

Future of Automated Vehicles

Graham Institute, TRB, AUVSI, and SAE Survey Results

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Sponsored by Graham Institute for Sustainability
University of Michigan

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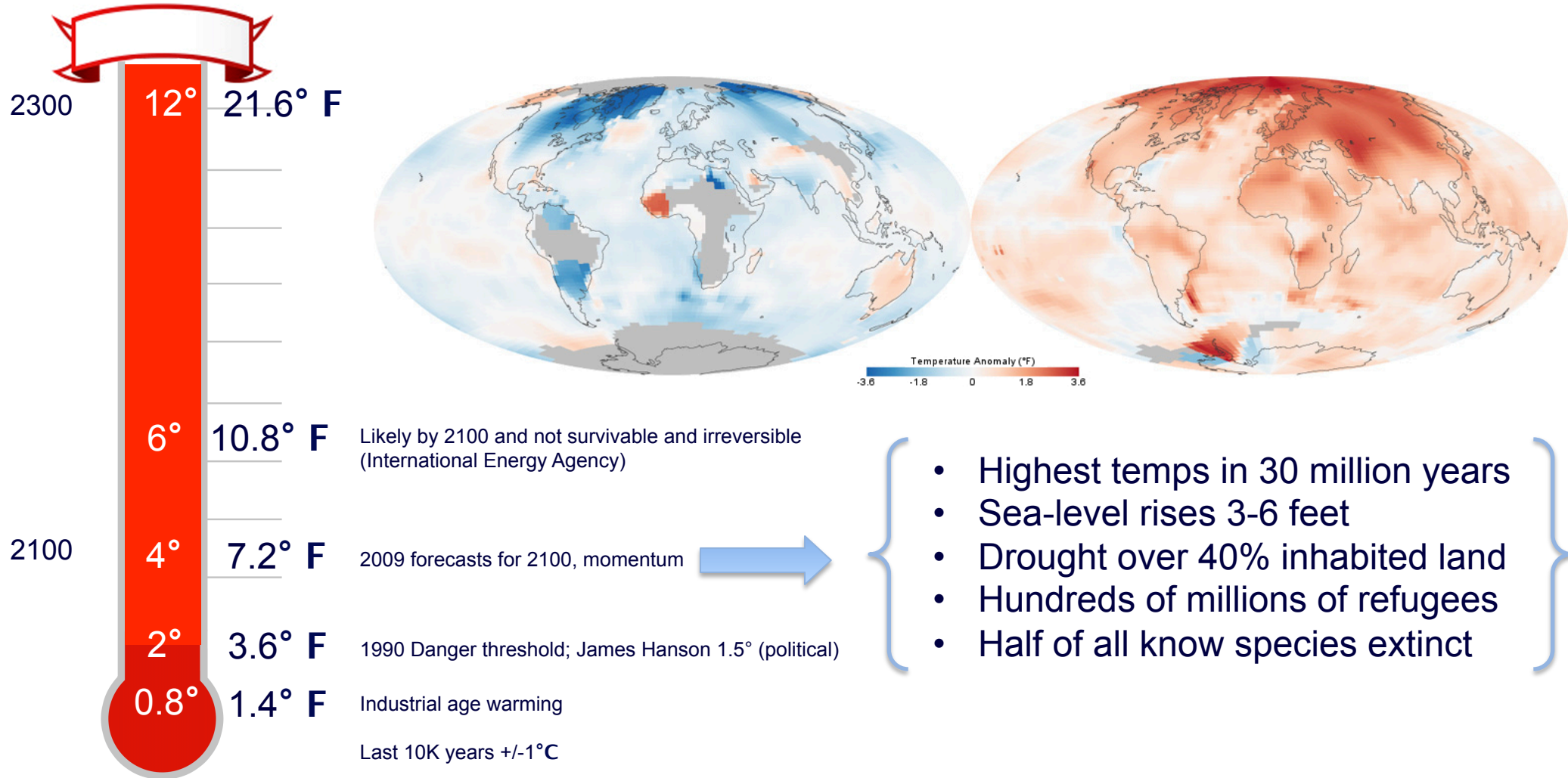
Connected Vehicle Proving Center
Institute for Advanced Vehicle Systems
University of Michigan - Dearborn



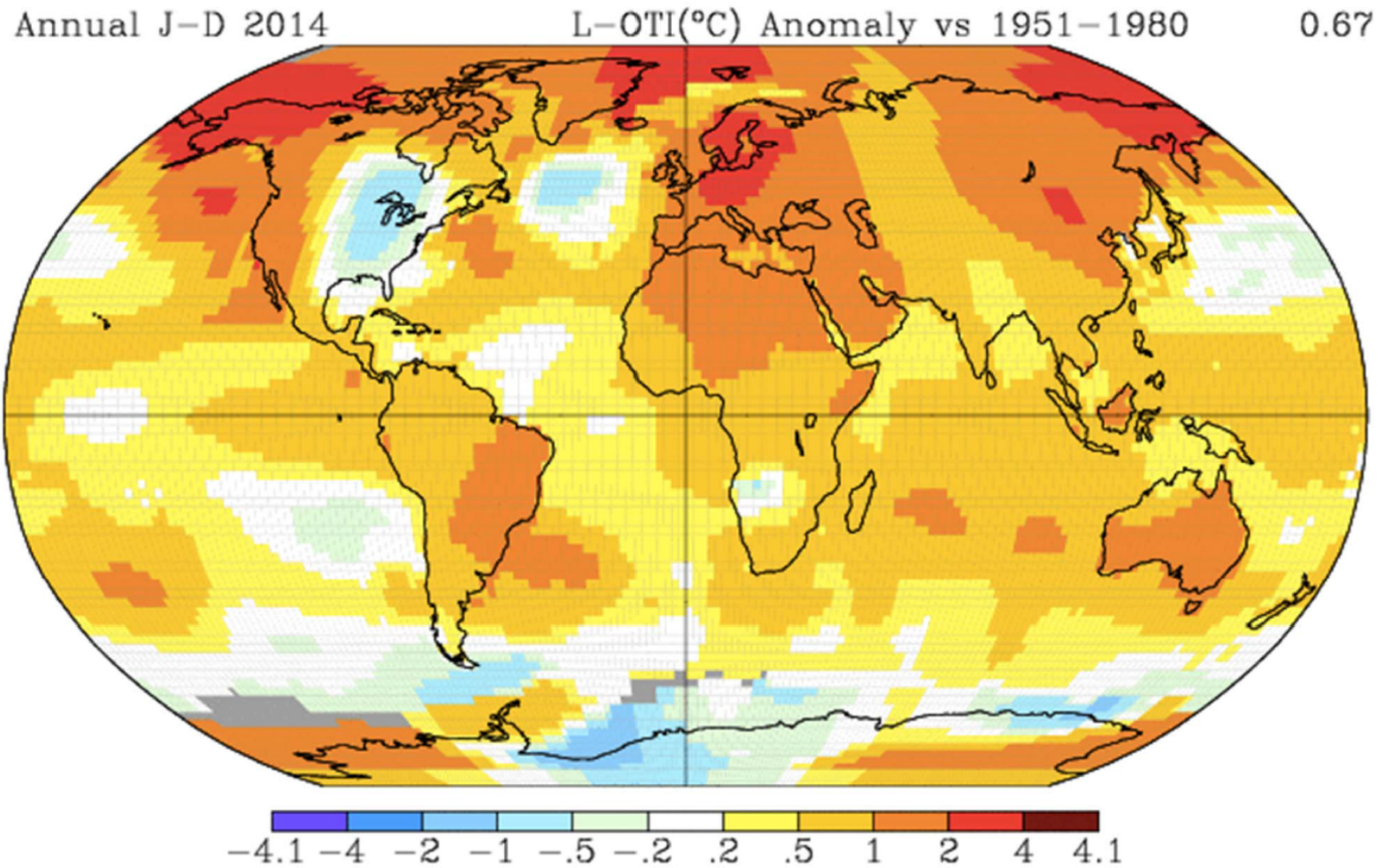
Arborland: The Wonder Years



IPCC: Fossil fuels must be gone by 2100 or we will pass a tipping point into a future calamity. (AP, 11/5/14)

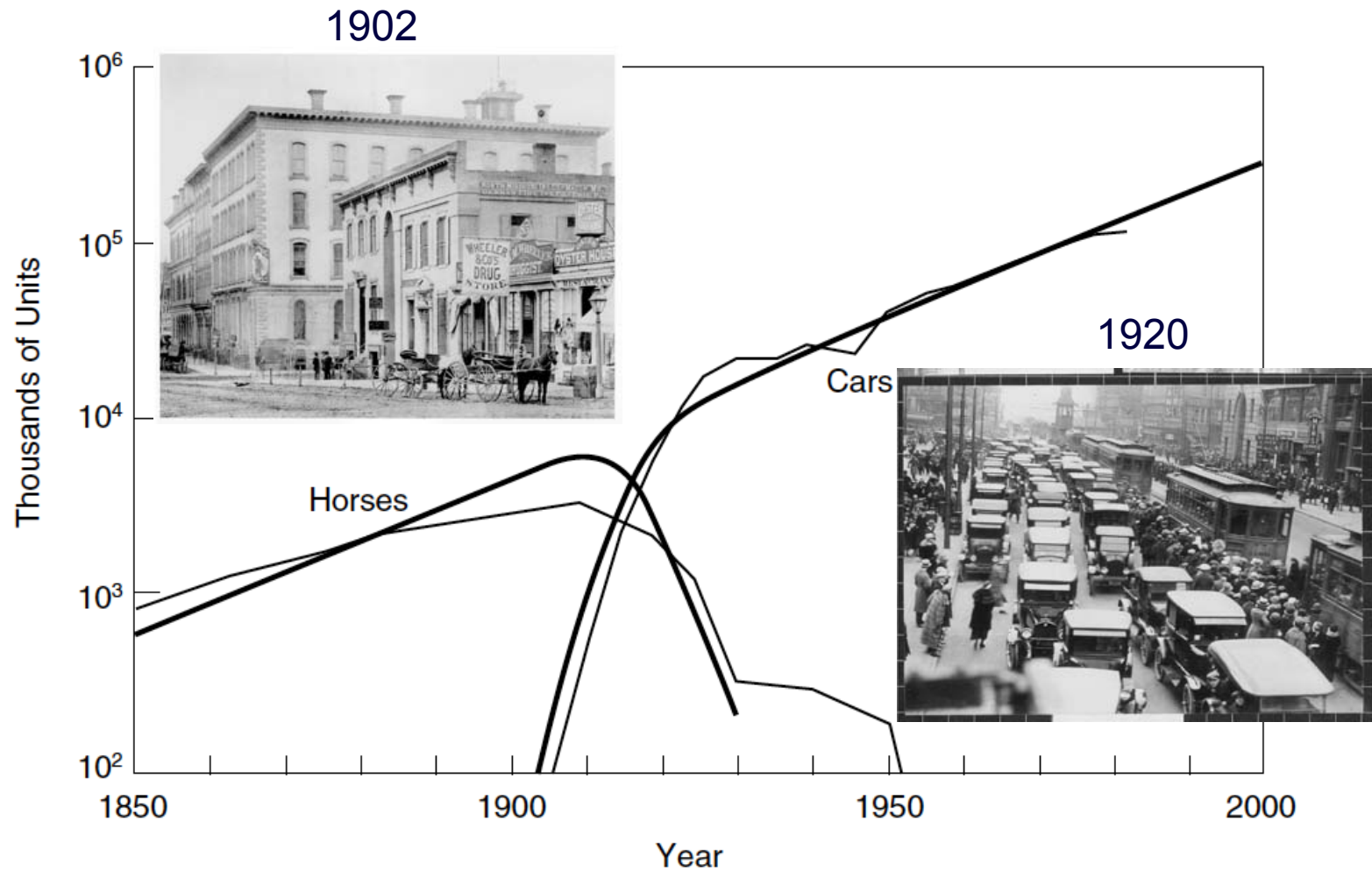


2014 Warmest Year on Record



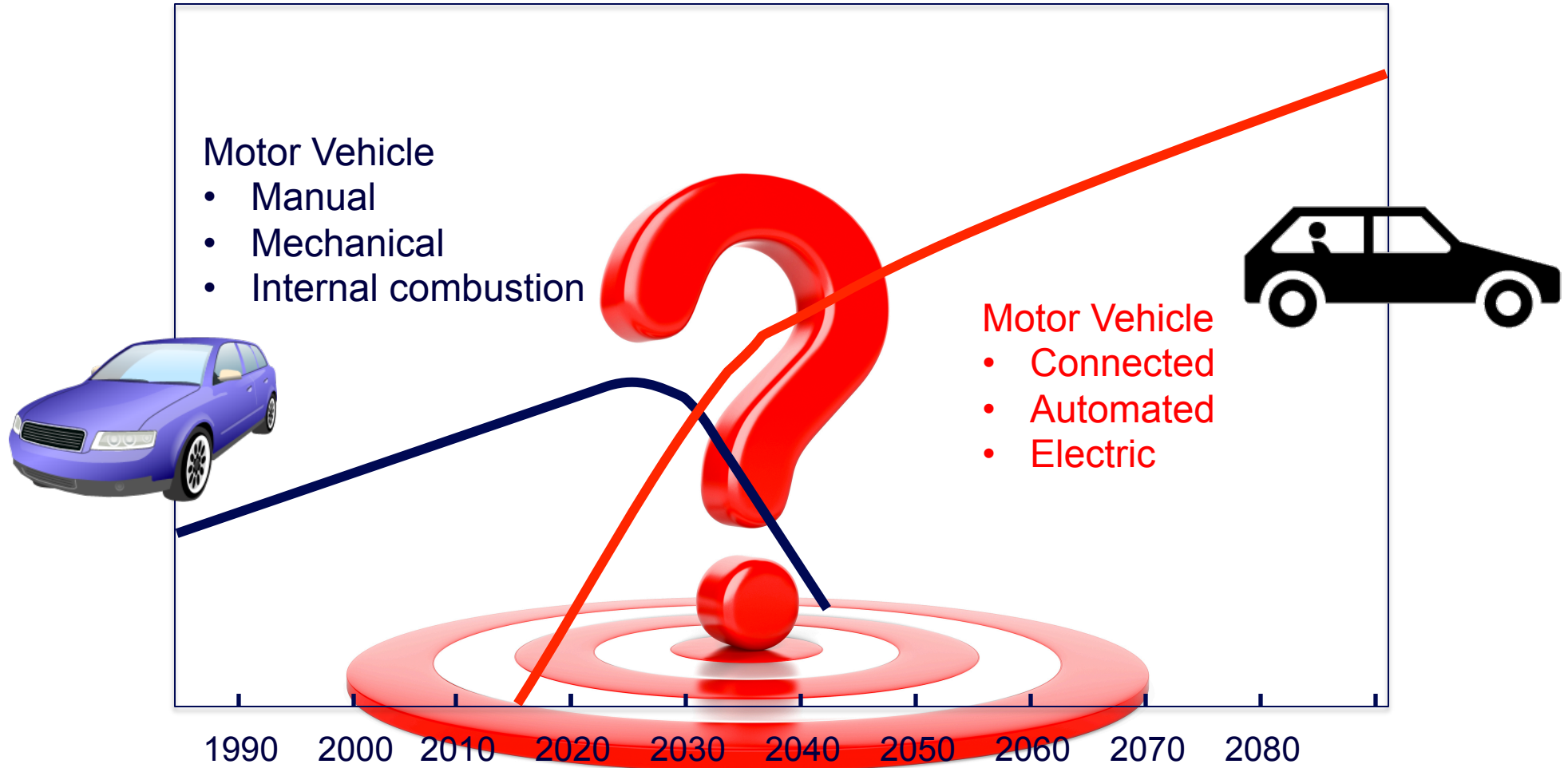
Disruptive Innovation: Griswold 1902-1920

