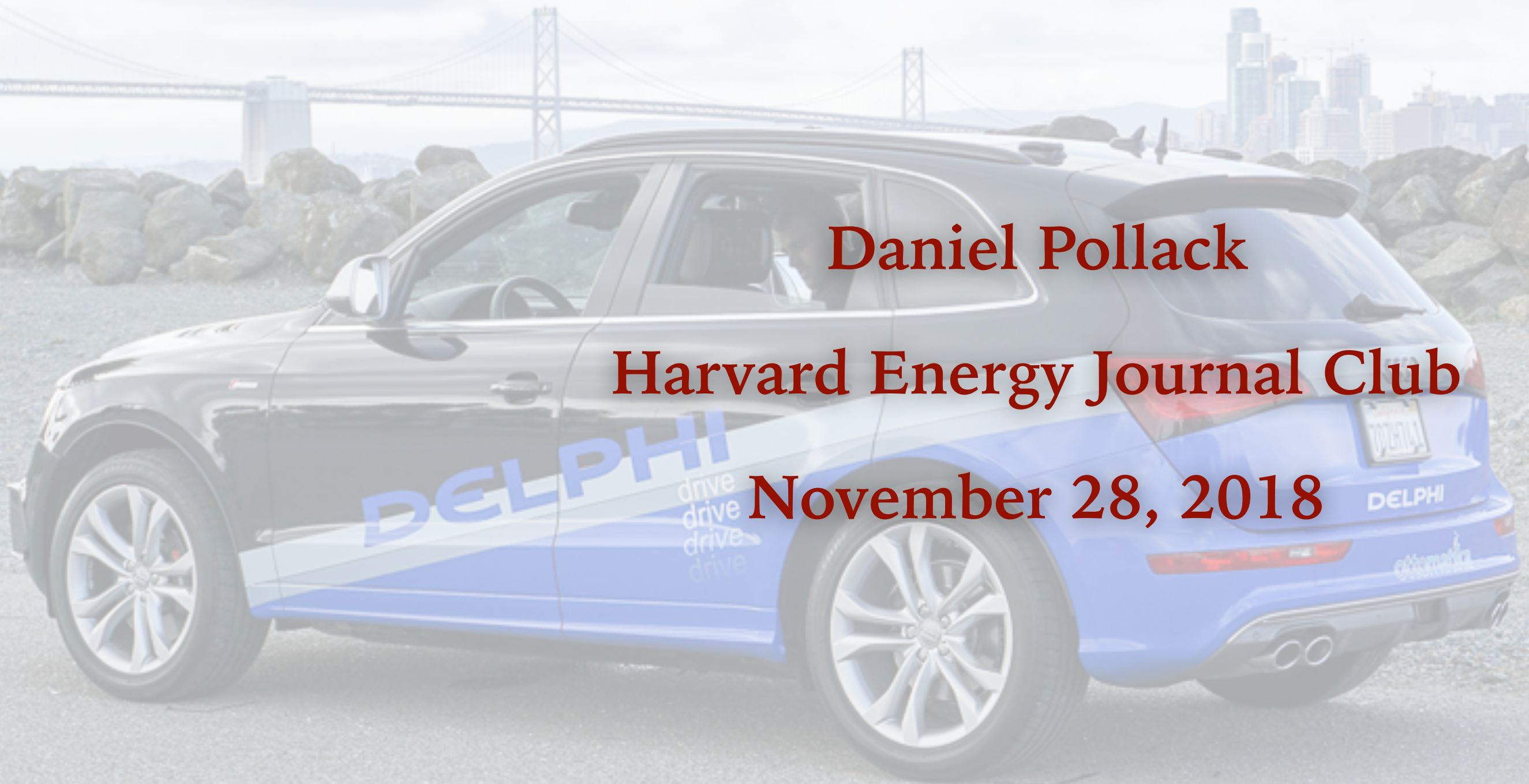


ENERGY AND SELF-DRIVING CARS: THE AUTONOMOUS VEHICLE FUTURE

Daniel Pollack

Harvard Energy Journal Club

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PRESENTATION OVERVIEW

➤ AUTONOMOUS VEHICLES

- *WHAT ARE AUTONOMOUS VEHICLES?*
- *WHO'S WORKING ON THEM?*
- *HOW DO THEY WORK?*

➤ AUTONOMOUS VEHICLES AND ENERGY USE

- *RIDE-SHARING*
- *WEIGHT REDUCTION (due to safety improvements)*
- *DRIVING EFFICIENCY*
- *ELECTRIFICATION*
- *REBOUND EFFECTS*



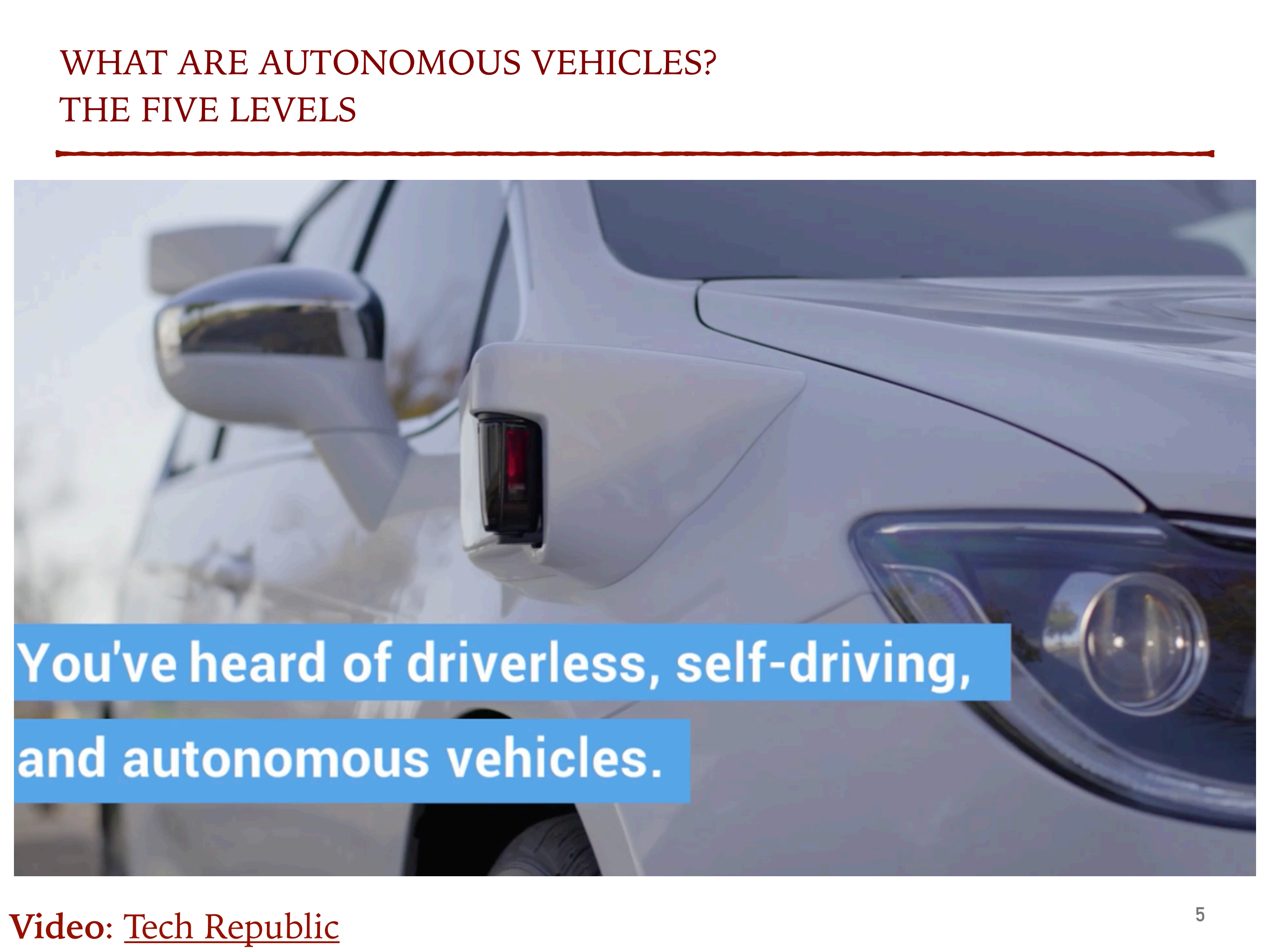
AUTONOMOUS VEHICLES

WHAT ARE AUTONOMOUS VEHICLES?



