White Paper

Diesel Engine Technology and the Midterm Evaluation: An Analysis of Compliance Costs and Benefits

Summer 2016

CHICAGO • DETROIT • GREEN BAY • FRANKFURT • SHANGHAI • BEIJING

An accurate Technical Assessment Report is critical for the CAFE 2022-2025 Midterm Evaluation

The purpose of this report is to provide updated cost/benefit analysis information for light-duty diesel cars and trucks during the 2016 Technical Assessment Report process. The report will also provide context with other advanced technologies. Questions arising from the 2015 National Academy of Sciences/National Research Council (NRC) report, "Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light Duty Vehicles", prompted Martec to update our cost estimates from previous CAFE rulemakings. Specifically, Martec wanted to update compliance costs for diesel vehicles to meet Tier III tailpipe emissions and the competitiveness of diesel technology against other technologies within the CAFE/GHG regulatory framework.

Key Findings of this paper include:

- Martec concludes that 4 and 6 cylinder diesel engines now have a lower total variable cost than 2007 EPA estimates due to Platinum Group Metals (PGM) cost reductions and technology improvements
- Cost for light duty diesel compliance with Tier III will be insignificant by 2025
- Martec's determined costs are ~40 percent below the 2015 NRC Report 2025 values for a diesel engine
- Diesel powertrain costs provide customers with significant cost/benefit for MPG gains and have a much smaller 2025 compliance gap than gasoline engines

MARTEC

Martec has a long history of supporting EPA/NHTSA/CARB rulemaking

The Martec Group is a partnership of technical market research professionals founded in 1984.

- Customized "tool box" of proven research methodologies and techniques employed to deliver insights that fully address client objectives
- Supporting customers across a wide variety of verticals: Automotive, Chemical, Energy, Healthcare, and Financial markets
- Finding creative solutions to provide research and assessment customized to meet every client's requirements

Martec has supported the agency's (EPA/NHTSA/CARB) regulatory process since 2003.

- Developed cost and technology content for a wide range of vehicle, engine, and transmission options
- Supported 3rd party engineering firms with rationalized fuel economy/CO_2 benefits based on interviews with leading suppliers and OEMs
- Participated in the public review process for the 2012-2016 and 2017-2022 regulations with rulemaking cost analysis and benefits for targeted technologies

MARTEC

Midterm Evaluation (MTE) for CAFE/GHG is underway, final in April 2018

Midterm Evaluation Schedule

Draft Technical Assessment Report (TAR) -- The first step in the process will be the issuance jointly by EPA, NHTSA, and CARB of a Draft TAR for public comment. The Draft TAR will be a technical report, not a decision document, and will examine a wide range of factors relevant to the 2022-2025 standards. Public input on the Draft TAR, along with any new data and information, will inform the next step - EPA's Proposed Determination.

Proposed Determination – The Proposed Determination will be the EPA Administrator's proposal on whether the 2022-2025 standards are appropriate under section 202(a) of the Clean Air Act. The Proposed Determination will be available for public comment, as required by EPA's regulations. If the Administrator's proposal is that the standards should change (either more or less stringent), then this action will be a Notice of Proposed Rulemaking (NPRM), jointly with NHTSA's CAFE NPRM. Public input on the Proposed Determination, as well as new data and information available, will inform the next step - EPA's Final Determination.

Final Determination –The Final Determination will be the Administrator's final decision on whether or not the 2022-2025 standards are appropriate, in light of the record then before the Administrator. Under EPA's regulations, the Final Determination is required no later than April 1, 2018. If the EPA determination is that the standards will not change, NHTSA will issue its CAFE final rule concurrently with the EPA Final Determination (77 FR 62652, October 15, 2012). If the EPA determination is that the standards will change, the agencies will issue a joint final rule, which could be by April 2018 or a later date. At the very latest, the agencies will complete the final rulemaking in sufficient time to promulgate final standards for MY 2022-2025 with at least 18 months lead time, but additional lead time may be provided (77 FR 62785, October 15, 2012).