Number of Nonfarm Draft Animals and Automobiles in US



SOURCE: Nakicenovic (1986)

Disruptive Solution?



Automotive Transportation Legacy in the US

- **Mobility in the US**

- Automobile ownership, 828/1000
- Interstate Highway System, 47,714 miles (2012)
- Suburban development, parking, commutes

- **Personal and public expense**

- Cost of vehicle ownership: depreciation, fuel, interest, insurance, maintenance and repair, tolls, parking, tax. Ford Fusion: \$7K, BMW 750Li: \$21.5K (Cons. Rept.)
- Taxes and public expenditures: \$20 billion per year more just to maintain infrastructure at the present levels

- **Fossil fuels and pollution**

- Transportation uses 70 percent of oil consumed in the United States
- 2.9 billion gallons of wasted fuel
- Deterioration in air quality – 28% of US Greenhouse Gas Emissions due to transportation

- **Congestion and delay**

- 4.2 billion hours of travel delay
- \$78 billion cost of urban congestion



- **Driver error and crashes**

- 5.8M crashes/year (2009)
- 2.5M injured, 33,963 deaths/year (2009)
- Leading cause of death for ages 4 to 34
- One collision every 18 years or 4 per lifetime, 1 injury per lifetime?
- Direct economic cost of \$230.6 billion (US 2000 data)

- **Time devoted to driving**

- Average commuter spends 250 hours on the road/year
- Urban Americans spend 5.5 billion hours sitting in traffic (2011, TTI)



Graham Institute, University of Michigan

Disruptive Innovation and Sustainable Transportation

“Cyber-Physical Systems Approach”

- Connected
 - Automated
 - Electric
- Shared
 - Lightweight



2. USA Roadmap (Expert Backcasts)

How do we get there?

Technical Input:
SAE, AUVSI, TRB

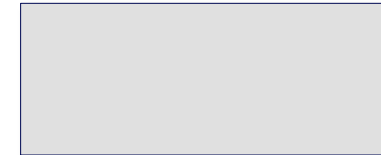
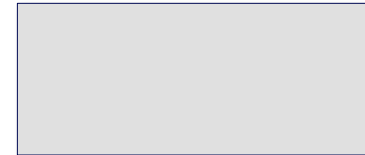
Policy Input:
DOT, DOE, DOD, HUD,
MPOs, WSDOT, JBLM

1. USA Visions (Expert Forecasts)

Where are we going?

Greenfield

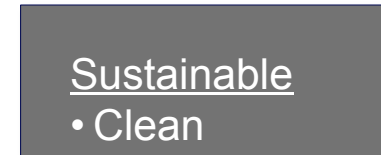
Legacy



Europe



Asia



US

Sustainable

- Clean
- Safe
- Efficient
- Door-to-door

USA Trends: Roads, Land Use, Population, Climate, Technology

2014

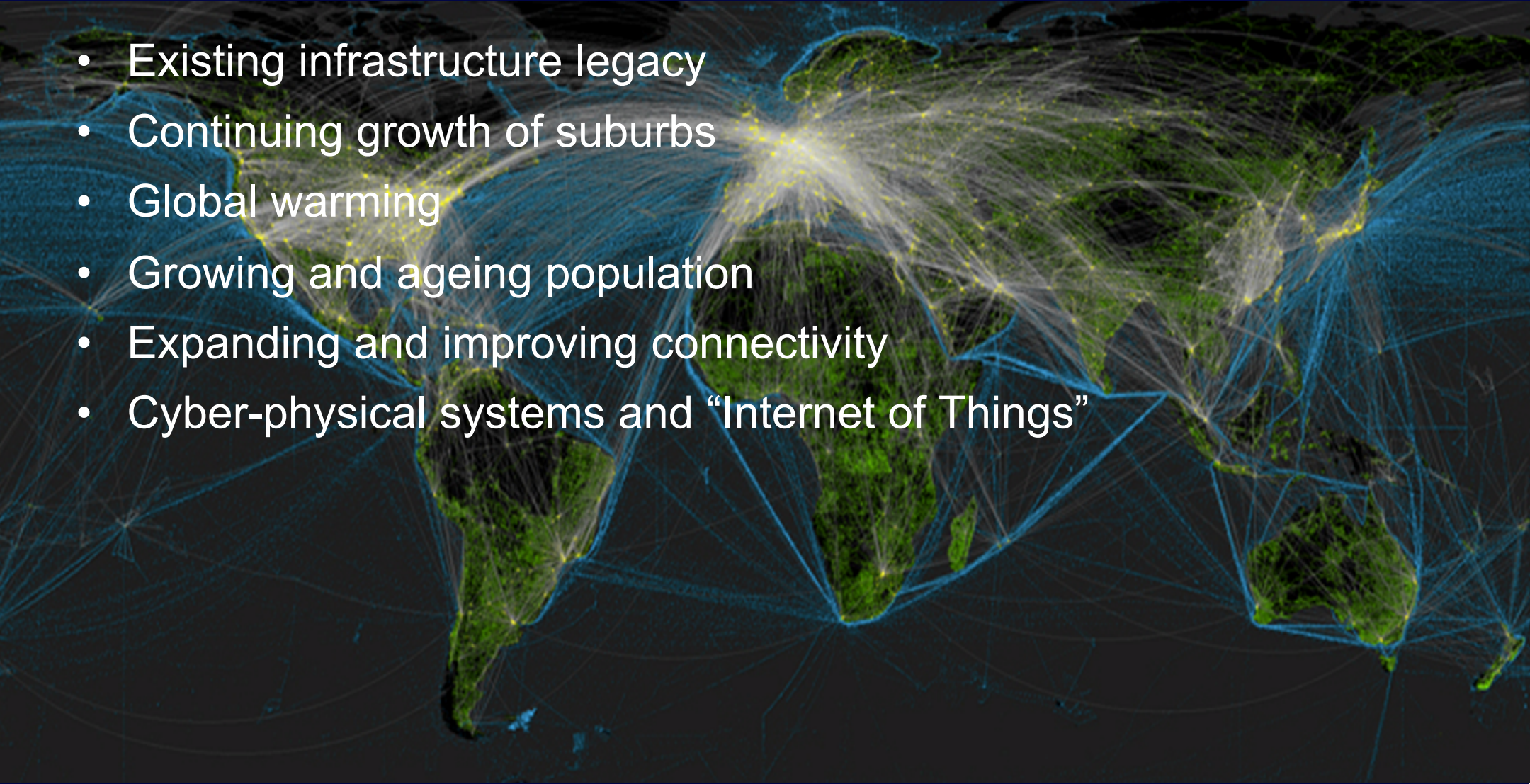
2024

2034

2044

Context for Sustainable Development in the US

- Existing infrastructure legacy
- Continuing growth of suburbs
- Global warming
- Growing and ageing population
- Expanding and improving connectivity
- Cyber-physical systems and “Internet of Things”



Background Population Forecast by Country

New world order

Asia North America Europe Latin America Africa

1950

2.5 Global population, bn

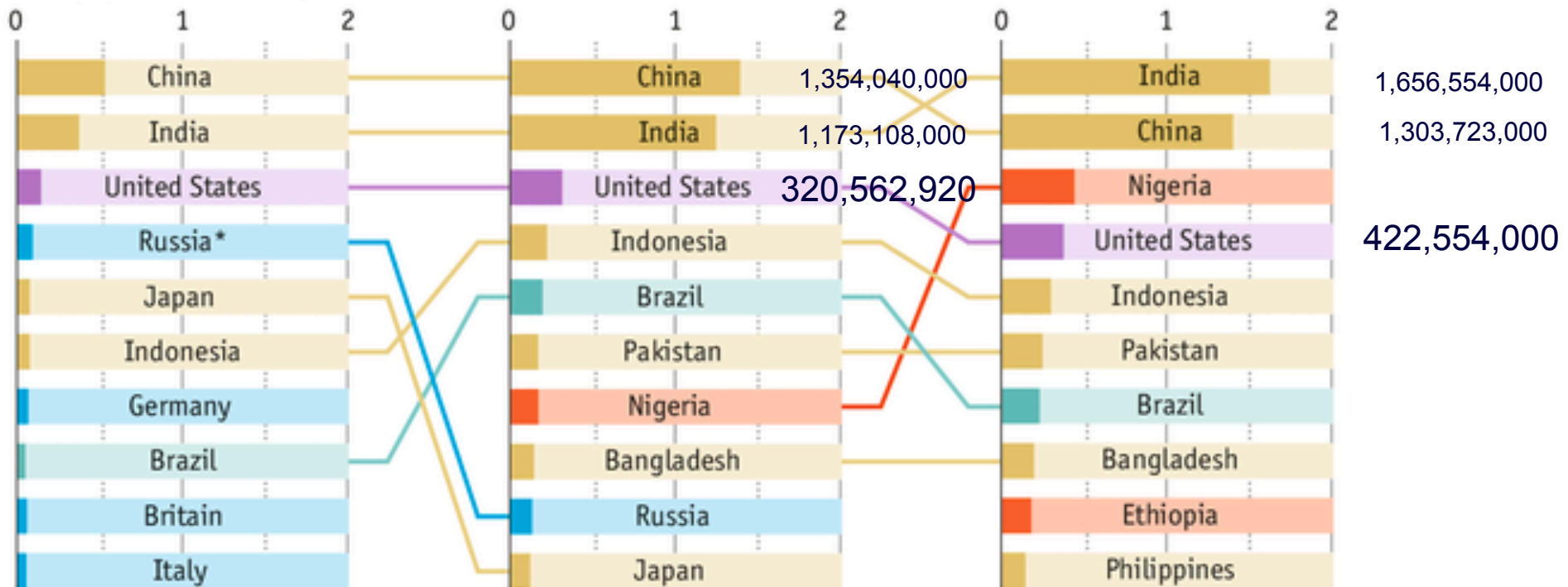
2013

7.2

2050 forecast

9.6

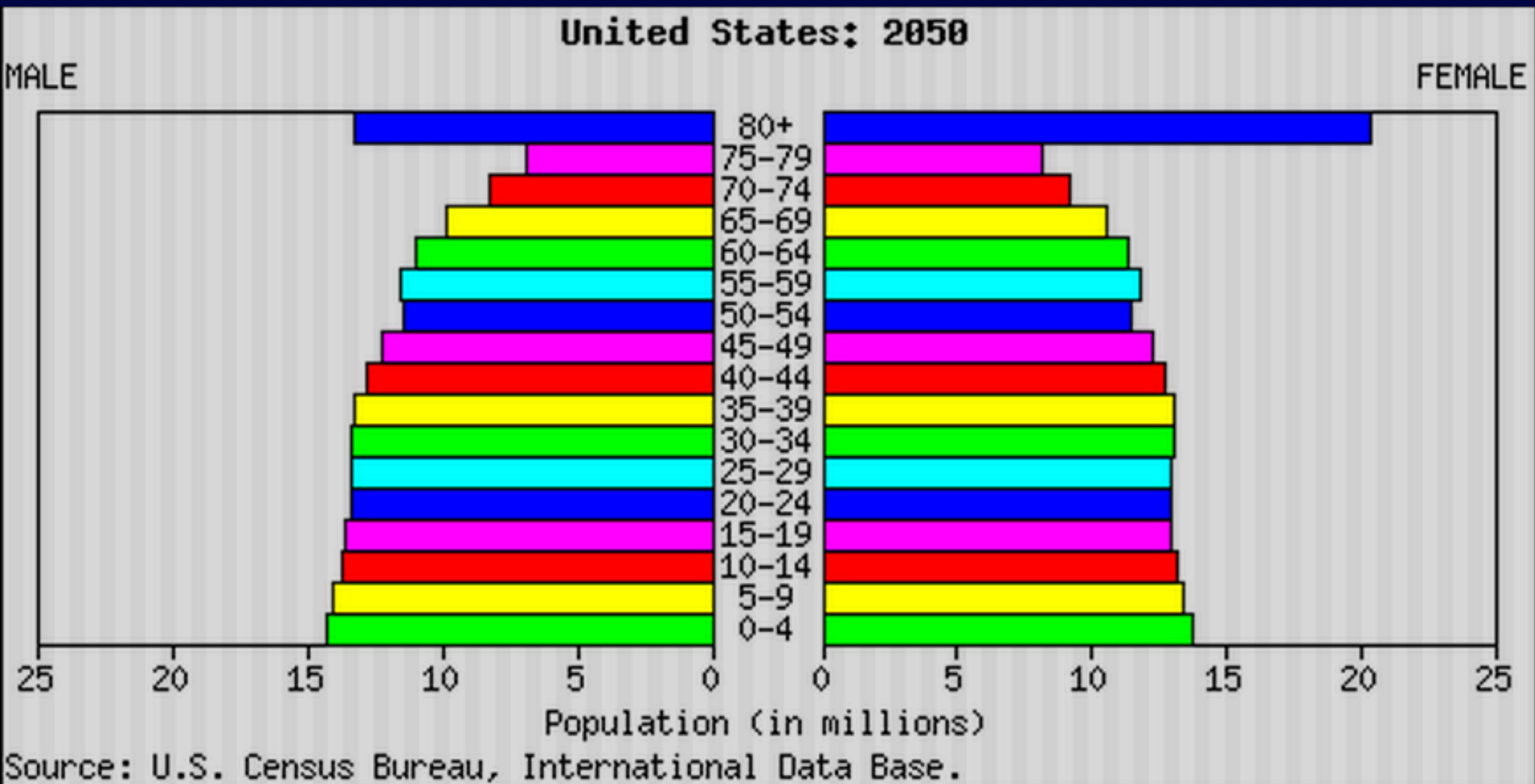
Most populous countries, bn



Source: UN

*Then part of Soviet Union (Russian Socialist Federative Soviet Republic)

