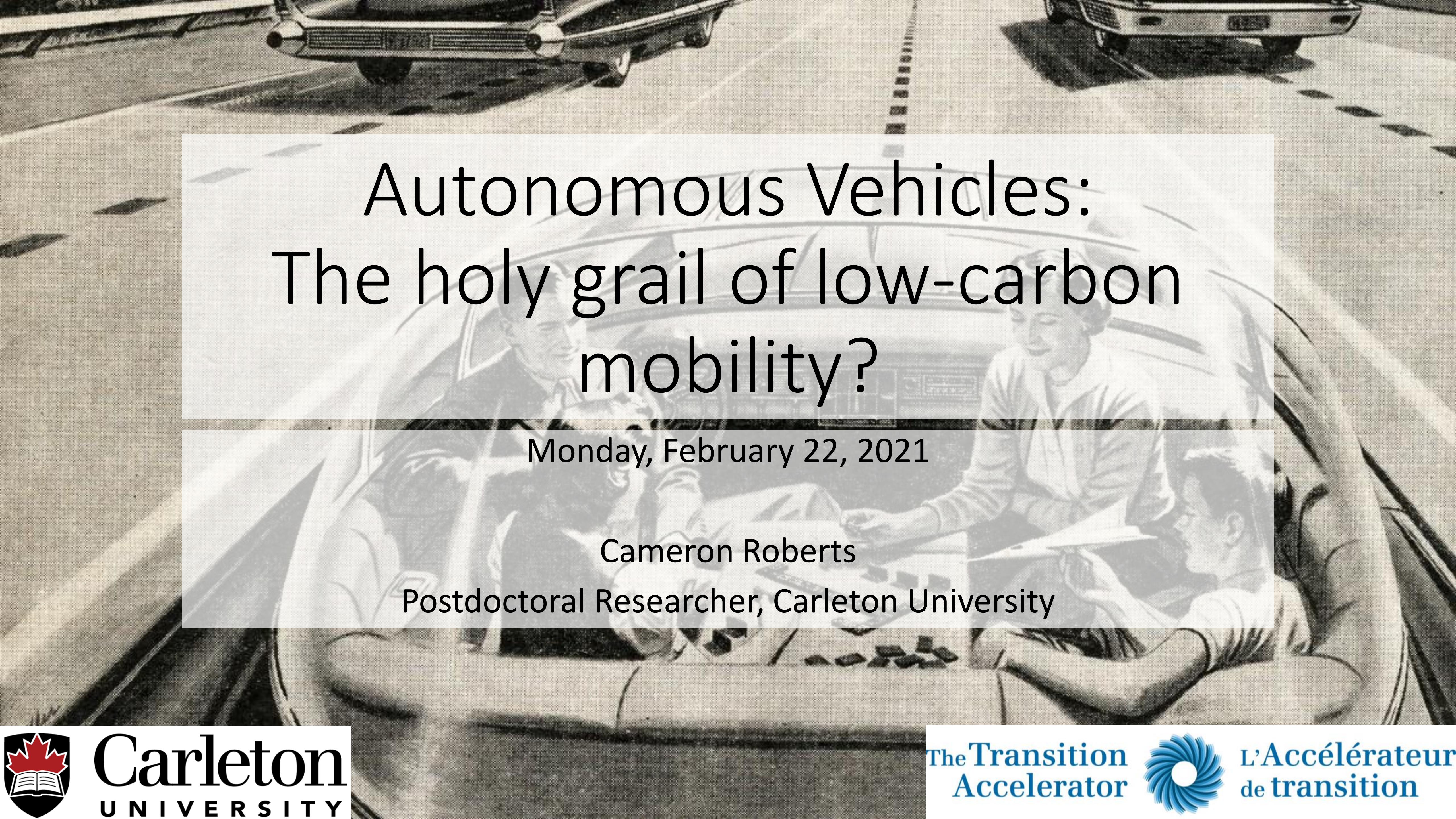

Autonomous Vehicles: The holy grail of low-carbon mobility?

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Outline

1. The vision
2. An introduction to autonomous vehicles
3. The climate context
4. What the evidence says:
   - Case 1: Limited Automation
   - Case 2: Full Automation
   - Case 3: Full Autonomy
5. Conclusion

The Vision

- “**People may outlaw driving cars** because it’s too dangerous. You can’t have a person driving a two-ton death machine.“ –Elon Musk
- “**By 2030, 95% of U.S. automobile miles traveled will be in on-demand, autonomous electric-vehicle fleets, in a new business model called transport as a service**. This disruption isn’t going to be one where individuals simply trade in their gasoline or diesel vehicles for electric vehicles. Both gasoline/diesel vehicles and the individual ownership of automobiles will be disrupted.” – Tony Seba, of RethinkX
- “**Roadway transportation is now as ripe for transformation as the telecommunications, photography, computer, media, television and pharmaceutical industries were over the past two decades**…It is now possible to supply better mobility experiences at radically lower costto consumers and society. This opportunity results from innovatively combining five emerging technology and business enablers” – Burns et al (2012)
- “**Analysis by leading organizations and individuals indicates the technical, logistical, and economic plausibility of a future where most mobility needs are met by mobility services, enabled by autonomous driving technology, and powered by electric powertrains**. This future system has the potential to reduce costs by over $1 trillion, reduce CO_2 emissions by a gigatonne, and save tens of thousands of lives per year in the U.S. alone” (Johnson and Walker, 2016)

The logic:

1. The current system of car ownership and use is very inefficient, since most cars are not used most of the time. This creates opportunities for major savings of money, energy, time, and space.
2. Shared autonomous vehicles will thus be able to make shared mobility cheaper than driving a privately-owned vehicle.
3. This will mean that a “robo-uber” system spells the end of private car ownership.
4. Due to economies of scale, these shared vehicles will be overwhelmingly electric. There will also be far fewer of them.
5. The results will be massive improvements in safety, traffic efficiency, time use, land availability, and, crucially, greenhouse gas emissions.

Best of all: The process itself is self-driving! We just have to let car companies and tech firms do their thing, and this will all just happen.

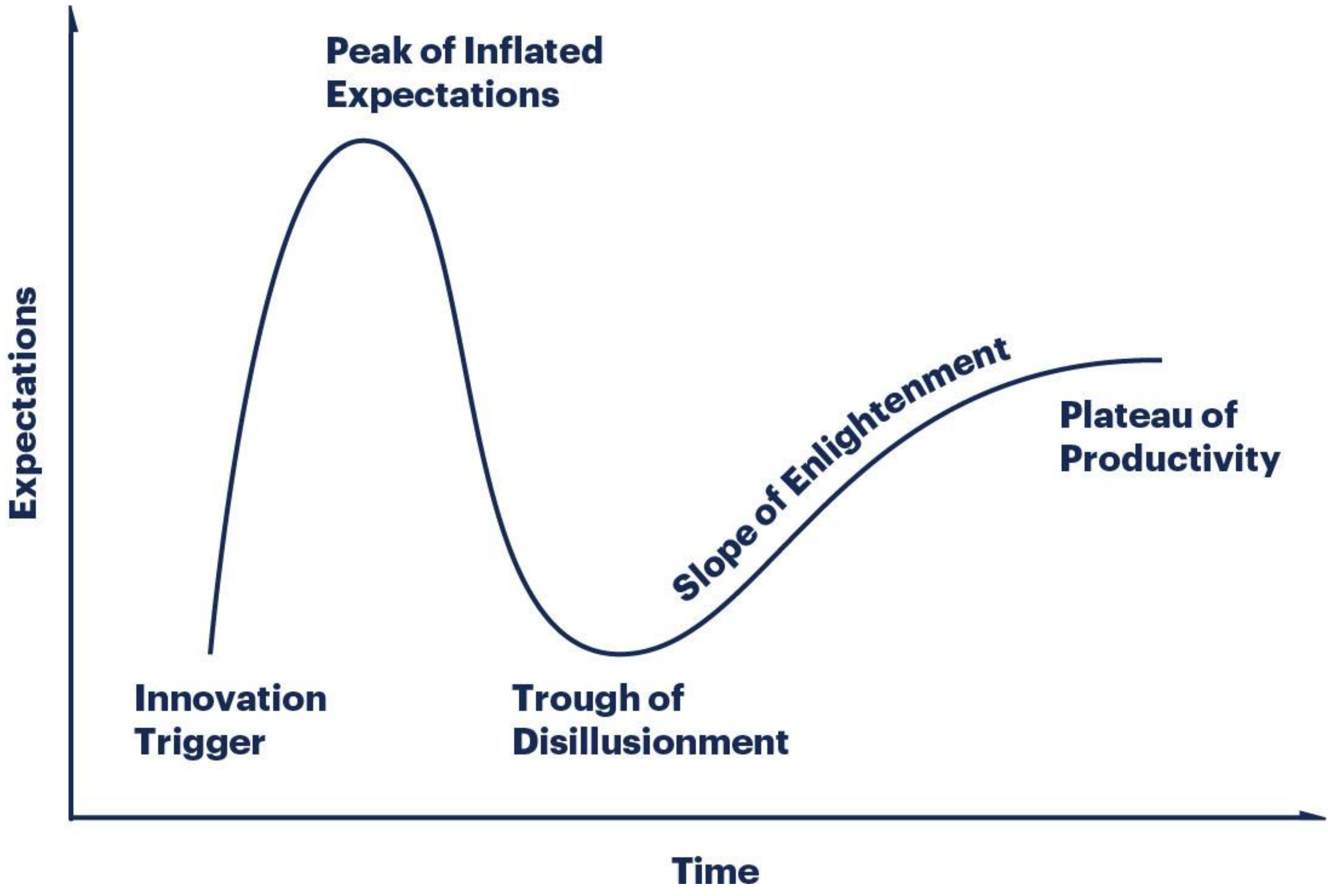
An Introduction to Autonomous Vehicles

A Brief History

- Autonomous vehicles have been a major vision of car manufacturers, drivers, and policymakers for almost as long as cars have been dominant in the transportation system.
    - Experiments and demonstration projects go back at least as far as the 1920s.
    - Most earlier versions required special kinds of road infrastructure so that the cars could recognise the road.
    - This has always been an appealing way to address persistent problems in the car-based transportation system, such as accidents and congestion.
- Advances in compact digital electronics around the turn of the 21^{st} century made them much more viable.
- November 2007: DARPA Grand Challenge III challenged autonomous vehicles to navigate an urban environment. This was an important proof of concept for autonomous vehicles.
- 2009: Google begins developing autonomous vehicles
- 2011: Nevada passes the first law permitting the operation of autonomous vehicles on the state’s roads.
- 2010s-present: Car companies and tech companies have both piled into the autonomous vehicle field.

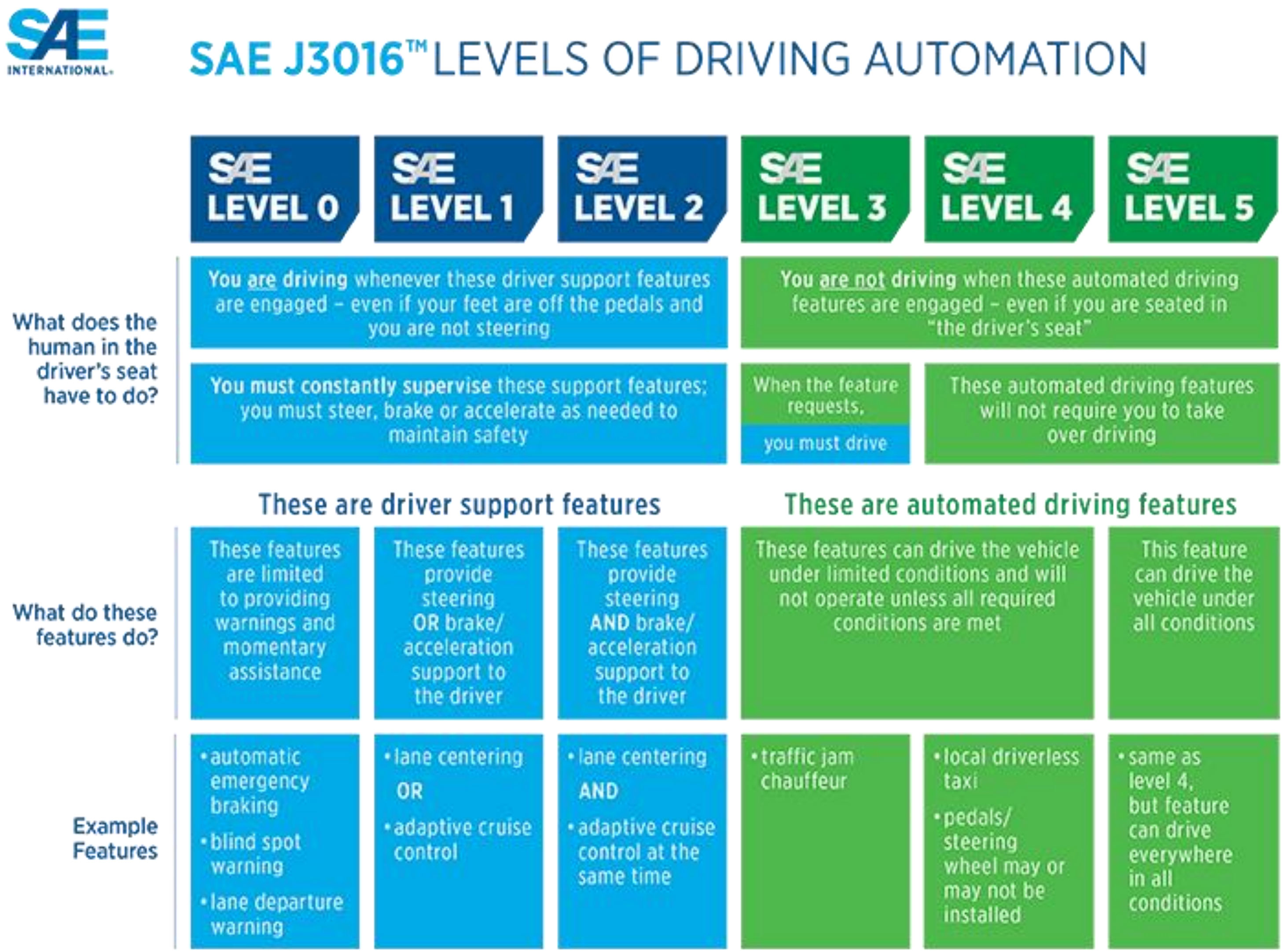
Technical Challenges

- During the early years of the 2010s, autonomous vehicles were the subject of extremely bold predictions.
- 2017: GM announced it would deploy self-driving electric cars as early as the following year.
- 2018: an Uber self-driving vehicle hits and kills a cyclist as she walks across a crosswalk in Arizona.
  - Predictions have become less bold since then.
- Autonomous vehicles have several persistent technical challenges:
  - Inclement weather
  - Poorly-marked roads
  - Unpredictable pedestrian behaviour
  - Hard-to-recognize road obstructions
  - Reliability of hardware and software