MARTEC

Martec decided to investigate why the 2015 NRC Report estimated significantly higher costs for diesel technology than earlier rulemakings

1. **EPA/NHTSA commissioned NRC to provide cost updates for numerous technologies in preparation for the 2016 Technical Assessment Report (TAR). One NGO presented findings from NRC's preliminary study indicating diesel engines were not competitive on a cost/benefit basis.**

2. **Previous studies by NRC (2011) indicated diesel technology was cost effective, with an estimate even lower than NHTSA.**

3. **Martec determined that both EPA/NHTSA and NRC continue to agree on diesel efficiency improvements.**
   - The 2015 NRC Report shows 29.5% fuel economy improvement for a diesel engine over Port Fuel Injection gasoline engine (NHTSA values at 29.4%)

4. **Further analysis by MARTEC found the NRC cost/benefit gap was due to significantly higher cost estimates for diesel technology than previous rulemakings.**

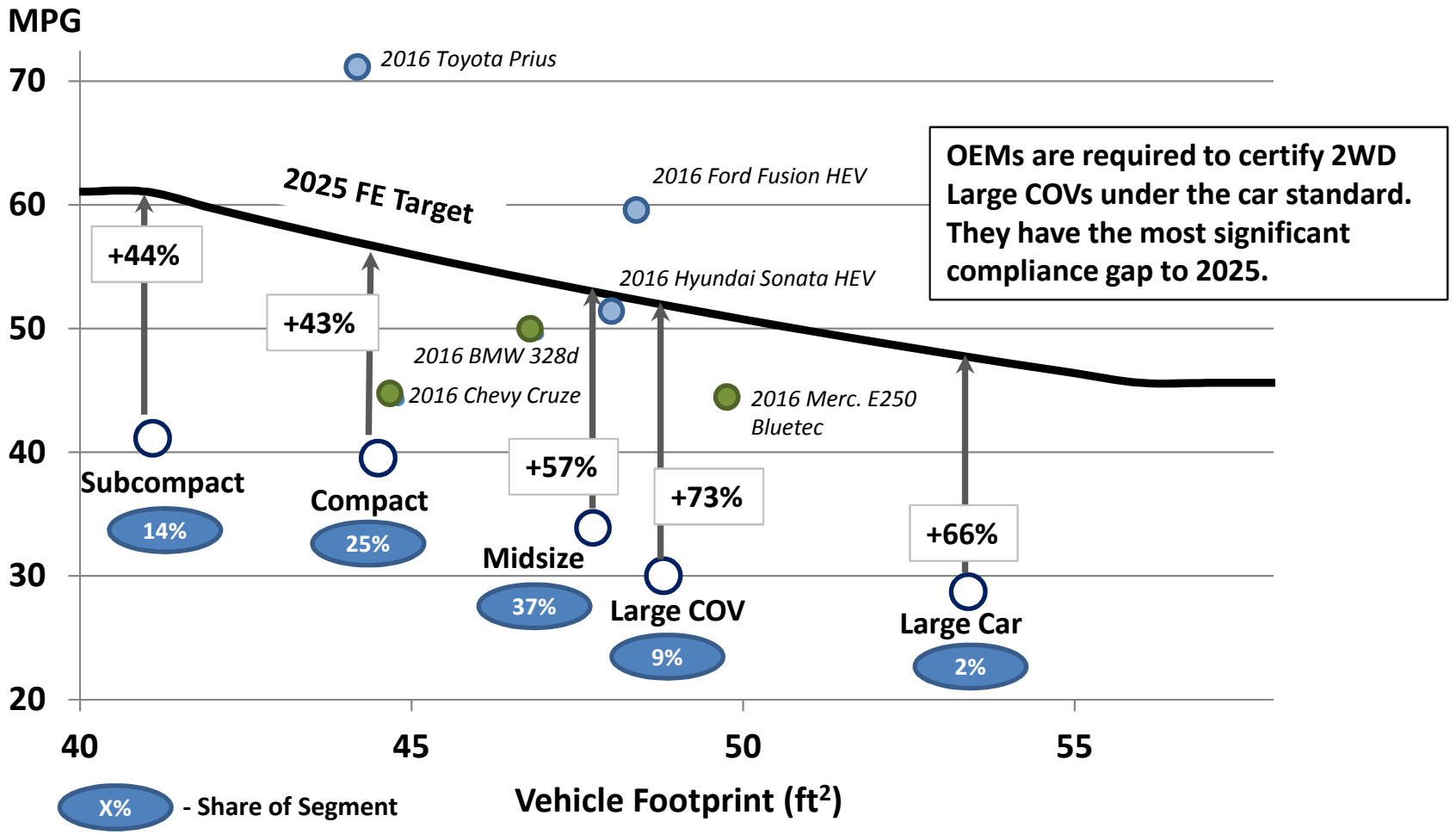
The NRC 2015 Report concluded diesel costs would increase by 50 percent over EPA/NHTSA current regulation estimates. However, the 2011 NRC Report estimated lower costs aligned closely with the estimates from EPA/NHTSA.