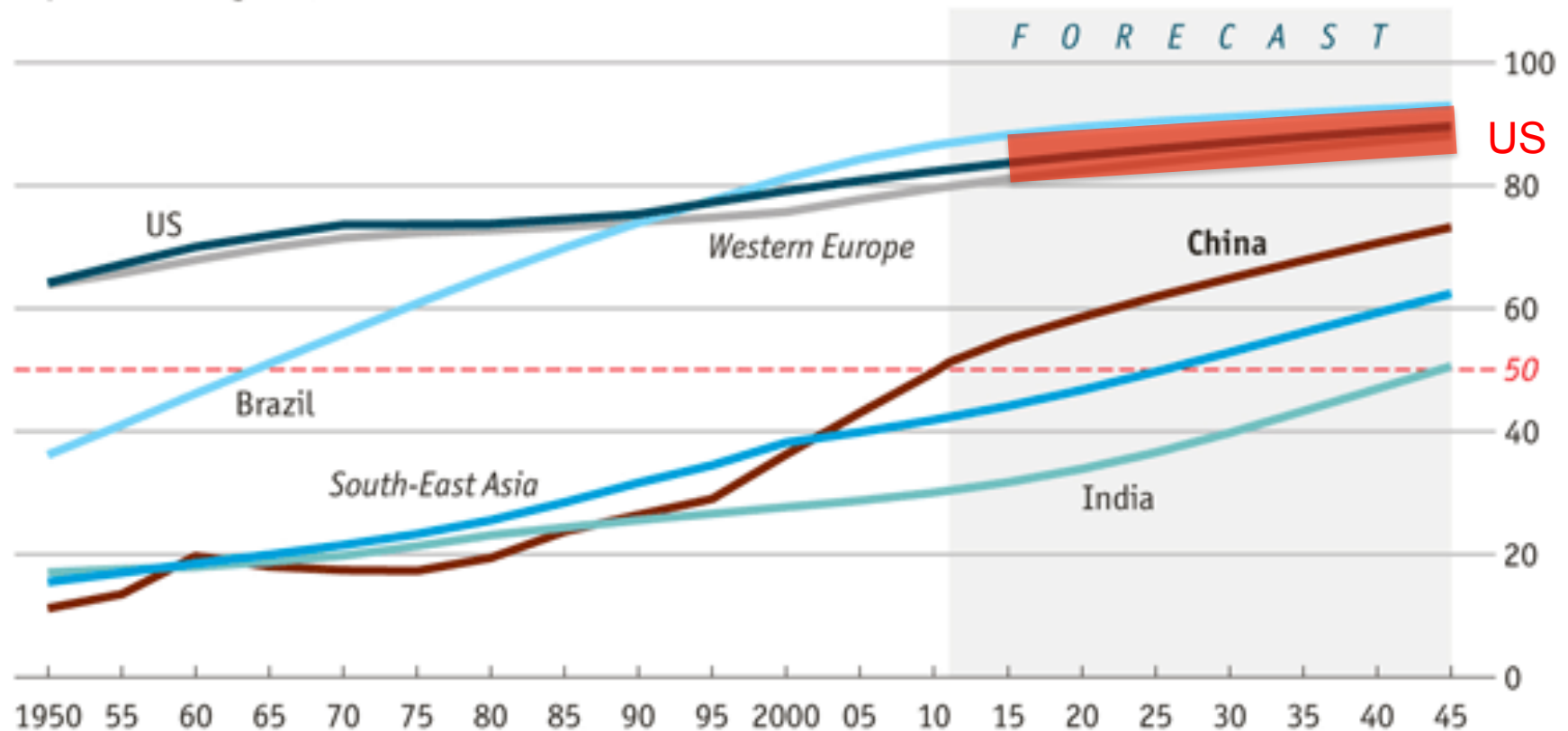
USA Population Projection 2050



Urbanization: Population Living in Urban Areas (% of total)