The Society of Automotive Engineers' 5-level Classification System

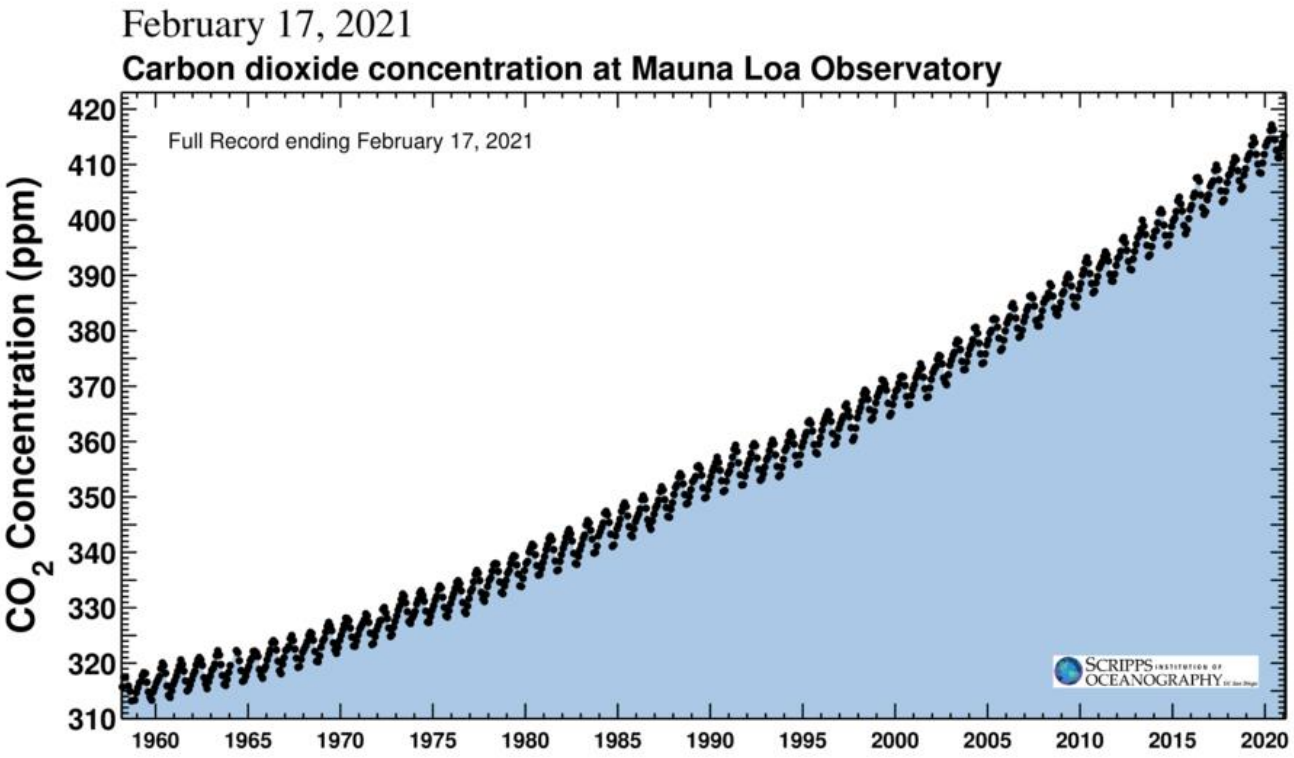
- All self-driving vehicles currently on the market have low-level autonomous features, which assist driving:
    - Lane-keeping assist
    - Collision warning
    - Automatic parallel parking
    - Tesla's "summon" function
- Experimental vehicles (including the one involved in the Arizona crash) have achieved level 3.
    - Level 3, incidentally, can be quite dangerous..



The Climate Context

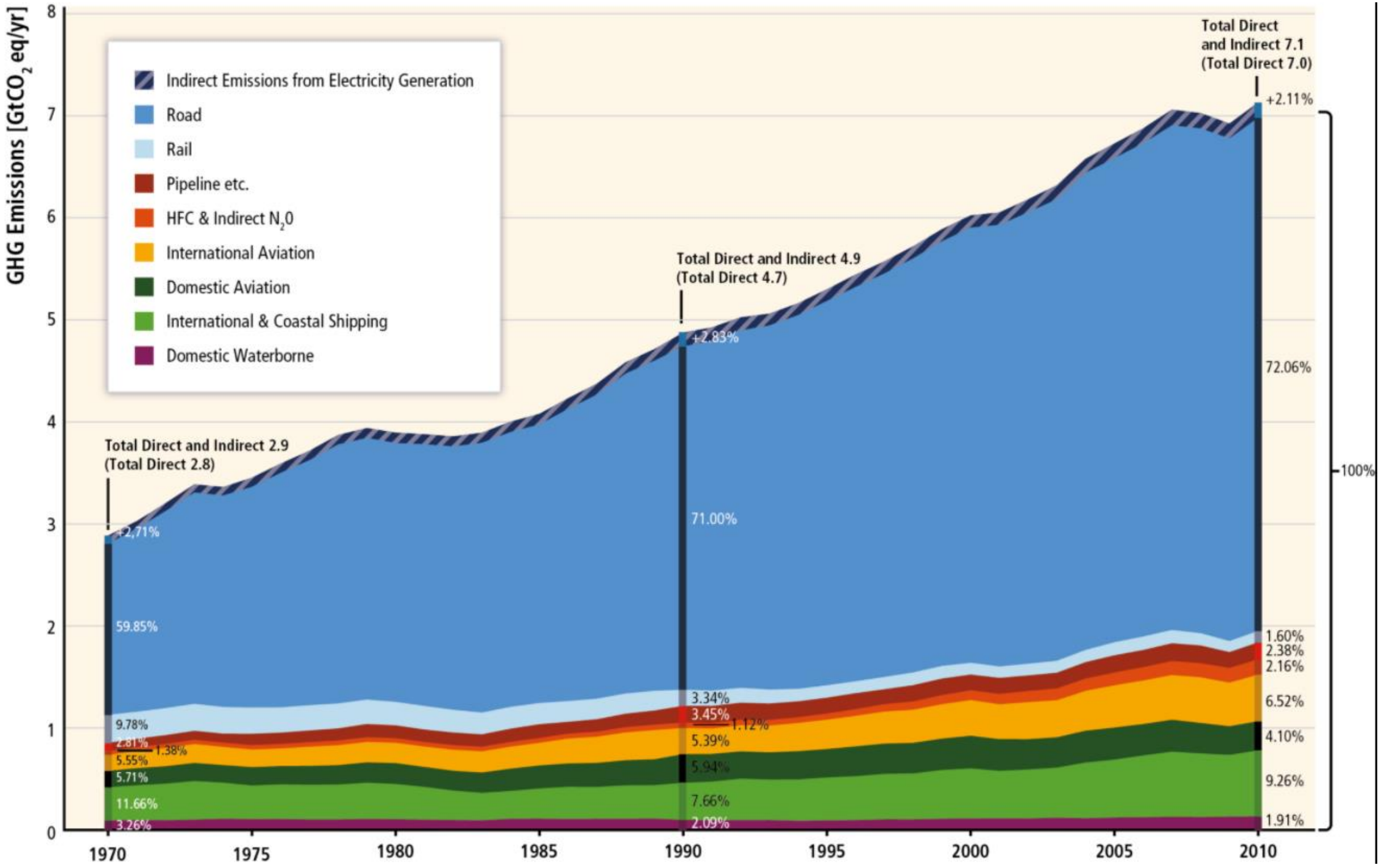
The Climate Context

- As of this writing, the atmospheric CO_2 concentration at Mauna Loa is 415 ppm.
  - The last time in the Earth's history that CO_2 was this high, there was very little ice anywhere on Earth, sea level was 1,000 feet higher.
  - We might already be reaching the point of lifetime toxicity from CO_2 exposure.
- The 2015 Paris agreement still has us on a trajectory for more than 3 degrees of warming by 2100.
  - Most signatories are not meeting their obligations under the agreement.
  - Many of the signatories' pledges depend on enormous and possibly unfeasible levels of negative emissions.



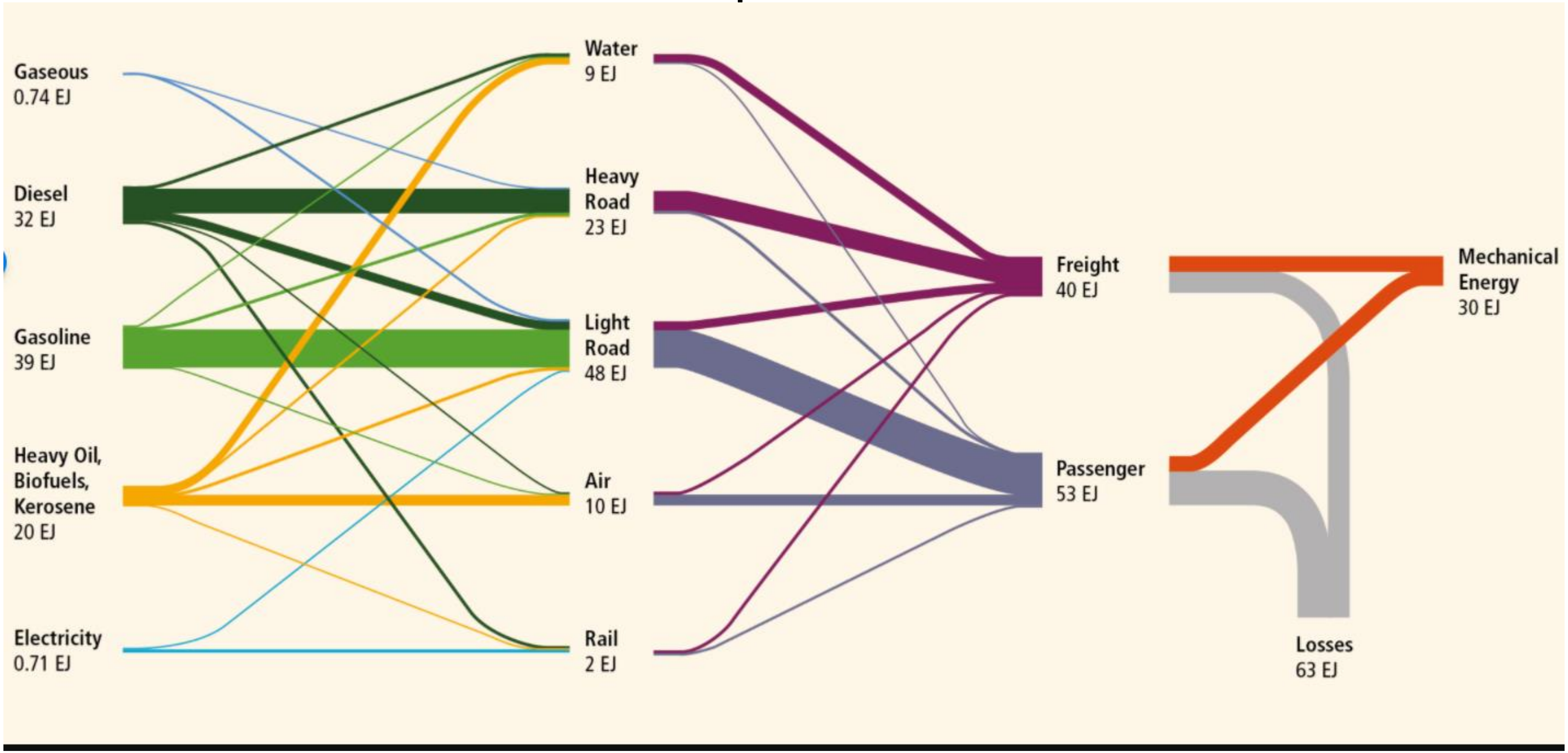
Transportation and Greenhouse Gas Emissions

- Transportation accounts for 23% of global greenhouse gas emissions (Sims et al, 2014).
- Same proportion of Canadian greenhouse gas emissions.
- The vast majority of these come from road transportation.
  - Aviation and shipping are also big issues.



