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ARE ELECTRIC VEHICLES REALLY THE ANSWER?

HIGHLIGHTS

- In 2015, there were 1.2 billion cars spread across every country on earth. We estimate that in 2017 this count rose to 1.4 billion.
- In 2017, Canada had ~34 million registered vehicles, of which 66% were machines less that 4,500kg, which we use as the proxy for personal transportation. B.C. is different, with 80% of registered vehicles counted as a personal vehicle.
- The transportation sector, its vehicle composition, trends, technology, economic and environmental impacts is an important area of conversation and public policy debate because of its associated greenhouse gas emissions. Globally, transportation represents 23% of all greenhouse gas emissions. In Canada the figure is 24%; in B.C it is 40%.
- Like some other countries and sub-national jurisdictions, B.C. now has a strategy targeted at the sales of more zero/low emissions vehicles — 10% of all vehicle sales by 2025, rising to 30% by 2030 and to 100% by 2040. The first target is probably achievable; the last looks remarkably optimistic.
- The commonly used term "zero emissions" is a misnomer. The main benefits of ZEVs come from reduced operating emissions and improved local air quality. But the overall environment footprint of ZEVs depends, crucially, on how electricity is produced.
- Should B.C. achieve its targets, emissions reductions from the transport sector would be real given our >95% carbon-free electricity system. But the total capital costs to consumers (via purchase prices) and taxpayers (via subsidies) of getting there are likely to be massive. Are consumers willing and able to make the necessary trade-offs in an accelerated transition?
- In the end, an increasing number of low/zero emissions vehicles will be part of B.C.'s transportation mix, but this shift is not a panacea and no electric vehicle Valhalla awaits. Electrifying transportation is another component of a complex policy and regulatory landscape for managing greenhouse gases.

CONTEXT

Greenhouse gas emissions — their levels, distribution, and sources, primarily carbon dioxide (CO_2) from fossil fuels — are a focus of many conversations and policy discussions these days. In and of itself, carbon dioxide is not a pollutant – in fact, it's essential for life, and almost every human being and living creature on earth emits it as a by-product of energy transformation or uses it as an ingredient to create sugar and oxygen, as plants do.

The challenge is the fine balance of atmospheric gases needed to sustain life and the incongruence with rising emissions from the continually expanding needs (and wants)[1] of a growing global population. The effects of modern lifestyles, by those who already enjoy these comforts and those who aspire to the same high standard of living, have involved the use of the internal combustion engine (ICE) and its energy source, fossil fuels, for transportation and some other activities. Together, the ICE and fossil fuels are responsible for much human advancement over the last 150 years, with the personal automotive ICE delivering more useful work than all other mobile and stationary prime movers combined.[2]

Definitions

Carbon is not the same as greenhouse gases. Carbon is a chemical element with symbol C and atomic number 6. It is non-metallic and tetravalent—making four electrons available to form covalent chemical bonds. It belongs to group 14 of the periodic table.

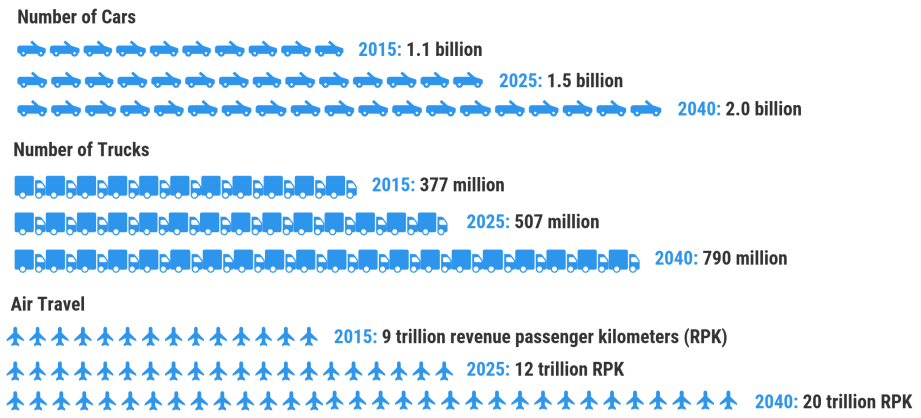
Greenhouse gases are a collection of gases, **carbon dioxide** (CO_2) is among the group. CO_2 is a colourless gas with one carbon atom and two oxygen atoms (element 8 in the periodic table).

