Mobility of the Future study

MITEI External Advisory Board Meeting

October 24, 2019

Overview

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Executive Director, Mobility of the Future study, MIT Energy Initiative

Mobility of the Future study: Motivation

The Mobility Challenge

Drivers of Change

Part of MIT's Plan for Action on Climate Change

Future mobility landscape could look **very different** from today in ways which are not adequately understood yet

Mobility of the Future study: Objectives and Topics

Objectives

To better understand:

- The future ground transportation system for the ***movement of people***
- Which ***fuels*** will be used
- How ***technology*** may disrupt the status quo
- How ***policies*** may establish trajectories of change
- How people make ***mobility decisions***

The study

- **3-year study:** *Final Report: November 19, 2019*
- ***11 Consortium Members***

Final report topics *(partial list)*

- **Oil demand** and **prices** under various climate policy scenarios
- **Impact of policy** on vehicle fleets
- Projected **cost of batteries**
- **Total cost of ownership** analyses for different powertrains
- **Life cycle analysis** of powertrains and fuels
- **Alternative fuel vehicle adoption**
- Understanding of **"car pride"**
- Impact of **Robo-taxis** on congestion, miles travels and energy

Mobility of the Future study: Breadth

Scope and Methods (partial list)

- **Global energy use and policy consequences** – Multi-region multi-sector model (EPPA)
- **Powertrains**: Internal combustion engines, hybrids, plug-in hybrids, battery electric, fuel cell
- **Fuels**: Gasoline, electricity, hydrogen
- **Life cycle analysis** – Sustainable Energy System Analysis Modeling Environment (SESAME)
- **Total cost of ownership**: purchase, maintenance, insurances, fuels
- **Vehicle adoption co-evolution with Infrastructure** – System Dynamics model
- **Urban mobility** – Agent-based model of diverse cities (SimMobility)
  Modes included: Cars, taxis, Uber/Lyft, subways, buses, motorcycles, bikes, walking, robo-taxis
- Attitudes about mobility – **Global survey of 42,000 people across 51 countries**
- **Policy making** – Examined car restriction policies across 287 Chinese cities

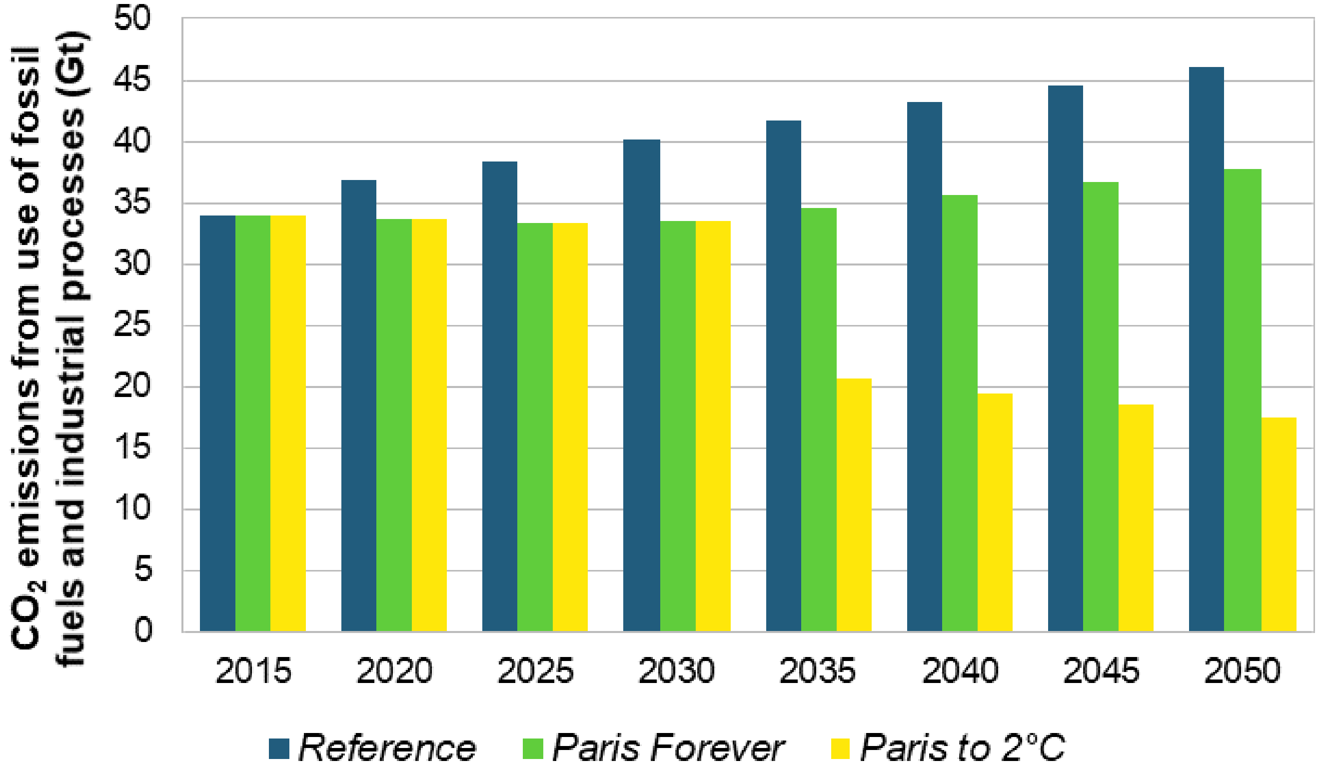
Mobility of the Future study: Global scenarios

Climate Policy Scenarios

- **Reference** – No implementation of Paris Agreement; No additional climate policies
- **Paris Forever** – All nations fulfill their Paris commitments by 2030 but no additional action
- **Paris to 2°C** – All nations fulfill Paris commitments by 2030 and then implement global economy-wide carbon pricing thereafter

Subcases:

- Lower battery electric vehicle costs
- Additional support for renewables
- Fuel cell mandate



Mobility of the Future study: Highlights

A Few Key Findings

- Climate change mitigation can be accomplished simultaneously with global economic growth
- Electricity carbon intensity is expected to fall more rapidly than carbon emissions from LDVs
- Only a fifth of oil consumption reductions due to strong carbon policy are expected to come from light duty vehicle electrification
- Vehicle emissions are sensitive to fuel production methods. Examples:
    - Fuel cell vehicles running on hydrogen generated from U.S. average electric grid today is almost 50% more carbon-intensive than driving a hybrid car fueled by gasoline
    - Battery electric vehicle running on electricity from the West Virginia grid is 30% more carbon intensive than a hybrid vehicles, while a BEV running on Washington electricity is 61% less carbon intensive than a hybrid

Conclusion: programs to shift to alternative fuel vehicles must look beyond tailpipe emissions and address decarbonization of the energy that power them

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Transition to Alternative Fuel Vehicles: Why, Which, Where, How, When, and at What Cost?

William H. Green

Hoyt C. Hottel Professor of Chemical Engineering and
Faculty Chair of the Mobility of the Future study

Why?

Many different alternative fuel vehicles (AFVs) are promoted for many very different reasons

In U.S., AFVs include: combustion vehicles using non-petroleum fuels, hybrid vehicles (use gasoline), electric vehicles, and fuel-cell vehicles

Stated Goals:

- Reduce CO_2 emissions (climate change)
- Reduce petroleum imports (national security, balance of trade)
- Reduce toxic pollutants (health)
- Promote domestic industry (employment, balance of trade)
- Biofuels support rural economy (income redistribution)

Which AFV are most valuable to society?

Requires assessing the harm caused by: **climate** vs. **petroleum imports** vs. **smog** vs. off-shore vehicle production vs. declining farm/forestry incomes.

