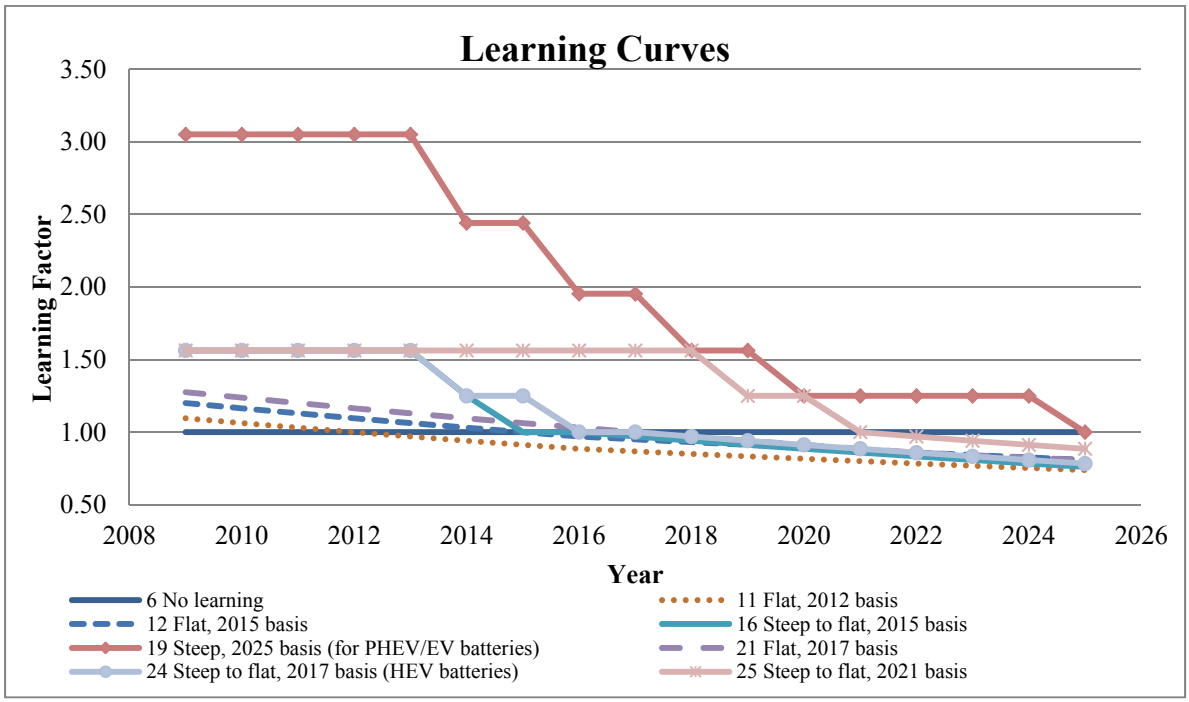
- All low complexity technologies will be estimated to equal the ICM of the modified Delphi based low technology - passive aerodynamic improvements.
- All medium complexity technologies will be estimated to equal the ICM of the modified Delphi based medium technology - engine turbo downsizing.
- Strong hybrids and non-battery PHEVs will be estimated to equal the ICM of the high complexity consensus based high technology – hybrid electric vehicle.
- PHEVs with battery packs and full electric vehicles will be estimated to equal the ICM of the high complexity modified Delphi based high technology – plug-in hybrid electric vehicle.

In addition to shifting the proxy basis for each technology group, the agencies reexamined each technology's complexity designation and adjusted the grouping of technologies. Some new technologies are also added to the groupings. Other changes to the ICMs for this rulemaking include basing them on the expected long-term average RPE rather than that of any one specific year (2007), which involved normalizing them to an average RPE multiplier level of 1.5; and distinguishing the ICMs into two parts, one applied to warranty cost and one applied to non-warranty cost. The latter was done because the agencies believe that learning curves are more appropriately applied only to direct costs, with indirect costs established up front based on the ICM and then held constant while direct costs are reduced by learning.
More detailed information about how the agencies applied ICMs in this FRM analysis can be found in Chapter VII of this FRIA.