Sims et al, 2014

Fossil Fuels and Transportation



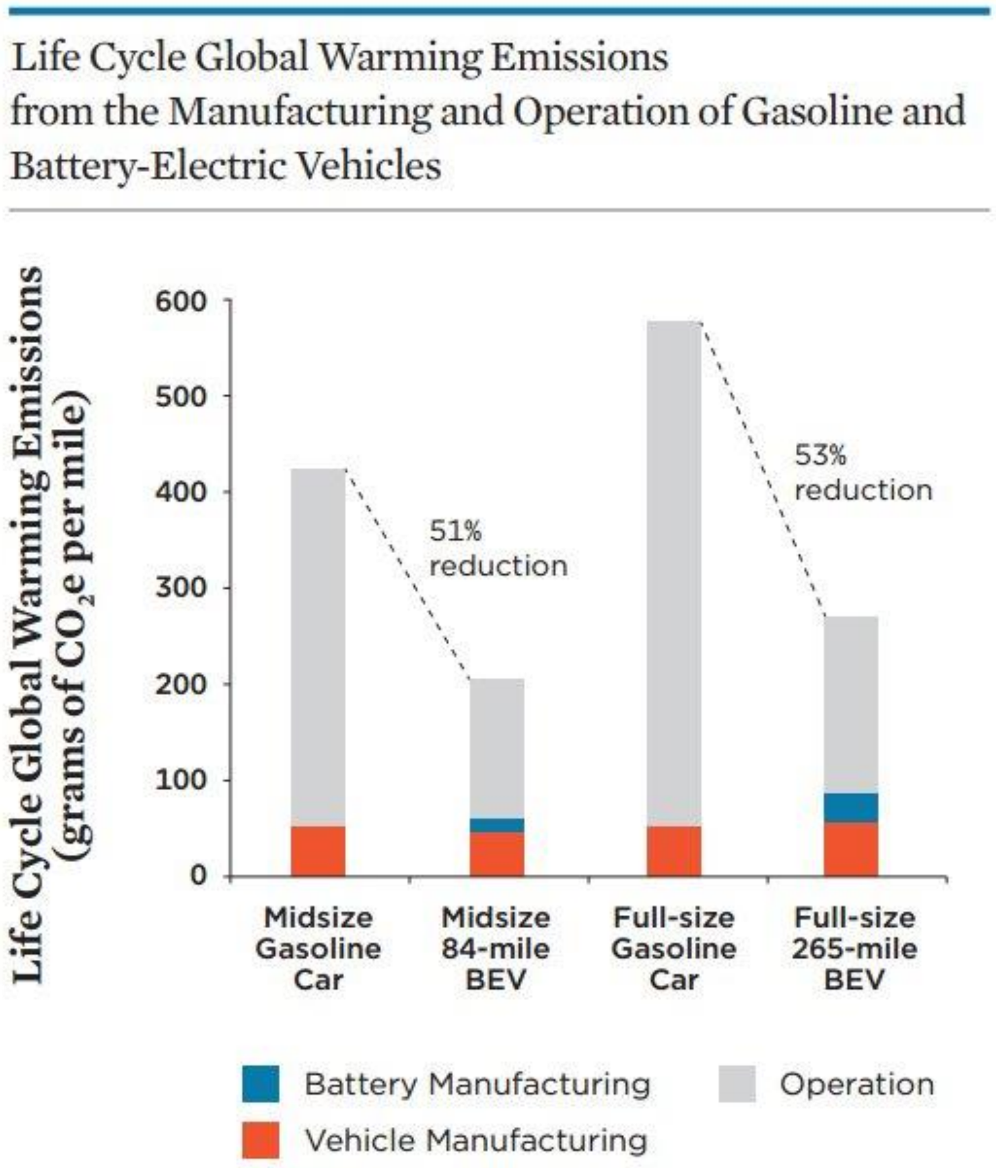
Sims et al, 2014

Other Environmental and Social Issues

- Air pollution: Responsible for 14,600 premature deaths in Canada per year.
    - Some of this comes from tires and brakes, rather than just out the tailpipe.
- Road deaths: Responsible for over one million deaths per year.
- High financial costs
    - On the individual level (car payments, gas, etc.)
    - On the societal level (roads, parking, subsidies)

Electric Vehicles

- Electric vehicle adoption is increasing rapidly, and are often being cast as a major source of hope in this area.
- Theoretically, if every vehicle is electric (and all electricity is renewable), then it doesn't matter very much how much cars are driven.
- **However:**
  - Electric cars are not inherently carbon-neutral
  - Today's conventional vehicles will remain on the road for an average of around 10 years
  - Making electric cars produces a lot of carbon
  - Even the most optimistic adoption forecasts fall far short of what would be necessary for mitigating the worst of climate change (Milovanoff et al, 2020)



From Union of Concerned Scientists.

What the evidence says

Different types of effects

- Autonomous vehicles, like any other major innovation have several layers of effects.
  - **First-order effects:** Direct, predictable, and often desired impacts of the change.

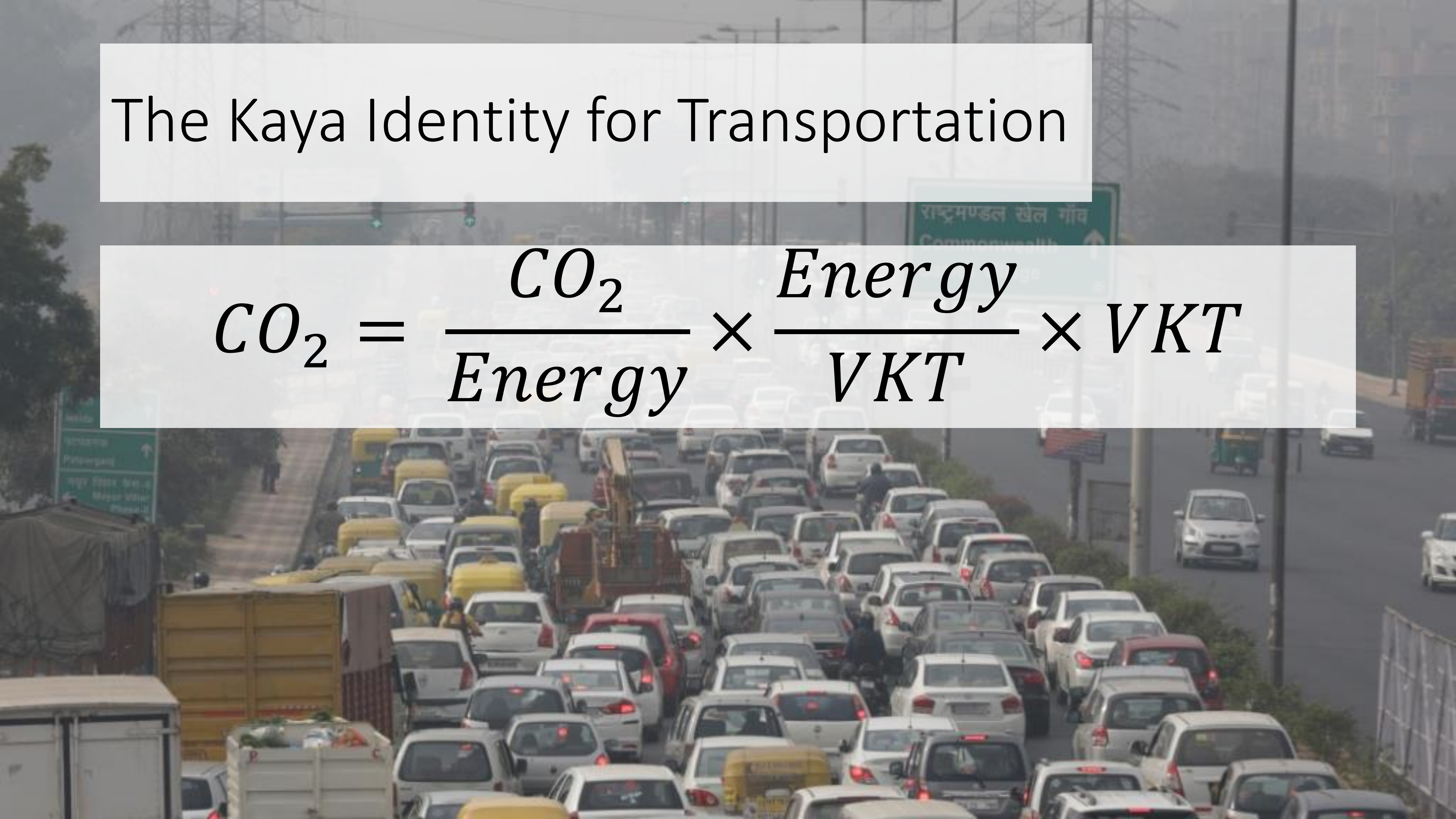
    Example: Fewer accidents due to autonomous mobility.
  - **Second-order effects:** Reactions to the change from other parties, and other less predictable and typically unintended consequences.

    Example: Changed driving habits due to increased vehicle safety.
  - **Third-order effects:** Reactions to the reactions, consequences to the consequences, etc.

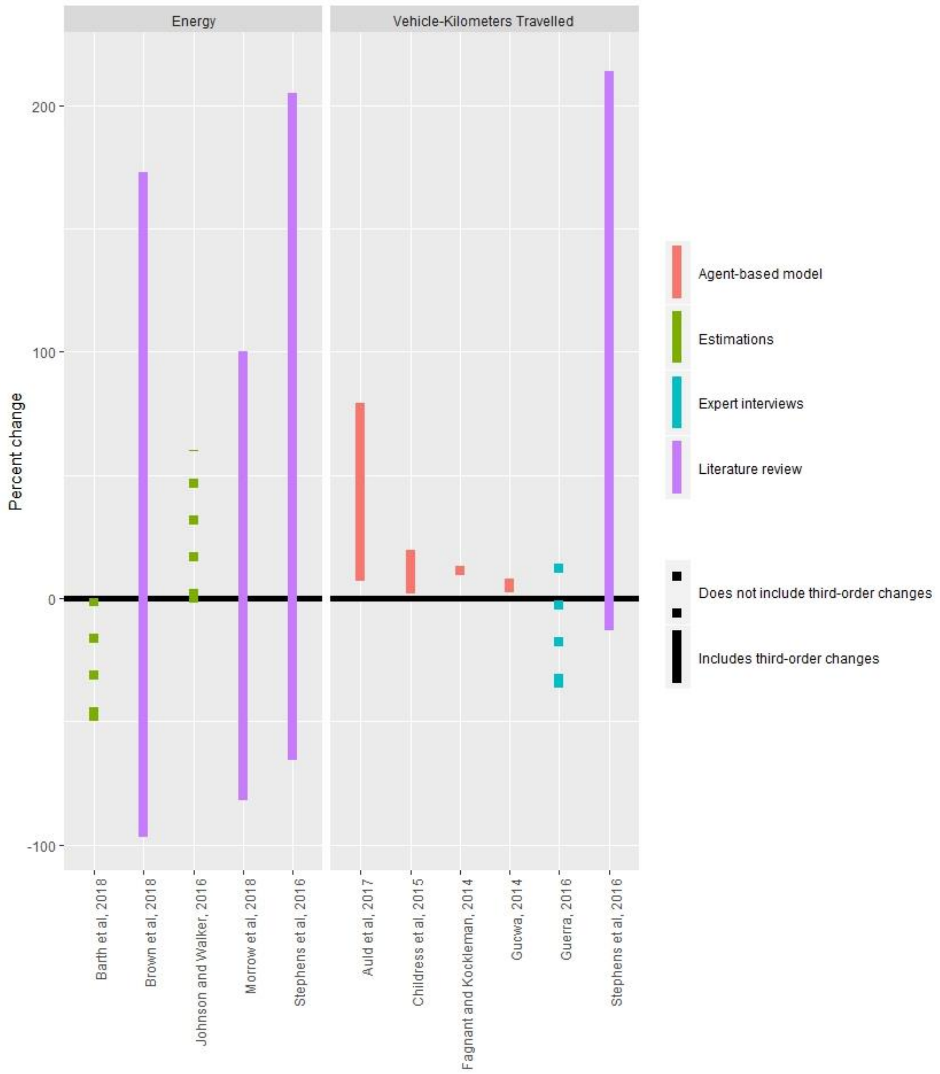
    Example: Increased air pollution due to cars driving faster.
- For autonomous vehicles, third-order effects encompass a lot of complex societal, political, and economic consequences.