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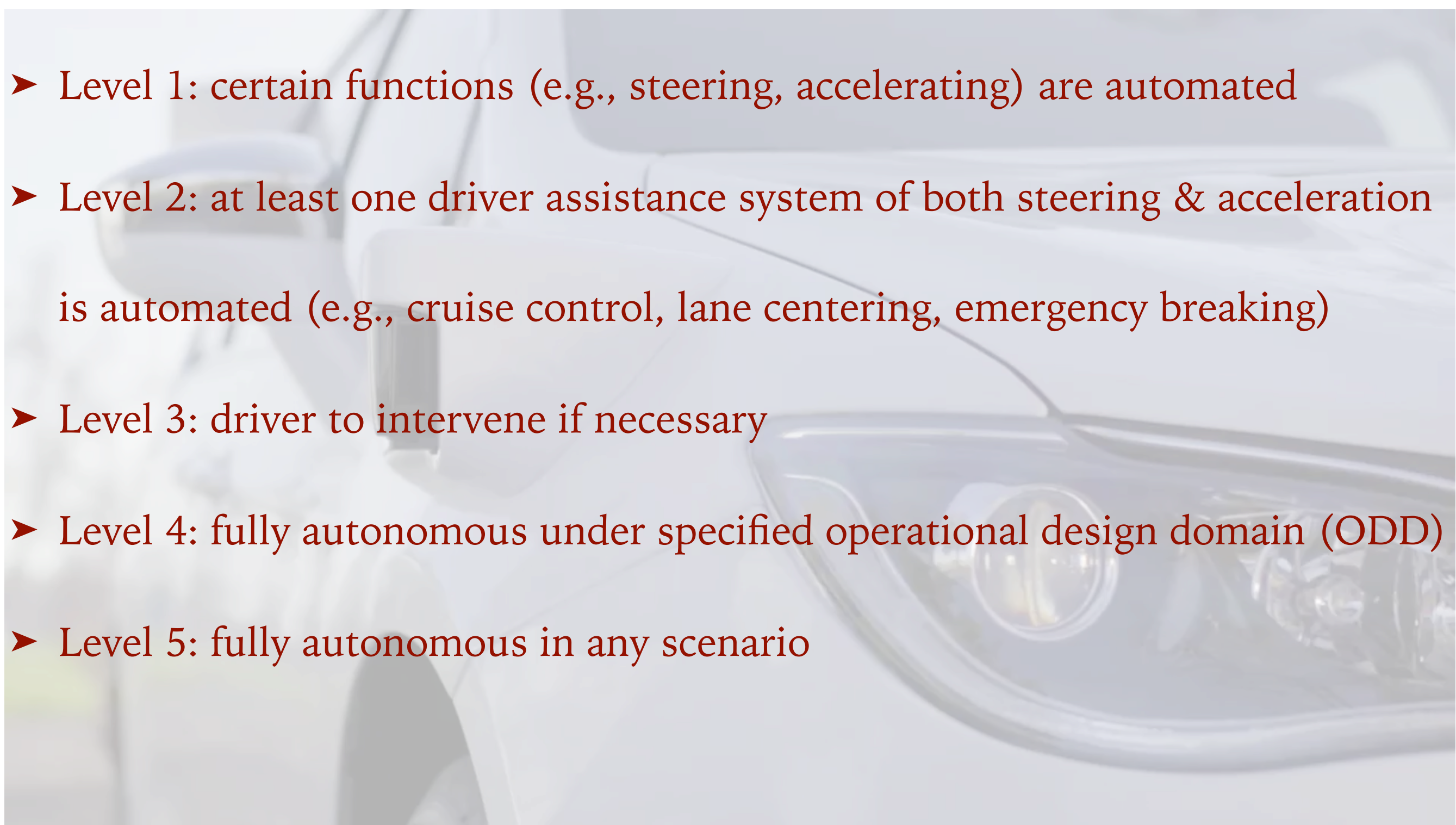
THE FIVE LEVELS

A close-up photograph of a white car, focusing on the side mirror and the front headlight. The car is parked on a street, and the background is slightly blurred.

You've heard of driverless, self-driving,
and autonomous vehicles.

WHAT ARE AUTONOMOUS VEHICLES?

THE FIVE LEVELS

- 
- Level 1: certain functions (e.g., steering, accelerating) are automated
 - Level 2: at least one driver assistance system of both steering & acceleration is automated (e.g., cruise control, lane centering, emergency breaking)
 - Level 3: driver to intervene if necessary
 - Level 4: fully autonomous under specified operational design domain (ODD)
 - Level 5: fully autonomous in any scenario

WHO'S WORKING ON THEM?



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AUTONOMOUS VEHICLES IN DEVELOPMENT



WHO'S WORKING ON THEM?

AUTONOMOUS VEHICLES IN DEVELOPMENT

- Birth of AVs: Carnegie Mellon University 1984 ^{1,2}
- Waymo (Alphabet, Google parent company) developing tech with vehicles from Toyota, Lexus, Chrysler, & Jaguar, as well as their own Firefly ³



Image Source: [Tech Republic](#)



Image Source: [Waymo](#)

WHO'S WORKING ON THEM?

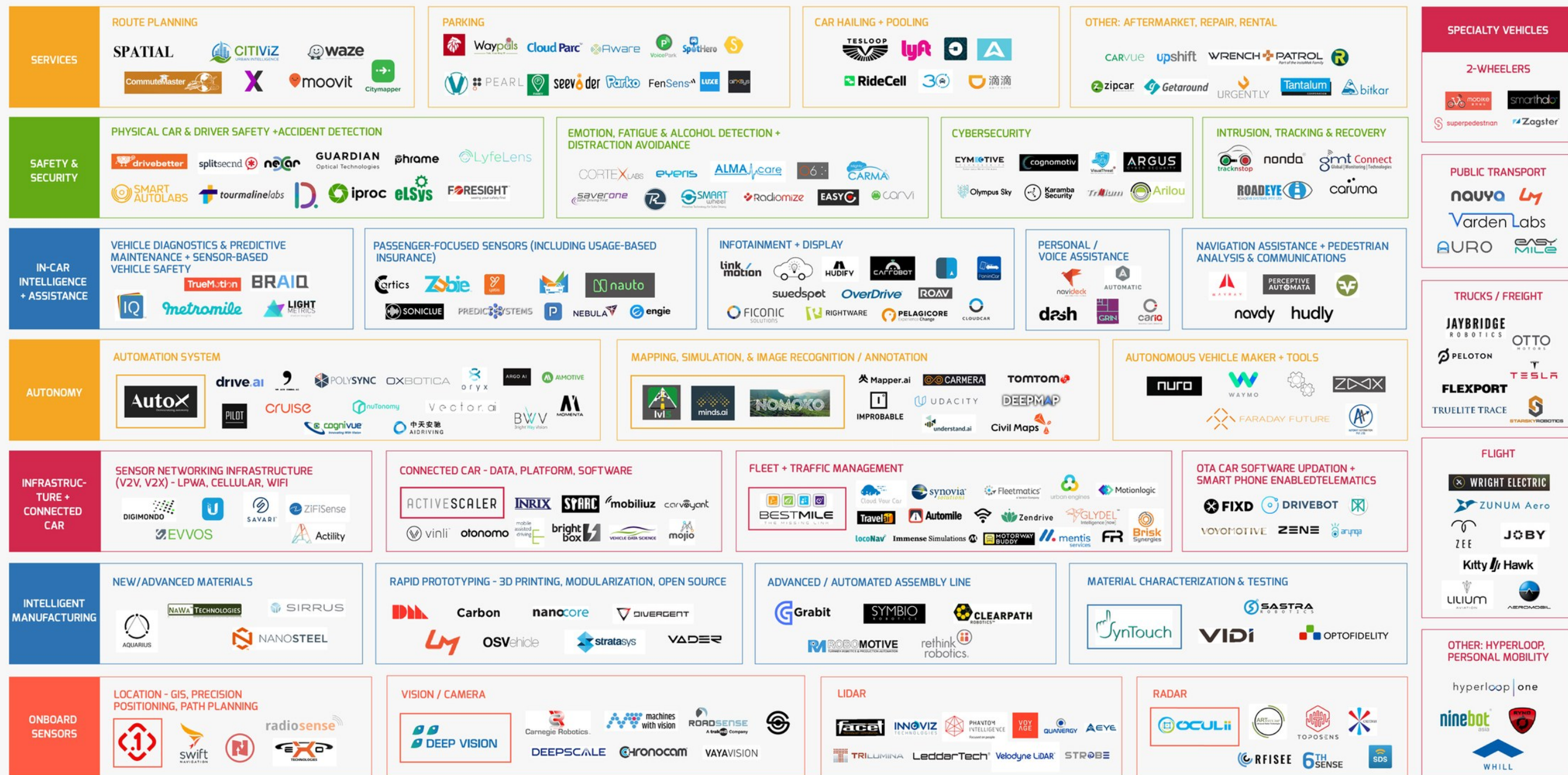
AUTONOMOUS VEHICLES IN DEVELOPMENT

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- Waymo (Alphabet, Google parent company) developing tech with vehicles from Toyota, Lexus, Chrysler, & Jaguar, as well as their own Firefly ³
- Uber partnering with Volvo and Ford ^{4,5}
- Lyft partnering with GM ⁴
- Ford plans to release fully autonomous vehicle by 2021 ⁶

WHO'S WORKING ON THEM? OVER 263 COMPANIES

THE FUTURE OF TRANSPORTATION STACK

COMET LABS



HOW DO THEY WORK?



