ITS UC DAVIS INSTITUTE of TRANSPORTATION STUDIES

National Center for Sustainable Transportation

Environmental Performance of Future Electric Vehicles: A Life Cycle Assessment Perspective

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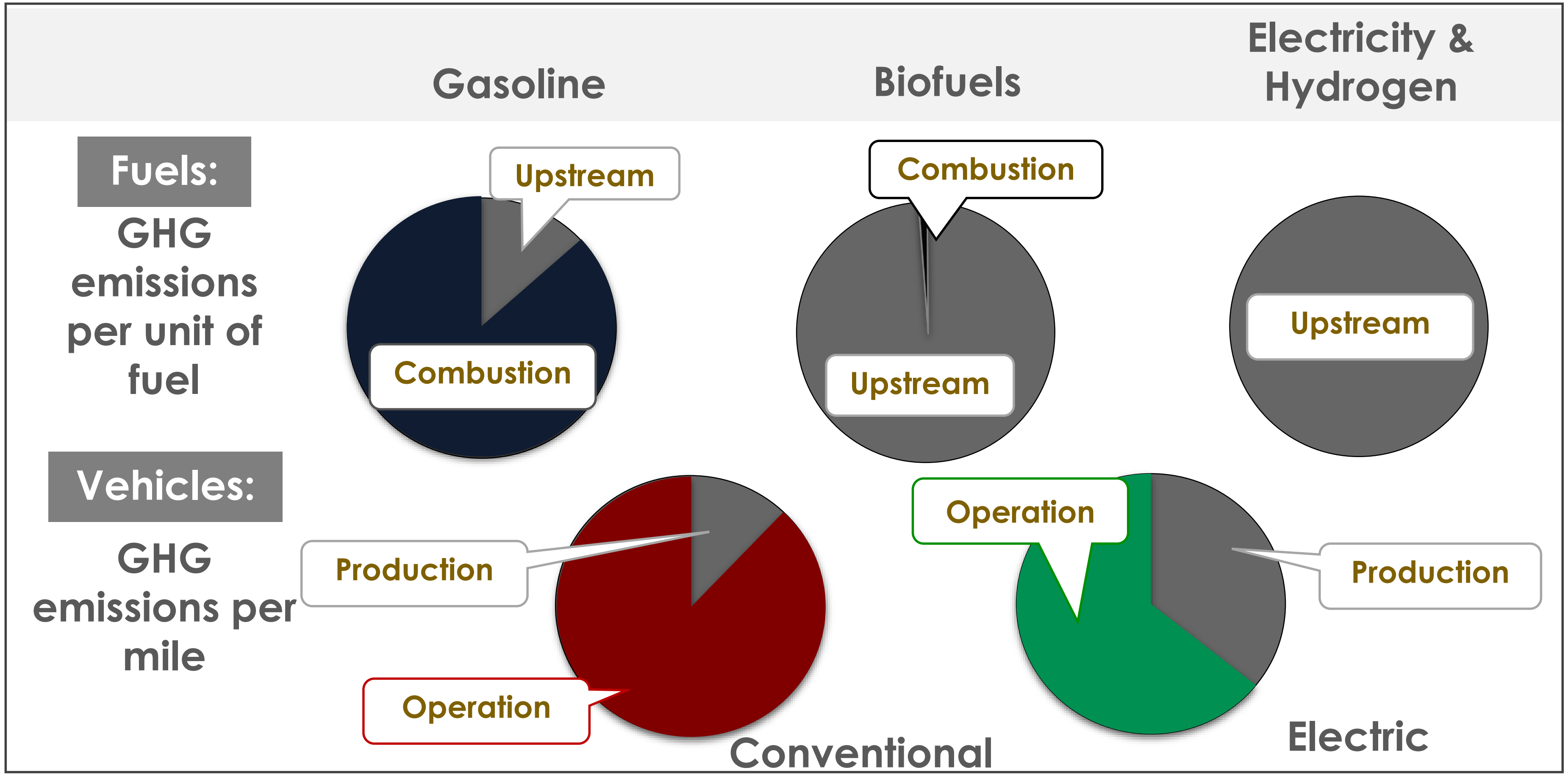
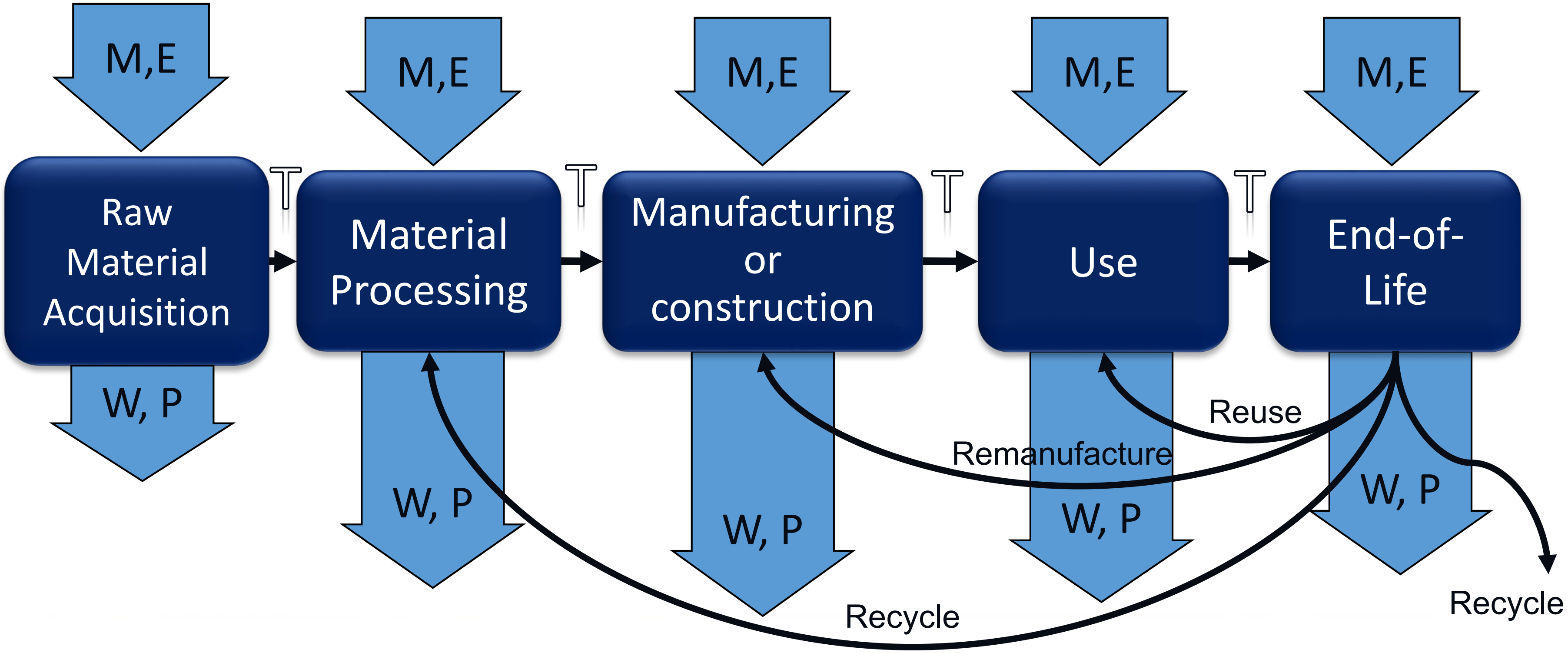
Why life cycle assessment (LCA)?



