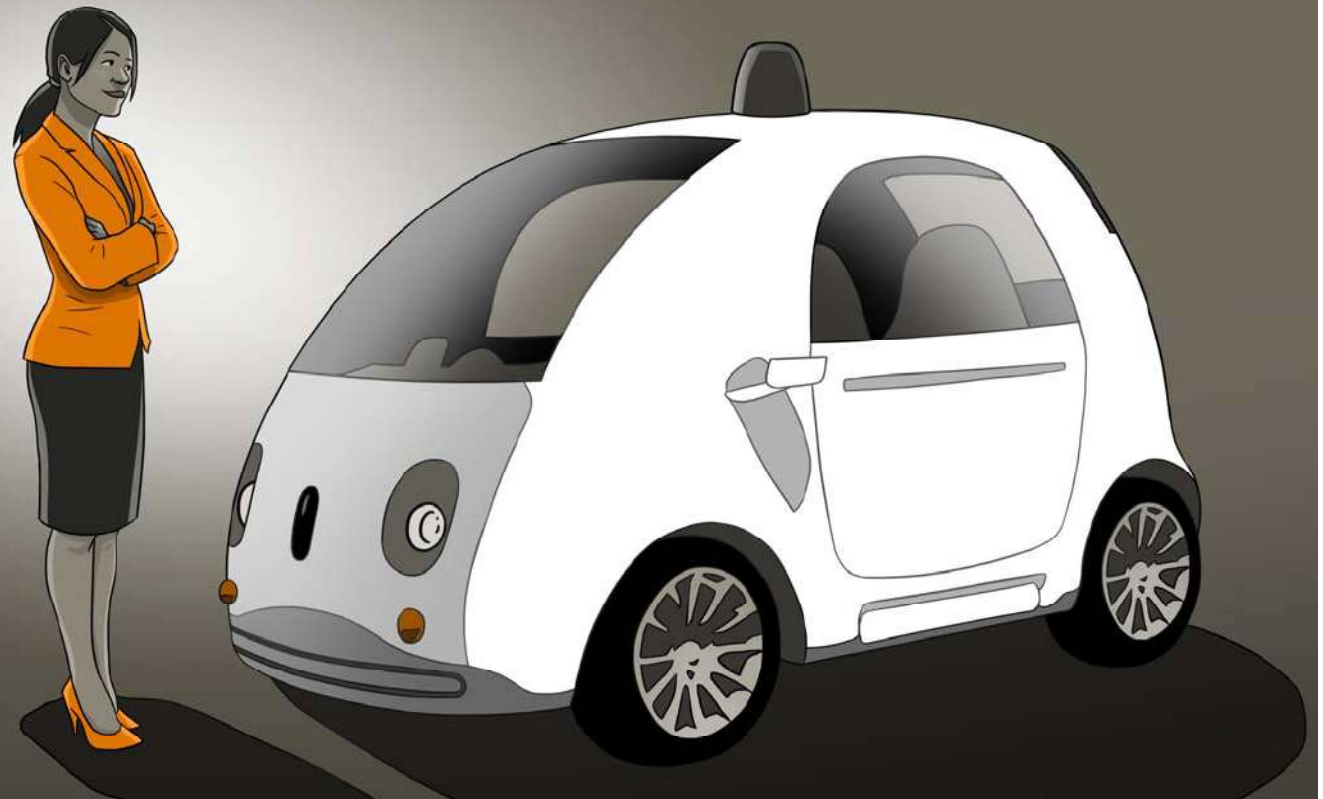


Shared Autonomous Vehicles and the Future of Transit

Denver City
Council

Land Use,
Transportation
& Infrastructure
Committee

April 18,
2017

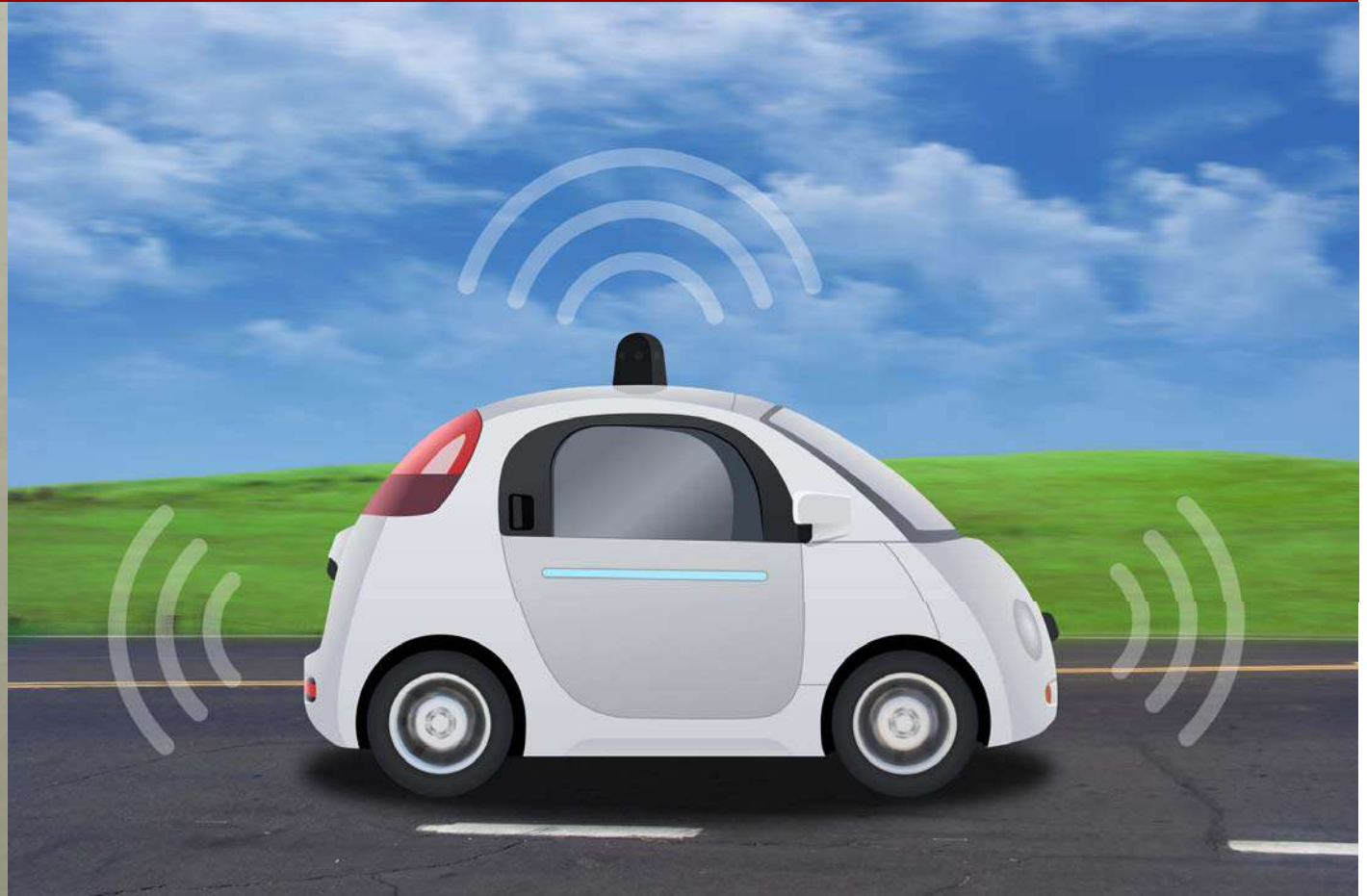


The intersection of disruptive technologies

Disruptive technology:

- Autonomous robotics
- LiDAR+radar+camera
- Supercomputers
- Battery density/cost
- Material sciences
- 3D printing
- AI-Deep Learning
- Dispatch-analytics
- The sharing economy

Source: iStock.com,
©MartialRed



Navigation uses LiDAR, radar, cameras and maps

LiDAR
images
people, cars,
trucks, pets,
bikes,
hazards



*Source: Universal
Design Style*

Quanergy's new solid state LiDAR, \$250

3.5" x 2.4" x 2.4"

Four of these
small devices
(\$1000) can
replace the
original Google
Car's \$75,000
LiDAR

Source: [IEEE Spectrum](#),
photo by Evan Ackerman



Early driverless computer hardware

The first autonomous vehicles were loaded with computers, sensors, recording and monitoring devices, plus a rat's nest of interconnecting wires



Compute power of a room full of 2001 mainframes



Nvidia/ZF Pro AI : 10 watts
Computation = 150 MacBook Pros
Integrates LiDAR, Radar, Cameras



Nvidia Drive PX 2: 250 watts
8 TFLOPS, 24 DL TOPS supercomputer
Integrates LiDAR, Radar, Cameras

Sources: [ZF/TechStunt](#), [Electrek Review](#)

Battery cost: Tesla/Panasonic Gigafactory

Batteries: largest single cost for EVs

2010 battery cost: \$700 per kW-hour; now \$145, by 2021, \$100

By 2018, annual production should equal 2016's global LiO_2 production.