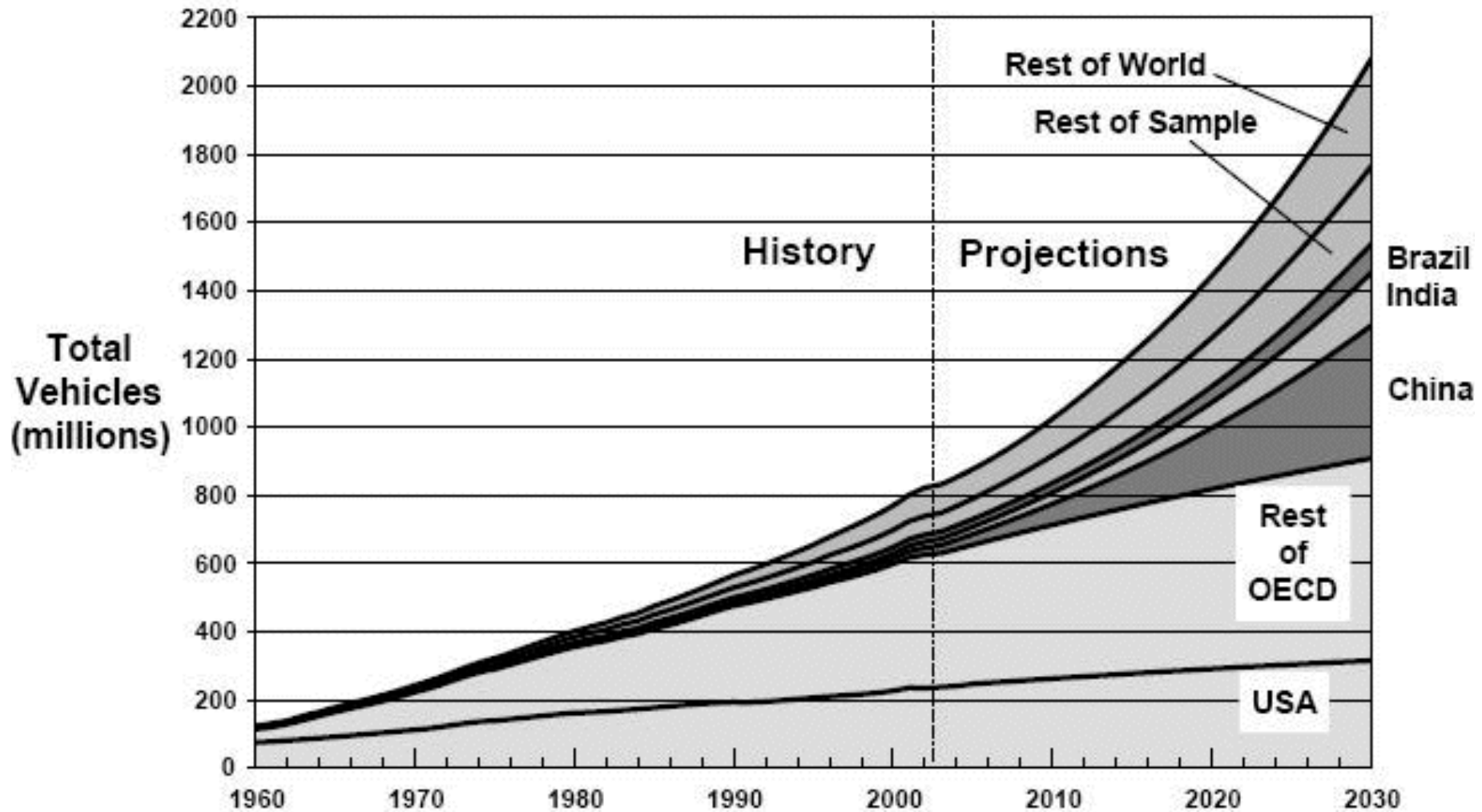
Urbanisation

Population living in urban areas, % of total

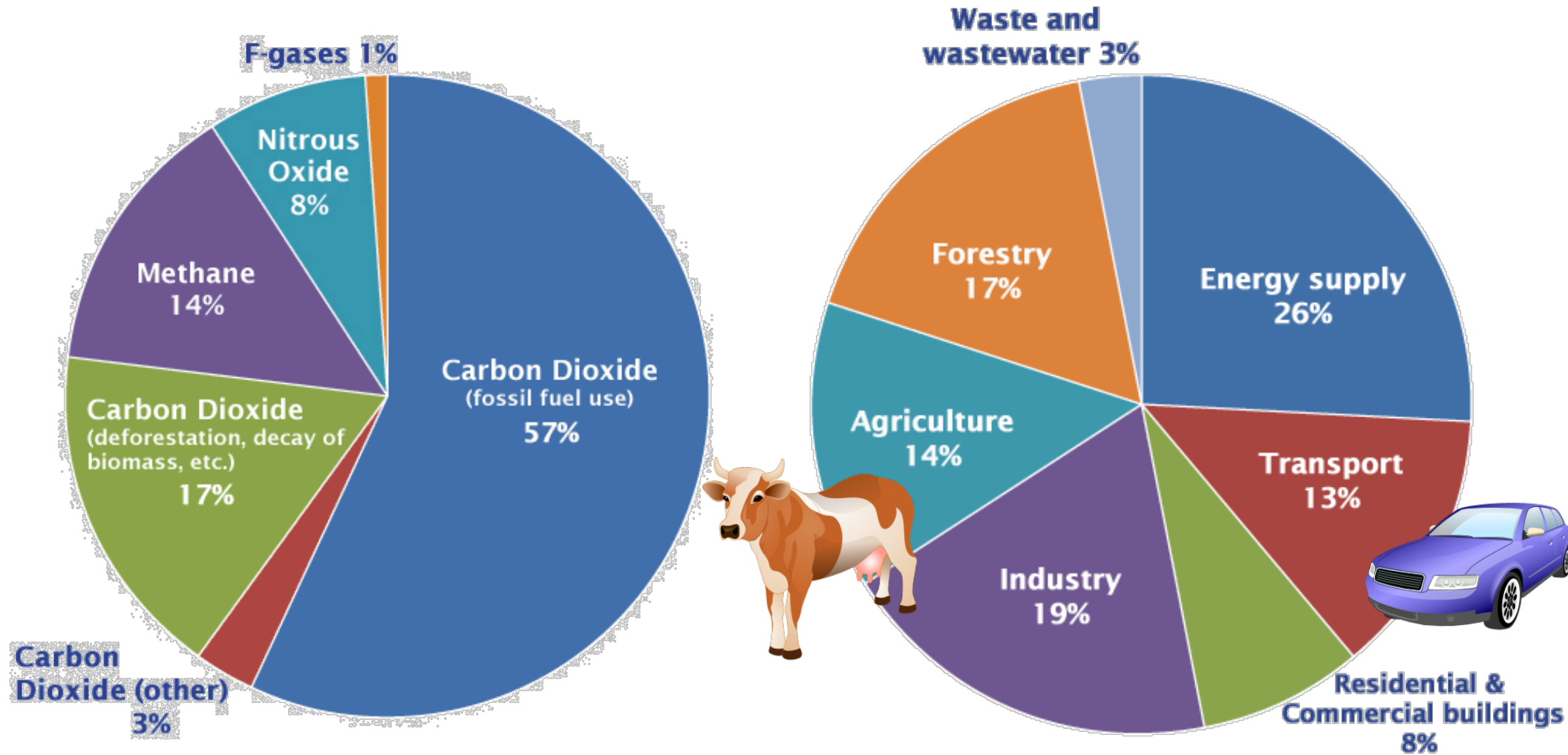


Sources: CEIC; UN Population Division; *The Economist*

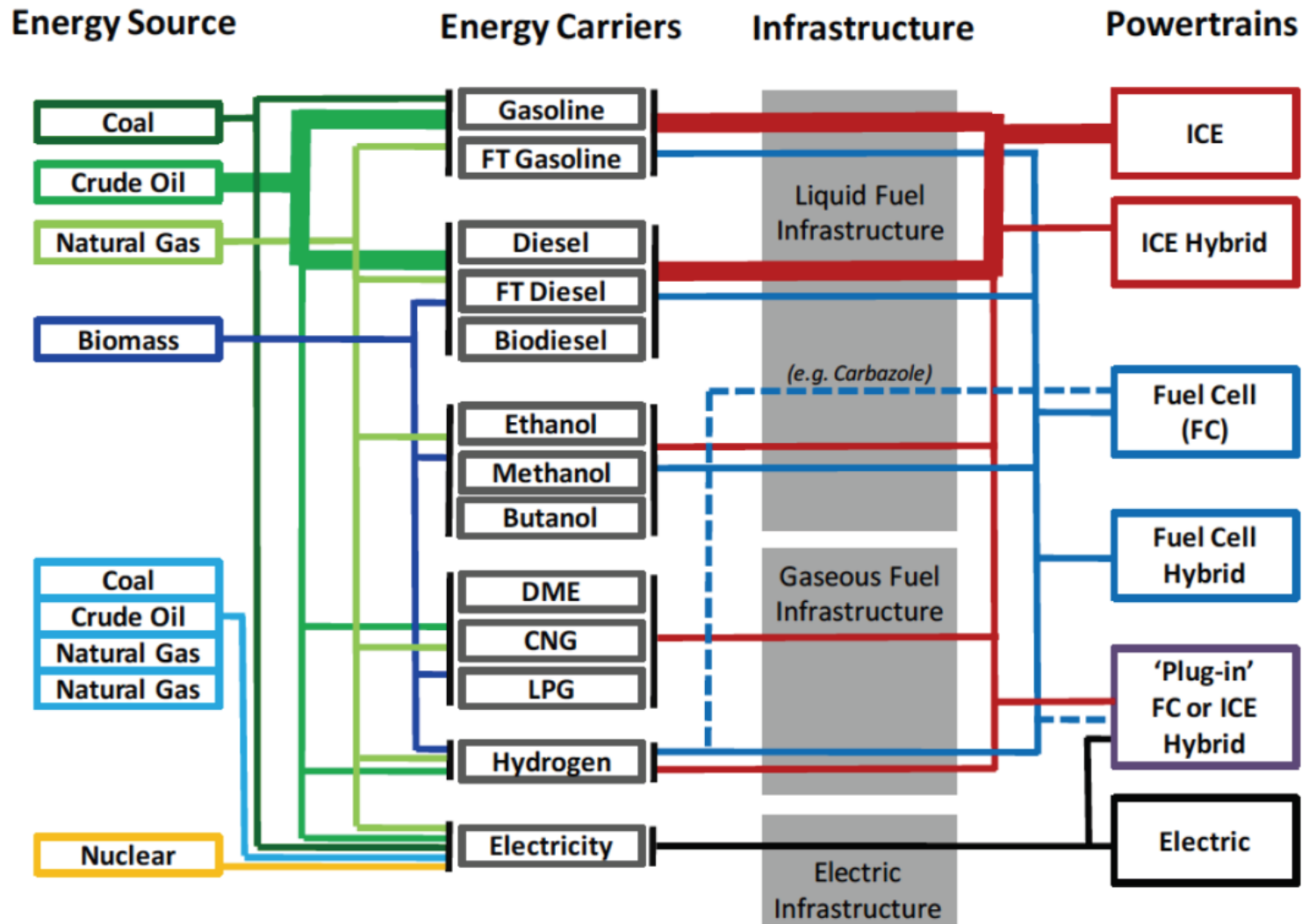
Total Vehicles by Country Forecast



Greenhouse Gases and Sources



Electricity: Agnostic Energy Carrier



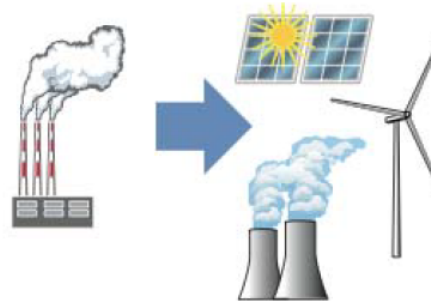
Decarbonization Strategy

Strategy

Energy Efficiency



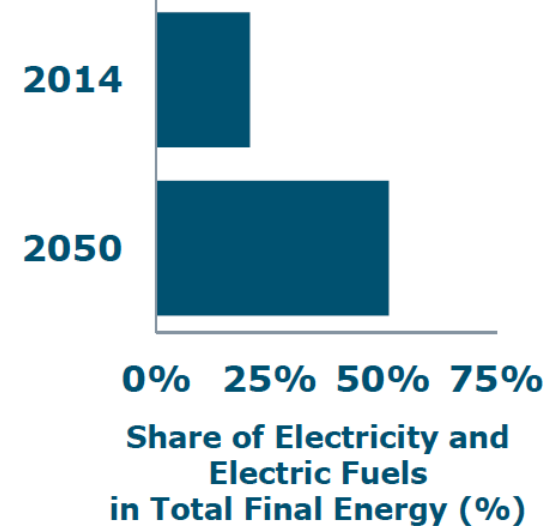
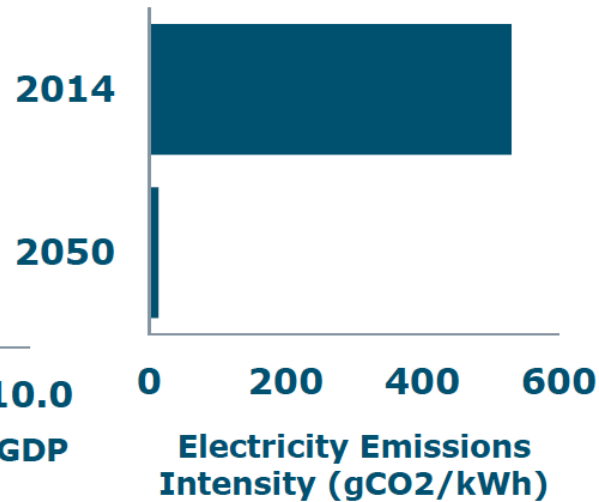
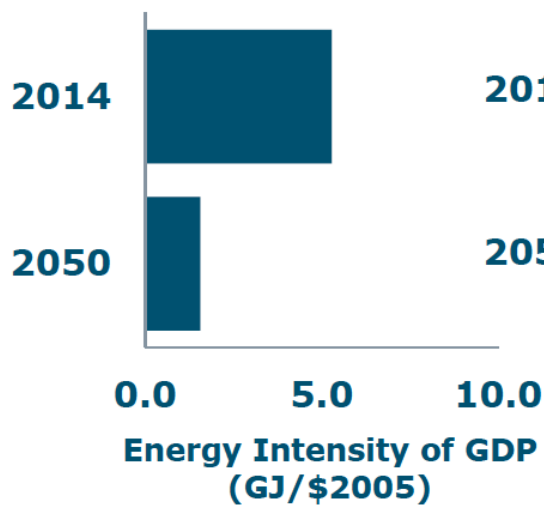
Decarbonization of Electricity



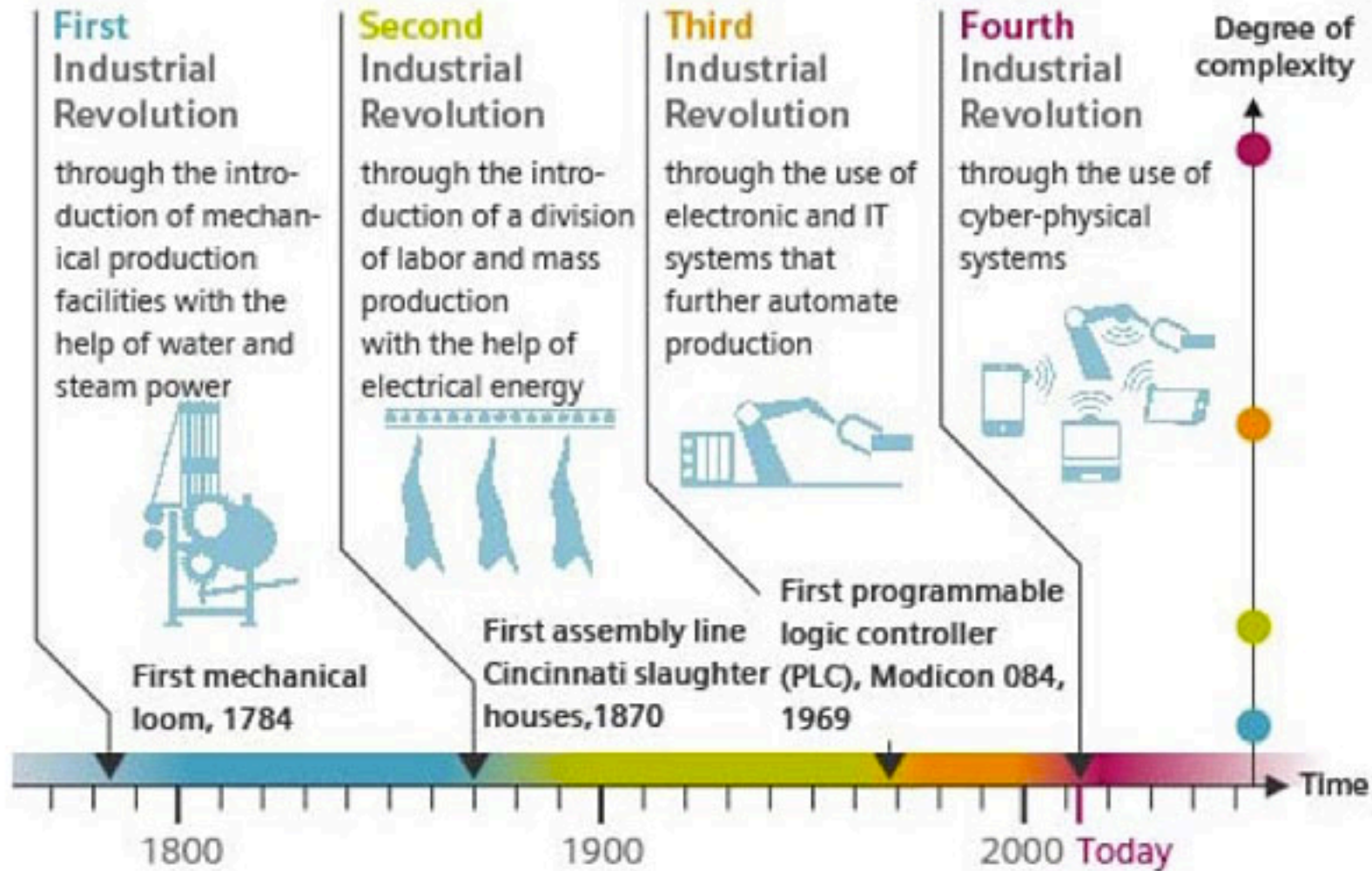
End Use Fuel Switching to Electric Sources



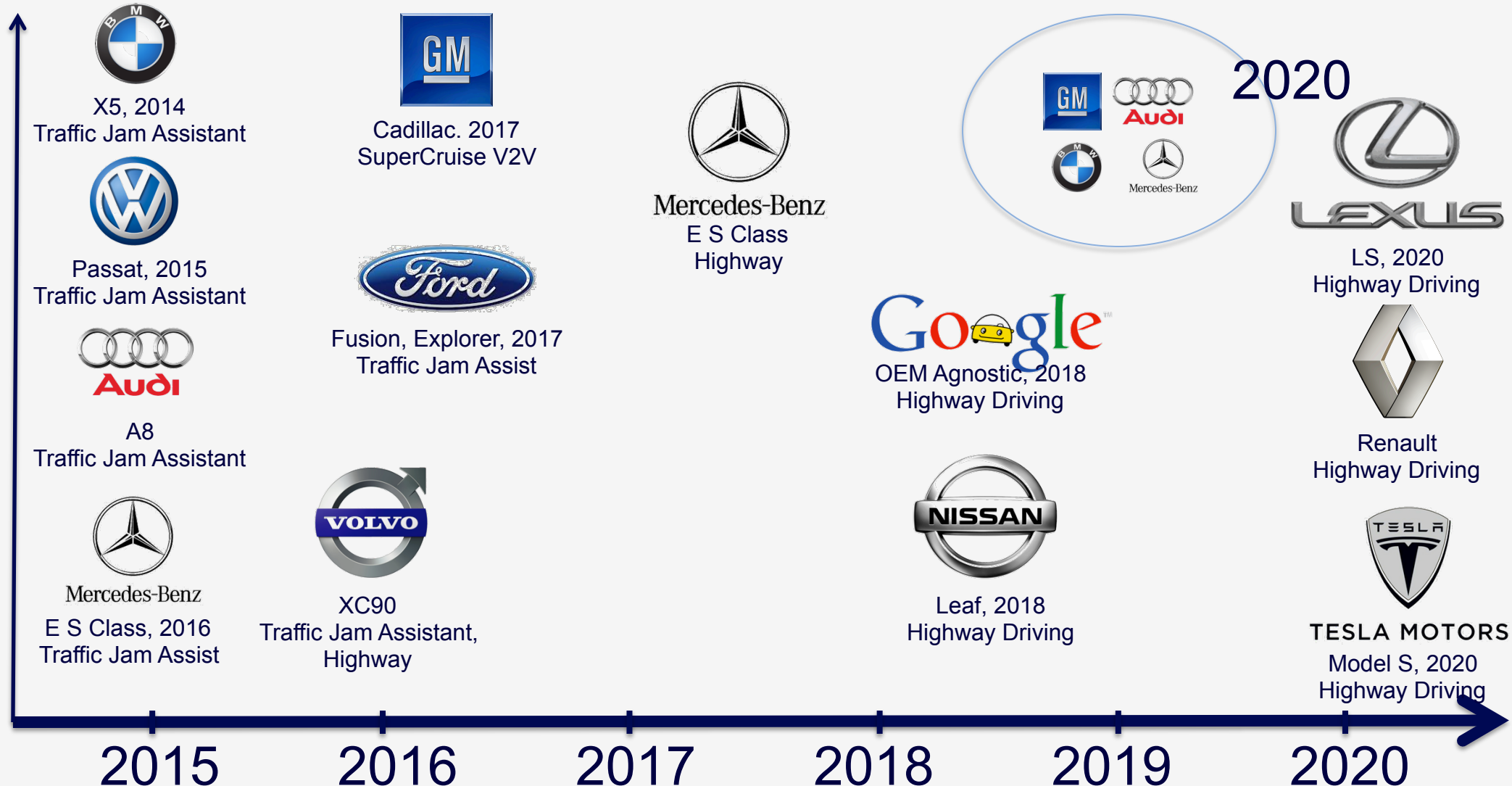
Key Metric of Transformation



Robotics Age, Cyber-physical Systems



Press Releases: Traffic Jam Assist, Highway Driving, Automated Parking



Killer Apps

- Crash warnings
- Freeway autopilot
- Truck and trailer maneuvers
- Electric charging maneuvers
- Automated chauffeur