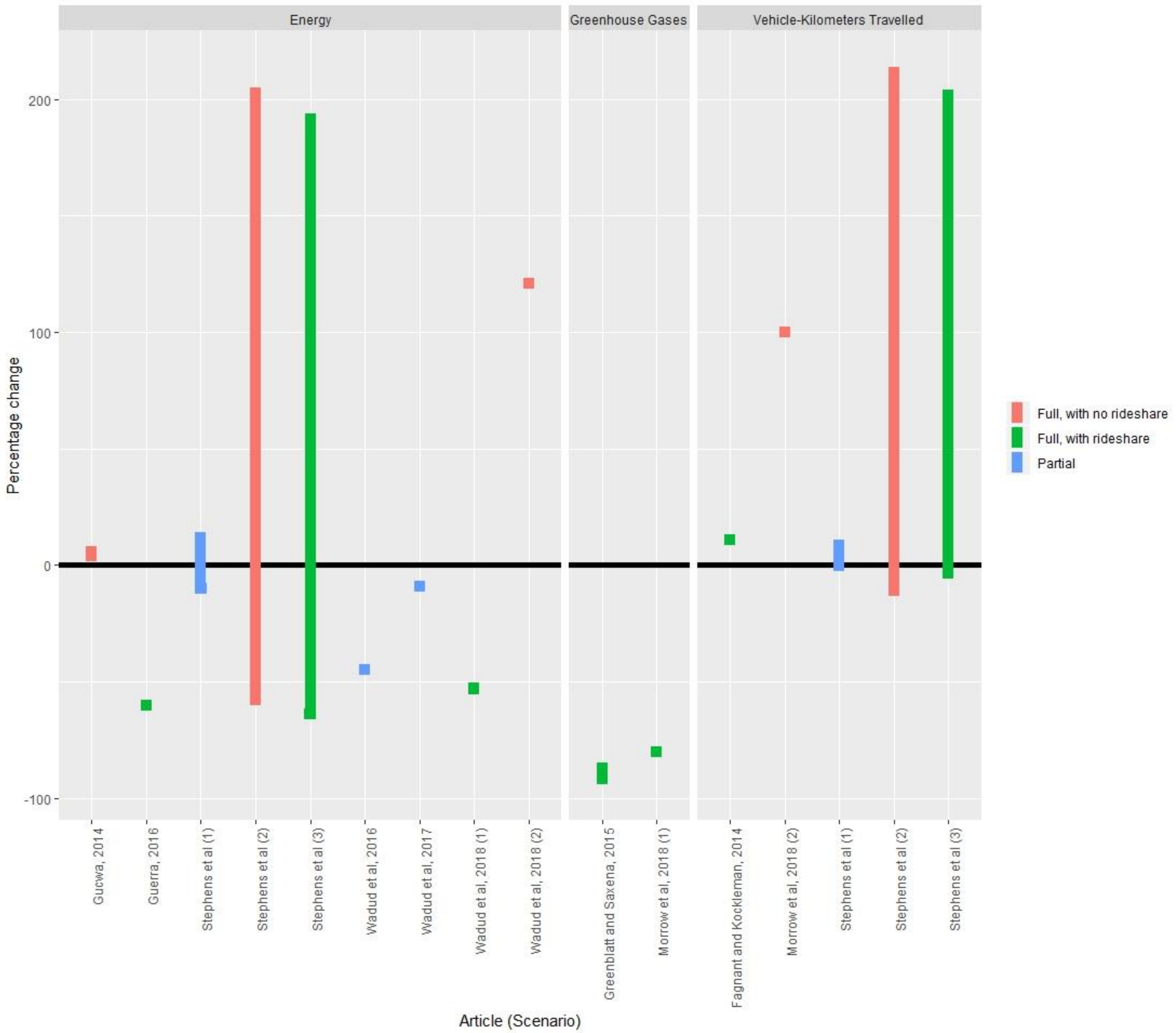
The Kaya Identity for Transportation

$$CO_2 = \frac{CO_2}{Energy} \times \frac{Energy}{VKT} \times VKT$$



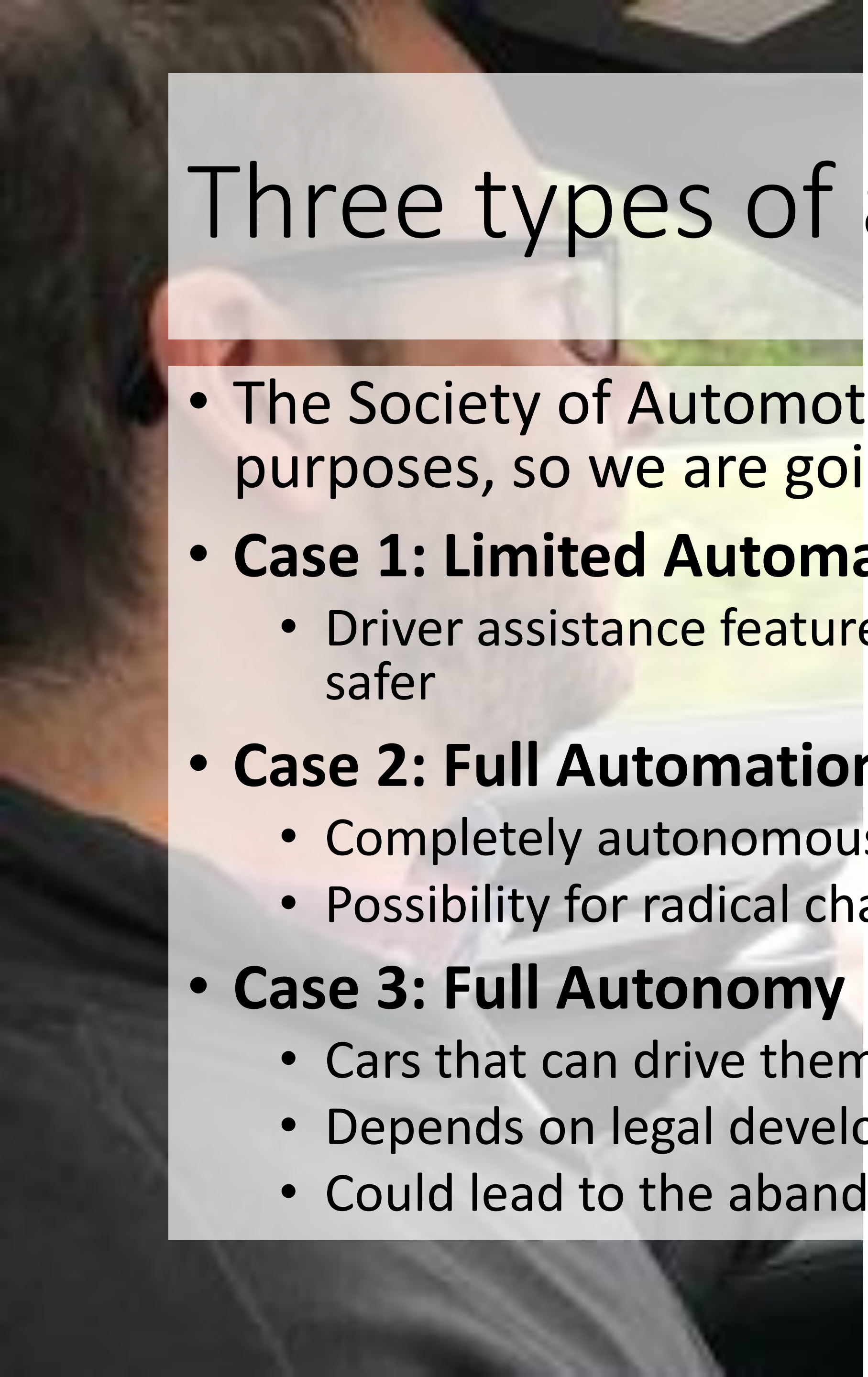
Modelling Autonomous Vehicles' Climate Impact





Three Types of Literature on Autonomous Vehicles

- **Technical literature**
  - Studies what autonomous vehicles, as a technology, will actually be able to do.
  - Example: A computer modelling study investigating efficiency gains from vehicle platooning.
  - Usually very narrow focus. Almost never considers social or environmental consequences.
- **Energy and climate literature**
  - Explores the fuel consumption of autonomous vehicle fleets in various scenarios
  - Example: An agent-based model studying total vehicle-kilometers travelled in a shared autonomous mobility system, and calculating climate impacts based on that.
  - Typically simply assumes a range of autonomous vehicle scenarios, and investigates each one.
- **Social science literature**
  - Studies how people will integrate autonomous vehicles into their everyday lives.
  - Also includes policy and legal studies.
  - Example: A survey asking respondents if they will be willing to give up their private car in exchange for a robotic taxi.
  - Often is not undertaken with environmental benefits in mind.



Three types of autonomous mobility

- The Society of Automotive Engineers scale is too fine-grained for our purposes, so we are going to simplify to three use cases:
- **Case 1: Limited Automation**
  - Driver assistance features increase efficiency, eliminate congestion, and make driving safer
- **Case 2: Full Automation**
  - Completely autonomous driving, with no need for a human occupant to intervene.
  - Possibility for radical changes to travel habits.
- **Case 3: Full Autonomy**
  - Cars that can drive themselves with no human present at all
  - Depends on legal developments as well as technical ones
  - Could lead to the abandonment of car ownership altogether.

Case 1: Limited Automation

Case 1: Limited Automation

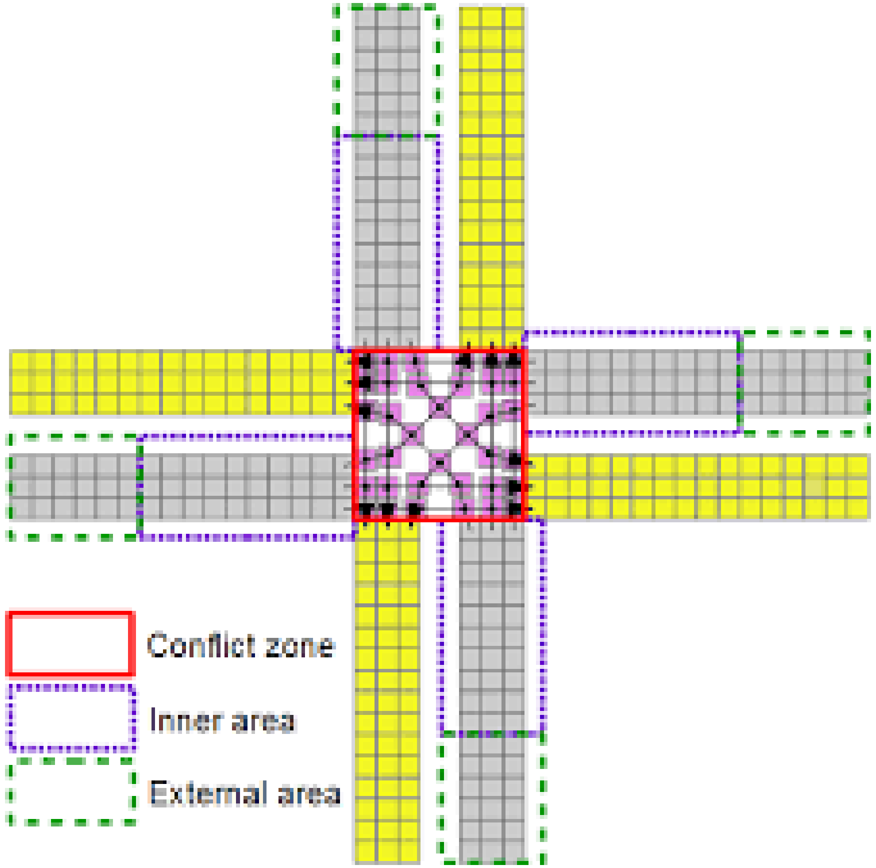
- Limited automation technologies already exist in many cars:
    - Parking assistance
    - Collision-avoidance
    - Lane-keeping assistance
    - Connected adaptive cruise control
- Future vehicles could make greater use of these technologies, possibly allowing the driver to disengage from the driving task at certain times and in certain places.
    - But would still require the driver to pay attention.
- Tesla’s Autopilot feature already allows this.