EV and Fuel-Cell Vehicles have potential for reducing the first 3 drastically, but only if the electricity or H_2 is made in a very low-carbon way.

Hybrids are less expensive options, may provide lower \$/ton CO_2 avoided, but cannot achieve such deep large-scale GHG reductions.

Car models chosen for GHG emissions comparison

- Car models chosen to facilitate apples-apples comparisons—that is, to minimize differences in non-powertrain features.
- Thus, Honda Clarity BEV analyzed because the Clarity also comes in PHEV and FCEV.
- For ICEVs, Toyota Camry analyzed because it is top-selling, mid-size sedan of comparable size to Clarity, and because it also comes in HEV.

Toyota Camry ICEV

Toyota Camry HEV

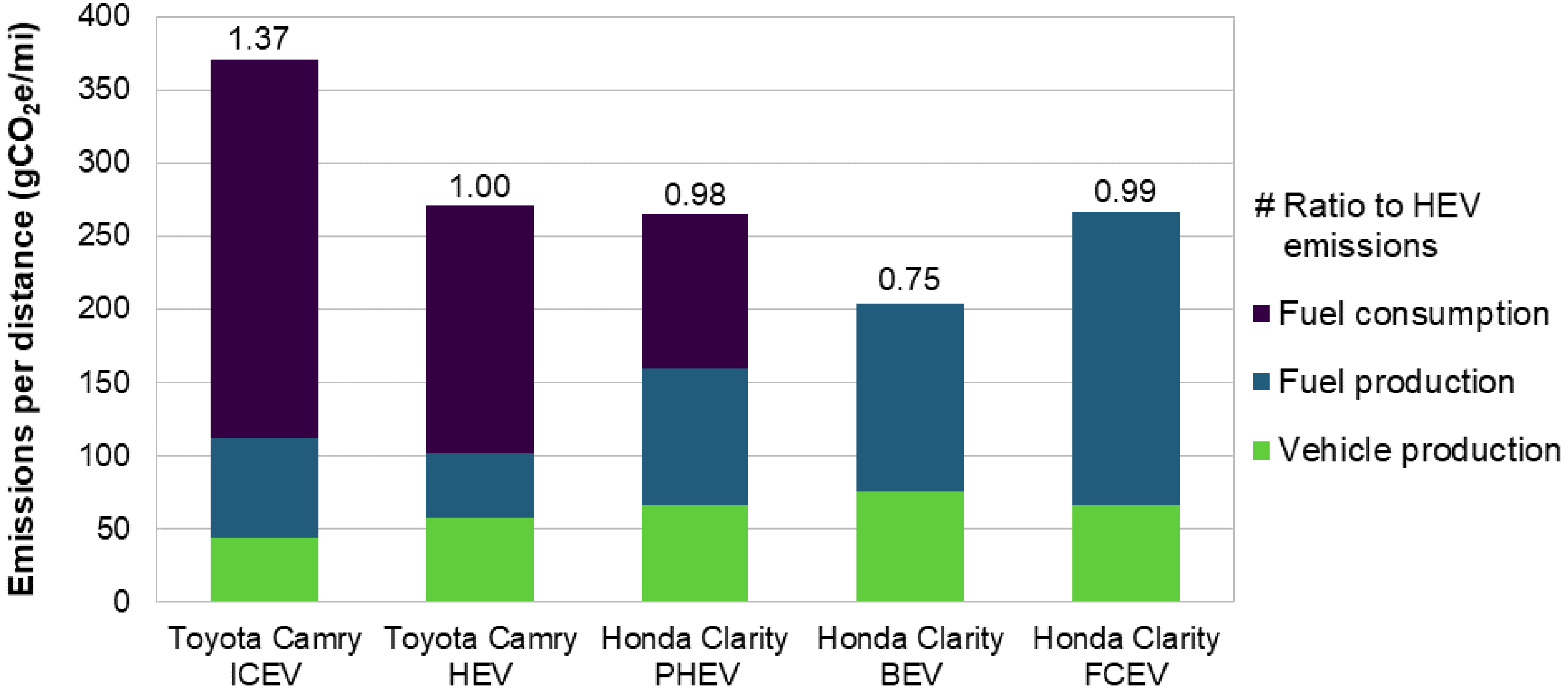
Honda Clarity PHEV

Honda Clarity BEV

Honda Clarity FCEV

	Toyota Camry ICEV	Toyota Camry HEV	Honda Clarity PHEV	Honda Clarity BEV	Honda Clarity FCEV
Interior volume (ft^3):	115	115	117	116	113

