Project Summary: Lifecycle Carbon Analysis and Total Cost of Ownership for 2030 Light Duty Vehicle Fleet

The United States Environmental Protection Agency (EPA) is considering rulemaking proposals to make significant reductions in greenhouse gas (GHG) emissions from the transportation sector in order to help meet President Biden's goal of 50-52% net economy-wide GHG reductions below 2005 levels in 2030. The President also set a target of 50% zero tailpipe emission (battery electric, plug-in hybrid, fuel cell electric) light-duty vehicle sales by 2030 to facilitate meeting the GHG reduction goal. Separately, California – and the Section 177 states that follow California's Advanced Clean Cars 2, light-duty vehicle regulations – plan to mandate 100% passenger car and light truck sales be plug-in or hydrogen fuel cell vehicles by 2035.

With the exception of fuel sulfur content, EPA and the California Air Resources Board (CARB) set emission standards for vehicles and fuels in separate regulations. The vehicle regulations focus on the emissions from the tailpipe only and therefore exclude upstream impacts due to production of the vehicle or energy (e.g., gasoline, diesel, electricity) that powers the vehicle. With the increased focus on transitioning from petroleum to electricity as the primary energy source for the transportation sector, there has been associated interest in better quantifying and comparing the emissions resulting from the manufacturing, energy production, and operation of a variety of vehicle and energy pairs. Vehicle life-cycle analysis (LCA) is a method to determine the impacts of the three major cycles of a vehicle: vehicle production (and disposal), fuel production (well-to-tank), and fuel consumption (tank-to-wheels). Most recently, the United Nations Economic Commission for Europe (UNECE) Informal Working Group (IWG) on Automotive Life Cycle Assessment (A-LCA) was formed with the objective to develop an internationally harmonized procedure to determine the carbon footprint of different technologies, also considering energy use, for energy pathways and automotive types from production to use and disposal.

To gain a better understanding of LCA fundamentals, MECA contracted with AVL to conduct a carbon LCA combined with a total cost of ownership (TCO) analysis. In addition to CO_2, life-cycle emissions of nitrogen oxides (NOx) and methane (CH_4) were modeled. Three representative vehicle classes were studied: City Sedan, Family SUV, and Pickup Truck. The technology pathways for the 2030 vehicle design space are based on those available in Argonne National Labs Lifecycle Analysis Tool GREET 2020. The GREET model determines emissions based on best available projections of future electricity generation sources, production and use of current and potential fuels, and mobile source regulations that have been finalized prior to the model's annual update. The study includes assumptions about the available types of vehicles, energy sources, costs and effects on GHGs for the vehicles and fuels forecast to exist in the passenger car and light truck fleet in 2030. These effects were aggregated into response surface models and embodied into two "Dashboards" (spreadsheet models) for vehicle-level analysis.

The vehicle-level analysis demonstrated that GHG emissions for a given vehicle are highly dependent on several factors. For vehicles with internal combustion engines (ICE), lower carbon fuels can have a large impact on GHG emissions. A hybrid electric vehicle (HEV) can reduce the GHG footprint of its ICE counterpart by upwards of 30%. Battery electric vehicle GHG emissions are zero at the tailpipe, but the life cycle GHG footprint is highly dependent on the carbon intensity of the upstream electricity generation, which varies regionally across the U.S.

A third Dashboard tool was developed in order to conduct a fleet-level analysis. From the vehicle candidates identified in the initial analyses, this study defined a baseline and five future fleet scenarios that represent differing levels of technology adoption. The six fleet scenarios include:

1. Baseline (2019) fleet
2. Low GHG Emissions fleet using conventional vehicles and HEV
3. Low GHG Emissions fleet using highly electrified vehicles (PHEV, FCEV, BEV)
4. Technology ready options
5. Moderate technology advancing
6. Aggressive technology advancing

Table 1. Fleet scenarios based on technology readiness.

