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

[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.

References

ANL (Argonne National Laboratory). 2017. "FC1_Improvements.csv" (version 20170825_150115) in ***Compliance and Effects Modeling System (The Volpe Model)***, released June 5, 2018, by the National Highway Traffic Safety Administration (NHTSA), US Department of Transportation. Accessed August 19, 2019. ftp://ftp.nhtsa.dot.gov/CAFE/2021-2026_CAFE_NPRM/CAFE_Model/CAFE_Model/cafe_model_2018-06-05.zip.

Bolon, Kevin. 2017. "Memorandum to Docket EPA-HQ-OAR-2015-0827 Regarding Stakeholder Meeting with Auto Alliance and Global Automakers and their contractor, Novation Analytics, and EPA Technical Response to Assertions of 'ALPHA-to-OMEGA Bias'." November 24, 2017. Document EPA-HQ-OAR-2015-0827-10988. Accessed August 19, 2019. https://www.regulations.gov/document?D=EPA-HQ-OAR-2015-0827-10988.

EIA (Energy Information Administration). 2019. ***Annual Energy Outlook 2019.*** Accessed August 20, 2019. https://www.eia.gov/outlooks/aeo/.

EPA (Environmental Protection Agency). 2016. ***Proposed Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation: Technical Support Document.*** EPA-420-R-16-021. Accessed August 19, 2019. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100Q3L4.pdf.

EPA. 2017. ***Advanced Light-duty Powertrain and Hybrid Analysis (ALPHA) Tool*** (v2.2). Accessed August 19, 2019. https://www.epa.gov/sites/production/files/2017-01/alpha-20170112.zip.

EPA. 2019. ***The 2018 EPA Automotive Trends Report: Greenhouse Gas Emissions, Fuel Economy, and Technology since 1975.*** EPA-420-R-19-002. Accessed August 27, 2019. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100W5C2.PDF?Dockey=P100W5C2.PDF.

EPA and NHTSA. 2010. ***Final Rulemaking to Establish Light-duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Joint Technical Support Document.*** EPA-420-R-10-901. Accessed August 20, 2019. https://nepis.epa.gov/Exe/ZyPDF.cgi/P1006W9S.PDF?Dockey=P1006W9S.PDF.

EPA and NHTSA. 2011. "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles," ***Federal Register*** 76, no. 179 (September 15, 2011): 57105. Accessed August 20, 2019. https://www.govinfo.gov/content/pkg/FR-2011-09-15/pdf/2011-20740.pdf.

FEV. 2015. ***2025 Passenger Car and Light Commercial Vehicle Powertrain Technology Analysis: Final Report.*** Prepared for the International Council for Clean Transportation, September 2015. Accessed August 20, 2019. https://theicct.org/sites/default/files/publications/PV-LCV-Powertrain-Tech-Analysis_FEV-ICCT_2015.pdf.

MacKenzie, Don, and John Heywood. 2012. "Acceleration Performance Trends and the Evolving Relationship Between Power, Weight, and Acceleration in US Light-Duty Vehicles: A Linear Regression Analysis," ***Transportation Research Record*** 2287(1): 122-131, 2012. https://doi.org/10.3141/2287-15.

NRC (National Research Council). 2015. ***Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles***. Washington, DC: The National Academies Press. https://doi.org/10.17226/21744.

OMB (Office of Management and Budget). 2003. "Circular A-4, to the Heads of Executive Agencies and Establishments Regarding Regulatory Analysis." Published September 17, 2003. Accessed August 20, 2019. https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/circulars/A4/a-4.pdf.

OMB. 2018. "Discount Rates for Cost-Effectiveness Analysis of Federal Programs," ***Federal Register*** 83, no. 247 (December 27, 2018): 66764. Accessed August 20, 2019. https://www.govinfo.gov/content/pkg/FR-2018-12-27/pdf/2018-27962.pdf.

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).