Some AFV can cut CO_2 emissions/mile in half

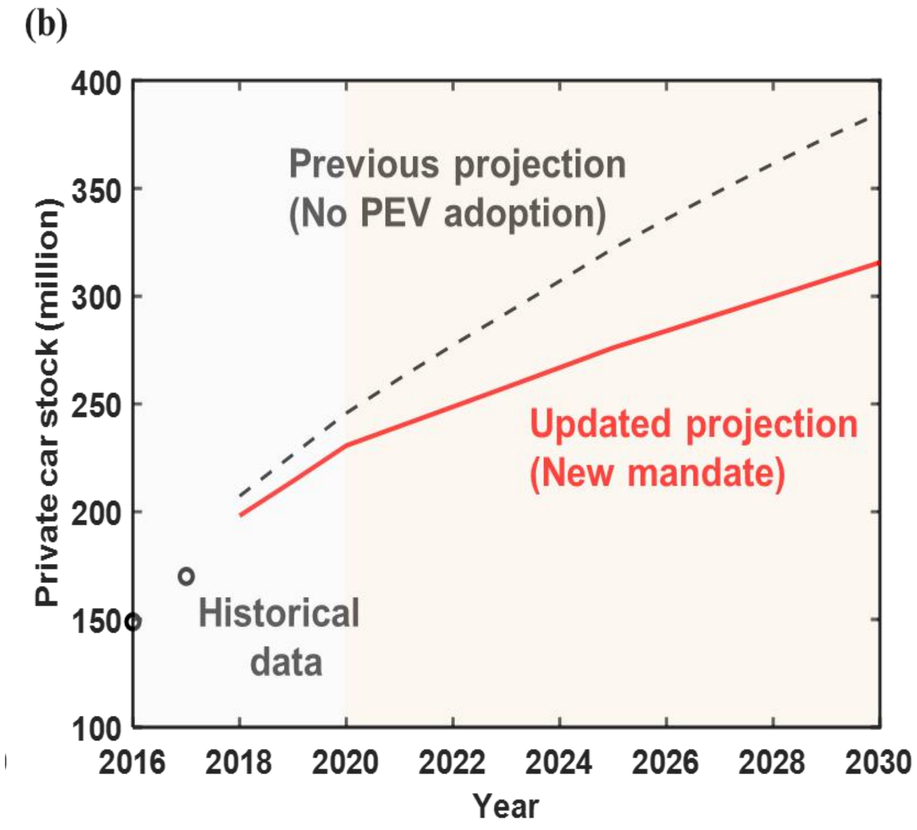


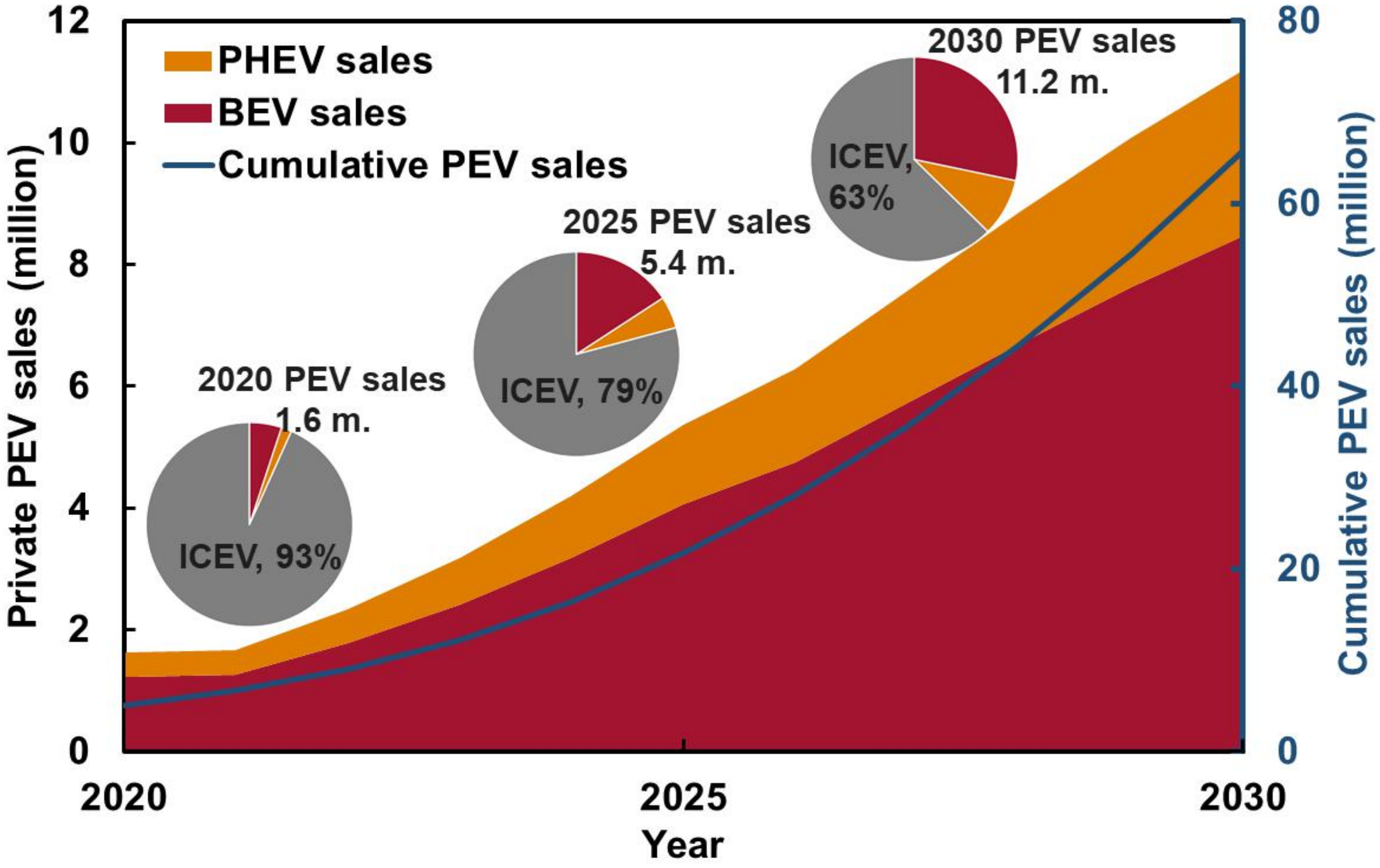
1. **BEV lifecycle emissions per mile are about 55% of comparable ICEVs.**
2. HEV, PHEV and FCEV emissions are all similar and fall between ICEV and BEV emissions.
3. BEV emissions are based on the average carbon-intensity of U.S. electricity today
4. FCEV emissions are based on hydrogen from steam methane reforming, no CCS

Where will AFV become mainstream?

- At present, AFV adoption is mostly **driven by government policies**; although there are a lot of policies, they mostly have not been sufficient to persuade most consumers to switch to AFVs. However:
  - **Norway** has pushed EV very hard. Over past year >50% car sales are battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV).
  - **China** has mandated 40% of car sales will be EV by 2030.
- Battery prices expected to drop as EV production volume increases.
- If battery prices drop enough, EV will become cost-attractive to consumers, particularly in countries with both high gasoline taxes and low sales taxes on EV.

China EV mandate will increase global battery production volumes by at least an order of magnitude by 2030



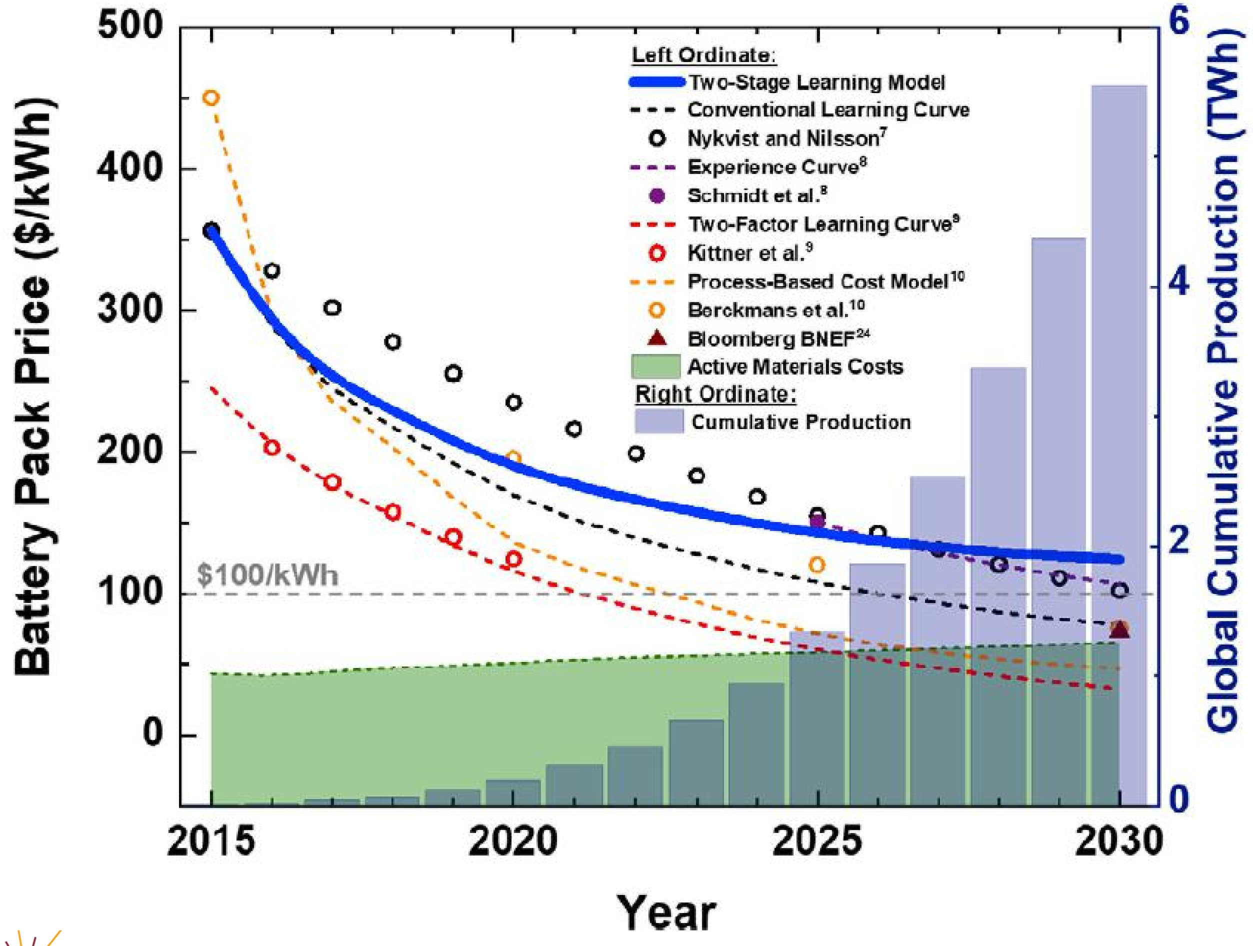


Potential effect on petroleum consumption

To date petroleum consumption is set mostly by vehicle sales and fuel efficiency (e.g. “mpg” or “liter/km”) of combustion vehicles – number of AFVs is too small to significantly change petroleum demand.