	Technology Ready Scenario 1	Moderate Technology Advancing Scenario 2	Aggressive Technology Advancing Scenario 3
Sedans	HEV E10	HEV E10	HEV Renewable Gasoline
	ICE E85	ICE E85	HEV E-Gasoline
	BEV-300	HEV Renewable Gasoline	BEV-300
		BEV-300	
SUVs and Pickups	HEV E10	HEV E85	ICE RNG (SUV only)
	HEV E85	HEV Renewable Gasoline	HEV RNG (Pickup only)
	PHEV E10 (SUV only)	HEV Renewable Gasoline (Pickup only)	HEV Renewable Gasoline
	HEV B20 (Pickup only)	PHEV E10 (SUV only)	HEV E-Gasoline
	BEV-400	HEV B20 (Pickup only)	HEV E-Diesel (Pickup only)
			FCEV Renewable H2
			BEV-400

The vehicles and fuels utilized in the three technology readiness scenarios are shown in Table 1 above. The "Technology Ready" level (Scenario 1) is marked by vehicles and fuels commercially available today. This includes ICE vehicles, hybrids, plug-in hybrids and BEVs that run on gasoline with 10% ethanol (and 85% ethanol to a limited extent) and diesel blended with 20% biodiesel. The "Aggressive Technology Advancing" level (Scenario 3) includes a greater penetration of renewable fuels (renewable natural gas, biofuels and e-fuels) as well as fuel cell vehicles operating on renewable hydrogen.

An example of these fleet-level results is shown in Figure 1, where the colored point clouds represent different cases within each of three 2030 fleet scenarios. The clouds on the left use the 2030 California (low GHG) electrical grid whereas the ones on the right use the 2030 US Average (medium GHG) electrical grid. The study assumed the 2030 in-use vehicle population would need to demonstrate a 30% reduction in overall CO_2 emissions to meet the Paris Accord targets, which is marked by the orange dashed line. The fleet analyses also incorporated TCO into the results. Thus, the future fleets can be assessed based on their overall benefits, not just on their technology or emissions benefits. Note that there is a weak correlation between TCO and lifecycle CO_2 emissions that is affected by the initial capital cost of the technologies and the lifetime use of the vehicles.

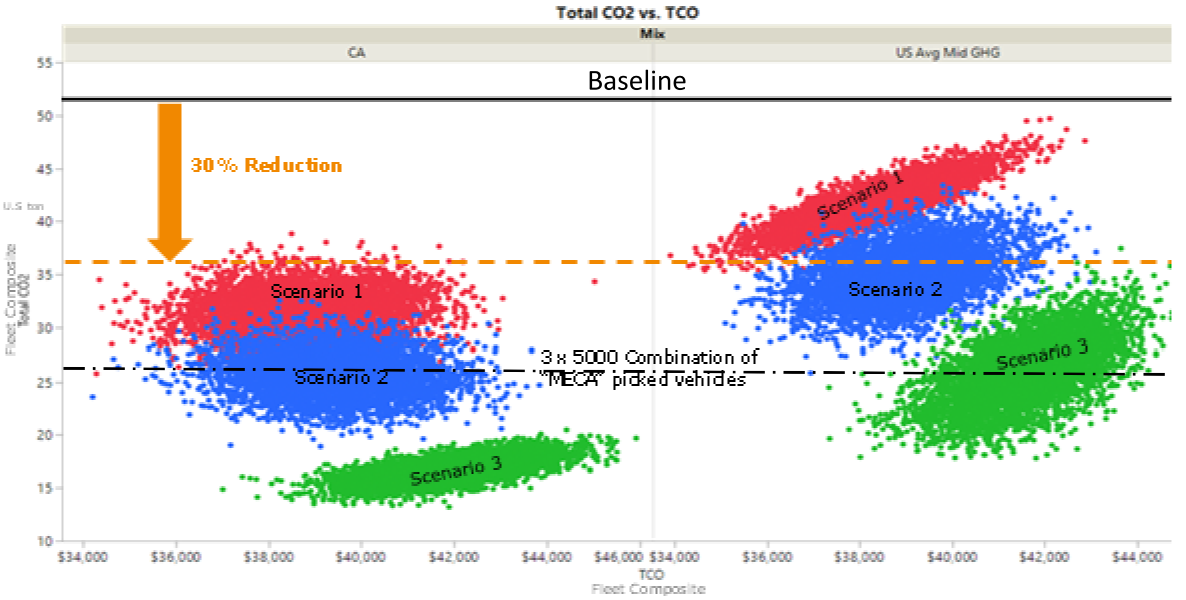

Figure 1. 2030 fleets comparing the results from various vehicle technology scenarios. Each point in the cloud is a mix of vehicles equal to a U.S. sales mix of new 2030 vehicles. The points below the black dashed line would be able to meet the 30% target assuming the total 2030 vehicle in-use population is a mix of 40% Baseline fleet and 60% 2030 MECA Scenario fleet results.