Source: [Bloomberg Tech](#)

Material sciences: Carbon plastic fiber frame

BMW i3



Source: The Economist

Manufacturing disruption: 3D printing

*Local Motors
Driverless Bus:*

Test rides now in
Washington DC

Pilot projects:
Berlin, Miami,
and Las Vegas

Source: [TechCrunch](#)



The intersection of disruptive technologies

Disruptive technology:

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Source: *iStock.com*,
©*MartialRed*



How a driverless car sees the road



TED

CHRISURMSON

Source: [TED.com](https://www.ted.com)



Handling various common traffic issues

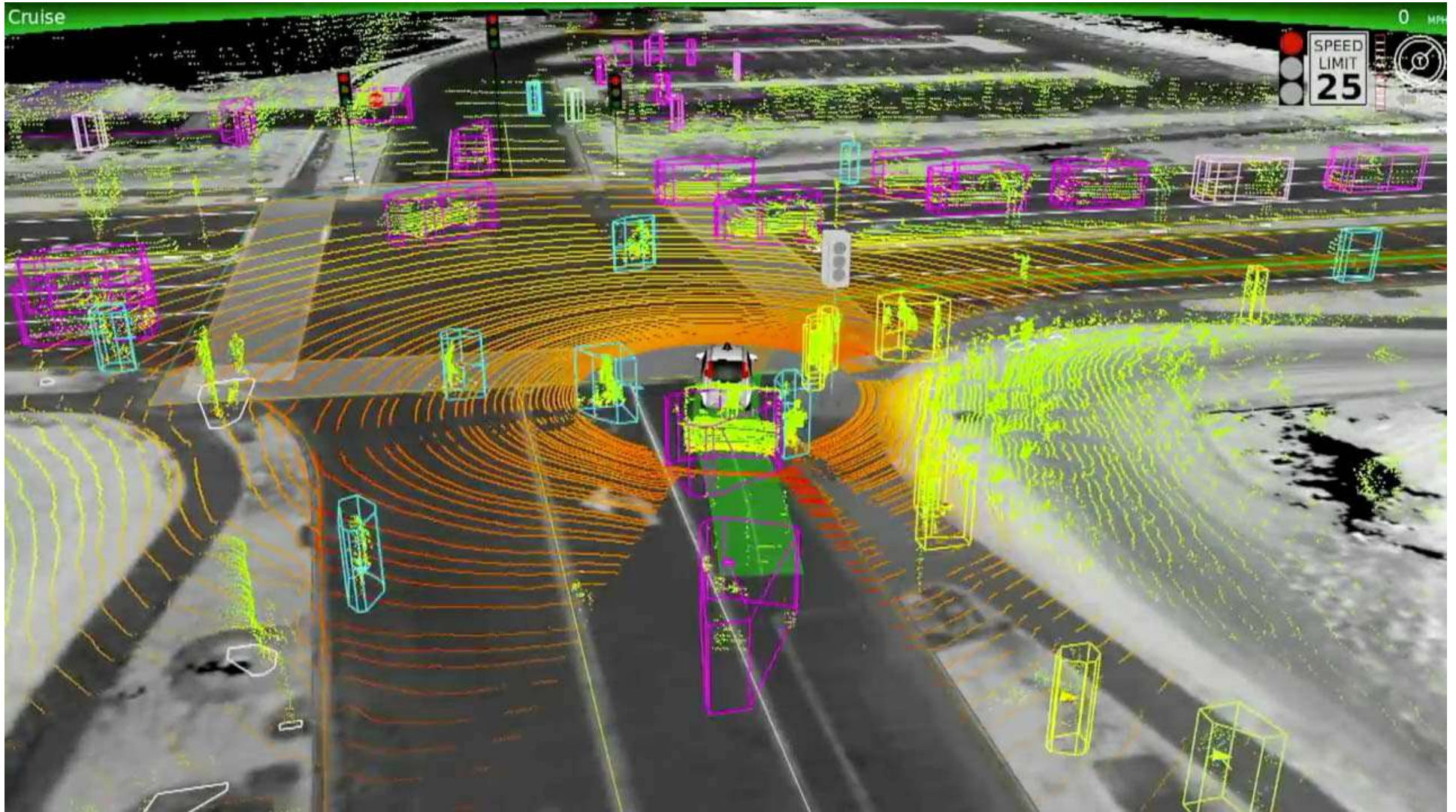


TED

CHRISURMSON

Source: [TED.com](https://www.ted.com)

Cruise



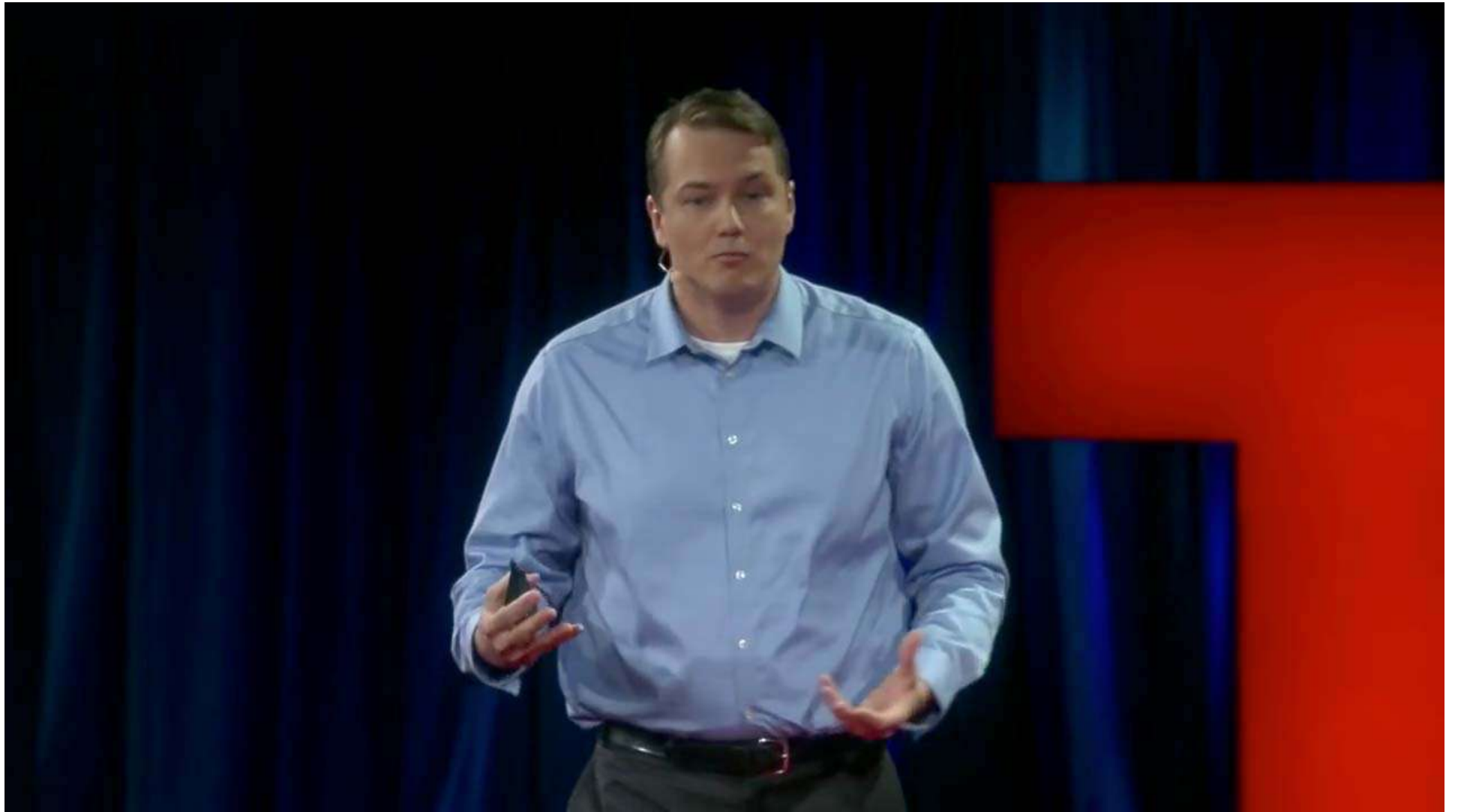
Handling the rare and unusual!



