[METHODOLOGY]

Today's Vehicles, Tomorrow (Blog Series)

The goal of this project is to identify and model technology pathways which would achieve the 2025 standards for a cross-section of vehicle types from different manufacturers. The technology costs are then estimated for these vehicles and the net benefits calculated, revealing how achieving the current federal standards through 2025 would provide a net benefit to consumers.

The modeling is focused on technologies that reduce fuel consumption; however, the results consider manufacturers switching over to alternative A/C refrigerants in order to take full advantage of the credits available to for reducing global warming emissions from vehicles' A/C systems, a trend already underway (EPA 2019, 90).

Modeling technology improvements

In order to accurately reflect the emissions of the 2025 vehicles, it is important to be able to capture characteristics unique to each model and the total scope of available trim options. For this reason, we have relied primarily upon the Advanced Light-duty Powertrain and Hybrid Analysis (ALPHA) tool developed by the Environmental Protection Agency (EPA 2017). EPA has used this peer-reviewed model for its own powertrain analysis in support of the mid-term review of the current 2025 standards (EPA 2016, 2-255) and benchmarked the model against the 2017 vehicle fleet (Bolon 2017).

The model itself can capture a wide range of inputs, including equivalent test weight, engine maps, transmission efficiencies, coast-down coefficients, and even different operation assumptions and transmission control strategies. Because much of this information is proprietary or would require detailed test facilities, our analysis frequently relies upon proxies based on available data—for example, to estimate the performance of a current-generation turbocharged, downsized inline-4, we would use a modified version of the map of the 1.6L EcoBoost, even though there may be subtle differences between Ford's turbo application and another manufacturers. Similarly, because not all transmission types have been fully implemented in ALPHA v2.2, the latest available public version of the model, we have relied upon the agency's representation of transmissions of the form TRX##, where ## is 10, 11, 12, 21, or 22 and represents different degrees of improvement in gear spread and transmission efficiency (EPA 2016, 2-326).

As mentioned above, not all technologies are captured in ALPHA v2.2—specifically, 48V mild-hybrid systems using an integrated starter generator and transmissions with 9 or 10 gears are not adequately captured in ALPHA v2.2. Because these technologies are two which are currently being deployed in the fleet and are expected to contribute significantly in future applications, we have augmented our ALPHA modeling runs with data from Argonne National Laboratory's Autonomie model (ANL 2017). In this case, we have post-processed improvements for these technologies relative to the final level of performance for the vehicle modeled in ALPHA—for example, to estimate the additional fuel reduction of an advanced 10-speed transmission and 48V mild hybrid deployed on a small car which has seen reductions in mass (as a percentage of curb weight[1]), rolling resistance, and aerodynamic drag of 10 percent and is powered by an

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[1] Argonne National Lab used 5 levels of mass reduction, corresponding to 5 different percentage reductions in glider mass, which it assumed was 50 percent of the curb weight. For example, MR5, the highest level modeled by ANL, corresponds to a 20 percent reduction in glider weight, which thus yields a total curb weight reduction of 10 percent.

advanced turbocharged, downsized engine, we would compare the fuel consumption for the “SmallCar” class corresponding to techkeys “;;;;;TURBO2;AT8L2;SS12V;ROLL10;MR5;AERO10” (ALPHA’s maximum state) and “;;;;;TURBO2;AT10L2;BISG;ROLL10;MR5;AERO10” (desired final states), which would result in an additional reduction of (1-0.640486245/0.69621341) = 8.0 percent.

The ALPHA model includes as an output calculations of different performance characteristics, including four separate acceleration times: 0-to-30 mph, 0-to-60 mph, 30-to-50 mph, and 50-to-70 mph. In order to ensure that the represented vehicles continue to meet the performance demands of those currently purchasing the vehicle, these characteristics were maintained or improved upon relative to the baseline model. The baseline model was, in turn, compared for accuracy to a calculated 0-to-60 mph performance based upon statistical analysis from MacKenzie and Heywood (2012) as well as available data from test drives where possible to help ensure the modeled results were consistent with real-world performance.

In addition to acceleration, payload and tow capability were considered for the trucks and SUVs. In this case, additional runs were utilized which increased the vehicles’ effective weight to consider the payload and towing capacity. Because a vehicle’s gross vehicle weight rating (GVWR) cannot be exceeded, regardless of tow capacity, the increased vehicle weight and rolling resistance for pick-up trucks has been modeled based upon the “work factor” used in the heavy-duty pick-up regulations, summing 25 percent of the maximum tow rating and 75 percent of the maximum payload capacity of the original vehicle (EPA and NHTSA 2011, 57164). The resulting weight exceeds the payload capacity in all cases, resulting in a slightly conservative approach to the vehicle’s capacity (i.e. requiring greater performance/capability); however, it allows for differentiation between trim levels which would have the same GVWR but different tow capability.

Modeling costs to consumers

Technology added to a vehicle may add to increased costs for consumers as manufacturers try to recoup any costs associated with additional technologies. While some manufacturers may defray those costs by increasing mark-ups elsewhere, in order to estimate costs we assume that the fully marked up cost for each technology will be seen by the consumer.

Estimates of technology costs were obtained from the National Academy of Sciences’ most recent consensus study (NRC 2015). Because the 48V mild-hybrid was not considered by the committee, these costs were supplemented for this particular technology with direct costs from EPA and FEV (EPA 2016, 2-350 and 2-399; FEV 2015, 84), representing low- and high-cost estimates, respectively. For all technologies, we use low- and high-cost estimates of direct costs for 2025.

To translate direct costs into consumer costs, we assume a simple retail-price equivalent (RPE) of 1.5 (i.e. a 50 percent mark-up). This represents another conservative assumption, since such an approach includes fixed costs which would exist regardless of whether or not a powertrain technology was improved, and it does not reflect the level of complexity in a technology nor the amount of time needed to recoup investment costs. Furthermore, the RPE approach generally results in higher consumer costs than the indirect-cost-multiplier (ICM) approach utilized by the agencies when the 2017-2025 rules were finalized, though EPA was able to show that the ICM reproduced the generally accepted RPE of 1.5, on average. However, for consistency with the technology costs, we use the 1.5 RPE observed by the NAS committee (NRC 2015, Finding 7.1).

Technology costs are assumed relative to the baseline technology package. Each trim level’s baseline package was estimated based on changes from previous versions of the platform and documented as possible. These specifics are outlined in each specific vehicle’s modeling description at the end of the methodology section (Appendices A-E).

In addition to mark-up, loan costs for consumers were also considered. Based on the latest data from Experian, we assume that 85.4 percent of new vehicles are financed, with an average loan rate of 6.16 percent and an average loan length of 69 months. This represents an additional nearly 20 percent mark-up on the direct technology costs.

Fuel costs are taken from the latest analysis from the Energy Information Administration, in constant dollars (EIA 2019). The mileage schedule and scrappage rate are consistent with the agencies’ analysis of the 2012-2016 rule, which projects an average vehicle lifetime mileage of 195,264 for cars and 225,865 for trucks (EPA and NHTSA 2010, 4-13). For small SUVs which straddle those two categories, the mileage is weighted according to the respective trim share associated with each regulatory class.

A three percent discount rate was assumed consistent with the Office of Management and Budget's recommendation that a regulation which primarily and directly affects private consumption should use the social rate of return (OMB 2003). This was consistent with the real rate of return on the relatively risk-free investment of long-term government debt, which averaged about 3 percent in real terms on a pre-tax basis. However, it should be noted that today that value is considerably lower (OMB 2018), which suggests that if anything this may be a conservative estimate of the appropriate level of discount for a consumer to consider.

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[APPENDIX A]

2025 Volkswagen Jetta

The Volkswagen (VW) Jetta was last redesigned for the 2019 model year and is due to be redesigned again in 2025. It is available in two separate model lines (the Jetta and Jetta GLI), each of which has its own set of trims. However, the only differences between the GLI trims are aesthetic—therefore, we consider only two differentiations based on whether the vehicle is equipped with a manual or automatic transmission. For the Jetta, we consider 3 packages, the S, SE, and SEL Premium. The SEL and R-Line packages fall in between the SE and SEL Premium packages, for which they are respectively quite similar. The S is the most basic model, so it is assigned a manual transmission. The other two packages are optioned with an automatic transmission—while the SE is offered with a manual (and vice versa for the S), the goal of this differentiation is to capture the breadth of options across all Jetta lines. The SEL Premium is the most expensive trim line and is fully-optioned, adding additional weight to the vehicle—based on the test data submitted for the 1.4L Jetta, we estimate this to add at least 72 pounds (VAG 2018, 57).

According to WardsAuto, the vast majority of buyers option an S, SE, or R-Line with an automatic transmission, which we have captured under the SE designation. The SEL and SEL Premium buyers are captured with the SEL Premium trim. We do assume a small share of buyers with the basest vehicle under the S, and GLI consumers are dictated by the transmission. These data are based on mid-year analysis (WardsAuto 2019a, 2019b, 2019c)—while they do not represent certification data provided by VW, it is largely consistent with the finalized 2016 marketshare data provided with the Volpe model (NHTSA 2018).

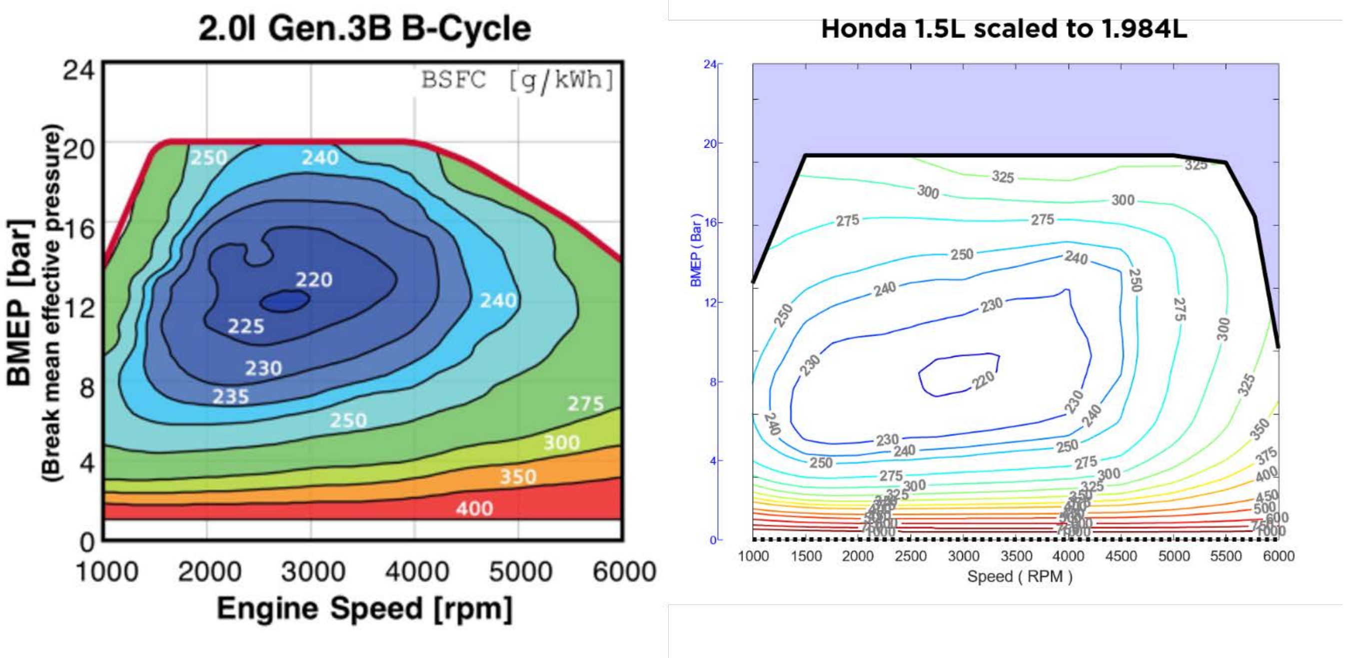
Engine

The Jetta features two different engine options, a 1.4L turbo from its EA211 family, and a 2.0L turbo from the EA888 family of engines. Neither of these engines is the efficiency leader in its family, and in both cases by adopting technologies already available in VW vehicles, there can be a significant gain in efficiency for both the Jetta and Jetta GLI.

