Costs and Travel Choices in a Three Revolutions World

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Breakfast Meeting

Berlin | 01 June 2018



Sustainable Transportation Energy Pathways (STEPS)

Costs and Travel Choices in a 3R World

Agora Verkehrswende
Breakfast Meeting, Berlin

1 June 2018

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ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

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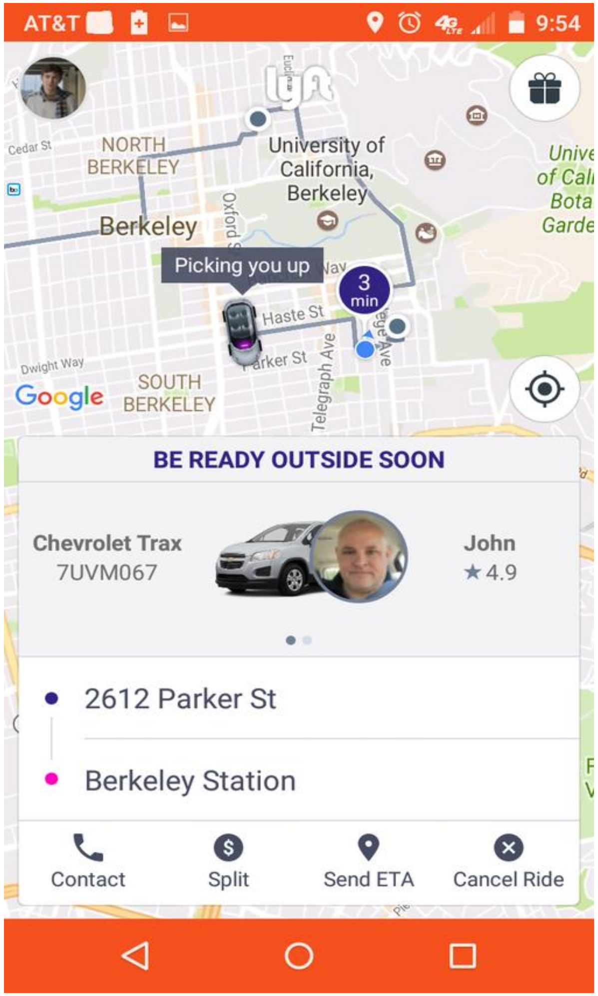
Passenger Transport Revolutions

1. Streetcars (~1890)
2. Automobiles (~1910)
3. Airplanes (~1930)
4. Limited-access highways (1930s….1956)

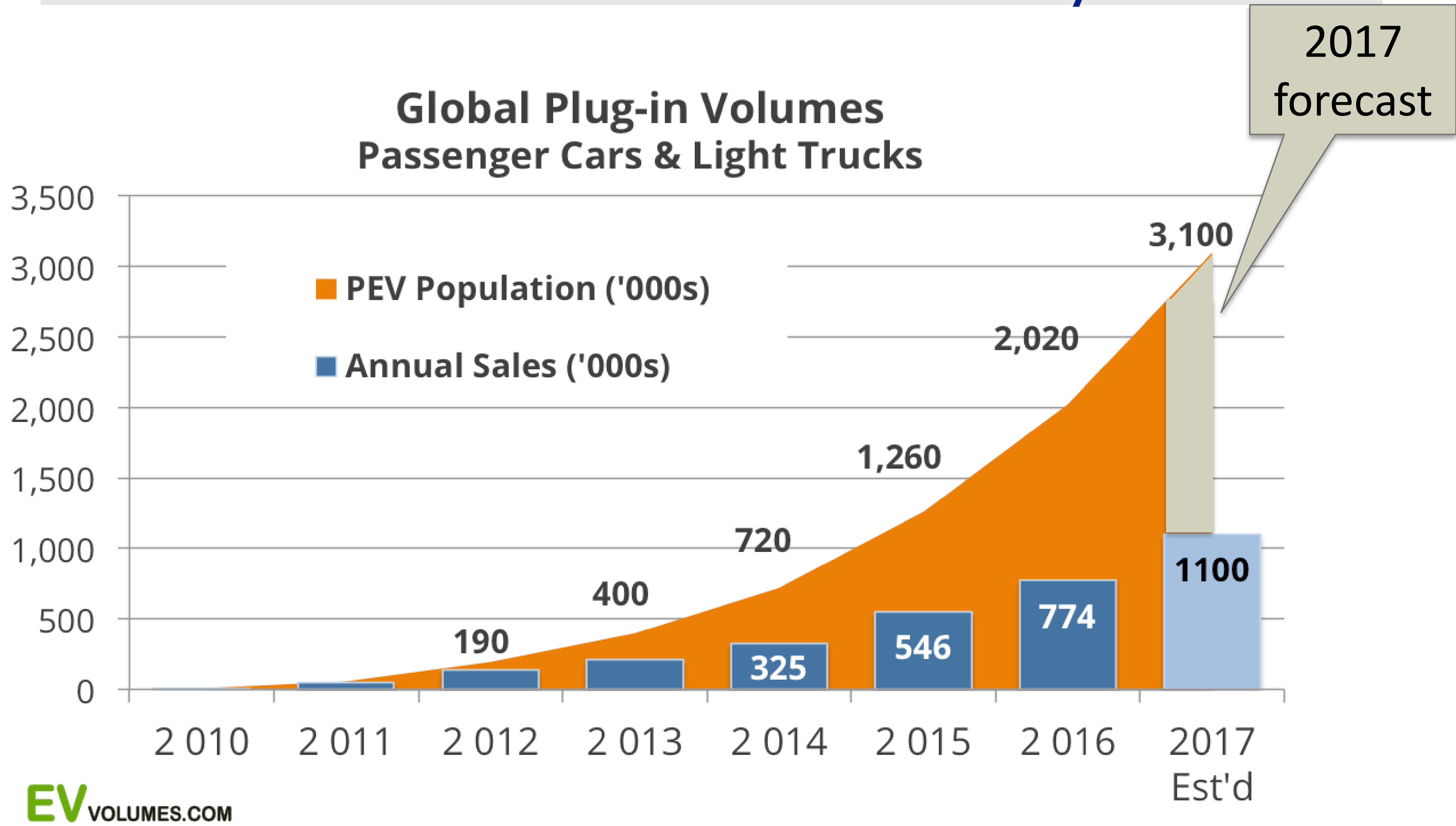
<u>2010+</u>

1. Vehicle electrification
   – low carbon vehicles and fuels
2. Real-time, shared mobility
   – less vehicle use
3. Vehicle automation (2025?)
   – Uncertain impacts

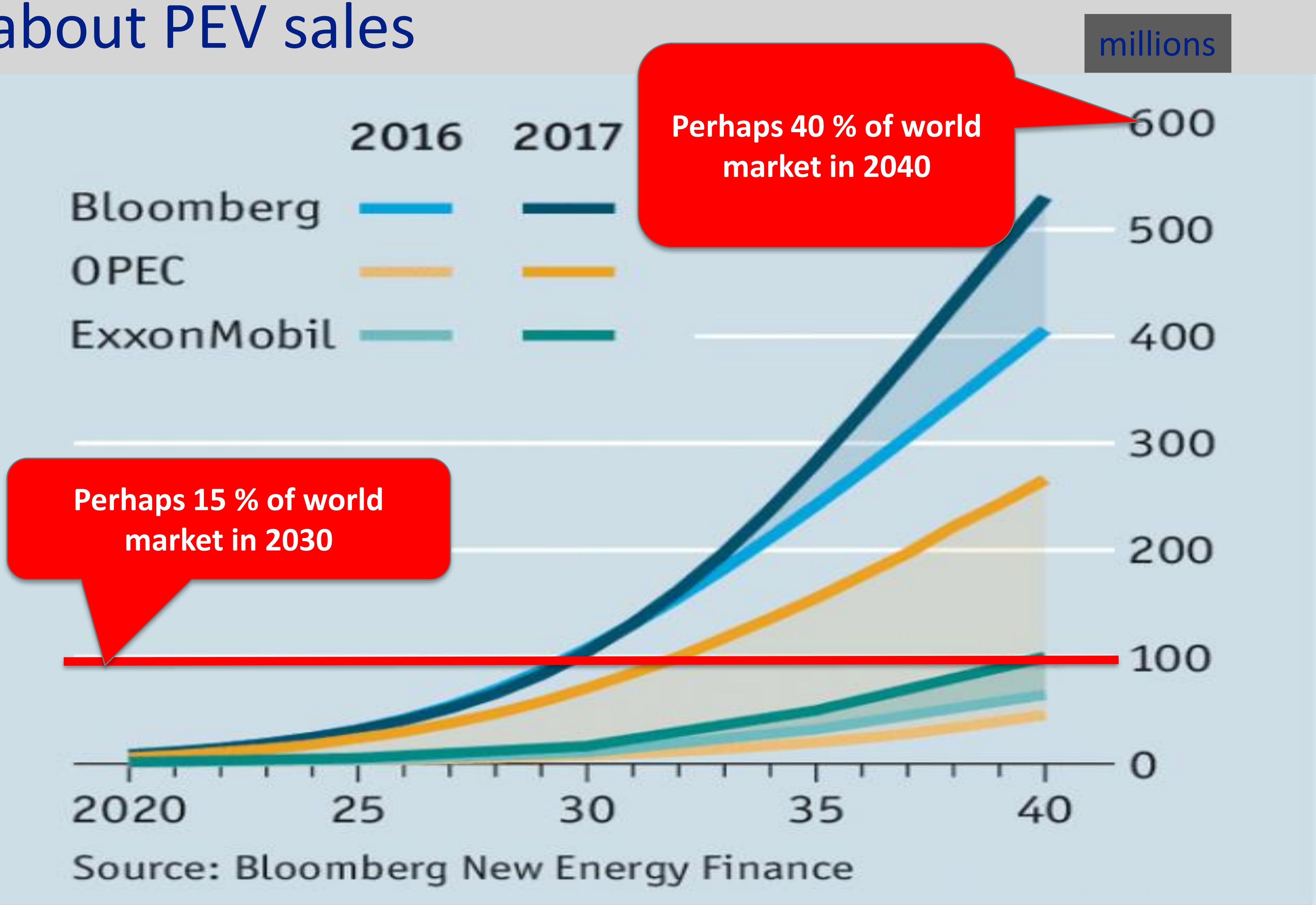


Have EVs arrived?