This prompted Martec to investigate what is driving this supposed cost gap.

MARTEC

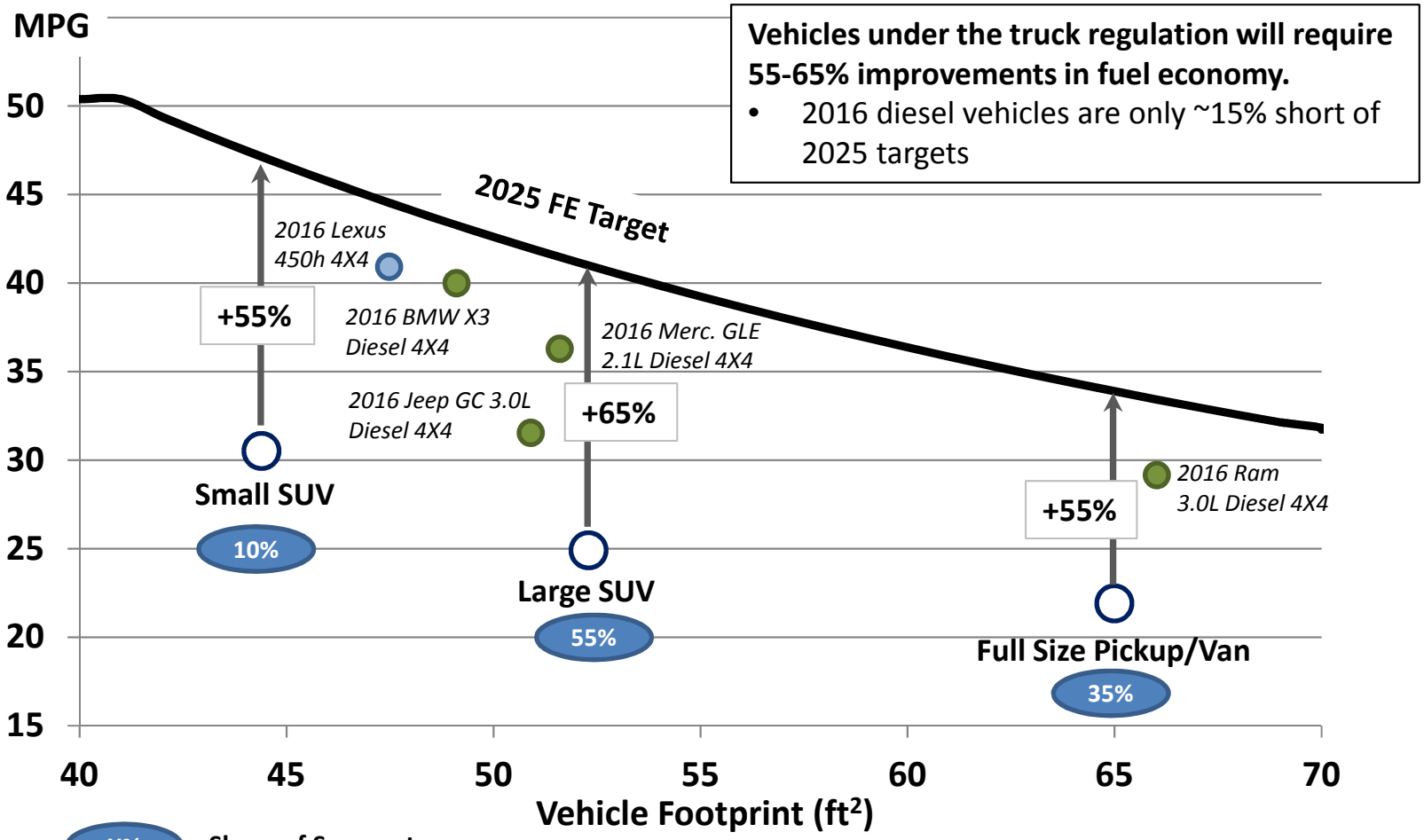
Martec began by analyzing the current CAFE compliance picture

The largest 2025 compliance gap is large cars and Crossover Vehicles (COVs)



Consumption reduction requirements are most significant in the Full Size Pick Up segment

2015 Truck Improvements to Meet 2025 CAFE



MARTEC

Martec concludes current diesel models are significantly closer to meeting 2025 CAFE standards than comparable gasoline models

The available diesel engines in the U.S. market predominantly:

- Have better performance than the base engine
  - Diesel engines have significantly more torque than base gasoline engines
  - Hybrid options are typically same torque level as base engine
- Have a lower price premium than their hybrid counter parts
  - Performance based pricing indicates that diesels are less costly than hybrids
- Provide a more competitive GHG reduction strategy for large vehicles where batteries would impact cargo room and towing capacity
- Have a significantly smaller gap to meeting the 2025 fuel economy regulations than comparable gasoline models

The Ram with the EcoDiesel option is now the number 1 selling diesel vehicle in the U.S.