For 2025, we suggest replacing upgrading the 1.4L turbo to the 1.5L turbo recently deployed in Europe in a number of other vehicles on the MQB platform (Murphy 2019). An update to the EA211 known as “evo”, the 1.5L relies upon the Miller cycle, which is more thermodynamically efficient than the conventional Otto cycle used in gasoline engines. The Miller cycle closes the intake valve much later than a traditional engine, similar to the Atkinson cycle—this improves combustion efficiency but typically reduces available power, which is why it is then paired with forced induction via either a turbocharger or supercharger (the former, the case of the 1.5L). In addition to running the Miller cycle, part of what makes the EA211 evo 1.5L engine more efficient is its use of cylinder deactivation, which shuts down two of the four cylinders under low load operation. To model this engine we apply cylinder deactivation (Bohac 2018) to the 1.5L Honda Civic engine benchmarked by EPA (EPA 2017)—though slightly different in design, the VW and Honda engines feature similarly broad areas of peak efficiency (EPA 2016, 2-316).

For the 2.0L engine, we turn to the EA888 “B-Cycle” 2.0L turbo (Green Car Congress 2017). Because this engine runs a modified Miller cycle (the Budack cycle, hence the “B” nomenclature of the Gen.3B), it has a lower power output than the current Gen.2 2.0L in the Jetta GLI. While the lighter body in our modeled 2025 vehicle will help with the power-to-weight ratio, the iteration of the Gen.3B available in the current Tiguan would not provide comparable performance to

FIGURE A-1. Comparison of modeled and actual engine maps for the VW Gen.3B 2.0L engine



The Gen.3B engine from Volkswagen is lower-powered than a comparably sized version of the Honda 1.5L. However, it has a comparably sized zone of maximum efficiency and the same level of minimum fuel consumption.

SOURCES: VOLKSWAGEN, UCS DATA

the 2025 GLI. To overcome this, VW would need to increase the amount of boost provided by the turbocharger. This is not uncommon, however, and resizing the turbo for increased performance could yield an engine with much greater peak power without sacrificing too much efficiency, and it is similar to the set of trade-offs considered by Honda in designing its new Civic engines (Nakano et al. 2016)—in this case, while the underlying engine technologies were similar, the 2.0L turbo generates more than twice as much power but with just one-third more fuel use.[1] In the case of the modified 2025 Gen.3B, this would be far less drastic an improvement in performance, moving from a peak output of 190 hp to 231 hp. Such an engine would deliver comparable efficiency and performance to the Honda 1.5L, scaled up to 2.0L, a comparison which is shown in Figure A-1.[2] Because cylinder deactivation has been demonstrated already on the Gen.3 engine (Ortiz-Soto et al. 2019), it would be an appropriate addition here to the modified Gen.3B as well to build additional efficiency gains by 2025. To model this engine, we scale the 1.5L Honda engine to 2.0L (Dekraker et al. 2017) and apply cylinder deactivation (Bohac 2018).

Because both engines have already been turbocharged, the only additional costs we have considered are for advanced cylinder deactivation. Because the National Academy of Sciences only costed out conventional cylinder

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[1] Based on a comparison of the fuel economy labels for a Honda Civic R (25 mpg) and hatchback (33 mpg), both with manual transmissions and operating on premium fuel (EPA 2019).

[2] Because the Honda engine's peak occurs at lower torque and hits its maximum power at a higher speed, it would be likely that a more strongly boosted version of the Gen.3B would be more strongly "peaked" than our model's map and potentially consume more fuel as a result. We therefore also modeled the vehicle using an engine map based on Ford's 2.7L V6, scaled down to a 2.0L I4. This had significantly higher torque, resulting in greater performance specs (e.g., sub-6 second 0-60). We were able to achieve test cycle fuel consumption less than 2 percent greater with this setup, which still allowed the 2025 Jetta to meet its targets; however, the technology and capability of the Honda engine is more comparable to that of the Gen.3B, which is why it is used for the reported data.

deactivation for V6 and V8 engines in their assessment, we have used estimates of cost from EPA and ICCT, with the former a lower bound for conventional cylinder deactivation on an I4 engine (as is currently accomplished in the 1.5L) and the latter an upper bound for advanced cylinder deactivation based on supplier data (EPA 2016, 2-290; ICCT 2018, I-72). The total direct cost of these more advanced engines was $69-153 over the current engines (in 2010$).[3]

Transmissions

There are three transmissions offered in the Jetta, a six-speed manual, a seven-speed dual clutch, and an eight-speed automatic. While ALPHA is designed to handle a variety of different transmission types, v2.2 is focused on using surrogates for transmissions in the form of the TRX## outlined in the broader methodology. As a result, there is not an explicit manual transmission model for ALPHA v2.2. Because the 2019 Jetta features a newer six-speed manual, we consider as a surrogate the six-speed automatic TRX11 in the baseline. Because an automatic transmission has significantly increased friction compared to an automatic, and because we did not adjust the shifting algorithm in any way for our runs, this represents a significantly conservative approach to the potential improvement of a manual transmission—for example, our runs saw a significant disparity between the manual and automatic transmission vehicles, while in actuality that gap is much smaller. A future manual transmission was modeled still as a six-speed, but with improved efficiency (TRX12). Both the 8-speed automatic and 7-speed dual-clutch were modeled as TRX21, consistent with EPA 's recommendation (EPA 2016, 2-238).

Future transmission improvements were modeled primarily as improved internals, moving the TRX#1 to TRX#2 for all three transmissions. However, because TRX22 also has a wider gear ratio than TRX21 and eight speeds, we have also considered the cost of adding an 8th gear to the dual-clutch on the GLI. VW was working on a 10-speed dual-clutch transmission but recently axed that product (Automotive News 2017); however, it seems plausible that they would want an improved dual-clutch transmission for their performance vehicles as opposed to an automatic, and therefore is reasonable to assume continued progress, even for a relatively low-volume transmission. For example, Porsche, a member of the VW Automotive Group, recently deployed in its Panamera a new 8-speed dual-clutch transmission from ZF (ZF 2017). Because the Jetta GLI with a dual-clutch represents a very small uptake of the Jetta platform, switching from the improved dual-clutch to the 8-speed automatic would only represent an increase in cost of $4-12 (2010$). The other costs associated with improving the Jetta's transmissions are related to a post-2020 "high efficiency gearbox" (HEG3 and HEG-DCT) as defined by the National Academy of Sciences (NRC 2015, 304). To account for the future improvements to the manual transmission, we considered the cost to be equivalent to the dual-clutch, though there was a negligible difference in cost between the two HEG applications. In total, improvements to the Jetta's transmissions result in a direct cost of $132 in 2010$ in 2025.

Road Load Reduction

In addition to more detailed analyses below, it was assumed that additional reduction in rolling resistance from the Jetta S, SE, and SEL Premium trims would be undertaken—due to performance constraints, we did not consider any reductions in rolling resistance for the Jetta GLI. This added $30 in direct costs to VW (in 2010$).

MASS REDUCTION

The 2019 VW Jetta is a compact sedan, so the maximum potential lightweight capability can be based on the studies of the Honda Accord (Singh et al. 2012, Singh et al. 2016). This leads to a maximum potential reduction of 16.7 percent mass reduction (excluding powertrain opportunities) from a vehicle almost exclusively based on mild steels.[4]

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[3] It is worth noting that the National Academies estimate for cylinder deactivation for a V6 engine falls in the middle of this range at $118 (NRC 2015, 303).

[4] See Figure 233, Singh et al. 2012, excluding the 56.5 kg of weight reduction related to downsizing the powertrain and adding back in 21.75 kg and 6.9 kg for safety corrections (from vehicle 1.0 → 1.1 and 1.1 → 1.2, respectively [Singh et al. 2016, 57 and 64]).

TABLE A-1. Comparison of grades of steel in the Honda Accord and VW's MQB platform-based Polo

Steel type	VW Polo	Accord (baseline)	Accord (LWV 1.0)
Mild/low-strength	30.3%	52%	3%
High strength (IF-HS, BH)	9.7%	6%	9%
High strength (low-alloy, C-Mn)	28.5%	0%	6%
Advanced high strength (DP, TRIP)	9.2%	42%	48%
Ultra-high strength (MS)	1.3%	0%	15%
Press-hardened AHSS	21.0%	0%	19%

Nearly one-third of the body of the VW Polo remains mild/low-strength steel, while the lightweight Honda Accord has shifted entirely to advanced and ultra-high strength steels.

NOTE: IF-HS = interstitial-free high strength; BH = bake-hardened; DP = dual phase; TRIP = transformation-induced plasticity; MS = Martensitic

SOURCE: SCHWERING AND HEUER 2017, SINGH ET AL. 2012

The 2019 Jetta was recently shifted to the MQB platform, on which a number of other vehicles are based, including the VW Polo. The VW Polo features only 30 percent mild steel (Schwering and Heuer 2017), well below the levels of the base Accord but also significantly more than that of the lightweight Accord (Table A-1). The share of steels in the Polo seem to correspond approximately to the values for the Jetta as well, based on stated tensile strengths (RDN 2018). While the amount of the most advanced steels are comparable between the Polo and the lightweight Accord, nearly a third of the weight in the MQB-based Polo is mild/low-strength steel, while essentially all of that has been shifted away to advanced high-strength steel (AHSS) and ultra-high-strength steel (UHSS) in the lightweight vehicle. Furthermore, while dual-phase AHSS (AHSS-DP) was used significantly in the baseline Accord, the share of even higher-grade steels was significantly increased, reducing the equivalent AHSS in the baseline Accord to just 7 percent in the lightweight vehicle. Considering the Polo to be representative of the MQB platform, it appears that considering the MQB-based Jetta halfway between the two Accord versions is a reasonable approximation.

VW began incorporating high-strength steel for safety with the 5th generation Jetta. Therefore, the most comparable baseline is the 2004 Jetta, which had a baseline curb weight of 2895 pounds for the 2.0L vehicle with a manual transmission, just 7 pounds heavier than the 2019 base trim. However, the 2004 vehicle had a significantly lower footprint than the current vehicle (40.66 square feet, compared to 44.45 square feet)—scaling up the weight of the vehicle to match this increase in size accordingly would yield a baseline curb weight of 3165 pounds. This would suggest a maximum mass reduction opportunity of 513 pounds from the body of the Jetta, some of which has already occurred.

A turbocharged version of the engine in the older Jetta (available in the 2006 VW cc) weighs nearly 300 pounds (A2Mac1 2018), so we can estimate the 2.0L itself to be about 10 percent of the weight of the vehicle, or 290 pounds. The new 1.4L engine in in the 2019 Jetta weighs 229 pounds, a decrease of 61 pounds (Szengel et al. 2013). The baseline weight of the current Jetta compared to the theoretically-sized 2004 vehicle is 277 pounds, suggesting that 216 pounds of lightweighting has been accomplished. This would still allow for nearly 300 pounds additional weight reduction.

Conservatively, we apply only 225 pounds additional lightweighting to the Jetta body, allowing for some additional flexibility related to the platform and future safety requirements. Because this is occurring at an additional level of lightweighting, its costs are calculated at the 5-10 percent and 10-15 percent levels of mass reduction beyond the initial 6.8 percent we are assuming has already occurred, yielding a total direct cost (in 2010$) of $286-414.

AERODYNAMICS

The 2019 Volkswagen Jetta saw a significant reduction in aerodynamics, making the Jetta one of the most aerodynamic vehicles in its class, with a coefficient of drag C_D = 0.27. Therefore, by 2025, we expect only modest potential improvement, with a 2 percent improvement in drag causing it to match EPA estimates for the BMW 3-series (0.263) and Honda Civic (0.264), the latter of which was touted as achieving a 12 percent reduction in drag by Honda after its redesign (Honda 2015).