During 2017, The number of PEVs worldwide will likely go over 3 million, with over 1 million in sales this year



Many PEV sales forecasts getting optimistic about PEV sales



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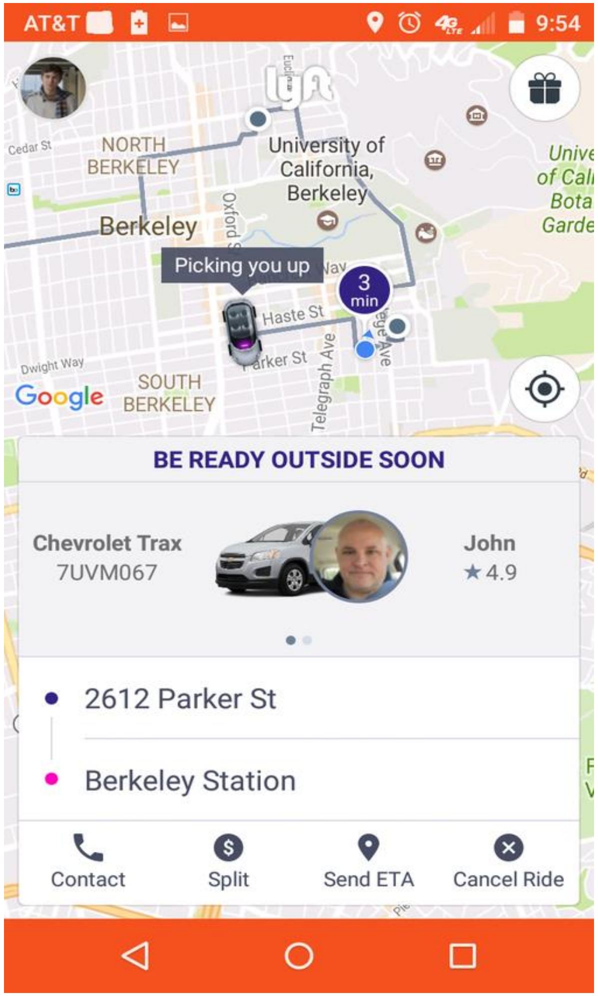
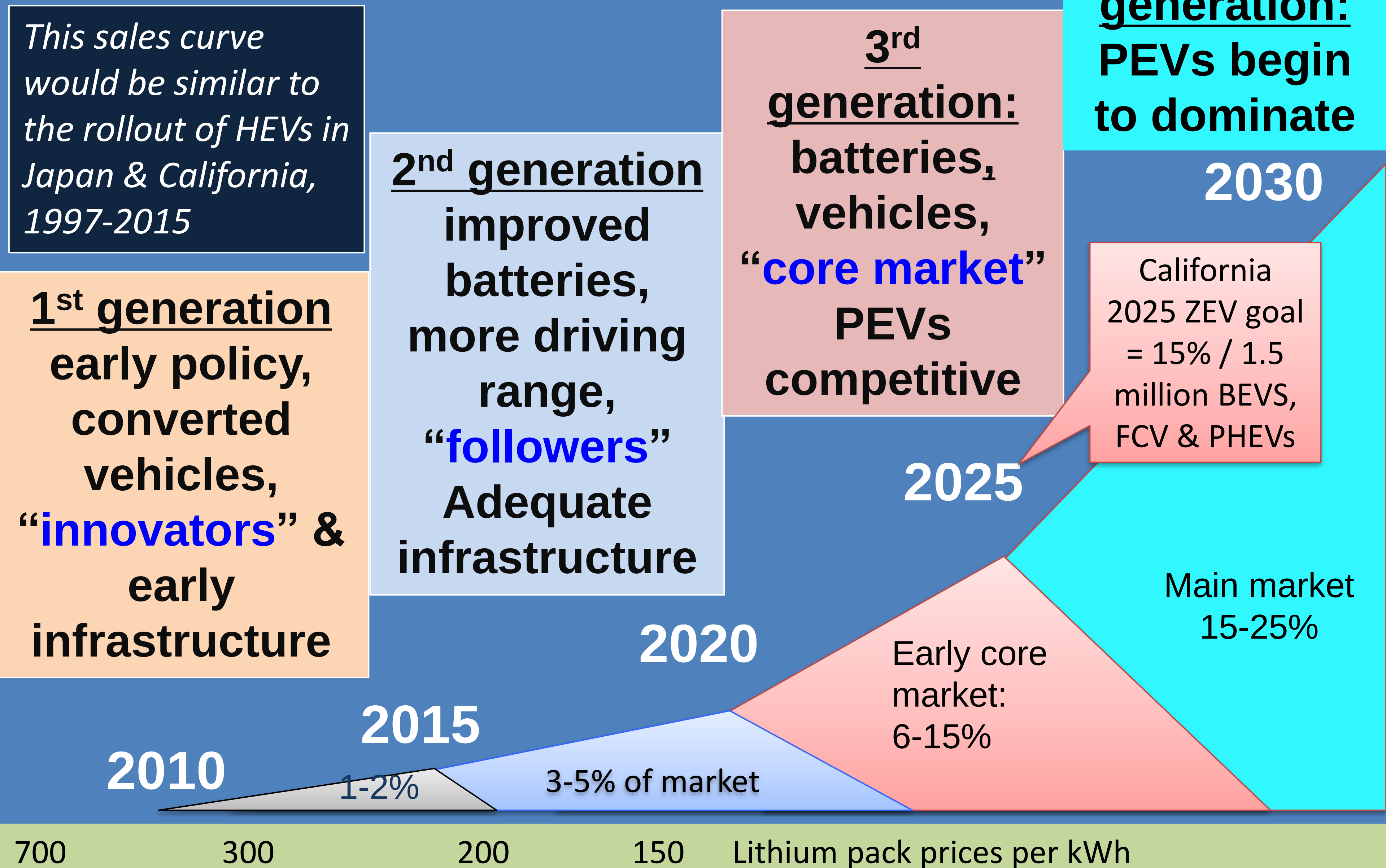


A plausible PEV rollout scenario based on technology change, incentives & history of previous technology rollouts



Car of the future?

Or this?

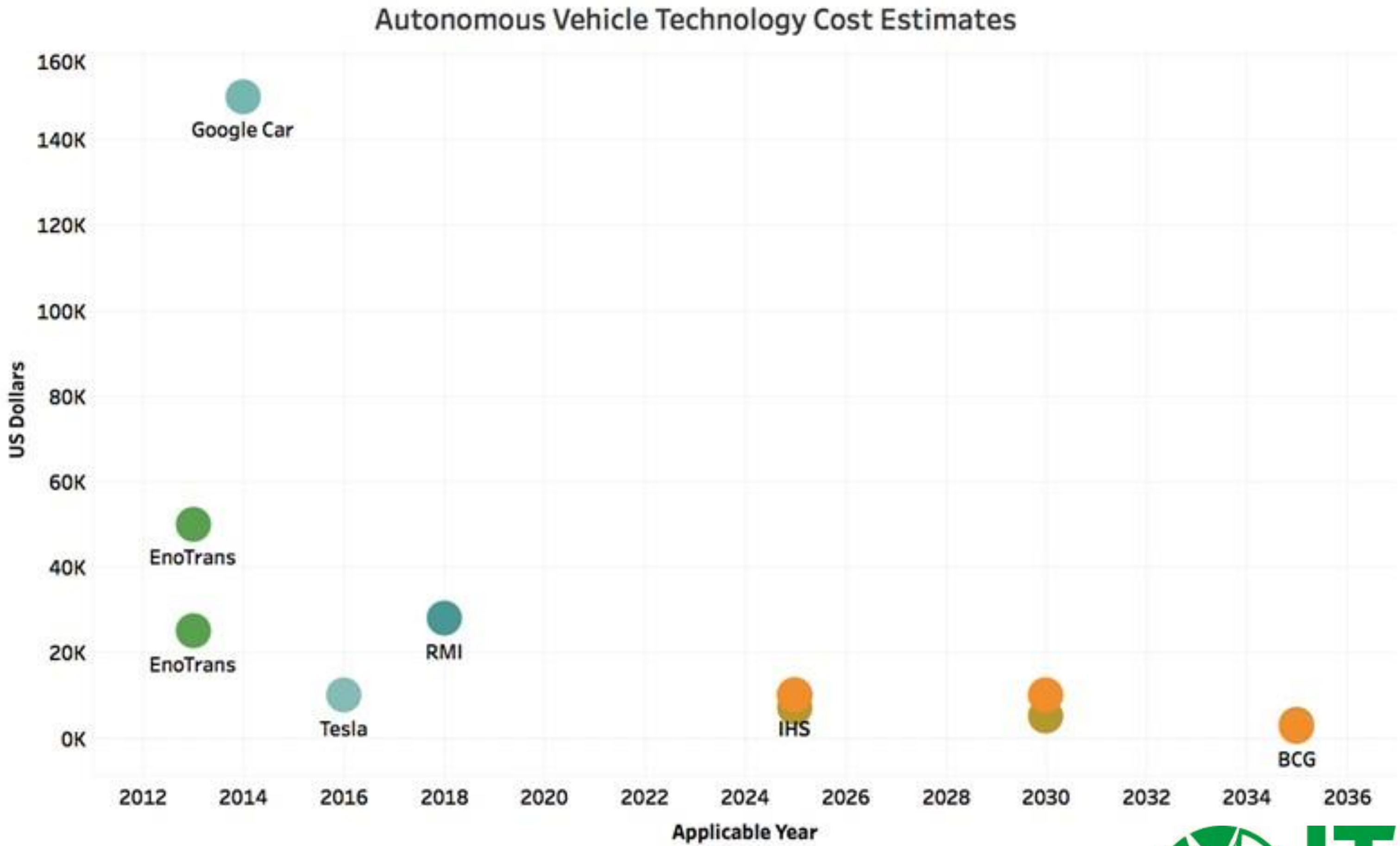
Electrification + Automation: likely, but not definitely, together

All autonomous vehicles in development feature some form of electrification

Parent Company	Make	Model	Powertrain	Production Goal	Notes
Nissan	Nissan	Leaf	Electric	2020	
GM	Chevrolet	Bolt	Electric		Testing 40 vehicles in SF and Scottsdale
FCA	Chrysler	Pacifica	Hybrid		Testing 100 vehicles with Google
Ford	Ford	Fusion	Hybrid	2021	
Volvo	Volvo	XC90	Hybrid		
Uber	Ford	Fusion Energi	PHEV		
Uber	Volvo	XC90	Hybrid		
Daimler	Mercedes-Benz	F015 Luxury in Motion	Hydrogen Fuel Cell Plug-In Hybrid		Research Vehicle

AV costs dropping quickly

Cost of LIDAR used on the Google car was $75 – 85,000, and by early 2016, Velodyne began selling LIDAR for $500 per unit to Ford.



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Ride sharing is exploding around the world…

…but is it really ride sharing?

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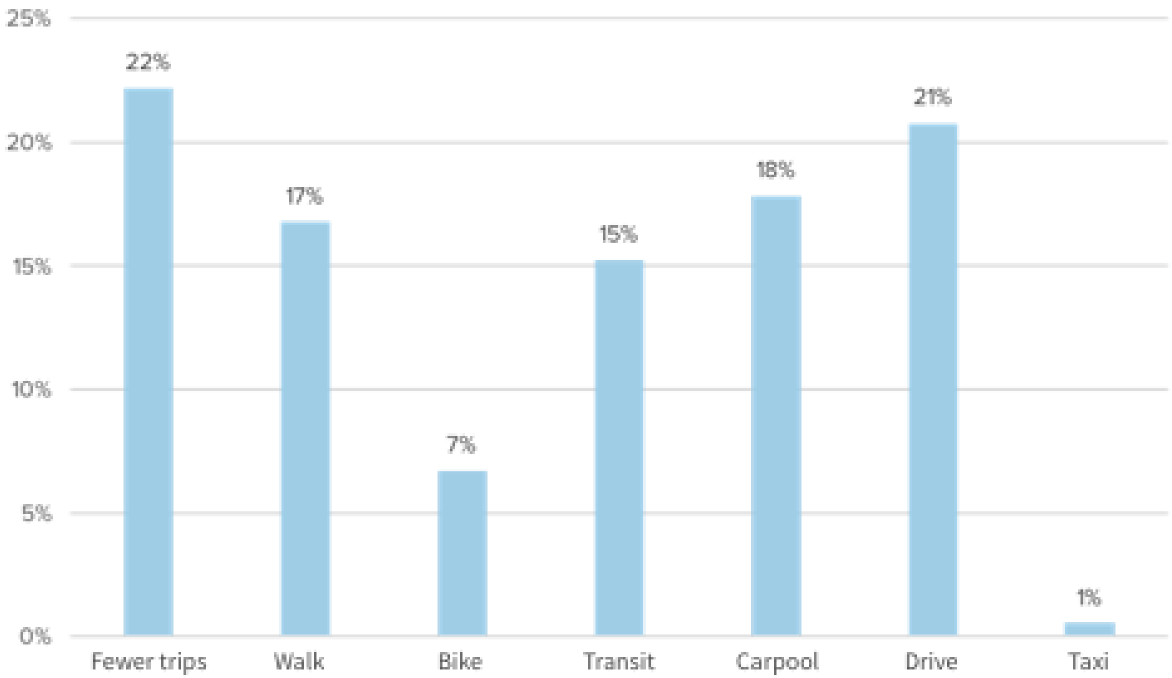
Ride-hailing in the U.S. currently substitutes for more sustainable modes than for driving



Source: Clewlow, Regina R. and G S. Mishra (2017) Disruptive Transportation: The Adoption, Utilization, and Impacts of Ride-Hailing in the United States.

