UNDERSTANDING THE FUTURE OF AUTOMATED VEHICLES –BATTERY ELECTRIC, PLUG-IN HYBRID OR INTERNAL COMBUSTION ENGINES?

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I. INTRODUCTION

A PRESENT FUTURE

A lot is being said about the future of transportation and the displacement of people. Cars that are able to fly, as well as cars that can drive themselves have been in vogue for some time– nonetheless, people fail to realize that this is happening *now*. Experts tend to think that the future of transportation will be autonomous, shared and electric[1]. The truth is, there are a series of variables which need to be assessed before plainly asserting that tomorrow, cars will be driven by rechargeable robots.

Perhaps the best way to understand why autonomy is not as simple as many people think it is, it's because it is misrepresented. The public often thinks that autonomy is basically a car that has a computer system capable enough to drive itself around, with no need of human control. Sure, science already has made that type of technology available – there are zillions of test tracks where cars are self-driven by robots for 100 meters. But what if you take that same car, and put it not in a steady, straightforward path, but rather in a muddy, topographically challenged landscape, with adverse weather conditions, such as rain and wind? "The trouble with the 'full autonomy' phrase, is that it covers a wide spectrum of possible competencies", says Toyota's Research Institute CEO, Gill Pratt[2]. We will unravel the different levels of automation in the next section.

Upon connoisseurs, a common conclusion is that without vehicle electrification and shared mobility, autonomous vehicles alone will not realize their potential promising benefits for air quality and global greenhouse gas emissions.[3] The emission reduction scenario that

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[1] Peter Slowik, *The Future of Transportation: Autonomous and…Internal Combustion?* https://www.theicct.org/blog/staff/future-transportation-autonomous-internal-combustion

[2] Gill Pratt, *Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy*, https://spectrum.ieee.org/cars-that-think/transportation/self-driving/toyota-gill-pratt-on-the-reality-of-full-autonomy

[3] Lew Fulton, Jacob Mason and Dominique Meroux, *Three Revolutions in Urban Transportation*, pgs. 1-2, May 2017, https://steps.ucdavis.edu/wp-content/uploads/2017/05/STEPS_ITDP-3R-Report-5-10-2017-2.pdf

scientists and environmentalists are envisioning for autonomous vehicles may even turn out to be counterproductive, without the appropriate infrastructure and implementation policies, as we will further depict.

Concomitant to the above is the fact that autonomous cars, per se, consume a ton lot of energy. The amount of energy required for computers, sensors and processing mechanisms in order for a car to drive itself is colossal. If you add to that the energy required for it to be electrically self-propelled, then you more than double its electricity consumption. For many, (although possible), the feasibility of having an electrical car drive all by itself is farfetched – at least until more efficient computer programs for self-driven cars is developed.

Alas, many are of the opinion that notwithstanding the fact that we are heading towards fully electric automated vehicles, in the near future self-driven cars will still need an internal combustion engine. Absent a huge gain in battery storage capacities, it's likely that robotaxis will be gas-electric hybrids[4].

ARE WE READY?

As we see it, there are two different variables that are influencing the viability and availability of autonomous vehicles, and which will likely have a direct impact on their types of engine. Are we ready to have self-driven vehicles in the streets, both from a technological and a policy/regulatory perspective?

From a technological standpoint, and leaving aside the own hurdles the driving range poses on vehicle automation (which will be described later in detail), the main car manufacturers have announced ambitious timelines for releasing their autonomous fleets. Some analyses even project that within 10 years, 95% of US passenger miles will be driven by some kind of autonomous vehicle[5]. Ford, BMW, Toyota, Audi and Nissan have announced to launch self-driven cars by 2021, while other companies have envisioned an earlier date, such as Tesla and General Motors[6].

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[4] http://autoweek.com/article/autonomous-cars/brain-drain-autonomous-systems-require-lot-power

[5] James Arbir and Tony Seba, *Rethinking Transportation 2020-2030*, pg. 16, May 2017

[6] Idem, Pg. 70

Thus, it seems that the true barrier autonomous vehicles are encountering is regulatory, rather than a technological one. Skepticism on self-driven cars has often stemmed out of safety related concerns that driverless vehicles implicate. Fully autonomous vehicles are restricted in most countries at this time[7]. In the US, the Department of Transportation (DOT) released in 2016 the first Federal Automated Vehicles Policy, which outlines an approach to accelerate the transition to autonomous vehicles[8]. And in late 2017, they unveiled a new policy that permits companies developing autonomous vehicles to self-police the technology's safety[9].