The models of the Jetta with the 1.4L already come equipped with active grille shutters; we do not assume such features on the GLI, either in the 2019 or 2025 variants. This aerodynamic feature results in a 2.4 percent reduction in drag (VAG 2018, 60), which makes it eligible for off-cycle credit.

To calculate the cost of the aerodynamic improvements, we have scaled the cost for an improvement from 10 percent to 20 percent reduction. Because this cost was based upon the addition of technologies like grille shutters (NRC 2015, 208), which are already on the vehicle, this may represent an overestimate. This adds a direct cost of $20 in 2010$ in 2025.

Accessories

Mechanical linkage for accessories like the water pump and cooling fans remain a source for potential efficiency gain through electrification—this trend is underway, and it is assumed that by 2025 these accessories on the Jetta will be electric. Similarly, alternators have gotten gradually more efficient over time, and we assume that trend to continue, with the 2025 Jetta achieving a 70 percent efficiency. Along with being more efficient, the 2025 Jetta's alternator will be capable of mild regeneration. These modifications to accessories result in direct costs of $97 in 2010$, in 2025.

Electrification of accessories goes hand in hand with a major addition to the Jetta—the 48V stop-start system. Unlike the 12V electrical systems currently operating in most vehicles, 48V allows for greater power draw, which can result in greater opportunity for "e-boost" similar to the "e-Torque" option found in FCA's trucks, higher levels of power for electrical accessories, and faster and smoother engine restart. This builds on the stop-start system currently available in the Jetta by utilizing the 48V system already deployed by VW in Europe in the new Golf (VAG 2019). We estimate the direct costs of this system to be $295-424 more than the system already deployed on the 2019 Jetta, in 2010$.

One final accessory change is that all exterior lighting is shifted to more efficient LEDs. This is currently already offered on the Jetta, and such lights are available for off-cycle credit.

Results

A summary of modeled performance characteristics is provided for all trim levels (Table A-1). Note that while performance data for 2019 vehicles are provided for comparison, actual fuel economy label data and estimated 0-to-60 mph performance data was used for benchmark comparisons. CO_2 test values for 2019 include estimates based on available credit and technology data.

Estimated direct costs range from $927-1268, in 2010$. This translates to a retail price equivalent of $1597-2184 for consumers, in 2018$. At zero discount, consumers would save $3194 over the lifetime of the vehicle, compared to today's model. Including loan costs (6.16 percent rate, 69-month average length, for 85.4 percent of new car purchasers) results in net present values of $250-900, in 2018$ and a 3 percent discount rate.

TABLE A-2. Comparison of modeled performance characteristics for the 2019 and 2025 VW Jetta

Year	Trim	%	Footprint	CO_2 (g/mi)		Fuel Economy (mpg)				Acceleration (s, from/to *x* mph)			
				Req'd	Test	Lab	City	Hwy	Label	0-30	0-60	30-50	50-70
2019	S	81.1	44.45	190	190	45.6	28	37	32	3.52	8.44	3.83	5.55
2019	SE	5.7	44.45	190	211	44.8	27	33	29	3.70	9.11	4.34	5.80
2019	SEL Premium	4.6	44.45	190	193	45.6	28	36	31	3.59	8.69	3.92	5.71
2019	GLI (DCT)	5.6	44.40	189	240	36.5	23	31	26	3.06	7.08	3.18	4.17
2019	GLI (Manual)	3.0	44.40	189	251	35.8	23	29	25	2.98	6.92	3.61	4.61
2019	**Average**	**100**	**44.44**	**190**	**196**	**44.6**	**28**	**36**	**31**	**3.49**	**8.37**	**3.82**	**5.47**
2025	S	81.1	44.45	142	136	56.0	36	46	40	3.19	7.54	3.57	4.51
2025	SE	5.7	44.45	142	144	53.3	35	43	38	3.20	7.81	3.91	4.89
2025	SEL Premium	4.6	44.45	142	138	55.4	35	46	39	3.25	7.75	3.67	4.66
2025	GLI (DCT)	5.6	44.40	142	191	41.6	27	35	31	2.88	6.68	3.21	4.19
2025	GLI (Manual)	3.0	44.40	142	201	40.3	27	35	30	2.81	6.63	3.2	4.44
2025	**Average**	**100**	**44.44**	**142**	**141**	**54.2**	**35**	**45**	**38**	**3.16**	**7.49**	**3.56**	**4.52**

The VW Jetta moves from slightly under compliance with 2019 standards to slight overcompliance in 2025, as modeled, while improving acceleration and improving up to as much as 40 mpg on the fuel economy label seen by consumers.

SOURCE: UCS DATA

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2025 Honda CR-V

The Honda CR-V was last redesigned for the 2017 model year and is due to be redesigned again for the 2022 model year (Wards 2019a). It is available in four different trim levels (LX, EX, EX-L, and Touring) and in either front- or all-wheel drive (FWD or AWD). The basic LX trim level uses a carryover engine (2.4L I4), while the other trim levels utilize the 1.5L turbocharged engine found in the Honda Civic, with which the CR-V shares a platform. To span the range of offerings of the CR-V, we consider only the most basic (LX) and most premium (Touring) trim levels, in both FWD and AWD configurations—this represents a conservative assessment of the trim configurations, since the Touring package adds weight beyond the EX and EX-L (20-40 pounds). Marketshare of the 4 different model trims is based on the 2017 final model year data listed in Volpe model (NHTSA 2018), which appears consistent with model year 2019 sales (WardsAuto 2019b).

Engine

The 2.4L baseline engine is dated and carried over from the previous generation. Therefore, it is a prime candidate for significant update in the next generation CR-V. The best candidate for this would be to adapt some of the lessons Toyota has developed in its ESTEC engine (Yamada et al. 2014) to Honda's most efficient engine, the 2.0L currently deployed in the Accord and CR-V hybrids (Wakamatsu et al. 2018). The Honda engine achieves more than 40 percent peak thermal efficiency thanks to running the Atkinson cycle, similar to the Toyota engine. However, there are some differences related to peak power, potentially as a function of some differences between the two engines, including the Toyota engine's use of direct and port injection, differences in exhaust valve control and the exhaust manifold, etc. However, as can be seen from Figure B-1 (next page), if the Toyota engine map is downsized to the same size as the Honda LFA1 engine, it is clear that there is substantial similarity between the two engines, so it would make sense to use the LFA1 as the basis for an Atkinson based engine in the next generation CR-V.

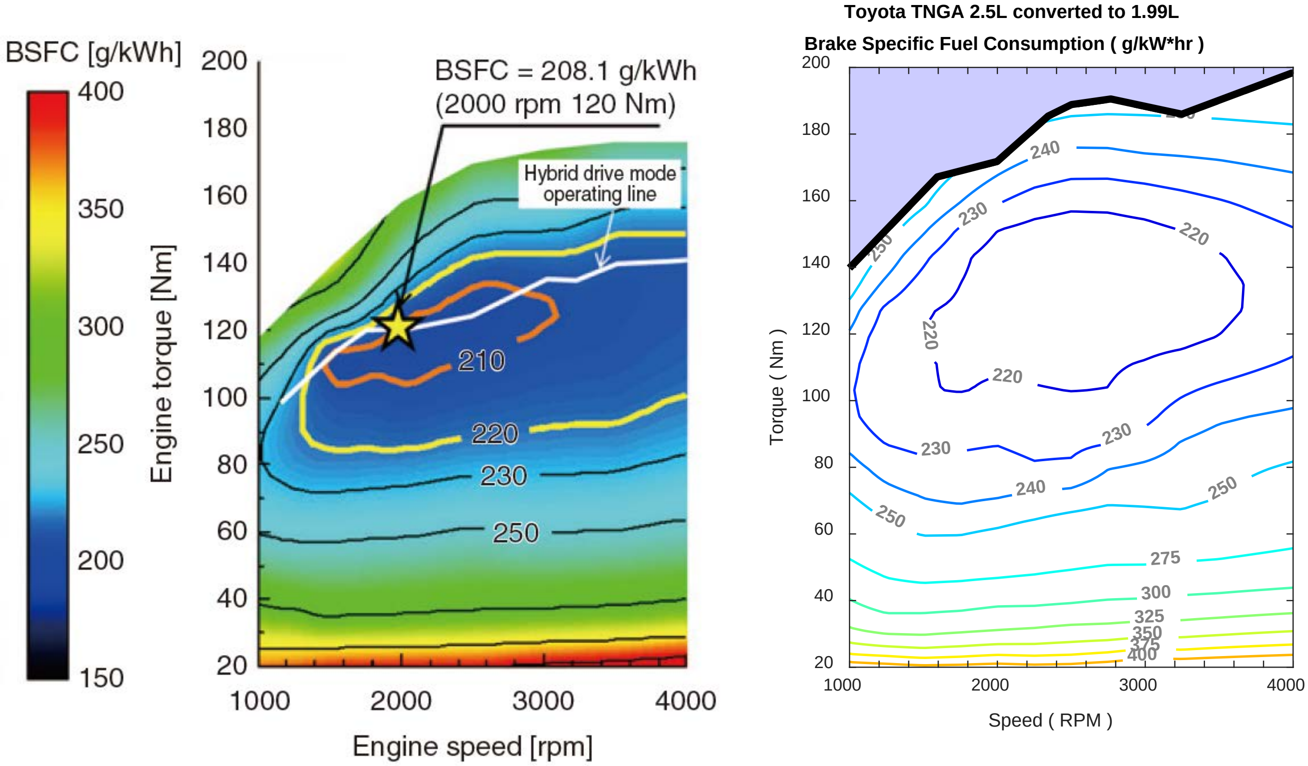
For the 1.5L turbocharged engine available now in the higher-level trims, we are not proposing significant changes. The one modification which could be deployed would be to incorporate cylinder deactivation, similar to VW's strategy in its comparable 1.5L EA211 "evo" engine (see Appendix A). Honda has previously deployed conventional cylinder deactivation in its V6 engines (disabling 2 or 3 cylinders, in different load situations, under the trade name Variable Cylinder Management)—it is therefore a technology with which the automaker is familiar and could easily deploy, even in a novel (for them) four-cylinder application. Because four-cylinder deactivation systems are novel, and Honda could choose to deploy either a conventional or advanced cylinder deactivation strategy, we have used the same brackets on cost as in the VW Jetta (Appendix A).

The 1.5L L15B7 turbocharged engine is the dominant powertrain by volume in the current model, and the carryover of this powertrain yields relatively low total increase in cost for the next generation vehicle ($113-182, in 2010$).

Transmissions

Currently, all versions of the CR-V use Honda's newest continuously variable transmission (CVT). This CVT is shared with the new Honda Accord and was recently redesigned to have a wider gear ratio for improved launch performance (Brooke

FIGURE B-1. Comparison of the Honda LFA1 engine map and the modeled 2.0L based on the Toyota TNGA 2.5L



While the Toyota TNGA 2.5L engine resized to 2.0L (right) has higher peak torque and power than the Honda LFA1 engine (left), the brake specific fuel consumption (BSFC) is quite similar around the most efficient region (at low speed, which is where the CR-V operating on the EPA test cycle would largely spend time).

SOURCES: WAKAMATSU ET AL. 2018, UCS DATA

2017). Because it's a brand new CVT, we consider the base vehicle's CVT to be best represented by a TRX21 according to EPA's nomenclature and have also included the cost of a high efficiency CVT gearbox as defined by the National Academies (EPA 2016, NRC 2015).

Honda recently developed a 10-speed automatic transmission, which we anticipate could be used more broadly across its fleet, including in the CR-V. The compact transmission was first deployed in the Odyssey minivan, but it was recently deployed in the Acura RDX crossover, which shares a platform with the CR-V and is also available in both FWD and AWD. The 10-speed transmission also will translate torque more than a CVT. An improved 8-speed is modeled as a TRX22, so we utilize Autonomie data to estimate the full improvement from the 10-speed transmission.