TED

CHRISURMSON

Source: [TED.com](https://www.ted.com)



When?

2025 Driverless Car?



Source: iStock.com, ©Chesky_W

Here is that car!

Mercedes-Benz

Das Beste oder nichts.

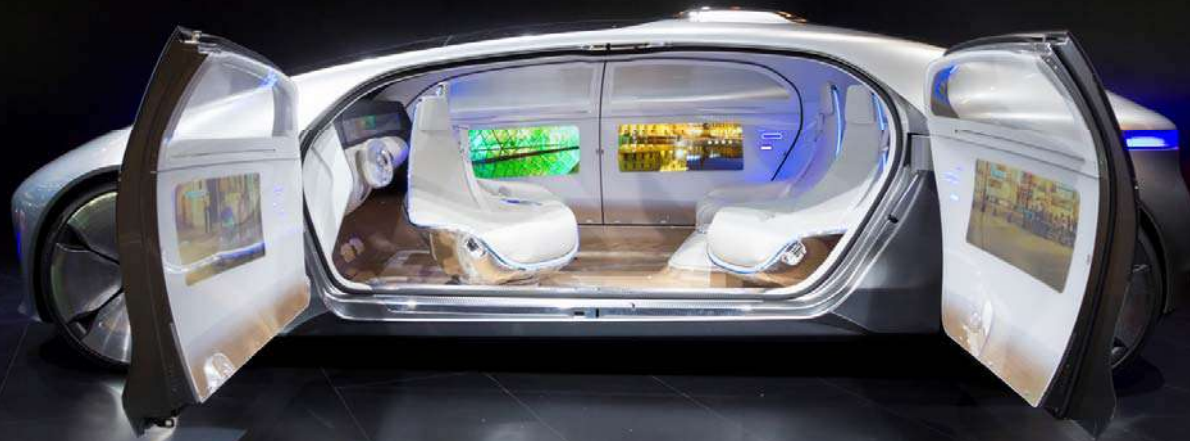
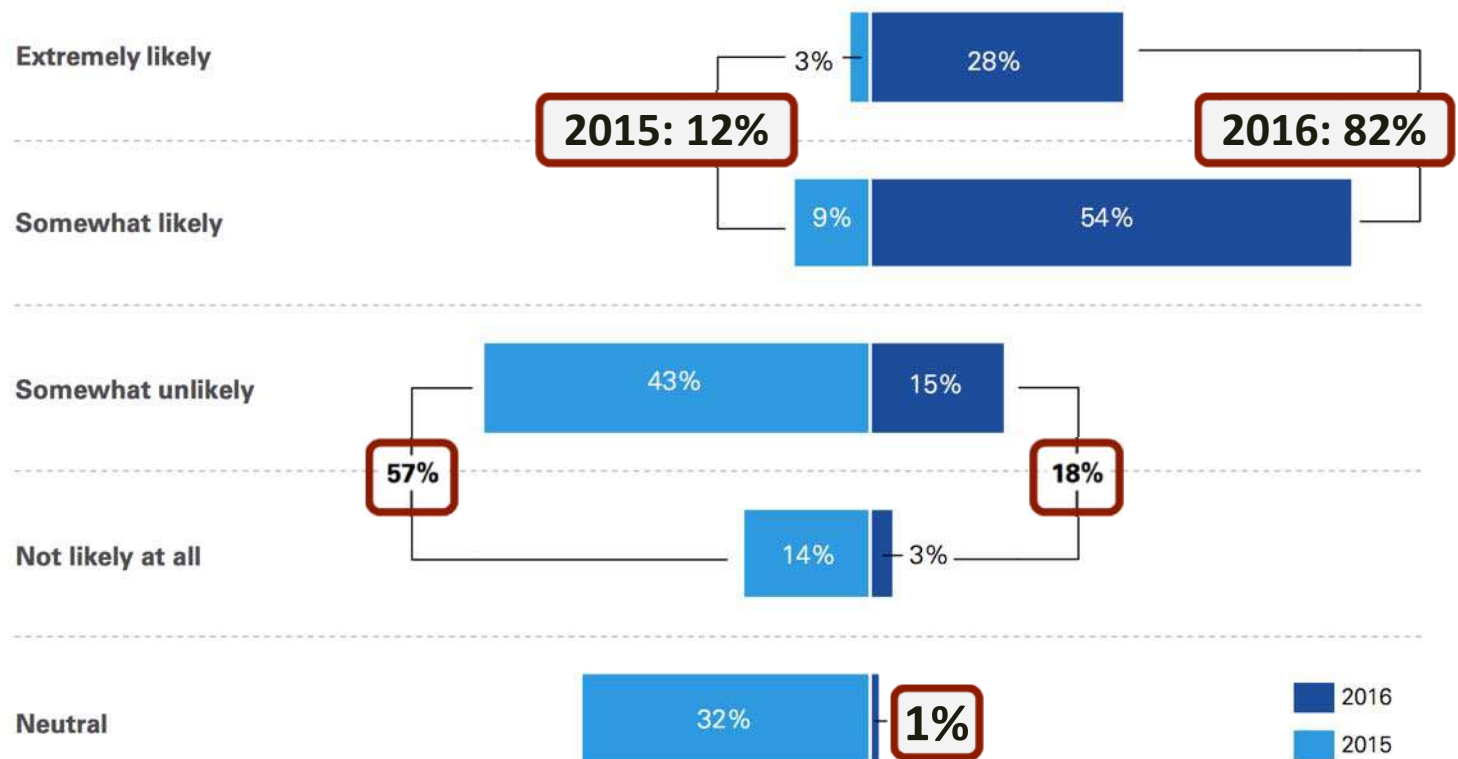


Photo:
iStock.com
©VanderWolf

KPMG Global Survey, 800 auto executives

How likely is a major business model disruption in the next five years?



Note: Percentages may not add up to 100% due to rounding
Source: KPMG's Global Automotive Executive Survey 2016

Automakers: Vehicle sales or mobility services?