Trends in vehicle design, fuels, etc. are shifting environmental impacts away from the operational life cycle stage

LCA: A method for quantifying environmental flows and impacts for a product or service from a "cradle-to-grave" perspective



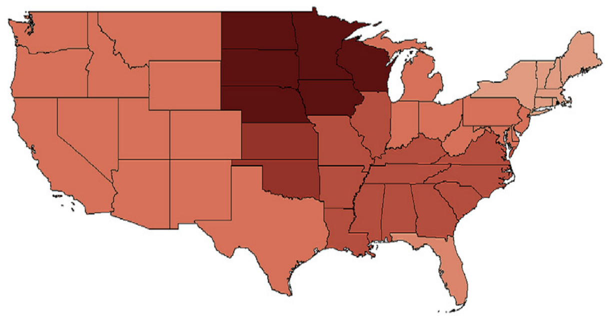
M = Materials
E = Energy
W = Waste
P = Pollution
T = Transport

LCA of Greenhouse Gases (GHGs)

- While traditional LCA considers a whole range of environmental impact categories, a GHG LCA, or *carbon footprint*, only considers the GHG caused by or emitted from the system
  - Many life cycle-based studies of battery electric vehicles (BEVs) are just focused on GHGs
- To understand the full burden of impact associated with a product or system, including the whole supply chain and burdens of disposal
  - To prevent trading one impact for another LCAs track many environmental impacts…

Background: LCA of battery electric vehicles (BEVs)

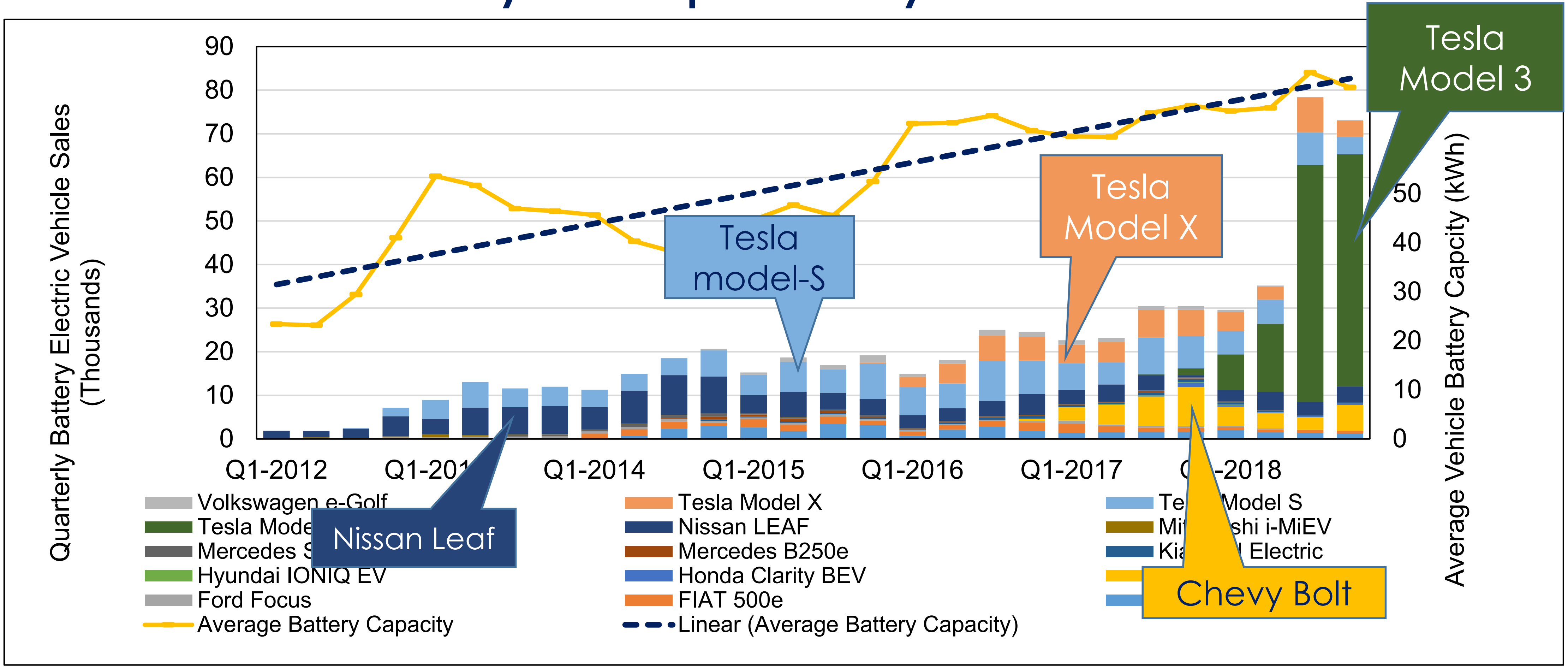
- Previous LCA studies of BEVs have almost uniformly considered small, efficiency-oriented EVs, with ~25 kWh batteries like the Nissan Leaf



- GHG LCAs of BEVs have long warned
  - the composition of the electricity grids that charge them [e.g., 1, 2, 3], and even the climate in which they are operate [2, 3], may have significant effects on life cycle greenhouse gas (GHG) intensity.