The difference in costs between the current CVT and Honda's new 10-speed transmission is estimated to be $118-186, in 2010$.

Road Load Reduction

In addition to more detailed analyses below, it was assumed that additional reduction in rolling resistance from the CR-V would be undertaken, on top of an assumed 10 percent reduction in the base vehicle. This added $31 in direct costs to the vehicle (in 2010$).

MASS REDUCTION

The latest CR-V has already utilized some fraction of lightweight materials, both for improved efficiency and safety—the company touted increased body rigidity resulting from a 36 percent share of high-strength steel (HSS) in the body, including 9 percent of the frame being made of ultra-high strength steel (UHSS), up from 10 percent use of HSS in the previous generation (Honda Motor Europe 2018). However, this is far short of the maximum mass reduction that could be accomplished on a vehicle of this type—for example, a study of the Toyota Venza achieved 15.4 percent reduction in curb weight just by deploying HSS and UHSS in the body, along with aluminum and a small share of magnesium in the closures (FEV 2012, Table F.1-1).[1] In this case, the baseline Venza had just 8 percent HSS in the body, similar to the previous generation CR-V; therefore, we consider all mass reduction relative to the previous generation of the CR-V.

Between the fourth and fifth generations, the Honda CR-V increased substantially in size, in part to create more of a differential between it and the subcompact crossover based on the Fit platform, the HR-V. The overall footprint increased by 3.4 percent between generations—multiplying this increase in size by the base curb weight of the previous generation (3358 pounds) results in a baseline for assessing mass reduction of 3472 pounds. A 15.4 percent reduction from that would yield a maximum reduction of 534 pounds from the body. Some of this reduction has already occurred—the base 2019 CR-V with the carryover 2.4L engine weighs just 3307 pounds, implying a reduction of 165 pounds. However, this yields further opportunity for up to 369 pounds additional reduction in weight, without considering advantage of powertrain reduction. For our purposes, we will consider just 250 pounds of further weight reduction, leaving ample further room for increases in weight due to luxury or safety improvements. Because nearly 5 percent mass reduction has already occurred, this additional reduction will occur at higher cost.

The lighter weight CR-V allows for a smaller engine to be deployed in the base trim. This downsizing results in additional weight savings. The Toyota Venza baseline engine weighed 10 percent of the initial vehicle, and just shifting to a smaller engine (2.7L downsized to a 2.4L) shaved 12 kg of weight, or 7 percent of the engine system weight (FEV 2012, Table F.2-5). Considering the reduction in volume, we estimate that for every percent reduction in displacement, the engine system mass (including mounts, etc.) is reduced by 0.63 percent, considering similar technology. Therefore, for the baseline engine downsizing from 2.4L to 2.0L, 37 pounds of additional lightweighting is achieved.

The total direct costs for lightweighting the Honda CR-V are assumed to be $258-443, in 2010$.

AERODYNAMICS

The new CR-V is one of the most aerodynamic crossovers on the market, with an estimated coefficient of drag of 0.31-0.33 (Autotk.com n.d., Zal 2019). This is up to a 10 percent reduction compared to the previous generation, likely do in part to the active aerodynamic grille deployed in the new model, but it is still not as good as the smaller HR-V or even the class leading Land Rover Evoque, which is more than 5 percent better (EPA 2018).

Reducing the CR-V's coefficient of drag by an additional 5 percent would improve fuel economy as well as performance, especially in the baseline engine, at a direct cost of $50, in 2010$.[2]

Accessories

Similar to the Jetta (Appendix A), it is assumed that by 2025 the CR-V's accessories will be electric. The agencies have assumed that Honda has already achieved the highest levels of accessory electrification identified, however, so while the 2025 CR-V is modeled as utilizing both a high-efficiency alternator and electrified accessories, no additional costs are assumed to be incurred, as these technologies were also assumed to be deployed in the current generation vehicle.

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[1] Here we ignore reductions in mass related to the engine and transmission, which we consider separately.

[2] The estimate is based on half the cost of an improvement from AERO10 to AERO20, though some of the AERO20 technology itself is already deployed on the CR-V (active aerodynamic grille).

One significant addition to the CR-V, however, is the addition of a 48V stop-start system. Historically, Honda has deployed stop-start systems in concert with full hybridization, only recently deploying what it calls “idle stop” in the latest versions of the Honda Odyssey and Pilot. A 48V system offers a compromise between the integrated motor assist (IMA) hybrids like the first-generation Insight and the current 12V stop-start system now in the Pilot—unlike the IMA system (P1 motor configuration), which was mounted directly on the crank, a 48V mild hybrid is coupled via a belt (P0). This is less efficient than the direct connection but is also lower cost and can be more easily integrated into different engine architectures. Currently, nearly all 48V mild hybrids are P0 configurations (x-engineer n.d.), including the Delphi system being tested on a Honda Civic in Europe (Delphi 2016). We estimate the direct costs of this system to be $534-721, in 2010$.

One final accessory change is that all exterior lighting is shifted to more efficient LEDs. This is currently already offered on the CR-V in the Touring trim, and such lights are available for off-cycle credit.

Results

A summary of modeled performance characteristics is provided for all trim levels (Table B-1). Note that while performance data for 2019 vehicles are provided for comparison, actual fuel economy label data and estimated 0-to-60 mph performance data was used for benchmark comparisons. CO_2 test values for 2019 include estimates based on available credit and technology data.

Estimated direct costs range from $1104-1614, in 2010$. This translates to a retail price equivalent of $1656-2421 for consumers, in 2018$. At zero discount, consumers would save $3740 over the lifetime of the vehicle, compared to today’s model. Including loan costs (6.16 percent rate, 69-month average length, for 85.4 percent of new car purchasers) results in net present values of $0-950, in 2018$ and a 3 percent discount rate.

TABLE B-1. Comparison of modeled performance characteristics for the 2019 and 2025 Honda CR-V

Year	Trim	%	Foot-print	CO_2 (g/mi)		Fuel Economy (mpg)				Acceleration (s, from/to *x* mph)			
				Req’d	Test	Lab	City	Hwy	Label	0-30	0-60	30-50	50-70
2019	EX FWD	6.4	46.1	196	211	38.0	25	32	28	3.92	8.5	3.73	5.17
2019	Touring FWD	29.6	46.1	196	215	37.5	25	33	28	3.48	8.28	3.78	5.31
2019	EX AWD	11.5	46.0	243	217	36.2	25	31	27	4.17	9.25	4.01	5.66
2019	Touring AWD	52.5	46.0	243	219	35.9	24	31	27	3.67	8.93	4.07	5.76
2019	Average	100	46.0	226	217	36.5	25	32	27	3.69	8.75	3.96	5.58
2025	EX FWD	6.4	46.1	147	158	48.3	32	39	35	3.28	7.85	3.54	5.55
2025	Touring FWD	29.6	46.1	147	155	49.2	32	40	35	3.25	7.57	3.57	4.66
2025	EX AWD	11.5	46.0	177	156	46.6	31	38	34	3.48	8.6	3.87	6.14
2025	Touring AWD	52.5	46.0	177	154	47.3	31	38	34	3.44	8.16	3.85	5.08
2025	Average	100	46.0	166	155	47.8	32	39	34	3.38	8.02	3.75	5.11

The Honda CR-V continues to be a credit earner in 2025 while improving acceleration and raising fuel economy by 7 mpg, matching the fuel economy of the current Honda Civic, with which it shares a platform and which is significantly smaller than the current CR-V.

SOURCE: UCS DATA

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[APPENDIX C]

2025 Toyota Tacoma

The Honda Tacoma was last redesigned for the 2016 model year, and is due to be redesigned again for the 2023 model year (Wards 2019a). It is available in 6 different trim levels (SR, SR-5, TRD Sport, TRD Off-Road, Limited, and TRD Pro), three different body configurations (Access Cab with 6-foot bed, or a Double Cab with either a 5- or 6-foot bed), , and in either rear- or four-wheel drive (RWD or 4WD). It is available with two different engines (a 2.7L I4 and a 3.5L V6) and with two different transmissions (a 6-speed automatic and a 6-speed manual). Twelve separate configurations of the Tacoma were considered, ranging from the most basic vehicle (Access SR trim, RWD, I4) to the most expensive (TRD Pro Double Cab, 4WD, V6, off-road tires) including both RWD and 4WD long-bed Double Cab configurations to ensure a range of vehicle footprints as well. Shares of these configurations were based on the 2018 baseline data collected by NHTSA (NHTSA 2018), taking care to configure as closely as possible as defined in the baseline, and ensuring a mix of SR, TRD Sport, and TRD Off-road/Pro trims to capture different tires, curb weights, power, etc.

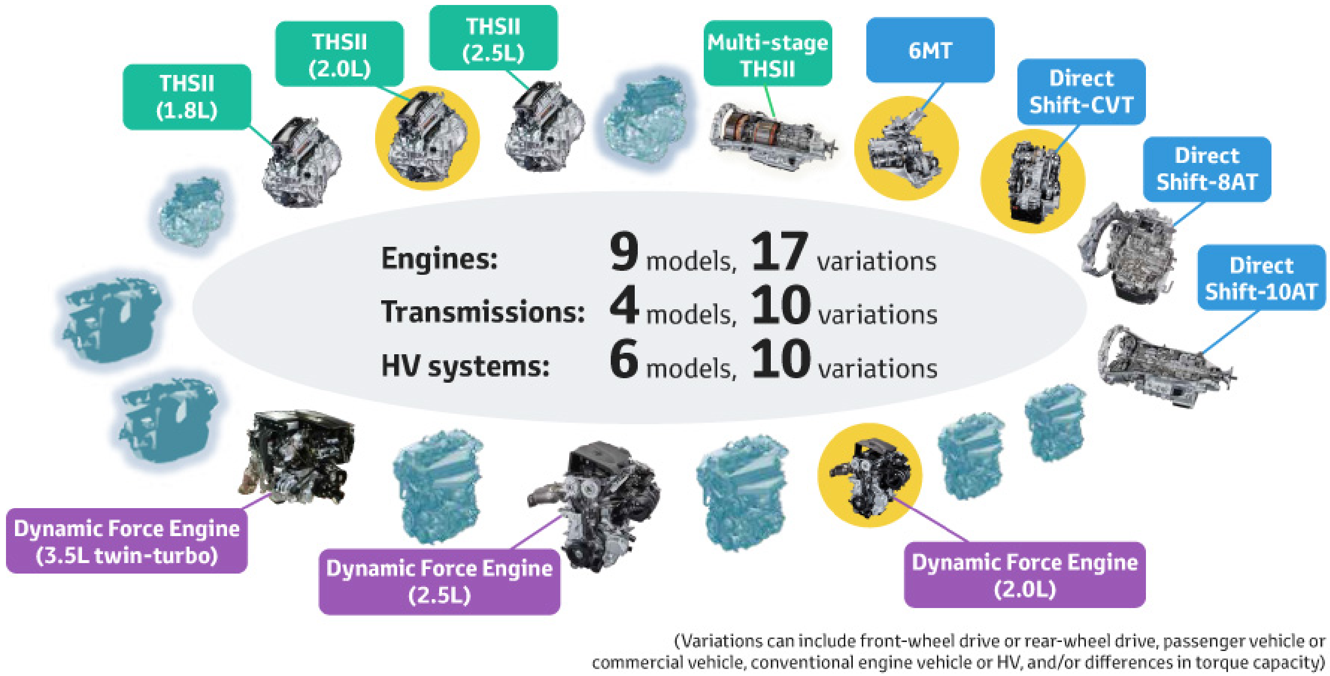
Engine

The 2.7L engine (2TR-FE) in the 2019 Toyota Tacoma has been around since 2004, though in 2015 it received an upgraded variable valve timing system (intake and exhaust). For its size, it is underpowered and "thirsty," and Toyota has indicated that it will be replaced as part of its switch to the Toyota New Global Architecture (TNGA) and its powertrain consolidation (Figure C-1). The most obvious replacement for the 2TR-FE is the Dynamic Force 2.5L engine (A25A-FKS) found in the Toyota Camry—though it is both smaller and runs the Atkinson cycle, it is more efficient and more powerful than the current 2.7L (203 hp/184 ft.-lbs. torque compared to 159hp/180 ft.-lbs. torque). While it is possible that Toyota could downsize the powertrain, this switch would allow for a significant improvement in capability for its base powertrain and probably at least put an end to headlines like, "The 4-Cylinder Toyota Tacoma is Completely Pointless" (Collins 2015).