However, if China follows through with its current EV mandate policy, (which will both increase average fuel efficiency and the price of new vehicles) its petroleum imports will be about **2 mbd lower** in 2030 than they would be without the mandate. The delta will increase with time. (N.B. China imports about 10 mbd today).

Battery prices will drop as production increases…
…until approach floor price set by material costs

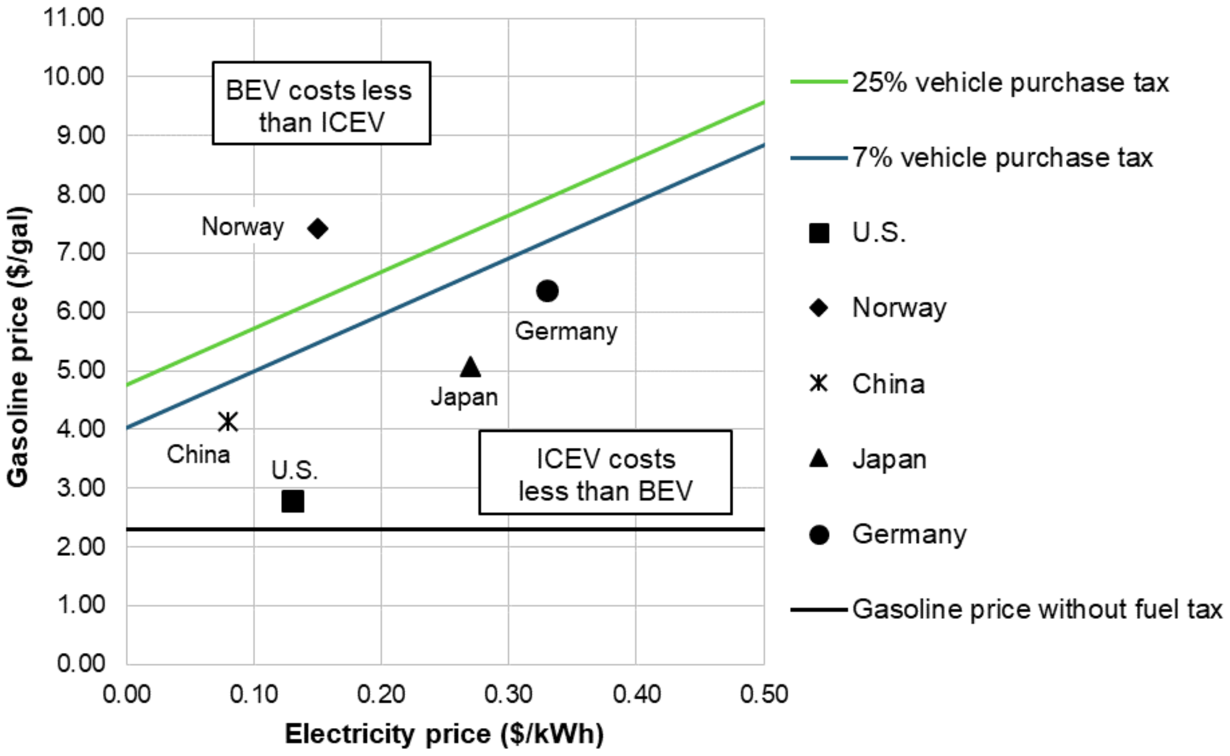


- EV battery prices are dropping fast, will drop further as production volumes increase
- However, they cannot keep dropping indefinitely, limited by raw material costs
- Many published numbers omitted this price floor

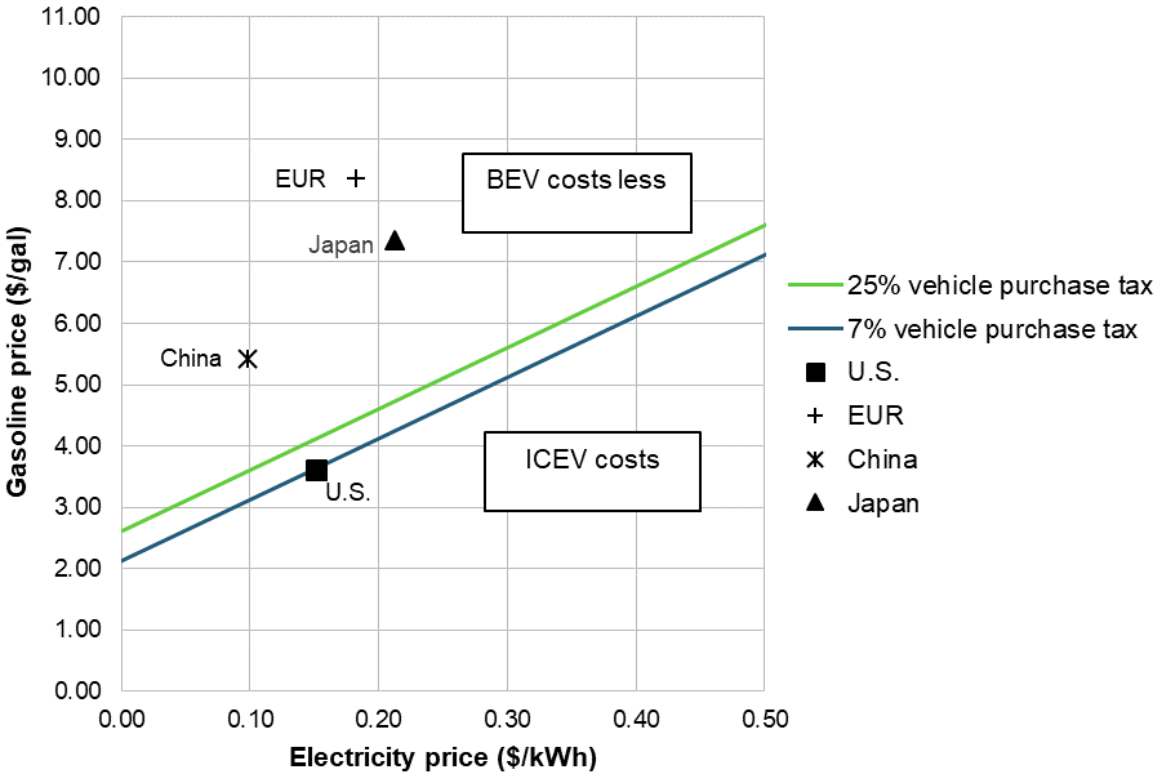
Cost?
Total Cost of Ownership of EV

Analysis done without BEV subsidies. Assumes price increase ~$1/gallon in US.