HOW DO THEY WORK?

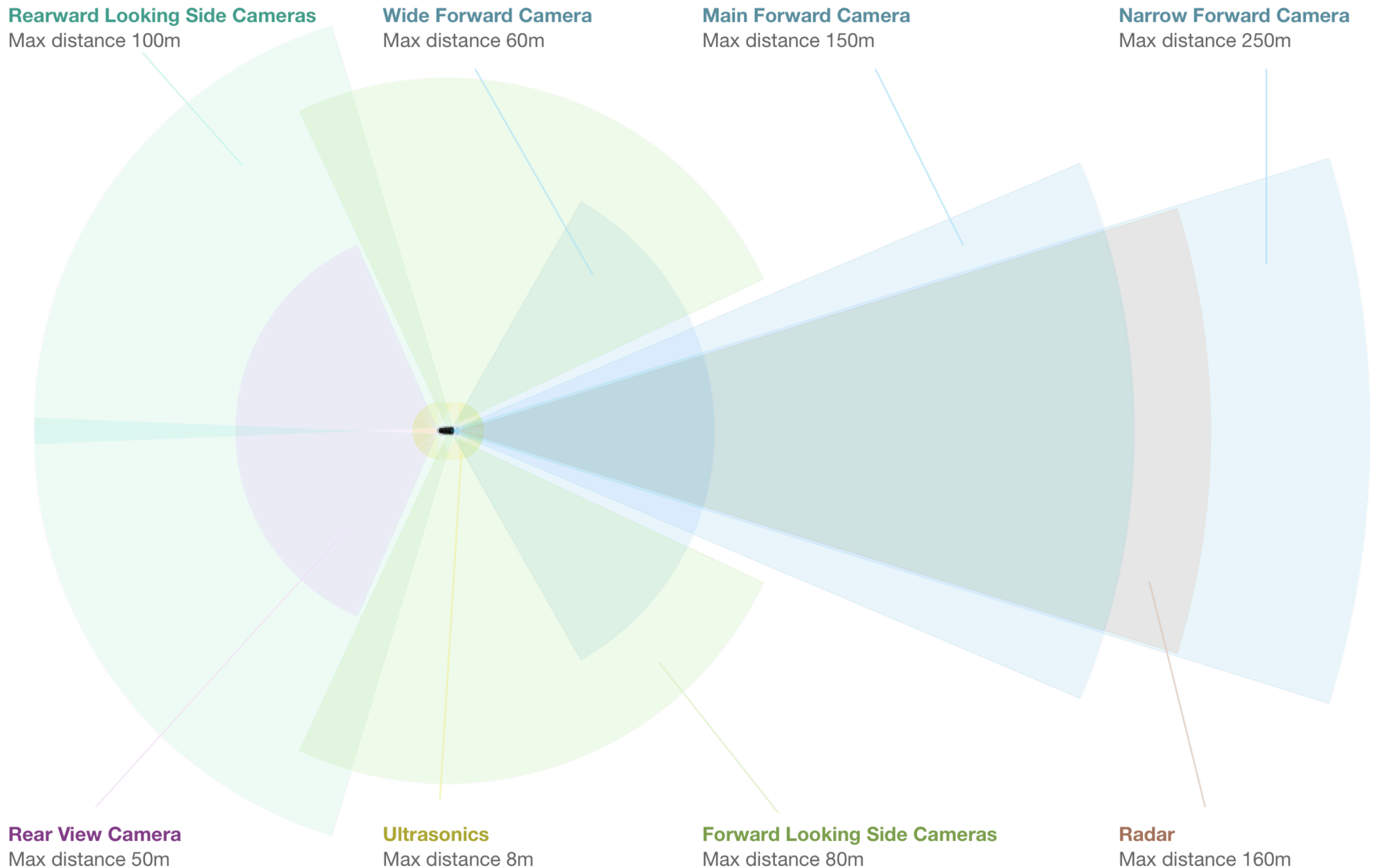
AN EXAMPLE: TESLA AUTOPILOT



Tesla Model X

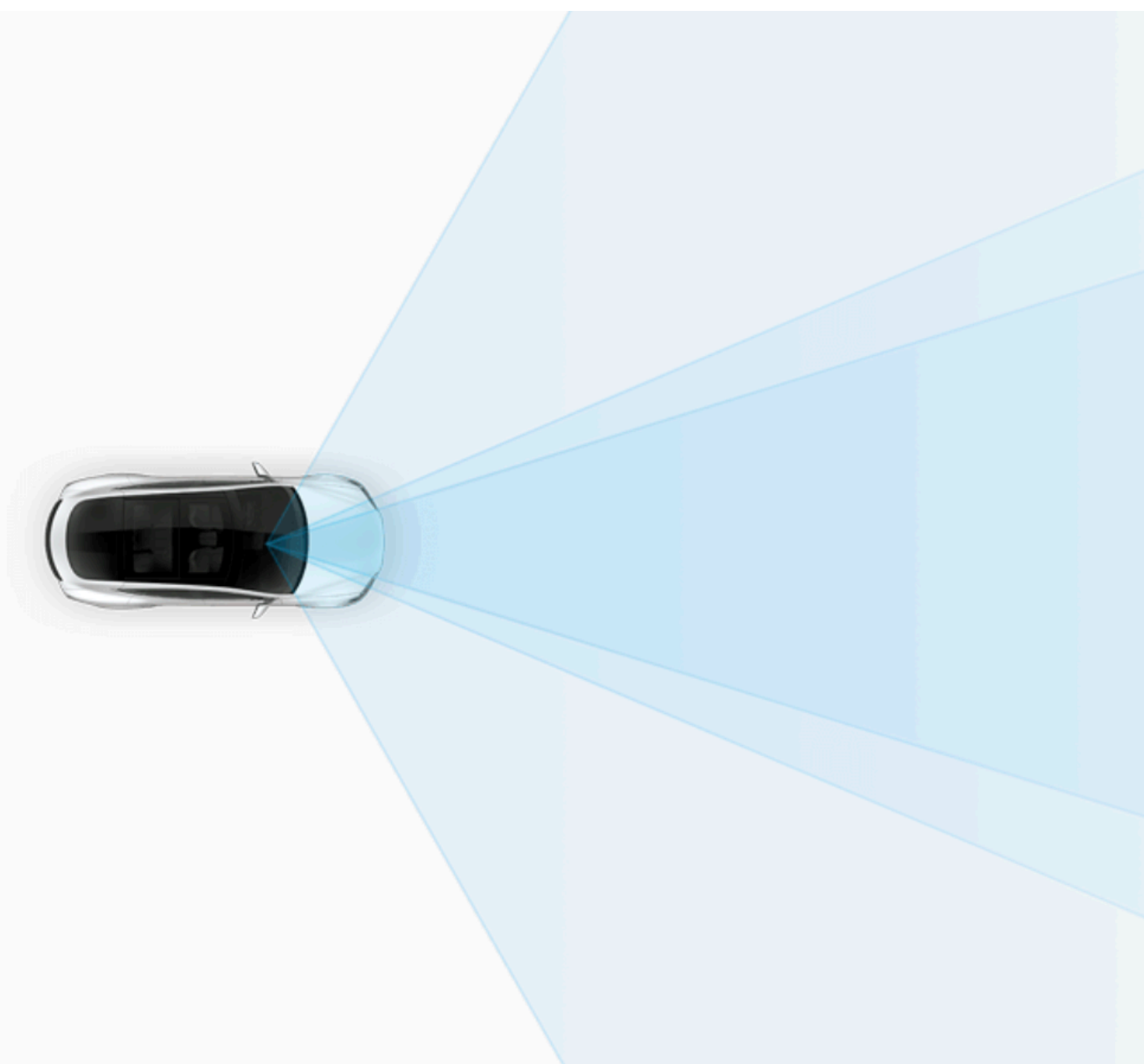
HOW DO THEY WORK?