The higher power engine option is a 3.5L V6 (2GR-FKS) which runs the Atkinson cycle part-time (Matsui et al. 2015). This fairly new engine was just introduced in 2016 and is already available in a large number of Toyota- and Lexus-branded vehicles, and with a 3.5L twin-turbo expected to power the next generation Tundra, it seems logical that the 3.5L V6 and its variants would continue to be part of Toyota's powertrain offerings. While the 2GR-FKS is efficient for its size, it runs at an 11.8:1 compression ratio, unlike the 13:1 ratio of both the A25A-FKS and its sibling the 2GR-FXS, both of which also feature cooled exhaust gas recirculation in part to deal with the knock. The 2GR-FXS runs an Atkinson cycle full-time and is currently used in hybrid applications. However, for a much lighter truck (see section below on mass reduction), the 2GR-FXS would have plenty of power to meet not just the demands of moving the truck, but also similar payload and towing capability as the current model, since the 2GR-FXS has less than a 10 percent reduction in power and torque, but the total GVWR of the V6 variants would have nearly a 15 percent reduction at current payload.

To the two new engine offerings, Toyota could also add cylinder deactivation. While Toyota claims that "cylinder deactivation provides insufficient benefit to the 2018 Camry 2.5L Atkinson engine considering the cost of the technology," (Gezelle 2019, 6) this is inconsistent with our own findings. Moreover, Toyota has not defined the basis for this cost-benefit analysis—as can be seen in our cost analysis for the Tacoma average package, this technology was an enabler of achieving huge fuel savings which overall more than paid off for consumers and helped the truck meet the 2025 standards, which is the objective of any such analysis.

FIGURE C-1. Toyota’s New Global Powertrain Architecture



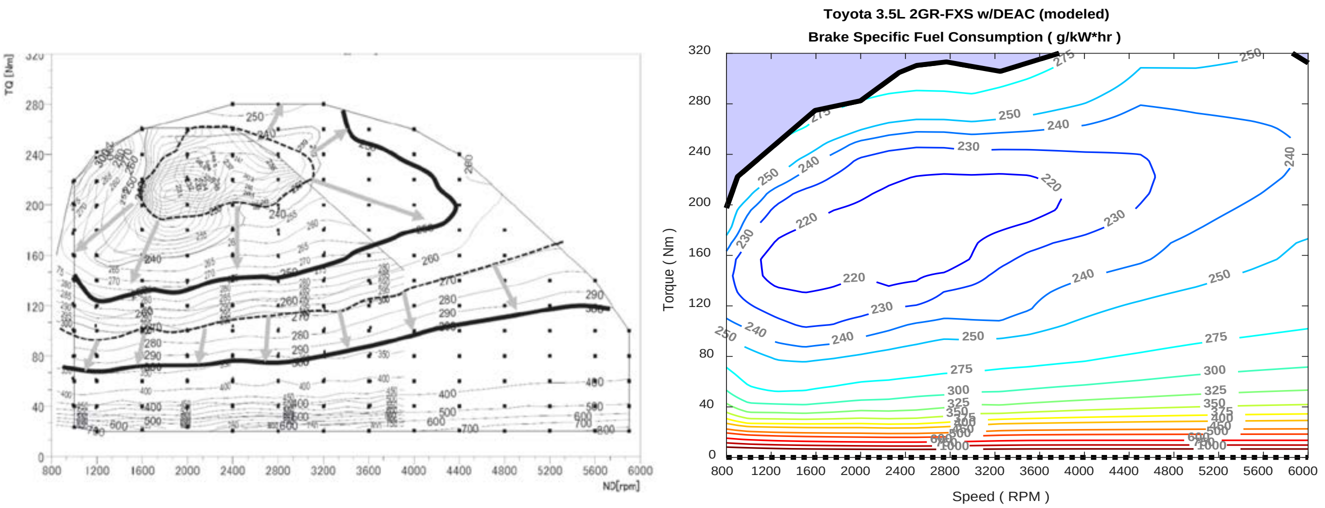
As part of its Toyota New Global Architecture (TNGA) initiative, Toyota is consolidating its engine platforms. The 2.5L and 3.5L engines featured in our analysis are represented as part of that future vision, along with the 10-speed automatic transmission.

SOURCE: TOYOTA 2018

To model the 2GR-FXS, we turned to the EPA benchmarking of the A25A-FKS, since this has all the same technologies. We then resized this for 3.456L and reshaping the maximum torque curve to be more representative of the engine’s actual properties. Cylinder deactivation was then added, consistent with EPA’s approach (Bohac 2018). There are a few noticeable differences between this modeled engine and Toyota’s published map of the 2GR-FKS. For example, because it is assumed that Atkinson is used over a wider area, the breadth of the efficient areas of the map run to higher speeds—while it is unknown whether this is consistent with the currently deployed 2GR-FXS, this has little impact on the simulated emissions of the vehicle because the HWFET and UDDS test cycles run predominantly at lower engine speeds. Another notable difference is the overall efficiency of the engine—while the 2GR-FKS is noted to have a maximum thermal efficiency of 38 percent, and the A25A-FKS one of 40 percent, our modeled 2GR-FXS falls in between, with a very small region of 39 percent thermal efficiency and a minimum brake specific fuel consumption of 213 g/kW-hr., a value 5 percent lower than the 2GR-FKS and 1.5 percent higher than the A25A-FKS (Matsui et al. 2015, Kargul et al. 2019). A comparison between the current 2GR-FKS and modeled 2GR-FXS with cylinder deactivation is shown in Figure C-2.

There is a substantial difference in the technologies of the baseline 2.7L and futured 2.5L engine. We consider the baseline engine to have deployed only basic friction reduction and variable valve timing, while the new I4 engine applies a second level of friction reduction an assessed pathway-dependent cost for variable valve lift before applying the high-compresstion ratio engine package, cooled exhaust gas recirculation, and cylinder deactivation, at a cost of $807-922 (in 2010$). The cost difference for the future 3.5L stems from the application of cooled EGR and cylinder deactivation, at a cost of $302-428 (in 2010$). The average direct cost applied to the Tacoma fleet for the engine is $367-490 (in 2010$).

FIGURE C-2. Comparison of current and future Toyota Tacoma engines



Moving to the 2GR-FXS reduces the total available power but would result in a broader range of efficient operation due to increased use of the Atkinson cycle and an increased compression ratio.

SOURCE: MATSUI ET AL. 2015, UCS DATA

Transmissions

Two transmissions are available in the Tacoma, a six-speed automatic and a six-speed manual. The current iteration of ALPHA does not have a “manual transmission” class available, so we have considered TRX10 to represent today’s manual transmission and TRX11 for today’s six-speed.

Toyota has in its line-up a 10-speed “direct shift” automatic transmission (Figure C-1), which is currently deployed in the Lexus LS500 sedan in both rear- and all-wheel-drive configurations, paired with an engine that exceeds the power demands of the Tacoma. While the gear ratios in the 10-speed are tuned differently than would be used in the Tacoma, this indicates the viability of the technology, and it’s hypothesized Toyota is putting a 10-speed automatic transmission in the forthcoming Tundra, with which the Tacoma would share its platform.

An improved 8-speed transmission is modeled as a TRX22, so we utilize Autonomie data to estimate the full improvement from the 10-speed transmission. For improvements to the manual transmission, we model it as a TRX11, which is also a 6-speed transmission, albeit automatic. This may be slightly optimistic, but it does not have a significant impact on the overall emissions results because such a small fraction of vehicles are assumed to utilize a manual transmission (6 percent, comparable to the 5.1 percent referenced by WardsAuto [2019b]).

The difference in costs between the current six-speed automatic and Toyota’s new 10-speed transmission is estimated to be $527-595, in 2010$. The cost of improving a six-speed dual clutch transmission was used to estimate the cost of improving the six-speed manual, at $127. On average, the direct cost related to improved transmissions averaged $503-567, in 2010$.

Road Load Reduction

In addition to more detailed analyses below, it was assumed that additional reduction in rolling resistance from the Tacoma would be undertaken, with a 10 percent reduction in all non-off-road trims. This added $5 in direct costs to the vehicle (in 2010$).

MASS REDUCTION

Previous generations of the Toyota Tacoma had problems with the steel frame, but while Toyota has incorporated some high-strength steels, the truck itself is still much less advanced than others in its class. The cab received a significant update in 2016 (Capozza 2016), but the majority of the steel used was a shift from mild to high-strength, with only a small amount of advanced high strength steel (AHSS) around the door frame (A-pillar, hinge pillar, B-pillar). This is actually a lower level of AHSS than used by the GM pick-up benchmarked by Transport Canada in its analysis of mass reduction from pick-ups (Purcell and Johnston 2015, 109), and it is significantly less than the grades of steel in the 2015 Chevy Colorado, a direct competitor to the Tacoma (GM 2014). While high-strength steel was incorporated into the redesigned Tacoma frame in 2016, it is unclear whether that was to a level beyond the Transport Canada baseline vehicle (Purcell and Johnston 2015, 127), since the frame itself is still the same basic design (Schweinsberg 2015). Based on repeated references emphasizing the similarity to the previous generation's frame (Brubaker 2015, Williams 2015a) and an admission from Toyota that they were not able to reduce the weight of the frame (Williams 2015b), we assume that high-strength steel was added to improve safety and performance (similar to the Transport Canada improvements to the base vehicle to meet increased safety), rather than a level of lightweighting beyond that achieved in the baseline of the Transport Canada study. Moreover, the mass reduction to the frame (58 pounds, comparing the T4-GA and T5-LW models that meet the same modern safety requirements) represents only a very small share of the total reduction in curb weight observed (1103 pounds).

Translating the results of the Silverado lightweighting study to the Tacoma require a number of additional considerations. First, there are no reductions in mass related to the engine—the 2.5L and 2.7L are characterized with almost identical weights (A2Mac1 2018), and we assume that there is no significant change in weight for moving from one variant of the 3.5L V6 to another. We similarly do not make any assumptions around the lightweighting of the transmission system. Together, this eliminates 157 pounds of available mass reduction. Additionally, not all vehicles are in the 4WD Double Cab configuration of the Silverado tested. Elimination of the mass reduction associated with the front-drive subsystem reduces the mass reduction on a RWD vehicle by 45 pounds. The difference in weight between the Crew and Extended cab of the Silverado for the 5.3L is about 50 pounds (GM 2013)—since the cab saw a mass reduction of 44.5 percent, we assume that this is a reduction of 23 pounds that is not available for the Extended Cab. The difference between the curb weight of a comparable configured Tacoma to the Silverado is 4425 pounds vs. 5510 pounds. Therefore, the total available mass reduction assumed is 760 pounds, minus 40 pounds for RWD v. 4WD configurations and 18 pounds for Access vs. Double Cab configurations. To account for possible inefficiencies related to sharing the platform with the future Tundra pick-up, we reduce the assumed potential reduction in mass by 20 percent to 608 pounds, with an average reduction in mass of 571 pounds.

The total direct costs for lightweighting the Toyota Tacoma are assumed to be $464-932, in 2010$.

AERODYNAMICS

The Toyota Tacoma claimed to have the lowest aerodynamic coefficient of any pickup truck when it was redesigned in 2016 (Williams 2015b), with a coefficient of drag of 0.384-0.391 (McElroy 2015). However, the redesigned Ram 1500 claims to be the most efficient full-size pickup truck with a coefficient of drag of 0.357, nearly 10 percent better than the Tacoma. It is assumed that a further 10 percent reduction in drag is possible from the truck.