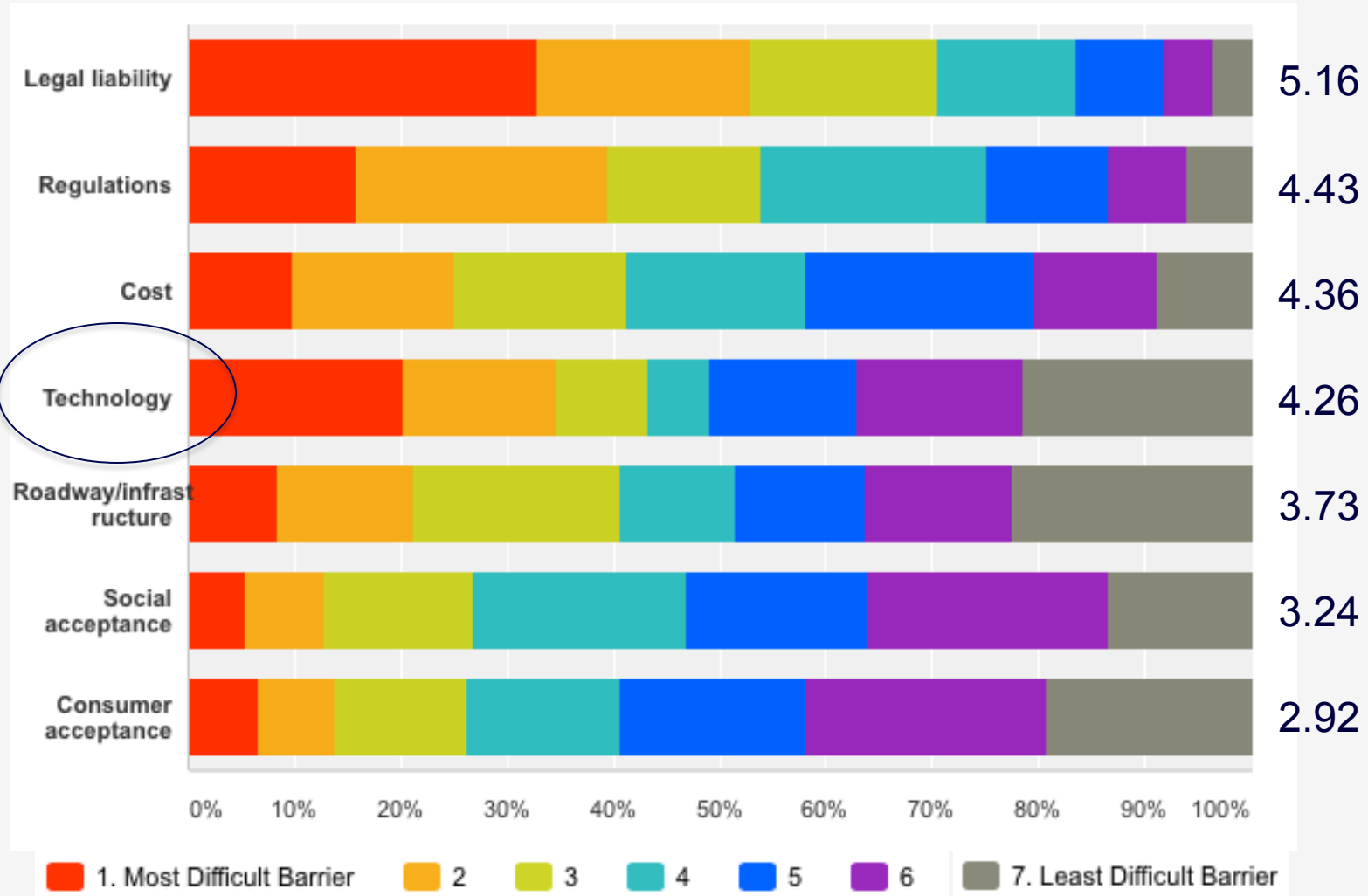
SAE Level	SAE Name	SAE Narrative Definition	Execution of Steering/ Acceleration/ Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System capability (driving modes)
Human Driver monitors the driving environment						
0	No Automation	Warnings, Driver Information The <i>human driver</i> performs all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention	Human Driver	Human Driver	Human Driver	N/A
1	Driver Assistance	Adaptive Cruise Control, (braking accel) Lane Keeping (steering), CACC Lane Centering (steering), ABS, ESC The <i>human driver</i> performs all remaining aspects of the <i>dynamic driving task</i>	Human Driver and Systems	Human Driver	Human Driver	Some Driving Modes
2	Partial Automation	Traffic Jam Assist, (braking, acceleration, & steering) The <i>human driver</i> performs one or more aspects of the <i>dynamic driving task</i> , with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human Driver	Human Driver	Some Driving Modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	Freeway Driving The <i>system</i> performs all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human Driver	Some Driving Modes
4	High Automation	Freeway Pilot, Campus Shuttle Freight Platooning, Urban Automation The <i>system</i> performs all aspects of the <i>dynamic driving task</i> , with the expectation that the <i>system</i> not respond appropriately to a <i>request to intervene</i>	System	System	System	Some Driving Modes
5	Full Automation	Robotic Taxi The <i>system</i> performs all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	Some Driving Modes

Three Surveys

- Graham Institute, Expert Panel, 20 expert panelists
- TRB/AUVSI Symposium, 250 attendees responded
- SAE Convergence, 151 attendees responded

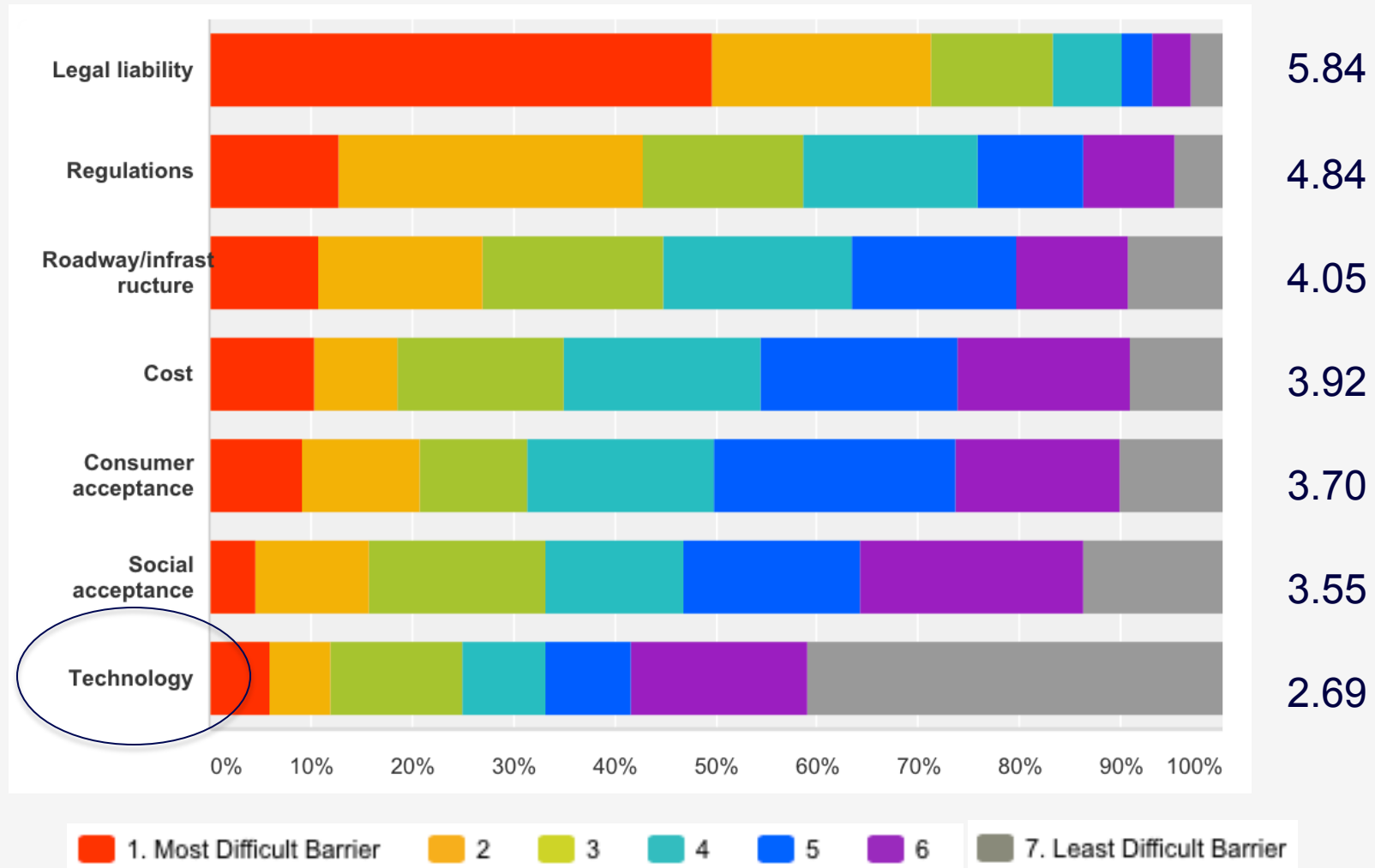
TRB Ranking Barriers: Liability, Regulations, Cost, Technology

Q1: What is your ranking of the difficulty of overcoming barriers in fielding SAE Level 5 fully automated vehicles in all environments, with the first column being the most difficult barrier and seventh column the least?