More recently, and in recognizing the imminence of autonomous transportation, the DOT has taken concrete measures to insure that policy gets ahead of driverless technology. The National Highway Traffic Safety Administration (NHTSA) recently issued a request for comment (RFC) to identify any regulatory barriers in the existing Federal Motor Vehicle Safety Standards to the testing, compliance certification and compliance verification of motor vehicles with automated driving systems[10]. In recognizing the gaps in current regulation, this RFC is an undeniable effort to pave the legislative road to self-driving vehicles (no pun intendend).

At state level, Nevada was the first state to establish definitions and rules for autonomous vehicles, back in 2011[11]. The Michigan state legislature recently passed a law permitting automakers to operate networks of self-driving taxis within the state[12]. Florida and California, for their part, have declared autonomous vehicle testing legal. However, all involved parties recognize that the current patchwork of regulations is a huge barrier for the successful advancement of autonomous cars[13].

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[7] Lew Fulton, Jacob Mason and Dominique Meroux, *Three Revolutions in Urban Transportation*, pgs. 10, May 2017, https://steps.ucdavis.edu/wp-content/uploads/2017/05/STEPS_ITDP-3R-Report-5-10-2017-2.pdf

[8] Peter Slowik and Fanta Kamakaté, *New Mobility: Today's Technology and Policy Landscape*, The International Council on Clean Transportation, pg. 11, July 2017

[9] Ryan Beene, *U.S. To Let Automakers Self-Police Self-Driving Car Development*, September 12, 2017, https://www.bloomberg.com/news/articles/2017-09-12/u-s-to-let-automakers-self-police-self-driving-car-development

[10] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/av-barrier_removal_rfc-jan_10_1133.pdf

[11] Peter Slowik and Fanta Kamakaté, *New Mobility: Today's Technology and Policy Landscape*, The International Council on Clean Transportation, pg. 10, July 2017

[12] Lew Fulton, Jacob Mason and Dominique Meroux, *Three Revolutions in Urban Transportation*, pgs. 10, May 2017, https://steps.ucdavis.edu/wp-content/uploads/2017/05/STEPS_ITDP-3R-Report-5-10-2017-2.pdf

[13] Peter Slowik and Fanta Kamakaté, *New Mobility: Today's Technology and Policy Landscape*, The International Council on Clean Transportation, pg. 11, July 2017

II. DECODIFYING AUTOMATION

The technological implications of self-driven cars (and thus, what distinguishes them from ordinary vehicles) is precisely what experts challenge and differ in opinion on whether they will be all electric, plug-in hybrid or internal combustion engines.

This section aims to depict the different variables which shape automated vehicles, providing an overview of their functioning mechanism and the challenges that come with it. In doing so, we will assess the implications of automation applied in the different forms of propulsion; all electric, plug-in hybrid or conventional engines, when (if) applicable.

A. Functioning/Mechanism

Levels of Automation

Automation is not a black and white concept; there are several different levels of autonomy, as we know it. In an effort for standardization and clarity, the Department of Transportation adopted the Society of Automotive Engineers' international classification system for autonomous vehicles[14]. Pursuant to the aforementioned, currently we can find the following levels of autonomy[15]:

Level 0: No Automation: Zero autonomy; the driver performs all the driving tasks.

Level 1: Driver Assistance: Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.

Level 2: Partial Automation: Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all time.

Level 3: Conditional Automation: Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicles at all times with notice.

[14] Peter Slowik and Fanta Kamakaté, *New Mobility: Today's Technology and Policy Landscape*, The International Council on Clean Transportation, pg. 3, July 2017

[15] https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

Level 4: High Automation: The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.

Level 5: Full Automation: The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

The abovementioned classification is not trivial for this paper. To the contrary; given the fact that energy consumption and the level of autonomy are directly proportional, the type of engine (electric, plug-in hybrid or ICE) that best suits each level will vary, as we will later see.

