residential buildings in the US have electricity as the main heat source, according to EIA surveys
  - Concentrated in regions with mild climates / favorable relative fuel prices, e.g. Florida and Pacific NW
  - Higher shares in smaller housing units / recent vintages
  - 25% share of floorspace in commercial buildings
- New opportunities for air source heat pump (ASHP) technology
- We model the economic trade-offs for ASHP vs. conventional furnace (+ A/C) in each region / climate zone based on temperature profile and retail fuel prices

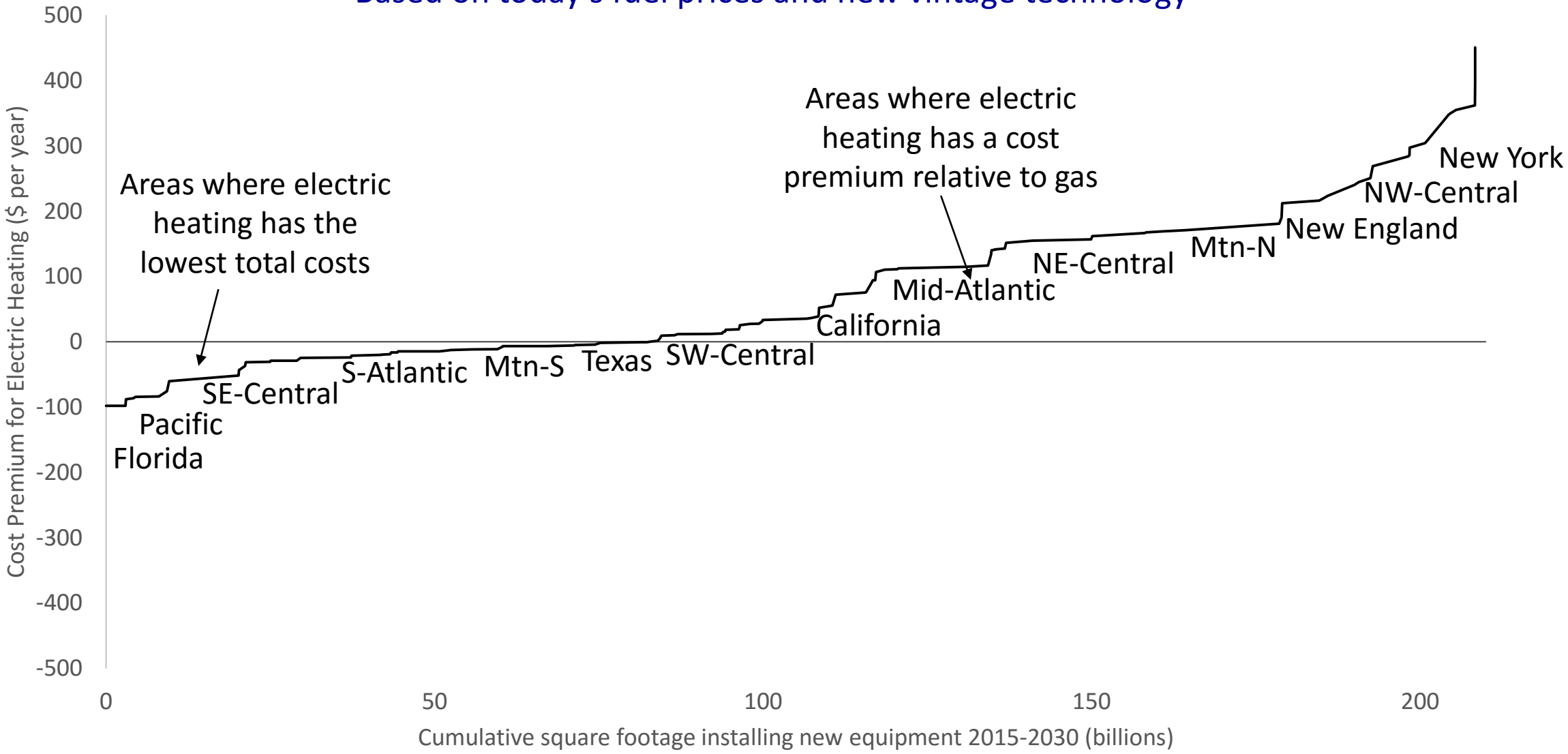
Heating/Cooling Zones based on HDD × CDD