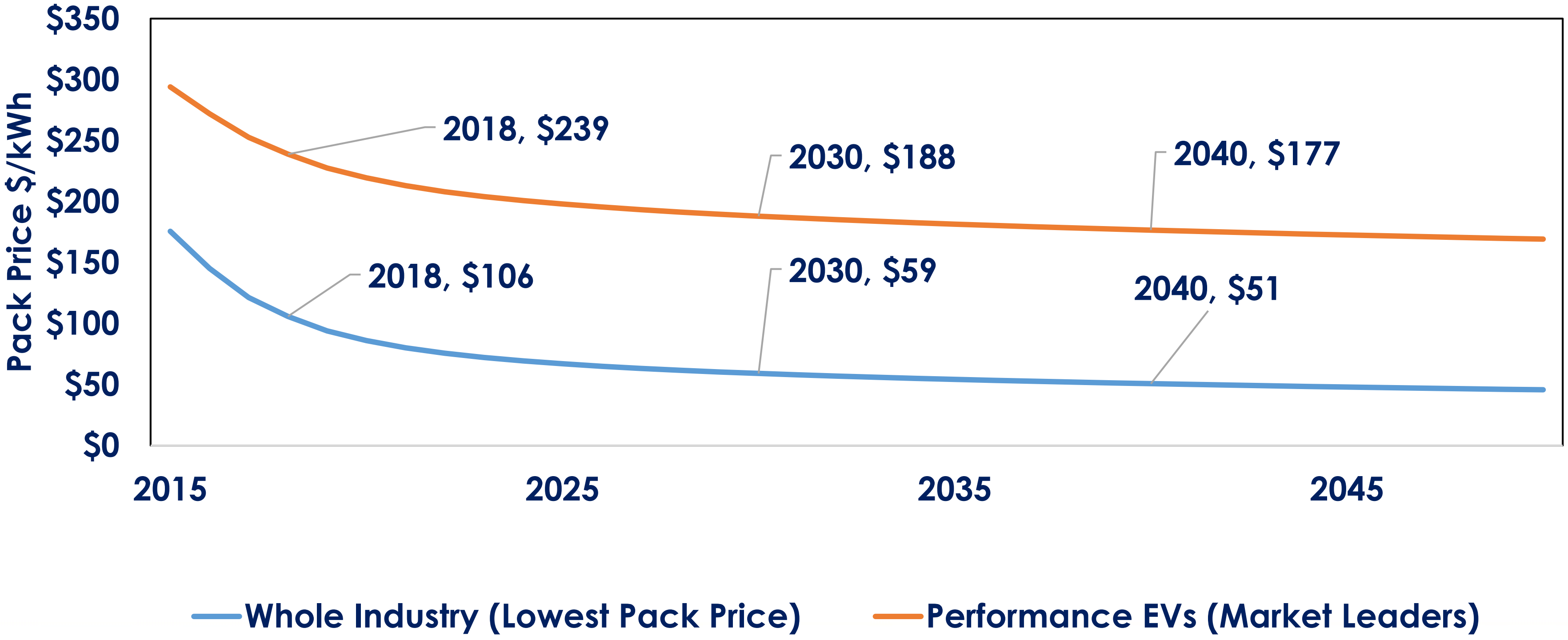
1. Hawkins, et al. (2013) DOI: 10.1111/j.1530-9290.2012.00532.x
2. Archsmith, et al. (2015) DOI: 10.1016/j.retrec.2015.10.007
3. Yuksel, et al. (2016) DOI: 0.1088/1748-9326/11/4/044007

Trends in BEV designs: Vehicle Sales and Battery Capacity for US



Trend: Battery costs and performance

- Battery Pack Price Forecast



Ambrose and Kendall, in preparation

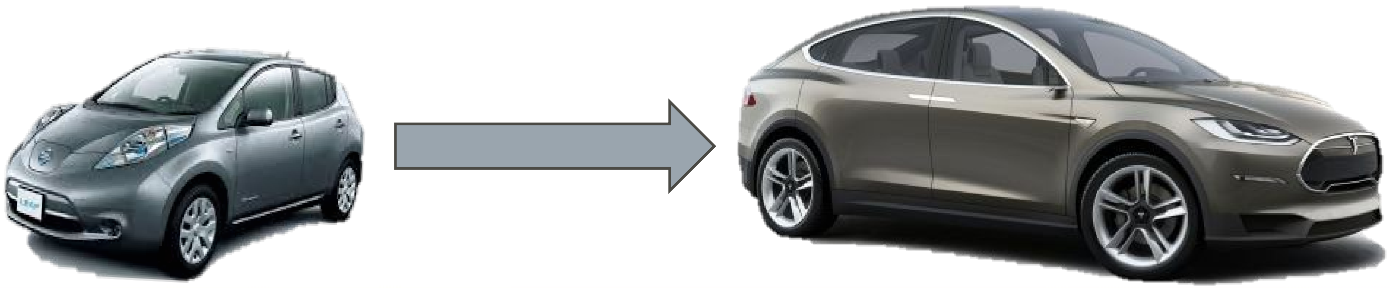
What happens when we try to account for trends

Vehicle design and market trends

- Dramatic decreases in battery pack costs
- Dominance of luxury and high performance cars in BEV sector
- Shared and autonomous vehicles (SAVs)

Electricity fuel mix trends

- Electricity grid is decarbonizing, especially where BEVs are being adopted fastest (e.g. California)



~25 kWh

~75 - 100 kWh

What are some implications of these trends that matter for vehicle LCA?

- Likely to be bad: Large, high-performance EVs mean larger batteries, and designs that may not focus on efficiency, or do so by investing in lightweight materials
- Likely to be good: Increasing range means that batteries may last much longer, reduce barriers to adoption, be used in higher-mileage operations
- Goal of this study: conduct preliminary LCA focusing on production and use of new-model and future model BEVs
  - Consider important spatiotemporal dynamics, like changing electricity fuel mixes