Reducing the Tacoma's coefficient of drag by an additional 10 percent would improve fuel economy as well as performance, at a direct cost of $100, in 2010$.

Accessories

Similar to the CR-V (Appendix B), it is assumed that by 2025 the Tacoma's accessories will be electric. While not a necessary addition for compliance, because higher powered alternators are already more efficient, on average (Mendrick 2017), the next generation Tacoma could be an opportunity for a more advanced alternator utilizing high-efficiency diodes, which could improve the alternator's efficiency by 6 percent (Denso 2019). The current Tacoma has a 130A alternator, which averages at least 67 percent efficiency (Mendrick 2017), which would correspond to a 73 percent efficient alternator after a 6 percent future improvement. This is well above the 70 percent threshold assumed for a high efficiency alternator by both the agencies and the National Academies, as well as the 67 percent baseline assumption on alternator efficiency. Additionally, it is likely that such an alternator would earn an additional 0.8-1.0 g/mi off-cycle credit (Mendrick 2017).

Similar to the CR-V, the Toyota Tacoma would benefit significantly from a 48V stop-start system. While Toyota has thus far looked at hybridization almost exclusively through the lens of the Synergy Drive system utilized in the Prius and other strong hybrids, it is far more plausible that a "hybrid" Tacoma would be something akin to the mild hybrid found on the Ram 1500 pick-up, which can supplement the engine's torque but is primarily designed for responsive stop-start operation. We estimate the direct costs of this system to be $534-721, in 2010$.

One final accessory change is that all exterior lighting is shifted to more efficient LEDs, a direction the industry is largely moving to already anyway.

Results

A summary of modeled performance characteristics is provided for all trim levels (Table C-1). While performance data for 2019 vehicles are provided for comparison, actual fuel economy label data and estimated 0-to-60 mph performance data was used for benchmark comparisons. CO_2 test values for 2019 include estimates based on available credit and technology data.

Estimated direct costs range from $2129-2971, in 2010$. This translates to a retail price equivalent of $3668-5119 for consumers, in 2018$. While this represents a significant increase in price over the current Tacoma, it is lower than the price increase seen over the past 6 years for comparable models (i.e. excluding regular cabs and at similarly equipped powertrain options), even after considering inflation—we estimate an equivalent MY2013 vehicle would have a manufacturer's suggested retail price (MSRP) of $28,344, on average, in 2018$, compared to a MY2019 vehicle's average MSRP of $33,274 (WardsAuto 2013, 2019c),[1] an increase of 17 percent, which is a greater increase than even if Toyota were to directly pass on the full cost of improving fuel economy and reducing emissions to its 2025 Tacoma customers.

Additionally, unlike the improvements from MY2013 to MY2019, which have led to virtually no improvement in fuel economy in the base engine and just 10 percent savings in the high-end model, these technology improvements actually pay themselves off in massive fuel savings. At zero discount, consumers would save $8,535 in fuel over the lifetime of the vehicle, compared to today's model. Including loan costs (6.16 percent rate, 69-month average length, for 85.4 percent of new car purchasers) results in net present values of $1,150-2,750, in 2018$ and a 3 percent discount rate.

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[1] These value are based upon the trims and weightings as categorized in this analysis, not the actual sales mix, since such information is proprietary.

TABLE C-1. Comparison of modeled performance characteristics for the 2019 and 2025 Toyota Tacoma

Year	Trim	%	Foot-print	CO_2 (g/mi)		Fuel Economy (mpg)				Acceleration (s, from/to *x* mph)			
				Req'd	Test	Lab	City	Hwy	Label	0-30	0-60	30-50	50-70
2019	SR Access, 4x2, I4, A6	7.8	55.8	289	311	27.1	19	23	21	4.07	9.47	5.71	7.43
2019	SR Access, 4x2, V6, A6	22.6	55.8	289	313	26.9	19	23	21	2.93	6.48	4.82	6.16
2019	SR Access, 4x4, I4, A6	2.8	55.8	289	332	25.5	18	22	20	4.29	9.40	6.01	7.95
2019	SR Access, 4x4, I4, M6	1.2	55.8	289	319	26.5	19	22	20	3.60	9.32	4.49	7.10
2019	SR Access, 4x4, V6, A6	39.2	55.8	289	329	25.7	18	22	20	3.09	6.98	5.05	6.55
2019	SR Access, 4x2, V6, M6	2.1	55.8	289	368	23.1	16	20	18	2.61	6.96	3.44	5.28
2019	SR Double, 4x2, I4, A6	4.7	55.8	289	316	26.7	19	23	20	4.22	9.91	5.89	7.70
2019	TRD Double, 4x2, V6, A6	1.5	56.1	290	320	26.4	18	23	20	3.04	6.82	4.97	6.41
2019	TRD Pro Dbl., 4x4 V6, A6	4.7	56.1	290	339	25.0	18	22	19	3.21	7.35	5.22	6.84
2019	TRD Off-Road Dbl, 4x4 V6, M6	1.2	56.1	290	393	21.7	16	19	17	2.74	7.30	3.53	5.11
2019	TRD Dbl. Long, 4x2 V6, A6	3.1	61.6	316	320	26.4	18	23	20	3.04	6.82	4.97	6.41
2019	TRD Dbl. Long, 4x4 V6, A6	9.0	61.6	316	339	25.0	18	21	19	3.21	7.35	5.22	6.84
2019	**Average**	**100**	**56.6**	**292**	**326**	**25.9**	**18**	**22**	**20**	**3.22**	**7.34**	**5.08**	**6.62**
2025	SR Access, 4x2, I4, A6	7.8	55.8	212	194	38.3	27	30	28	3.61	7.99	3.70	5.43
2025	SR Access, 4x2, V6, A6	22.6	55.8	212	205	36.6	26	29	27	2.92	5.99	2.90	4.02
2025	SR Access, 4x4, I4, A6	2.8	55.8	212	208	36.1	26	28	27	3.83	8.65	3.96	5.90
2025	SR Access, 4x4, I4, M6	1.2	55.8	212	216	34.9	25	27	26	3.61	8.45	5.57	7.43
2025	SR Access, 4x4, V6, A6	39.2	55.8	212	219	34.5	24	28	26	2.88	6.91	3.01	3.97
2025	SR Access, 4x2, V6, M6	2.1	55.8	212	233	32.7	24	25	25	2.76	7.11	4.22	5.11
2025	SR Double, 4x2, I4, A6	4.7	55.8	212	194	38.3	27	30	28	3.68	8.21	3.78	5.56
2025	TRD Double, 4x2, V6, A6	1.5	56.1	213	209	36.0	25	29	27	2.80	6.65	2.90	3.80
2025	TRD Pro Dbl., 4x4 V6, A6	4.7	56.1	213	228	33.4	24	27	25	2.93	7.09	3.07	4.09
2025	TRD Off-Road Dbl, 4x4 V6, M6	1.2	56.1	213	255	30.3	22	23	23	2.82	7.32	4.31	5.28
2025	TRD Dbl. Long, 4x2 V6, A6	3.1	61.6	233	210	35.7	25	29	27	2.80	6.65	2.90	3.80
2025	TRD Dbl. Long, 4x4 V6, A6	9.0	61.6	233	228	33.4	24	27	25	2.93	7.08	3.07	4.08
2025	**Average**	**100**	**56.6**	**215**	**214**	**35.2**	**25**	**28**	**26**	**3.02**	**6.93**	**3.18**	**4.31**

The Toyota Tacoma moves from credit burner to credit earner in 2025 while improving acceleration and raising fuel economy by an average of 6 mpg, all while maintaining the same payload and towing capacities.

SOURCE: UCS DATA

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[APPENDIX D]

2025 Ford Ecosport

The Ford Ecosport was introduced to the United States for the 2018 model year, though it was last redesigned in the 2013 model year and is due to be redesigned again for the 2023 model year (Wards 2019a). It is available in four different trim levels (S, SE, Titanium, and SES) and in either front- or all-wheel drive (FWD or AWD). All FWD vehicles use a 1.0L 3-cylinder EcoBoost engine, while the AWD variants utilize a 2.0L naturally-aspirated engine. To span the range of offerings of the Ecosport, we consider each of the seven combinations of drivetrain and trims offered (the top-line SES is only offered in AWD). Marketshare of the 7 different model configurations is based on data from WardsAuto, using data on safety and interior features to estimate relative trim levels (2019b, 2019c, 2019d).

Engine

The 1.0L 3-cylinder EcoBoost on the current Ecosport dates back to 2012 and is shared amongst numerous Ford vehicles around the globe, though it did not make its way to the U.S. until the 2014 model year. A naturally aspirated version of the 1.0L is also available globally, though not in the United States. The engine itself has already been updated, incorporating cylinder deactivation for the first time in a 3-cylinder engine (Ford 2019). Given the efficiency of the existing 1.0L EcoBoost, this change is likely to be the only upgrade to the next-generation Ecosport base engine. We have modeled this engine using the EPA-benchmarked 2.7L V6 EcoBoost engine (Stuhldreher and Butters 2016), reducing it to 999cc (and adding cylinder deactivation for the future variant, consistent with EPA [Bohac 2018]).

The 2.0L naturally aspirated I4 has been around since 2010 (Lassa 2011), though it is based on a Mazda engine dating back to 2001, when Ford maintained a controlling interest in the company. The Duratec 2.0L has seen numerous upgrades over the years, with the HE Ti-VCT variant in the current Ecosport employing both gasoline direct injection and "twin independent variable camshaft timing," Ford's Ti-VCT system which allows variable camshaft timing on intake and exhaust camshafts independently. However, the engine itself is quite dated and is likely to be replaced by an EcoBoost engine. Our modeling shows Ford deploying the brand new 1.5L 3-cylinder EcoBoost in the next generation Ecosport, the so-called "Dragon" engine (Myles 2018). Combining direct- and port-injection, Ti-VCT, cylinder deactivation, and a newly designed radial-axial turbocharger (RAAX^{TM} from Continental), the 1.5L Dragon is already available in the Ford Focus, Escape, and Fiesta ST, with power output ranging from 150 to 200 horsepower. Given the significant suite of technologies (which helped to make the base 1.5L engine 7 percent more efficient [Firfiray 2017]) and product development chief on the optimization of thermal efficiency, Honda's 1.5L turbocharged engine was used as the basis for the modeled Dragon engine, resized to a 3-cylinder variant (EPA 2016, p. 2-265) and incorporating cylinder deactivation (Bohac 2018).

The Duratec engine being replaced was assumed to have 1 level of low-friction lubricant and engine friction reduction, variable valve timing, and direct injection. The replacement engine features a second level of engine friction reduction, variable valve lift, two levels of turbocharging, a downsizing benefit moving from an inline-4 to an inline-3 engine, and cylinder deactivation. The additional cost for the baseline engine was simply the addition of cylinder deactivation. On average, the cost for the engine upgrades were $380-502, in 2010$.

Transmissions

The current transmission in the Ecosport is a six-speed automatic based on a transmission developed with General Motors back in 2002. Though the 6F15 is a newer variant of that transmission (debuted in 2012), it is still fairly outdated, and it is anticipated that the next generation Ecosport will replace it with Ford's newest 8-speed automatic, which was coincidentally also developed with General Motors (Brzozowski 2018).

Both the 1.0L and 1.5L engines have already been paired with the new 8-speed automatic, in the latest Ford Focus (Ford 2018), and this is expected to be the default transmission for the platform underpinning the future Ecosport (Gibbs 2018). This transmission features improved shift logic and gearbox, in addition to an increase in gears, at a cost of $234-302, in 2010$.

Road Load

In addition to more detailed analyses below, it was assumed that additional reduction in rolling resistance from the Ecosport would be undertaken, on top of an assumed 10 percent reduction in the base vehicle. This added $31 in direct costs to the vehicle (in 2010$). It was also assumed that a secondary axle disconnect would be deployed, improving the efficiency of the all-wheel-drive version of the Ecosport at a direct cost of $52, in 2010$.