Computer Processing System Mechanism

The ability for a car to drive itself basically depends on intertwined mechanisms that perform three main functions: sensing, perception and decision[16].

The *sensing* feature of a vehicle involves its ability to localize itself in space and its surroundings, performing functions such as mapping, localization, obstacle avoidance and object recognition, among others. In an autonomous vehicle, the following sensors often worked combined: GPS/IMU[17] systems; LiDAR[18] technology; cameras; radar and sonar systems[19].

The *perception* stage/function processes the gathered sensor data in order to understand the vehicle's environment. Its main tasks are localization, object detection and object tracking[20].

[16] Shaoshan Liu, Jie Tang, Zhe Zhang and Jean-Luc Gaudiot, *CAAD: Computer Architecture for Autonomous Driving*, pg. 1

[17] Global Positioning System and Inertial Measurement Unit

[18] Light detection and ranging. It works by bouncing a laser beam off of surfaces and measures the reflection time to determine distance.

[19] Shaoshan Liu, Jie Tang, Zhe Zhang and Jean-Luc Gaudiot, *CAAD: Computer Architecture for Autonomous Driving*, pg. 2

[20] Shaoshan Liu, Jie Tang, Zhe Zhang and Jean-Luc Gaudiot, *CAAD: Computer Architecture for Autonomous Driving*, pg. 2

Finally, the equipment must engage in decision making tasks that will determine the actual action the vehicle will make. The *decision* stage mainly consists in prediction, path planning and obstacle avoidance tasks. Obstacle avoidance tasks include both a proactive level (based on traffic predictions), and a reactive mechanism, that operates if the former fails[21].

As we will describe in the next section, the amount of energy required to perform the aforementioned basic autonomous functions is, to say the least, a whole lot.

B. Energy Consumption of Automation

The energy use and emission impact of automated vehicles will be based on the type of fuel used to power the vehicle, as well as the vehicle efficiency, vehicle miles traveled and consumer travel behavior.[22] Autonomous vehicle technology may also provide opportunities for increasing vehicle travel efficiency. Leading transportation researchers and forecasts are showing that the deployment of automated vehicles could have a significant impact on transportation energy use and emissions. Whether this results in a dramatic increase or decrease in emissions may be highly dependent on fuel type and the strength of public policy intervention, as well as the public transportation infrastructure used by these vehicles[23].

A recent bounding study conducted by several U.S. national labs concluded that the deployment of highly automated vehicles (in the absence of electrification) could lead to a 300 percent increase or 50 percent decrease in fuel use[24].

Vehicle Efficiency

Imagine having 50 to 100 laptops running simultaneously in the back of your car. That is what experts say is the equivalent of energy consumption in autonomous vehicles[25]. The energy drain by the sensors and computers is massive, and increases as we go higher in

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[21] Shaoshan Liu, Jie Tang, Zhe Zhang and Jean-Luc Gaudiot, *CAAD: Computer Architecture for Autonomous Driving*, pg. 3
[22] U.S. Department of Energy, Energy Information and Administration, *Study of the Potential Energy Consumption Impacts of Connected and Automated Vehicles*, March 2017
[23] For example, see work by Zia Wadud, Don MacKenzie, and Paul Leiby (2016) https://www.sciencedirect.com/science/article/pii/S0965856415002694
[24] https://www.nrel.gov/docs/fy17osti/67216.pdf
[25] https://www.bloomberg.com/news/articles/2017-10-11/driverless-cars-are-giving-engineers-a-fuel-economy-headache

the automation levels. That is why it is not rare to find level 1 or 2 automation cars driving around, but are much more challenged to encounter from level 3 upwards.

This computing power implicates actual *electric* power – we are talking around 2 to 4 kilowatts of electricity, for the lower automation levels[26]. Aside from the problem of battery storage capacity, this power drain by autonomous vehicles is actually running counterproductive from the ever more stringent fuel economy standards that developed countries are currently seeking. "*In essence, fuel economy requirements are pulling the engineers of electric and hybrid cars in one direction, while the race towards greater automation is pulling energy demands in another direction*"[27].

Henceforth, it seems that absent a huge gain in battery storage capacity, that will enable to serve both the autonomous and the the electric operation of the car, it is likely that vehicles will be gas-electric hybrids[28].