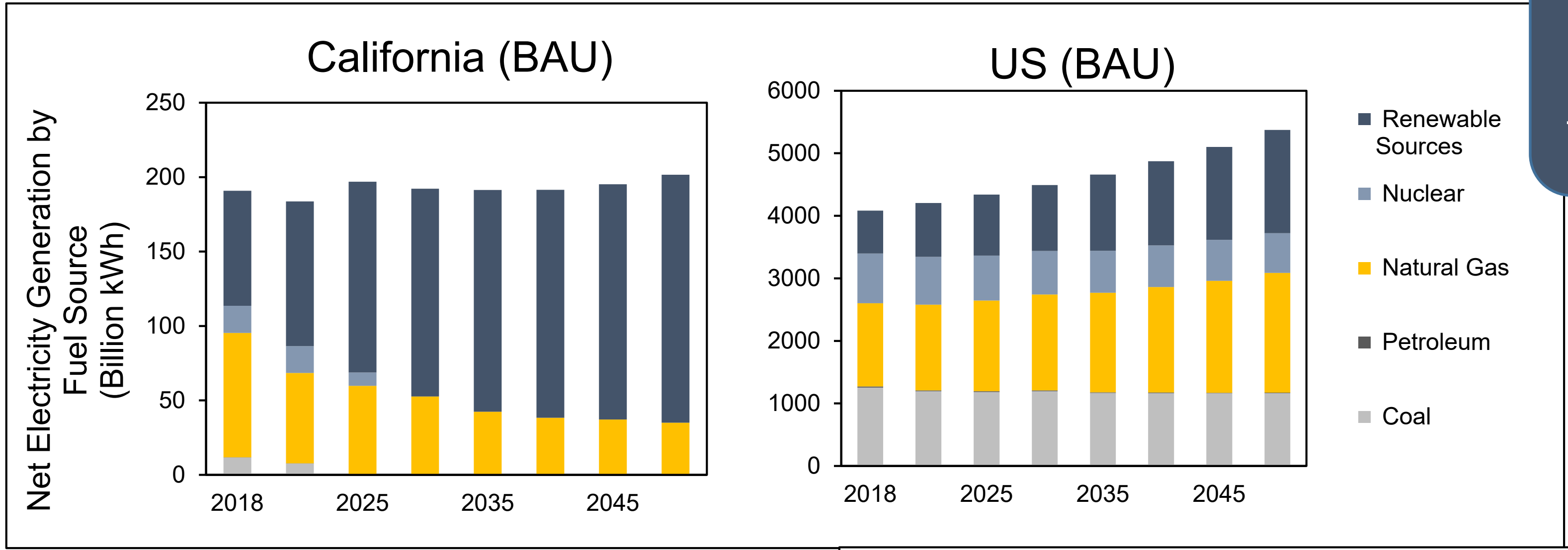
Modeling: Approach

- Conduct a GHG LCA of three archetypal BEVs:
  - EOV: Efficiency-oriented compact vehicle (e.g. Chevy Bolt)
  - PLS: Performance luxury sedan (e.g. Tesla Model S)
  - PSUV: Performance SUV (e.g. Tesla Model X)
- Use scenarios to explore space, time and use models, and longer-range vehicle designs.
  - California electricity
  - US Average
    - Present and future, with and without a carbon tax
  - Shared and autonomous applications

Modeling: Approach

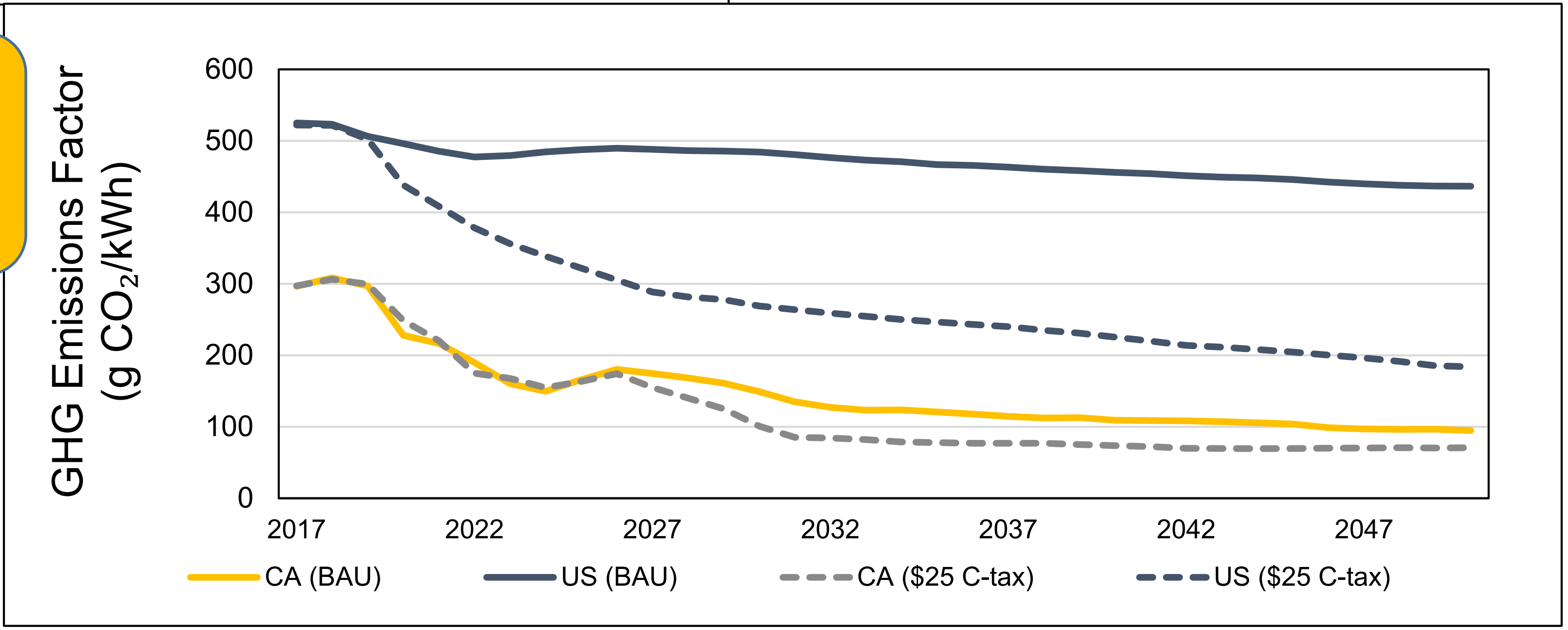
- Combine existing and new LCA models for vehicle components or systems
  - Use battery LCA model from Ambrose and Kendall (2015) to model battery production impacts
  - Use GREET to model the vehicle gliders based on vehicle class and curb weight
  - Estimate use phase impacts by
    - Considering annual mileage estimates from the National Highway Transportation Survey (NHTS) and data from EPA on mileage over vehicle aging
    - Range restriction (or removal of those restrictions) means different use patterns over time
    - BEV operation assumes combined city-highway energy economy (using FASTSim, based on vehicle specifications)