- Ford:
 - CEO: “Become a mobility company, not just an automaker”
 - \$4.5 billion investment in electrified vehicle solutions
 - Ford Smart Mobility LLC: Car sharing & mobility services
 - \$1 billion committed to Argo AI startup (driverless software)
- GM:
 - \$581 million acquisition of Cruise Automation
 - \$500 million to buy 10% of Lyft
 - Thousands of GM/Lyft Bolt AV’s by 2018
 - R&D hires: CA 1100, Canada 1000

First commercial driverless availability?

nuTonomy: Aug. 2016

Uber: Aug. 2016

Google: 2017

Tesla: 2018

GM-Lyft: 2018

Ford: 2018-2021

VW/Audi: 2020

Baidu: 2018-2020

*Mobility as a Service:
Think very cheap Uber*

Driverless mobility's value proposition

- Safe, efficient, door-to-door transportation
- A quarter to an eighth the cost of owning a car
- Faster commutes, less congestion, less pollution
- No parking or vehicle ownership hassles
- Low-stress service while you work, read, relax

Say hello to Waymo



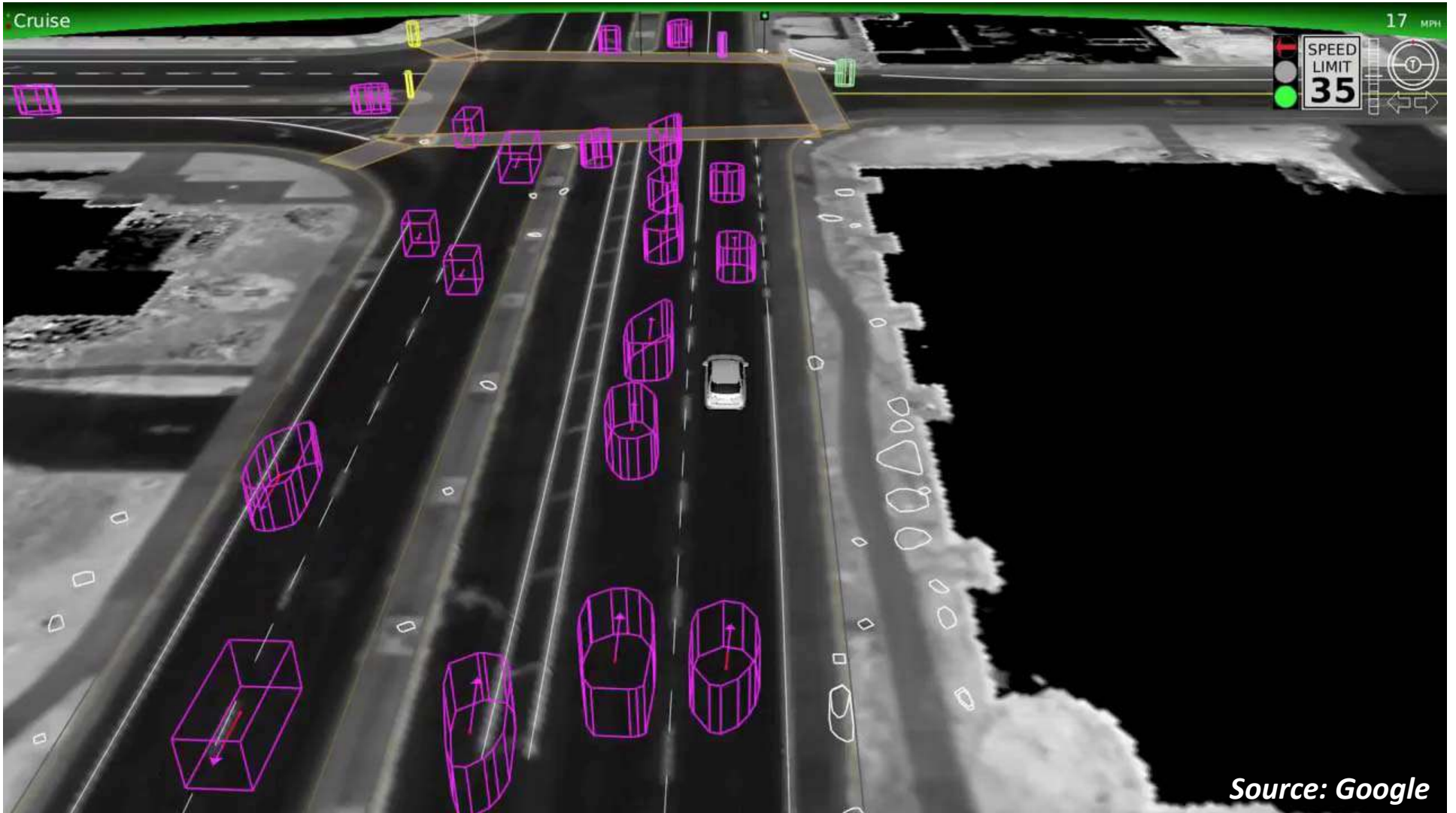
Source: [Waymo](https://www.waymo.com/)

Safety

2015: 35,092 fatalities / 4.4 million injuries

- Imagine 250 Boeing 737 crashes every year w/ no survivors
- More deaths in 21st century than all U.S. wars since 1900
- 94% of crashes are due to distraction, drowsiness, drunkenness, or driver error
- McKinsey & Company: Driverless cars can reduce crashes by 90%

Sources: NHTSA, National Safety Council, Wikipedia



Source: Google

The newest danger on our roads...

2015 fatalities
were up 7.2%
over 2014

First half 2016
fatalities are up
another 10.4%

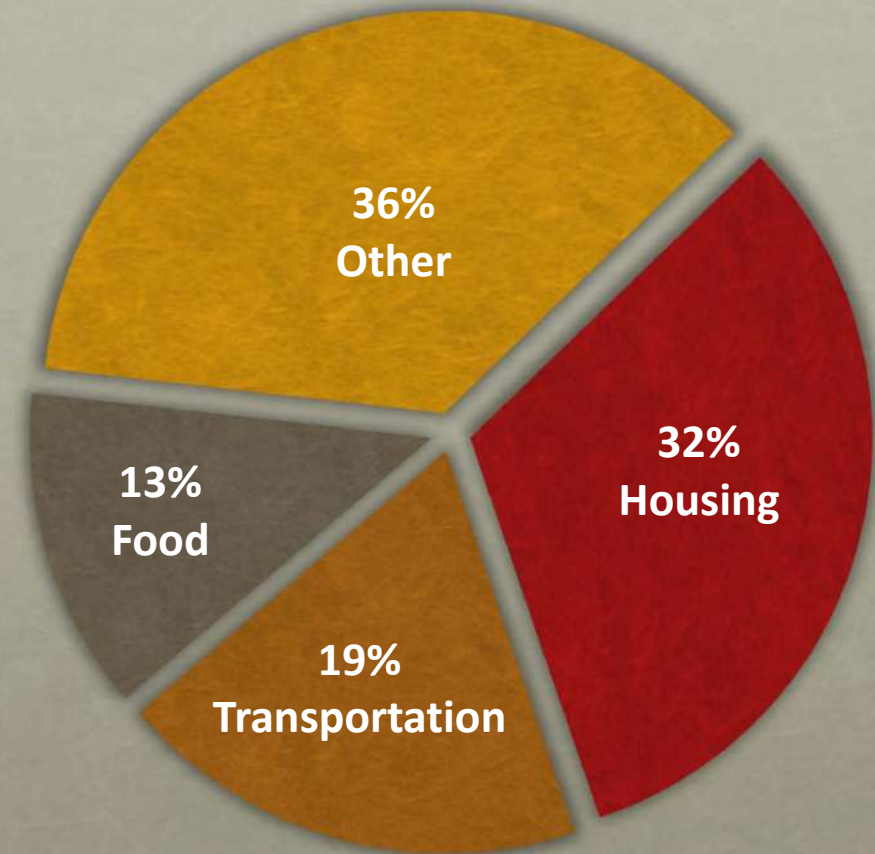
Source: [U.S. DOT](#)
Photo: istock, @fstop123