- Improved performance and fuel economy over the Hemi V8
- Fit with vehicle segment for towing and image
- 15% short of 2025 target for fuel economy vs Hemi V8 which needs greater than a 50% increase in fuel economy to meet the 2025 target

Compared to the F-150 with a 3.5L Ecoboost gasoline engine, the Ram EcoDiesel has ~18% better fuel economy.

- Recall, the F-150 reduced the vehicle mass by ~700lbs by changing the body to higher cost aluminum
- Towing performance is equivalent
- Fuel consumption and operating costs are lower for the EcoDiesel

MARTEC

The Ram EcoDiesel outperforms the Hemi on torque and is much closer to 2025 fuel economy targets

	3.6L "Pentastar"V6 Gasoline	5.7L "Hemi" V8 Gasoline	3.0L "EcoDiesel" V6 Diesel
Horsepower	305	395	240
Torque (lbft)	269	410	420
Fuel Economy	18/25	15/21	19/27
Option Price	--	$1,150	$4,270
2015 Share	10% of Ram 1500 Sales	70% of Ram 1500 Sales	20% Ram 1500 Sales
Certification	T2 B4 / LEV2 ULEV	T2 B4 / LEV2 ULEV	T2 B5 / LEV2 LEV
NMOG + NOx	0.075g/mi	0.075g/mi	0.104g/mi
2025 FE Target	~33MPG	~33MPG	~33MPG
Gap to 2025 FE	+27%	+34%	+12%

MARTEC

Similarly equipped and powered EcoDiesel Ram and gasoline Ford F-150 retail at comparable prices: EcoDiesel provides better cost/benefit

	Ram 3.0L "EcoDiesel" V6 Diesel	F-150 2.7L "Ecoboost" Gasoline	F-150 3.5L "Ecoboost" Gasoline
Horsepower	240	325	365
Torque (lbft)	420	375	420
Fuel Economy	19/27	18/23	16/22
Option Price	--	-$1,200	--
2015 Option	20% of Ram Sales	30% of F-150 Sales	50% of F-150 Sales
Certification	T2 B5 / LEV2 LEV	T2 B4 / LEV3 ULEV70	T2 B4 / LEV3 ULEV125
NMOG + NOx	0.104g/mi	0.052g/mi	0.086g/mi
2025 FE Target	~33MPG	~33MPG	~33MPG
Gap to 2025 FE	+12%	+23%	+26%

MARTEC

The Grand Cherokee EcoDiesel outperforms the Hemi V8 on torque and delivers 40 percent fuel economy improvement for $1,200 premium

	3.6L "Pentastar"V6 Gasoline	5.7L "Hemi" V8 Gasoline	3.0L "EcoDiesel" V6 Diesel
Horsepower	295	360	240
Torque (lbft)	260	390	420
Fuel Economy	17/24	14/20	21/28
Option Price	--	$3,795	$5,000
2015 Share	75% of Grand Cherokee Sales	20% of Grand Cherokee Sales	5% of Grand Cherokee Sales
Certification	T2 B4 / LEV2 ULEV	T2 B4 / LEV2 ULEV	T2 B5 / LEV2 LEV
NMOG + NOx	0.064g/mi	0.075g/mi	0.104g/mi
2025 FE Target	41.9MPG	41.9MPG	41.9MPG
Gap to 2025 FE	+40%	+51%	+26%

MARTEC

Colorado diesel engine option is ~$4,000 but includes additional content not found with the base engine

	3.6L V6 Gasoline	2.8L "Duramax" Diesel
Horsepower	305	181
Torque (lbft)	269	369
Fuel Economy	17/24	20/29
Option Price	--	$3,905 (incl. electric 2-speed transfer case, trailer brake controller)
2015 Share		10% (year 1 target)
Certification	T2 B4 / LEV2 ULEV	T2 B5 / LEV3 ULEV125
NMOG + NOx	0.027g/mi	0.041g/mi
2025 FE Target	38.9MPG	38.9MPG
Gap to 2025 FE	+34%	+23%