Electricity Grid Trends



Business as usual (BAU) Assumptions for electricity fuel mix

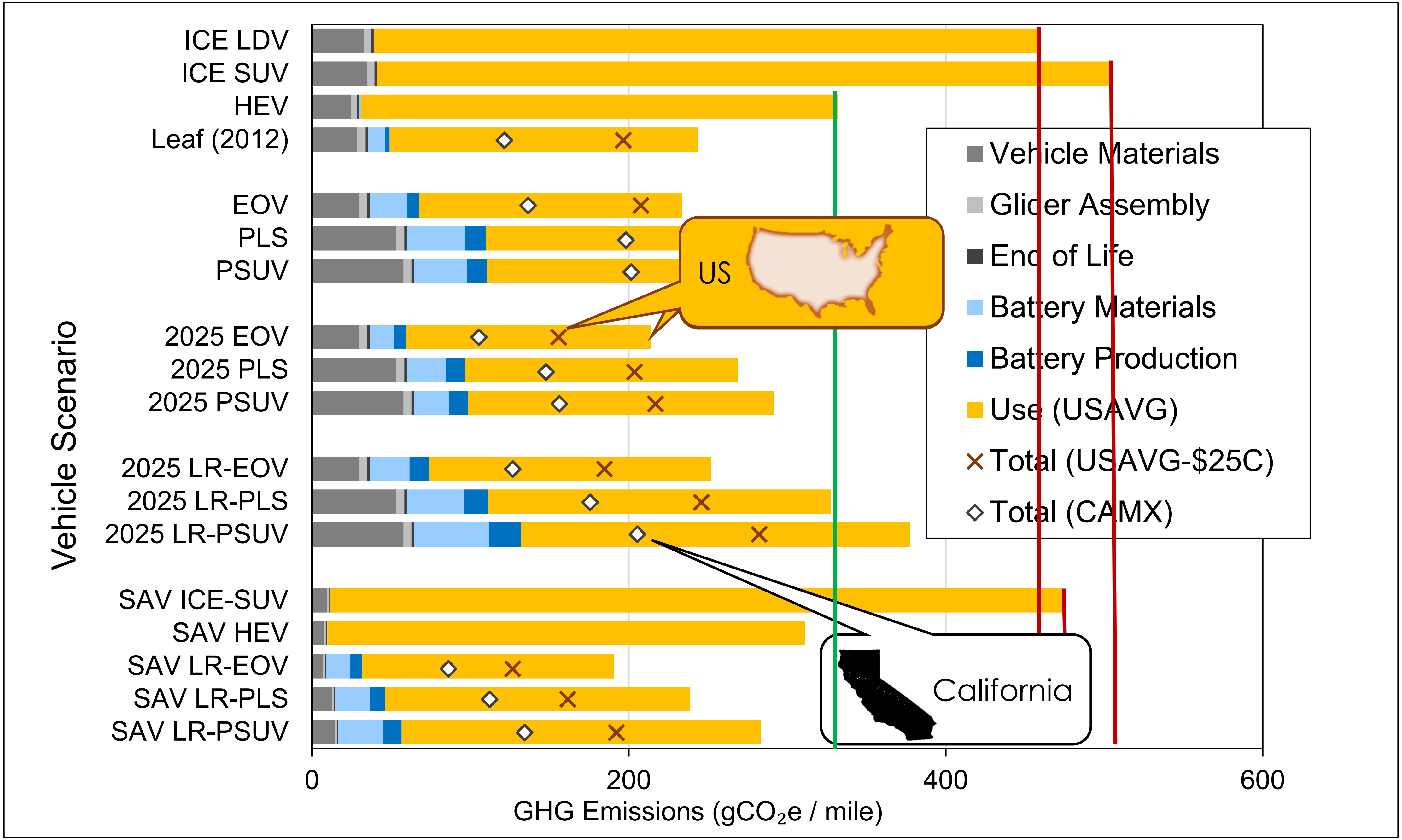
BAU and Carbon Tax (C-Tax) Assumptions for CO_2e intensity



Vehicle Scenarios

- EOV = Efficiency-oriented EV (60 kWh battery)
- PLS = high-performance luxury sedan EV (100 kWh battery)
- PSUV = high-performance SUV EV (100 kWh battery)
- SAV = Shared & autonomous vehicle (200 mi/day in service, a declining utilization factor, and a survival rate based on livery taxicabs)
- LR = longer-range (battery capacity increases of 40-75 kWh)
- ICE = Internal combustion engine
- HEV =Hybrid electric vehicle