*Mobility's economic
impact on Denver's
residents and work force*

Why it matters: Average family budgets

Transportation consumes almost a fifth of a family's disposable income



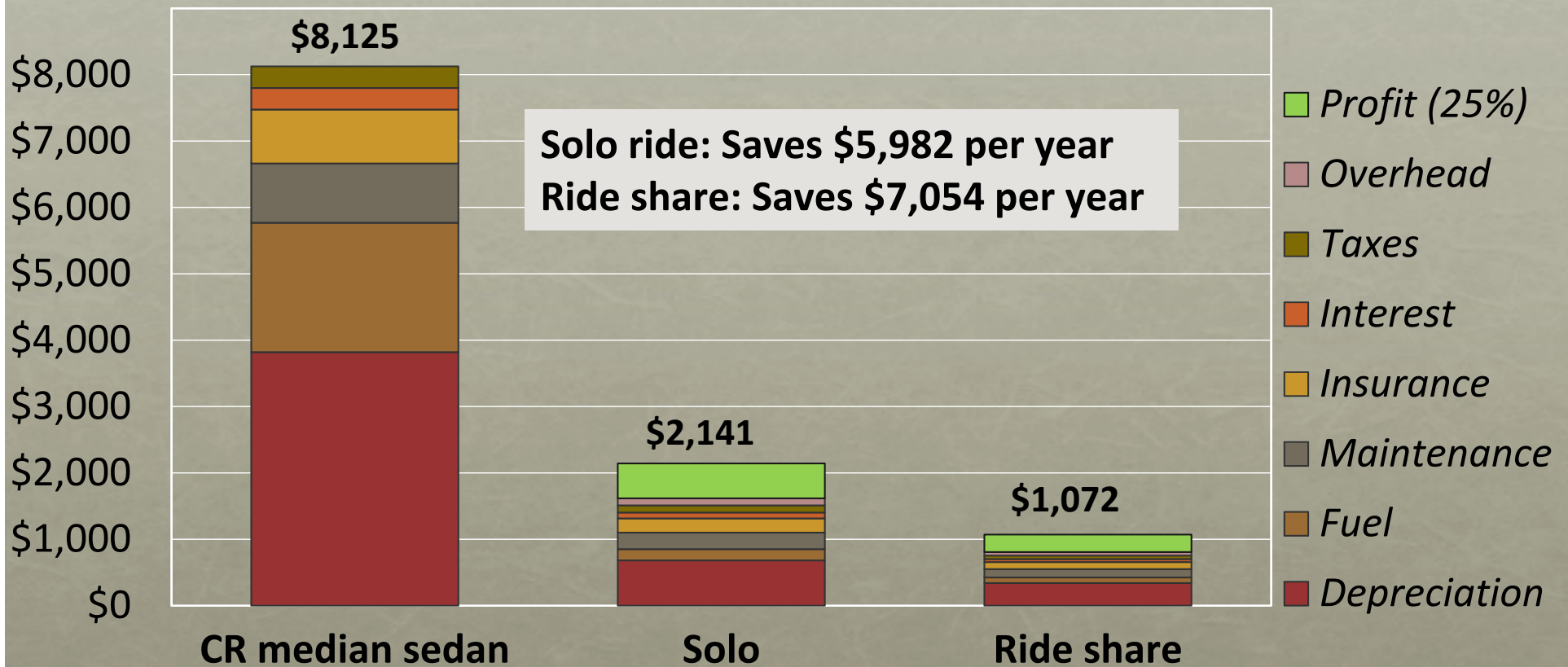
Source: [Federal Highway Administration](#)

The low cost of driverless mobility services

- *Electric driverless mobility-on-demand (by 2027)*
 - 4 seats, 25¢/mile, 9¢-25¢/passenger mile,
 - 2 seats: 18¢/mile, 9¢-18¢/passenger mile,
 - at a 25% pre-tax profit for the operator.
- Barclays Capital: 8¢/mile

Source: [Barclays Capital, May 2015](#)

Economics drives adoption: Cost per 12,000 miles



Sources: Consumer Reports, [Driverless Conquers Congestion](#)

Other annual driverless transit savings

- \$1,700: Downtown parking @\$140/month
- \$2,000: 50 min/day, 245 days/year @ \$10/hour
- \$2.06 billion: Denver-Aurora congestion cost

Source: Texas A&M Transportation Institute

Why mobility matters: Low-income communities

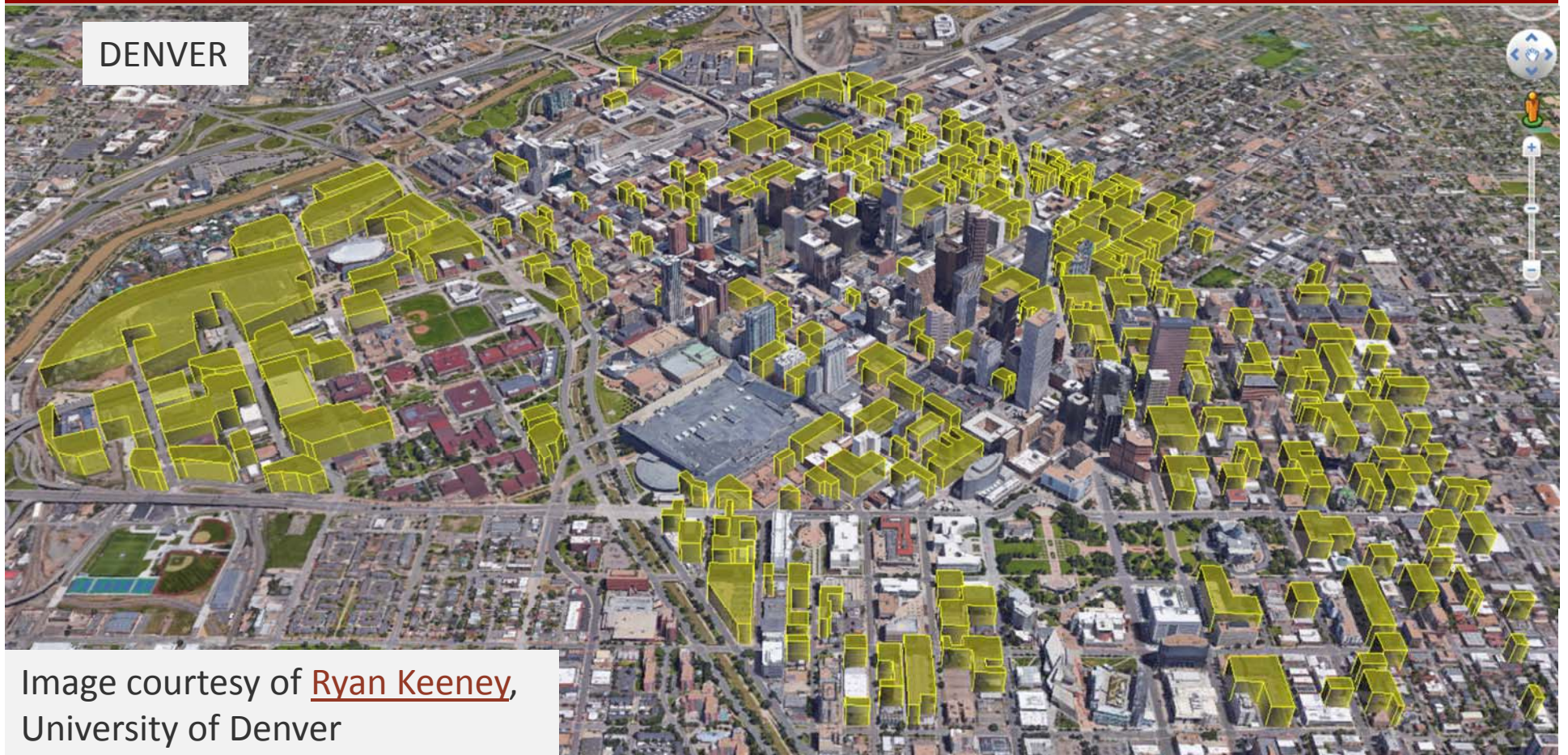
- 24/7 door-to-door service for far less than bus fare
- Cheap, reliable transportation means better jobs
- Faster commutes mean more time with families
- On-demand transportation for seniors, youth, people with disabilities, and the “alcohol-impaired”

Greatest economic risks of driverless vehicles

- Without an effective strategy, congestion gets worse?
- Jobs will be lost. Will cost savings create more jobs?
 - Drivers, parking, EMTs, insurance, auto sales/repair
- Less gov't income: Fines, fees, parking, gas tax
- Offsets: a mileage tax, fewer road expansions and traffic cops, accident response, smarter cities

*Parking spaces are
Denver's land savings
account for creating a
more livable city*