- 49% to 61% of ride-hailing trips in major U.S. metro areas would have not been made at all, or by walking, biking, or transit.
- Ride-hailing attracts Americans away from bus services (a 6% reduction) and light rail services (a 3% reduction).
- Ride-hailing serves as a complementary mode for commuter rail services (a 3% net increase in use).
- Directionally, we conclude that ride-hailing is currently likely to contribute to growth in vehicle miles traveled (VMT).

Research undertaken by UC Davis and ITDP, part 3 of a series

Global scenario study to 2050 focused on potential 3 Revs impacts on CO2, energy use, costs

Study supported by UC Davis STEPS Consortium and by Climate Works, Hewlett Foundation, Barr Foundation

https://steps.ucdavis.edu/three-revolutions-landing-page/

Three Revolutions in Urban TRANSPORTATION

How to achieve the full potential of vehicle electrification, automation and shared mobility in urban transportation systems around the world by 2050

Lew Fulton, UC Davis
Jacob Mason, ITDP
Dominique Meroux, UC Davis

May 2017

Research supported by:
ClimateWorks Foundation, William and Flora Hewlett Foundation, Barr Foundation

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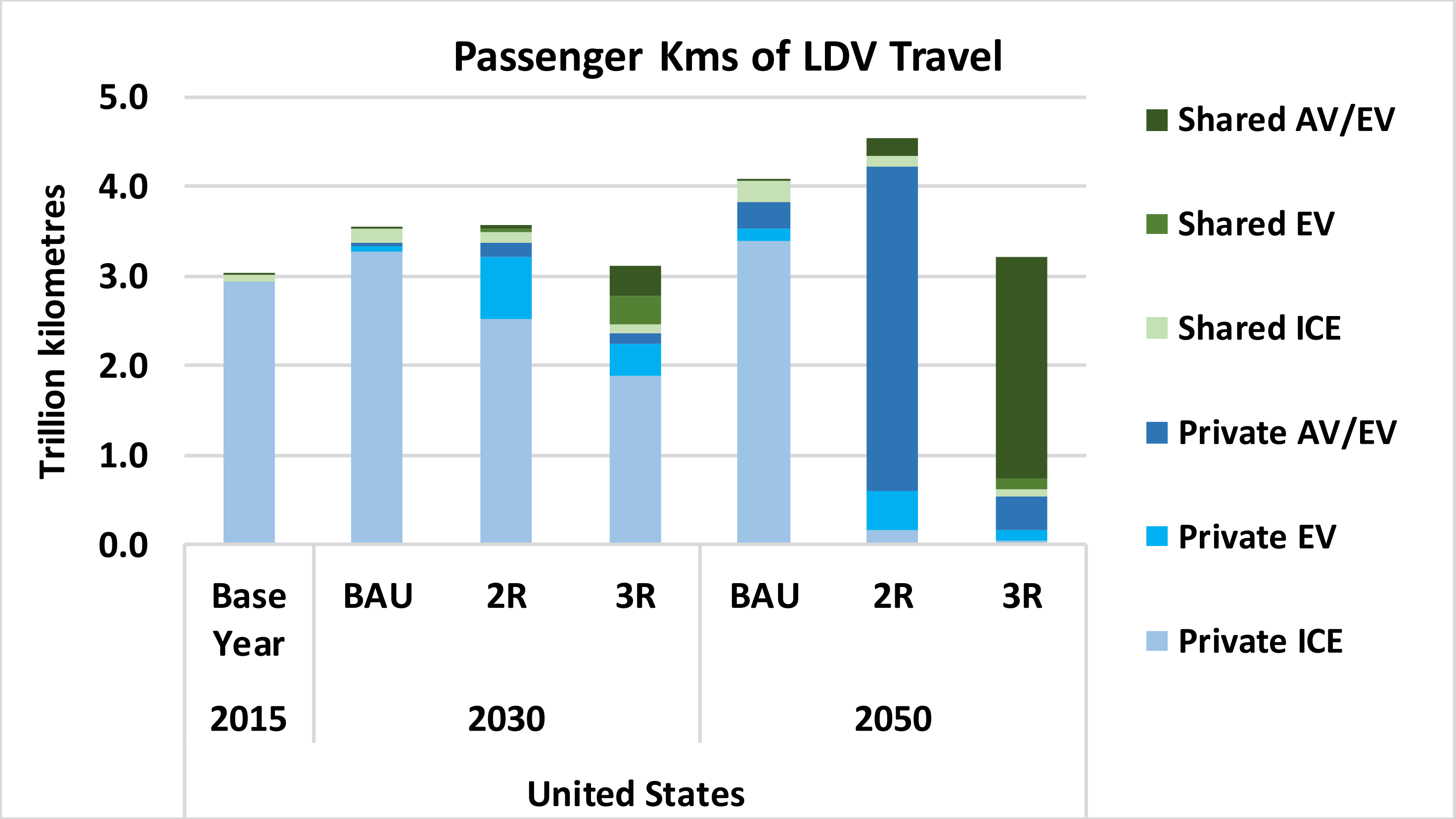
Rough guide to the three scenarios

	Auto-mation	Electrifi-cation	Shared Vehicles	Urban Planning/ Pricing/TDM Policies	Aligned with 1.5 Degree Scenario
Business as usual, Limited Intervention	Low	Low	Low	Low	No
1R Automation only	HIGH	Low	Low	Low	No
2R With high Electrification	HIGH	HIGH	Low	Low	Maybe
3R With high shared mobility, transit, walking/cycling	HIGH	HIGH	HIGH	HIGH	YES

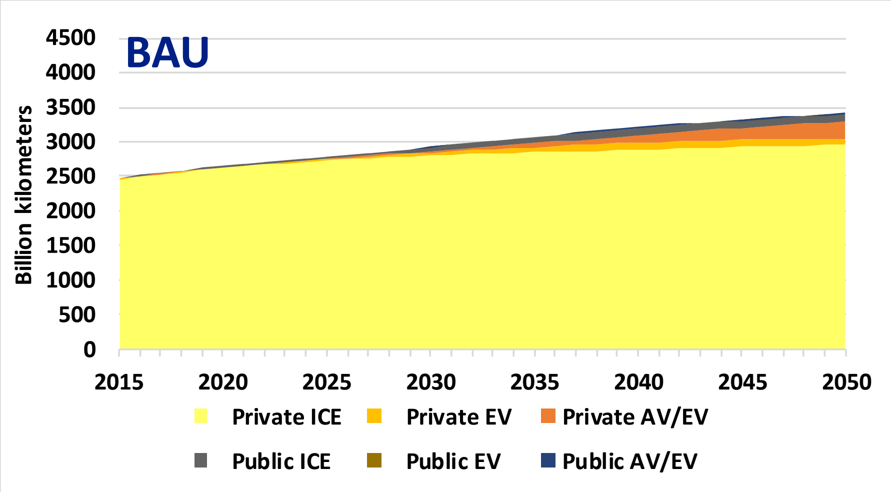
Urban LDV passenger kms by scenario, USA

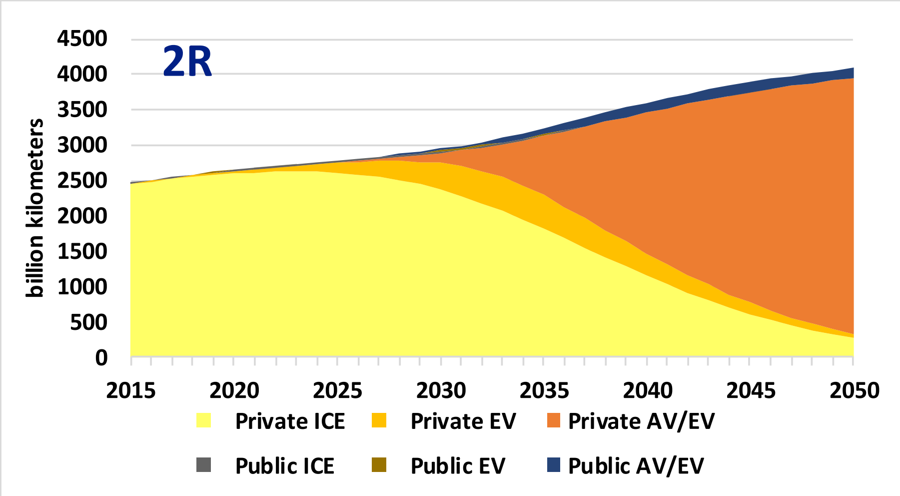
- Electric vehicle travel reaches nearly 1/3 of PKMs by 2030
- Automated vehicle travel not significant by 2030 in any scenario, but dominates in 2R and 3R 2050. Results in much higher travel in 2R

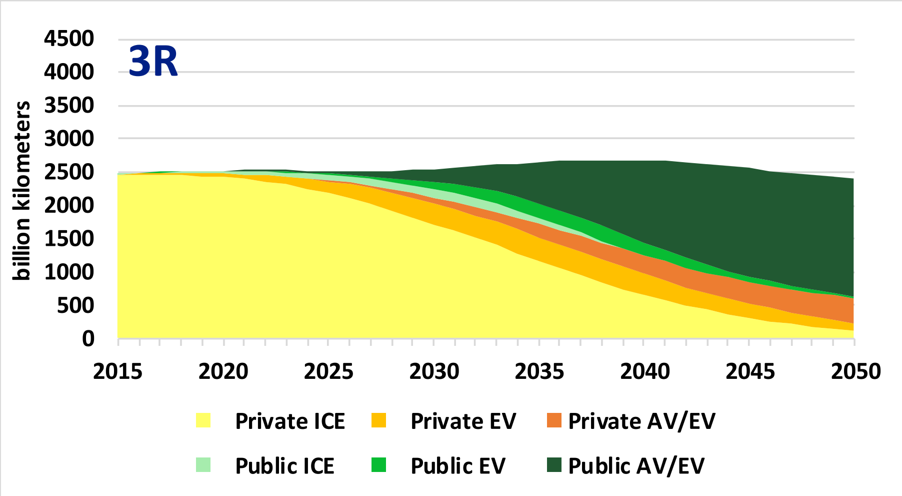


Urban LDV travel (VKm) by scenario, USA

- 2R vehicle travel rises sharply after 2030 due to lower travel costs from automated vehicles
- 3R vehicle travel flat despite declining vehicle stock, given higher travel per vehicle of public vehicles