FOOTPRINT

Apart from fuel economy, one of the central complaints of the current Ecosport is that it is simply too small (e.g., Bangeman 2018, Capparella 2018, Duffer 2018, Payne 2018). While the next generation will certainly want to maintain the higher SUV profile as opposed to the sleeker vibe of the similarly sized and brand new Ford Puma, lengthening the wheelbase by a few inches could provide the vehicle with a little extra space, make it easier for the vehicle to become more aerodynamic with softer sloping angles, and still provide enough of a gap in capability and size to distinguish itself from the larger Escape. As an additional benefit for Ford, increasing the vehicle's footprint slightly will also reduce the vehicle's fuel economy and emissions targets for 2025.

Spy shots of what was reported to be a mule for the next generation Ecosport powertrain seem to confirm a larger wheelbase as well (Kurczewski 2018). Therefore, we propose increasing the 2025 Ecosport's wheelbase by 2", from 99.2" to 101.2". (For comparison, this is still a large gap with the 106.7" wheelbase of the Ford Escape.) This change leads to a 2 percent increase in vehicle footprint, and a 1.9 percent increase in the emissions target (g/mi) for the vehicle, from an average of 149 g/mi to 151 g/mi.

MASS REDUCTION

The base Ecosport has used some small amount of high strength steel (HSS) in the body, and even ultra-high strength steel (UHSS) in the passenger "cage" in particular (Huetter 2018, Mahendra 2013). However, this indicates that there is substantial room for improvement, with the vehicle not even maximizing the use of UHSS, let alone even lighter materials like the aluminum found in Ford's highest-volume vehicle, the F-150. Because the vehicle exclusively uses steel and only very little of the most advanced grades of steel, we conservatively estimate that the baseline vehicle has already applied a level of mass reduction consistent with NHTSA's definition of MR2 (5 percent of the glider weight, estimated to be 75 percent). This total mass reduction of 3.75 percent in the baseline, is then substracted from the total potential opportunity for mass reduction, and its costs are considered when assessing future mass reduction costs.

Based on the assumed sales mix of the Ecosport, the curb weight is estimated to be 3236 pounds. Compensating for a 2 percent increase in size and reflecting the 3.75 percent reduction in mass that has already occurred yields a baseline mass of 3430 pounds for the Ecosport. A study of the Toyota Venza achieved 15.4 percent reduction in curb weight just by deploying HSS and UHSS in the body, along with aluminum and a small share of magnesium in the closures (FEV 2012,

Table F.1-1).[1] Such reductions applied to the Ecosport would yield a maximum opportunity for mass reduction from the body of 528 pounds, with 129 pounds of reduction already applied to the current vehicle.

The current Ecosport is built on the Ford B3 platform, which also includes vehicles like the Ford Fiesta, Ka, and the brand new Puma. However, it has been announced that the next generation Ecosport will share the consolidated global platform, first utilized by the current Focus (Gibbs 2018). Leveraging increased use of UHSS across the platform, along with additional opportunities for aluminum enclosures provides ample opportunity for the next-generation Ecosport to be significantly lighter. To the body, we apply 376 pounds of the remaining 399 pounds.

In addition to reduction in mass from the body, there is a benefit of downsizing the powertrain for the 2.0L vehicles. According to A2Mac1, the difference between the original 1.0L EcoBoost and the 2.0L GDI engine was 42 pounds. Our assumption is that the 1.5L will approximately split that difference, leading to an additional reduction from downsizing of 21 pounds. The final estimated weight of the 1.5L engine would be 5 pounds lighter than the 1.6L I4, consistent with the 1.5L I4 being lighter than the 1.6L I4 and the Dragon I3 being lighter than the I4 (Kreindler 2013, Arul 2017).

In total, the 2025 Ecosport sees a reduction in curb weight of 302-323 pounds from the 2019 Ecosport, despite a 2 percent increase in footprint. The total direct costs for lightweighting are $433-662, in 2010$.

AERODYNAMICS

With an aerodynamic coefficient of 0.37, the Ford Ecosport is one of the least aerodynamic vehicles in its class—for comparison, the Chevrolet Equinox and Honda HR-V have aerodynamic coefficients below 0.32 (EPA 2018). The next generation Ecosport will have an opportunity to match these vehicles with a 15 percent reduction in drag, without veering too far from the Escape/Edge family style that the Ecosport is trying to mimic.

Reducing the Ecosport's coefficient of drag by 15 percent would improve fuel economy as well as performance, especially in the baseline engine, at a direct cost of $83, in 2010$.[2]

Accessories

The current Ecosport has deployed a 12V stop-start system with both powertrain options; however, Ford is deploying both the 1.0L and 1.5L Ecoboost engines paired with a higher voltage (48V) mild hybrid system in Europe, and this mild hybrid option will be an option across the range of other vehicles sharing the global platform on which the next Ecosport will be built (Attwood 2019, Gibbs 2018). We estimate the incremental direct costs of this system over the 12V to be $279-416, in 2010$.

Results

A summary of modeled performance characteristics is provided for all trim levels (Table D-1). Note that while performance data for 2019 vehicles are provided for comparison, actual fuel economy label data and estimated 0-to-60 mph performance data was used for benchmark comparisons. CO_2 test values for 2019 include estimates based on available credit and technology data.

Estimated direct costs range from $1,491-2,048, in 2010$. This translates to a retail price equivalent of $2658-3528 for consumers, in 2018$. At zero discount, consumers would save $6,337 over the lifetime of the vehicle, compared to today's model. Including loan costs (6.16 percent rate, 69-month average length, for 85.4 percent of new car purchasers) results in net present values of $1,273-2,311, in 2018$ and a 3 percent discount rate.

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[1] Here we ignore reductions in mass related to the engine and transmission, which we consider separately.

[2] The estimate is based on half the cost of an improvement from AERO10 to AERO20, along with a shift from AERO0 to AERO10.

TABLE D-1. Comparison of modeled performance characteristics for the 2019 and 2025 Ford Ecosport

Year	Trim	%	Foot-	CO$_2$ (g/mi)		Fuel Economy (mpg)				Acceleration (s, from/to *x* mph)			
			print	Req'd	Test	Lab	City	Hwy	Label	0-30	0-60	30-50	50-70
2019	S FWD	12.7	41.2	176	212	39.9	28	31	29	4.64	11.09	5.19	7.73
2019	S AWD	3.0	41.2	220	226	35.0	25	28	26	4.76	10.62	4.82	7.05
2019	SE FWD	20.4	41.2	176	213	39.8	28	31	29	4.62	11.04	5.16	7.68
2019	SE AWD	27.7	41.2	220	226	34.9	25	28	26	4.79	10.62	4.82	7.06
2019	Ti FWD	6.3	41.2	176	213	39.8	28	31	29	4.62	11.04	5.16	7.68
2019	Ti AWD	22.9	41.2	220	227	34.9	25	28	26	4.76	10.63	4.82	7.06
2019	SES AWD	7.0	41.2	220	230	34.4	24	28	26	4.85	10.94	4.94	7.24
2019	**Average**	**100**	**41.2**	**203**	**221**	**36.7**	**26**	**29**	**27**	**4.72**	**10.82**	**4.97**	**7.32**
2025	S FWD	12.7	42.0	134	142	52.8	36	40	37	4.18	9.85	4.17	6.10
2025	S AWD	3.0	42.0	163	155	45.5	30	38	33	3.57	8.73	3.98	5.16
2025	SE FWD	20.4	42.0	134	144	52.0	35	40	37	4.28	10.19	4.30	6.30
2025	SE AWD	27.7	42.0	163	155	45.5	30	38	33	3.57	8.73	3.98	5.16
2025	Ti FWD	6.3	42.0	134	144	52.0	35	40	37	4.28	10.19	4.30	6.30
2025	Ti AWD	22.9	42.0	163	157	45.0	30	37	33	3.63	8.97	4.09	5.32
2025	SES AWD	7.0	42.0	163	158	45.0	30	37	33	3.63	8.97	4.09	5.32
2025	**Average**	**100**	**42.0**	**151**	**151**	**47.8**	**32**	**38**	**34**	**3.85**	**9.33**	**4.12**	**5.63**

The Ecosport moves to a segment leader in conventional vehicle efficiency in 2025 while improving acceleration and raising fuel economy by 7 mpg, even while increasing by 2 percent in size, besting the FWD-only Nissan Kicks and its current 31/36/33 fuel economy.

SOURCE: UCS DATA

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2025 Chevrolet Malibu

The Chevrolet Malibu was last redesigned for the 2016 model year and is due to be redesigned again in 2023 (WardsAuto 2019a). For the 2019 model year, there were 6 trims (L, LS, RS, LT, Premier, Hybrid), but the hybrid option is being eliminated for 2020. The LS is almost identical to the RS, except for some exterior additions to make the vehicle sporty—therefore, the LS sales have been consolidated with the RS, leaving 4 different trims considered to account for the breadth of configurations found on the Malibu. For 2019, there were 3 different engines, but only the two conventional powertrains (1.5L turbo and 2.0L turbo) were modeled due to limitations in ALPHA v2.2.

According to WardsAuto, two-thirds of Malibu buyers opt for satellite radio, an option only available on the hybrid, LT, and Premier trims (WardsAuto 2019b). While using the powertrain share of hybrid, 1.5L, and 2.0L engines) differentiates between those three vehicle trims (WardsAuto 2019c), share of power seats was used to distinguish between the remaining L and LS/RS shares (WardsAuto 2019d). Because the interior options of the hybrid were most similar to the LT trim package, the assumed uptake of those two trim levels were combined in this analysis.

Engine

For the 2019 model year, General Motors (GM) offered three different powertrain options, a base engine (1.5L), a sporty, premium engine (2.0L), and a fuel-efficient offering that provided power in between the two (hybrid). With the exit of the hybrid and a focus on meeting the 2025 standards boosting the efficiency of the remaining two options, GM could again offer a third powertrain that slots in between the two, providing increased power over the base engine while allowing the Premium trim to get even sportier.

The base engine is an inline-4 cylinder, 1.5L turbocharged engine (LFV) that has been around since 2016. It is part of GM's small gasoline engine family, under the Ecotec brand, and was developed globally with Opel, SAIC, MG Motor, and Shanghai GM. In addition to the Malibu, it is also sold in the Buick Envision, and its naturally-aspirated sibling (L3A) was used in the now-discontinued Chevrolet Volt. It has an aluminum block and utilizes direct injection and variable valve timing. In the Malibu, its peak output is 163 hp, with a peak torque of 184 ft.-lbs. For the ALPHA runs, the engine was modeled based on the Ford 1.6L I4 turbo, downsized to 1.5L, which provided similar power.

After pursuing a lightweighting strategy on the future Malibu, maintaining the same 1.5L engine would lead to a massive increase in performance. For a base engine, it would make more sense to decrease the power, creating space between this and the more premium trim levels. To that end, the 1.5L turbo could be replaced with an update of the 1.8L engine (LKN) currently deployed in the hybrid. The 1.8L is already designed to run on the Atkinson cycle, similar to Toyota's highly efficient Camry engine, and if that were resized to 1.8L, it would have a comparable peak torque. And since this base engine is being optimized for efficiency, GM could incorporate cooled EGR and cylinder deactivation into an iteration of the engine designed to serve as the sole source of propulsion. GM has already deployed what it calls "active fuel management" in the 2.7L turbo I4 found in its full-size pickups (GM 2018a). For the ALPHA runs, the engine was modeled based on the Toyota 2.5L I4, downsized to 1.8L, and utilizing cylinder deactivation consistent with EPA's modeling efforts (Bohac 2018).