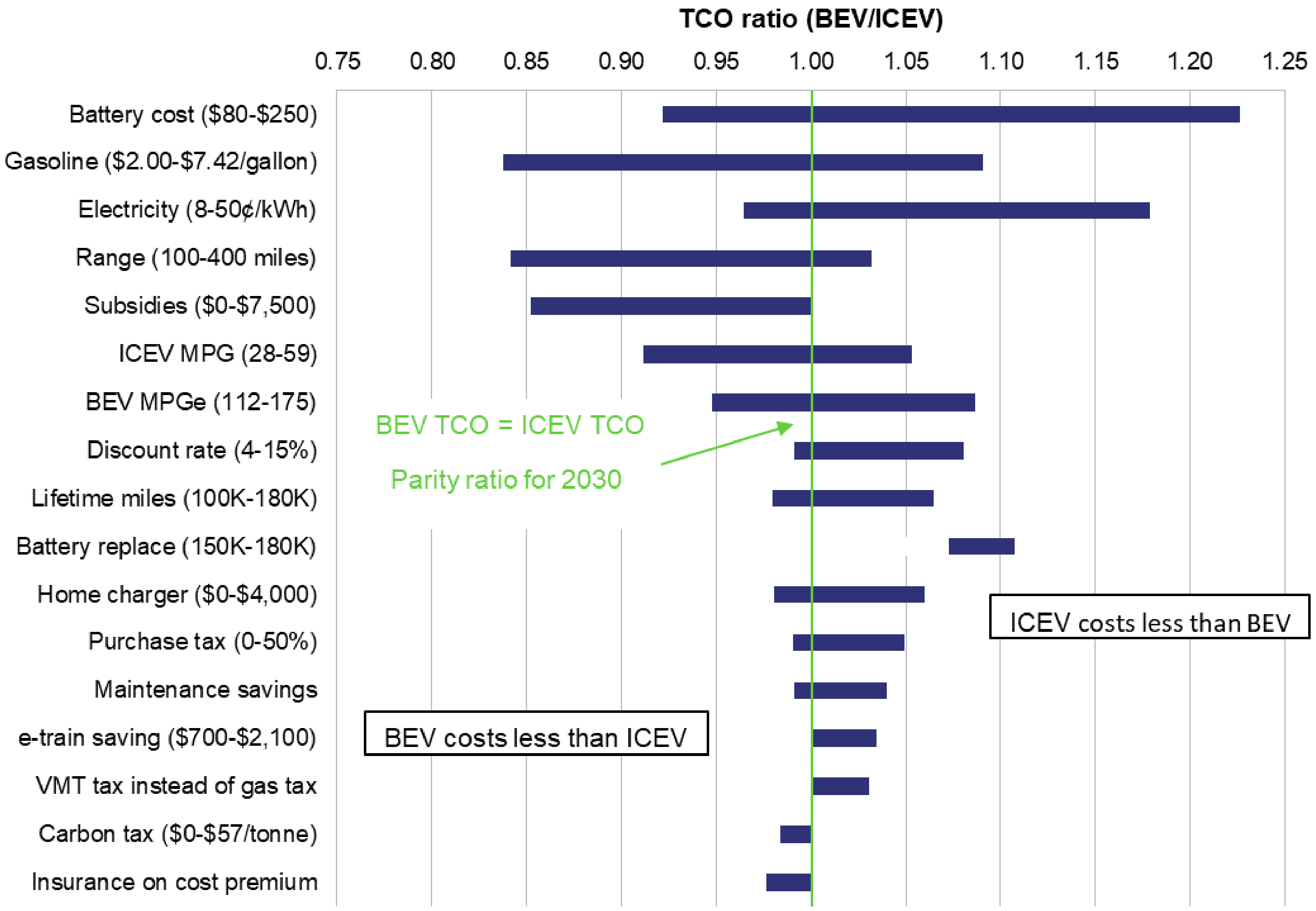
TCO Parity in 2018 with batteries at $229/kWh



TCO Parity in 2030 with batteries at $124/kWh



Sensitivity analysis centered on 2030 estimated battery cost



When will BEVs start to penetrate market in big way?

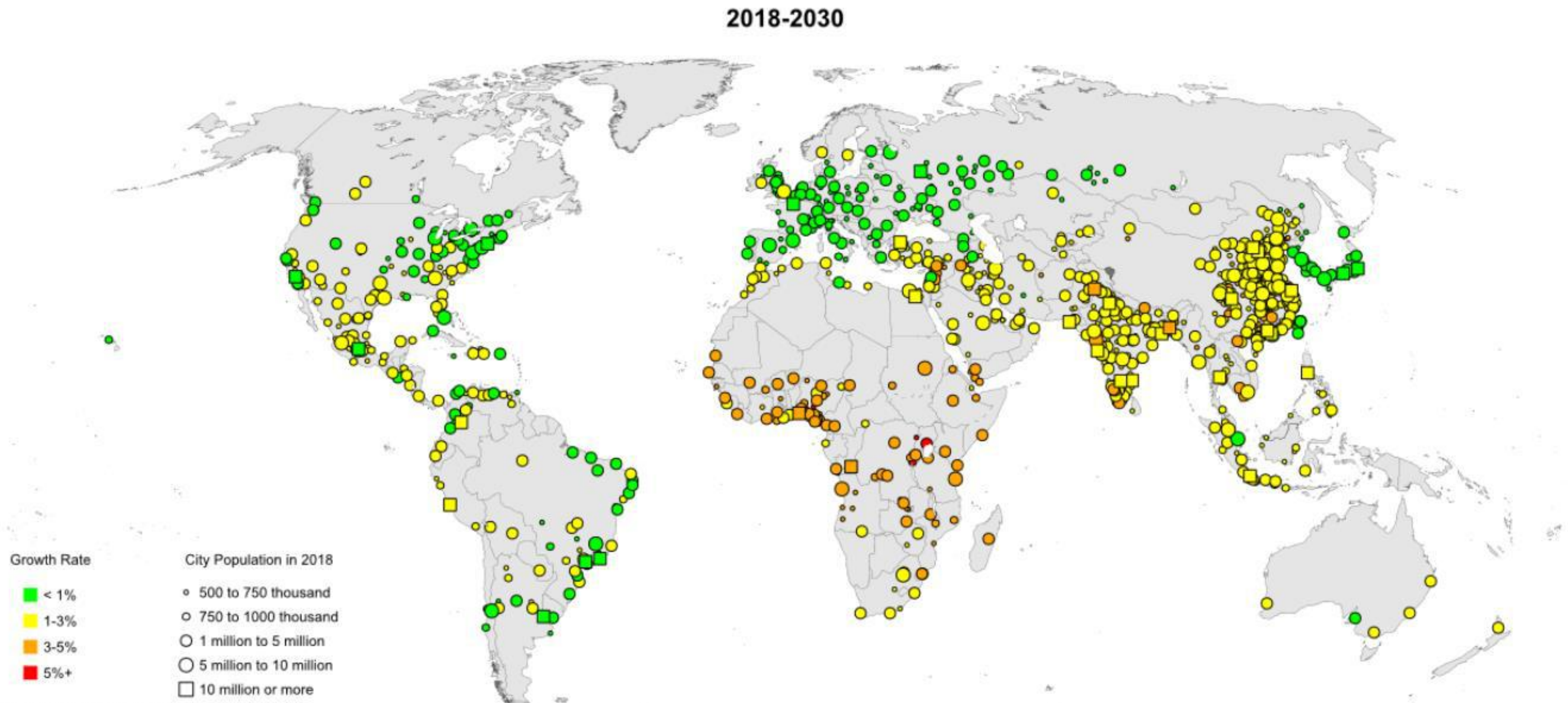
- Today both economics and convenience favor ICEVs over BEVs.
- If China sticks to its declared mandate, BEV production volumes will increase by more than an order of magnitude by 2030.
- Large-scale production will drive battery prices down into a range where consumer Total Cost of Ownership will be comparable for ICEV and BEV in the USA after 2030. By then, BEV would have a noticeable TCO advantage in some countries with high gasoline prices.
- Once economics clearly favors BEV, consumers still have to overcome range anxiety and charging convenience issues. Under the *Paris to 2˚C scenario* we project plug-in electric vehicles to reach 50% of the global fleet in 2050.

The urbanization and motorization challenge: The role of new mobility technologies, services, and policies in shaping sustainable cities

Joanna Moody

Research Program Manager, Mobility Systems Center, MIT Energy Initiative

Our world is rapidly urbanizing



Data source: World Urbanization Prospects: The 2018 Revision
The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Republic of Sudan the Republic of South Sudan has not yet been determined. A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas).