Aside from the energy drain that comes inherent to autonomous vehicles, due to their particular gear, there are a series of other factors that have a direct influence on the total energy consumption – perhaps the more notorious one, is the vehicle miles traveled.

Vehicle Miles Traveled

Several studies have come to the conclusion that autonomous vehicles will increase the total amount of miles travelled (VMT, or the aggregate of number of miles driven by vehicles in a given year)[29], although this still remains uncertain. The factors that will have an impact on that include the reduced travel costs, higher speed highways, longer commuter distances, car and ride sharing, and the inclusion of previously underserved user groups[30], all of which would lead to significant more driving.

Because full automation relieves the "driver" of operating the vehicle, individuals may have greater tolerance for longer trips due to their ability to engage in other tasks other than driving and, as travel comfort and tolerance increases with vehicle automation, people may be willing to travel more frequently and for further distances[31].

[26] http://autoweek.com/article/autonomous-cars/brain-drain-autonomous-systems-require-lot-power
[27] http://autoweek.com/article/autonomous-cars/brain-drain-autonomous-systems-require-lot-power
[28] http://autoweek.com/article/autonomous-cars/brain-drain-autonomous-systems-require-lot-power
[29] Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016
[30] U.S. Department of Energy, Energy Information and Administration, *Study of the Potential Energy Consumption Impacts of Connected and Automated Vehicles*, March 2017, pg. iv
[31] Peter Slowik and Fanta Kamakaté, *New Mobility: Today's Technology and Policy Landscape*, The International Council on Clean Transportation, pg. 18, July 2017

A particular thought-provoking scenario is the incorporation of a new class of vehicle users. In a fully autonomous scenario, the elderly, young and disabled would be able to travel alone, severely increasing the number of people on the road[32]. Even zero occupant vehicles may also emerge as a new source of traffic[33].

The emergence of car and/or ride sharing services, which is also expected to be one of the side effects of automation, poses its own set of hurdles. "While the number of vehicles on the road could decline, overall distance travelled by the autonomous vehicles could increase"[34]. This contributes to the overall uncertainty that surrounds the projections for autonomous vehicles and carbon emissions.

Car sharing services will also produce the aggregate effect of reducing the overall transportation costs, having a direct effect in travel patterns and transportation behavior of the people. While nowadays pedestrians and bikers are currently in the rise, they could easily shift toward a more faster (yet affordable) transportation method, such as car sharing. In a 2016 study carried out by Google, each of their self-driving test vehicles drove an average of 10,000 to 15,000 autonomous miles per week[35]. According to the Federal Highway Administration, as of July 2016, the average U.S. driver drives 13,476 miles *annually*[36].

Carbon Emissions

Needless to say, the VMT augmentation redounds in a direct increase in carbon emissions. "On its own, autonomous vehicle technology will not significantly affect carbon emissions from light-duty vehicles; however, the application of the technology will herald changes in how Americans travel from one place to another"[37].

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[32] Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016

[33] Lew Fulton, Jacob Mason and Dominique Meroux, *Three Revolutions in Urban Transportation*, pgs. 9, May 2017, https://steps.ucdavis.edu/wp-content/uploads/2017/05/STEPS_ITDP-3R-Report-5-10-2017-2.pdf

[34] Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016

[35] Google, "*Google Self-Driving Car Project Monthly Report: January 2016*" (2016), available at https://static.googleusercontent.com/media/www.google.com/en//selfdrivingcar/files/reports/report-0116.pdf, as cited by Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016, pg. 14

[36] Federal Highway Administration, *Average Annual Miles per Driver by Age Group*, available at https://www.fhwa.dot.gov/ohim/onh00/bar8.htm, as cited by Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016, pg. 14

[37] Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016, pg. 11

Efficient Energy Consumption

Not all energy usage in autonomous vehicles has a negative aspect. Eco-driving may change the energy output in autonomous vehicles through its different applications, such as platooning. This consists in a group of vehicles traveling close together to minimize aerodynamic drag[38]. Platooning may be achieved through vehicle to vehicle connectivity, by which information received by the car's sensors is processed in order to make the vehicles courses of action. There are different types of vehicle connectivity; vehicle to infrastructure ("V2I"); vehicle to vehicle ("V2V"), and even vehicle to pedestrian ("V2P") technology[39]. The direct consequence of these communications is the decrease in braking, which is a direct waste of energy[40]. Other benefits include safety, due to crash avoidance and decrease in congestion.