Efficiency Benefits from Limited Automation

- **Traffic Smoothing**: Cars communicate with each other, to reduce traffic congestion and the emissions it causes.
- **Eco-Driving:** Autonomous vehicles accelerate and decelerate more smoothly, which greatly improves energy efficiency of the vehicle.
    - This would also fit well with driving patterns that are most comfortable for the vehicles' occupants.
- **Platooning:** Multiple vehicles travel close to each other, thereby gaining a major aerodynamic advantage.
    - Autonomous technology makes this safe, by allowing all the vehicles in the platoon to travel as a single vehicle
    - Particularly applicable to freight transportation
- **Light-weighting**
    - Autonomous features could make driving much faster, which would allow the removal of safety features, thereby making vehicles lighter and more efficient.
- Taken together, these could lead to energy savings per vehicle-kilometer travelled of around 20 percent. (Wadud et al, 2016)

The Trouble with Autonomous Traffic Efficiency

- **A "hard core" of devoted motorists** who are attached to the experience of driving, and would be very resistant to autonomous driving.
  - 50% of respondents in one survey cited reasons like this as reasons they would not use autonomous vehicles (Zmud and Sener, 2016)
- **Privacy issues**
  - To get the greatest possible benefits from these systems, it would be necessary to have the vehicles networked not only with each other but also with the road itself.
  - Privacy and autonomy are the largest objections that survey respondents have to using autonomous vehicles. (Webb et al, 2019; Kyriakidis et al, 2015)
- **Economic inequality**
  - There are already proposals to use "market-based" software to auction off places at autonomously-controlled intersections. (Dresner and Stone, 2006; Fajardo et al, 2011; Gettmann et al, 2018)

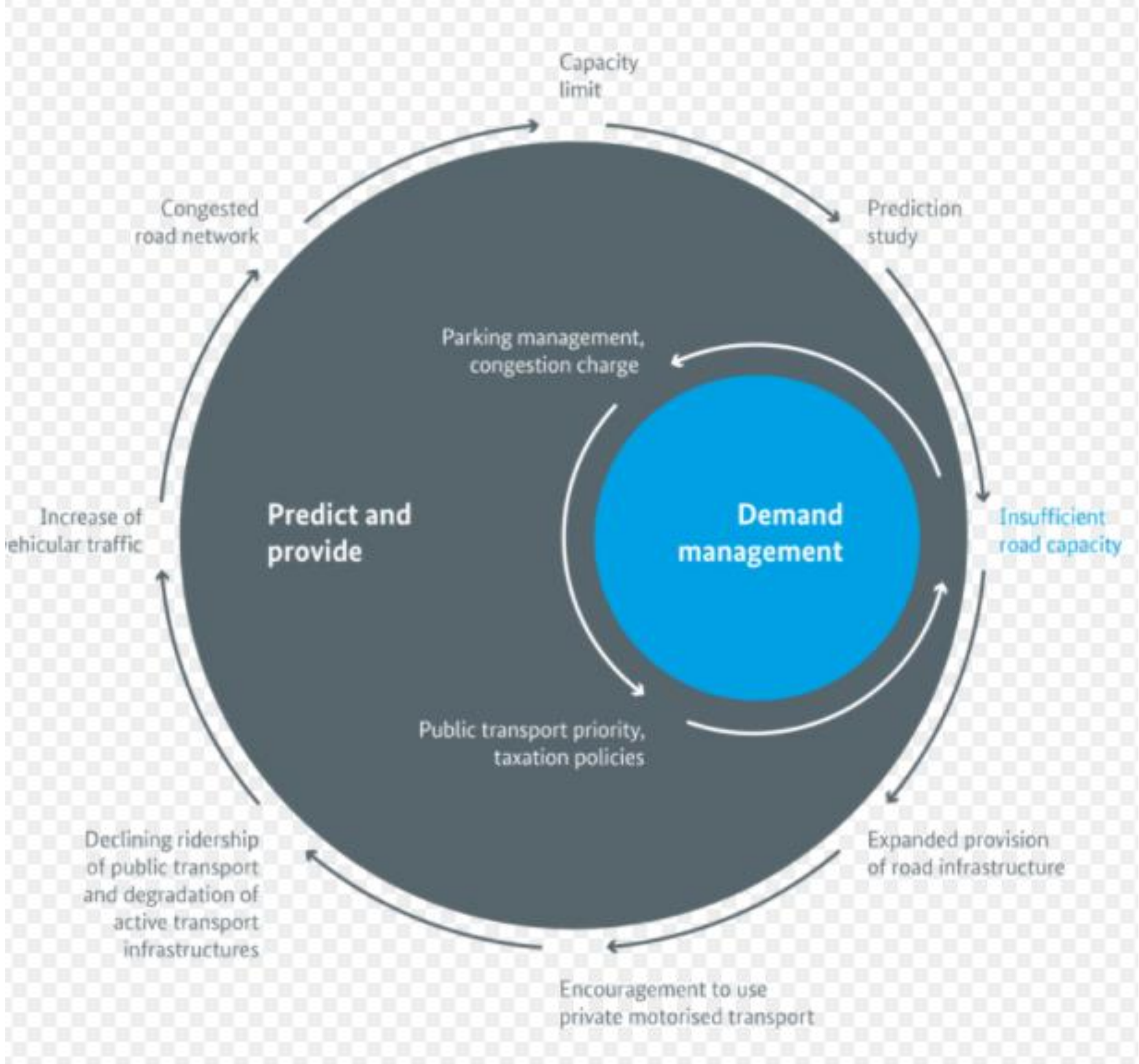


Light-Weighting

- Even if autonomous vehicles do, in fact, improve safety, three things need to happen for this to have an impact on energy efficiency:
    1. Policymakers have to take the **political risk** to repeal safety regulations
    2. Car companies have to take the **commercial and reputational** risks to market cars with reduced safety features
    3. These safety features have to not be replaced by other heavier features.
- Also: Safer traffic could also lead to the **loosening of speed limits**, which would reduce efficiency.

The Threat of Rebound Effects

- Robert Moses, 1948: “Today we are well underway to a solution of the traffic problem” (Smith, 2012).
  - At the time, he was talking about expanded road capacity.
- In practice, it doesn’t really work that way, due to the phenomenon of **induced demand.**
- More roads lead to more trips, which leads to more congestion.
- Autonomous relief of traffic congestion could run into the same problem.



Case 1: Limited Automation

Conclusion:

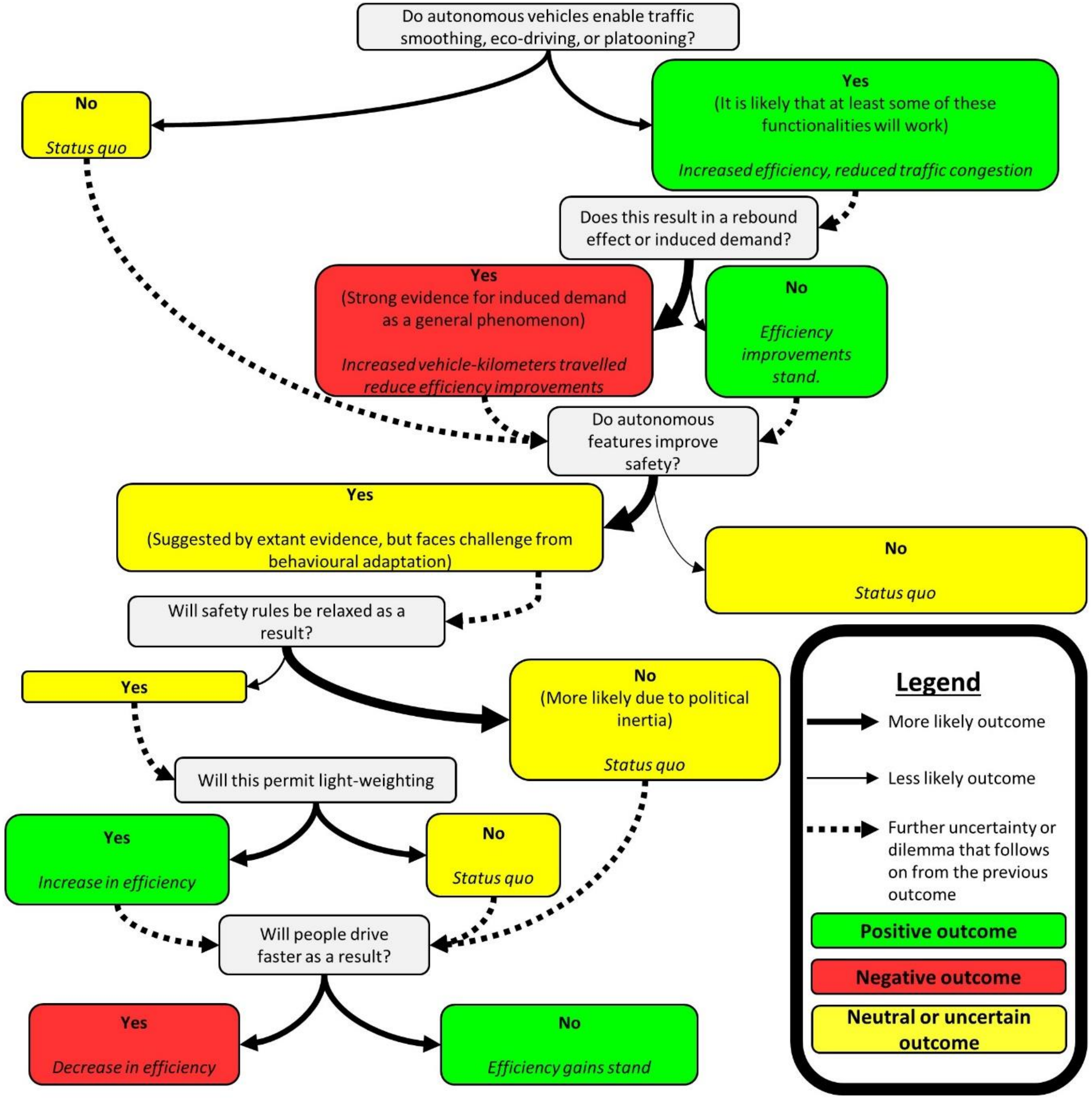
- At best, this offers marginal improvements in efficiency per vehicle-kilometer travelled, but would also increase total vehicle-kilometers travelled.
- The result is likely to be minimal changes (positive or negative) in total carbon emissions from road transportation.

Increase
(due to induced demand)

$$CO_2 = \frac{CO_2}{Energy} \times \frac{Energy}{VKT} \times VKT$$

Decrease
(due to efficiency improvements)

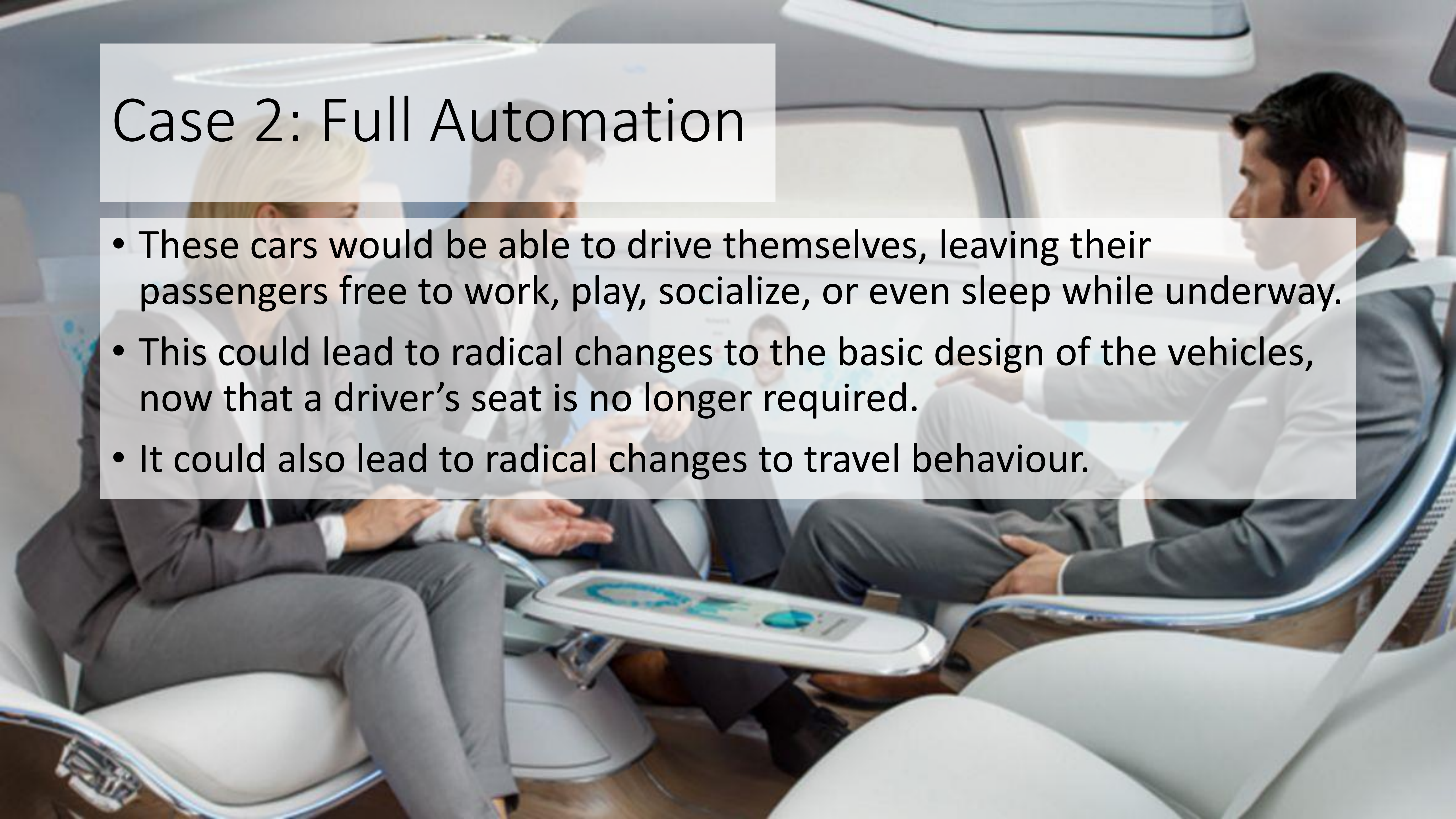
Case 1: Limited Automation



Case 2: Full Automation

Case 2: Full Automation

- These cars would be able to drive themselves, leaving their passengers free to work, play, socialize, or even sleep while underway.
- This could lead to radical changes to the basic design of the vehicles, now that a driver’s seat is no longer required.
- It could also lead to radical changes to travel behaviour.