More and Refined Learning Schedules

In MYs 2012-2016 rulemaking, the agency applied two types of learning, "time-based" learning and "volume-based" learning. For this FRM the agency has, however, adopted new terminology to distinguish the two different learning applications. Emerging technologies are adjusted using what we now call the "steep "learning schedule, which involves 20% decreases, while mature technologies are modified using one of a number of "flat" schedules, involving the smaller 3%, 2%, or 1% decreases. The "flat" curves assume a learning rate of 3% over the previous years' cost for a number of years, followed by 2% over several more years, followed by 1% indefinitely. The "steep" curves assume larger decreases of 20% every 2 years during the initial years of production, for a maximum of two learning cycles, before converting to the "flat" learning curve rates. For this FRM analysis, the agency has determined where on the learning curve each technology lies and then applied learning effects based on those determinations. Figure V-28 shows how these determinations impact the level of learning effects applied in our analysis. Chapter VII of this FRIA contains a detailed discussion of the changes to the ICM and their application to individual technologies.

Figure V-28. Learning Factors used in the Analysis to accommodate Technologies at Different Places on the Learning Curve and Having Costs Based in Different Years



Inclusion of Stranded Capital Costs

There is also the potential for stranded capital[196] if technologies are introduced too rapidly for some indirect costs to be fully recovered. Due to the capital-intensive nature of producing automotive components, it is possible for substantial capital investments in manufacturing equipment and facilities to become "stranded." While the FEV tear-down analysis results are assumed to be generally valid for the 2017-2025 timeframe for fully mature, high sales volumes, FEV perform a supplemental analysis to consider potential stranded capital costs. For a select group of technologies NHTSA has included that ability account for stranded capital costs, as supplied by FEV, into the analysis. The agency refers readers to Chapter 3 of the joint TSD for a more detailed description of how FEV estimated stranded capital costs and later in this chapter the agency describes how stranded capital costs were integrated into the analysis.

What's new in this final rulemaking from NPRM?

Inclusion of Mild Hybrid/Belt Integrated Starter Generator (BISG)

[196] The potential for stranded capital occurs when manufacturing equipment and facilities cannot be used in the production of a new technology.

Table V-15 Mapping between NHTSA and EPA Vehicle Classifications

NHTSA/CAFE model Classification	EPA Vehicle Class for Cost Purpose	EPA Lumped Parameter Model Classification	Example
Subcompact Subcompact Perf PC	Subcompact/Small Car	Small Car	Yaris
Compact Compact Perf PC			
Midsize PC Midsize Perf PC	Standard Car	Standard Car	Camry
Large PC Large Perf PC	Large Car	Large Car	Chrysler 300
Small LT	Small MPV	Small MPV	Saturn Vue
Midsize LT	Large MPV	Large MPV	Dodge Grand Caravan
Minivan LT			
Large LT	Truck	Truck	Ford F150

How much of the technology can be applied to the fleet this year? (phase-in caps)

Besides the refresh/redesign cycles used in the CAFE model, which constrain the rate of technology application at the vehicle level so as to ensure a period of stability following any modeled technology applications, the other constraint on technology application employed in NHTSA's analysis is "phase-in caps." Unlike vehicle-level cycle settings, phase-in caps constrain technology application at the vehicle manufacturer level.[205] Phase-in caps are intended to function as a proxy for a number of real-world limitations in deploying new technologies in the auto industry. These limitations can include, but are not intended to be limited to, engineering resources at the OEM or supplier level, financial resources, restrictions on intellectual property that limit deployment, and/or limitations in material or component supply as

[205] While phase-in caps are expressed as specific percentages of a manufacturer's fleet to which a technology may be applied in a given model year, phase-in caps cannot always be applied as precise limits, and the CAFE model in fact allows "override" of a cap in certain circumstances. When only a small portion of a phase-in cap limit remains, or when the cap is set to a very low value, or when a manufacturer has a very limited product line, the cap might prevent the technology from being applied at all since any application would cause the cap to be exceeded. Therefore, the CAFE model evaluates and enforces each phase-in cap constraint after it has been exceeded by the application of the technology (as opposed to evaluating it before application), which can result in the described overriding of the cap.

engine, drivetrain and vehicle characteristics that are averaged over the EPA fuel economy drive cycle.