One study estimates that at least 90% of car accidents will be reduced, because 94% of collisions are related to human error[41].

The main problem, of course, is the viability of all this. Absent a national autonomous fleet, all of the aforementioned benefits seem to dissipate. "The potential benefits depend in part on the level of fleetwide automation achieved and whether the vehicles are able to communicate with each other and their surrounding infrastructure"[42]. Even worse; in the short term, to the extent that autonomous vehicles join the fleet without displacing traditional vehicles, the congestion could worsen[43].

Driving Range

Yet perhaps the biggest challenge autonomous vehicles pose in regards to their energy usage, is precisely the amount of it involved in the different driving ranges. This is a strong

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[38] Peter Slowik and Fanta Kamakaté, *New Mobility: Today's Technology and Policy Landscape*, The International Council on Clean Transportation, pg. 5, July 2017

[39] Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016

[40] US Department of Energy, Energy Information and Administration, *Study of the Potential Energy Consumption Impacts of Connected and Automated Vehicles*, March 2017, pg. 44

[41] James Arbir and Tony Seba, *Rethinking Transportation 2020-2030*, pg. 62, May 2017

[42] Anderson and others, *Autonomous Vehicle Technology*, cited by Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016

[43] Anderson and others, *Autonomous Vehicle Technology*, cited by Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016

reason to believe that, absent new technologies that enhance the energy storage capacities or refueling in self-driven vehicles, their engines will remain with a fuel powered engine.
As Toyota's Gill Pratt puts it, "Not all miles are the same"[44]. Whereas driving in an interstate highway has a steady flow of energy – because of the speed limits, road conditions and closed, favorable environment surroundings – not all driving scenarios are the same. The terrain, weather, traffic and overall environment that surrounds a vehicle directly affects its energy requirements. A rocky path needs that the sensors be vibrant-resistant; a foggy and rainy road, that they double their precision efforts; and a cold, below freezing point surrounding will require powerful software. Actually, cold weather reduces a battery range, which reduces the time a car can be on the road[45].
As many experts see it, all-electric vehicles do not have yet the capacity do self-drive themselves around on all landscapes. The energy drain by their sensors, when exposed to harsh exterior conditions, is too much to be borne by an all electrical engine. Without a revolution in battery technology, it seems that engines will still require a fuel back-up engine to drive that extra mile.

Costs

Finally, where all comes to rest. Even assuming there is a technological revolution and the computer hardware capacities increase in a way that will tolerate self-drivelessness and electric vehicles combined, the cost of automation is too far-fetched for the average American car owner. Once again, though, the studies are not conclusive. One of them[46] estimates strong cost reductions over time, due to the decline in the price of its key components, such as LiDAR technology. But as of today, even though lithium ion battery packs have fallen in price by about 80% since 2010, they still remain expensive[47].

The big expenditure seems to be only at the beginning, though. Due to the complexity of the autonomous computing system, the upfront costs of purchasing a self-driven vehicle are notably more than ordinary cars, which lack that technology.

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[44] Gill Pratt, *Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy*, https://spectrum.ieee.org/cars-that-think/transportation/self-driving/toyota-gill-pratt-on-the-reality-of-full-autonomy

[45] Robert Ferris, *Ford says Hybrids Beat Electric for Self-Driving Cars*, https://www.cnbc.com/2017/12/11/ford-says-hybrids-beat-electric-for-self-driving-cars.html

[46] Lew Fulton, Jacob Mason and Dominique Meroux, *Three Revolutions in Urban Transportation*, pgs. 10, May 2017, https://steps.ucdavis.edu/wp-content/uploads/2017/05/STEPS_ITDP-3R-Report-5-10-2017-2.pdf

[47] *Electric Cars May Stall Without Battery Revolution*

Operating and maintenance costs appear more favorable than upfront ones. One study suggests that autonomous electrical vehicles have longer lifetimes and lower maintenance costs, at 20% of the equivalent internal combustion engine[48]. The same study has an interesting projection: *"As autonomous vehicles gain a bigger market share and safety improves dramatically, hardware requirements that were engineered under the assumption that there would be millions of car crashes per year will be less important. Metal that was used to increase vehicles' body strength and weight will be shed, resulting in lower manufacturing costs"*[49]. This surely sounds promising.