AN EXAMPLE: TESLA AUTOPILOT



HOW DO THEY WORK?

AN EXAMPLE: TESLA AUTOPILOT



The diagram shows a top-down view of a car on the left. Three overlapping, semi-transparent blue cones extend forward from the car's windshield area, representing the fields of view of the cameras. The innermost cone is the narrowest, the middle one is wider, and the outermost one is the widest, covering a large area in front of the car.

Wide, Main and Narrow Forward Cameras

Three cameras mounted behind the windshield provide broad visibility in front of the car, and focused, long-range detection of distant objects.

Wide

120 degree fisheye lens captures traffic lights, obstacles cutting into the path of travel and objects at close range. Particularly useful in urban, low speed maneuvering.

Main

Covers a broad spectrum of use cases.

Narrow

Provides a focused, long-range view of distant features. Useful in high-speed operation.

HOW DO THEY WORK?

AN EXAMPLE: TESLA AUTOPILOT

Forward Looking Side Cameras

90 degree redundant forward looking side cameras look for cars unexpectedly entering your lane on the highway and provide additional safety when entering intersections with limited visibility.

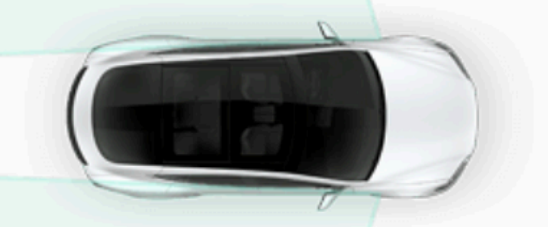


HOW DO THEY WORK?

AN EXAMPLE: TESLA AUTOPILOT

Rearward Looking Side Cameras

Cameras monitor rear blind spots on both sides of the car, important for safely changing lanes and merging into traffic.

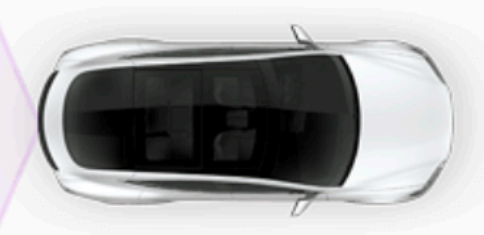


HOW DO THEY WORK?

AN EXAMPLE: TESLA AUTOPILOT

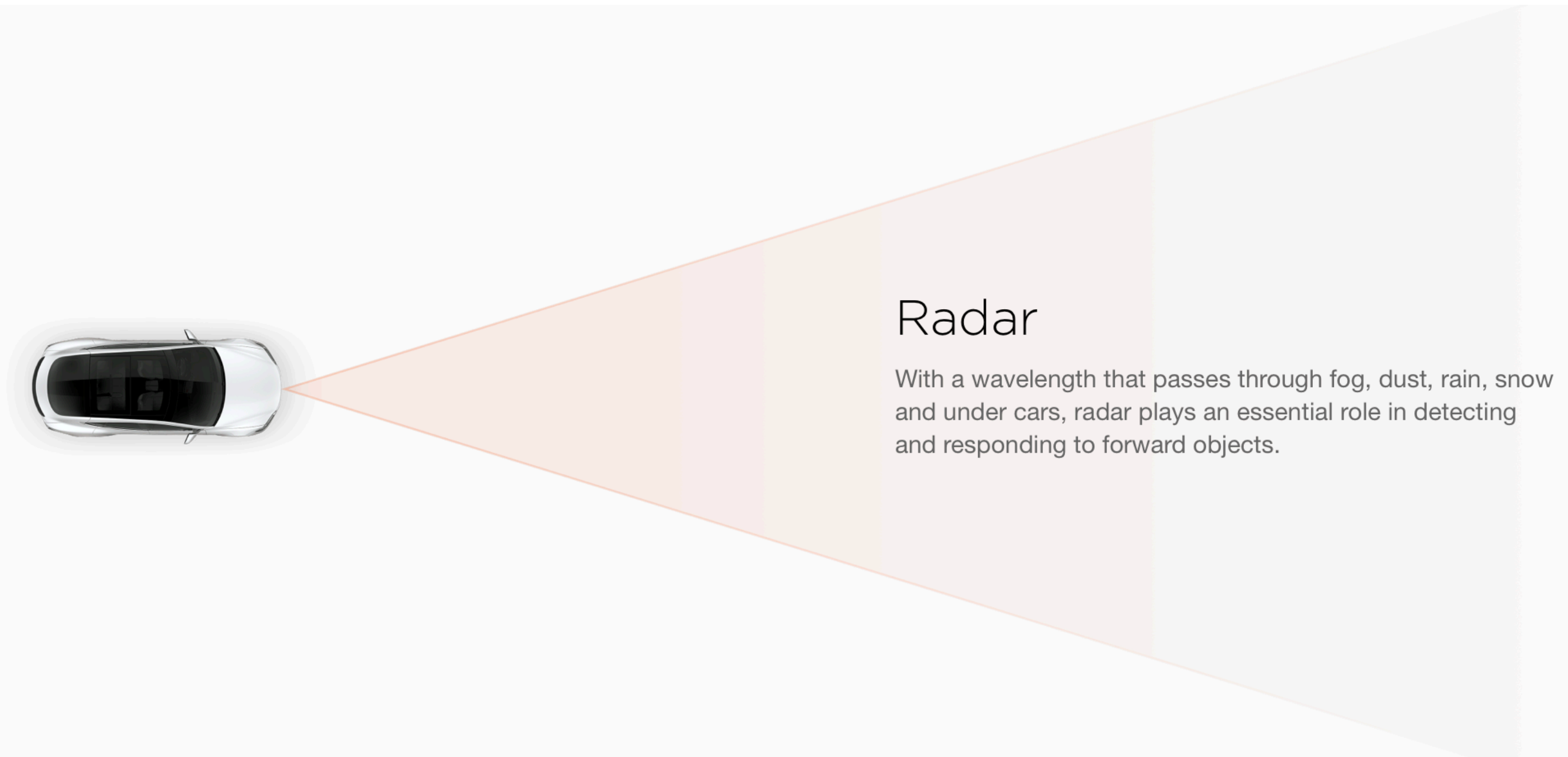
Rear View Camera

Not just for backing up safely, the rear view camera is now a contributing member of the Autopilot hardware suite with enhanced optics. The rear view camera is useful when performing complex parking maneuvers.



HOW DO THEY WORK?