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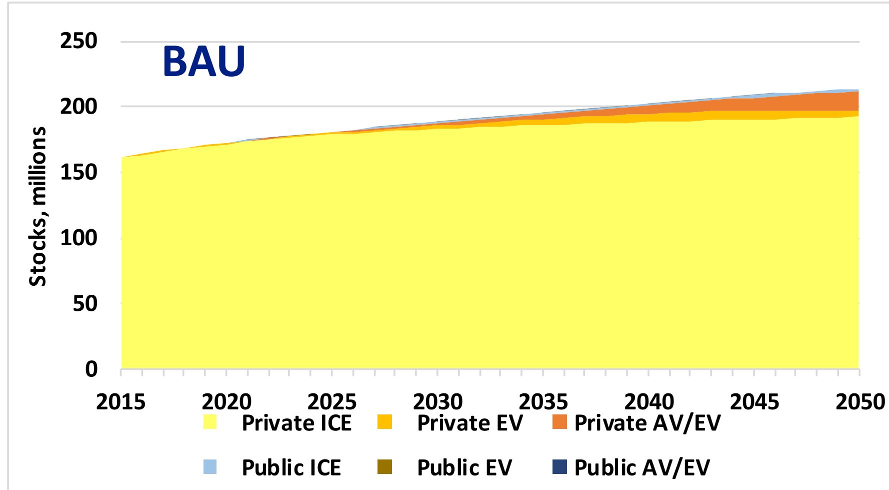
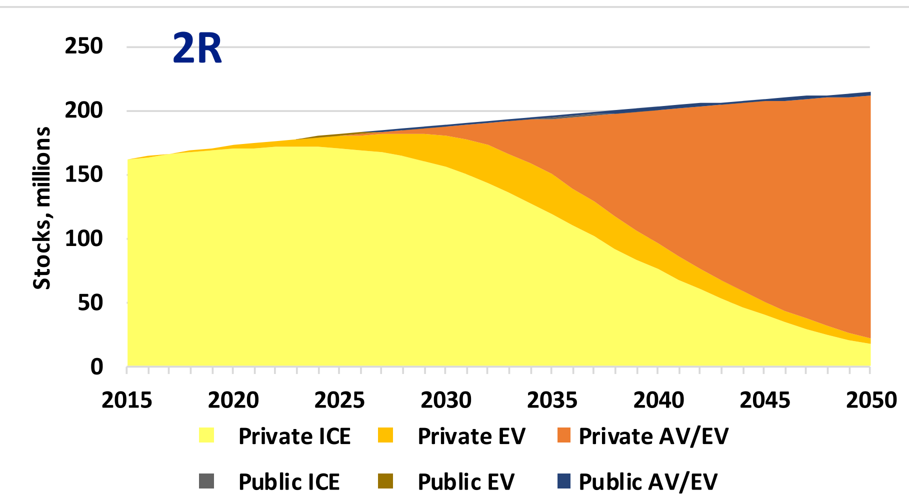
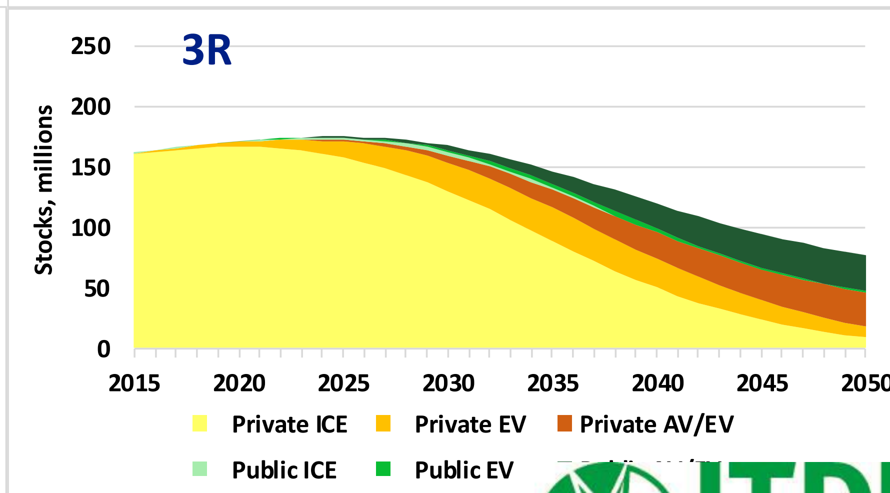
Urban LDV stock evolution by scenario, USA

- 2R stocks nearly completely autonomous by 2050
- 3R stocks strongly decline after 2030, due to lower passenger travel levels, intensive vehicle use and higher load factors







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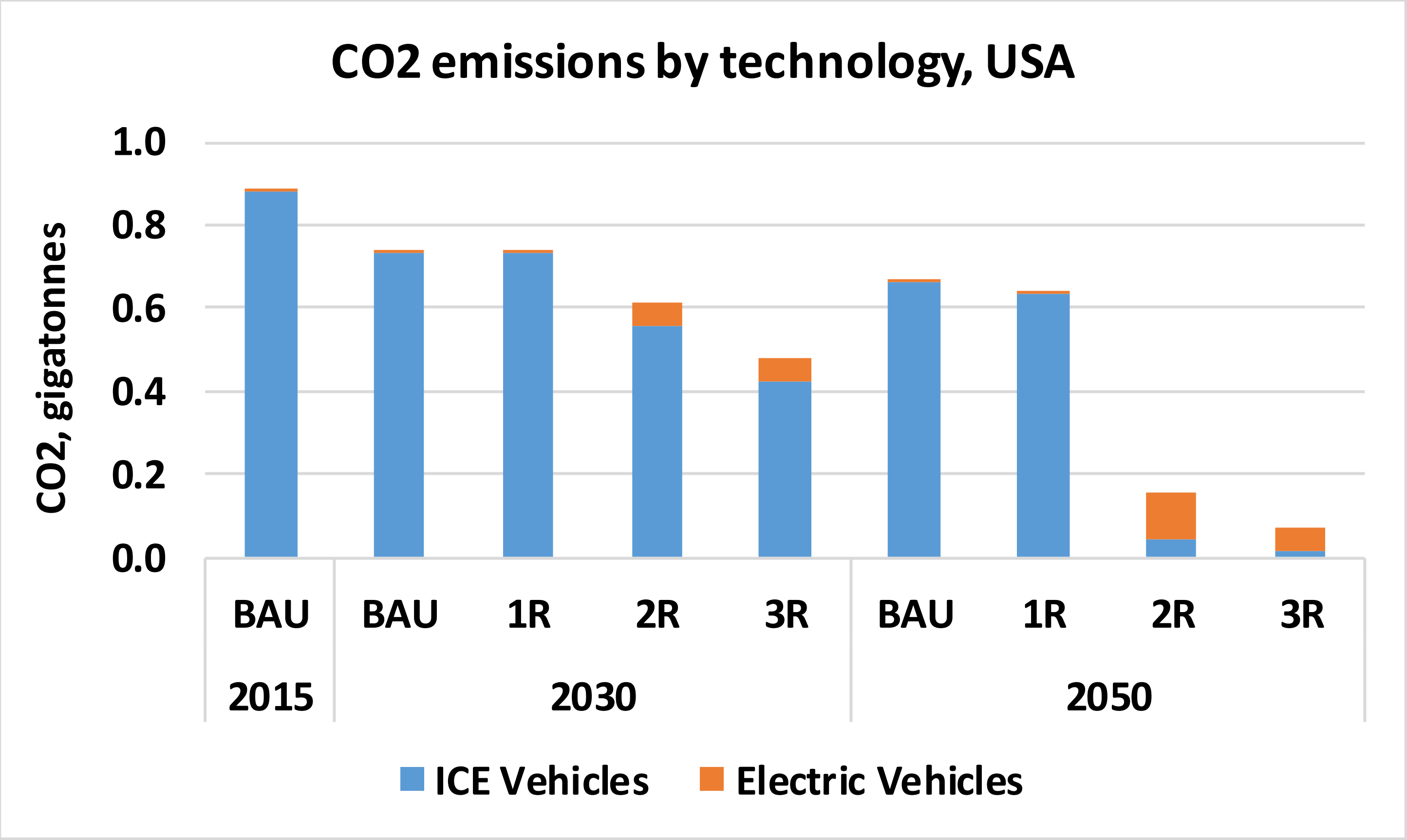
Well-to-wheels CO2 by scenario/technology, USA

4DS electricity shown; in 2DS, CO2 from electricity drops to near zero in 2050



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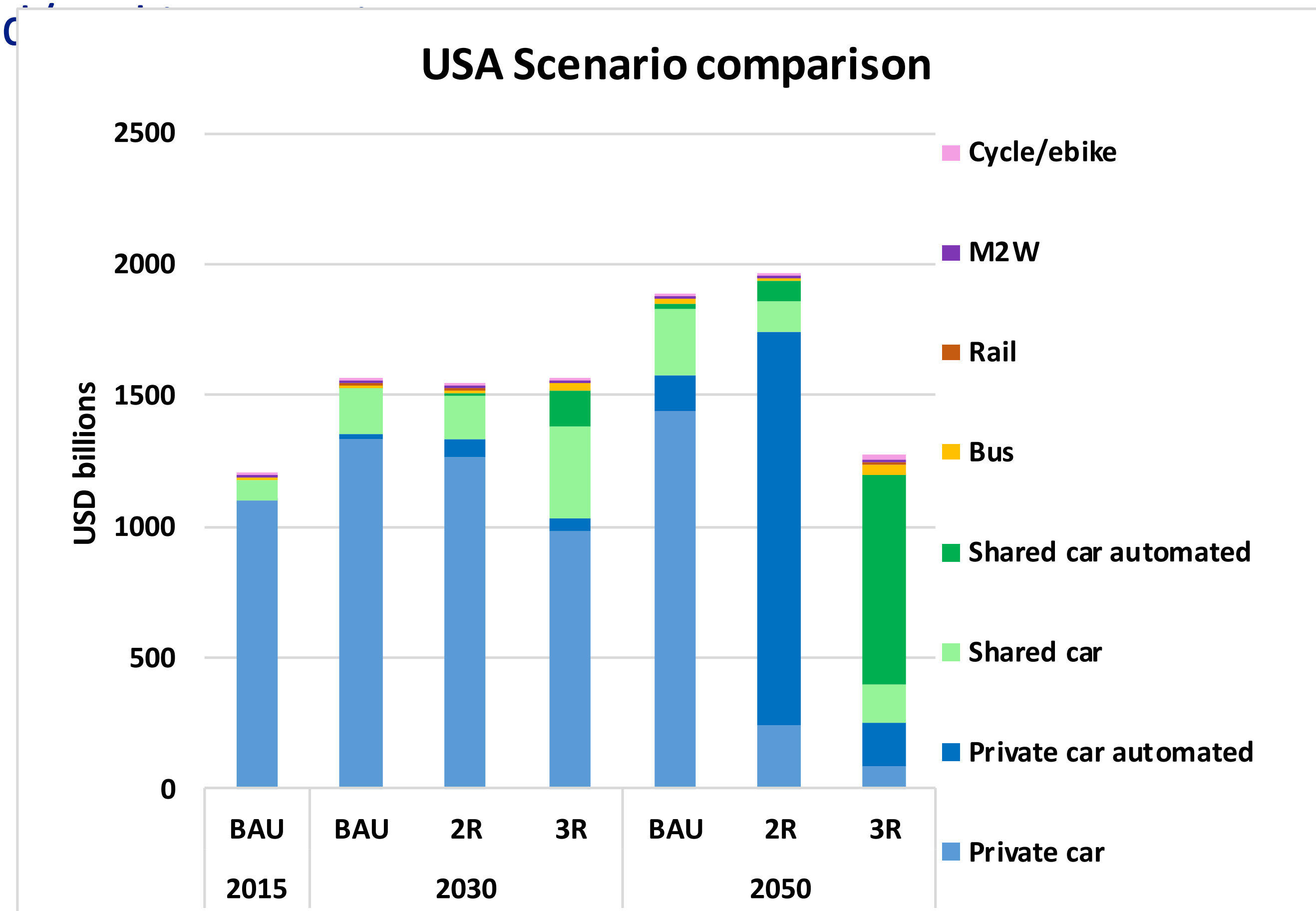
Total cost by scenario and mode, USA

- Total societal (out-of-pocket) 3R cost in 2050 is only 2/3 of BAU or 2R cost, thanks to deep cuts in car ownership, energy use, and road



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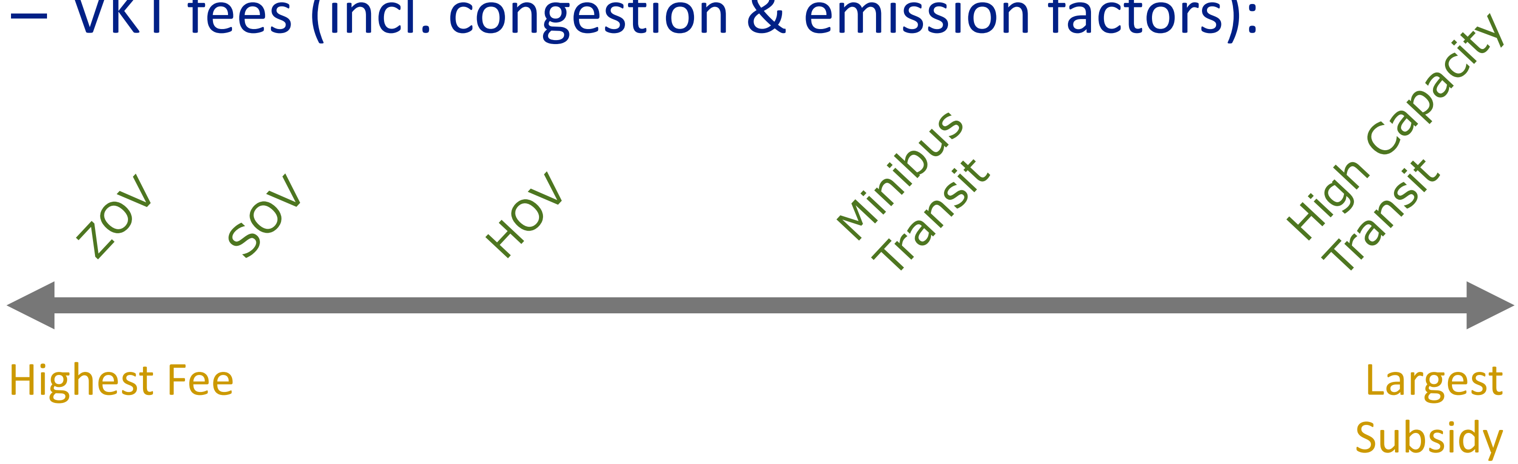
Supportive Policies – critical to success of the scenarios

- 3R Scenario (Automation + Electrification + **Sharing**):
  - Compact Urban Development policies
  - Efficient parking policies
  - Heavy investment in transit/walking/cycling
  - VKT fees (incl. congestion & emission factors):



Some questions and conflicts

- **Automation: lower per-trip costs, lower "time cost" for being in vehicles**
  – Just how much cheaper will it be?
  – Private automated vehicles = longer trips?
  – Empty running (zero passengers) of vehicles
  – Resulting relative costs of private vehicles, shared mobility, transit?