Results



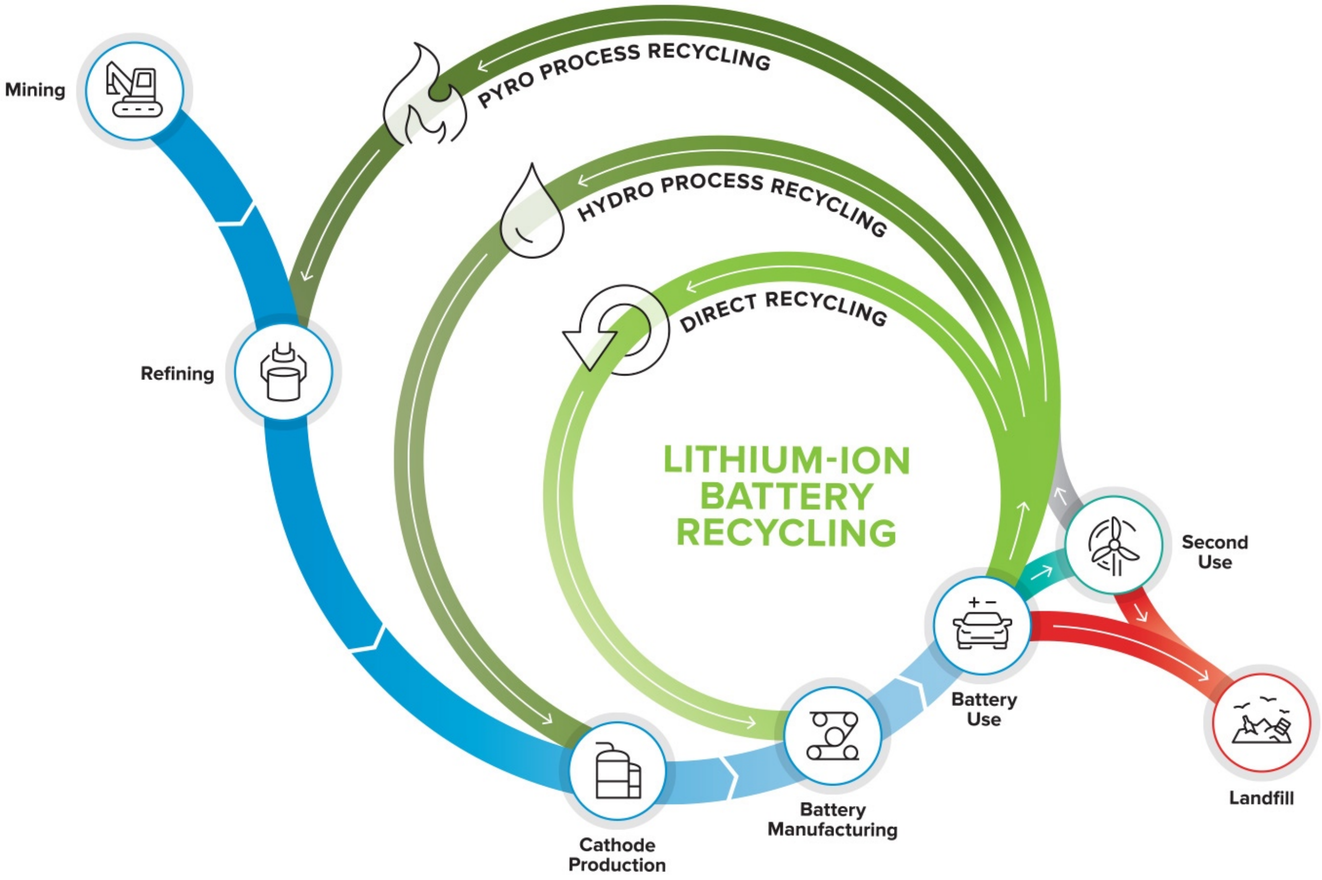
Vehicle Scenario
ICE LDV
ICE SUV
HEV
Leaf (2012)
EOV
PLS
PSUV
2025 EOV
2025 PLS
2025 PSUV
2025 LR-EOV
2025 LR-PLS
2025 LR-PSUV
SAV ICE-SUV
SAV HEV
SAV LR-EOV
SAV LR-PLS
SAV LR-PSUV
0
200
400
600
GHG Emissions (gCO_2e / mile)
Vehicle Materials
Glider Assembly
End of Life
Battery Materials
Battery Production
Use (USAVG)
Total (USAVG-$25C)
Total (CAMX)
US
California

Battery EOL

- The fate and reuse or recycling potential of end-of-life (EOL) BEV batteries is still quite uncertain and not specifically addressed in this study.
- While the CO_2e emissions associated with battery EOL and potential benefits of reuse and recycling are not necessarily large from a CO_2e standpoint, other environmental impacts are of concern
- The falling costs of batteries and relatively low value of constituent elements post-recycling present challenges for robust recycling systems

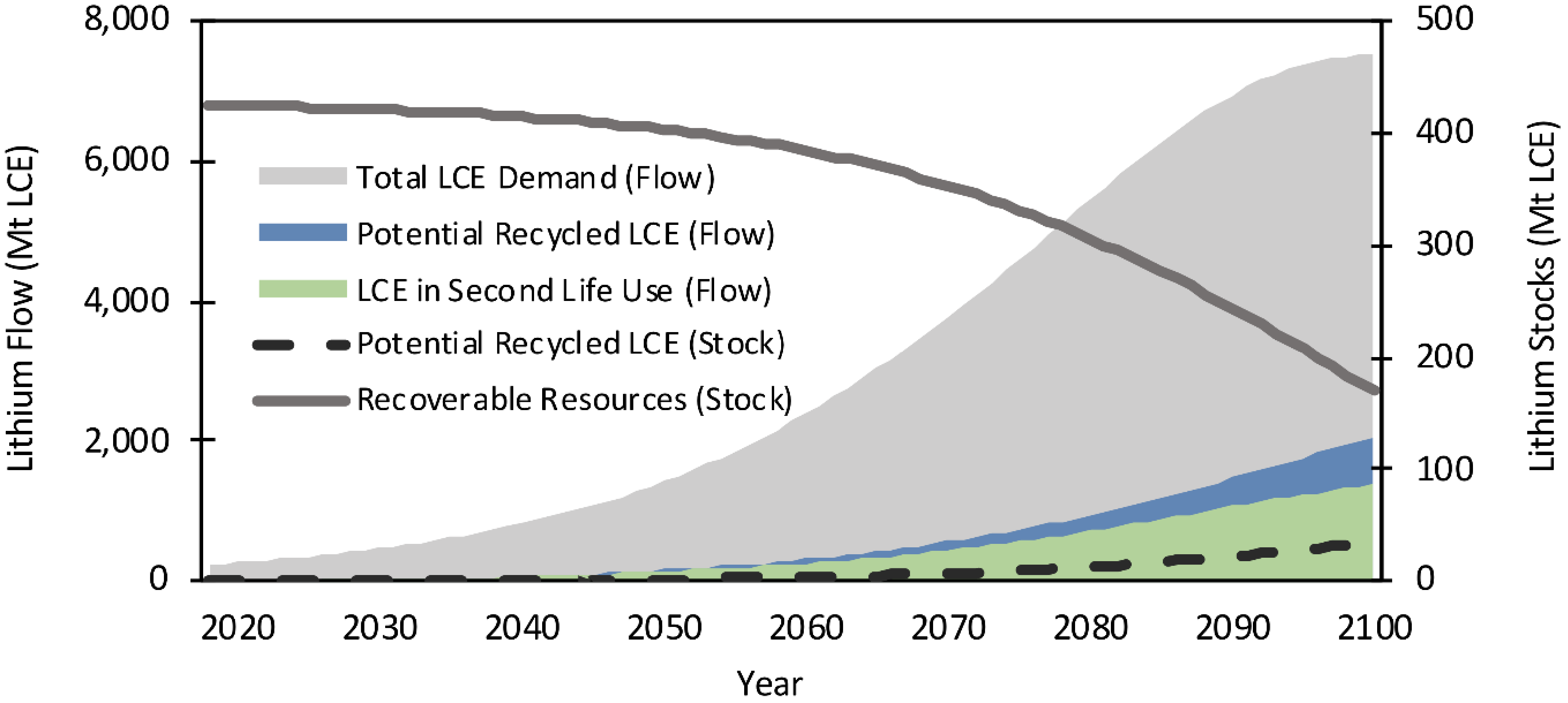
Battery EOL Alternatives

- Reuse or cascading uses (in secondary applications)
- Recycling and Refunctionalization (direct cathode recycling)
- Direct disposal (i.e. landfilling)