[1] https://www.bcbc.com/content/2710/EEBv8n5.pdf.
[2] Smil, Vaclav. Energy Transitions. History, Requirements, Prospects. Praeger. 2010 (p.90).

The personal automobile has been around in some form since the mid 1700's – steam-powered to begin with, and like most innovations, evolving ever since. In its more modern form, the first gasoline-powered internal combustion engine car became a reality in the late 1880s. But as a mass-produced, on-demand mobility method, the personal automobile is only 105 years old, dating from 1913 when The Ford Motor Company sold its first Model T.

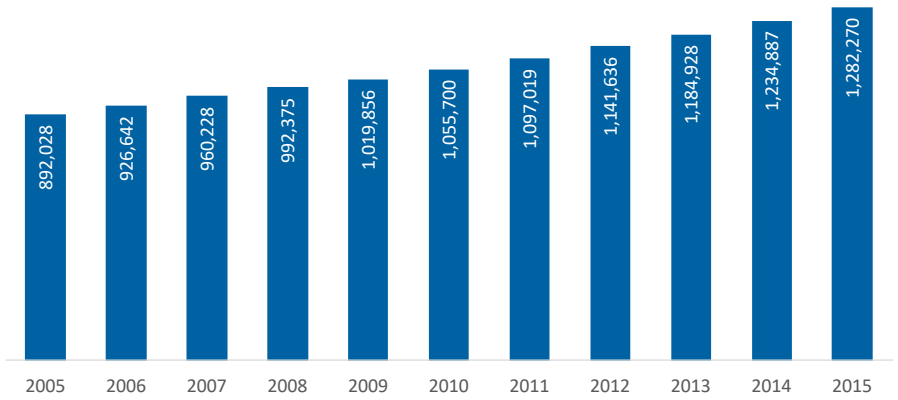
It is hard to imagine modern life without the ubiquitous personal vehicle and its many conveniences. It is a mark of status like no other, a symbol of progress, a connector of people, a mover of goods, and a facilitator of trade and commerce. Modern countries depend on them, developing nations increasingly do so too. Cars are one of the world's largest export products and account for almost 4% of global GDP.[3] Most urban centres are designed around and for the automobile. Canada's auto industry generates >$20 billion, annually, towards our GDP, mostly in manufacturing but it also supports related economic activity spanning insurance, auto repair and sales, etc. The industry is engaged in continuous innovation as it responds to consumer preferences, new technologies, and changing regulatory requirements (e.g., efficiency and other non-GHG emissions).[4] Car ownership is an important part of "embourgeoisement" and has enormous effects on personal and professional mobility. In short, we have a complex relationship with the car.

FIGURE 1: **WORLD ECONOMIC FORUM FORECAST OF VEHICLES**



Source: World Economic Forum.

FIGURE 2: **NUMBER OF VEHICLES IN THE WORLD (000'S)**



Source: International Organization of Motor Vehicle Manufacturers.

NUMBER OF LIGHT DUTY VEHICLES — WORLD

It took only about two generations for humans to convert physical labour to machine labour. By 1950, people and working animals accounted for about 1% of all useful work. Today, the world's most numerous fuel-powered working machines are gasoline-fueled sparking engines found in passenger cars and light trucks and diesel engines in cars, heavy trucks, trains, ships, and heavy machinery. By 2010, the aggregate count of these machines was about 1 billion, with the installed world-wide capacity exceeding 150 TW.[5] By 2015, this count rose to 1,282,270[6] of which 74% consisted of passenger cars/trucks/light duty vehicles and 26% of commercial vehicles — trucks

[3] Saberi, Behzad. The role of the automobile industry in the economy of developed countries, May 2018. https://medcraveonline.com/IRATJ/IRATJ-04-00119.pdf.
[4] Canadian Vehicle Manufacturers' Association, https://www.cvma.ca/industry/facts/; Statistics Canada.
[5] Smil, Vaclav. Energy Transitions. History, Requirements, Prospects. Praeger. 2010 (p.127/8).
[6] International Organization of Motor Vehicle Manufacturers, http://www.oica.net/.

and buses. The increase in the total number of vehicles between 2005 and 2015 was a whopping 44%, equal to a 4% growth per year — car ownership has outpaced global population growth by three times over the same period.[7] In 2017, there were almost 1.4 billion vehicles on the world's roads. On the current trajectory, by 2040 the World Economic Forum says the number of cars will nearly double, while both the global trucking fleet and the number of passenger miles flown by air will more than double.[8]

LIGHT DUTY VEHICLES — CANADA AND B.C.