MARTEC

Diesel option is cost competitive against other alternative powertrain options. Lexus 450h hybrid option offers increased (city) fuel economy

	3.5L V6 Gasoline	3.5L V6 Hybrid
Horsepower	295	295
Torque (lbft)	268	268
Fuel Economy	19/26	30/28
Option Price	--	~$4,000 (with equalized content)
2015 Share	90% of 450 Sales	10% of 450 Sales
Certification	T2 B5 / LEV3 ULEV70	T2 B3 / LEV3 SULEV30
NMOG + NOx	0.032g/mi	0.020g/mi
2025 FE Target	44.2MPG (Truck)	44.2MPG (Truck)
Gap to 2025 FE	+38%	+13%

MARTEC

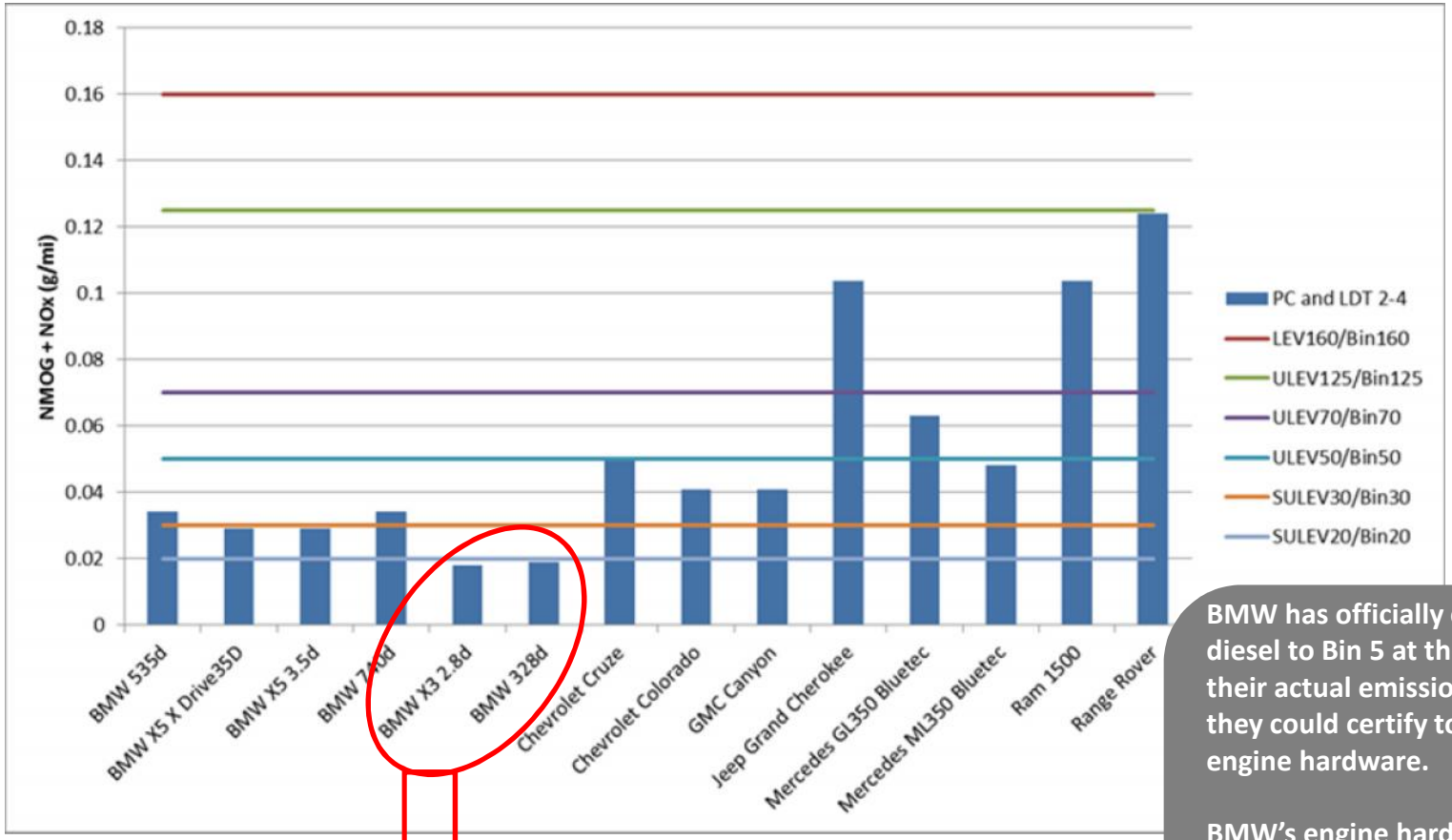
BMW 5 series diesel option is very cost competitive given the torque and fuel economy improvements compared to gasoline and hybrid options