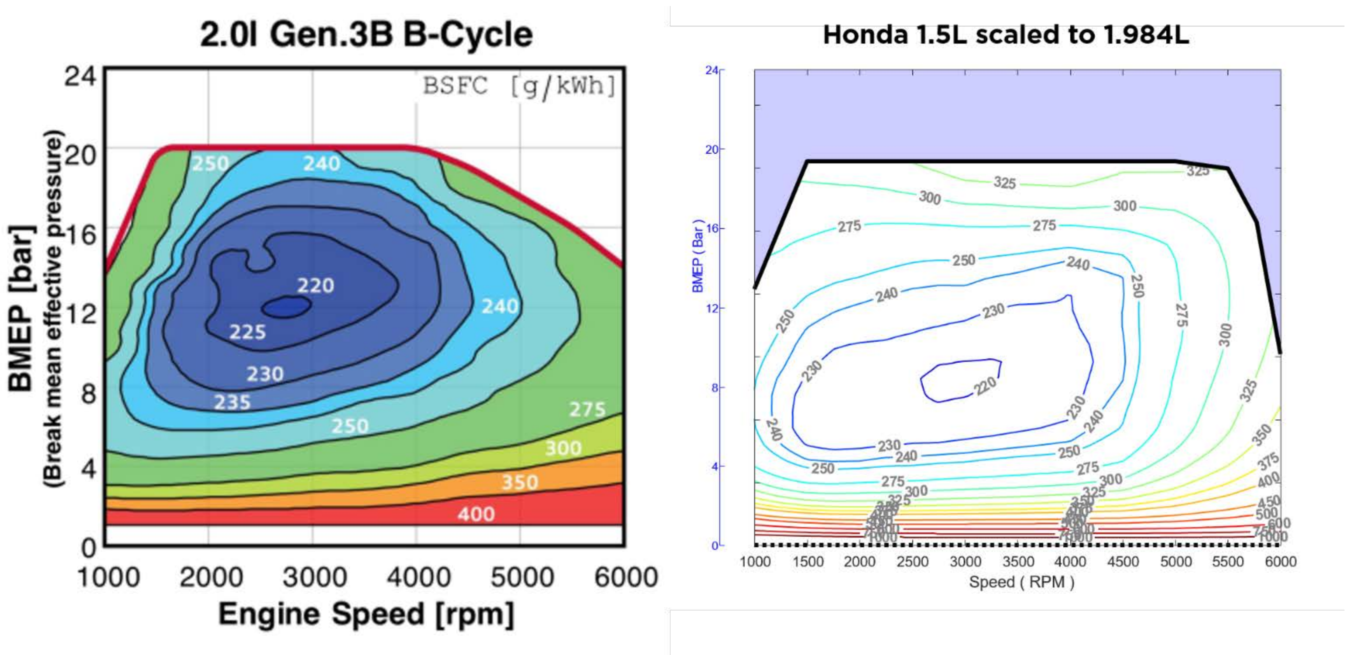
Engine

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

---

[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, which showed similar (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]

---

[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	%	Foot-print	CO_2 (g/mi) Req'd	Test	Fuel Economy (mpg) Lab	City	Hwy	Label	Acceleration (s, from/to *x* mph) 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

References

A2Mac1. 2018. "Glider Weight Report," A2Mac1 Automotive Benchmarking Database. http://www.a2mac1.com.

Automotive News. 2017. "At Volkswagen, the 10-speed Dream Is Over," ***Automotive News,*** May 8, 2017. Accessed August 23, 2019. https://www.autonews.com/article/20170508/OEM06/170509852/at-volkswagen-the-10-speed-dream-is-over.

Bohac, Stani. 2018. "Benchmarking and Characterization of Two Cylinder Cylinder Deactivation Systems – Full Continuous and Partial Discrete" (Presentation at SAE World Congress, Detroit, Michigan, April 10, 2018). Accessed August 23, 2019. https://www.epa.gov/sites/production/files/2018-10/documents/deact-sae-world-congress-bohac-2018-04.pdf.

Dekraker, Paul, John Kargul, Andrew Moskalik, Kevin Newman, Mark Doorlag, and Daniel Barba. 2017. "Fleet-Level Modeling of Real World Factors Influencing Greenhouse Gas Emission Simulation in ALPHA," ***SAE International Journal of Fuels and Lubricants*** 10(1): 217-235. Accessed August 23, 2019. https://doi.org/10.4271/2017-01-0899.

EPA (Environmental Protection Agency). 2016. ***Proposed Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation: Technical Support Document.*** EPA-420-R-16-021. Accessed August 19, 2019. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100Q3L4.pdf.

EPA. 2017. "ALPHA Engine Generation for Honda 1.5L L15B7 Earth Dreams Turbo 130kW," ***Engine Mapping Test Data***. Version 01-12-2017. Accessed August 23, 2019. https://www.epa.gov/sites/production/files/2017-01/documents/process-gen-engine-fuel-consumption-map-honda-civic.pdf.

EPA. 2019. "2019 Datafile (version 08-15-2019)," ***Fuel Economy Guide Data***. Accessed August 23, 2019. https://www.fueleconomy.gov/feg/download.shtml.