This will increase strain on urban transportation systems that are already struggling to meet demand for personal mobility

Road Safety

Congestion

Air Pollution

Greenhouse Gas Emissions

Emerging Technologies:

Alternative Fuel Vehicles

Autonomy and Connectivity

Service Innovations:

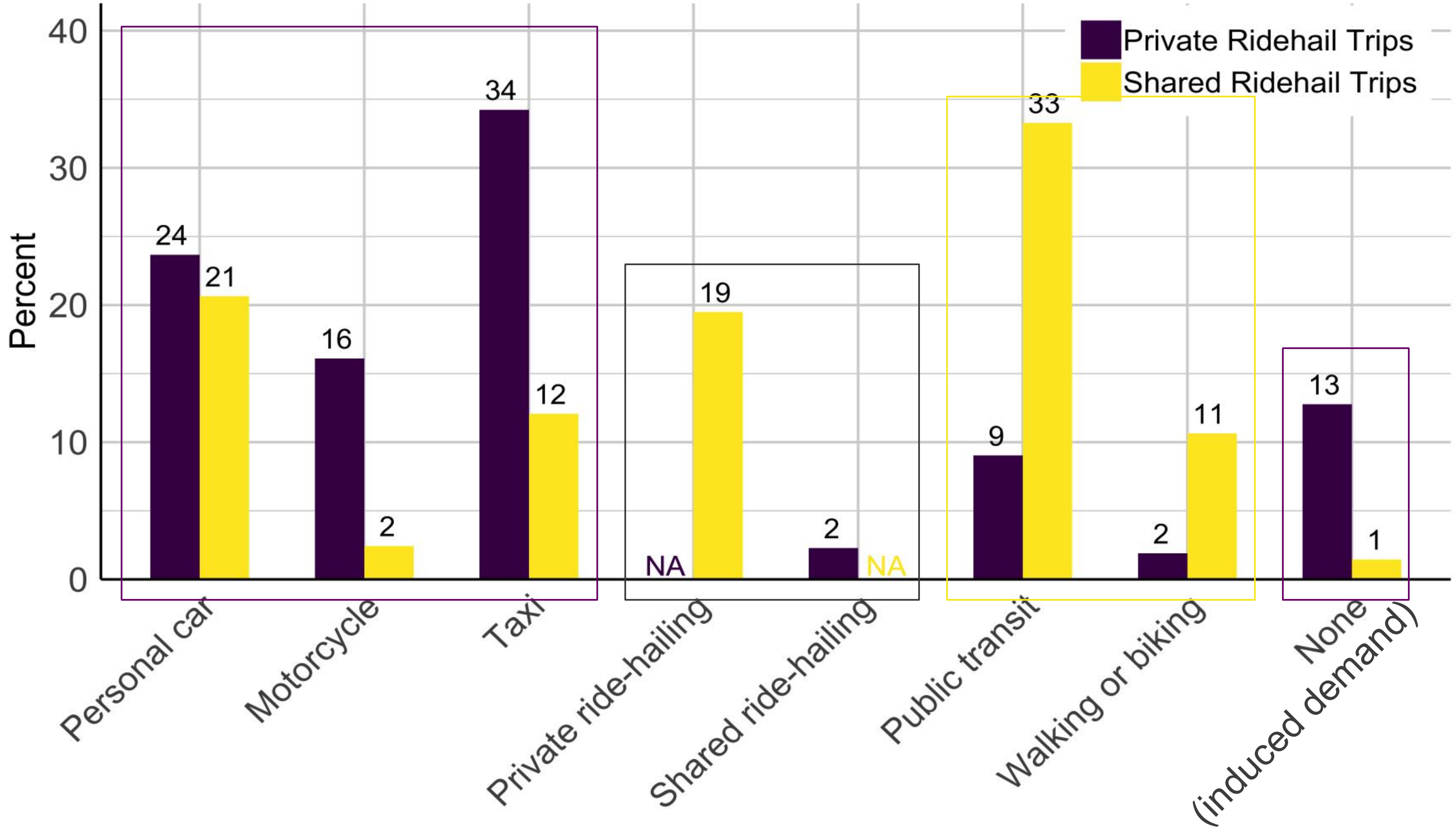
On-demand

Sharing/Pooling

Key Findings:
On-demand mobility services are primarily replacing trips by sustainable/efficient modes such as public and nonmotorized transport in U.S. cities

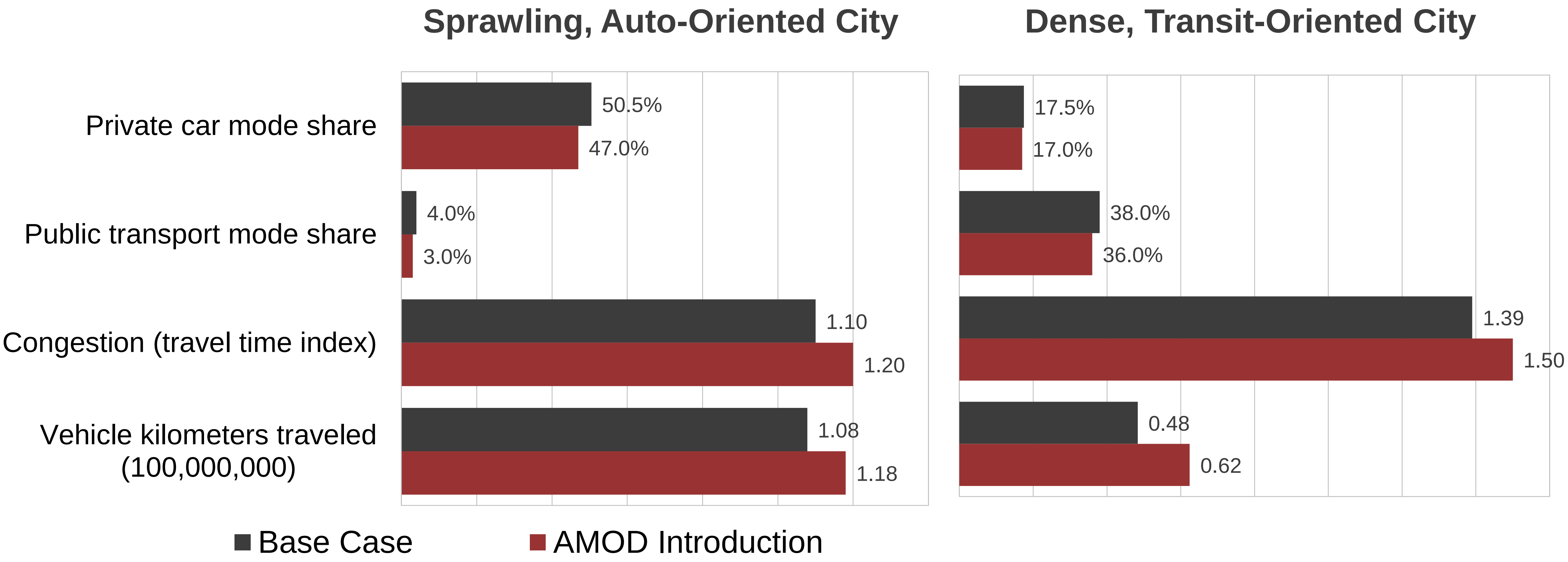
Location	Date of data collection	Induced demand	Substitution of public transport and nonmotorized modes	Substitution of motorized transport (personal car, taxi, or other car-based)
San Francisco Bay Area	Spring 2014	8%	43% (of those who would take the trip)	57% (of those who would take the trip)
Denver	Fall 2016	12%	34%	53.7%
Boston metro area	Fall 2017	5%	54%	41%
New York City	Spring 2017*	3%	65%	55%
7 U.S. metro areas	2015-2016	22%	39%	40%
Singapore	Spring 2019	9%	26%	65%