237 acres is lost to surface lots & garages



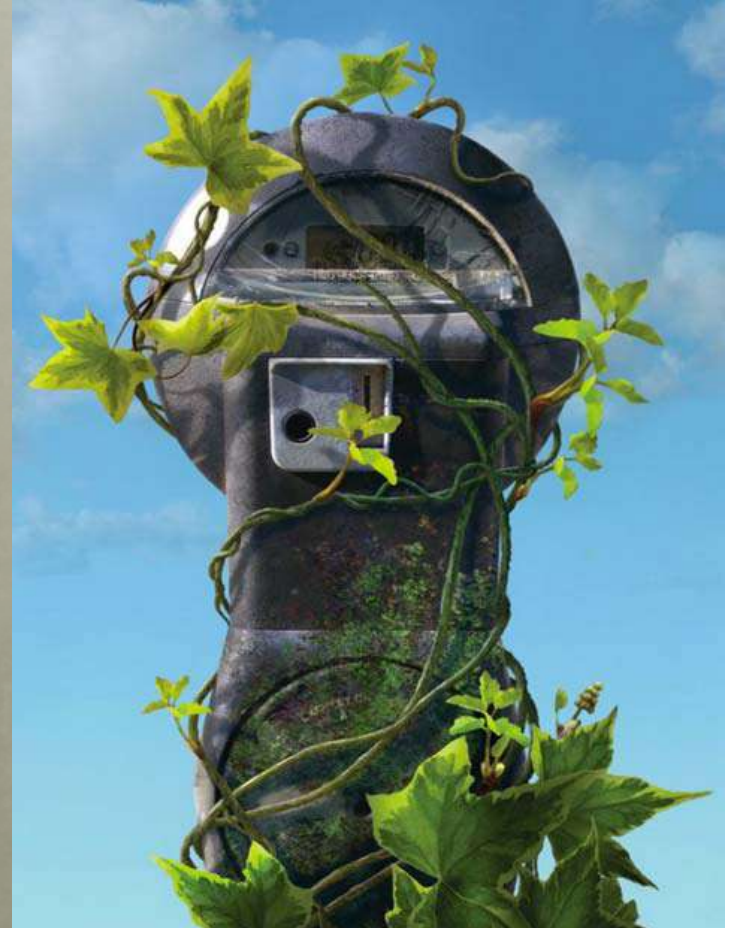
DENVER

Image courtesy of [Ryan Keeney](#),
University of Denver

Re-use of parking space

- Personally-owned vehicles sit parked 95% of the time
- America has a billion parking spaces for 253 million vehicles
- 30% of downtown cores are used for parking

Sources: [UC Berkeley](#), [New Republic](#)

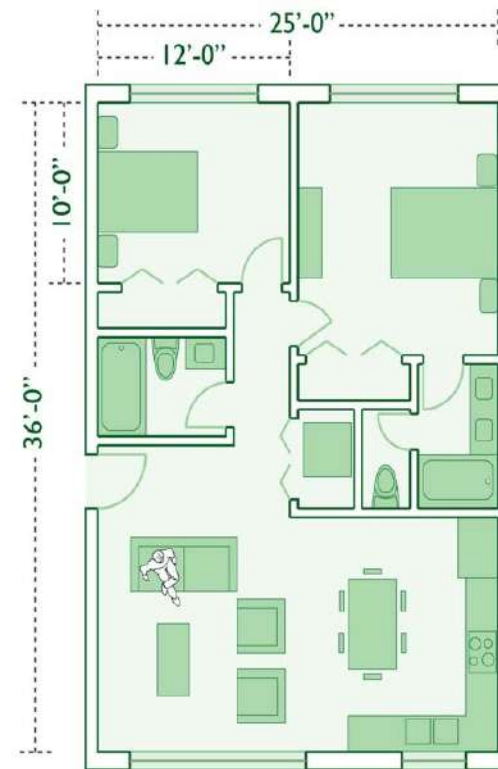


Parking-optional affordable housing

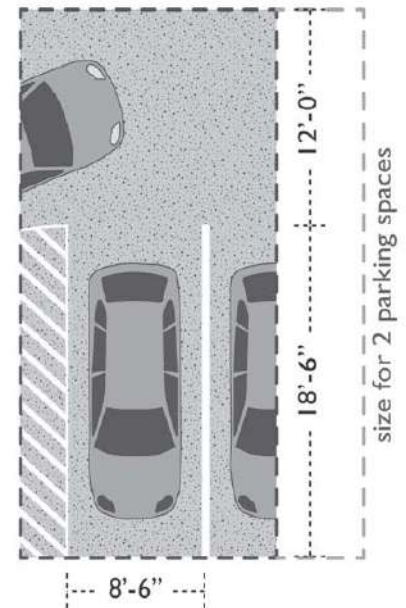
The median two-bedroom city code requirement of 1.5 parking spaces consumes more than half the area of a typical two-bedroom apartment and adds \$375 per month in rent.

Requires strict enforcement of residential parking permits in established neighborhoods.

Source: Seth Goodman, [Graphing Parking](#)



2 BEDROOM APARTMENT
900 FT²



**1.5 PARKING SPACES
INCLUDING AISLES**
488 FT²

*Can our public transit
buses compete against
Mobility as a Service?*

Why don't more people use public transit?

“...the travel time by public transit is almost twice the travel time by driving alone.”

(U.S. DOT, Federal Highway Administration)

“Buses take me from where I'm not to not quite where I want to go...”

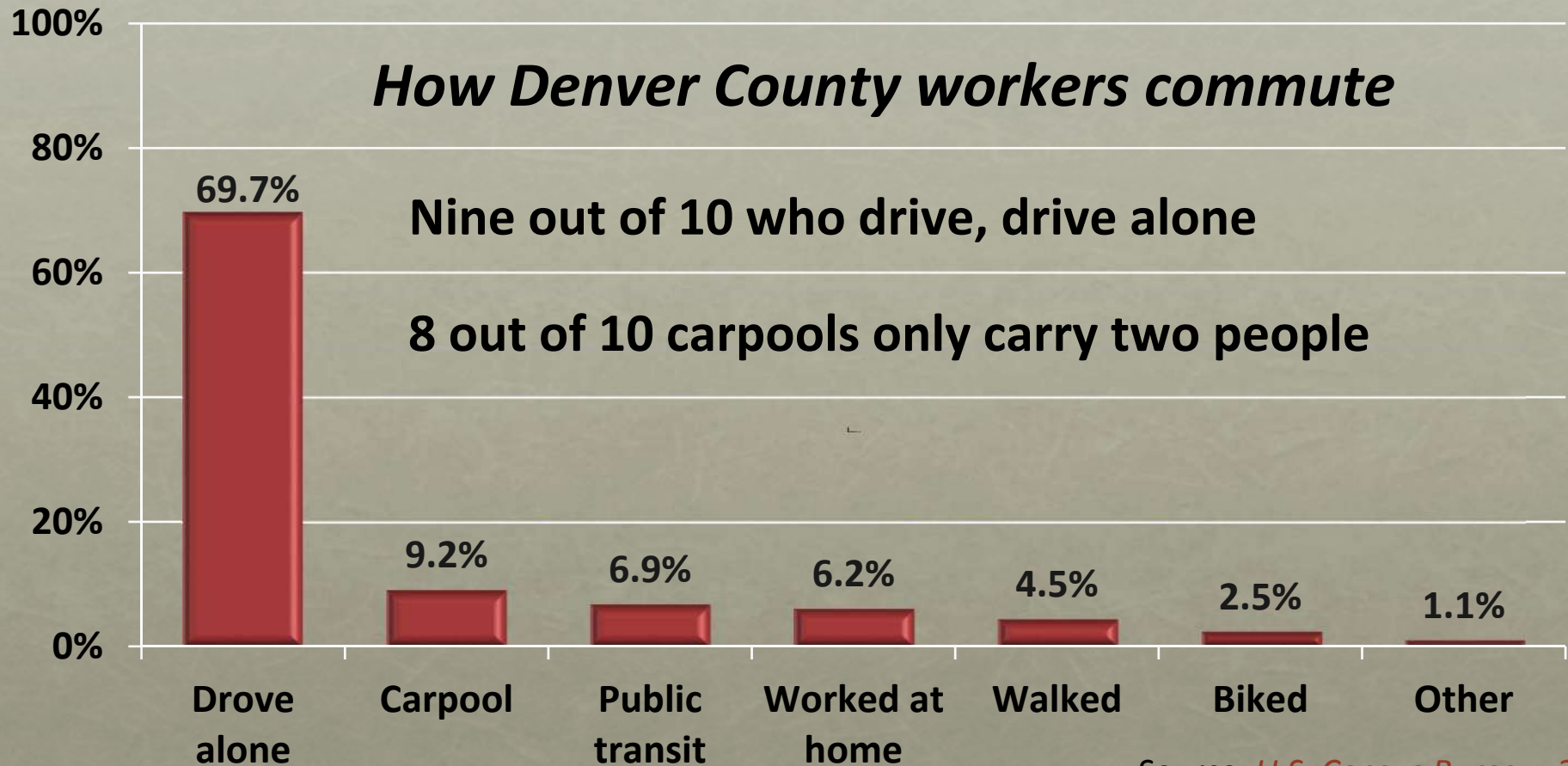
(Interview for my next book)