As part of the calibration/updating process, EPA adjusted the LPM inputs to ensure that the results closely aligned with those of the Ricardo work. Thus the results of this analysis using the LPM were generally consistent with Ricardo's most recent full-scale vehicle simulation modeling.[208] Detailed information about how the LPM works and how EPA used it to develop technology effectiveness values for this analysis can be found in Chapter 3 of the joint TSD.

The technology effectiveness inputs used in the CAFE model for this analysis are based on entirely on the outputs of the newly updated LPM, and thus incorporate the Ricardo simulation work from 2007 and 2011. Table V-17 to Table V-27 below define how NHTSA mapped technology effectiveness calculations from the LPM into CAFE model-specific inputs. The LPM defines technologies specific to EPA's OMEGA model so NHTSA had to create a process of mapping technologies in the LPM that are consistent with those found in the CAFE model's decision trees. For example, to generate the effectiveness for the Improved Automatic Transmission Controls/Externals (IATC) NHTSA had to enable both "Early Upshift" and "Aggressive Torque Converter Lockup" in the LPM. NHTSA used this mapping technique to calculate the absolute effectiveness of each technology relative to a baseline vehicle. NHTSA then used these absolute effectiveness estimates, for each step in the decision trees, to calculate the incremental effectiveness estimates for each technology, which is what the CAFE model ultimately needs to analyze a heterogeneous fleet baseline fleet on a model year by model year basis.

Table V-17. CAFE Model and LPM Mapping for Engine Technologies (non-Valvetrain Dependent Engine Technologies)

NHTSA Techs	LPM Selection	
Model Years	**2012-2016**	**2017+**
LUB1	Low Fric Lubes	Low Fric Lubes
EFR1	Low Fric Lubes EF Reduction (Level=1)	Low Fric Lubes EF Reduction (Level=1)
LUB2_EFR2		EF Reduction (Level=2)

[208] Regardless of a generally consistent set of results for the vehicle class and set of technologies studied, the lumped parameter tool is not a full vehicle simulation and cannot replicate the physics of such a simulation.

Table V-18. CAFE Model and LPM Mapping for Engine Technologies (SOHC Path)

NHTSA Techs	LPM Selection	
Model Years	2012-2016	2017+
SOHC Path		
CCPS	Low Fric Lubes EF Reduction (Level=1) CCP	EF Reduction (Level=2) CCP
DVVLS	Low Fric Lubes EF Reduction (Level=1) CCP DVVL	EF Reduction (Level=2) CCP DVVL
DEACS	Low Fric Lubes EF Reduction (Level=1) CCP DEAC	EF Reduction (Level=2) CCP DEAC
SGDI	Low Fric Lubes EF Reduction (Level=1) CCP DEAC GDI (stoich)	EF Reduction (Level=2) CCP DEAC GDI (stoich)
TRBDS1 18bar	Low Fric Lubes EF Reduction (Level=1) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)	EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)
TRBDS2 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=50%)
CEGR1 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=50%)
CEGR2 27bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=56%)
Adv Diesel		Advanced Diesel (2020)

Table V-19. CAFE Model and LPM Mapping for Engine Technologies (DOHC DVVL Path)

NHTSA Techs	LPM Selection	
Model Years	2012-2016	2017+
DOHC DVVL Path		
ICP	Low Fric Lubes EF Reduction (Level=1) ICP	EF Reduction (Level=2) ICP
DCP	Low Fric Lubes EF Reduction (Level=1) DCP	EF Reduction (Level=2) DCP
DVVLD	Low Fric Lubes EF Reduction (Level=1) DCP DVVL	EF Reduction (Level=2) DCP DVVL
DEACD	Low Fric Lubes EF Reduction (Level=1) DCP DEAC	EF Reduction (Level=2) DCP DEAC
SGDI	Low Fric Lubes EF Reduction (Level=1) DCP DEAC GDI (stoich)	EF Reduction (Level=2) DCP DEAC GDI (stoich)
TRBDS1 18bar	Low Fric Lubes EF Reduction (Level=1) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)	EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)
TRBDS2 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=50%)
CEGR1 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=50%)
CEGR2 27bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=56%)
Adv Diesel		Advanced Diesel (2020)