Possible benefits from Full Automation

- Multiplication of all the gains (and hazards) of partial automation, discussed before.
  - Massive, coordinated traffic intelligence systems could radically reduce congestion
  - Even more impressive improvements to road safety.
- Would totally change the emotional experience of travelling by car, which could increase the incentive for greater efficiency.
  - A return to the acceleration capabilities of the 1980s would result in an increase in vehicle fuel efficiency of 23 percent!
- Could potentially lead to substitution of air trips with overnight car trips (since the occupants can sleep in the car)
  - There has been no serious modelling of this

Rights to the Road

- Fully autonomous vehicles have trouble realizing their most ambitious benefits if they have to interact with non-autonomous vehicles
  - Pedestrians and cyclists are particularly challenging here.
  - Some autonomous vehicle advocates have even suggested gates at crosswalks, or requiring cyclists and pedestrians to wear special “here I am” devices so that autonomous vehicles can recognize them.
  - The presence of non-autonomous vehicles would make the vision of stop-free autonomous intersections virtually impossible.
- So this gives us a few options:
  - Dedicated autonomous vehicle lanes (who would pay? Where would the land come from? What about when they intersect with conventional traffic?)
  - Banning non-autonomous vehicles altogether (Major political objections)
  - **Abandoning many of the efficiency gains that were promised.**
- **Remember: Pedestrians and cyclists have lower carbon emissions than autonomous vehicles.**

The Threat of Multitasking

- Multitasking is one of the most widely-cited benefits of autonomous driving that people look forward to (Cyganski, 2015; Hazan et al, 2016)
- The theory of induced demand depends critically on the **perceived cost of driving**
  - This cost is not only financial. Driving also costs **time, energy, aggravation, etc.**
  - So what happens to those perceived costs if you can travel by car while asleep? Or if your home office is also in your car?
- There is evidence that in such a scenario, people would radically increase the total distance they travel in several ways:
  - Every historical increase in the speed and convenience of personal mobility has led to increased urban sprawl (Laberteaux, 2014)
  - More long-distance recreational trips
  - Travel by classes of people who don’t currently use cars (drunk people, children, disabled people, etc.)
  - Changes to vehicle design…

Changes to Vehicle Design

- Vehicles designed for multitasking could have radically different interior setups.
  - Literally a mobile living room, according to some visions!
- This would have implications for efficiency.
  - Reduced aerodynamic performance
  - Increased weight

Honda's LeMobi Concept

Case 2: Full Automation

Conclusion:

- The potential efficiency gains from full automation are just as contingent as those from partial automation, although they are much larger.
- The downsides, however, appear much more certain.

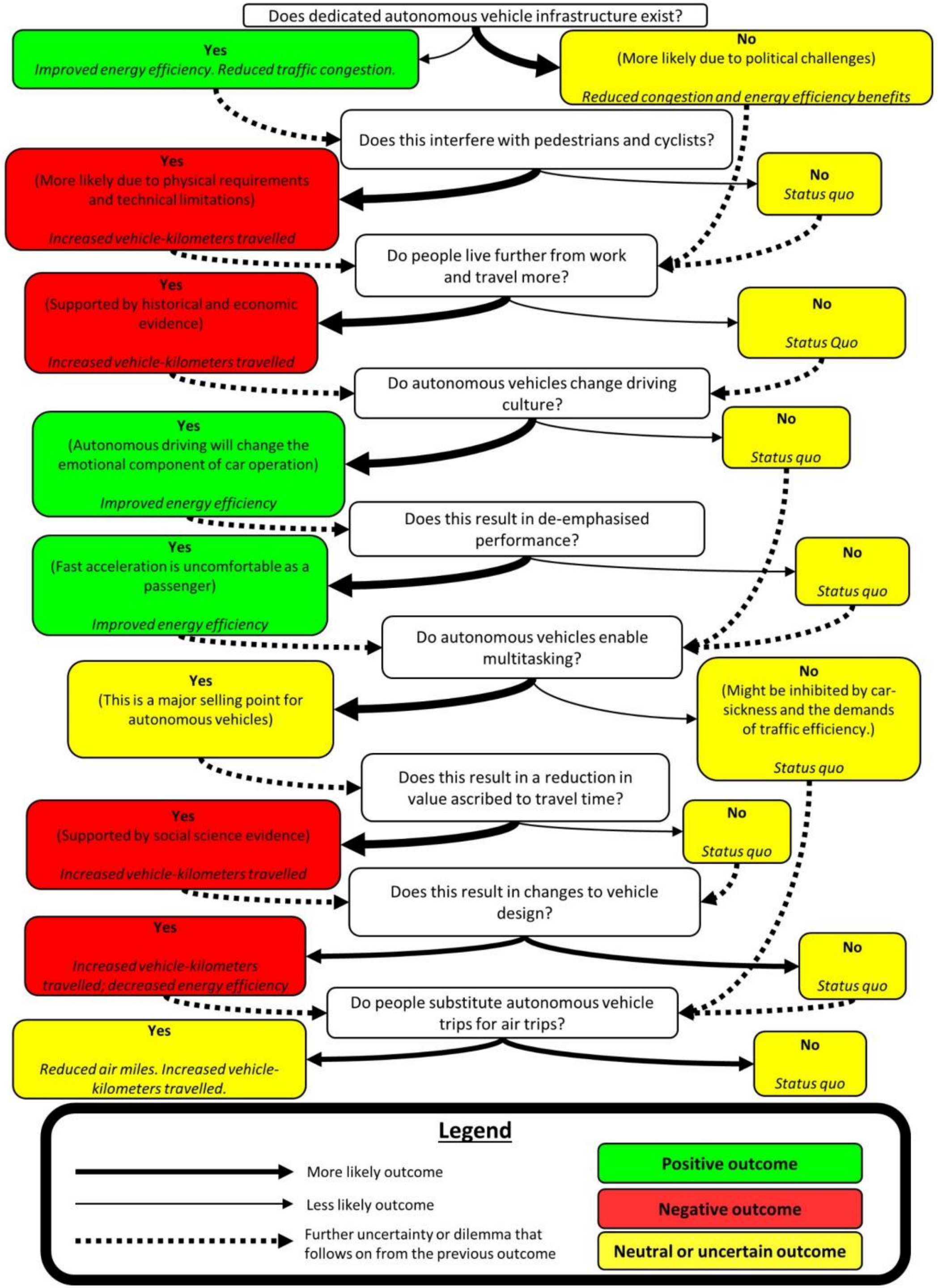
Increase
(due to larger vehicles)

Increase
(due to induced demand)

$$CO_2 = \frac{CO_2}{Energy} \times \frac{Energy}{VKT} \times VKT$$

Decrease
(due to efficiency improvements)

Case 2: Full Automation



Case 3: Full Autonomy

Full Autonomy: The Holy Grail

- The biggest proposed benefit for this technology involves a total re-envisioning of passenger mobility, taking advantage of the abilities of autonomous vehicles.
- This implies a few things:
  - Most people stop owning cars, because autonomous taxis are so available, convenient, and cheap
  - These autonomous taxis are all electric, both due to marginal fuel costs and due to the ease of automated charging vs. automated refueling
  - This results in a vastly improved efficiency of the vehicle fleet (currently most vehicles are idle for most of the time), which reduces embodied emissions.
  - Total vehicle-kilometers travelled could be further decreased through shared rides
  - This could result in reduced total trips by car, since the greatest predictor of car ownership is car use. (~cite)
- Synergies with public transit and other forms of mobility

Some Models of Shared Autonomous Mobility

- LaMondia et al (2016) used the Michigan travel survey to develop a statewide simulation of long-distance autonomous vehicle travel.
  - Found that travel time benefits of hands-free travel tend to outweigh monetary costs in the long run.
- Greenblatt and Saxena (2015) predict a rapid increase in autonomous vehicle market share, along with vehicle right-sizing. This would result in near-100% falls in greenhouse gas emissions.

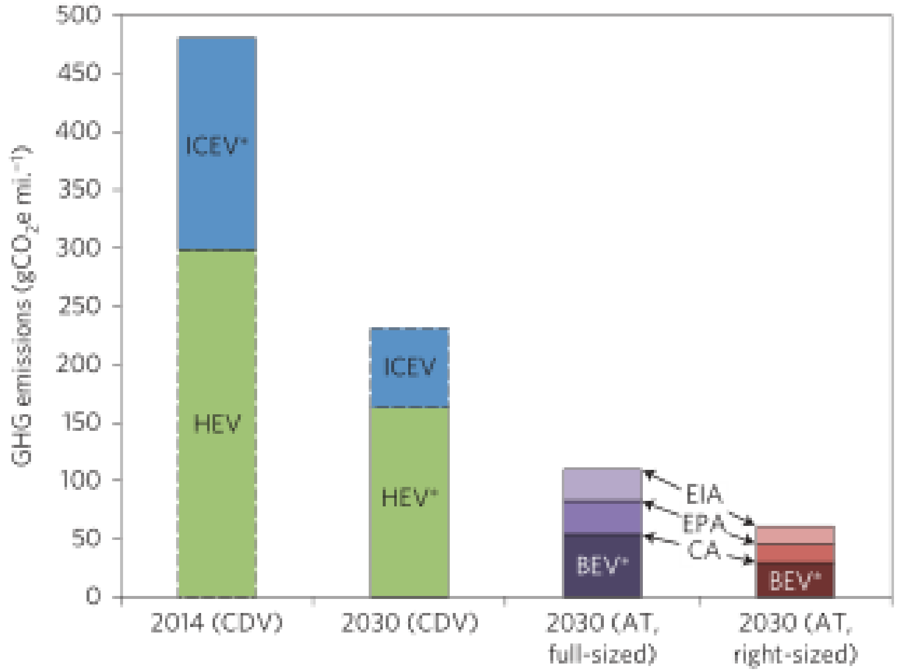


Figure 3 | GHG emissions intensities per mile for CDVs in 2014 and 2030, and ATs in 2030. Cost-optimal vehicle technologies indicated by asterisks. Both full-sized (purple) and right-sized (red) ATs are shown, each with three sets of electricity GHG intensity assumptions. Right-sized ATs have per-mile GHG emissions intensities 87–94% below 2014 ICEVs, and 63–82% below 2030 HEVs, depending on electricity GHG intensity.

Greenblatt and Saxena, 2015

Shared Autonomous Mobility

- Fagnant and Kockleman (2014) predict a 5.6% fall in emissions per vehicle due to shared autonomous vehicles.
- Burns (2012) did case studies for several communities:
  - Ann Arbor, MI: A fleet of 18,000 vehicles could provide almost instantaneous vehicle access, with an 80% cut in vehicle fleet from private vehicles.
    - Cost per customer per day would be $2 (vs. $21 for private vehicles)
  - Babcock Ranch, FL: A fleet of 3,000 and 4,000 vehicles would enable weight times of under a minute. Costs could be as low as $1 per trip.
  - Manhattan, NY: A fleet of 9,000 vehicles could yield wait times of 0.6 minutes, with costs of around $0.80 per trip.
- Arbib and Seba (2018): By 2030, 95% of US passenger-miles will be served by on-demand, electric, transport-as-a-service.
  - This will reduce energy demand by 80% and tailpipe emissions by 90%.