Key Findings:
Exclusive and pooled on-demand mobility services exhibit very different trip-substitution patterns, with exclusive rides primarily replacing trips by private vehicles and pooled rides replacing trips by public and nonmotorized transport



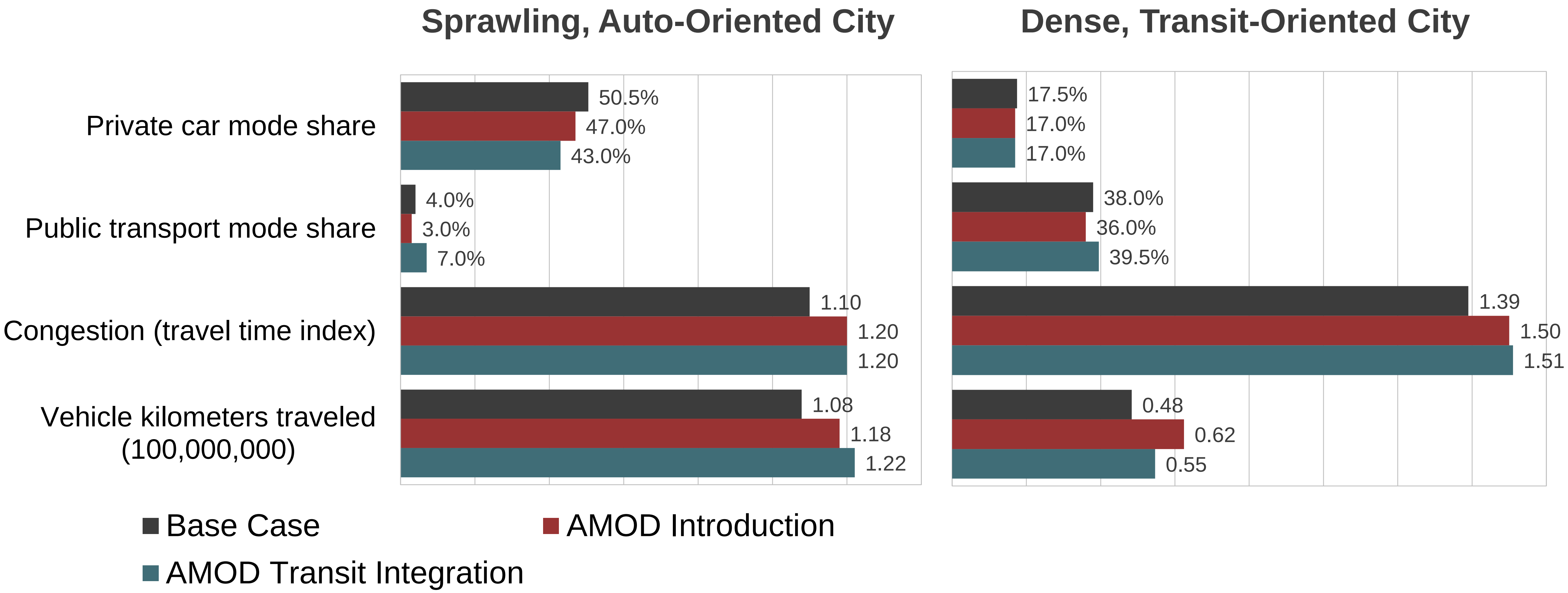
"If the ridehailing service had not been available, what percentage of these ridehailing trips would you have made by the following modes instead?" [aggregate weighted by frequency of each individual's ridehail use]

Key Findings:
Introduction of low-cost mobility services is likely to replace existing public transport trips, increasing congestion and vehicle kilometers traveled



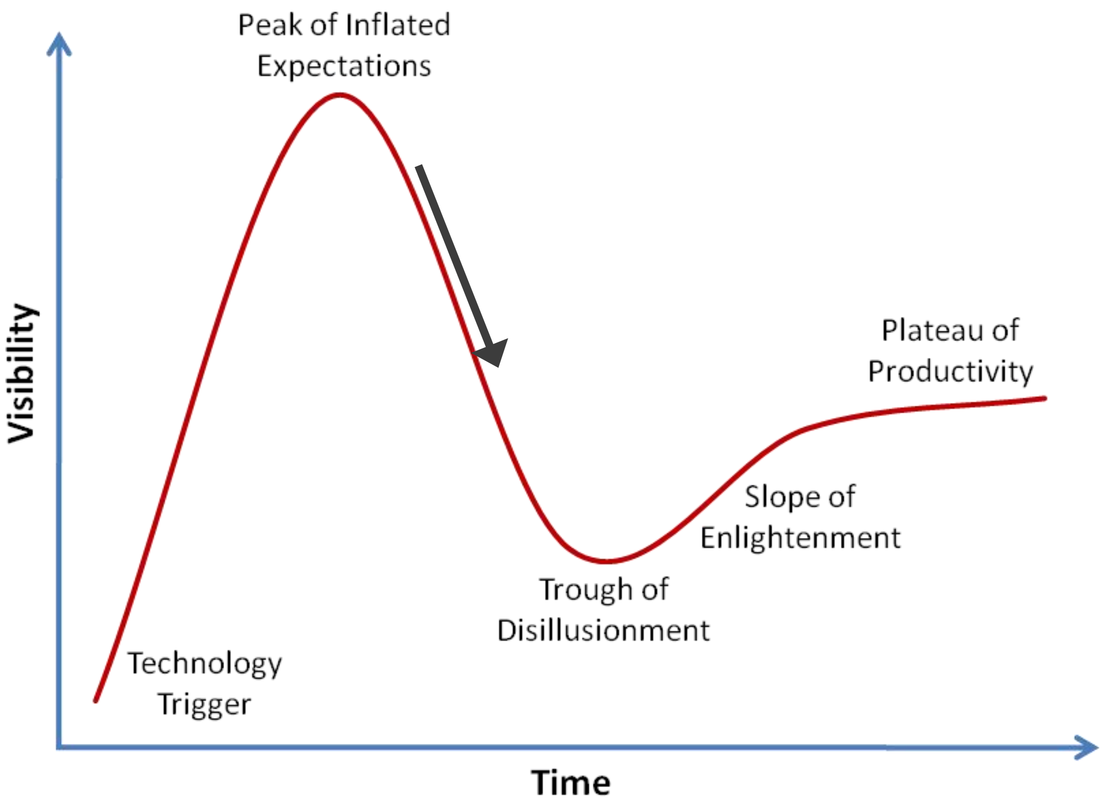
AMOD = autonomous mobility-on-demand

Key Findings:
Policies that encourage introduction of on-demand mobility services as first-/last-mile connections to mass transit can expand accessibility while mitigating negative impacts