Green Car Congress. 2017. "2018 VW Tiguan and New 2.0 TSI B-cycle Engine Gives VW a Strong Offering in Compact SUV segment," ***Green Car Congress***, June 27, 2017. Accessed August 23, 2019. https://www.greencarcongress.com/2017/06/20170627-tiguan.html.

Honda. 2015. “2016 Honda Civic Sedan Press Kit – Overview.” Press release, October 18, 2015. Accessed August 26, 2019. https://hondanews.com/releases/2016-honda-civic-sedan-press-kit-overview.

ICCT (International Council on Clean Transportation). 2018. ***International Council on Clean Transportation Comments on the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks.*** Public submission to EPA Docket No. EPA-HQ-OAR-2018-0283 and NHTSA Docket No. NHTSA-2018-0067, October 25, 2018. Accessed August 23, 2019. https://theicct.org/news/comments-safe-regulation-2021-2026.

Murphy, Tom. 2019. “VW Working Toward U.S. Launch of Upgraded 1.5L TSI 4-Cyl.,” ***WardsAuto***, January 22, 2019. Accessed August 23, 2019. https://www.wardsauto.com/engines/vw-working-toward-us-launch-upgraded-15l-tsi-4-cyl.

Nakano, Koji, Yusuke Wada, Mitsutaka Jono, and Shigeru Narihiro. 2016. "New In-Line 4-Cylinder Gasoline Direct Injection Turbocharged Downsizing Engine," ***Honda R&D Technical Review***, April 2016: 139-146. Accessed August 23, 2019. https://www.hondarandd.jp/point.php?pid=1201&lang=en.

NHTSA (National Highway Traffic Safety Administration). 2018. ***Compliance and Effects Modeling System*** (version 2018-06-05). Accessed August 26, 2019. ftp://ftp.nhtsa.dot.gov/CAFE/2021-2026_CAFE_NPRM/CAFE_Model/CAFE_Model/cafe_model_2018-06-05.zip.

NRC (National Research Council). 2015. ***Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles***. Washington, DC: The National Academies Press. https://doi.org/10.17226/21744.

Ortiz-Soto, Elliott, Benjamin Wolk, Hao Chen, and Matthew Younkins. 2019. "mDSF: Improved Fuel Efficiency, Drivability and Vibrations via Dynamic Skip Fire and Miller Cycle Synergies (paper presented at SAE WCX)." SAE Technical Paper 2019-01-0227. Accessed August 23, 2019. https://doi.org/10.4271/2019-01-0227.

RDN (Repairer Driven News). 2018. “2019 Volkswagen Jetta 47% Ultra High-strength Steel,” ***Repairer Driven News***, February 13, 2018. Accessed August 20, 2019. https://www.repairerdrivennews.com/2018/02/13/2019-volkswagen-jetta-47-ultra-high-strength-steel/

Schwering, Christian, and Karsten Heuer. 2017. “VW Polo—car body benchmarking data summary” (Presentation at EuroCarBody 2017, 19th Global Car Body Benchmarking Conference, Bad Nauheim, Germany, October 18, 2017).

Singh, Harry, Bijoo Kabeer, Wolfgang Jansohn, James Davies, Cing-Dao Kan, David Kramer, Dhafer Marzougui, Richard M. Morgan, Spencer Quong, and Ian Wood. 2012. ***Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025.*** Report No. DOT HS 811 666. Washington, DC: National Highway Traffic Safety Administration. Accessed August 20, 2019. ftp://ftp.nhtsa.dot.gov/CAFE/2017-25_Final/811666.pdf.

Singh, Harry, Cing-Dao Kan, Dahfer Marzougui, Richard M. Morgan, and Spencer Quong. 2016. ***Update to future midsize lightweight vehicle findings in response to manufacturer review and IIHS small-overlap testing.*** Report No. DOT HS 812 237. Washington, DC: National Highway Traffic Safety Administration. Accessed August 20, 2019. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/812237_lightweightvehiclereport.pdf.

Szengel, Rüdiger, Hermann Middendorf, Niels Möller, and Hans Bennecke. 2013. “New Modular Gasoline Engine Platform from Volkswagen,” ***Auto Tech Review*** 2(2), February 2013: 24-31. Accessed August 23, 2019. https://autotechreview.com/media/attachments/New_Modular_Gasoline_Engine_VW.pdf.