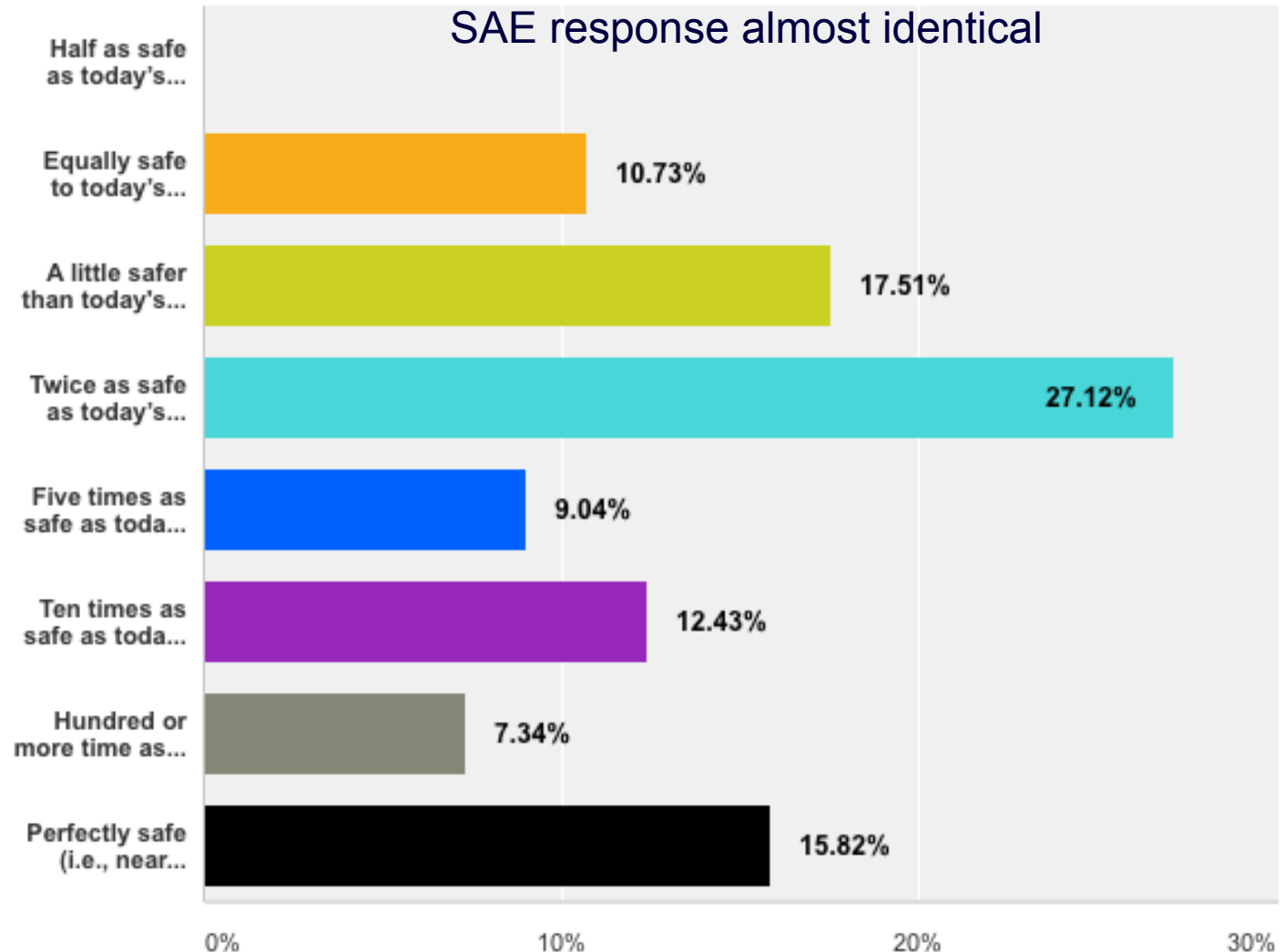
SAE Ranking Barriers: Liability

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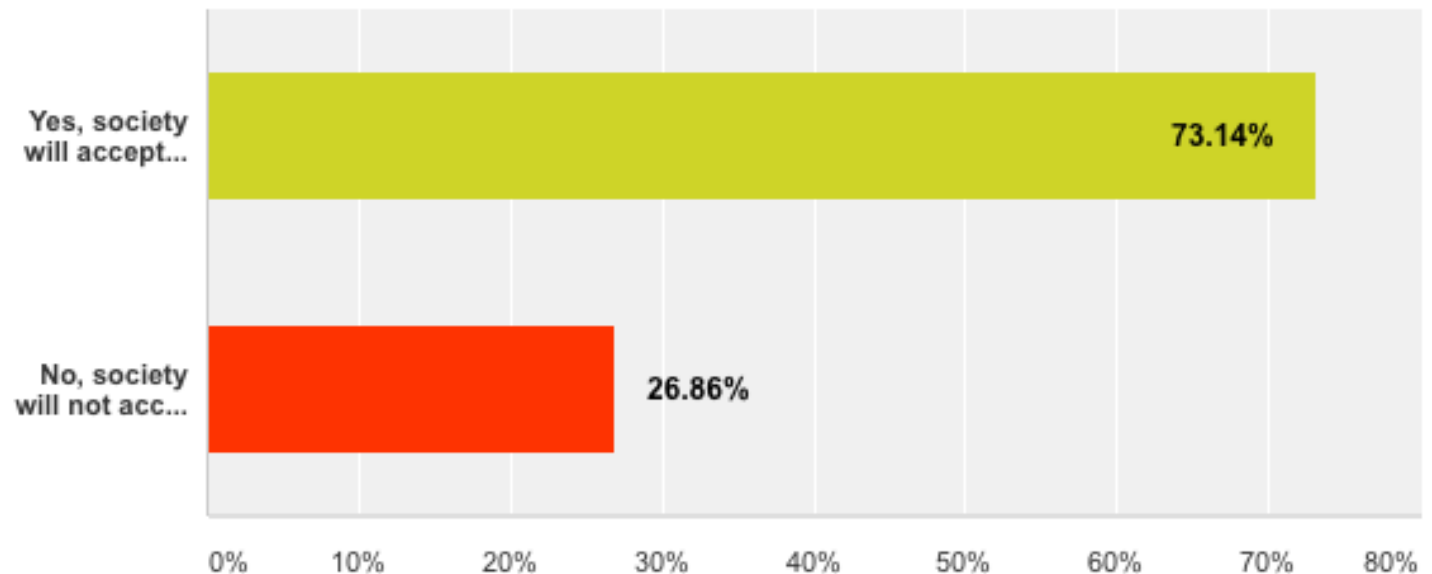
TRB Required Level of Safety: Little Safer to Very Safe

Q2: What level of safety do you believe an automated driving system (at any level of automation) should be required to demonstrate before it is authorized for public use?



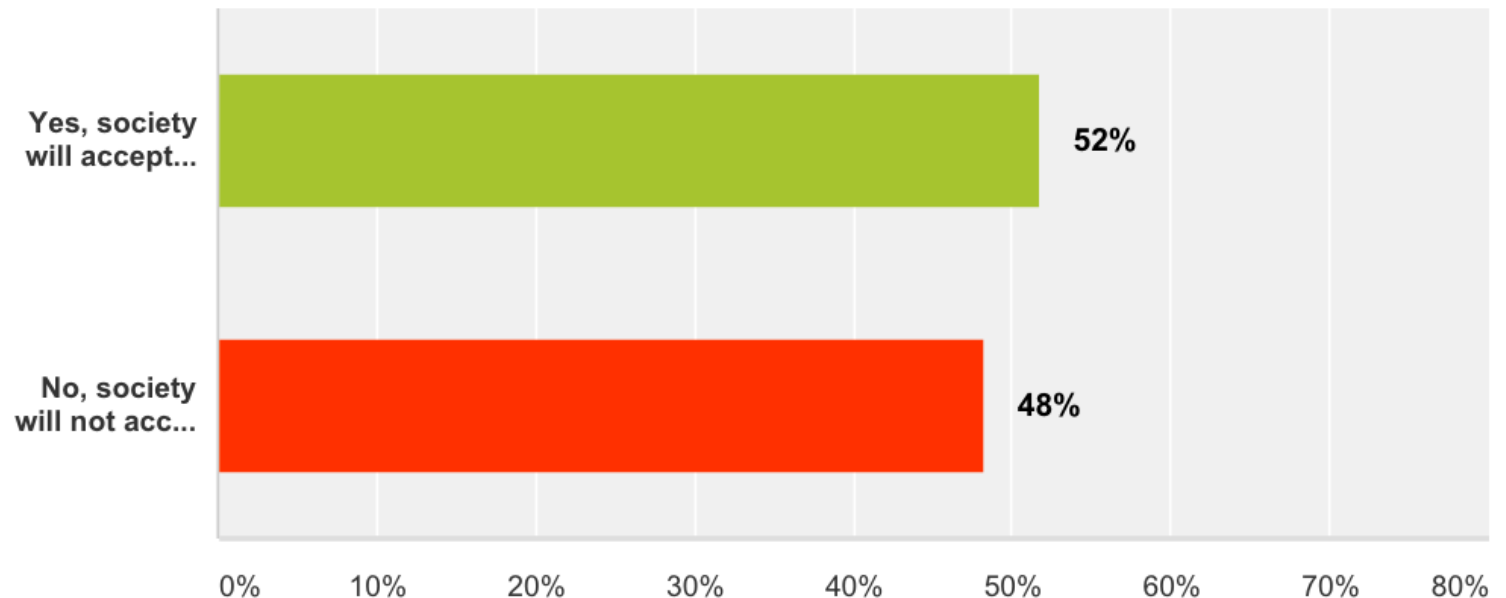
TRB Accept Automated Vehicles Causing Crashes

Q3: If automated vehicles result in a significant reduction in road accidents and fatalities, will society accept that automated vehicles occasionally cause some of the remaining accidents and fatalities?



SAE Accept Automated Vehicles Causing Crashes

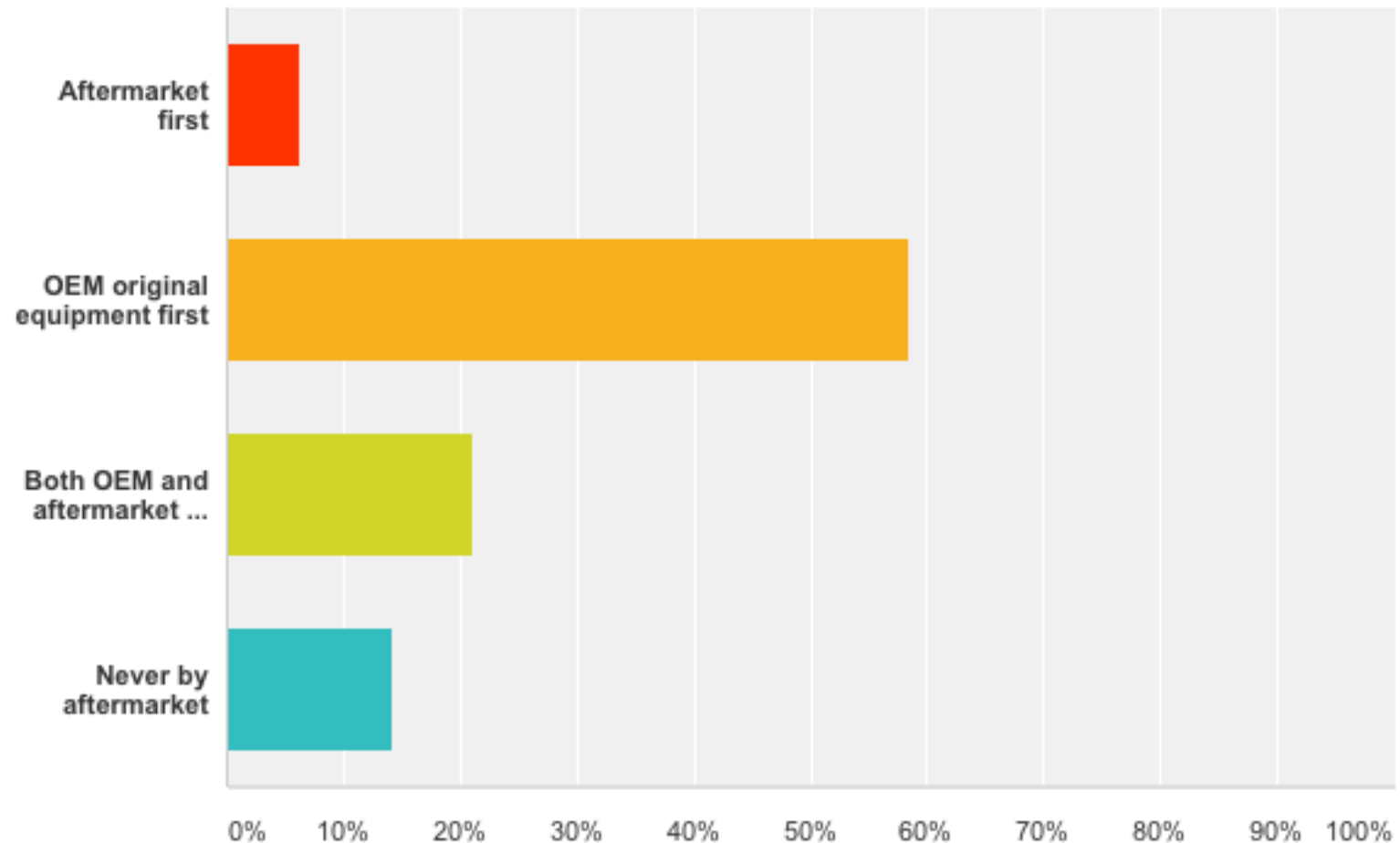
Q3: If automated vehicles result in a significant reduction in road accidents and fatalities, will society accept that automated vehicles occasionally cause some of the remaining accidents and fatalities?



TRB First Sales: OEM?

Q4: Do you expect automated driving systems (SAE Level 3 or above) to be first sold to the general public as after-market retrofits to existing vehicles, or as original equipment on new vehicles, or both?

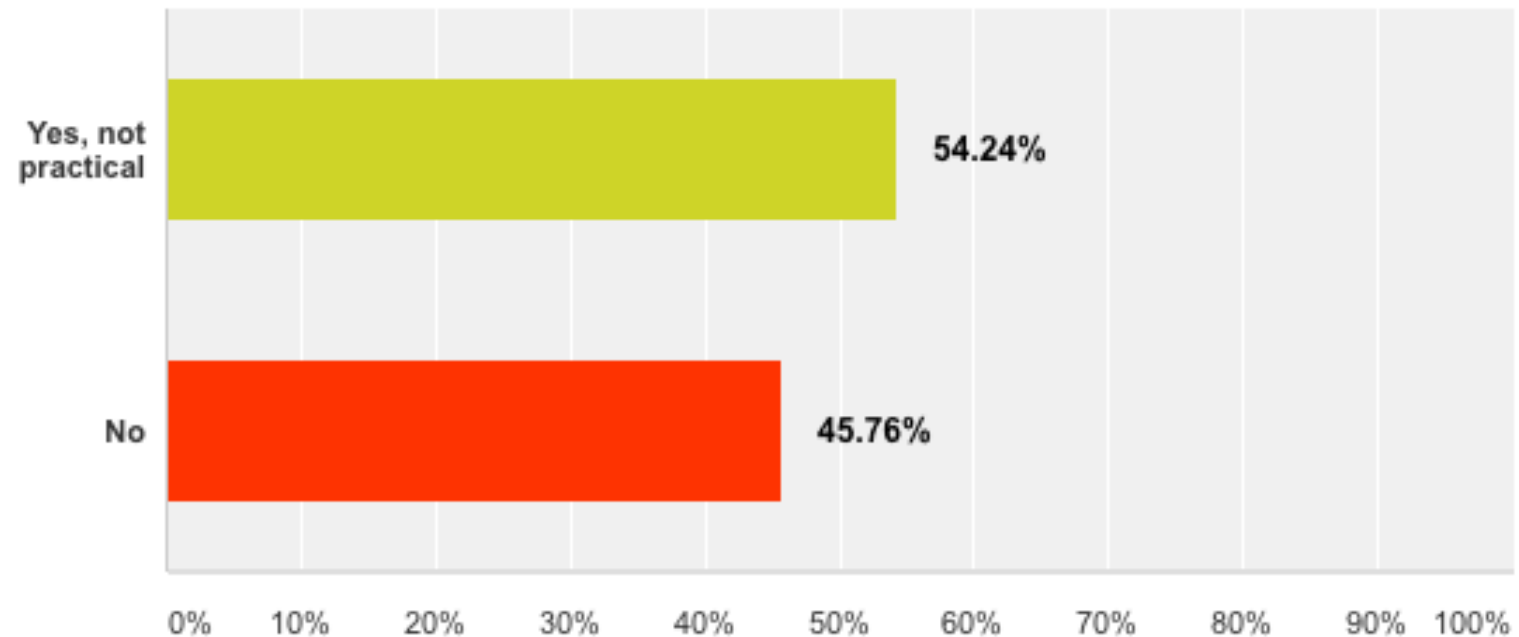
SAE response almost identical



TRB, Conditional Automation (Level 3) Not Practical?