In addition to the 1.8L, which is a lower-powered option (147 hp, 133 ft.-lbs.), GM could drop in the 1.3L inline-3 cylinder turbo it's already deployed in the Malibu in South Korea (Centeno 2018). While there would be a slight step down in fuel economy compared to the 1.8L, there would be an accompanying performance increase, slightly reduced from the current 1.5L I4 turbo, but substantially more torque perfect for an upgraded trim. For the ALPHA runs, the engine is modeled on the 2.7L EcoBoost, downsized to 1.3L. While the L, LS, and RS trims were assumed to utilize the base 1.8L, the 2025 LT trim receives the 1.3L I3 turbo. GM may instead want the more powerful engine in the RS trim (its sport option), to compete with vehicles like the Accord Sport, but doing so would result in a significantly different pricing of trims than the current trims, so we keep it limited to the LT, which is both higher priced and higher volume (according to WardsAuto).

The 2019 Malibu utilizes the 2.0L Ecotec (LTG) turbocharged engine in the Premier trim. For 2025, it is assumed that this will be updated with the LSY engine, which incorporates cylinder deactivation and offers stop-start capability (GM 2018b). With a longer stroke, the new LSY is part of a recent trend in engine design centered around so-called "under-square" engines (Sherman 2015). In ALPHA, both 2.0L engines were modeled based on the Ford 2.7L EcoBoost, downsized. Modeling of the LSY engine incorporated cylinder deactivation consistent with EPA's modeling efforts (Bohac 2018).

Comparing the 1.3L and 1.5L turbos, no cost different is assumed, despite a reduction in cylinders in moving to the 1.3L. For the 1.5L compared to the 1.8L engine, while there is a reduction in cost for eliminating the turbo, there are increased costs for improved friction reduction, increasing the compression ratio, and adding cooled EGR and cylinder deactivation. The only increase in cost assumed for the LSY vs. the LTG 2.0L engine is the addition of cylinder deactivation. On average, the total direct cost of these upgrades result in $99-125 over the current engines (in 2010$). Additionally, there is a net reduction in direct costs of $32 related to eliminating the hybrid powertrain.

Transmissions

There are two transmissions offered in the current Malibu, a 9-speed automatic transmission and a continuously variable transmission (CVT). Both transmissions are less than five years old, making them relatively advanced, though with room for incremental improvement before the next redesign.

The 9-speed automatic (Hydra-matic 9T50) is currently paired exclusively with the 2.0L turbo in the Premier trim and was new for the 2017 model year. This transmission was modeled as a TRX21 in ALPHA. It is thus assumed that additional gains are possible for the 9-speed, due to further reduction in friction. For the 2025 model, the 9-speed receives this improvement, and its use is expanded to the 1.3L engine in the LT trim. The 1.3L has already been paired with the current iteration of the 9-speed in the new Buick Encore GX (Capparella 2019).

The CVT (VT40) was introduced to the Malibu in 2019 and is the first GM CVT since 2005 (Sabatini 2019). It is currently paired with the 1.5L turbo, though the 1.8L hybrid uses an "e-CVT" thanks to its power-split hybrid configuration. The current ratio spread is 7.0:1, which is wider than the six-speed it replaces (6.1:1) but is not as wide as the 9-speed available in the Premier (7.6:1). For comparison, EPA's TRX22 transmission has an 8.7:1 spread. The CVT is also designed to mimic a standard automatic with simulated shifting behavior, which improves drivability, even if it sacrifices some efficiency.

Both transmissions were modeled in ALPHA as TRX21 in 2019 and TRX22 in 2025. However, the gear ratio was changed for 2025 to more closely replicate the 9-speed transmission in the future LT and Premier trims,[1] reducing the gear spread but still taking advantage of improved efficiencies.

We apply increased costs for "high efficiency gearboxes" for both the 9-speed (HEG3) and CVT (HEG-CVT). Costs are also incurred for swapping out the LT trim's CVT for a 9-speed automatic. The average direct costs related to transmissions in the 2025 Malibu are $161-204 (in 2010$).

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[1] The 9 forward gear ratios in the current 9T50 are [4.69 3.31 3.01 2.45 1.92 1.45 1 0.75 0.62]. The TRX22 has just 8 gears but, by default, a wider spread: [5.501 3.473 2.2 1.737 1.326 1 0.817 0.632]. To model a future 9-speed within the TRX22 constraint, we eliminate 3rd gear from the 9T50 ratios, since this results in roughly equal gear spacing in the 8-speed. Interestingly, while Ford eliminated a gear from the 9-speed in adapting it for its Ford Edge, they removed GM's 4th gear (2.45) instead (Ford 2019); however, in our simulations, this resulted in both reduced efficiency in the city cycle and no improvement to performance, which is why we swapped out 3rd gear.

Road Load Reduction

In addition to more detailed analyses below, it was assumed that additional reduction in rolling resistance from all Malibu trims would be undertaken. This added $31 in direct costs to GM (in 2010$).

MASS REDUCTION

The 2019 Chevrolet Malibu is a midsize sedan, so the maximum potential lightweight capability can be based on the studies of the Honda Accord (Singh et al. 2012, Singh et al. 2016). This leads to a maximum potential reduction of 16.7 percent mass reduction (excluding powertrain opportunities) from a vehicle almost exclusively based on mild steels.[2]

The current generation Malibu already underwent significant lightweighting in the last redesign, so this must be taken into account when considering future opportunities for further reduction (GM 2015). For comparison, the baseline 2015 Malibu had a curb weight of 3393 pounds, compared to the 2016 base trim with a curb weight of 3086 pounds. Some of this weight differential comes from moving from the 2.5L to the 1.5L turbo (86 pounds)—mass reduction related to the powertrain is considered separately. Using the baseline by which mass reduction is assessed is assumed to be 3373 pounds, leading to a maximum reduction in weight related to the body of 567 pounds, with 221 pounds already incurred. Leaving 75 pounds available as a margin by which GM could include further luxury items, 271 pounds of further reduction from the body is possible.

It is likely that further reductions could be enabled via the powertrain—for example, the curb weight of the Malibu was reduced in upgrading from the six-speed to the CVT and from the 8-speed to the 9-speed, despite more complexity. However, little data is available on the extent of these potential improvements. Similarly, while there would likely be a penalty for upsizing from the 1.5L turbo to the 1.8L Atkinson engine, future improvements to the engine block could offset this. Conservatively, we have estimated a small increase in weight of 23 pounds related to upsizing from a 1.5L to a 1.8L engine using scaling based on the difference in weight of the 1.5L and 2.0L engines (A2Mac1 2018). However, the revamped Camry saw virtually no change in weight between redesigns, and the removal of the turbocharger would more than likely offset this based on comparison of the same engine with and without a turbo (e.g., Opel B10XE and B10XFL, both within GM's small gasoline engine family).

Taking into account the costs already incurred for lightweighting the current version of the Malibu, which thus increases costs for 2025 since it will require more advanced materials, results in an estimated direct cost of $346-498, in 2010$, for 271 pounds of lightweighting.

AERODYNAMICS

The Chevrolet Malibu had its coefficient of drag (C_D) reduced to 0.29 for the 2016 model year ("Mini Wind Tunnel" 2015). While this was an improvement over the previous generation, this is still well short of luxury leaders in its size class like the BMW 5 Series (0.22 [BMW Group 2016]) or even direct competitors like the Mazda 6 (0.26 [Voss 2017]) and Ford Fusion (0.275 [Ramsey 2017]). A 5-percent reduction in drag would not put it on par with the Fusion, and still well behind the Mazda 6, but this would still offer modest reductions in fuel use at very low cost. The Malibu already comes equipped with active grille shutters, which is eligible for off-cycle credit signaling additional, real world reductions from aero.

To calculate the cost of the aerodynamic improvements, we have scaled the cost for an improvement from 10 percent to 20 percent reduction based on the reductions already incurred by the Malibu. Because this cost was based upon the addition of technologies like grille shutters (NRC 2015, 208), which are already on the vehicle, this may represent an overestimate. For a 5 percent reduction, this adds a direct cost of $50 in 2010$ in 2025.

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[2] See Figure 233, Singh et al. 2012, excluding the 56.5 kg of weight reduction related to downsizing the powertrain and adding back in 21.75 kg and 6.9 kg for safety corrections (from vehicle 1.0 → 1.1 and 1.1 → 1.2, respectively [Singh et al. 2016, 57 and 64]).

Accessories

Mechanical linkage for accessories like the water pump and cooling fans remain a source for potential efficiency gain through electrification—this trend is underway, and it is assumed that by 2025 these accessories will be electric. Similarly, alternators have gotten gradually more efficient over time, and we assume that trend to continue, with the 2025 Malibu achieving a 70 percent efficiency. Along with being more efficient, the 2025 Malibu's alternator will be capable of mild regeneration. These modifications to accessories result in direct costs of $97 in 2010$, in 2025.

Electrification has already been underway for the Malibu, including electro-hydraulic brakes and an electric water pump (Centeno 2018). Additionally, the base engine already has a 12V stop-start system, and the 1.3L and 2.0L (LSY) engines proposed for 2025 have already been deployed with such systems (Centeno 2018, GM 2018). The direct cost for adding 12V stop-start to those engines not already utilizing it is just $8-10 in 2010$, since only the 2.0L doesn't already have it.

One final accessory change is that all exterior lighting is shifted to more efficient LEDs. This is already the case for the Premier trim, and the LT trim has LED daytime running lights and taillights. LED exterior lighting is available for off-cycle credit.[3]

Results

A summary of modeled performance characteristics is provided for all trim levels (Table E-1). Note that while performance data for 2019 vehicles are provided for comparison, actual fuel economy label data and estimated 0-to-60 mph performance data was used for benchmark comparisons. CO_2 test values for 2019 include estimates based on available credit and technology data.

Estimated direct costs range from $760-983, in 2010$. This translates to a retail price equivalent of $1309-1693 for consumers, in 2018$. At zero discount, consumers would save $2378 over the lifetime of the vehicle, compared to today's model. Including loan costs (6.16 percent rate, 69-month average length, for 85.4 percent of new car purchasers) results in net present values of $103-523, in 2018$ and a 3 percent discount rate.

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[3] While LED daytime running lights are noted to show that the technology is currently deployed, because they are not a mandated safety technology and therefore an optional accessory, they are not available for off-cycle credit.

TABLE E-2. Comparison of modeled performance characteristics for the 2019 and 2025 Chevrolet Malibu

Year	Trim	%	Foot-	CO_2 (g/mi)		Fuel Economy (mpg)				Acceleration (s, from/to *x* mph)			
			print	Req'd	Test	Lab	City	Hwy	Label	0-30	0-60	30-50	50-70
2019	L/LS	23.2	48.39	206	210	39.2	26	33	29	3.55	8.50	4.22	5.62
2019	RS	10.2	48.39	206	210	39.2	26	33	29	3.55	8.50	4.22	5.62
2019	LT	61.9	48.39	206	213	38.7	26	33	29	3.63	8.82	4.31	5.77
2019	Premier	3.5	48.39	206	236	35.4	23	32	26	2.82	6.10	2.76	3.66
2019	Hybrid	1.2	48.39	206	121	64.5	49	43	46				
2019	**Average**	**100**	**48.39**	**206**	**211**	**38.8**	**26**	**33**	**29**	**3.57**	**8.62**	**4.23**	**5.65**
2025	L/LS	23.2	48.39	155	144	41.6	34	41	37	3.59	8.53	3.75	5.84
2025	RS	10.2	48.39	155	144	56.0	34	41	37	3.59	8.53	3.75	5.84
2025	LT	63.1	48.39	155	158	55.4	31	39	34	3.37	7.50	3.32	4.71
2025	Premier	3.5	48.39	155	177	53.3	29	36	32	2.71	5.72	2.58	3.47
2025	**Average**	**100**	**48.39**	**155**	**154**	**54.2**	**32**	**40**	**35**	**3.42**	**7.78**	**3.44**	**5.04**

Eliminating the highly efficient (but low-volume) hybrid model doesn't dampen the Malibu's potential fuel economy improvement for 2025, thanks to a lighter, stiffer body and more efficient engine and transmission offerings. This leaves room for a mid-level trim with improved performance (2025 LT) in addition to the highest level luxury option (Premier).

Note: The 2019 hybrid was not explicitly modeled, but it is included here to more accurately reflect the baseline emissions and fuel economy.

SOURCE: UCS DATA

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