- **Electrification goes with automation – does it really?**
  – Can get the job done with upgraded electrical system (such as hybrids)
  – But electric running will be much cheaper – and durable?

- **Ride hailing: cost savings v. convenience and risk**
  – Complementary or at conflict with public transit use?
  – Will lower costs reduce the incentive to ride share?

The wide range of costs related to mobility choices

Out-of-pocket Costs

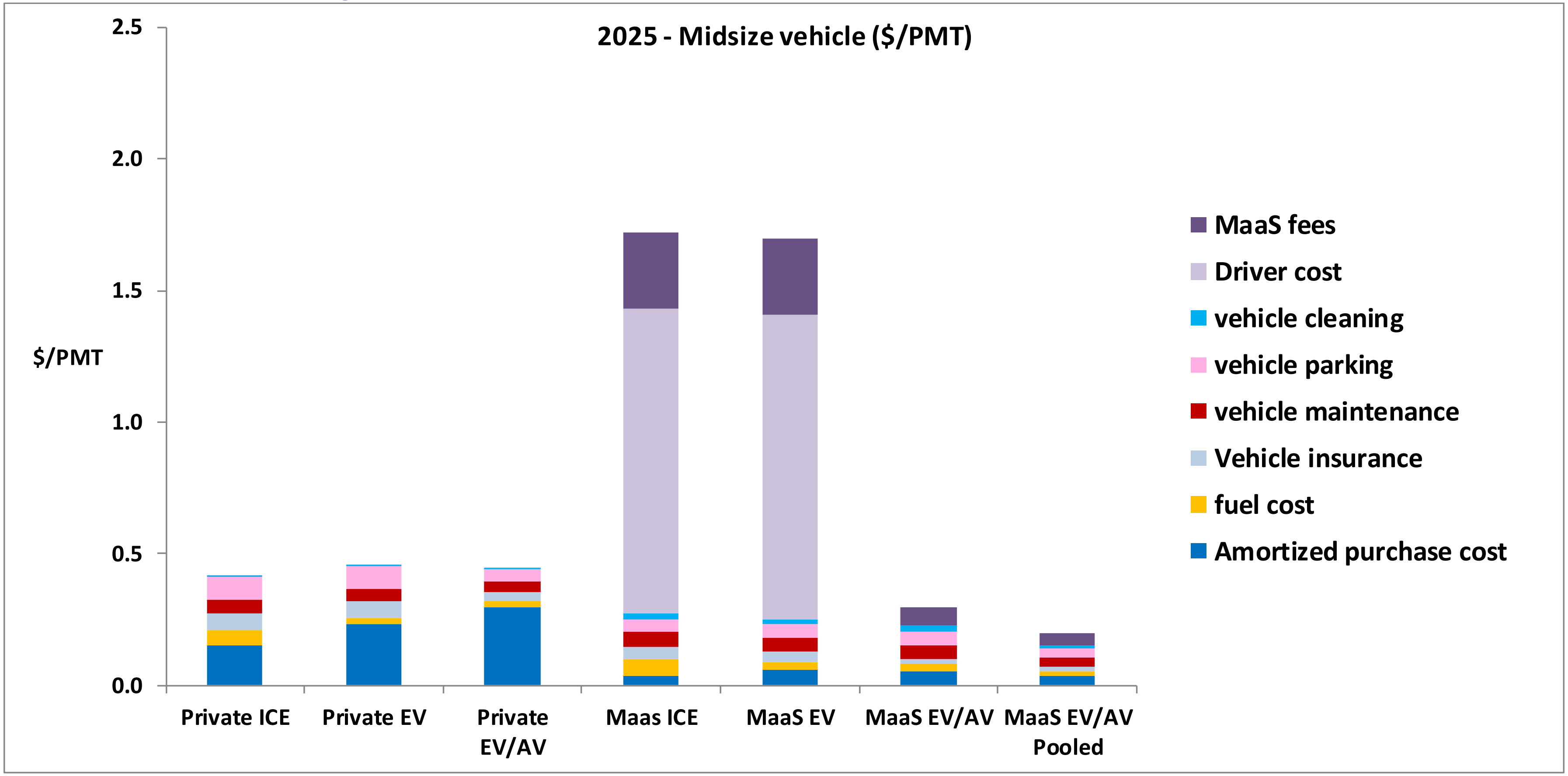
- Vehicle purchase
- Vehicle maintenance
- Fuel
- Insurance
- Cleaning
- Parking
- Driver
- MaaS fees
- Tolls
- Registration-related fees

Hedonic costs

- **Travel time (driving)**
- **Travel time (passenger)**
- **Parking search time**
- **Walking time**
- **Driving stress**
- **Shared trips (e.g. lack of privacy)**
- **EV range, charging anxiety**
- **Car ownership negatives (maintenance, registration, inspections etc.)**
- **Car ownership positives (car pride, guaranteed ride; can leave personal belongings in the car)**
- **Perceived Environmental Cost**

Out-of-pocket costs: Comparison of modes

- ***Driven TNC vehicles are premium service, automation makes these competitive***



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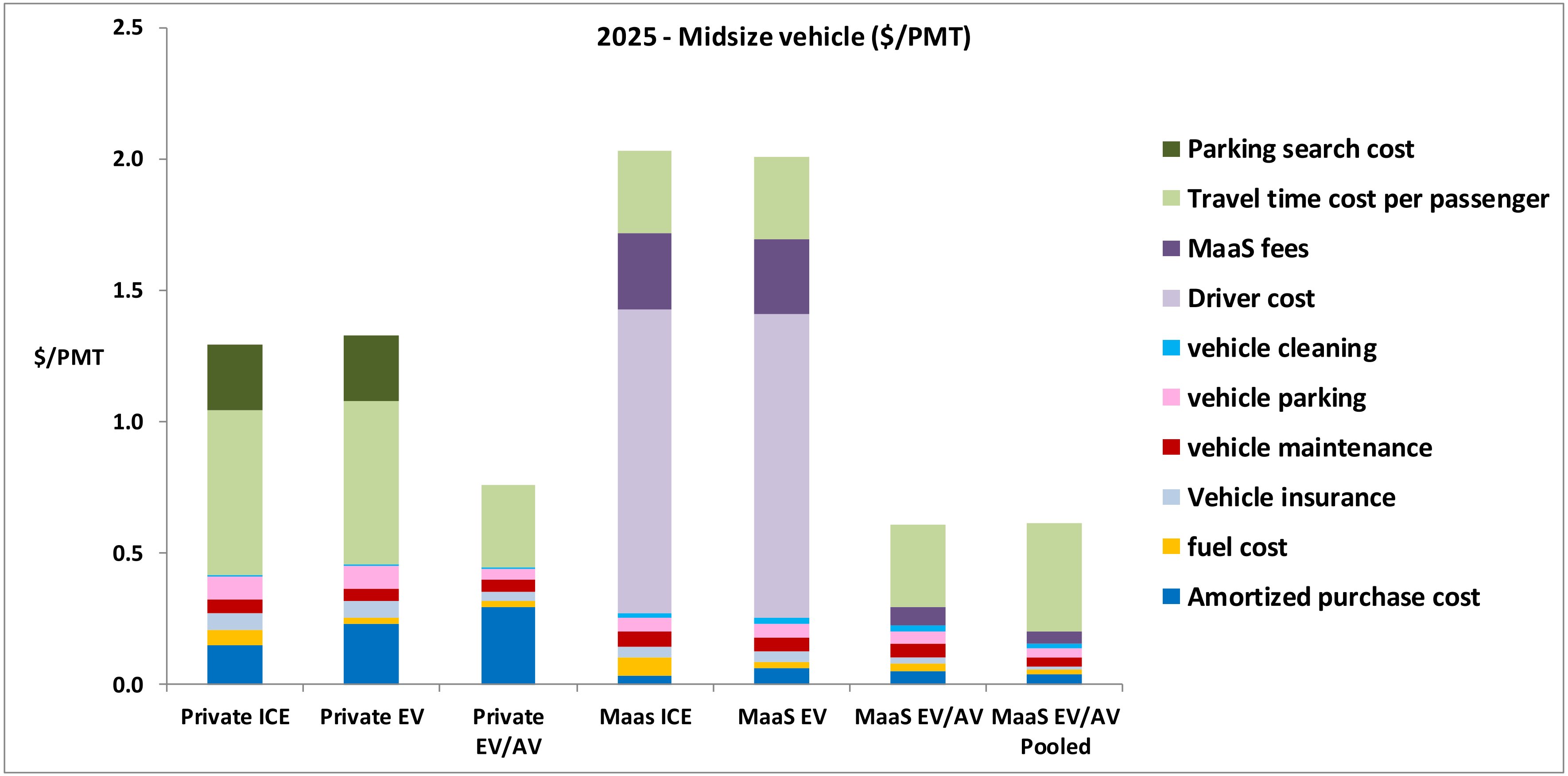
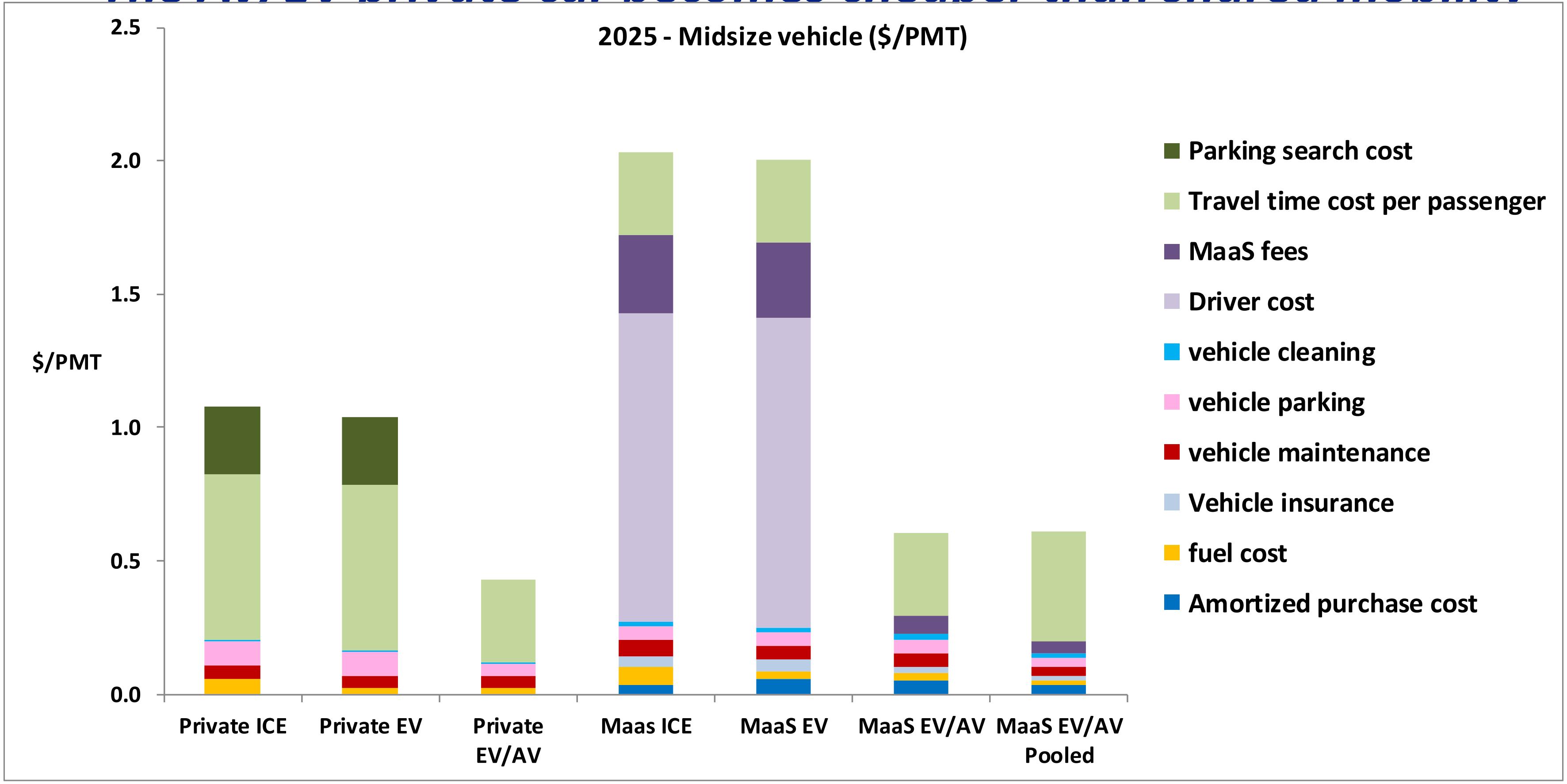
Added a value of time for driving, travelling, parking