Original Image: ttps://recellcenter.org/publications/

Lag times in available recycled materials also illustrate that virgin materials will continue to dominate



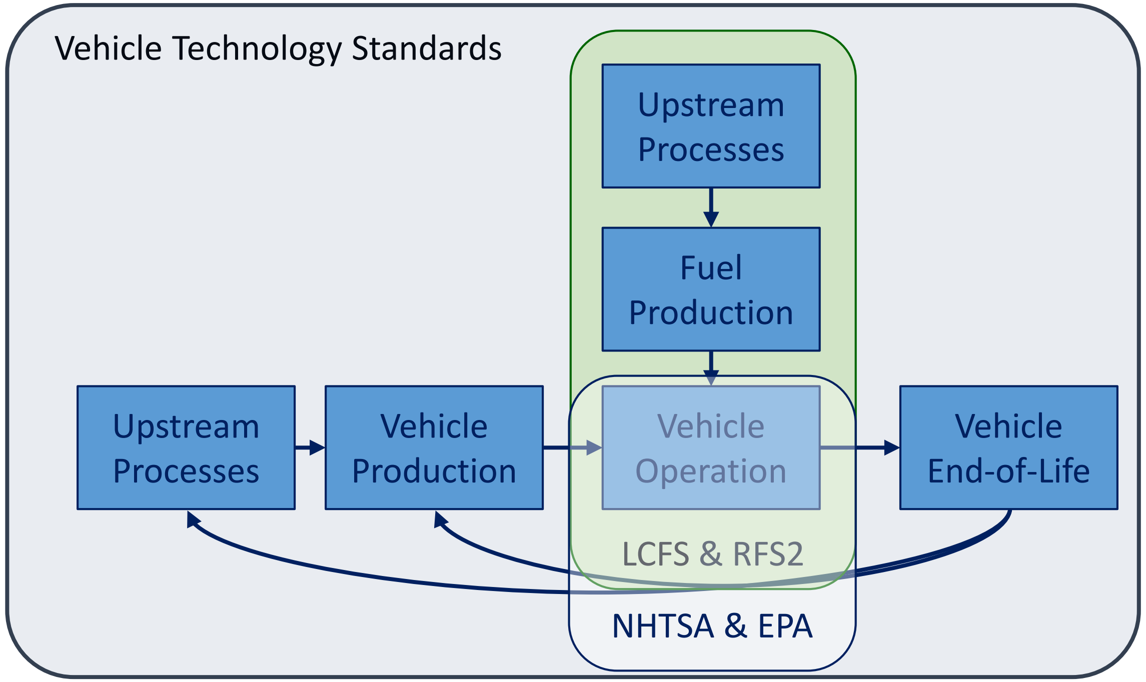
LCE = Lithium carbonate equivalent. (Ambrose and Kendall (2019a) Journal of Industrial Ecology

Discussion of findings

- Many conclusions echo those of previous work
  - where you charge a BEV matters
  - BEVs will typically outperform comparable ICE vehicles from a CO_2e standpoint
- The relative contribution of emissions from vehicle and battery production is increasing on a g/mile basis
  - This gets more important over time, and will grow if high-performance/large vehicles are preferred in EV designs and sales
  - Do we need life-cycle based fuel economy standards to achieve climate mitigation goals?
- Stay tuned on battery EOL
  - lots of potential innovation that could occur to address this challenge, and policy development that could shape it

Policy Context in the U.S. and California

- We regulate vehicle efficiency/fuel economy and tailpipe emissions
- We already think about the life cycle of fuels in some contexts (e.g. the Low Carbon Fuel Standard – LCFS, and RFS2 in a more limited way)
- But we don't have a context for thinking about the whole vehicle life cycle

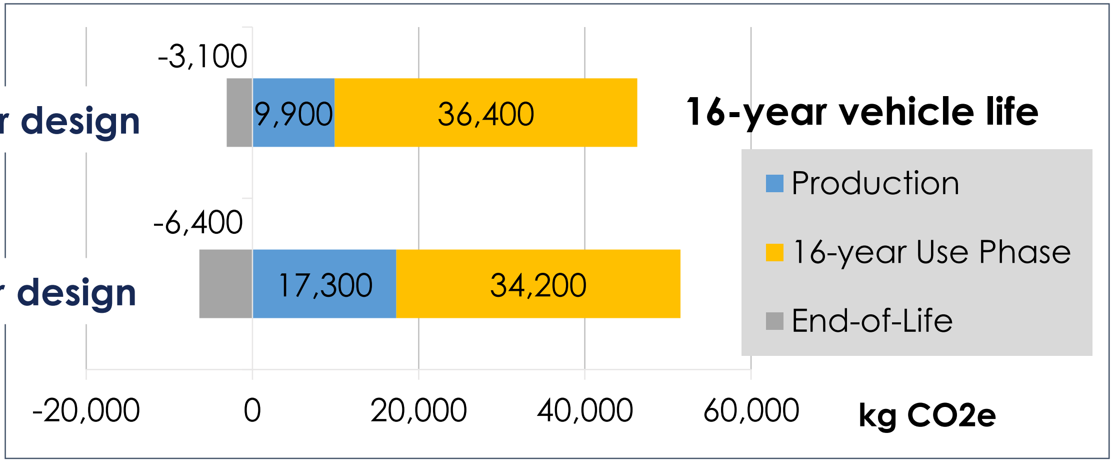


Are life cycle-based policies needed?

- Omitting life cycle emissions can lead to paradoxical policy outcomes, where vehicles with higher life cycle emissions but lower operation (i.e., tailpipe) emissions are preferred over vehicles with lower total emissions.
- Could provide flexibility in meeting GHG targets for vehicles
- But a life cycle based policy could be really complex and actually hinder compliance if not managed well

Life cycle based policies are relevant for ICEs and HEVs too

- Preferences for vehicle light-weighting actions, for example, can also require a life cycle assessment to understand benefits.