Maintenance cost is also linked to the mechanical complexity of the vehicles. "After disassembling General Motor's Chevrolet Bolt, UBS Group AG concluded it required almost no maintenance, with electric motor having just three moving parts compared with 133 in a four-cylinder internal combustion engine"[50].

In regards to the operating costs, the most optimistic studies have demonstrated that self-driving vehicles could end up costing only US $ 0.60 per mile[51].

Yet there are factors external to the vehicles physiognomy that influence the cost of driverless transportation. The charging infrastructure needed to support fully-electric and autonomous fleets implicates a massive expenditure of public funds. Due to their shorter driving range (because of their electricity consumption), streets and freeways would have to be well equipped with charging stations and proper gear that will assure cars will not be left adrift. Most likely, these costs will be transferred to the general public, either by indirect taxes, tolls, or even fees, that will increase the overall cost of this transportation.

C. Automakers Ambitions and Announcements

It is fair to say that currently, car makers are shifting significant research and investment toward innovative design for driverless vehicles. The main automaker companies have

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[48] James Arbir and Tony Seba, *Rethinking Transportation 2020-2030*, pg. 61, May 2017

[49] James Arbir and Tony Seba, *Rethinking Transportation 2020-2030*, pg. 21, May 2017

[50] Jess Shankleman and Hayley Warren, How Electric Cars Can Create the Biggest Disrution Since the iPhone, https://www.bloomberg.com/news/articles/2017-09-21/how-electric-cars-can-create-the-biggest-disruption-since-iphone?utm_source=Master+Contacts&utm_campaign=437e27e126-Newsletter_2017_12_19&utm_medium=email&utm_term=0_43f9bc72fb-437e27e126-34004274, Sept. 21, 2017

[51] Fred Lambert, *A ride in a Self-Driving Tesla Model 3 on a 'Tesla Network' Could end up Costing only $0.60 per Mile*, https://electrek.co/2016/10/28/tesla-model-3-self-drivin-ride-tesla-network-cost-per-mile/, October 28, 2016

anticipated that they are bringing driverless cars to the roads as soon as this year (Tesla), and a few the years that follow (Honda; Nissan; Toyota; Volvo; BMW; General Motors and Ford, among others)[52]. And although all of them agree that their fleets are shifting towards being autonomous, they have not been made similarly strong commitments toward electric propulsion method. Perhaps, this is due to the scientific uncertainty that haunts this technology. Yet while some of them have broadcasted ambitious announcements regarding all-electrical engines, the majority have been quite cautious, recognizing the energy hurdles that an all-electrical autonomous fleet may pose upon their cars.

General Motors has been perhaps the most aggressive one. The Chevy-Bolts are targeted to be its primary all-electric autonomous vehicle platform, out in 2019, although not without challenges: the chief technology architect of autonomous systems at GM revealed that their first autonomous vehicles utilized around 3 to 4 kW of electric power for their self-driving system. If you project that for 20 hours, it could end up using the entire 60 kW capacity of the Bolt battery, even before the car moves. However, they are positive and moving forward towards their next autonomous vehicle's equipment using less power[53]. They are even experimenting with new, cheaper sensor technology, in an attempt to rely less on their extremely expensive LiDAR sensors: while the currently cell cost of the Bolt battery is about $ 145/kWhr, their new, improved battery system will cost less than $ 100 per kWhr[54]. According to Electrek[55], with both electric power and autonomous driving, GM aims to bring the cost of travel per mile under $1.00.