Source: [Census Transportation Planning Products](#)

Transit buses vs. shared mobility services

Station-to-station	Door-to-door
2x driving alone time	≈ driving alone time
Fixed route & schedule	24/7, on demand
Empty diesel buses	EVs, only as needed
Frequent stops	Very few stops
\$2.60 to \$4.50	9¢ per mile /\$1 min

Only 7% market share for Denver public transit



Source: [U.S. Census Bureau, 2014](#)

*Reinventing transit
as a
public-private partnership*

How to reinvent public transit

True cost of bus service including subsidies

Farebox ratio	Local bus fare	Subsidy from taxes and grants	True “ <i>total cost</i> ” of a bus ride
21%	\$2.60	\$9.78	\$12.38

Is there a better way to deliver transit services for those \$9.78 subsidies?

Nine free carpool rides can be provided for a single bus ride subsidy, with \$1.68 left over to provide mobility-on-demand shuttle service to all Bus Rapid Transit and Light Rail stations.

Coordinated door-to-door BRT's and Rail



*Conquering
Congestion*

Why driverless matters: Congestion

- Fewer crashes, less road construction
- Connected vehicles will bypass congestion
- No added congestion from looking for parking
- Connected vehicles can platoon in express lanes

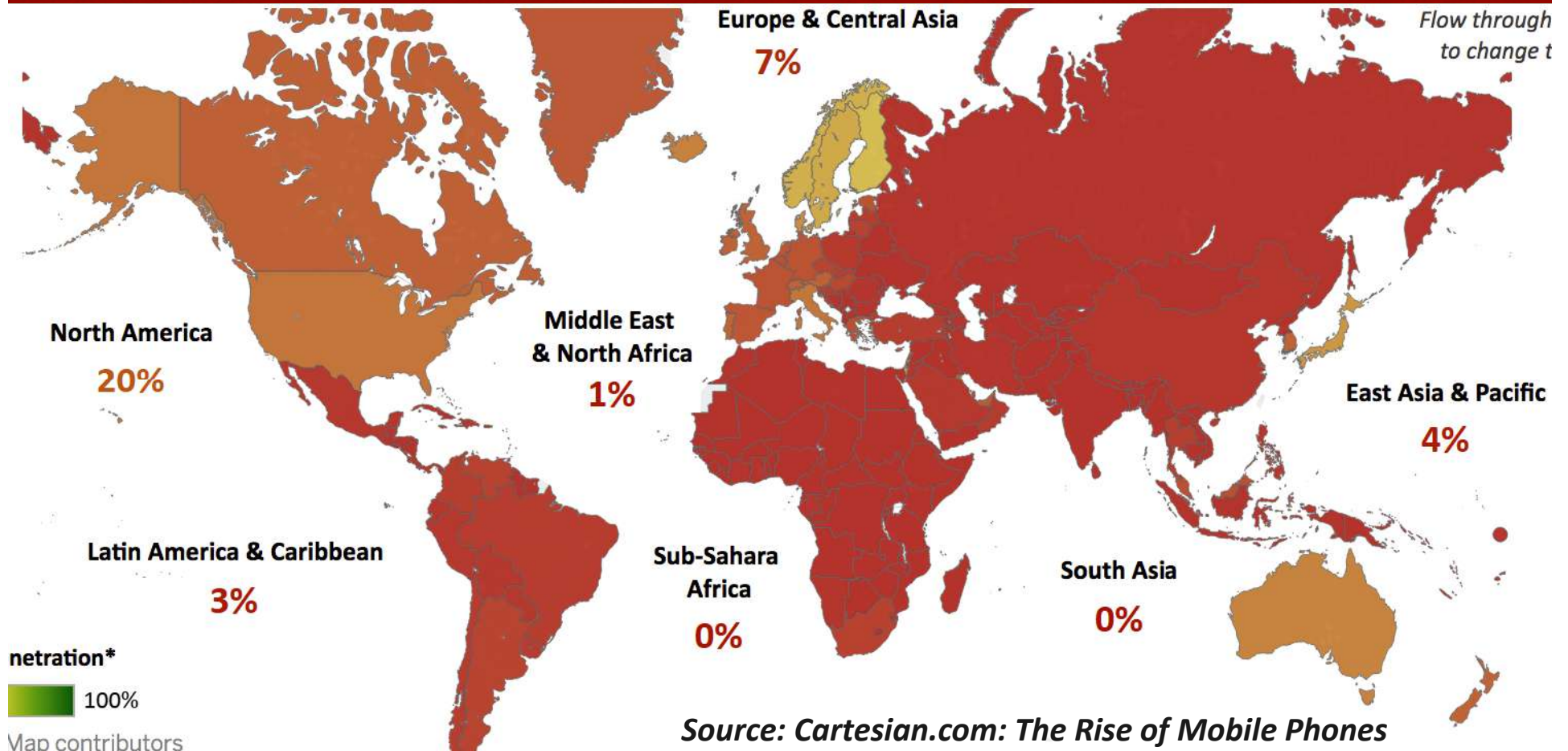
HOV Carpool Platooning = five conventional lanes