Source: Kendall, A., and Price, L. (2012) Incorporating Time-Corrected Life Cycle Greenhouse Gas Emissions in Vehicle Regulations *Environmental Science & Technology* 46(5) 2557-2563

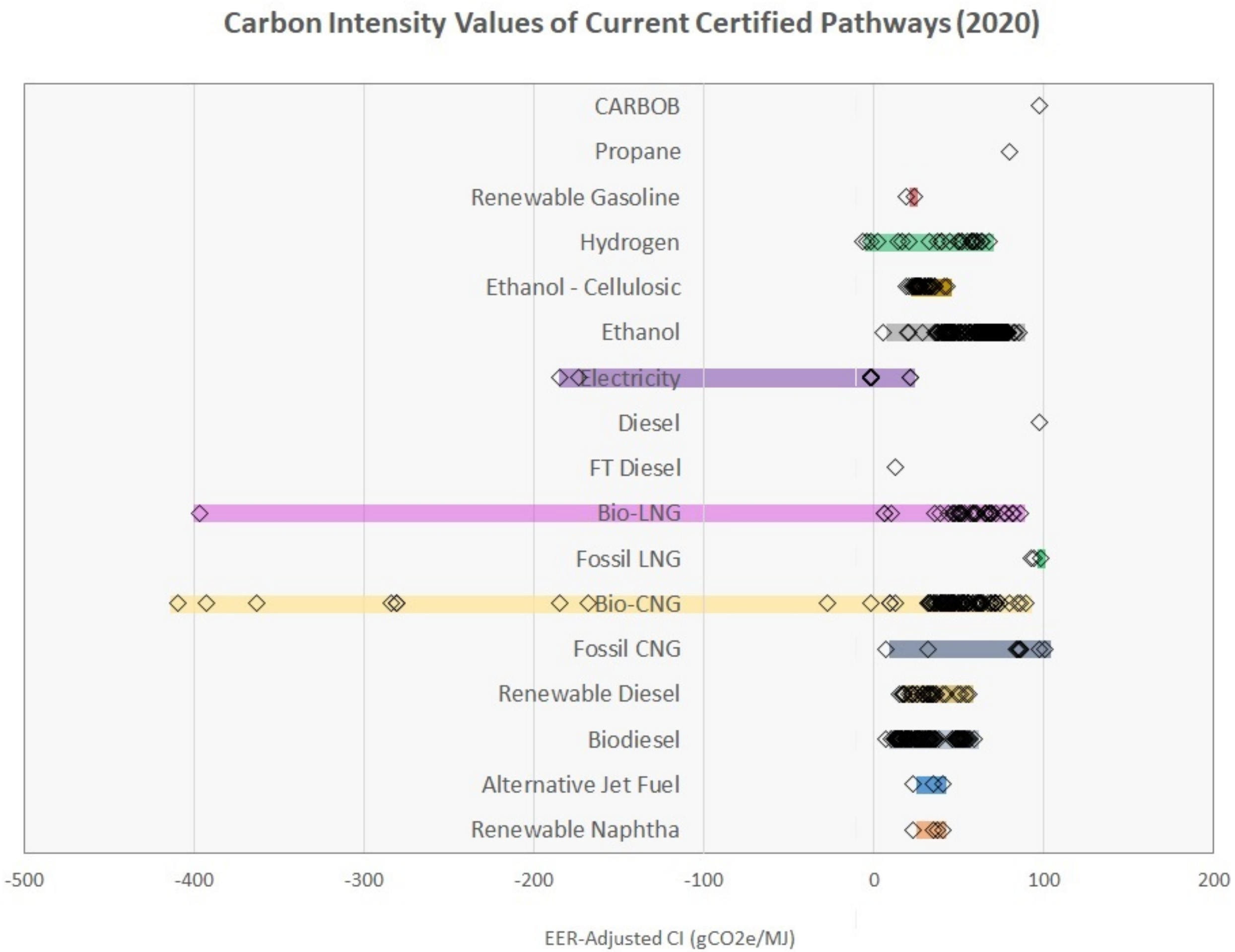
LCA-based Policy – can it be done?

- Critical review of existing policies that incorporate life cycle thinking or use life cycle assessment
  - experiences from biofuel policy
  - the environmental product declaration (EPD) system (including adoption in the U.S. building sector due to the LEED green building certification system)
  - the End-of-Life Vehicle Directive in Europe
  - to a lesser extent eco-labeling schemes as informative for potential vehicle life cycle policies.

Actual LC-based policies

- Only one class of policies, Low Carbon Fuel Standards, actually require life cycle carbon calculations to be done by producers.
  - In California, a common government-provided model (GREET) is used with the option for producers to submit their own calculations
  - In this model the government defines many of the assumptions, but all those who are regulated are submitting to those same assumptions

Life cycle-based policies



- A system of fuel pathway carbon-intensity look-up or estimation modeled using the CA-GREET model
- Providing a tool and default carbon intensity estimates, the risk of high variability and of a lack of transparency is reduced

https://ww3.arb.ca.gov/fuels/lcfs/lcfs.htm

https://ww3.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm

LEED – What we can learn from a voluntary program

- LEED offered extra points towards their certification levels if contractors sources materials and parts that are characterized by Environmental Product Declarations (EPDs)
  - EPDs are comprised of product-specific life cycle assessment impact results
- Within a short time frame we've seen an enormous number of new EPDs for the North American market, where once there had been none
- LEED is a highly influential <u>voluntary certification</u> system that is used mostly in the *commercial* building sector

EPDs for vehicles

- The production of EPDs requires a product category rule (PCR)
  - A PCR for vehicles and vehicle parts in the United States (or a coordinated international effort for common PCR development) should be developed
  - Parts *could* be associated with EPD information through part-based labeling, such as what has been done for the End-of-life Vehicle Directive in Europe.
- EPDs are not JUST about carbon intensity – in theory a primary goal of LCA is to understand many environmental impacts and ensure we're not trading one for another…

Image source:
https://awc.org/sustainability/epd

EPDs could be deployed different ways

- Could envision a voluntary process to initially build capacity (think LEED)
- Vehicle policy that awards manufacturers credits/ecolabel/etc. for using parts that have environmental product declarations (EPDs)
  - could build capacity in the industry for collecting and processing the necessary data.

Europe's EOL Directive

- Europe's end-of-life vehicle directive requires the labeling and tracking of parts, probably a requirement for life cycle-based policy (even if they are not labeled with life cycle information, a verifiable mechanism that tracks the material type and mass, likely will be)
- Combined either with an EPD or a government-based life cycle calculation, this could support a life-cycle based policy

What might we draw from this?

1. An EPD for every part would be much more of a wild-west, but would probably allow for more innovation than
2. A LCFS-like approach, which would guarantee more transparency in calculations, and traceable carbon intensity estimates

1+2. In a perfect scenario we could combine the two approaches – EPDs for every part, but consistent underlying data and assumptions to minimize gaming and high variability

Thanks!

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