In 2017, Canada had 34,320,737 registered vehicles.[9] Of these, 66% were machines weighing less than 4,500 kg — we use this weight classification to capture the average household/personal vehicle. British Columbia had 3,705,906 registered vehicles, of which 80% are less than 4,500 kg. As in many other jurisdictions, between 2005 and 2015 the number of vehicles in Canada and B.C. grew. The percentage increases over the 10-year period were 28% and 24%, respectively. This is compared to 44% for the world, as noted above. Interestingly, the proportion of total personal vehicles weighing <4,500 kg declined by about 4% in Canada and by 3% in B.C. over the same 10-year period, with more people shifting to larger vehicles. For example, in 2017, 10 of the 15 most popular brands sold in Canada were SUVs, vans, or trucks.

TABLE 1: **TOTAL NUMBER OF REGISTERED VEHICLES IN CANADA AND B.C., BY TYPE, 2017**

	Canada	% of Registered Vehicles	B.C.	% of Registered Vehicles
Total, vehicle registrations	34,320,737		3,705,906	
Total, road motor vehicle registrations	24,566,696	71.6%	3,208,699	86.6%
Vehicles weighing less than 4,500 kilograms	22,678,328	66.1%	2,964,236	80.0%
Vehicles weighing 4,500 kilograms to 14,999 kilograms	605,353	1.8%	122,159	3.3%
Vehicles weighing 15,000 kilograms or more	471,541	1.4%	43,516	1.2%
Buses	90,925	0.3%	10,211	0.3%
Motorcycles and mopeds	720,549	2.1%	68,577	1.9%
Trailers	7,514,793	21.9%	442,987	12.0%
Off-road, construction, farm vehicles	2,239,248	6.5%	54,220	1.5%
The number of electric vehicles in Canada as of the third quarter of 2017 was 35,000. There is limited public data on the number of EVs currently registered in B.C. One estimate suggests about 8,500 with about half of these electric only and the balance hybrids. (Source: Fleetcarma, https://www.fleetcarma.com/electric-vehicles-sales-update-q2-2018-canada/.)				

Source: Statistics Canada, Road motor vehicle registrations, by type of vehicle, Annual, Table: 23-10-0067-01.

TRANSPORTATION AND GREENHOUSE GAS EMISSIONS

Why is the number of vehicles on the roads important? The simple answer is — because they are a major source of greenhouse gas emissions, largely emitted from personal ICE vehicles.

Globally, transportation is responsible for 23% of energy-related emissions and growing.[10] For Canada, transportation accounts for about 24% of GHG emissions and, in 2015, light-duty vehicle emissions (i.e., personal automobile) made up ~50% of Canada's transportation-related greenhouse gas emissions, and 12% of total emissions.[11]

B.C. is different. Transportation generates 40% of the province's GHG emissions. Emissions from light-duty cars and trucks amount to 15% of all provincial emissions (and to 55% of road emissions), while heavy-duty industry transportation emissions represent about 13% of total emissions (45% of road emissions).

Most nations that have made commitments under the Paris climate change agreement have placed a

[7] Since 2005 global population has risen 13%.
[8] https://www.weforum.org/agenda/2016/04/the-number-of-cars-worldwide-is-set-to-double-by-2040.
[9] Statistics Canada, Road motor vehicle registrations, by type of vehicle, Annual, Table: 23-10-0067-01.
[10] Tracking Clean Energy Progress 2017, International Energy Agency, https://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2017.pdf.
[11] https://www.canada.ca/en/transport-canada/news/2017/05/government_of_canadatodevelopanationalzero-emissionsvehiclestrat.html.

priority on transportation, with a bias toward mitigating the effects of emissions from passenger vehicles. For developed countries, a transition of the economy-wide fleet to electric is often cited as a key goal. For developing countries, the focus is on urban public transit, such as bus rapid transit systems.[12] Regardless, vehicles are an important factor when thinking about greenhouse gas emissions management.

But let's be clear: the idea of zero emissions, while appealing to some, is not about zero emissions, more about marketing. The life-cycle emissions from electric vehicles (EVs) are fewer than for ICE vehicles, but not by much according to some recent research. So, we really should use the term FOEVs — fewer operating emission vehicles, rather than zero emissions.