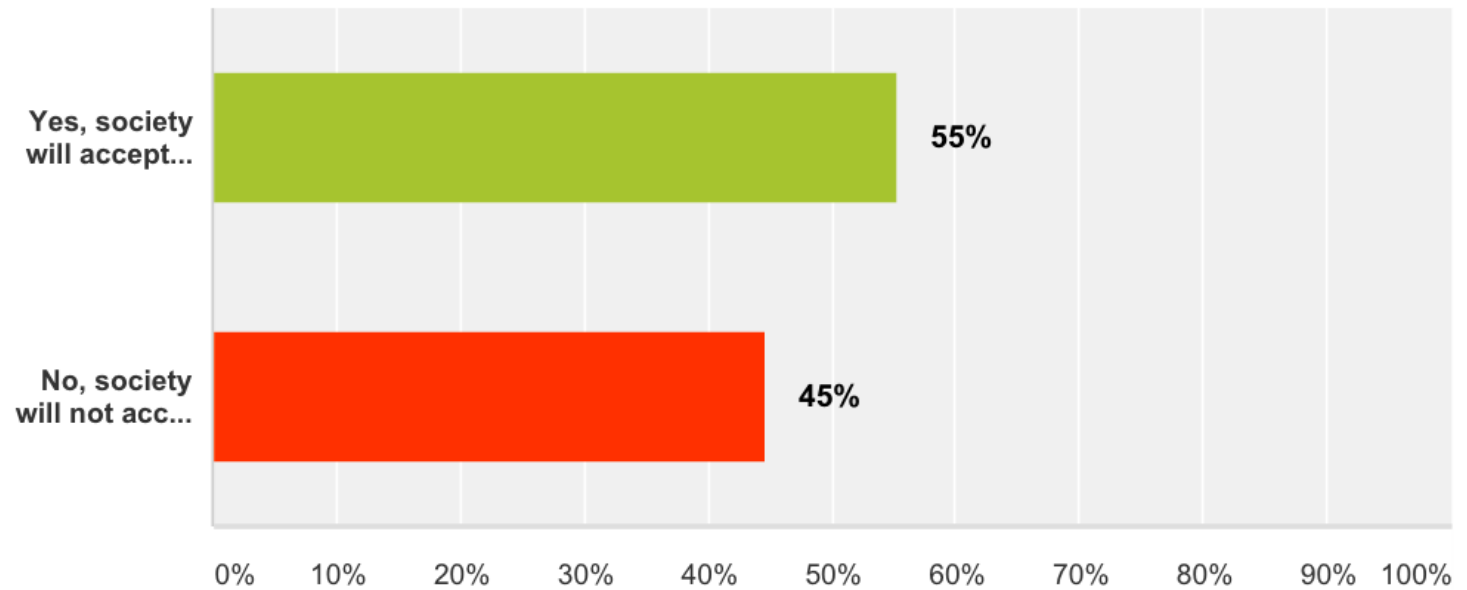
Q5: Is SAE Level 3 conditional automation, in which the driver is expected to intervene quickly if needed, not practical or safe because drivers are likely to become complacent with automated operation and not behave as required?

SAE response almost identical



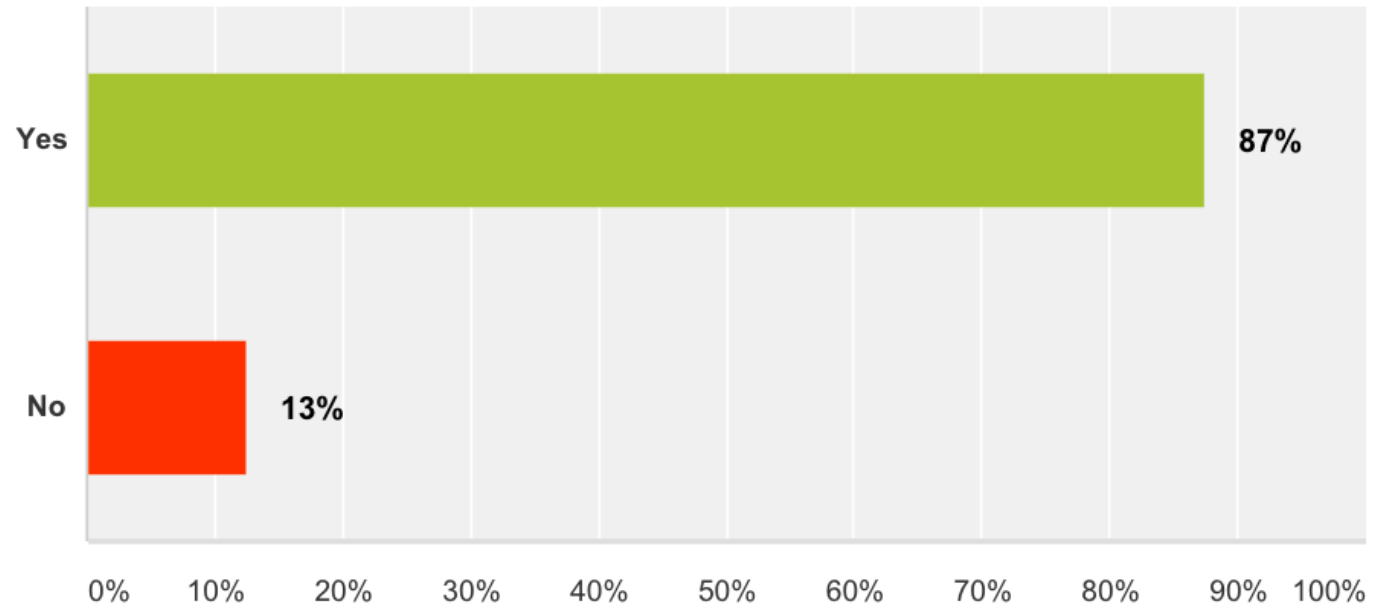
TRB, V2V Necessary for SAE Level 5?

Q6: Do you believe that vehicle-to-vehicle communication will be necessary for fully automated SAE Level 5 operation, to extend the sensing horizon to other vehicles or to improve the availability of information about the other vehicles?



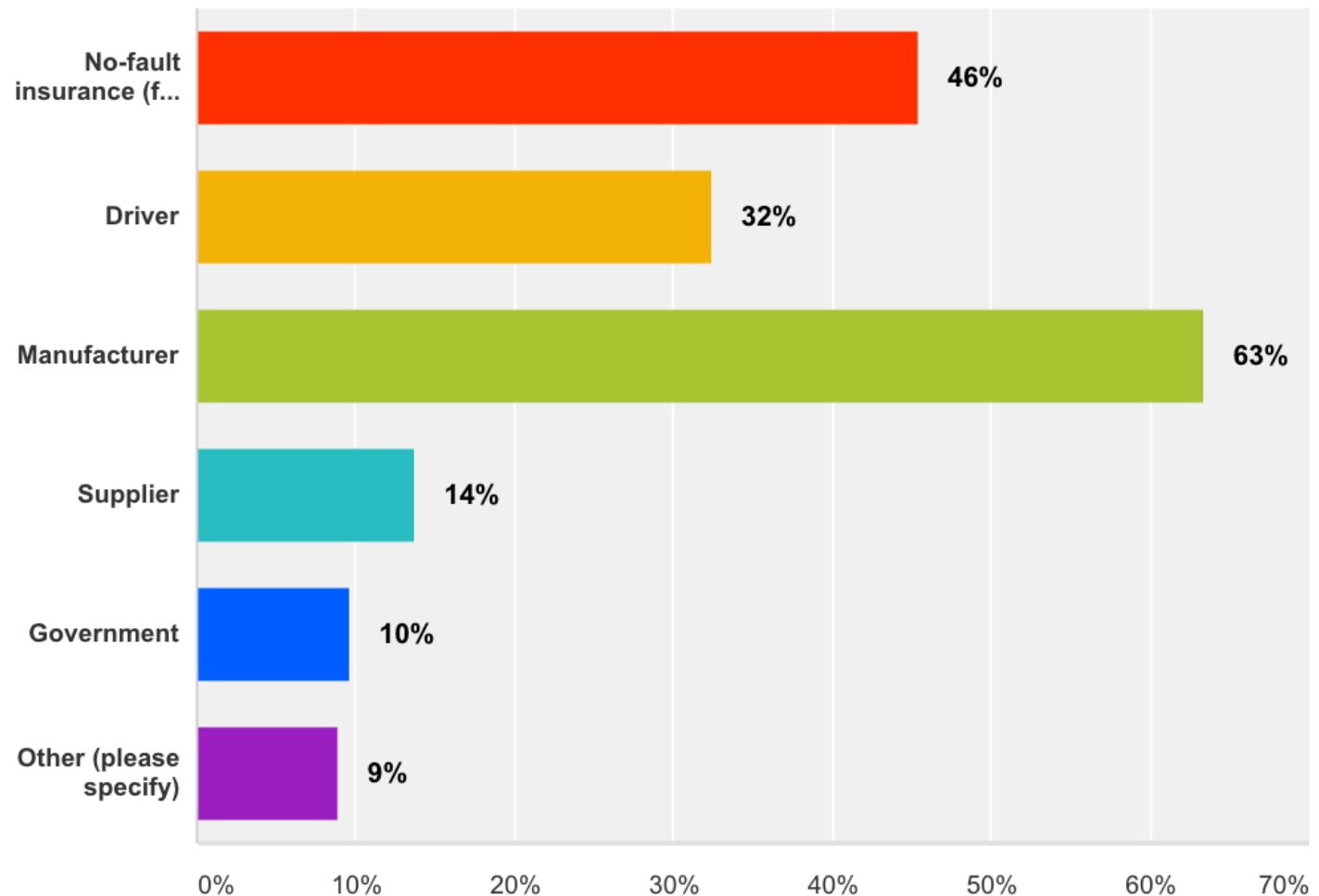
SAE, V2V Necessary for SAE Level 5?

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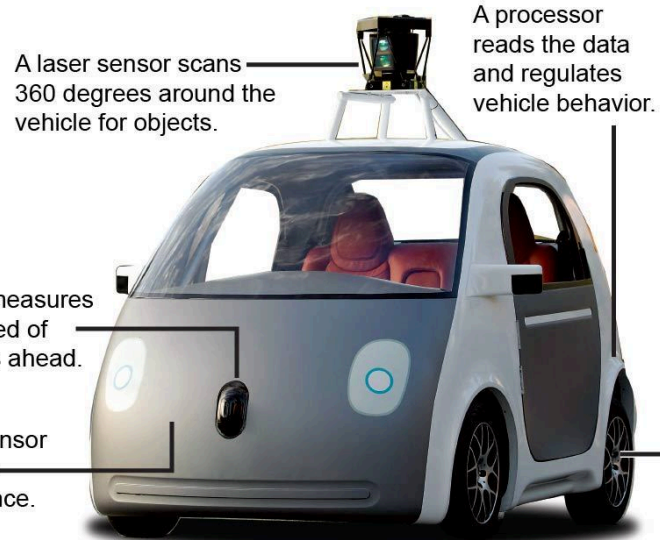


Liability and Responsibilities for Crashes In Automated Mode

It is speculated that the more advanced automated vehicle systems will enable driver to disengage from the driving task (e.g., feet off the pedals, hands off the steering wheel, and eyes off the road) and attend to other activities in the vehicle (e.g., communicating on smart devices) while relying on the automated vehicle systems to perform the driving tasks in complete safety and even in the case of electrical or other failure it will fail safely. In case of system failure and a crash with such a high level of automation who do you believe will accept responsibility and liability in most cases while the automated vehicle system is engaged and driving the vehicle? (Select multiple of you believe the responsibility/liability will be shared)