VAG (Volkswagen AG). 2018. ***Application for Emissions Certification Part 1, 2019 Model Year, Test Group KVGAV01.4V1P.*** October 8, 2018. Accessed August 20, 2019. https://iaspub.epa.gov/otaqpub/display_file.jsp?docid=44915&flag=1.

VAG. 2019. “The New Golf: with 48V Technology.” Press release, May 16, 2019. Accessed August 26, 2019. https://www.volkswagen-newsroom.com/en/stories/the-new-golf-with-48v-technology-5004.

WardsAuto. 2019a. % Powertrain Installations on U.S. Cars and Lt. Trucks, '19 Model Year MID YEAR. August 16, 2019. Accessed August 26, 2019. https://wardsintelligence.informa.com/WI964057/Powertrain-Installations-on-US-Cars-and-Lt-Trucks-19-Model-Year-MID-YEAR.

WardsAuto. 2019b. % Factory Installed Equipment on U.S. Cars and Light Trucks, '19 Model Year MID YEAR. August 16, 2019. Accessed August 26, 2019. https://wardsintelligence.informa.com/WI964059/Factory-Installed-Equipment-on-US-Cars-and-Light-Trucks-19-Model-Year-MID-YEAR.

WardsAuto. 2019c. % Factory Installed Electronic/ADAS Equipment on U.S. Cars and Light Trucks, '19 Model Year MID YEAR. August 16, 2019. Accessed August 26, 2019. https://wardsintelligence.informa.com/WI964060/Factory-Installed-ElectronicADAS-Equipment-on-US-Cars-and-Light-Trucks-19-Model-Year-MID-YEAR.

ZF. 2017. “With Optional Integrated Hybrid Module: ZF’s new 8-Speed Dual Clutch Transmission for Sports Vehicles.” Press release, February 16, 2017. Accessed August 30, 2019. https://press.zf.com/press/en/releases/release_2662.html.

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.

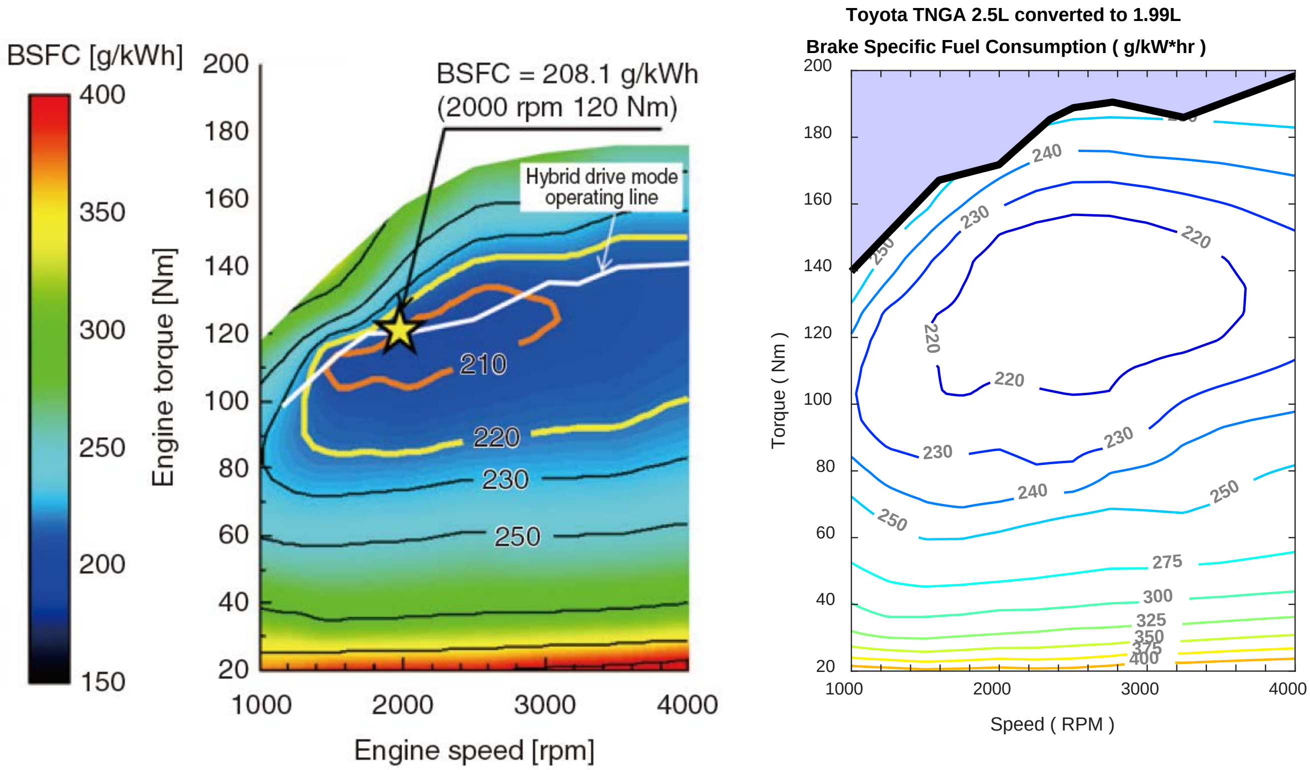
For the 1.5L turbocharged engine available now in the higher-level trims, we are not proposing significant changes. The one modification which could be deployed would be to incorporate cylinder deactivation, similar to VW's strategy in its comparable 1.5L EA211 "evo" engine (see Appendix A). Honda has 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.