Table V-20. CAFE Model and LPM Mapping for Engine Technologies (DOHC CVVL Path)

NHTSA Techs	LPM Selection	
Model Years	**2012-2016**	**2017+**
DOHC CVVL Path		
CVVL	Low Fric Lubes EF Reduction (Level=1) DCP CVVL	EF Reduction (Level=2) DCP CVVL
DEACD	This is ignored because effectiveness is less than CVVL	
SGDI	Low Fric Lubes EF Reduction (Level=1) DCP CVVL GDI (stoich)	EF Reduction (Level=2) DCP CVVL GDI (stoich)
TRBDS1 18bar	Low Fric Lubes EF Reduction (Level=1) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)	EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)
TRBDS2 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=50%)
CEGR1 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=50%)
CEGR2 27bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=56%)
Adv Diesel		Advanced Diesel (2020)

Table V-21. CAFE Model and LPM Mapping for Engine Technologies (OHV Path)

NHTSA Techs	LPM Selection	
Model Years	**2012-2016**	**2017+**
OHV Path		
DEACO	Low Fric Lubes EF Reduction (Level=1) DEAC	EF Reduction (Level=2) DEAC
VVA	Low Fric Lubes EF Reduction (Level=1) CCP DEACO	EF Reduction (Level=2) CCP DEACO
SGDI	Low Fric Lubes EF Reduction (Level=1) CCP DEACO GDI (stoich)	EF Reduction (Level=2) CCP DEACO GDI (stoich)
TRBDS1 18bar	Low Fric Lubes EF Reduction (Level=1) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)	EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)
TRBDS2 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=50%)
CEGR1 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=50%)
CEGR2 27bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=56%)
Adv Diesel		Advanced Diesel (2020)

Table V-22. CAFE Model and LPM Mapping for Transmission Technologies

NHTSA Techs	LPM Selection	
Model Years	**2012-2016**	**2017+**
IATC	Early upshift (formerly ASL) Agg TC Lockup	Early upshift (formerly ASL) Agg TC Lockup
Baseline for the following technologies is 5-speed automatic transmission		
NAUTO	6-spd gearbox Early upshift (formerly ASL) Agg TC Lockup High efficiency gear box (auto) (Percent= 7%)	6-spd gearbox Early upshift (formerly ASL) Agg TC Lockup High efficiency gear box (auto) (Percent= 7%)
DCT (Dry)	6-spd gearbox DCT Dry Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)	6-spd gearbox DCT Dry Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
DCT (Wet)	6-spd gearbox DCT Wet Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)	6-spd gearbox DCT Wet Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
8 SPD (Auto)		8-spd gearbox Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
8 SPD (Dry DCT)		8-spd gearbox DCT Dry Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
8 SPD (Wet DCT)		8-spd gearbox DCT Wet Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
HETRANS		*(Additional Selection over previous selection)* High efficiency gear box (auto) (Percent= 25%)
SHIFTOPT		*(Additional Selection over previous selection)* Optimized shift strategy*

Notes

* Make sure "Early upshift (formerly ASL)" is turned off.

Table V-23. CAFE Model and LPM Mapping for Accessory Technologies

NHTSA Techs	LPM Selection
EPS	EPS
IACC1	EPS Electric access (12v) High eff alternator (70%)
IACC2	EPS Electric access (12v) High eff alternator (70%) Alternator regen on braking
MHEV (12v SS)	EPS Electric access (12v) High eff alternator (70%) Alternator regen on braking 12V SS (idle off only)
ISG	EPS 6-spd AT Electric access (high V) Hybrid drivetrain (15 kW motor)[a]

[a]Motor size is adjusted to 10 kW for small cars and 18 kW for pickup trucks

Table V-24. CAFE Model and LPM Mapping for Strong Hybrid Technologies (MY2012-2016 Technologies)