Indeed, FOEVs are much quieter and they emit no tailpipe emissions. This is good for local air quality like nitrogen oxides, ozone formation, and particulates. *But FOEVs are only as clean as their electricity source.* In addition, related exploration, extraction and processing of the materials, including rare earth metals, that go into their sophisticated electronics and large batteries, need to be considered as these related activities can have significant environmental impacts.[13] A 2012 study[14] concluded:

- The GWP [global warming potential] from EV production [is] 87 to 95 grams of carbon dioxide equivalent per kilometer (g CO2-eq/km), which is roughly twice the 43 g CO2-eq/km associated with [internal combustion engine vehicles] production.
- Batteries contribute 35% to 41% of the global-warming potential of the production phase of an EV; by comparison, the electric engine contributes only 7% to 8%. Other powertrain components, notably inverters and the passive battery cooling systems with their high aluminum content, contribute 16% to 18% of the embodied GWP of EVs.

TABLE 2: **B.C. GREENHOUSE GAS EMISSIONS, CO2e, KILOTONNES AND % OF TOTAL B.C. EMISSIONS**

	2016 Total (kt)	% of total B.C. emissions
Total B.C. Emissions (all sources)	62,264	
Transport	**24,890**	**40%**
Road Transportation	17,291	27.8%
Light-Duty Gasoline and Diesel Vehicles, Trucks and Motorcycles	*9,443*	*15.1%*
Heavy-Duty Gasoline and Diesel Vehicles	*7,842*	*12.6%*
Propane and Natural Gas Vehicles	*6*	*0.01%*
Domestic Aviation	1,331	2.1%
Railways	789	1.3%
Domestic Navigation	949	1.5%
Other Transportation	4,530	7.3%
Off-Road Agriculture, Forestry, Manufacturing, Mining, Construction, Other	*2,653*	*4.3%*
Pipeline Transport	*1,445*	*2.3%*
Off-Road Commercial & Institutional	*291*	*0.5%*
Off-Road Residential	*141*	*0.2%*

Source: 1990-2016 GHG Emission Summary for British Columbia, Province of B.C.

Modern Energy Use and Households

Modern energy use has seen a steady decline of industrial and agricultural consumption and increasing claims of transportation and household sectors. For example, in the 1950s industries consumed more than half of the world's primary commercial energy, at the time of the first oil crisis (1973) their share was about one-third, and by 2010 it declined to about 25%. Major appliances (refrigerators, electric stoves, washing machines) became common in the United States after World War 1, in Europe only after World War II, and private car ownership followed the same trend. As a result, by the 1960s households became a leading energy using sector in all affluent counties. (Smil)

[12] Tracking Clean Energy Progress 2017, International Energy Agency, https://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2017.pdf.
[13] Most of the world's cobalt production comes from the Democratic Republic of the Congo, where human rights and labour conditions are questionable at best.
[14] Hawkins. Troy R. Singh, Bhawna. Majeau-Bettez, Guillaume. Hammer Strømma, Anders. Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles, Journal of Industrial Ecology, https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1530-9290.2012.00532.x.

- Because production impacts are more significant for EVs than for conventional vehicles, assuming a vehicle lifetime of 200,000 km exaggerates the [environmental] benefits of EVs to 27% to 29% relative to gasoline vehicles or 17% to 20% relative to diesel because production-related impacts are distributed across the longer lifetime.
- An assumption of 100,000 km [lifetime use] decreases the benefit of EVs to 9% to 14% with respect to gasoline vehicles and results in impacts indistinguishable from those of a diesel vehicle.
- EVs powered by the present European electricity [in 2012 this was about 75% fossil fuels] mix offer a 10% to 24% decrease in global warming potential (GWP) relative to conventional diesel or gasoline vehicles assuming lifetimes of 150,000 km.