AMOD = autonomous mobility-on-demand

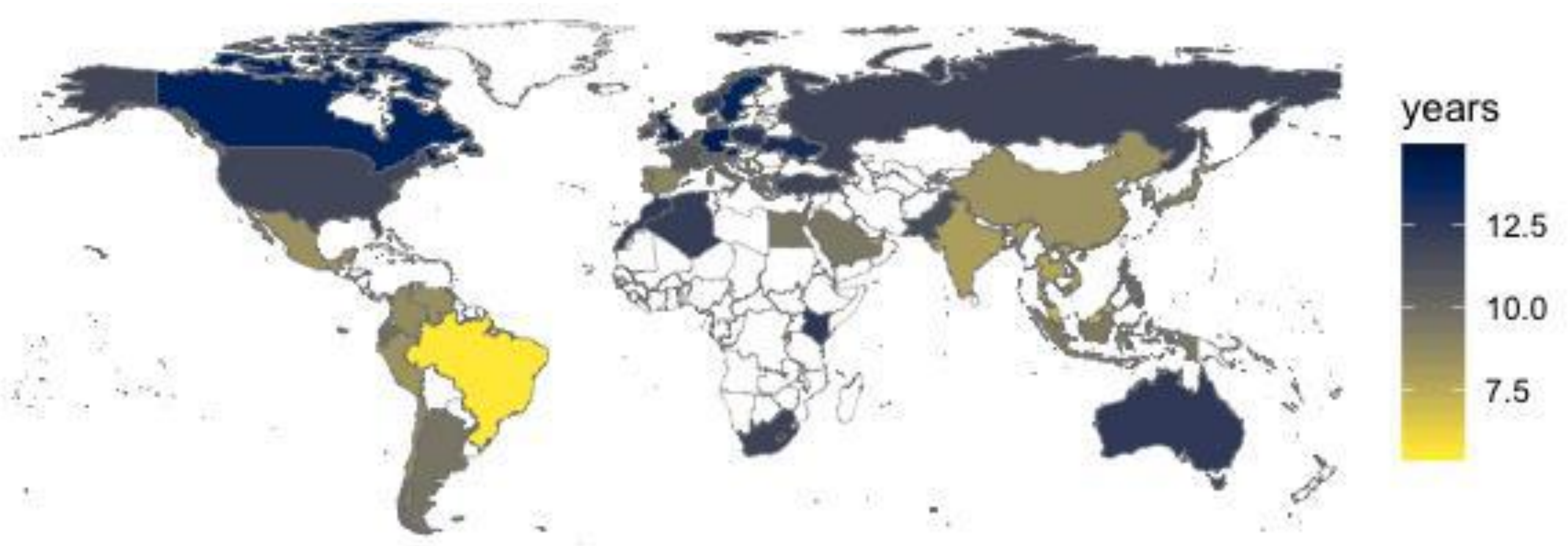
Key Findings:
Autonomous vehicles (AVs) are not close to widespread deployment



Remaining barriers:

- Technology
- Regulatory frameworks, particularly regarding safety
- Public perceptions

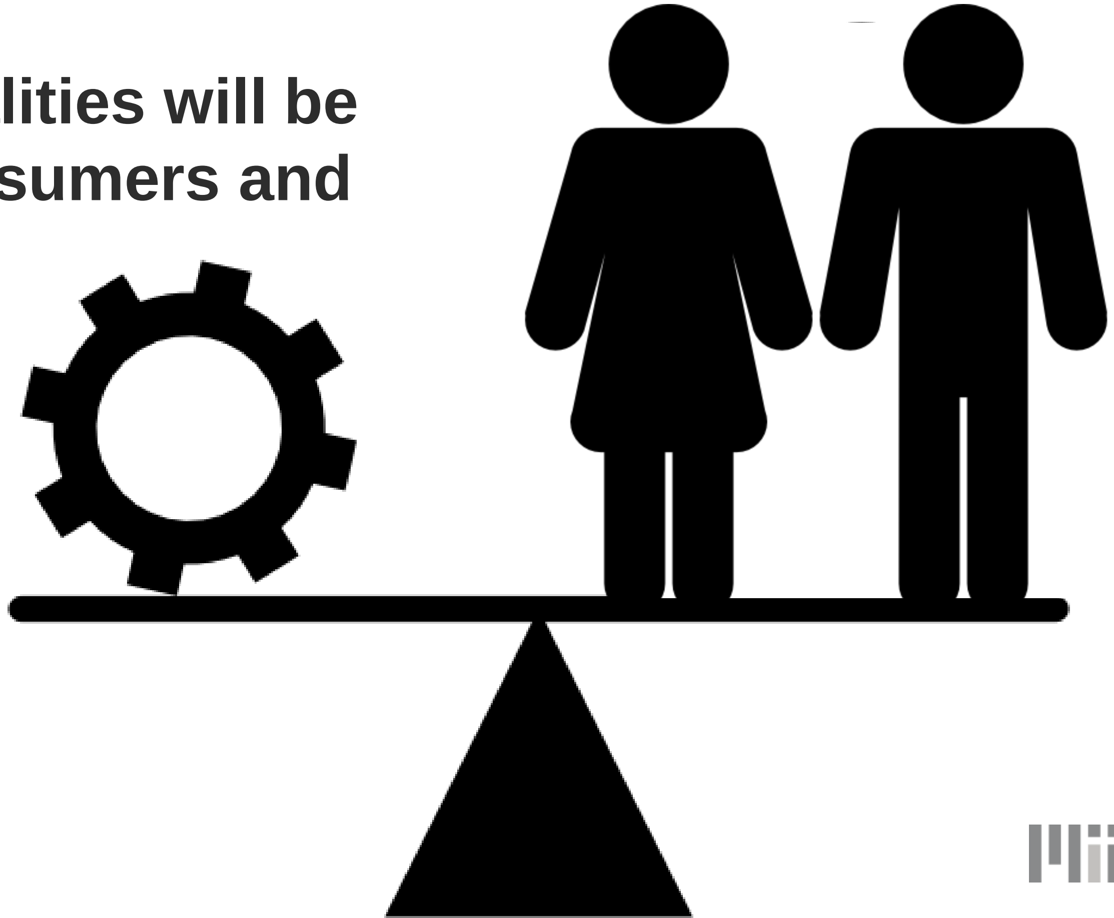
International Survey Results:
Reported years until AVs are safe enough to use (by country)



What does this all suggest?

Emerging technologies and service innovations have as much potential to exacerbate problems in our urban transportation systems as they do to solve them

The balance of their benefits and externalities will be determined by how they are used by consumers and shaped by policymakers



Mobility Systems Center

MITEI’s newest Low-Carbon Energy Center

Directors:

William Green

Sanjay Sarma

Mobility Systems Center will focus on 5 areas during next 3 years

A **Global policy, urban mobility, light-duty vehicles**

Continue from MITEI's Mobility of the Future study:

- *Global economics & policy*
- *Light-duty vehicles*
- *Urban mobility*

+

B **New focus areas**

	Challenge	Focus Area
1	Mobility needs for high-growth countries	**Mobility evolution in high-growth countries**
2	*Global energy demand of freight is large and growing*	**Freight ground transportation**
3	*Air quality in urban areas*	**Clean fuels & propulsion systems**
4	*Disruptors offer the potential to revolutionize mobility*	**Disruptive technologies & supporting infrastructure**

Collaboration between members, Center, and the research teams

Focus topics	***Every 3 years***, sponsors and MITEI jointly identify the **areas of focus**	***Agenda shaping***
Yearly project selection	Projects will be selected through a **yearly Call for Proposals (CfP)**: • *Sponsors propose research questions for the CfP* • *Sponsors vote on proposals submitted in response to the CfP*	
In-person meetings	**Two yearly meetings at MIT** to gather researchers and consortium members to discuss current projects	***Discussion of research***
Project Advisory Committees (PAC)	**Sponsors join up to 2 Project Advisory Committees each year:** *PAC membership provides in-depth insights into current research*	
Data Sharing	Center encourages **data sharing**	***Data input***

Current research projects

1 **Long-haul freight on highways – technoeconomic assessment of options for powertrains and fuels**

PI: William H. Green

2 **Can Mobility-as-a-Service (MaaS) really disrupt the private car ownership model?**

PIs: David Keith & Joanna Moody

3 **Design, planning and operation of highly responsive & sustainable urban last-mile delivery networks**

PIs: Matthias Winkenbach & Yossi Sheffi

4 **Price of Privacy: Towards the quantification of the value of location data in smart mobility**

PI: Jinhua Zhao