Automated Shuttle



Google

Raoul Rañoa / @latimesgraphics



Navia/Induct

Source: Google

Automated Freeway Driving



Truck Platooning



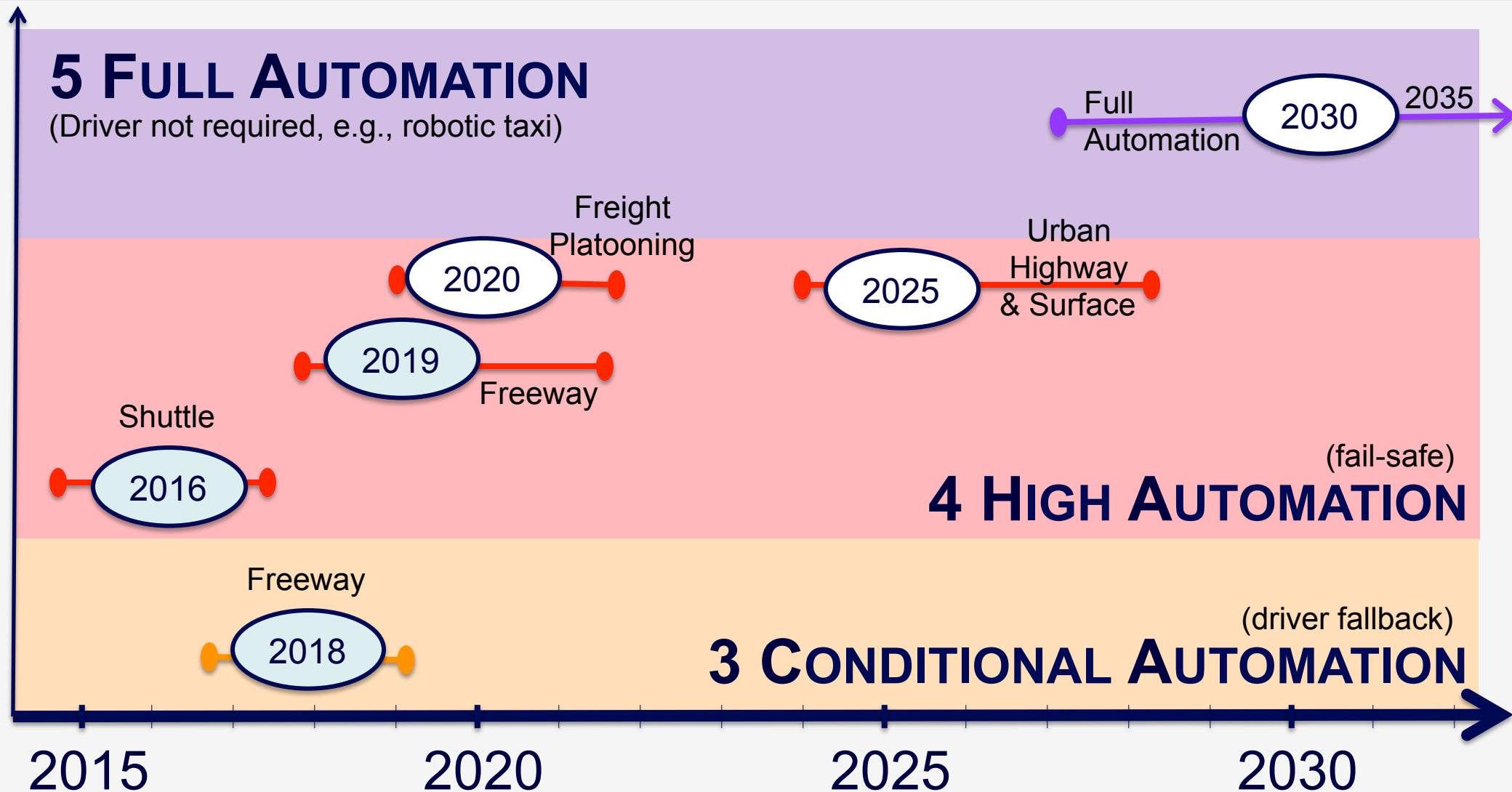
Freightliner Inspiration Freeway Pilot



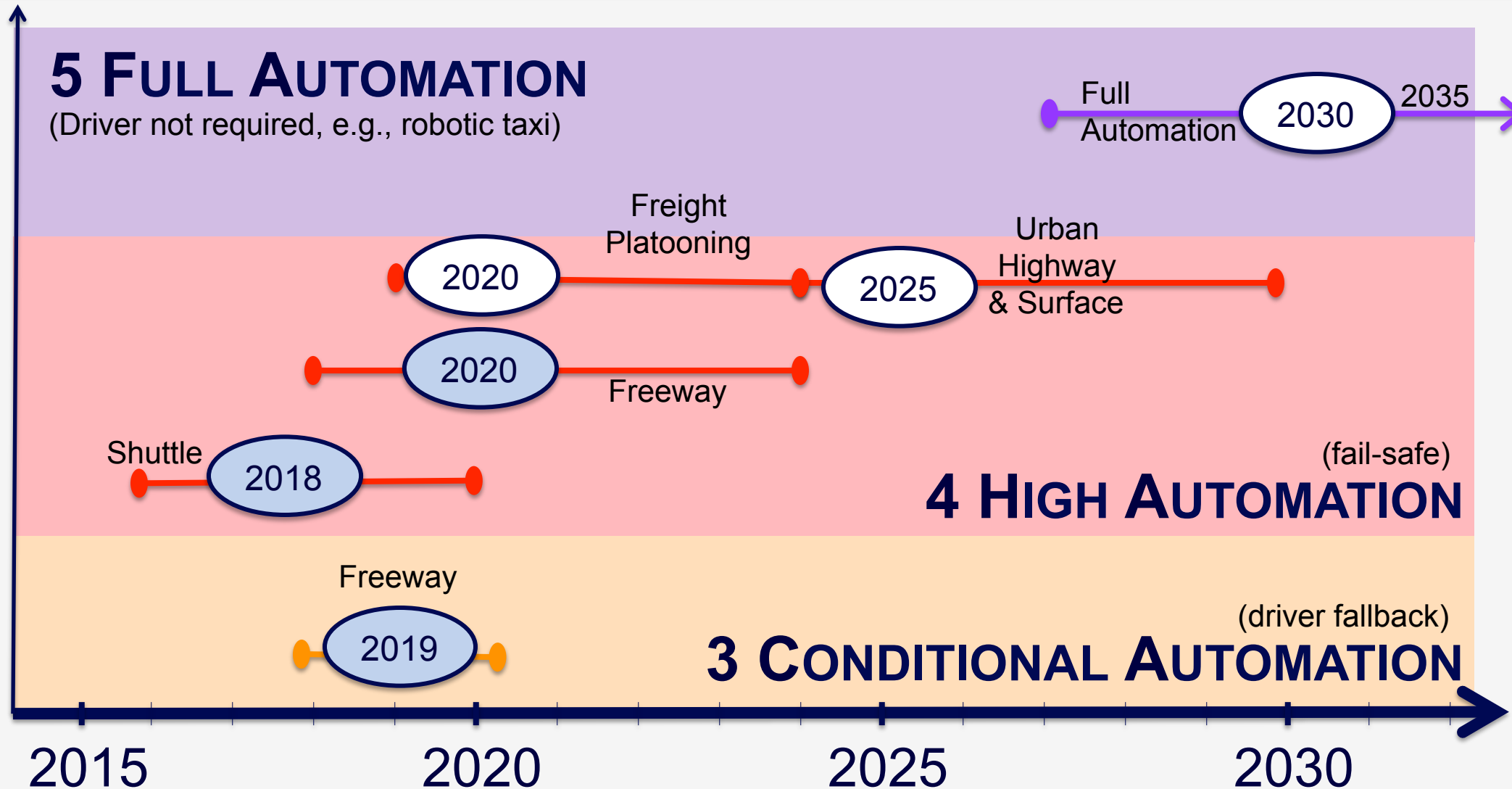
Full Automation



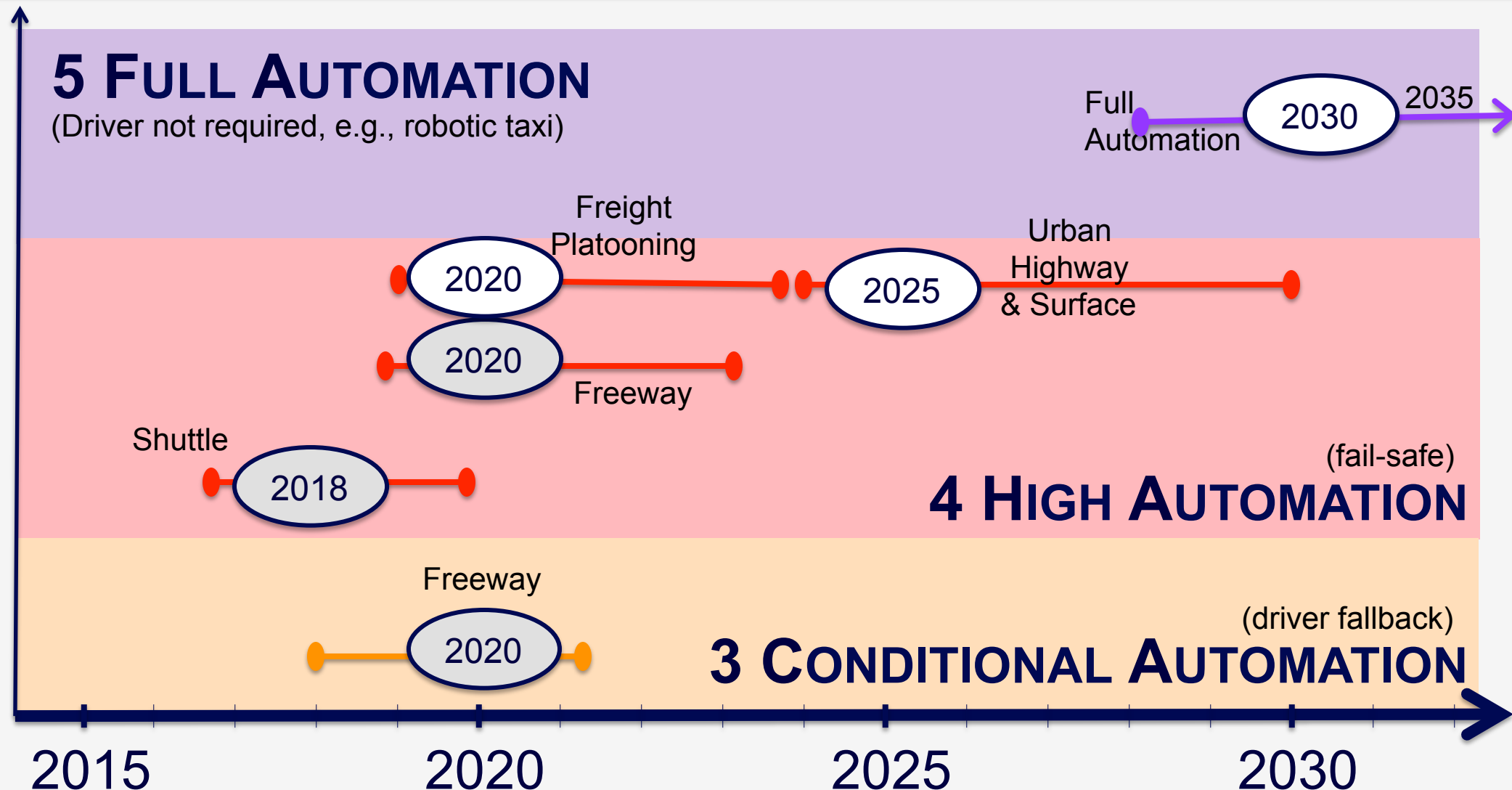
Automated Vehicle System, Graham Institute Market Introduction (SAE Levels), Median, IQR



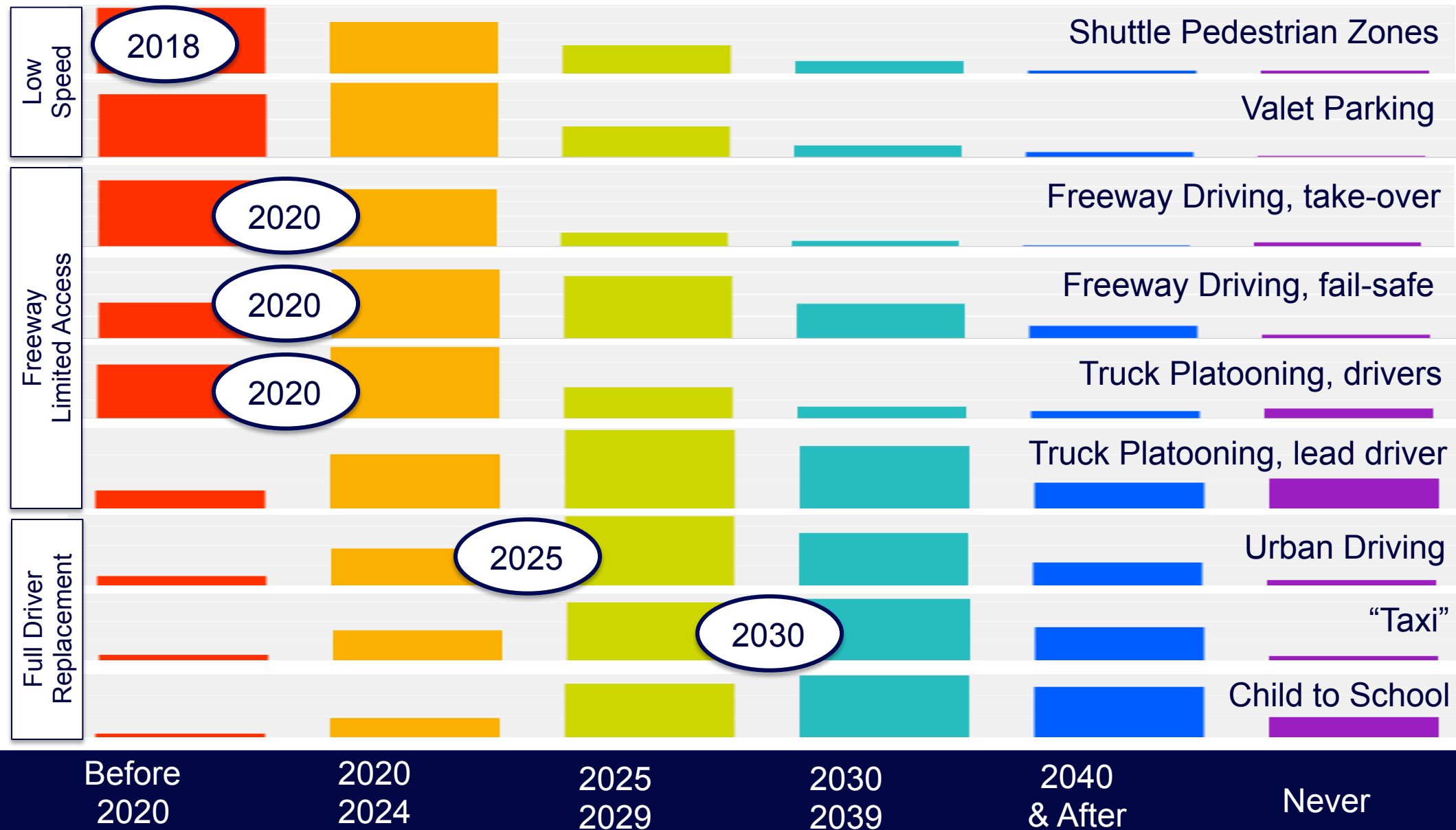
Automated Vehicle System, TRB/AUVSI Market Introduction (SAE Levels), Median, IQR



SAE Convergence, Automated Vehicle System Market Introduction (SAE Levels), Median, IQR



AUTOMATED VEHICLE SYSTEMS FORECAST, SAE



Connected, automated, and electric...

...and eat more chicken!