- ***Time costs are equal to or in some cases far greater than the out-of-pocket costs***



Included only variable costs (daily decision)

- Ignore private car purchase, insurance cost
- ***The AV/EV private car becomes cheaper than shared mobility***



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Costs of Mobility…

- Still trying to get a handle on monetary costs of different modes
  - Wide range of fixed and variable costs
  - ICE vs electric and automated vehicles
  - Differences by trip type and location
- But at the same time, we have reason to believe that non-monetary costs are as important or potentially more important.
  - Even harder to quantify
  - But let’s try

Considering these costs by when, and how often, paid

	Separate from trip	Once per trip	Lumpy	Roughly per-mile
Monetary	• Insurance • Registration and other annual or monthly fees	• Parking cost • TNC "first mile" fee	• Tolls • Vehicle cleaning	• Depreciation • Maintenance • Fuel cost • TNC per-mile fees • Per-mile road user fees (taxes)
Non-monetary	• Maintenance and inspections events (time, loss of vehicle use) • Car ownership pride and other hedonic ownership benefits • Per-vehicle environmental impacts (vehicle production, disposal)	• Time spent parking and searching for parking • Walking to/from vehicle to "door“ • Loading/ unloading vehicle	• Refueling/ cleaning time • Recharging search, recharging time, anxiety • Keeping items in vehicle	• Travel time • Driving stress/enjoyment • Ride sharing (pooling) stress/enjoyment • Other in-ride hedonic factors • In-ride productivity • Per-mile environmental impacts (CO_2, air pollutants)

Important when in own vehicle (positive/negative)

	Separate from trip	Once per trip	Lumpy	Roughly per-mile
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Important when Ride-hailing (positive/negative)

	Separate from trip	Once per trip	Lumpy	Roughly per-mile
Monetary	• Insurance • Registration and other annual or monthly fees	• Parking cost • **TNC "first mile" fee**	• Tolls • Vehicle cleaning	• Depreciation • Maintenance • Fuel cost • **TNC per-mile fees** • **Per-mile road user fees (taxes)**
Non-monetary	• Maintenance and inspections events (time, loss of vehicle use) • Car ownership pride and other hedonic ownership benefits • Per-vehicle environmental impacts (vehicle production, disposal)	• Time spent parking and searching for parking • Walking to/from vehicle to "door" • **Loading/ unloading vehicle**	• Refueling/ cleaning time • Recharging search, recharging time, anxiety • Keeping items in vehicle	• Travel time • Driving stress/enjoyment • **Ride sharing (pooling) stress/enjoyment** • **Other in-ride hedonic factors** • **In-ride productivity** • Per-mile environmental impacts (CO_2, air pollutants)

Cost types where we have **poor or no data**

	Separate from trip	Once per trip	Lumpy	Roughly per-mile
Monetary	• Insurance • Registration and other annual or monthly fees	• Parking cost • TNC "first mile" fee	• Tolls • Vehicle cleaning	• Depreciation • Maintenance • Fuel cost • TNC per-mile fees • Per-mile road user fees (taxes)
Non-monetary	• **Maintenance and inspections events (time, loss of vehicle use)** • **Car ownership pride and other hedonic ownership benefits** • **Per-vehicle environmental impacts (vehicle production, disposal)**	• **Time spent parking and searching for parking** • **Walking to/from vehicle to "door"** • **Loading/ unloading vehicle**	• **Refueling/ cleaning time** • **Recharging search, recharging time, anxiety** • **Keeping items in vehicle**	• Travel time • **Driving stress/enjoyment** • **Ride sharing (pooling) stress/enjoyment** • **Other in-ride hedonic factors** • **In-ride productivity** • **Per-mile environmental impacts (CO_2, air pollutants)**

Fixed, lumpy and per-mile costs – for those costs we have

- ***Many costs are fixed or lumpy***
- ***TNC fees and travel time dominate per-mile costs***

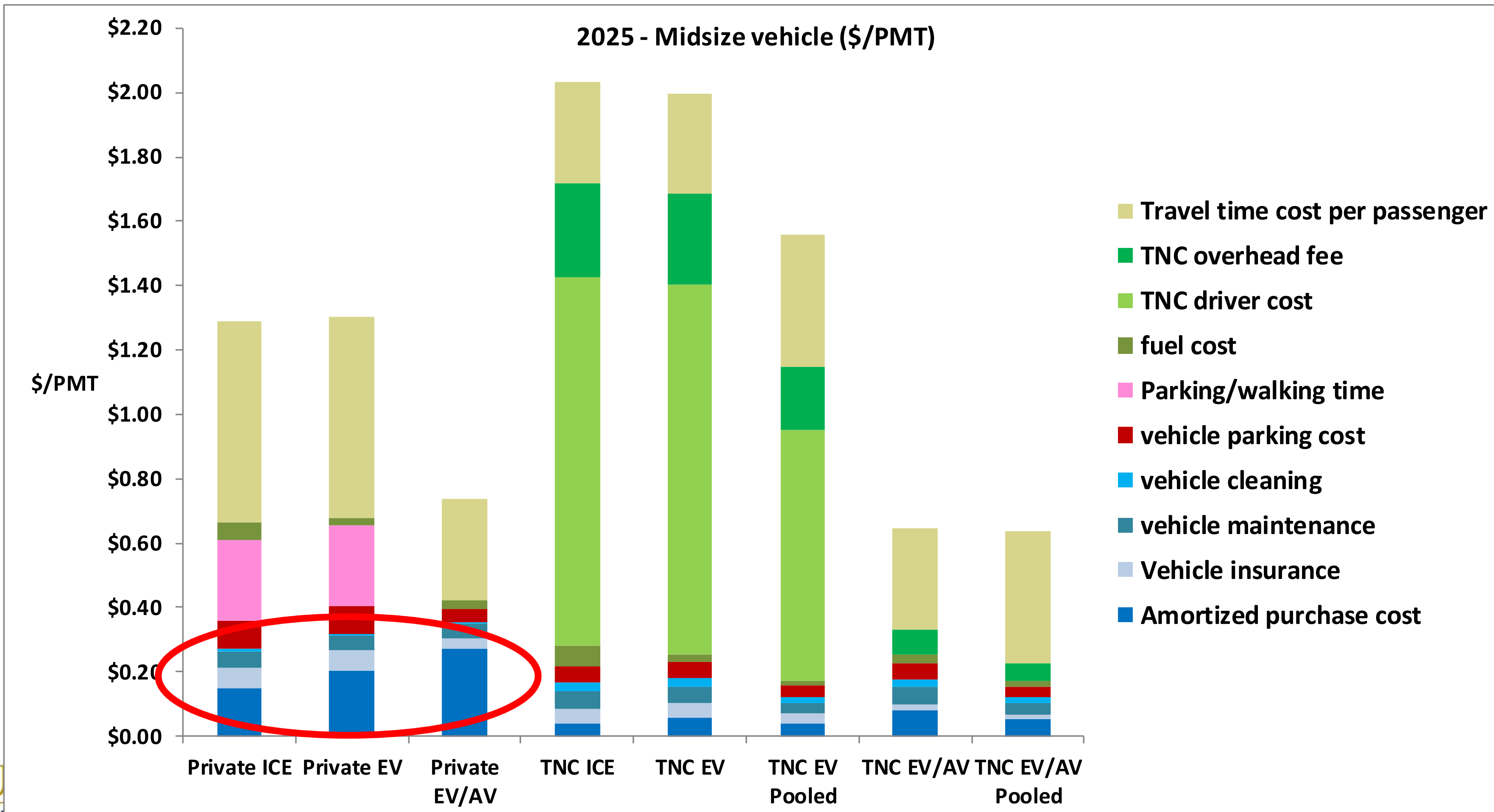
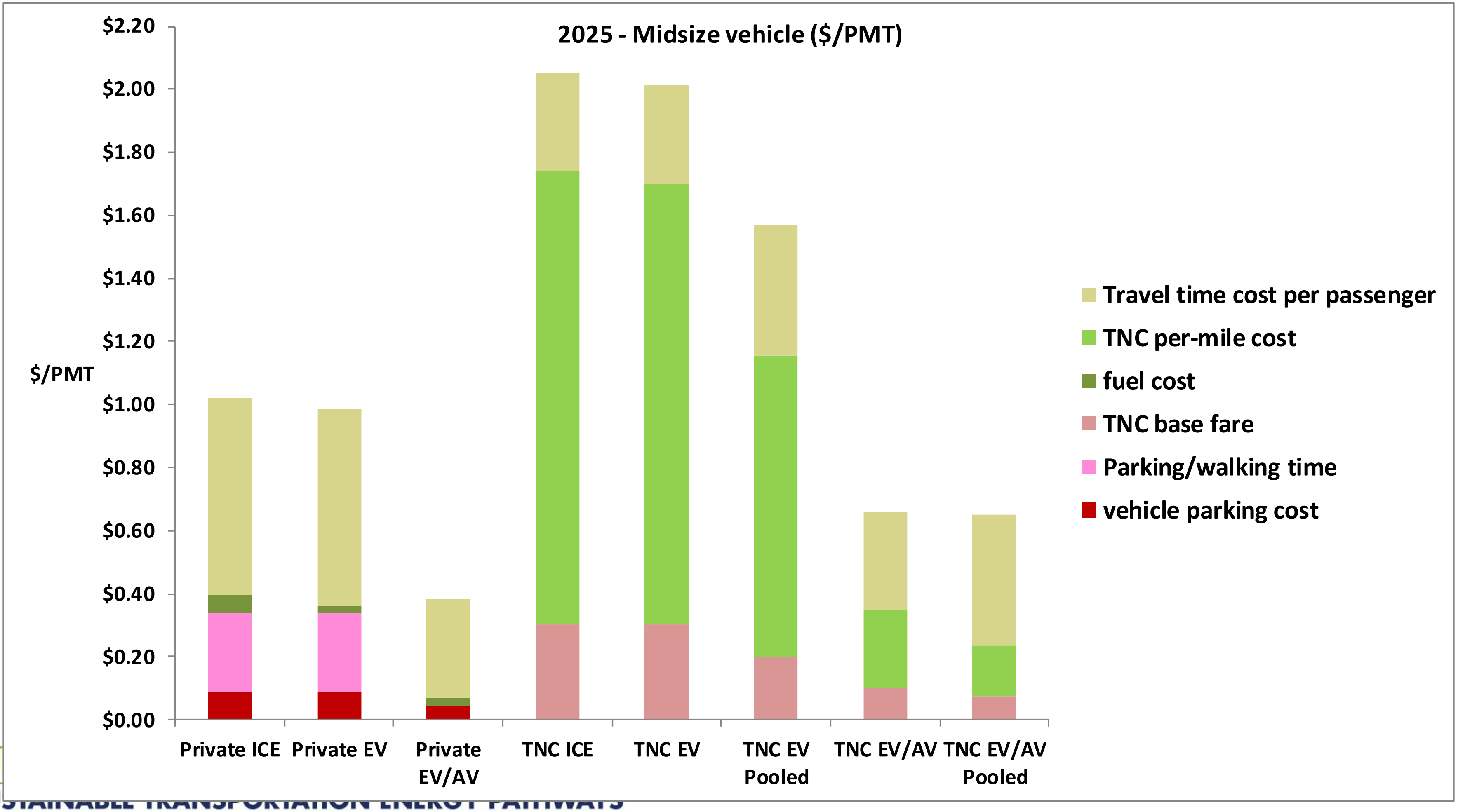