	535 Turbo Gasoline	535d Diesel	ActiveHybrid 5
Horsepower	300	255	335
Torque (lbft)	300	413	300
Fuel Economy	20/31	26/38	23/30
Option Price	--	$1,500	$6,050
2015 Share	50%	3%	<1%
Certification	T2 B5 / LEV2 ULEV	T2 B5 / LEV2 ULEV	T2 B5 / LEV2 ULEV
NMOG + NOx	0.030g/mi	0.034g/mi	0.030g/mi
2025 FE Target	49.3MPG	49.3MPG	49.3MPG
Gap to 2025 FE	+59%	+21%	+49%

MARTEC

Martec analyzed current diesel models' emissions compliance to determine the feasibility for meeting 2025 certification requirements

Emission Certification Levels for Various Diesel Engines



BMW has officially certified their 328 diesel to Bin 5 at the federal level but their actual emissions results show that they could certify to Bin 2 with current engine hardware.

BMW's engine hardware for this engine includes:

- 2,000 bar injectors
- Single VGT
- High pressure EGR
- NOx storage catalyst, DPF, and SCR

MARTEC

Updated Martec Diesel Technology Analysis

Martec has a long history of providing accurate cost information in support of the joint regulation for GHG between EPA, NHTSA and California ARB.

- Our original study was completed in 2003 and updated in 2007
- This work included costs and benefits for a wide range of technologies:
  - Mass reduction, valvetrain improvements, injection improvements, turbocharging, transmissions, hybridization and dieselization

The NRC 2015 Report, commissioned by EPA, reviewed various technology costs/benefits and they determined that diesel engine costs will be dramatically higher in the 2022-2025 timeframe

- NRC does not list the specific content that is costed
- Where NRC does mention specific content, the costs appear to be double counted based on a flawed methodology
- Through a series of miscalculations and over estimations, NRC reached the conclusion that the agencies needed to increase their assumed cost for diesel engines by 50%

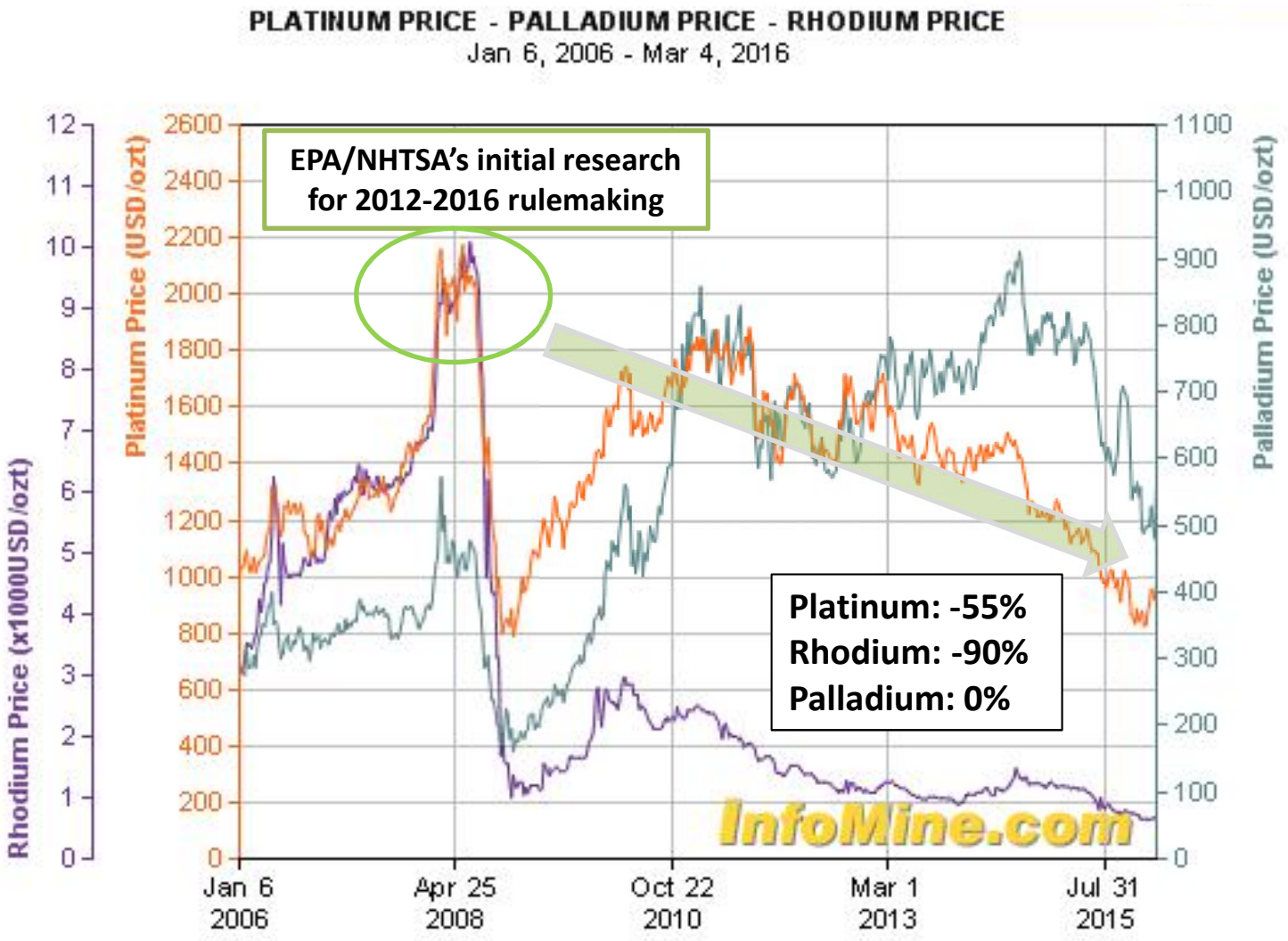
The NRC 2015 Report cost estimates were such a significant departure from previous estimates, Martec updated our diesel engine technology content and costs