More recent work corroborates this and notes, "the energy and GHG benefits of EV introduction are less than usually assumed."[15]

TARGETS AROUND THE WORLD

The common conclusion since the Paris accord is that the advanced economies must reduce wheel-to-wheel emissions by more than 20% by 2025 to offset continued emissions growth of more than 18% in non-OECD countries.[16] While this outcome seems unlikely, it is notable that a growing number of countries have adopted EV/ICE banning targets:

- Australia: no new ICE vehicles sold after 2020
- United Kingdom: no new ICE vehicles (excludes hybrids) sold after 2040
- China: end production and sales of ICE vehicles after 2040
- Costa Rica: initiate phase out of ICE vehicles by 2021
- Denmark: 5,000 EVs on the road by 2019
- France: no new ICE vehicles sold after 2040
- Germany: no registration of ICE vehicles allowed after 2030
- India: no new ICE vehicles sold after 2030
- Ireland: no new ICE vehicles sold after 2030
- Israel: no ICE imports after 2030
- Netherlands: no new ICE vehicles sold after 2030 with phase out started in 2025
- Norway: only EVs available for sale as of 2025
- Scotland: no new ICE vehicles sold after 2032
- South Korea: EVS to account for 30% of vehicle sales by 2020
- Taiwan: phase out of fossil fuel ICE vehicles by 2040.

We can add British Columbia to the list, with its November 2018 transportation policy response setting FOEV sales targets, which in practical terms means electric vehicles only (eventually). These targets are: 10% of new vehicle sales by 2025, 30% by 2030, and 100% by 2040. What this implies is that in 2025, 7,000 new car purchases must be electric; by 2030 this rises to 23,000, and by 2040 to 90,000.[17] On the current path, 10% is probably achievable by 2025, whereas 100% by 2040 looks very optimistic even if the targets are mandated in legislation.

For some perspective, in 2018 Canadian EV-only sales were 17,000 units; Q3 2018 sales in B.C. were 2,500 units.[18] For a variety of reasons, including price, reliability, and carrying capacity given many consumers' preference for larger, heavy vehicles, B.C. consumers may simply shop in Alberta or neighbouring states for less expensive used and new gasoline and diesel vehicles. Also, outside the Lower Mainland and other urban centres (e.g., Kelowna), EVs may not make sense given their limited range and cold-weather performance issues. In the long-run, poorly thought out public policy could make B.C. into a kind of "Cuba-north", where ICE vehicles are kept on life-support for decades, with their owners having to cross into the USA or Alberta for fuel and parts.

THE COST OF REPLACING ICE VEHICLES

It is ironic that today's best-in-class vehicles are engineered to run for longer than ever in the history of automobiles, using less fuel, and on a continuous efficiency improvement path. For example, some of today's most popular brands, including the Toyota Corolla, Honda Accord/Civic/CRV, and Ford F150, can last for about 20 years and be driven beyond 300,000 km with proper care and

[15] Moriartya, Patrick. Jia Wang, Stephen. Can Electric Vehicles Deliver Energy and Carbon Reductions? Elsevier, Science Direct, Energy Procedia, The 8th International Conference on Applied Energy – ICAE2016.
[16] IEA Sustainable Development Scenario, corresponds to the 1.5-degree target of the Paris Agreement.
[17] Growth rate of 2% per year in number of units 1999-2017, straight-line extrapolation with 2017 as the starting point.
[18] https://www.fleetcarma.com/electric-vehicles-sales-update-q3-2018-canada/.

maintenance. It is unclear whether the individual consumer or business owner will walk away from this paid-off-after-5-years-investment in exchange for a small government subsidy on the purchase price of a new EV, regardless of the operating cost savings. The more likely path, as currently seen in the North American electricity sector — with the shift to natural gas from coal — is a gradual replacement of the vehicle stock with new electric technology or more efficient ICE vehicles.

But as a thought experiment, we wanted to estimate the theoretical costs of a complete replacement of British Columbia's <4,500kg passenger ICE fleet, today. We know that in 2017 there were 2.9 million registered vehicles of less than 4,500kg.[19] The total capital cost, based on the average cost of the vehicle shown (not luxury vehicles), is $102 billion (in today's dollars). We can subtract $15 billion, assuming the purchase subsidy at $5,000 per vehicle would apply.[20] This does not include the cost of installing lots of new infrastructure, such as residential or commercial charging stations or upgrades/changes to the electric distribution and transmission system. So, the total capital outlay by individual car-owning B.C. residents would be $88 billion, which strikes us as an impossibly large number in a $290 billion economy.[21] Regardless of whether the cost is paid today or at some point in the future, it will ultimately be born by local consumers/taxpayers. Will they be willing to accept the costs and the trade offs involved in an accelerated push to electric vehicles?