---

[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

References

Autotk.com. No date. “2017 Honda CR-V Ground Clearance Height.” Accessed September 10, 2019. https://autotk.com/dimensions/honda/cr-v/2017/.

Brooke, Lindsay. 2017. “2018 Honda Accord drops mass, adds turbos and 10-speed,” ***Automotive Engineering*** July 14, 2017. Accessed September 9, 2019. https://www.sae.org/news/2017/07/2018-honda-accord-drops-mass-adds-turbos-and-10-speed.

Delphi. 2016. “Delphi Unveils New 48-volt, Mild Hybrid.” Press release, April 13, 2016. Accessed September 10, 2019. https://www.delphi.com/newsroom/delphi-technologies/delphi-unveils-new-48-volt-mild-hybrid.

EPA (Environmental Protection Agency). 2016. Proposed Determination on the Appropriateness of the Model Year 2022-2025 Light-duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation: Technical Support Document. EPA-420-R-16-021. Accessed September 9, 2019. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100Q3L4.pdf.

EPA. 2018. 2016-2035 Production Summary OMEGA Baseline Fleet. Excel file, posted to regulatory docket EPA-HQ-OAR-2018-0283, October 24, 2018. Accessed September 11, 2019. https://www.regulations.gov/document?D=EPA-HQ-OAR-2018-0283-3264.

FEV. 2012. Light-duty Vehicle Mass Reduction and Cost Analysis—Midsize Crossover Utility Vehicle. Prepared for EPA, August 2012. EPA-420-R-12-026. Accessed September 10, 2019. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100EWVL.PDF?Dockey=P100EWVL.PDF.

Honda Motor Europe. 2018. “Honda Reveals Engineering Behind Strongest, Safest and Most Dynamic CR-V Ever.” Press release, June 27, 2018. Accessed September 10, 2019. https://hondanews.eu/eu/en/cars/media/pressreleases/133577/honda-reveals-engineering-behind-strongest-safest-and-most-dynamic-cr-v-ever.

NHTSA (National Highway Traffic Safety Administration). 2018. ***Compliance and Effects Modeling System*** (version 2018-06-05). Accessed August 26, 2019. ftp://ftp.nhtsa.dot.gov/CAFE/2021-2026_CAFE_NPRM/CAFE_Model/CAFE_Model/cafe_model_2018-06-05.zip.

NRC (National Research Council). 2015. ***Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles***. Washington, DC: The National Academies Press. https://doi.org/10.17226/21744.

WardsAuto. 2019a. North America Product Cycle Chart, 2015-2026. Revised August 28, 2019. Accessed September 6, 2019. https://wardsintelligence.informa.com/WI964000/North-America-Product-Cycle-Chart-20152026.

WardsAuto. 2019b. % Powertrain Installations on U.S. Cars and Lt. Trucks, '19 Model Year MID YEAR. August 16, 2019. Accessed August 26, 2019. https://wardsintelligence.informa.com/WI964057/Powertrain-Installations-on-US-Cars-and-Lt-Trucks-19-Model-Year-MID-YEAR.

x-engineer. n.d. “Mild Hybrid Electric Vehicle (MHEV) – architectures.” ***x-engineer.org.*** Accessed September 10, 2019. https://x-engineer.org/automotive-engineering/vehicle/hybrid/mild-hybrid-electric-vehicle-mhev-architectures/

Zal, Pawel. 2019. “2018 Honda CR-V EX-L AWD (for North America) specs review,” ***Automobile Catalog.*** Accessed September 10, 2019. https://www.automobile-catalog.com/car/2018/2511665/honda_cr-v_ex-l_awd.html.