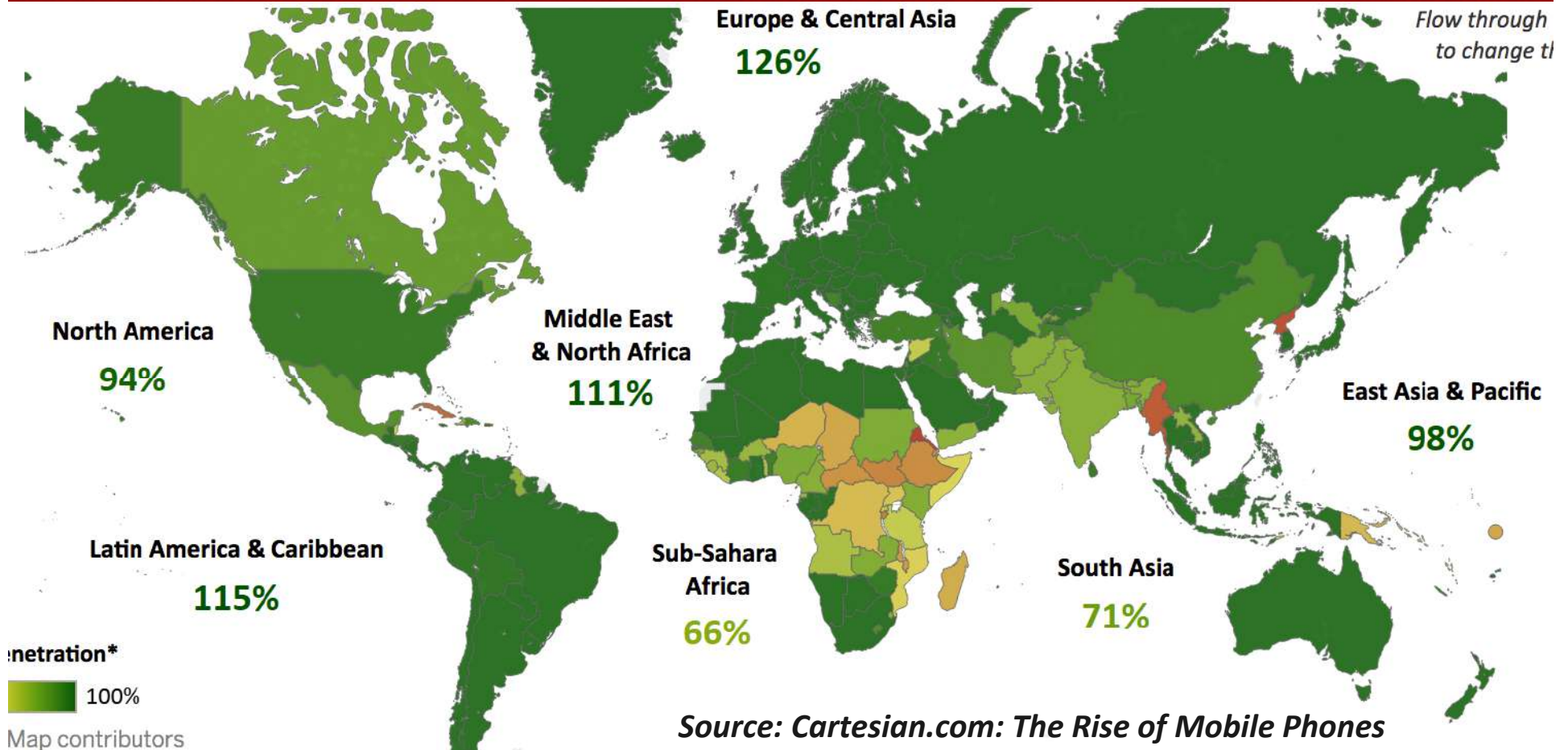
Source: iStock.com,
©peterhowell

*Truly compelling
technologies
often have
rapid adoption rates...*

Global mobile phone penetration - 1997



Global mobile phone penetration - 2013



*How fast will driverless
mobility services propagate?*

*How fast are Uber and Lyft
growing?*

*Brainstorming:
Two potential pilot projects*

Pilot 1: Belleview Station Light Rail Shuttle Service

Free circulating driverless vans feed commuters into Light Rail or Bus Rapid Transit stations near high-density housing. Riders app that shows when vans pass by their apartment.

1.5-mile/8 minute round trip, no highway access required. An inexpensive 1 or 2 van pilot.

Source: Google Maps



Advantages of high-density Shuttle Services

- High-density housing = large customer base
- Ease of use for apartment dwellers
- Moderate cost: Service expands/contracts by demand
- Shifts traffic from I-25 to Light Rail, increasing rail use
- Encourages high-density transit-oriented development

Pilot 2: Free driverless shuttle service into downtown



Near-in neighborhoods residents use an app to determine pickup times for next shuttle and request a ride. No elaborate bus stops, just pickups spots along the route. Connects to south end of Free MallRide or Free MetroRide. Add more shuttles based on demand.

Advantages of downtown Shuttle Service

- Near-in neighborhoods = large customer base
- Ease of use for Denver residents (no fixed schedules)
- Moderate cost: Service expands/contracts by demand
- Relieves single-passenger traffic from feeder streets
- Saves residents the high cost of Denver parking
- Relieves residential street parking demand

Local Motors Driverless Bus

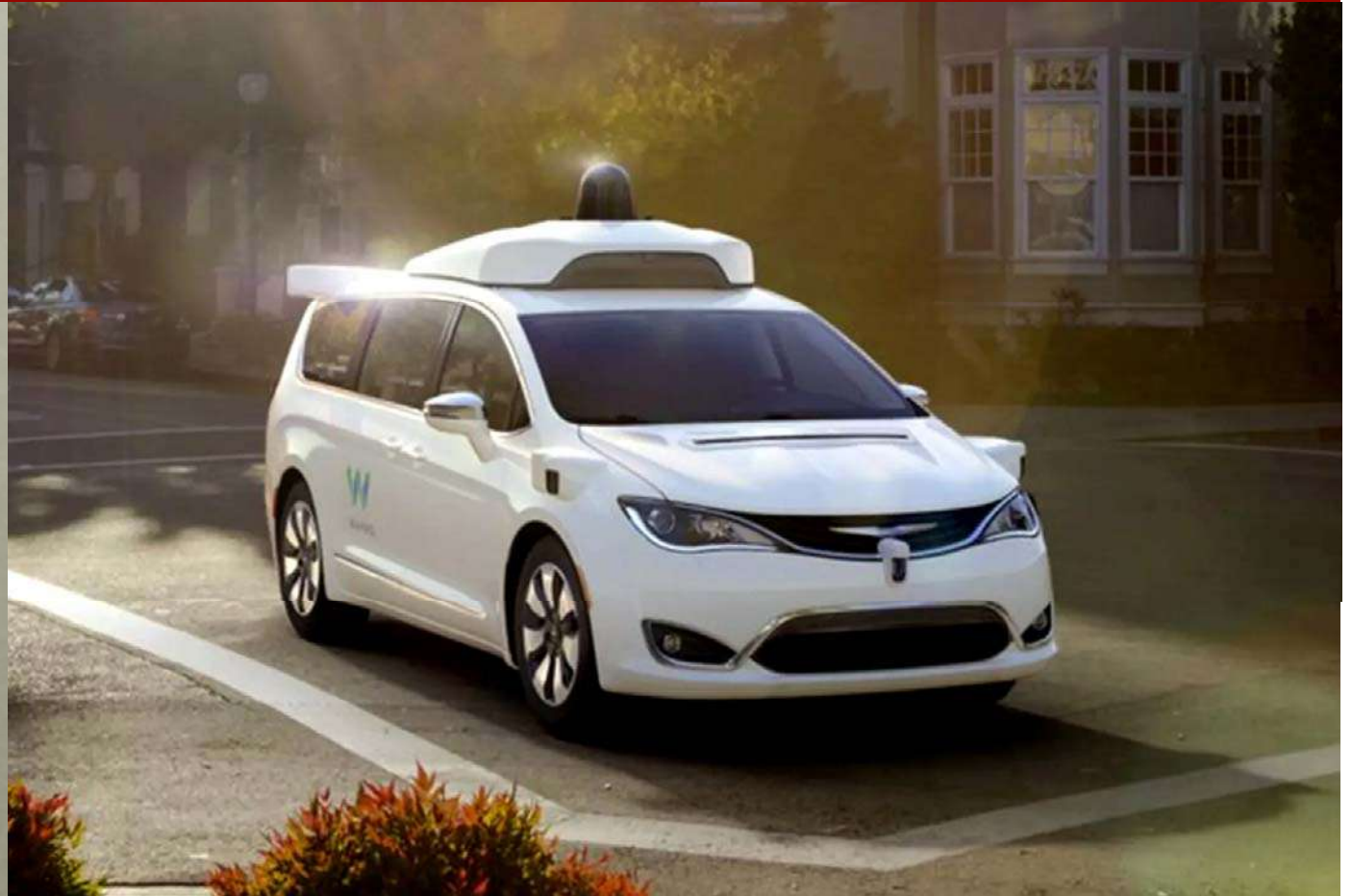
*In partnership
with Local Motors
or Panasonic's
driverless vendor?*



Driverless Waymo-Chrysler Pacifica

Partnership?

- Chrysler Pacifica
- Waymo technology
- Tech cost 90% less
- Waymo plans?
 - SAVs
 - Shuttles
 - Logistics
 - First/last mile



Volvo's Vision: City of Tomorrow

Drive Me

SELF-DRIVING CARS FOR
SUSTAINABLE MOBILITY

DRIVE SWEDEN



Göteborgs
Stad



City of Tomorrow

Drive Me

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Stad