TABLE 3: **2017 AVAILABLE EV BRANDS, COST AND RANGE**

Brand	Cost	Range (kms)
Ford Focus	$31,199	122
MiEV	$27,998	100
Nissan Leaf	$32,698	135
Smart	$26,900	109
BMWi3	$45,300	130
Kia Soul	$35,195	150
Chevy Bolt*	$43,000	383
Average	*$34,613*	*124*
Following models for reference only:		
Tesla X	$106,100	381
Tesla S	$77,700	286

* Included for average pricing of vehicle capital cost but excluded for average range

Source: BC Hydro.

TABLE 4: **TOTAL CAPITAL COST OF REPLACING 2017 <4,500 KG VEHICLES**

Total # of vehicles multiplied by the avg price from Table 3	$102,600,677,206
Current $5,000/EV car subsidy	($14,821,180,000)
Total capital outlay by citizens	$87,779,497,206

Note - does not include the capital cost of charging station infrastructure.

Fundamentally, dealing with transportation emissions means rethinking how we move people and goods over the long term. On the positive side of the ledger, regardless of what British Columbia achieves, our >95% clean electricity system means that any future transport emissions reductions are likely to be real, as will improvements in local air quality from fewer NOx, ozone, and particulate matter emissions. But the truth is that B.C. targets tinker on the margins, making some people feel good but mattering not at all in the larger picture. And implementing made-in-B.C. goals may have unintended consequences and be fiendishly difficult to engineer in practice.

CONCLUSIONS

What climate change conversations enable, and EV targets facilitate, is thinking by individuals and policy-makers about transportation choices. As consumers, our demands drive the industrial production of vehicles and the fuels needed to keep them working. In the case of road transportation, GHG emissions are not primarily an industry issue but rather a result of the actions of millions of individuals and firms. Given the intrinsic and complicated role of the automobile in our lives, the challenges of transition are enormous.

If global warming potential is part of your calculus, then consider that "it takes just 4,900 miles of driving to pay back the extra global warming emissions from producing a mid-range EV. Similarly, it takes 19,000 miles with the full-size long-range EV compared with a similar gasoline car. Based on typical usages of these vehicles, this amounts to about six months' driving for the midsize mid-range and 16 months for the full-size long-range EV."[22] In B.C. this payback is longer, given our >95% clean electricity system.

[19] Using this rounded number take care of the estimated ~8,500 BEV and PHEV vehicles in the fleet.
[20] We ignore the fact that the government subsidy must be financed through higher taxes on B.C. businesses and residents, resulting in a cost to the economy.
[21] Nominal GDP in 2018.
[22] US Union of Concerned Scientists, Cleaner Cars from Cradle to Grave, https://www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-exec-summary.pdf, 2015.

EVs are gaining in popularity, to be sure. There are ~2 million electric cars on the world's roads, and over 750,000 EVs were sold worldwide in 2016.[23] But electric and hybrids represent only a bit more than 1% of the total in-use vehicles globally and have yet to reach critical mass despite impressive growth in sales.[24] Other options like hydrogen-powered vehicles, once seen as a near-term technology disruptor, have failed to achieve scalability. Therefore, the probability is low of either EVs or alternate fueled vehicles replacing the current and growing world-wide fleet of ICE vehicles in the medium term, given cost, reliability, and durability issues, and absent dramatic coordinated global public policy and regulatory action that looks to be increasingly improbable.

But you never know, and the rate at which newly commercialized technologies get adopted by consumers does appear to be accelerating. In the early 1990s, only a few people had desktop computers. Today, everyone does. Ten years ago, we used a flip phone; today, almost everyone has a smart phone. It is conceivable that EVs could make breakthroughs or that an extraordinary ICE innovation could drive down costs and spur faster adoption of cleaner vehicles than is suggested by existing projections. Such an outcome would be good for global GHG emissions and thus for the climate.

EVs are no panacea, and EV Valhalla is not right around the corner. In the end, EVs are best thought of as another component of a complex problem with no easy solutions.

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[23] International Energy Agency.

[24] *"Global Plug-in Sales for 2017-Q4 and the Full Year (prelim.)"*. Global registrations totalled around 1.2 million units in 2017, 57 % higher than 2016. These include all global BEV and PHEV passenger cars sales, light trucks in USA/Canada and light commercial vehicles in Europe. In 2017, 66 % of sales were pure electric (BEV) and 34 % were plug-in hybrids (PHEV). The segment market share was 1.3%, and in December 2017 the global plug-in share touched the 2 % mark for the first time. http://www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/.