SHEV1 (non-towing) (subcompact PC, compact PC with dry DCT)		SHEV1 (non-towing) (midsize PC, large PC, small LT with wet DCT)		SHEV1 (towing)* (Midsize LT, Minivan and Large LT with ATX)	
	% or Level		*% or Level*		*% or Level*
Low Fric Lubes		Low Fric Lubes		Low Fric Lubes	
EF Reduction	1	EF Reduction	1	EF Reduction	1
DCP		DCP		DCP	
DVVL		DVVL		DVVL	
				Turbo/Downsize (gas engines only)	35%
6-spd gearbox		6-spd gearbox		6-spd gearbox	
DCT Dry		DCT Wet			
Early upshift (formerly ASL)		Early upshift (formerly ASL)		Early upshift (formerly ASL)	
				Agg TC Lockup	
High efficiency gearbox (auto)	7%	High efficiency gearbox (auto)	7%	High efficiency gearbox (auto)	7%
EPS		EPS		EPS	
Electric access (12V)		Electric access (12V)		Electric access (12V)	
High efficiency alternator (70%)		High efficiency alternator (70%)		High efficiency alternator (70%)	
GDI (stoich)		GDI (stoich)		GDI (stoich)	

	Motor kW		*Motor kW*		*Motor kW*
Hybrid drivetrain	17	Hybrid drivetrain	24	Hybrid drivetrain	36
Atkinson cycle engine		Atkinson cycle engine			

Notes

*Vehicle with towing will have automatic transmission and non-Atkinson cycle engine with downsizing.

Table V-25. CAFE Model and LPM Mapping for Strong Hybrid Technologies (MY2017+ Technologies)

SHEV2 (non-towing) (subcompact PC, compact PC with dry DCT)		SHEV2 (non-towing) (midsize PC, large PC, small LT with wet DCT)		SHEV2 (towing)* (Midsize LT, Minivan and Large LT with ATX)	
	% or Level		*% or Level*		*% or Level*
EF Reduction	2	EF Reduction	2	EF Reduction	2
DCP		DCP		DCP	
DVVL		DVVL		DVVL	
				Turbo/Downsize (gas engines only)	48%
8-spd gearbox		8-spd gearbox		8-spd gearbox	
DCT Dry		DCT Wet			
Optimized shift strategy		Optimized shift strategy		Optimized shift strategy	
				Agg TC Lockup	
High efficiency gearbox (auto)	25%	High efficiency gearbox (auto)	25%	High efficiency gearbox (auto)	25%
Alternator regen on braking		Alternator regen on braking		Alternator regen on braking	
EPS		EPS		EPS	
Electric access (12V)		Electric access (12V)		Electric access (12V)	
High efficiency alternator (70%)		High efficiency alternator (70%)		High efficiency alternator (70%)	
GDI (stoich)		GDI (stoich)		GDI (stoich)	
	Motor kW		*Motor kW*		*Motor kW*
Hybrid drivetrain	17	Hybrid drivetrain	24	Hybrid drivetrain	36
Atkinson cycle engine		Atkinson cycle engine			

Notes

*Vehicle with towing will have automatic transmission and non-Atkinson cycle engine with downsizing.

Table V-26. CAFE Model and LPM Mapping for Plug-in Hybrid Technologies (20-Mile Range)

PHEV 20 Mile (subcompact PC, compact PC with dry DCT)		PHEV 20 Mile (midsize PC, large PC, small LT with wet DCT)	
	% or Level		*% or Level*
EF Reduction	**2**	EF Reduction	2
DCP		DCP	
DVVL		DVVL	
8-spd gearbox		8-spd gearbox	
DCT Dry		DCT Wet	
Optimized shift strategy		Optimized shift strategy	
High efficiency gearbox (auto)	**25%**	High efficiency gearbox (auto)	25%
Alternator regen on braking		Alternator regen on braking	
EPS	**100%**	EPS	100%
Electric access (12V)		Electric access (12V)	
High efficiency alternator (70%)		High efficiency alternator (70%)	
GDI (stoich)		GDI (stoich)	

	Motor kW		*Motor kW*
Hybrid drivetrain	**30**	Hybrid drivetrain	30
Atkinson cycle engine		Atkinson cycle engine	
Plug-In	**40%**	Plug-In	40%

Table V-27. CAFE Model and LPM Mapping for Plug-in Hybrid Technologies (40-Mile Range)