- Updates to loadings on aftertreatment due to improved chemistries
- Changes to system level demands (SCRf, ASC, DOC size and loadings)
- Clearer assumptions on injection and boosting demands to meet new emission regulations (Tier III)

Martec has determined that the cost for a Tier 3 compliant diesel is **BELOW** agency estimates due to improvements in technology and reductions in PGM prices

MARTEC

Martec concluded Platinum Group Metals (PGM) prices have dropped considerably since 2007 EPA/NHTSA estimates



Martec concludes that 4 cylinder diesel engines now have a lower total variable cost than 2007 EPA estimates due to PGM cost reductions and technology improvements.

2008 Martec Values Estimating Bin 5 Compliance in 2015

4 Cylinder Diesel Technology Package	Variable Cost
Fuel system: 1,800 bar piezo	$675
Air system/cyl. count: VGT, cooling, downsizing credit	$65
Electrical system w/cabin heater	$125
Cam, Crank, Bearings, Pistons, and NVH improvements	$161
EGR: HP/LP	$215
Emissions control: DOC, CDPF, LNT	$980
OBD and sensors: Pressure sensing glow plug, Delta P, NOx, Temp	$140
Total	**$2,361**

2015 Martec Values Estimating Bin 5 Compliance in 2015

4 Cylinder Diesel Technology Package	Variable Cost
Fuel system: **2,000 bar solenoid**	$615
Air system/cyl. count: VGT, cooling, downsizing credit	$65
Electrical system **(no cabin heater needed)**	$65
Cam, Crank, Bearings, Pistons **(NVH improvements from pilot injection strategy)**	$90
EGR: HP/LP	$215
Emissions control: DOC, CDPF, **SCR**	$550
OBD and sensors: PM, NOx, Temp	$123
Total	**$1,723**

2015 Martec Values Estimating Bin 2/T3 Compliance in 2025

4 Cylinder Diesel Technology Package	Variable Cost
Fuel system: **2,500 bar solenoid**	$650
Air system/cyl. count: VGT, cooling, downsizing credit	$65
Electrical system	$65
Cam, Crank, Bearings, Pistons	$90
EGR: HP/LP	$215
Emissions control: **Improved DOC for startup, SCRF, SCR, ASC**	$620
OBD and sensors: PM, NOx, Temp	$123
Total	**$1,828**

Note: Variable cost compared to 2008 3.0L MPI V6 gasoline engine per EPA/NHTSA 2012 rulemaking