AN EXAMPLE: TESLA AUTOPILOT

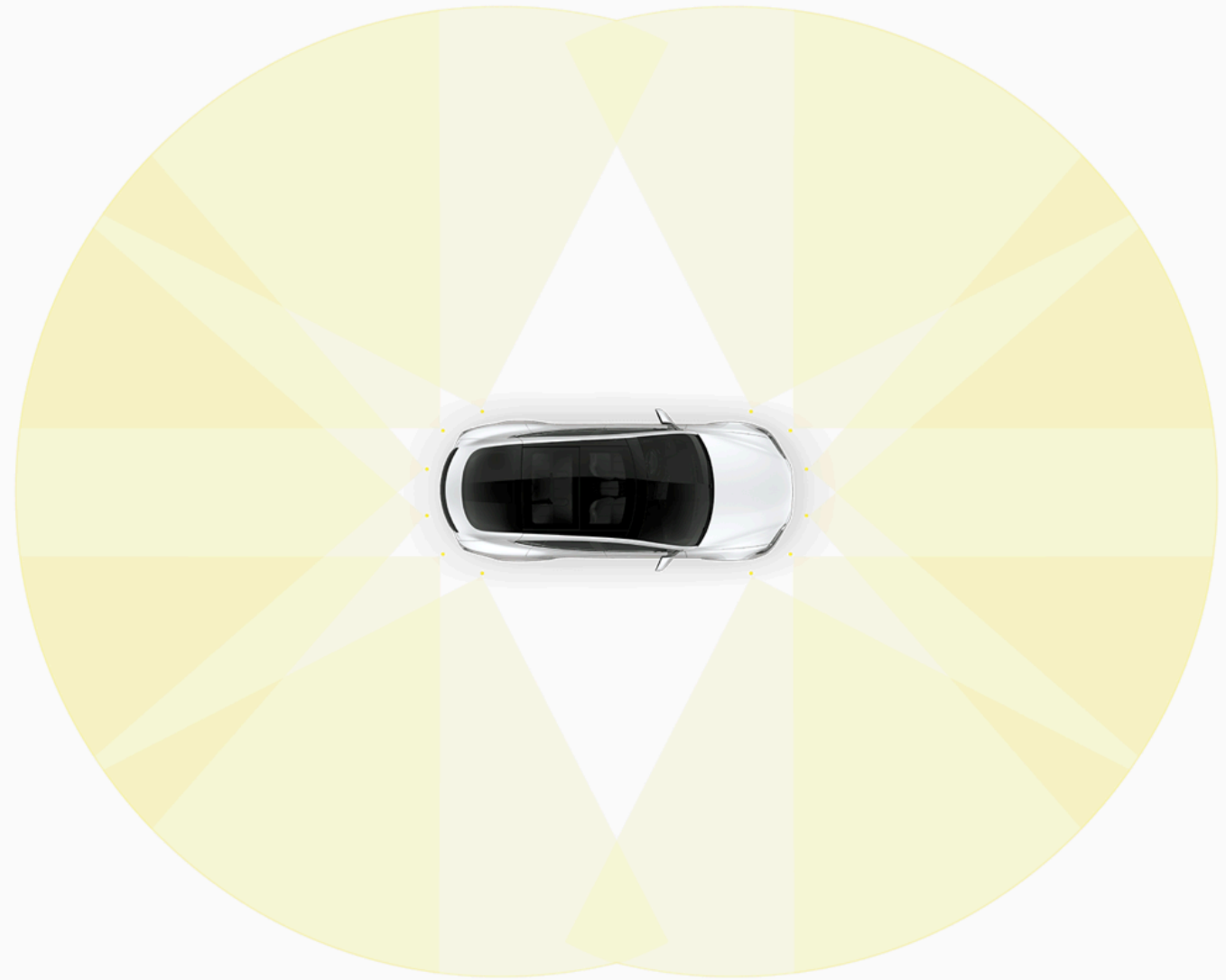


HOW DO THEY WORK?

AN EXAMPLE: TESLA AUTOPILOT

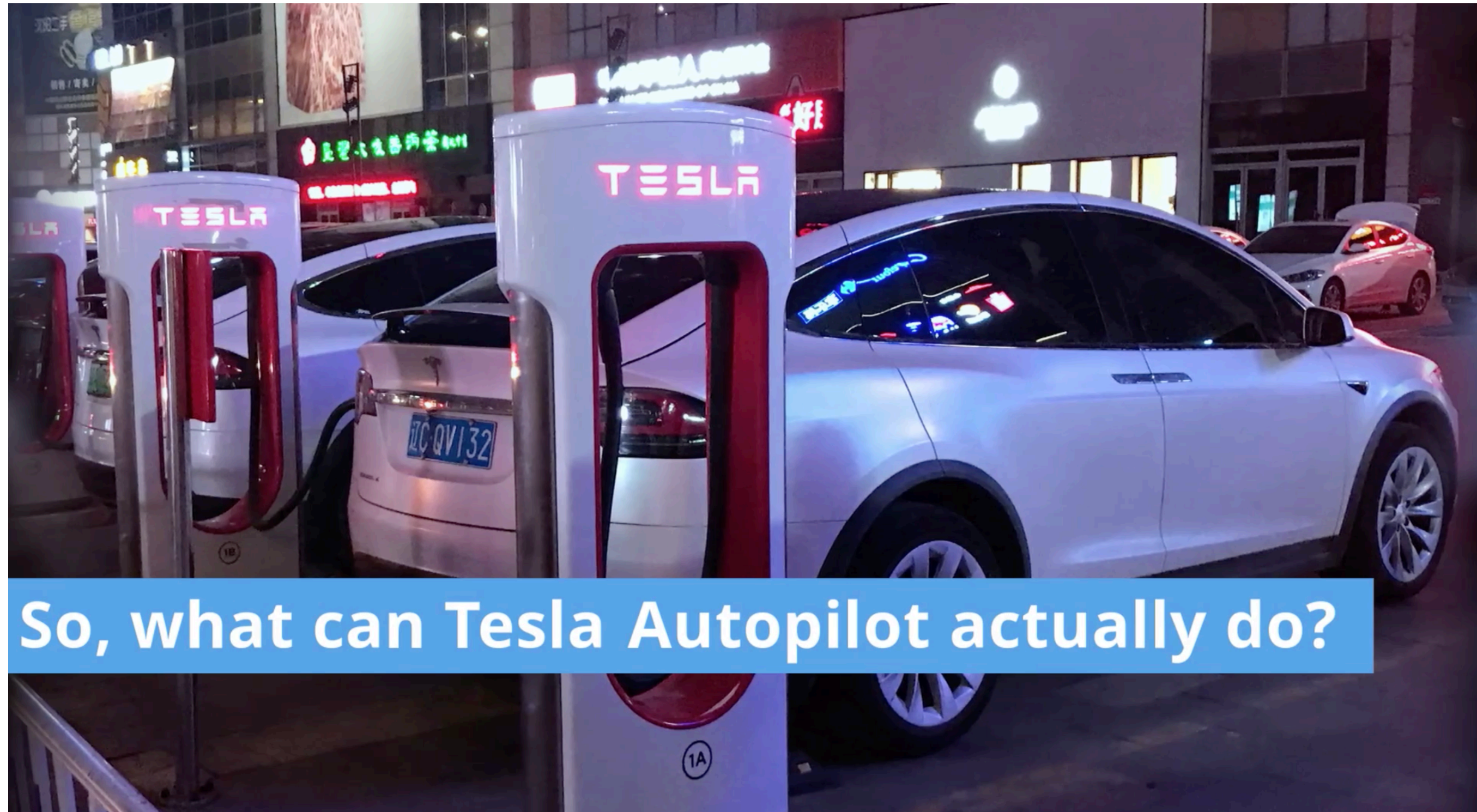
Ultrasonic Sensors

Effectively double the range with improved sensitivity using uniquely coded signals. These sensors are useful for detecting nearby cars, especially when they encroach on your lane, and provide guidance when parking.



HOW DO THEY WORK?

AN EXAMPLE: TESLA AUTOPILOT



So, what can Tesla Autopilot actually do?

HOW DO THEY WORK?

AN EXAMPLE: TESLA AUTOPILOT

➤ Features include:

- Auto-steering
- Traffic-aware cruise control
- Speed assist
- Blind spot detection
- Side collision warning
- Automatic emergency breaking and steering
- Automatic lane change
- Auto-park
- Summon

➤ Safety features (lane-departure warning, side collision warning, and emergency breaking) included

➤ Autopilot convenience features for extra charge

THE FIRST CROSS-COUNTRY AUTONOMOUS RIDE



In 2015, an Audi SQ5 AV developed by Delphi completed a 9 day cross-country ride from the Golden Gate Bridge in SF to Midtown Manhattan, driving autonomously 99% of the time