PHEV 40 Mile (subcompact PC, compact PC with dry DCT)		PHEV 40 Mile (midsize PC, large PC, small LT with wet DCT)	
	% or Level		*% or Level*
EF Reduction	2	EF Reduction	2
DCP		DCP	
DVVL		DVVL	
8-spd gearbox		8-spd gearbox	
DCT Dry		DCT Wet	
Optimized shift strategy		Optimized shift strategy	
High efficiency gearbox (auto)	25%	High efficiency gearbox (auto)	25%
Alternator regen on braking		Alternator regen on braking	
EPS	100%	EPS	100%
Electric access (12V)		Electric access (12V)	
High efficiency alternator (70%)		High efficiency alternator (70%)	
GDI (stoich)		GDI (stoich)	
	Motor kW		*Motor kW*
Hybrid drivetrain	30	Hybrid drivetrain	30
Atkinson cycle engine		Atkinson cycle engine	
Plug-In	63%	Plug-In	63%

We note that the U.S. D.O.T. Volpe Center, which supports NHTSA in its CAFE rulemaking work, contracted with Argonne National Laboratory (ANL) to provide full vehicle simulation modeling support for this MYs 2017-2025 rulemaking. While modeling was not completed in time for use in the NPRM, NHTSA used this modeling to update technology effectiveness estimates and synergy factors as appropriate for the CAFE model for the final rulemaking analysis. Specifically, the results were used to define the effectiveness of mild hybrids for both agencies, and NHTSA used the results to update the effectiveness of advanced transmission technologies coupled with naturally-aspirated engines for the CAFE analysis This simulation modeling was accomplished using ANL's full vehicle simulation tool called "Autonomie," which is the successor to ANL's Powertrain System Analysis Toolkit (PSAT) simulation tool, and that includes sophisticated models for advanced vehicle technologies. The ANL simulation modeling process and results are documented in multiple reports that can be found in NHTSA's docket.[209]

[209] Docket No: NHTSA-2010-0131

Table V-31 Stranded Capital Costs (2010$)

		Stranded Capital Cost Table									
Technology	**Abbr.**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Low Friction Lubricants - Level 1	LUB1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Engine Friction Reduction - Level 1	EFR1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cylinder Deactivation on SOHC	DEACS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Continuously Variable Valve Lift (CVVL)	CVVL	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cylinder Deactivation on DOHC	DEACD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cylinder Deactivation on OHV	DEACO	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Variable Valve Actuation - CCP and DVVL on OHV	VVA	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement	TRBDS1_SD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement	TRBDS1_MD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement	TRBDS1_LD	$78.48	$69.69	$60.90	$52.20	$43.50	$34.80	$26.10	$17.40	$8.70	$0.00
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement	TRBDS2_SD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement	TRBDS2_MD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement	TRBDS2_LD	$78.48	$69.69	$60.90	$52.20	$43.50	$34.80	$26.10	$17.40	$8.70	$0.00
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	$78.48	$69.69	$60.90	$52.20	$43.50	$34.80	$26.10	$17.40	$8.70	$0.00
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	$78.48	$69.69	$60.90	$52.20	$43.50	$34.80	$26.10	$17.40	$8.70	$0.00
Advanced Diesel - Small Displacement	ADSL_SD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Advanced Diesel - Medium Displacement	ADSL_MD	$73.38	$65.16	$56.93	$48.80	$40.66	$32.53	$24.40	$16.27	$8.14	$0.00
Advanced Diesel - Large Displacement	ADSL_LD	$78.48	$69.69	$60.90	$52.20	$43.50	$34.80	$26.10	$17.40	$8.70	$0.00
6-Speed Manual/Improved Internals	6MAN	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
High Efficiency Gearbox (Manual)	HETRANSM	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Improved Auto. Trans. Controls/Externals	IATC	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