Figure with only the trip fixed and per-mile costs shown

- ***Private automated vehicle trips starting to look good, especially for shorter trips (this one is 6 miles, 30 mph)***



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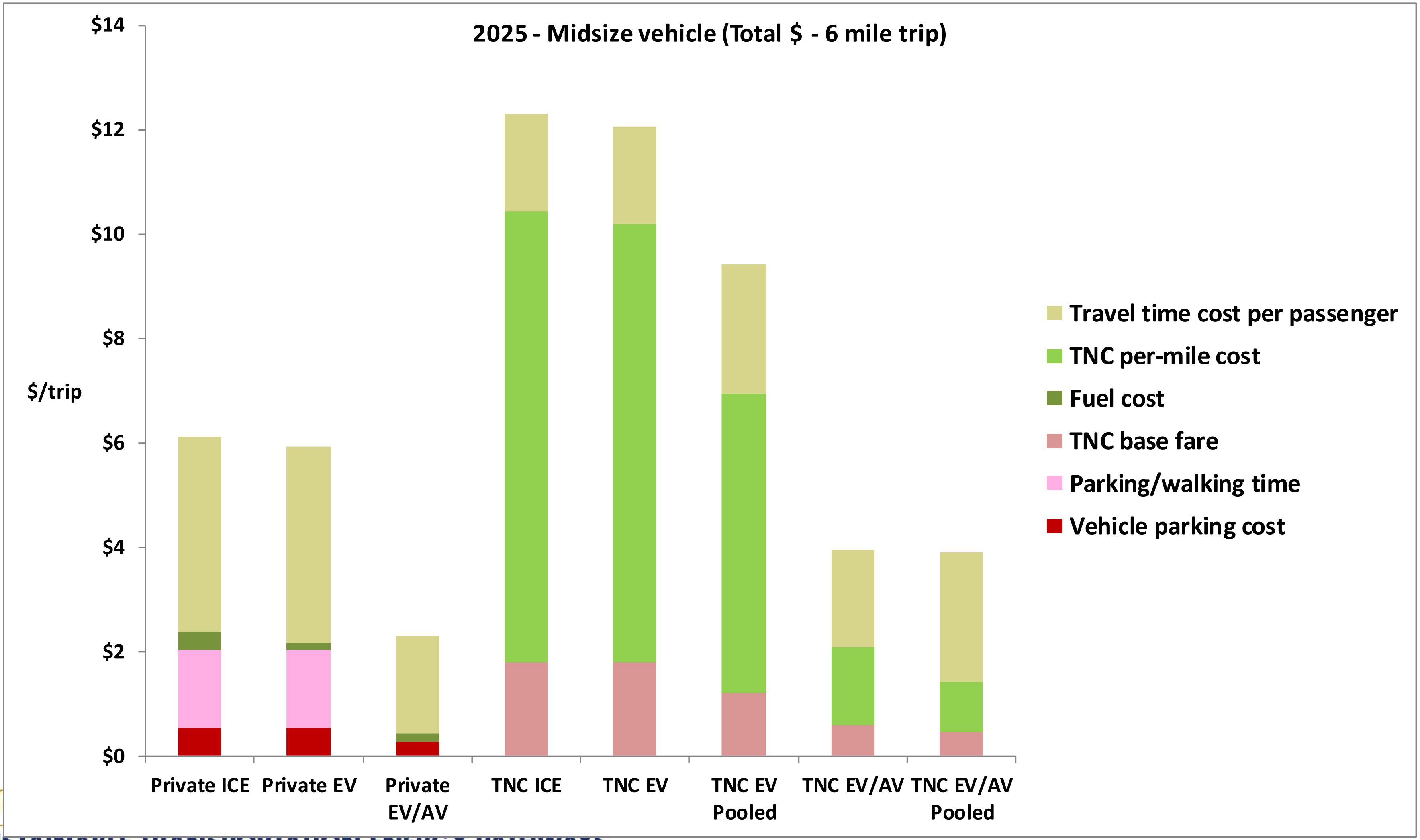
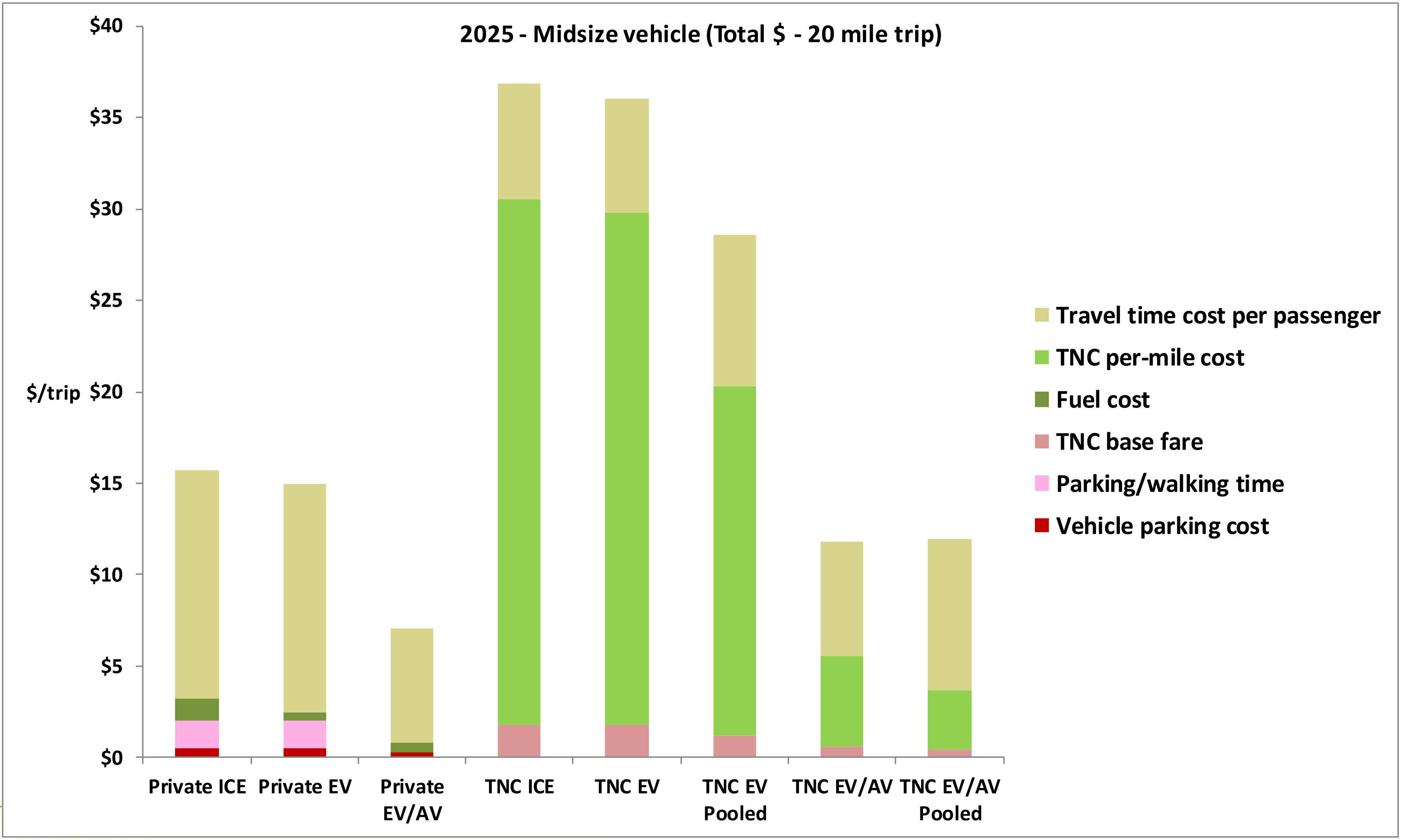
Same scenario, but shown as total costs for a six mile trip

- Costs range from $2 to $12 per trip; driverless modes below $4



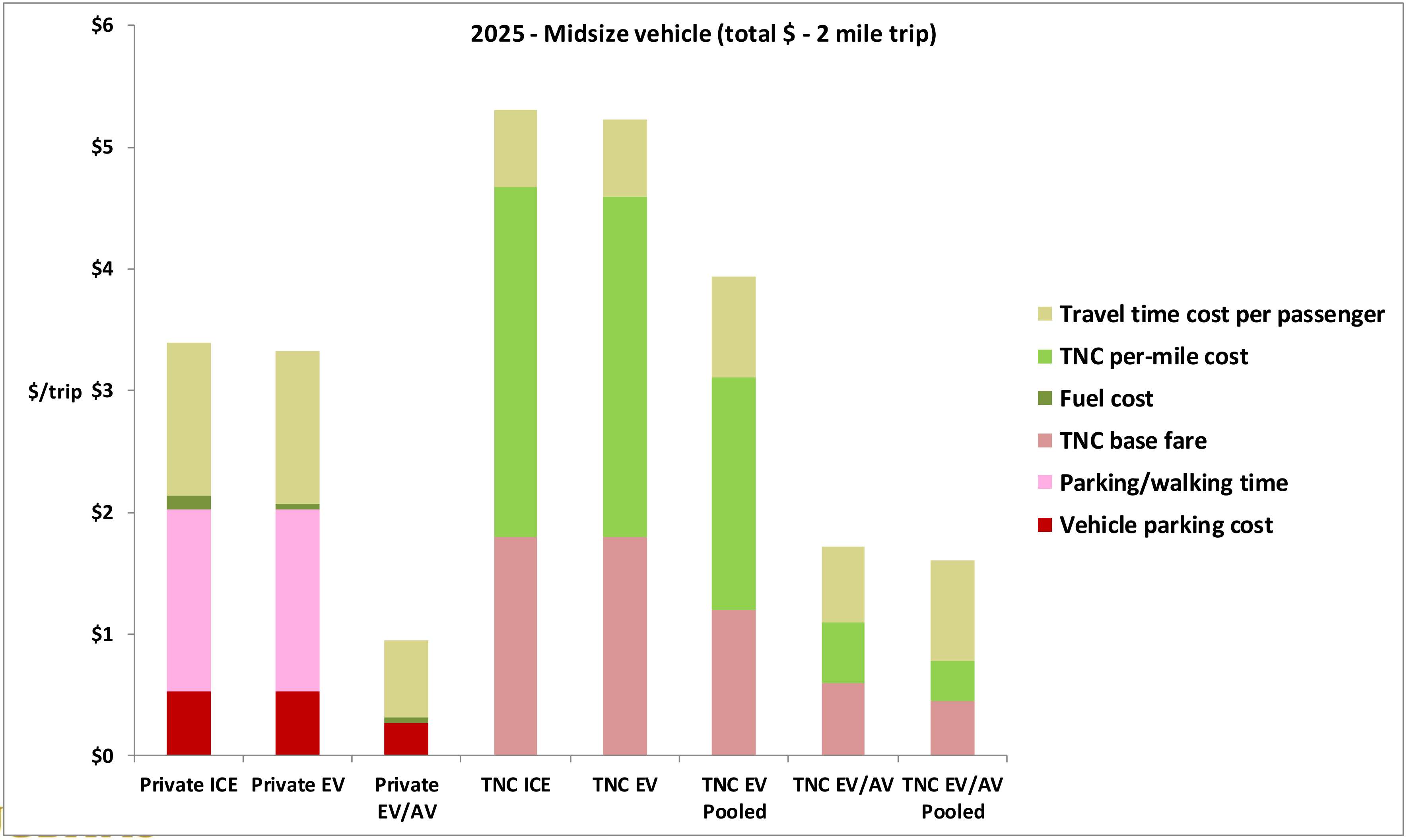
Data converted to per-trip costs for a 20 mile trip

- Fixed costs become less important for longer trips



And for a 2 mile trip

- Fixed costs start to dominate short trips



What about other non-monetary costs?