Box 3: A-ICE vs. A-EV for fleets

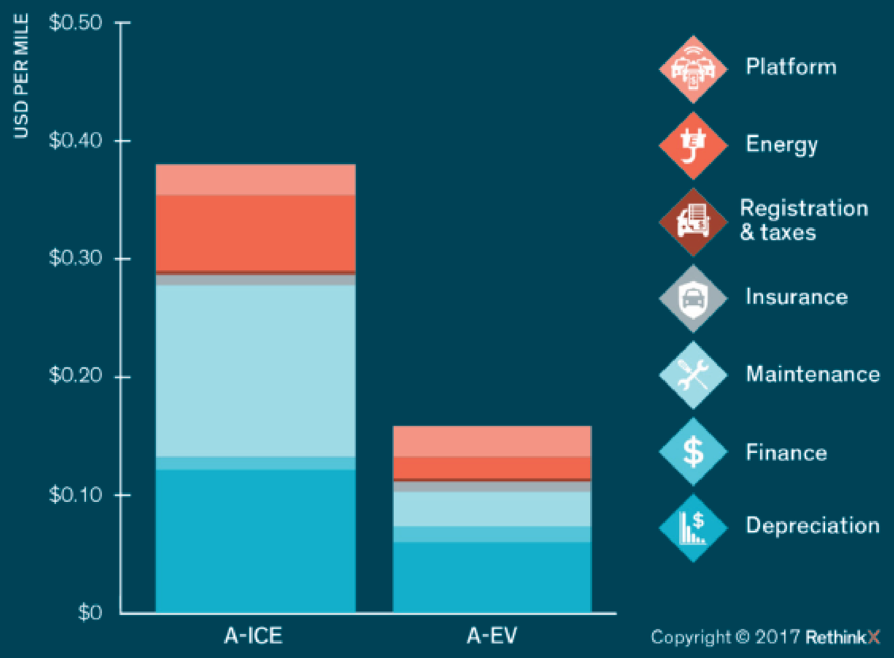
TaaS providers will choose A-EVs over A-ICEs

The key initial choice facing TaaS fleet operators is either to use A-EVs or to seek to place autonomous functionality into an ICE (A-ICE). It is likely that some ICE manufacturing companies will offer A-ICE in their fleets to preserve their existing ICE manufacturing investments. The comparison of costs in Figure 3 shows that A-EVs are far cheaper to operate. Furthermore, they offer greater reliability, reducing down-time or outages. We therefore predict that all TaaS vehicles will be A-EVs.

Figure 3. Relative costs-per-mile of A-ICEs vs. A-EVs[12]

Sources: Authors' calculations. For further details see Appendix A

» A-ICE vs. A-EV as basis for fleet choice in 2021



How likely is shared autonomous mobility?

	Estimate of cost per kilometer	Notes
Litman, 2015	$0.48-0.81	Considers cleaning costs, but not overhead.
Johnson and Walker, 2015	$0.24	Focuses on capital and operational costs. No cleaning or overhead.
Hazan et al, 2016	$0.46	Considers capital, operational costs, and overhead, but not cleaning.
Burns et al	$0.23-$0.47	Focuses on capital utilization and efficiency.
Bösch et al	$0.42-$0.57	Explicitly considers administrative overhead and cleaning.
Arbib and Seba, 2017	$0.08-$0.13	Focuses on advantages of shared autonomous vehicles over private cars, including vehicle utilization, longer lifetime mileage of cars, and cost reductions (finance, maintenance, insurance, fuel).
Dandl and Bogenberger, 2019	$0.36-$0.39	Considers capital, operational costs, and overhead, but not cleaning.
Bauer et al, 2018	$0.24-$0.50	Considers capital costs, operational costs, and administrative overhead, but not cleaning.

	Cost per km of shared autonomous vehicles	Percentage of people willing to rely on the system entirely
Johnson and Walker, 2016	$0.81	10%
Bansal et al, 2016	$0.81	13%
Bansal and Kockelman, 2016	$0.81	7.3%
Bansal et al, 2017	$1.62	3%
Bansal et al, 2018	$2.43	1.9%
Haboucha et al, 2017	$0.00	75%

Why People Like their Private Cars

- **Social status:** Car ownership has been a signaller of identity and status since at least the 1920s.
- **Storage:** People use their car not just to transport themselves, but also to transport their things.
- **A living space:** A car can be like a second living room, offering privacy, peace and quiet, etc.

- “I just kind of want my car all the time”, she says. Why? She offers a couple of reasons. First and foremost, is safety: What if 'in the middle of the night...there's an emergency [and] I have to get to the hospital' she asks. Besides, her car is like her personal office with all her stuff inside. 'Like a large purse,' another female panelist interjects. “Exactly!” says Gail. (KPMG, 2013)

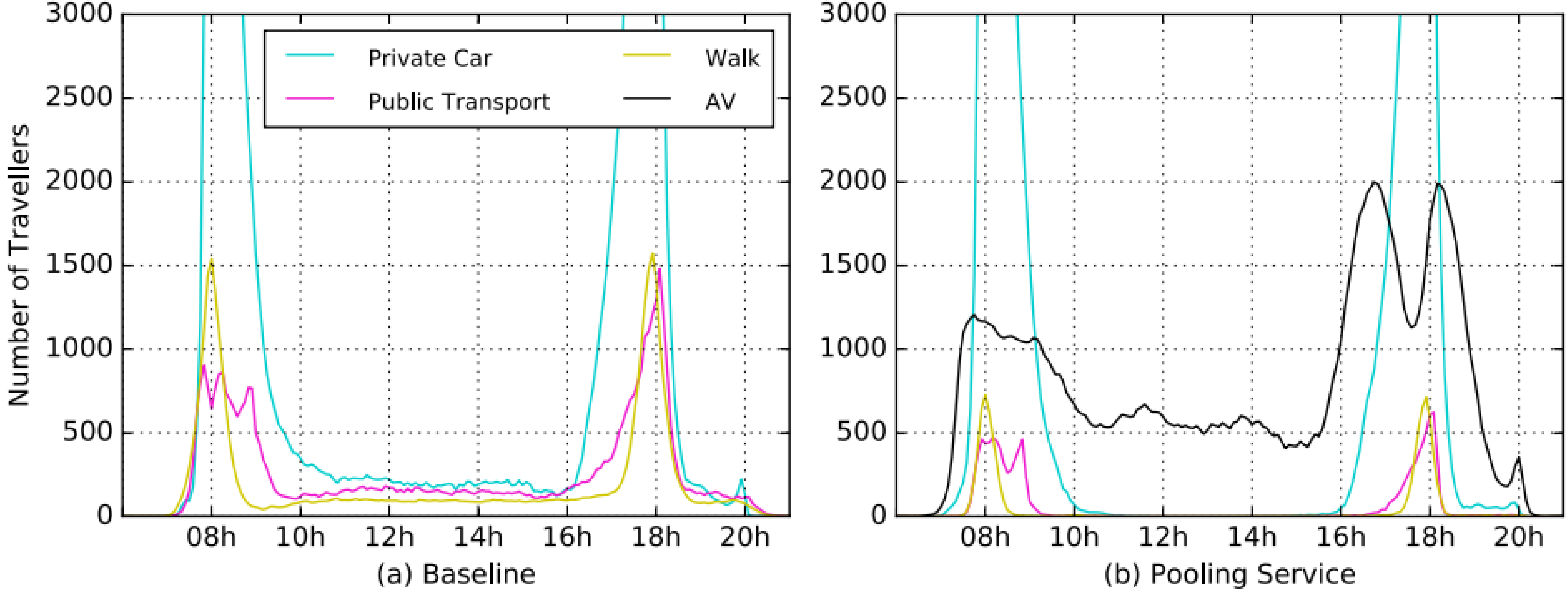
Shared Autonomous Vehicle Design

- Shared autonomous taxis would have to be "hardened" against vandalism and mess (Nordhoff et al, 2018).
    - This would mean they would most likely be less comfortable than people's personal vehicles.
    - If used for shared **rides,** they would also most likely need security features, which wouldn't help.
- Hypothetically, a "right-sized" vehicle should be far more efficient (and therefore cheaper) than a standard four-seater taxi. However:
    - The commercial penalties for having a vehicle show up that is too small would be severe.
    - Vehicle size and design is determined as much by constraints of vehicle **production** as it is by vehicle **use**
    - The four-seater car is standard in large part because of economies of scale in the car production industry.

Negative Climate Impacts of Shared Autonomous Mobility

- Induced demand: If travel becomes cheaper, then people will travel more.
    - All the aforementioned impacts of multitasking, reduced congestion, etc. still apply.
- Competition with other sustainable modes
    - Several studies have identified a severe competitive threat that autonomous vehicles would pose for public transit and active mobility (Hazan et al, 2016; Becker and Axhausen, 2017; Hörl, 2017).
    - Any price-point that out-competes private vehicles would also out-compete buses.
    - This is particularly problematic for cyclists and pedestrians, who might find themselves deterred and excluded from “autonomized” roads.
- Increased vehicle-kilometers travelled due to repositioning trips
    - Multi-destination trips pose major safety and security issues, especially for women.
- Some of this could be mitigated with electrification, but that has its own uncertainties.

Shared autonomous mobility vs. public transit



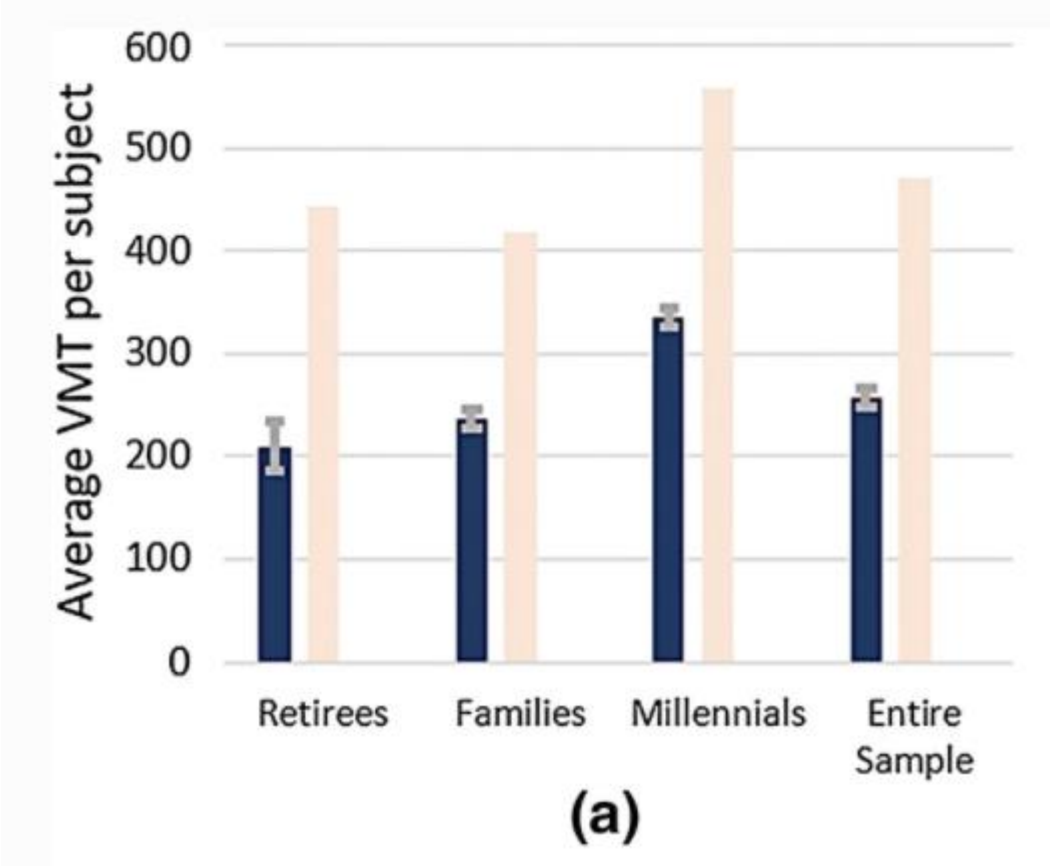
(Hörl, 2017)

Private Fully-Autonomous Vehicles

- Some words that are used in the literature to describe this scenario:
  - “Dystopian”
  - “Nightmare”
  - “Hell”
- If you don’t even have to be *in* the car to send it to do an errand, then the induced demand effects become catastrophic:
  - Cars sent to drive home every day rather than paying for parking
  - Autonomous drive-through errands
  - Etc
- GHG emission forecasts in this scenario could increase by more than 200%.