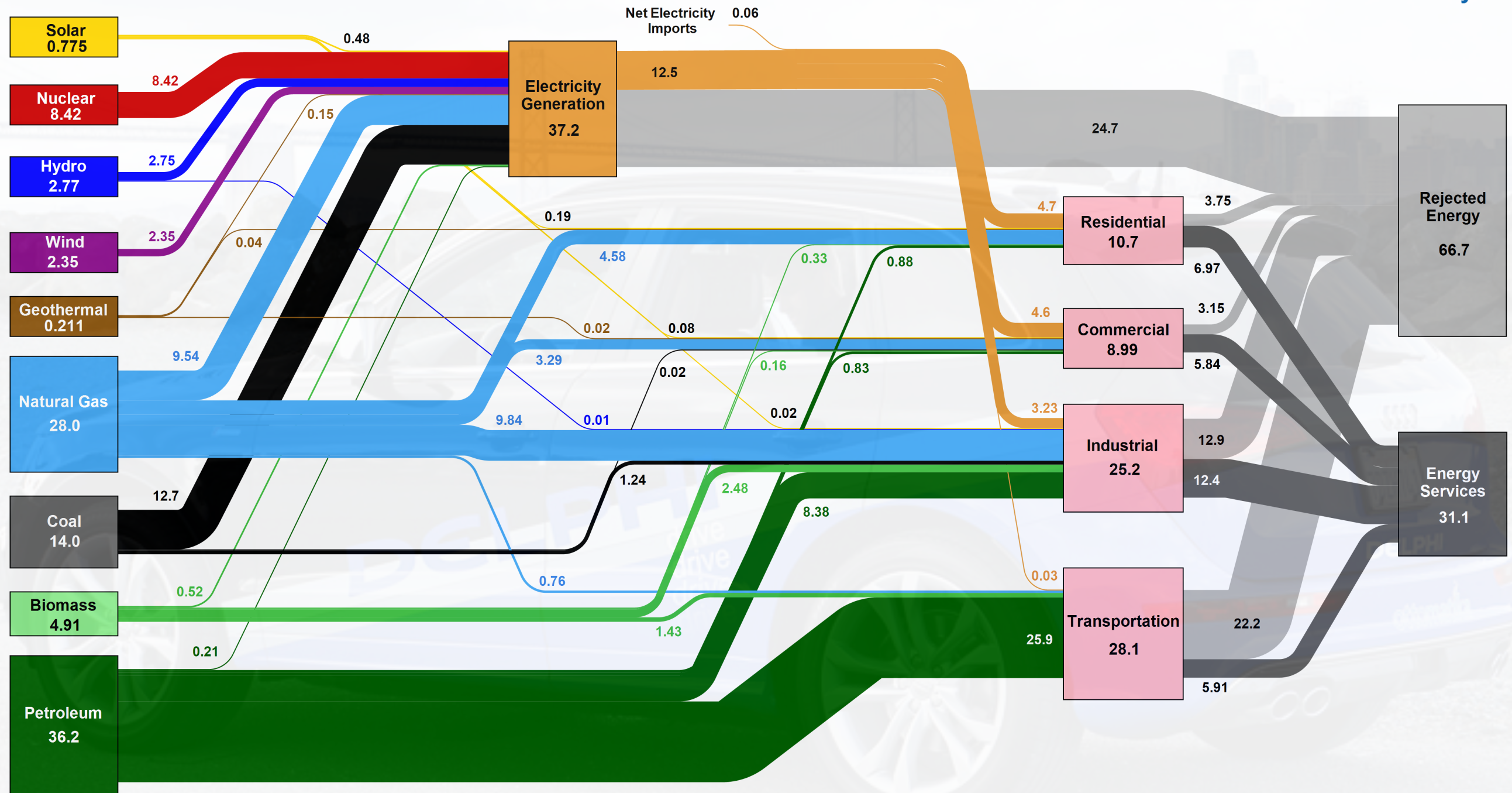
Sources: [ExtremeTech](#), [Tech Republic](#), [NBC](#)

AUTONOMOUS VEHICLES AND ENERGY USE



THE TRANSPORTATION SECTOR ACCOUNTED FOR 29% OF U.S. ENERGY CONSUMPTION IN 2017 AND 92% IS PETROLEUM-BASED

Estimated U.S. Energy Consumption in 2017: 97.7 Quads



Source: LLNL April, 2018. Data is based on DOE/EIA MER (2017). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

RIDE-SHARING

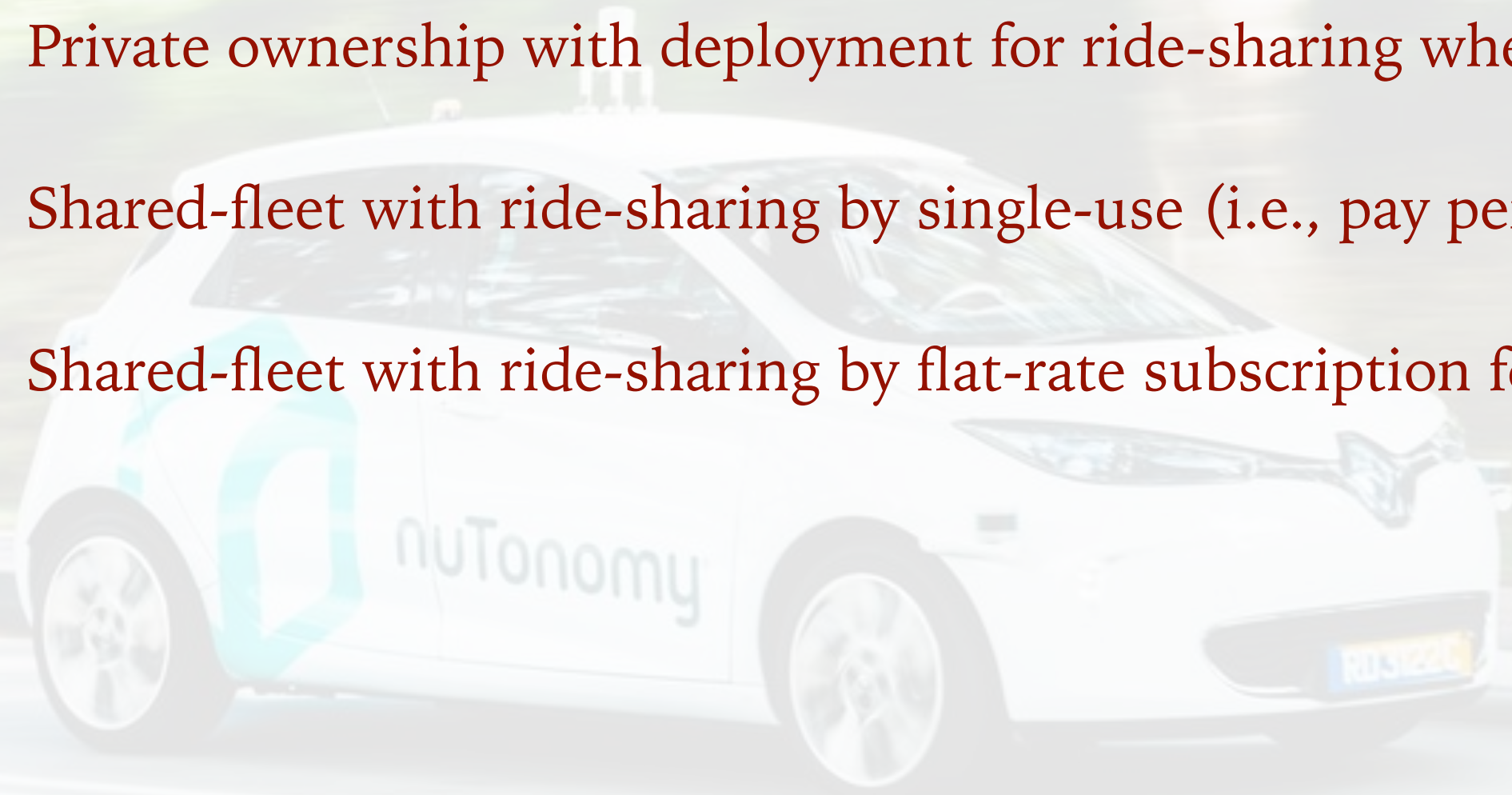
Increased carpooling could decrease energy use in transportation



HOW MIGHT AV TECHNOLOGY PROMOTE RIDE-SHARING?

With AVs, a number of ride-sharing capabilities are possible:

- Private ownership with deployment for ride-sharing when not in use ^{1,2}
- Shared-fleet with ride-sharing by single-use (i.e., pay per ride or per mile) ²
- Shared-fleet with ride-sharing by flat-rate subscription for unlimited use ²