- We need to do much in-depth survey work, and maybe experiments to judge behavior in different situations
- Some aspects will be difficult to assess until situations change
  - Driverless vehicles:
    - Attitudes about travel, effective time cost penalties
    - Changes in total travel
  - EVs: recharging anxiety in an age of fast charging, abundant charging
  - Shared mobility: attitudes about pooling with no driver

A couple of thought experiments (don't try this at home)

- **Value of being able to store things in the vehicle**
  - If it takes 2 minutes (twice) to load/unload things like car seats and generally get all your stuff in and out of your car every trip, and it's an unwelcome hassle, this might be valued $15k/hour. That's a $1 hedonic cost per trip (4/60 * $15) . For a 6 mile trip, that's **$0.17 per mile**

- **Cost of an uncertain ride**
  - A "certain" ride means there is a car in a known location and you have the keys. There may be a cost to any uncertainty about available commercial rides, as well as time variance.
  - If one expects to ride hail with vehicle arrival in, say, 5 minutes there might be a hedonic cost if it arrives later than this. Each additional minute might cost 1/60 * $15/hr. This cost may also rise per minute, as frustration (or lateness) mounts. A vehicle that is 4 minutes late would incur a $1 hedonic cost; if it happens (or is expected to happen) every 4th trip, this amounts to an average of about **$0.04 per mile** for a 6 mile trip

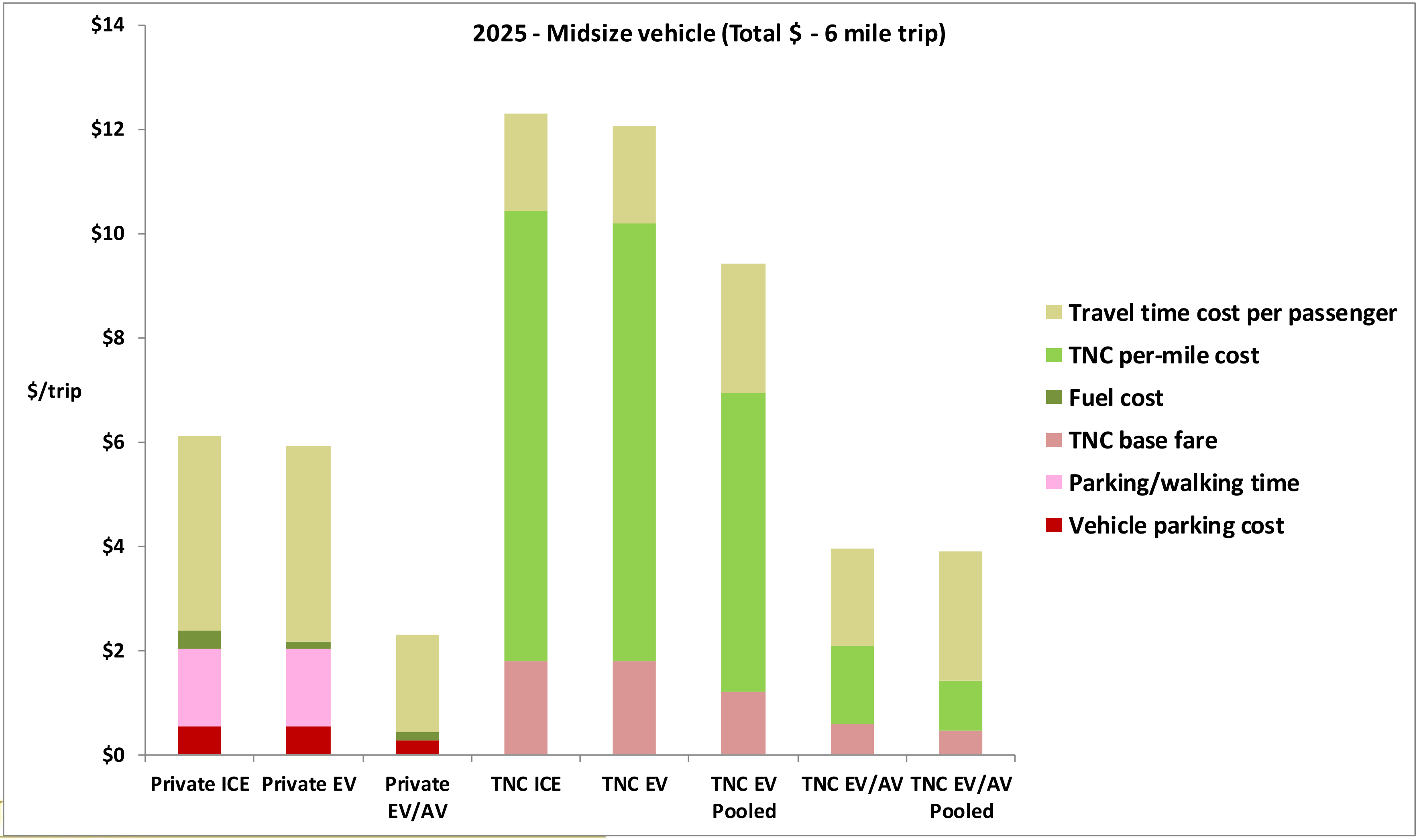
Simple $15/hour time cost analysis across activities
(Example of a 6 mile, 12 minute trip, 30 miles per hour)

- A few activities stand out as possibly "expensive"

Activity	Time (mins)	$ / hour	$ / event	Events / trip	$ / trip	$ / mile	Notes
Loading / unloading	4	15	0.50	0.50	1.00	0.08	2 minutes twice per trip
Uncertain ride	5	15	1.25	0.25	0.31	0.05	5 minutes wait time, 1/4 of trips
Maintenance events	30	15	7.50	0.01	0.08	0.01	20 minutes for dropoff, 10 for pickup
Parking / searching	5	15	1.25	1.00	1.25	0.21	5 mins for parking search and parking, once per trip
Walking to / from car	3	15	0.75	2.00	1.50	0.25	3 minutes twice per trip (short walks, one could be driveway)
Refueling / cleaning time	5	15	1.25	0.10	0.13	0.02	Assumes one refueling per 10 trips
Public recharging search time, anxiety	5	20	1.67	0.20	0.33	0.06	Search time at higher per-hour cost
Driving	12	15	3.00	1.00	3.00	0.50	General travel time cost
Driving stress	12	5	1.00	0.50	1.00	0.08	Additional time cost due to stressful driving

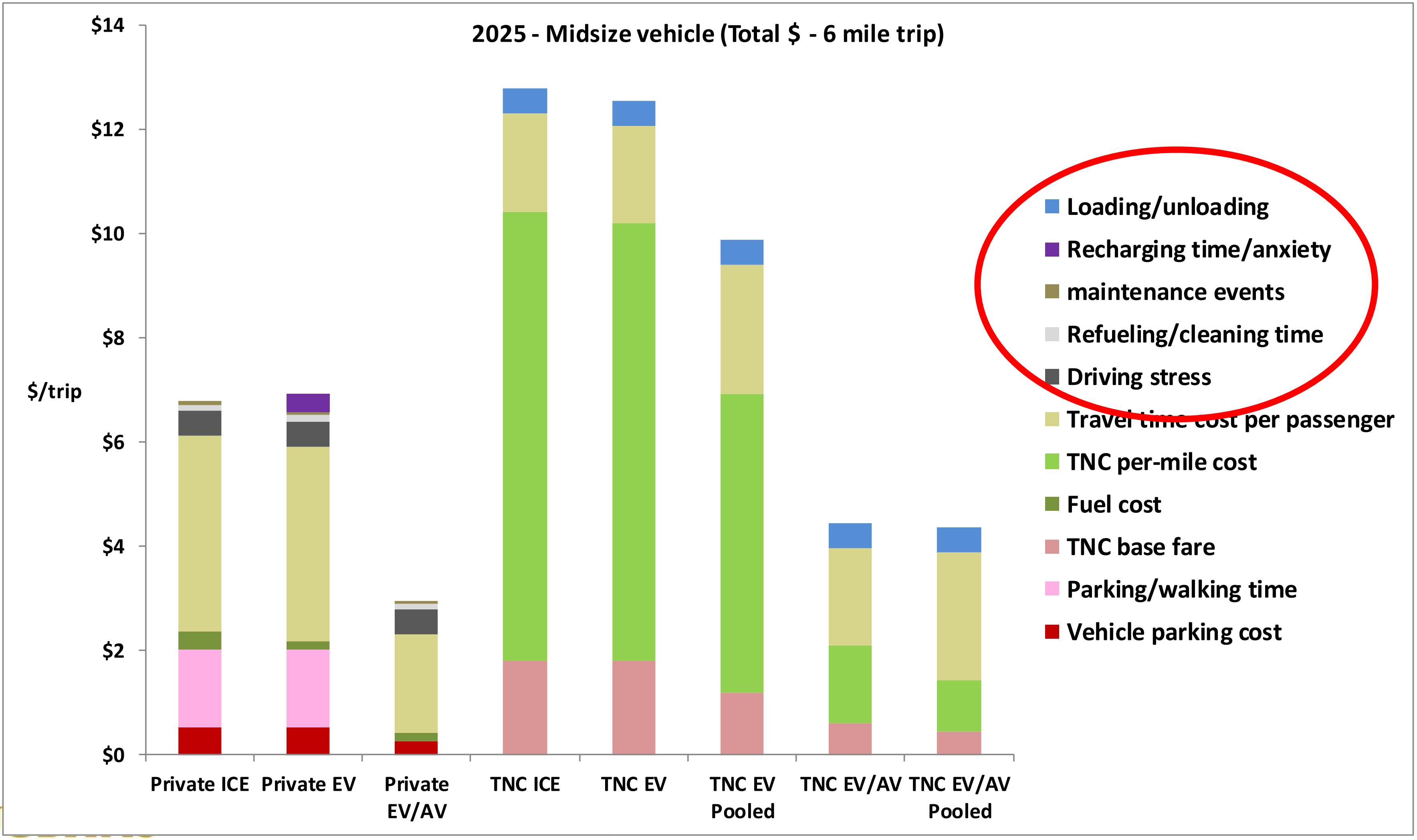
Back to our 6 mile trip

- Costs range from $2 to $12 per trip; driverless modes below $4



6 mile trip, now with the additional categories

- The new categories, together, don't change things much



Conclusions

- Non-market cost factors are many, varied and difficult to measure
- My very simplistic first cut suggests that some may be relatively unimportant, *on average*
  - May still be critical in certain situations, or for certain people
- More research is needed, such as focus groups and surveys

Thank you

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