The Chauffeur Experiment

- Harb et al (2018) gave research participants 24/7 access to a personal chauffer to see how they would use an “autonomous” vehicle in their real lives.
  - “During the chauffeur week, we observed sizeable increase in vehicle-miles travelled and number of trips, with a more pronounced increase in trips made in the evening and for longer distances and a substantial proportion of ‘zero-occupancy’ vehicle-miles travlled”



Two Optimistic Scenarios

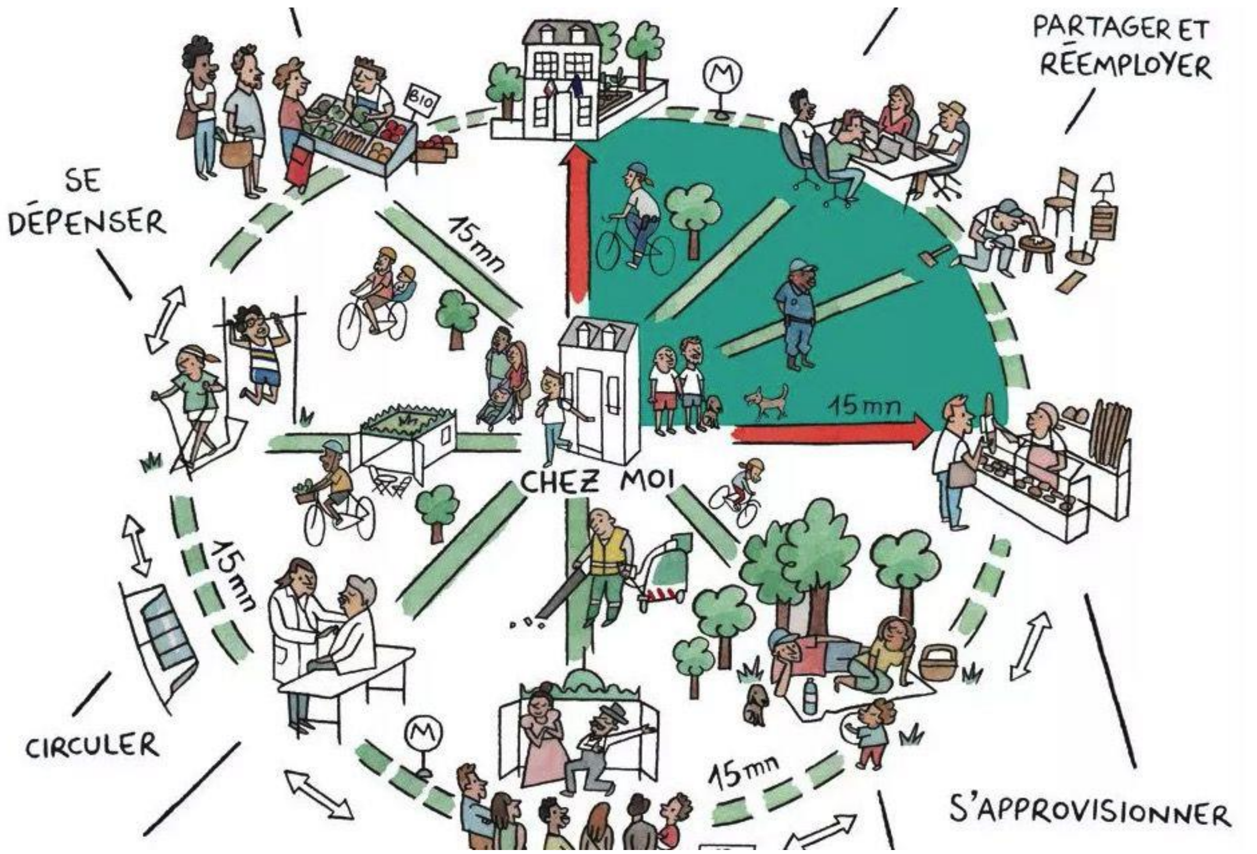
Last-Mile Autonomous Vehicles

- Small, slow, safe autonomous vehicles serve as a force-multiplier for public transit.
- These would solve the critical “last-mile” problem that is a major issue for public transit.
- If they operate only over short distances on residential streets, they can be much slower, and can simply stop if they come into problems.
    - This makes safety issues less pressing…
    - Which in turn means the system can be developed faster and sooner.
- This could solve the labour cost issue of existing micro-transit schemes.

Two Optimistic Scenarios

The 15-Minute City with Autonomous Vehicles

- Everyone, anywhere in a city, should be able to meet all their basic needs within 15 minutes of travel without a car.
- This requires big changes to the fundamentals of how cities are built.
  - **Not just density!**
- But there's a chicken-and-egg problem here: People with cars tend to use them, and therefore to pass over local businesses and services.
- If autonomous taxis start to undermine car ownership, it could reverse this logic.
  - Would require supportive policies on the municipal level.
- There is, as of yet, no serious investigation of this possibility. It involves a lot of "ifs".



Scenario 3: Full Autonomy

- Everything hinges on the viability of the shared model
  - But whether this actually appears in practice appears doubtful.
  - And the shared model has its own problems!
- Meanwhile, private full autonomy imposes massive risks of increased greenhouse gas emissions.

Increase
(due to induced demand and empty VKT, competition with other modes)

Shared scenario:

$$CO_2 = \frac{CO_2}{Energy} \times \frac{Energy}{VKT} \times VKT$$

Decrease
(due to electrification)

Decrease
(due to reduced fleet size)

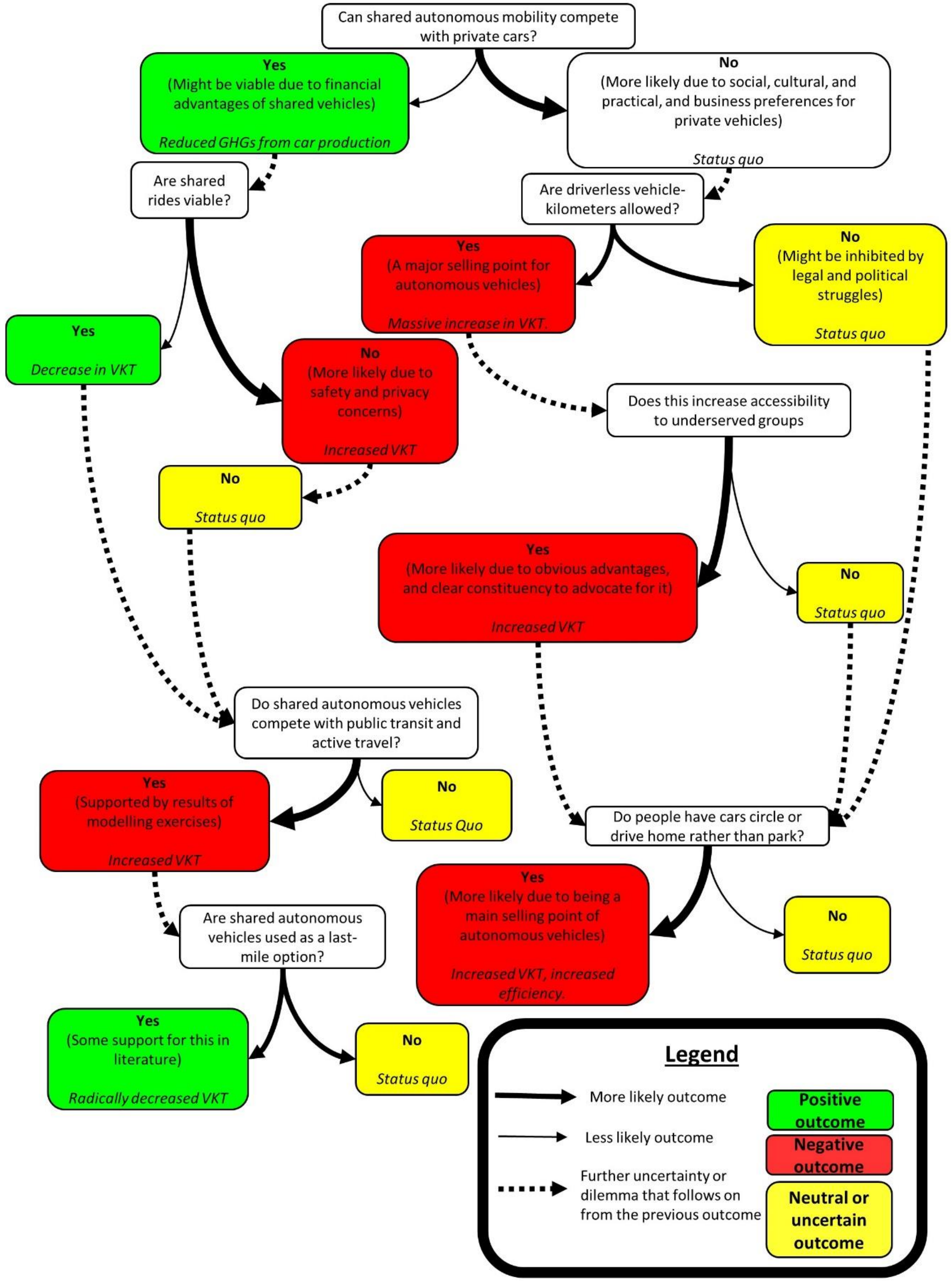
Increase
(due to changes to vehicle design)

Increase
(due to massive induced demand)

Private scenario:

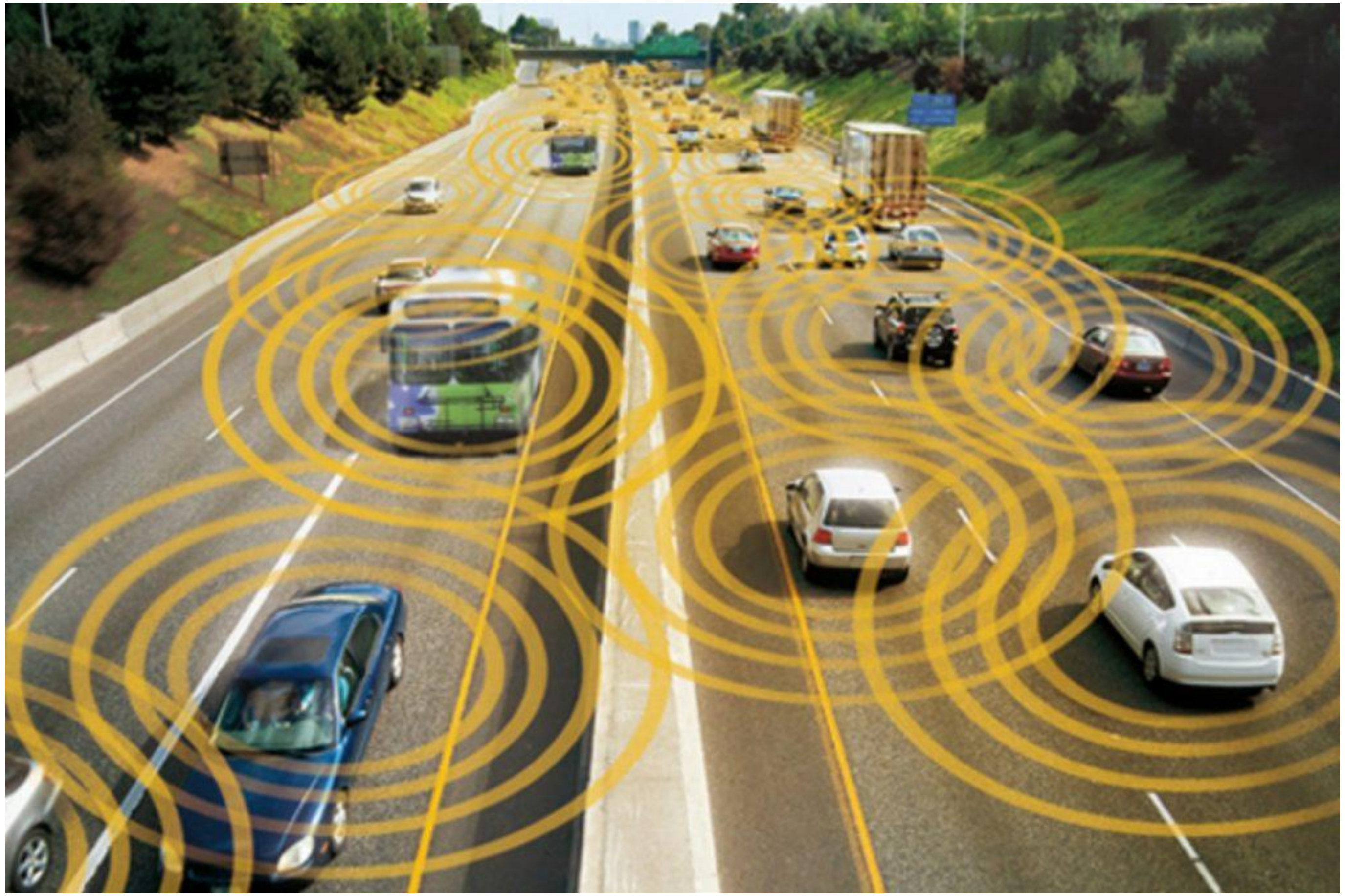
$$CO_2 = \frac{CO_2}{Energy} \times \frac{Energy}{VKT} \times VKT$$

Scenario 3: Full Autonomy



Conclusion

Conclusion



Conclusion

- The most likely climate benefits of autonomous vehicles (especially in the short-term) are relatively marginal, and will not meet global climate goals.
- The most dramatic potential environmental benefits of autonomous vehicles rest on a lot of “ifs”, and will probably require heavy policy interventions.
- The worst potential consequences of autonomous vehicles appear distressingly likely, based on the social science evidence.

Conclusion

- Autonomous vehicles are only a “holy grail” if we do **a lot** to overcome their tendencies to harm sustainability objectives.
  - This would mean major regulations to deal with induced demand, public transit competition, private autonomous vehicles, etc.
- **These interventions would be politically contentious.**
  - They would challenge people’s mobility habits, class status, and assumptions about how the world should work.
  - They would challenge the business models of major, powerful companies
  - They would challenge the earning potential of workers in massive and important industries.
- The takeaway: **Autonomous vehicles are not a shortcut around contentious mobility politics.**
  - But if we are already engaging with those political contests, why not focus on more reliable low-carbon mobility options that already exist?
- Autonomous vehicles, to the extent they are used, **should be a force-multiplier for other low-carbon modes.**
  - Last mile for public transit
  - Occasional long-distance or heavy-load trips for pedestrians and cyclists
  - An option for the elderly, people with young children, and people with disabilities.
  - Etc

With apologies to Monty Python…

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