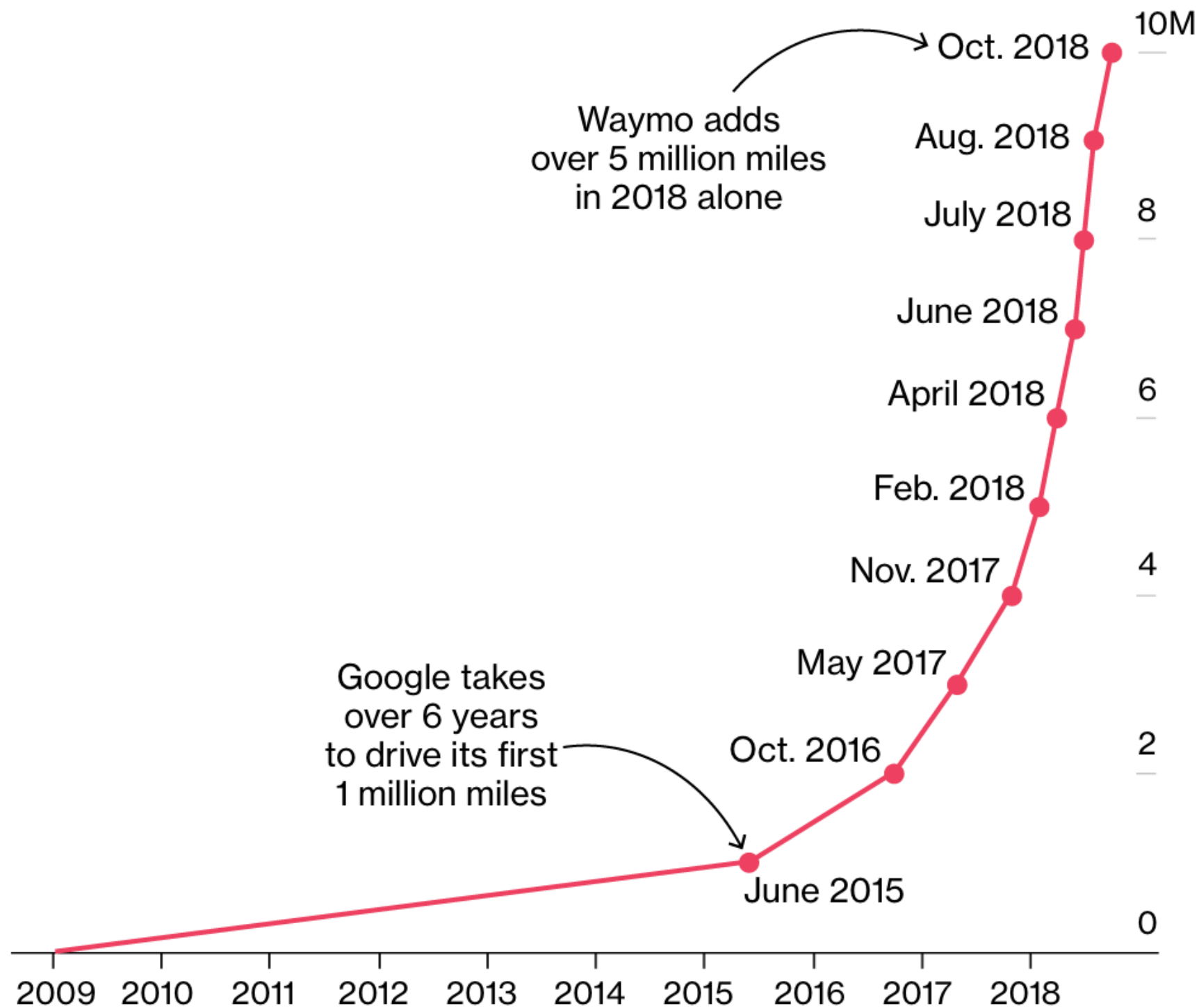


PROGRESS IN AUTONOMOUS VEHICLE RIDE-SHARING

- Uber rolling out self-driving Volvos and Fords in Pittsburgh ^{1,2}
- Lyft testing autonomous vehicles with GM ¹
- NuTonomy (MIT spinoff) released self-driving taxis in Singapore ^{2,3}
- Waymo to launch first driverless car service in Phoenix in December
(initially with backup drivers in the car) ⁴

Driverless Cars Prepare to Launch

Waymo racks up autonomous miles by the millions



Source: Waymo

Note: Alphabet Inc. removed the Google branding from its cars and created the Waymo subsidiary in December 2016.

SAFETY IMPROVEMENTS

*Safety improvements could lead to lighter vehicles,
decreasing energy use*

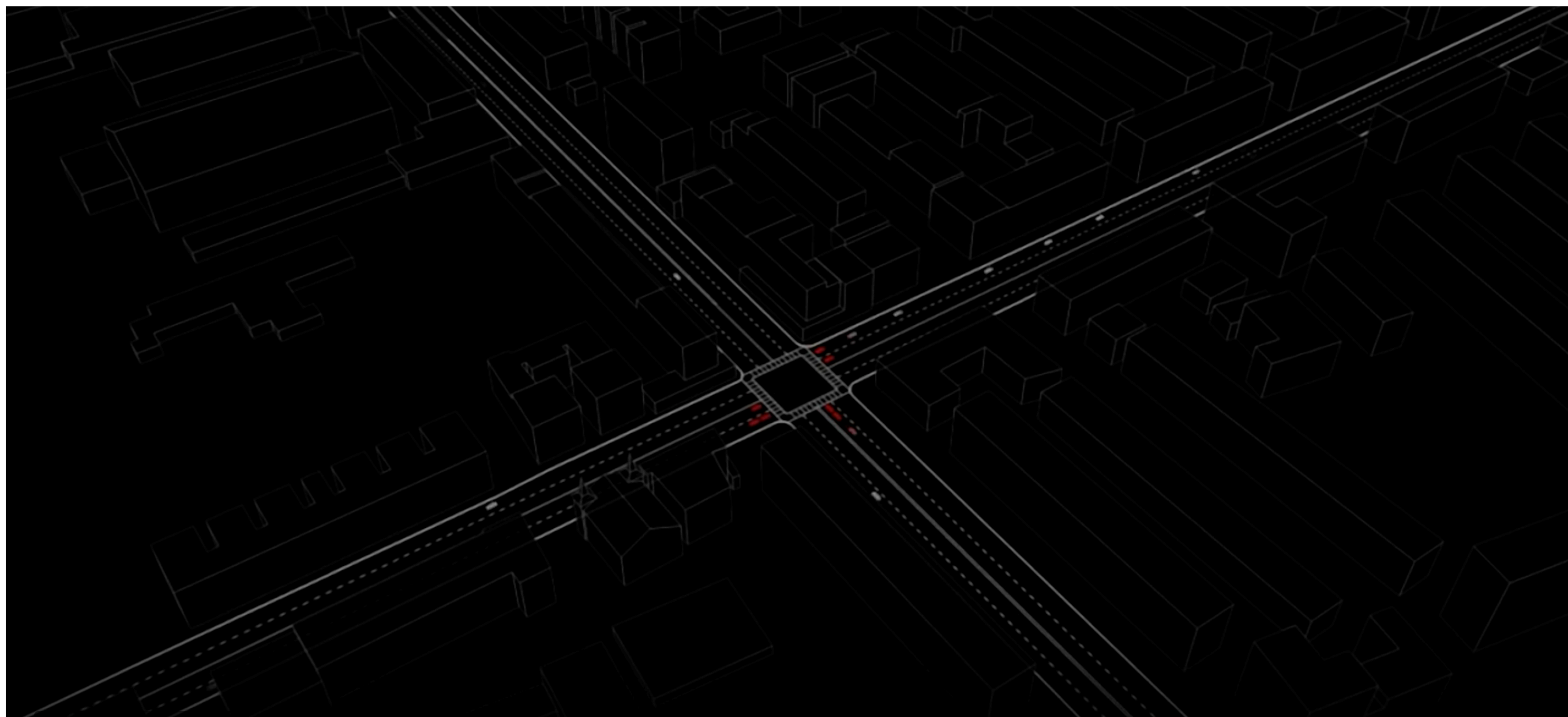


SAFETY IMPROVEMENTS

- According to several reports, humans responsible for 90-94% of crashes ¹⁻⁹
- One report predicts 80% fewer crashes by 2040 ³
- Vehicle-to-vehicle communication could also reduce crashes by 79%
according to the National Highway Traffic Safety Administration (NHTSA) ⁸

Sources: ¹[NHTSA](#), ²[NHTSA](#), ³[KPMG](#), ⁴[Stanford Law](#), ⁵[Tech Republic](#), ⁶[Tech Republic](#), ⁷[Waymo](#), ⁸[YaleE360](#), ⁹[Quartz](#)

SAFETY IMPROVEMENTS: VEHICLE-TO-VEHICLE (V2V) & VEHICLE-TO-INFRASTRUCTURE (V2I)