6-Speed Trans with Improved Internals (Auto)	NAUTO	$79.99	$67.61	$55.23	$47.34	$39.45	$31.56	$23.67	$15.78	$7.89	$0.00
6-speed DCT	DCT	$36.18	$32.16	$28.14	$24.12	$20.10	$16.08	$12.06	$8.04	$4.02	$0.00
8-Speed Trans (Auto or DCT)	8SPD	$65.10	$56.68	$48.26	$41.36	$34.47	$27.58	$20.68	$13.79	$6.89	$0.00
High Efficiency Gearbox (Auto or DCT)	HETRANS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Shift Optimizer	SHFTOPT	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Power Steering	EPS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Improved Accessories - Level 1	IACC1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	IACC2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
12V Micro-Hybrid (Stop-Start)	MHEV	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Integrated Starter Generator	ISG	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Strong Hybrid - Level 1	SHEV1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Conversion from SHEV1 to SHEV2	SHEV1_2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Strong Hybrid - Level 2	SHEV2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Plug-in Hybrid - 30 mi range	PHEV1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Plug-in Hybrid	PHEV2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Vehicle (Early Adopter) - 100 mile range	EV2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Vehicle (Early Adopter) - 150 mile range	EV3	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Vehicle (Broad Market) - 150 mile range	EV4	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Fuel Cell Vehicle	FCV	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 1	MR1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 2	MR2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 3	MR3	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 4	MR4	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 5	MR5	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Rolling Resistance Tires - Level 1	ROLL1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Rolling Resistance Tires - Level 2	ROLL2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Rolling Resistance Tires - Level 3	ROLL3	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Drag Brakes	LDB	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Secondary Axle Disconnect	SAX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Aero Drag Reduction, Level 1	AERO1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Aero Drag Reduction, Level 2	AERO2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

Learning Curves

The agency uses learning curves to account for the cost reductions that manufacturers realize through experiential learning achieved through applying technologies. A complete discussion on the development and application of learning curves can be found in Chapter VII of this FRIA.

NHTSA and EPA reviewed estimates from MYs 2012-2016 final rule, the TAR, and existing public literature. The previous estimate from the MYs 2012-2016 assumed a 12 to 14 percent absolute effectiveness improvement, which included low friction lubricant (level one), engine friction reduction (level one), DCP, DVVL and SGDI, over a baseline fixed-valve engines, similar to the estimate for Ford's Ecoboost engine, which is already in production. Additionally, the agencies analyzed Ricardo vehicle simulation data for various turbocharged engine packages. Based on this data, and considering the widespread nature of the public estimates, the agencies believe that the effectiveness of turbocharging and downsizing is highly dependent upon implementation and degree of downsizing.

Given these variances, for this final rule, consistent with the proposal, the agencies evaluated 4 different levels of downsized and turbocharged high Brake Mean Effective Pressure (BMEP)[238] engines: 18-bar (TRBDS1), 24-bar (TRBDS2), 24-bar with cooled exhaust gas recirculation (CEGR1), and 27-bar with cooled EGR (CEGR2). All engines are assumed to include gasoline direct injection (SGDI), and thus the effectiveness values for TRBDS include the benefits of this technology. In addition, the agencies believe that in order to implement in production a 27-bar level engine, it is necessary to incorporate cooled exhaust gas recirculation (EGR), and also to require a 2-stage turbocharger as well as engine changes to increase robustness of the engine to allow the engine to operate at these higher BMEP levels. The cooled EGR technology is discussed later in this section. To mitigate potential issues with launch performance for these highly downsized engines, NHTSA does not allow the application of 24- or 27-bar engines unless the vehicle utilizes an 8-speed automatic or DCT transmission or a 6-speed manual transmission. This requirement helps to ensure that the transmission's gear ratio spread can accommodate a lower first gear, a.k.a. "granny gear", to aid in launching the vehicle from a complete stop. Table V-42 lists the possible engine downsizing options that the agencies considered in this FRM analysis.

Table V-42 Possible Engine Downsizing Options

Base Engine	18-bar Engine	24-bar Engine	27-bar Engine
I4	I4	I3	I3
V6	I4	I4	I4
V8+	V6	V6	I4

[238] Brake Mean Effective Pressure is the average amount of pressure in pounds per square inch (psi) that must be exerted on the piston to create the measured horsepower. This indicates how effective an engine is at filling the combustion chamber with an air/fuel mixture, compressing it and achieving the most power from it. A higher BMEP value contributes to higher overall efficiency.