Ford, on the other hand, has recognized that "The most important thing is uptime and profitability[56]. For them, applying hybrid-electric technology to their self-driving vehicles is a much better cost-of-ownership model than all electric, because they have longer ranges, maximizing the mileage to keep the vehicle on the road[57]. In Ford's eyes, pairing

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[52] Myriam Alexander-Kearns, Miranda Peterson and Alison Cassady, *The Impact of Vehicle Automation on Carbon Emissions*, Center for American Progress, November 2016, pg. 7

[53] Andrew J. Hawkins, *Not All of Our Self-Driving Cars will be Electrically Powered – Here's Why*, https://www.theverge.com/2017/12/12/16748024/self-driving-electric-hybrid-ev-av-gm-ford, December 12, 2017

[54] https://electrek.co/2017/11/30/gm-electric-vehicle-autonomous-driving-tesla/

[55] https://electrek.co/2017/11/30/gm-electric-vehicle-autonomous-driving-tesla/

[56] James Farley, as interviewed by Michael Martinez for Autonews; December 11, 2017, *Hybrids are Better for Autonomy, Ford Says*, http://www.autonews.com/article/20171211/OEM06/171219941/ford-hybrid-autonomous-technology

[57] James Farley, Executive Vice President and President of Global Markets, Ford Motor Company, https://medium.com/self-driven/optimizing-our-self-driving-vehicle-to-better-serve-you-3f5d394e1df0

autonomous systems exclusively with electric cars is restrictive as a business model[58]. At least for now. “Hybrids are the right tech to start with”[59].
The Volvo Car Group has signed a framework agreement with Uber, to sell up to 24,000 autonomous driving XC90 vehicles between 2019 and 2021[60], but the announcement was silent as to the propulsion method of the fleet.
Waymo has launched a public trial of 100 autonomous Chrysler Pacifica[61], which are plug-in hybrid, while Volkswagen is developing the “V-Charge” project, which focuses on a car system that allows self-driving valet services and automated electric vehicle charging.

Meanwhile, the alliance of Renault, Nissan and Mitsubishi has announced a plan to produce a fleet of electric, autonomous and robotic vehicles, using a shared platform[62]. This union aims to collaborate in the development of state-of-the-art autonomous and electric vehicles, projected to be out in the market by 2022.

Hyundai, on the other hand, has stated that because of the power requirements of autonomous vehicles, a full battery-electric propulsion system likely will not work for them, for which they will momentarily stick with the plug-in hybrids. “We are developing the fully autonomous technology, the driverless car – (SAE) Level 4 and Level 5, but as of now the power consumption is really huge, it can go up to 1 kW or 2 kW, so it could dramatically decrease the driving range of EVs” [63], said Woongjung Jang, director-advanced driver assist systems for Hyundai. And while he recognizes that although technological improvements will likely make next generation chips to dramatically reduce power consumption, it will not be at the rate Hyundai wants.

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[58] http://autoweek.com/article/autonomous-cars/brain-drain-autonomous-systems-require-lot-power

[59] James Farley, as cited by Gabrielle Coppola and Esha Dey, *Driverless Cars are Giving Engineers a Fuel Economy Headache*, October 11, 2017, https://www.bloomberg.com/news/articles/2017-10-11/driverless-cars-are-giving-engineers-a-fuel-economy-headache

[60] Volvo Press Release, November 20, 2017, https://www.media.volvocars.com/global/en-gb/media/pressreleases/216738/2348206974

[61] Peter Slowik, *The Future of Transportation: Autonomous and…Internal Combustion?*, January 16, 2018, https://www.theicct.org/blog/staff/future-transportation-autonomous-internal-combustion

[62] Sam Sheehan, *Renault-Nissan-Mitsubishi to Invest £8.9bn in electric and Autonomous Cars*, September 15, 2017, https://www.autocar.co.uk/car-news/new-cars/renault-nissan-mitsubishi-invest-%C2%A389bn-electric-and-autonomous-cars

[63] Woongjung Jang, cited by Christie Schweinsberg, *Hyundai: Electrical Consumption, Cost to Slow AV Rollout*, November 27, 2017, http://wardsauto.com/technology/hyundai-electrical-consumption-cost-slow-av-rollout

Not surprisingly, Tesla is going all electric. This makes sense, since Tesla began as an electric car company before it ventured into autonomous driving systems.[64] It's Enhanced Autopilot is an upgrade of the original version, although it does not guarantee not to require human intervention at extreme circumstances. Still, "The system is designed to be able to conduct short and long distance trips with no action required by the person in the driver's seat"[65].

And the announcements add and continue.