Based on hourly temperature data in NASA MERRA2 dataset

Distribution across US of Electric Heating Cost Premium

Based on today's fuel prices and new vintage technology



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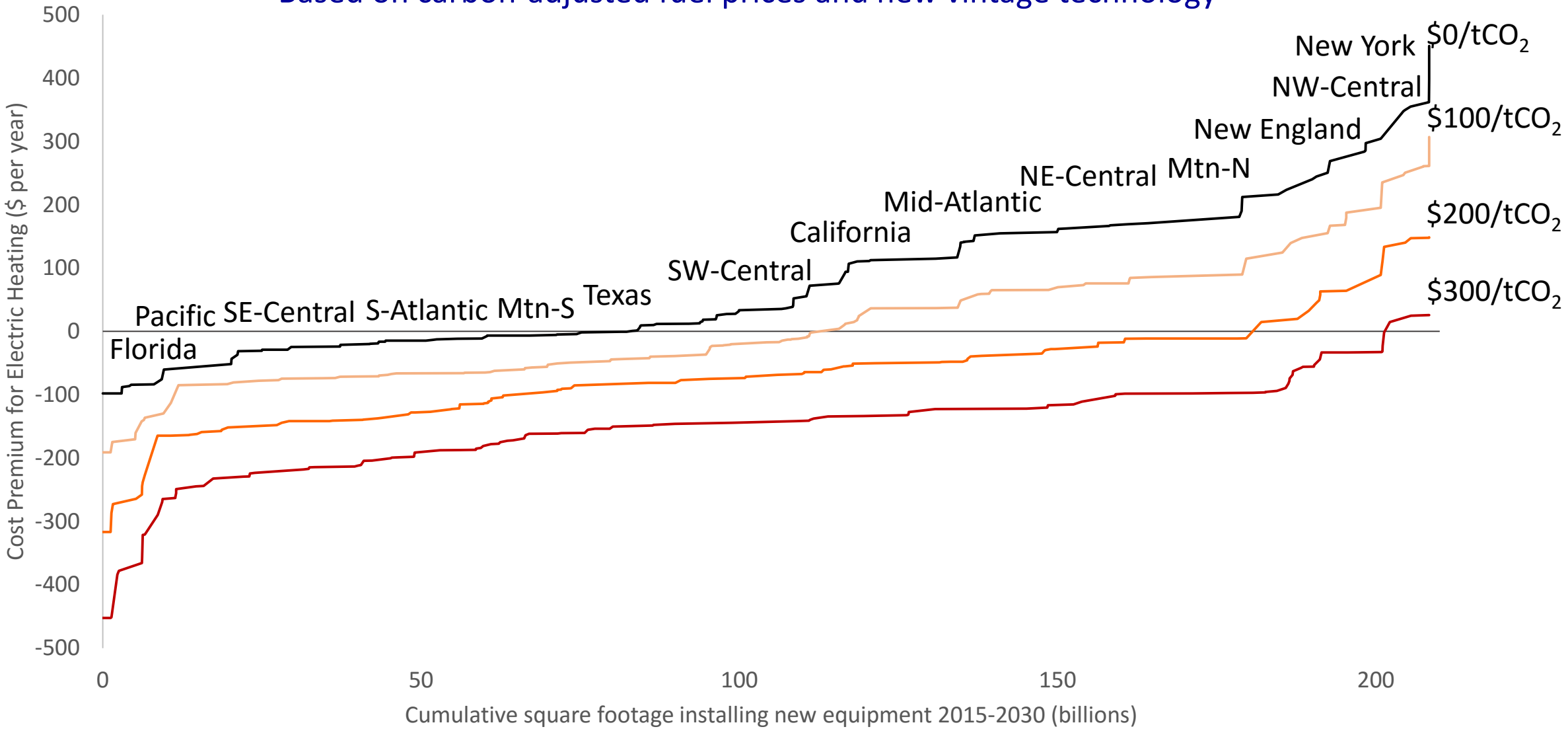
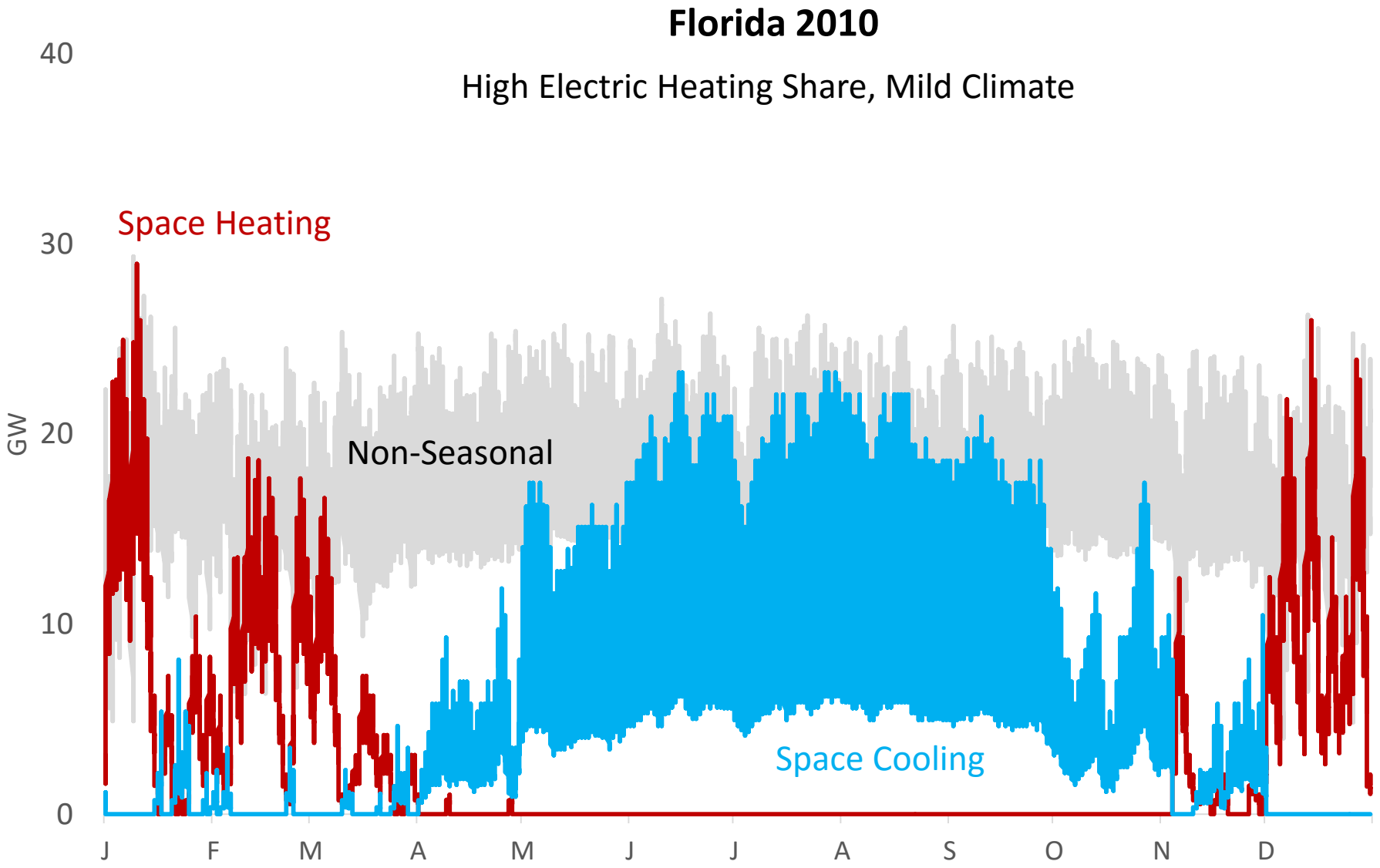
Higher carbon prices → more electric heating in the money

Based on carbon-adjusted fuel prices and new vintage technology



Effect of Electrification on Load Shapes



- As end-use mix changes, relative size of heating and cooling vs. non-seasonal loads will result in potentially very different aggregate profile / alignment with renewables
- New shapes will be introduced, in particular vehicle charging
- Result could improve or exacerbate generation asset utilization
- Better resource integration could allow more flexibility in demand response

 Preliminary: Subject to further calibration

Key Insights and Ongoing Research

- What is the role of the electric sector along potential pathways for energy system transformation?
  - Significant potential to reduce non-electric fossil fuel use and emissions through increased electric share, especially in vehicles and buildings
  - Some energy applications unlikely to be electrified even with carbon policy incentives, e.g. aviation, heavy industry, heating in cold climates
  - Need to ensure that policies, regulations, and rate structures align incentives for electrification where appropriate
  - First-order electric system impacts: need integrated modeling approach
- National Electrification Assessment: EPRI study → Dec 2017

Together…Shaping the Future of Electricity