Since the 2030 in-use vehicle population will include both new vehicles—represented by the point clouds—and older vehicles—represented by the Baseline Fleet average lifecycle CO_2 emissions value of 51.5 US tons calculated for this study—achieving a given level of overall CO_2 emissions reduction puts the onus on the new vehicles to meet the target. Depending on the assumed fraction of old vehicles in 2030, the CO_2 emissions target for the new vehicles will need to increase or decrease accordingly, with lower new vehicle CO_2 targets needed to offset higher numbers of used vehicles in operation. This analysis did not evaluate how fuels with a lower CO_2 content would affect the emissions of the Baseline (2019) fleet. For example, if fuels with a near-zero well to pump (WTP) CO_2 content become widespread, then the overall fleet lifecycle CO_2 emissions will be correspondingly lower.

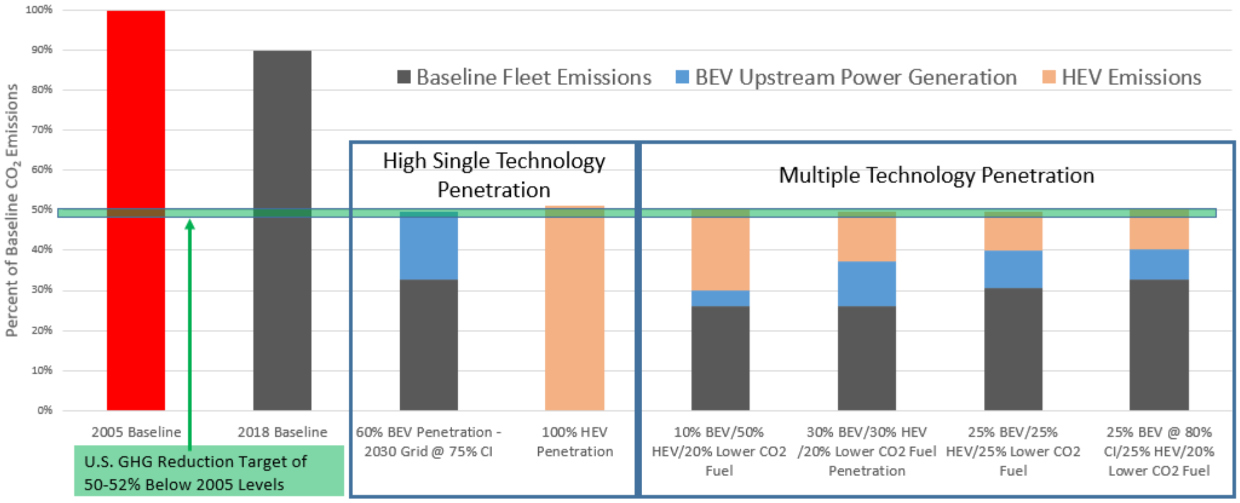

Figure 2. Comparison of life cycle CO2 emissions from the U.S. population of vehicles in operation. Baseline years for 2005 and 2018 (left) are shown as well as two "high single technology" (middle) and several "multiple technology" (right) penetration scenarios aimed at reducing fleet CO2 emissions. Note that vehicle percentages are actual vehicles in operation in 2030 and not sales of new vehicles in 2030.

From the results shown in Figure 1, it is possible to analyze several combinations of vehicles, technologies and energy sources (e.g., fuel, electricity) to meet future GHG reduction targets. One such example analysis is displayed in Figure 2, which focuses on the current U.S. GHG target of 50-52% below 2005 levels. The results indicate that U.S. GHG emission targets could be achieved through policies and incentives that simultaneously advance technologies and strategies that decarbonize both vehicles and the energy sources that propel them. The study also demonstrates that the fleet fraction and emissions level of legacy vehicles operating in 2030 will influence the level of emissions reduction needed by new vehicles to meet an overall emissions target for the operational fleet. This suggests that any CO_2 reductions that are achieved by legacy vehicles in the transition years to 2030 will build in fleet robustness needed to ensure that ultimate CO_2 emission reduction goals from transportation are met.