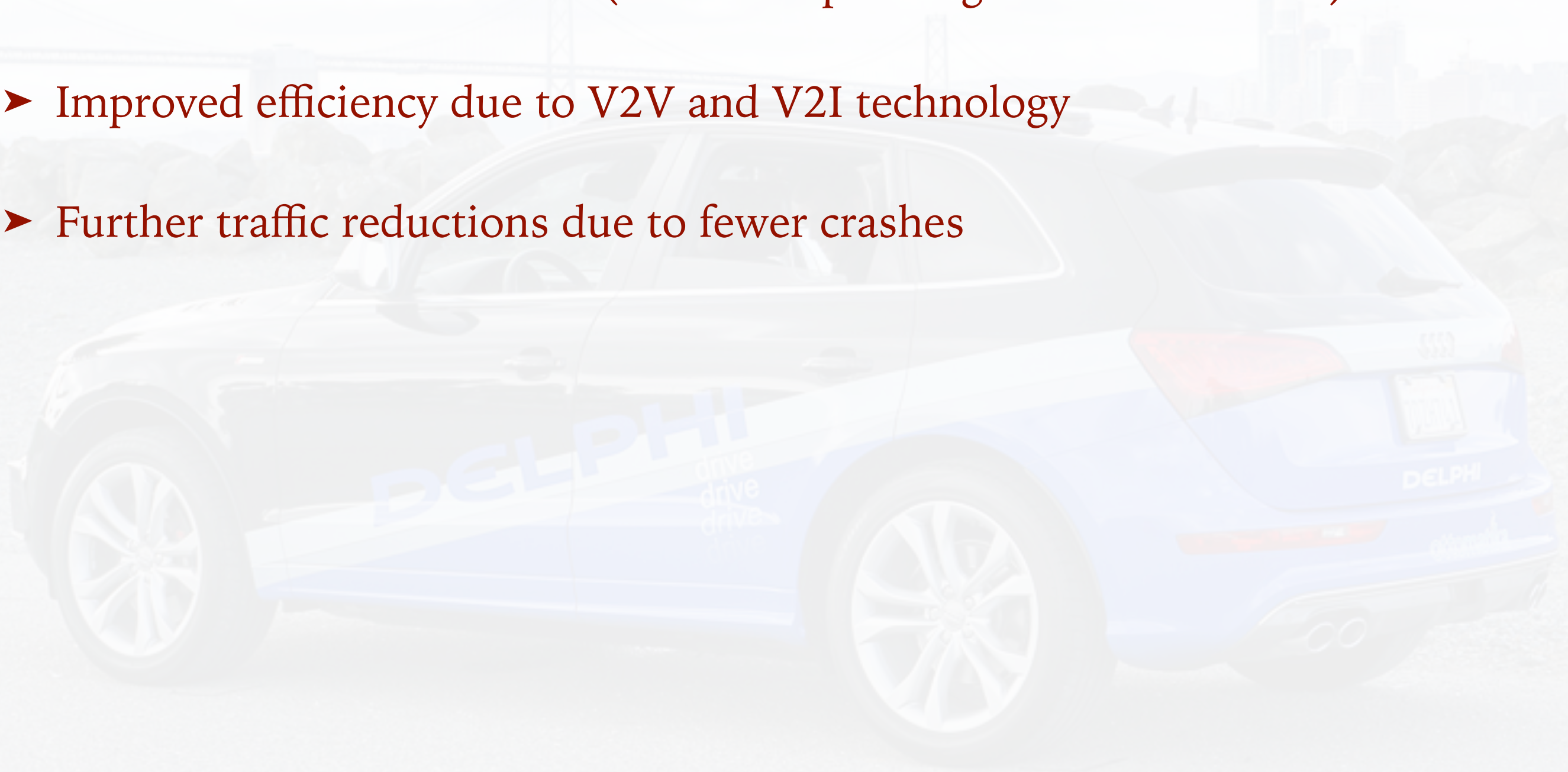
DRIVING EFFICIENCY

Improved driving efficiency could also decrease energy use



IMPROVED DRIVING EFFICIENCY

- More efficient travel routes (and corresponding traffic reductions)
- Improved efficiency due to V2V and V2I technology
- Further traffic reductions due to fewer crashes



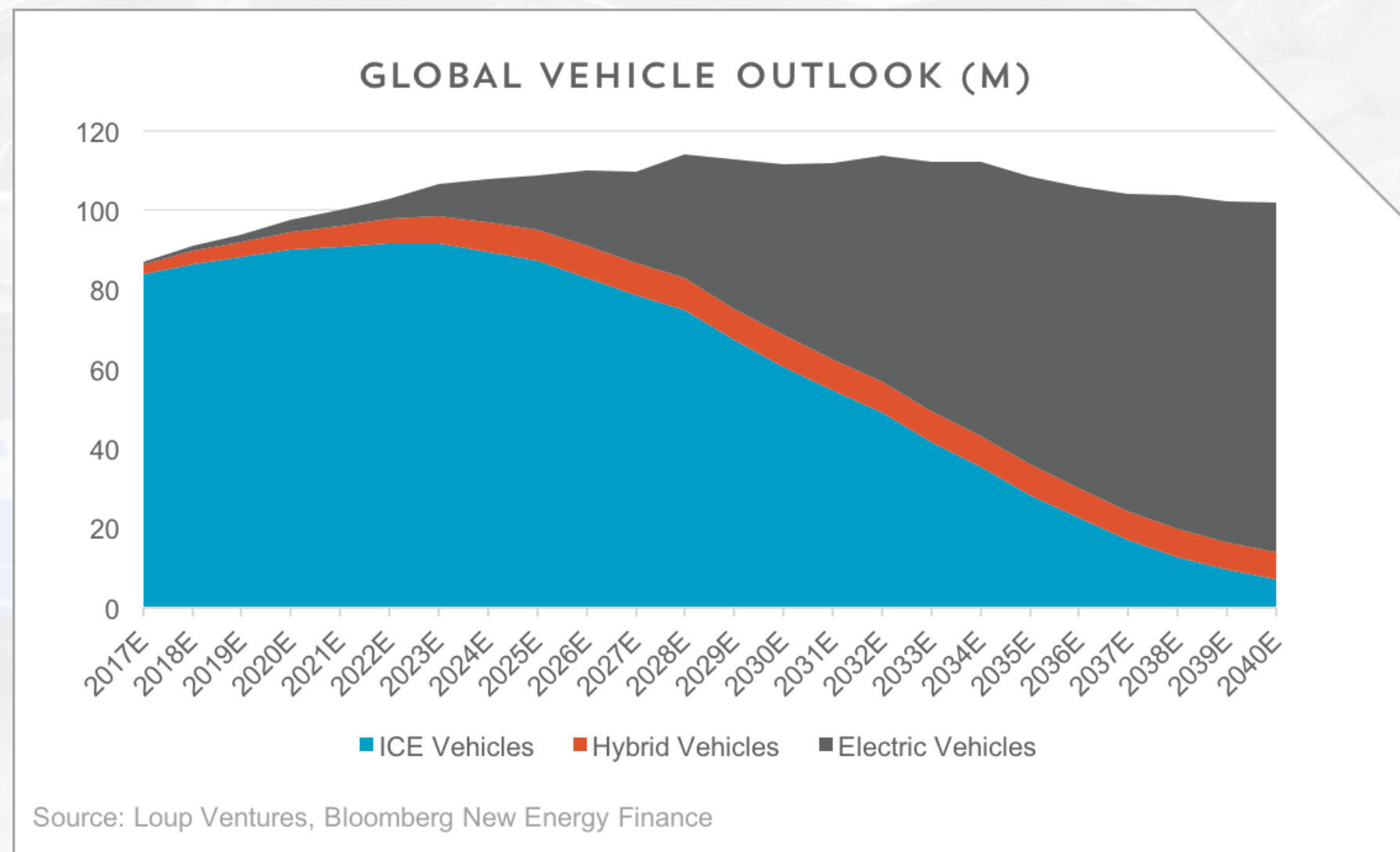
ELECTRIFICATION

*Electrification of AVs could improve energy efficiency
and reduce emissions*



ELECTRIFICATION

- Electrification of AVs could result in improved energy efficiency
- Electrification could further reduce emissions with increased penetration of renewables on the grid



REBOUND EFFECTS

Rebound effects, however, could lead to increases in energy use



REBOUND EFFECTS

- Increased cost-effectiveness of driving using AVs for mobility as a service (vs. car ownership by individuals or families) could increase utilization
- Moreover, even vehicles privately owned by individuals and families could be deployed when not needed, further increasing utilization
- Increased driving access for the elderly and disabled (49 million Americans over 65, 53 million with some form of disability) ¹
- Increased utilization could, in turn, lead to increases in traffic, contributing to decreases in energy efficiency

ADDITIONAL CHALLENGES



ADDITIONAL CHALLENGES

- Object identification and machine learning challenges (e.g., snow, altered stop signs, exiting vehicles, hills, bridges, tree shadows, seagulls) ¹
- False positives and false negatives ²
- Hacking and cybersecurity ³⁻⁵ (Waymo to avoid Internet for now ⁴)
- V2V communication with different developers
- Land use questions ⁶ (e.g., overnight parking, suburbanization)
- Regulatory challenges
- Ethical challenges ⁷

Sources: ¹[Quartz](#), ²[Wired](#), ³[NHTSA](#), ⁴[MIT Technology Review](#), ⁵[SHFFT](#), ⁶[SHFFT](#), ⁷ [The Economist](#)

CONCLUSIONS

- Autonomous vehicles, under rapid and widespread development, will soon become ubiquitous
- AVs will likely lead to significant reductions in energy use and emissions in the transportation sector due to ride-sharing, weight reductions due to safety improvements, driving efficiency improvements, and electrification
- Rebound effects, however, may also arise due to increased utilization

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