D. Conclusion
An Uncertain Future

As we see it, the main hurdle autonomous vehicles present (although not the only one), is their energy consumption, which, in turn, is the variable which shapes the viability of them being electric or not. Of *all* the challenges presented by autonomous technology, we think that almost all of them are directly influenced by the unavailability of a constant energy input/supply-chain: electricity requirement is massive, yet battery capacity is limited. Limited battery capacity triggers the need to charge them many times a day. Multiple charging brings its own set of problems: on the one hand, it considerably decreases the battery lifetime, by deteriorating its shelf life. On the other hand, it also requires a nationwide battery charging infrastructure, which nowadays is hard to imagine.

Battery charging also poses an inconvenience to 21st century citizens, which are dramatically time-obsessed: fueling up an internal combustion engine takes about 3 to 5 minutes, while charging an electric vehicle may take anywhere between 30 minutes and 12 hours[66].

In many ways, then, it seems that for the next decades, hybrid gasoline-electric vehicles are the ones which make more sense.

Not only for car users, but also for car makers. Absent a revolutionary technological improvement in autonomous computing systems, one that is not so energy hungry – or better yet; absent a true revolution in battery storage capacities and efficiency, it seems that all-

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[64] http://autoweek.com/article/autonomous-cars/brain-drain-autonomous-systems-require-lot-power

[65] https://www.tesla.com/en_CA/autopilot?redirect=no

[66] https://pod-point.com/landing-pages/how-long-does-it-take-to-charge-an-electric-car

electric autonomous vehicles are, for the moment, not worth it. Not for the time, and certainly, not for the cost. “Autonomy and battery power could end up being at odds”[67].

Many experts agree, however, that hybrid-electric vehicles make sense for the *first* driverless cars[68]. Certainly, once new technology and scientific improvement help to better meet the power-hungry needs of autonomous vehicles, it is likely that their propulsion methods will shift towards all electric.

Raj Rajkumar, an engineering professor at Carnegie Mellon University stated that “[Autonomous vehicle] equipment can consume anywhere from about 500 watts to 1,500 watts, depending upon the sensor configuration, processors used and whether GPUs are used and how many […] This power draw is neither negligible nor substantial enough for serious concern in a typical AV.[69]”

And as Andrew Hawkins has put it, “Economies of scale, and not commitment to environmentalism, will determine how many driverless cars are powered by electricity, and how many are not”[70].

The solution, for now, appears to be gasoline-electric hybrids before a big enough breakthrough in battery technology is achieved that will offer plenty of range and autonomous functions for pure electric vehicles[71].

It seems that the hope of “all electric and all autonomous”, though plausible, will have to wait. The current infrastructure, policy, regulation and overall technology available seems insufficient to sustain fleets of completely autonomous, and completely electric cars. How many years will we have to wait? We are not sure. Though we know where we are heading

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[67] Gabrielle Coppola and Esha Dey, *Driverless Cars are Giving Engineers a Fuel Economy Headache*, October 11, 2017, https://www.bloomberg.com/news/articles/2017-10-11/driverless-cars-are-giving-engineers-a-fuel-economy-headache

[68] Sam Jaffe, cited by Gabrielle Coppola and Esha Dey, *Driverless Cars are Giving Engineers a Fuel Economy Headache*, October 11, 2017, https://www.bloomberg.com/news/articles/2017-10-11/driverless-cars-are-giving-engineers-a-fuel-economy-headache

[69] Raj Rajkumar, cited by Andrew J. Hawkins, *Not All of Our Self-Driving Cars will be Electrically Powered – Here’s Why*, https://www.theverge.com/2017/12/12/16748024/self-driving-electric-hybrid-ev-av-gm-ford, December 12, 2017

[70] Andrew J. Hawkins, *Not All of Our Self-Driving Cars will be Electrically Powered – Here’s Why*, https://www.theverge.com/2017/12/12/16748024/self-driving-electric-hybrid-ev-av-gm-ford, December 12, 2017

[71] http://autoweek.com/article/autonomous-cars/brain-drain-autonomous-systems-require-lot-power

to, we do not know how fast we'll get there. It all depends on a conundrum of roles that legislators, automakers, scientists and we, normal car users, have a direct influence upon.