Source: Martec interviews with leading component suppliers February-March 2016

EPA/NHTSA 17-25 4 cyl. Diesel: **$2,069**
Gap between Martec and EPA/NHTSA: **-$241**

MARTEC

6 cylinder diesel engines also have a lower total variable cost

2008 Martec Values Estimating Bin 5 Compliance in 2015

6 Cylinder Diesel Technology Package	Variable Cost
Fuel system: 1,800 bar piezo	$911
Air system/cyl. count: WG+ VGT, cooling, downsizing credit	$760
Electrical system w/cabin heater	$167
Cam, Crank, Bearings, Pistons, and NVH improvements	$194
EGR: HP/LP	$226
Emissions control: DOC, CDPF, SCR	$980
OBD and sensors: Pressure sensing glow plug, Delta P, NOx, Temp	$227
Total	**$3,465**

2015 Martec Values Estimating Bin 5 Compliance in 2015

6 Cylinder Diesel Technology Package	Variable Cost
Fuel system: **2,000 bar solenoid**	$850
Air system/cyl. count: **VGT**, cooling, downsizing credit	$100
Electrical system **(no cabin heater needed)**	$68
Cam, Crank, Bearings, Pistons **(NVH improvements from pilot injection strategy)**	$109
EGR: HP/LP	$226
Emissions control: DOC, CDPF, **SCR**	$650
OBD and sensors: PM, NOx, Temp	$123
Total	**$2,126**

2015 Martec Values Estimating Bin 2/T3 Compliance in 2025

6 Cylinder Diesel Technology Package	Variable Cost
Fuel system: **2,500 bar solenoid**	$900
Air system/cyl. count: VGT, cooling, downsizing credit	$100
Electrical system	$68
Cam, Crank, Bearings, Pistons	$109
EGR: HP/LP	$226
Emissions control: **Improved DOC for startup, SCRF, SCR, ASC**	$720
OBD and sensors: PM, NOx, Temp	$123
Total	**$2,246**

Note: Variable cost compared to 2008 4.8L MPI V8 gasoline engine per EPA/NHTSA 2012 rulemaking

Source: Martec interviews with leading component suppliers February-March 2016

EPA/NHTSA 17-25 6 cyl. Diesel: **$2,522**
Gap between Martec and EPA/NHTSA: **-$276**

MARTEC

Martec's 2025 determined costs are ~40% below NRC estimates for diesel Tier III compliance

2015 Martec Values Estimating Bin 2/T3 Compliance in 2025

4 Cylinder Diesel Technology Package	Variable Cost
Fuel system: **2,500 bar solenoid**	$650
Air system/cyl. count: VGT, cooling, downsizing credit	$65
Electrical system	$65
Cam, Crank, Bearings, Pistons	$90
EGR: HP/LP	$215
Emissions control: **Improved DOC for startup, SCRF, SCR, ASC**	$620
OBD and sensors: PM, NOx, Temp	$123
Total	**$1,828**

Note: Variable cost compared to 2008 3.0L MPI V6 gasoline engine per EPA/NHTSA 2012 rulemaking

2015 NRC Values Estimating Bin 2/T3 Compliance in 2025

4 Cylinder Diesel Technology Package	Variable Cost
Fuel system:	Undefined by NRC
Air system/cyl. count: dual turbo system	
Electrical system:	
Cam, Crank, Bearings, Pistons, etc.	
EGR:	
Emissions control:	
OBD and sensors:	
Total	**$3,023**

Note: Variable cost compared to 2008 3.0L MPI V6 gasoline engine per EPA/NHTSA 2012 rulemaking

Thoughts:

- NRC does not specifically call out performance and cost for individual components making it difficult to compare with other sources
- NRC mentions a 2,000 bar injection system but it is unclear if that system is included in their Bin2/T3 diesel
- Dual turbo system is indicated as part of their "advanced diesel" package but unclear if it is still used in their Bin2/T3 diesel
- NRC does cite a derived value for Bin2/T3 compliance of $602 from EPA's cost estimates. This is in addition to NRC assumptions and costs on improved technology (injection and charging) potentially included in EPAs $602 value

MARTEC

Even when assuming reduced technology burden requirements, NRC still estimates a 25% cost premium over EPA

Source	2008 (T2B5)	2011 (T2B5)	2015 (T2B5)	2015 (Tier 3)
Martec	$2,361		$1,723	$1,828
EPA		$2,052		$2,069
NRC		$2,393	$2,913	$3,023
NRC w/ similar technology assumptions as EPA and Martec			$2,393	$2,542

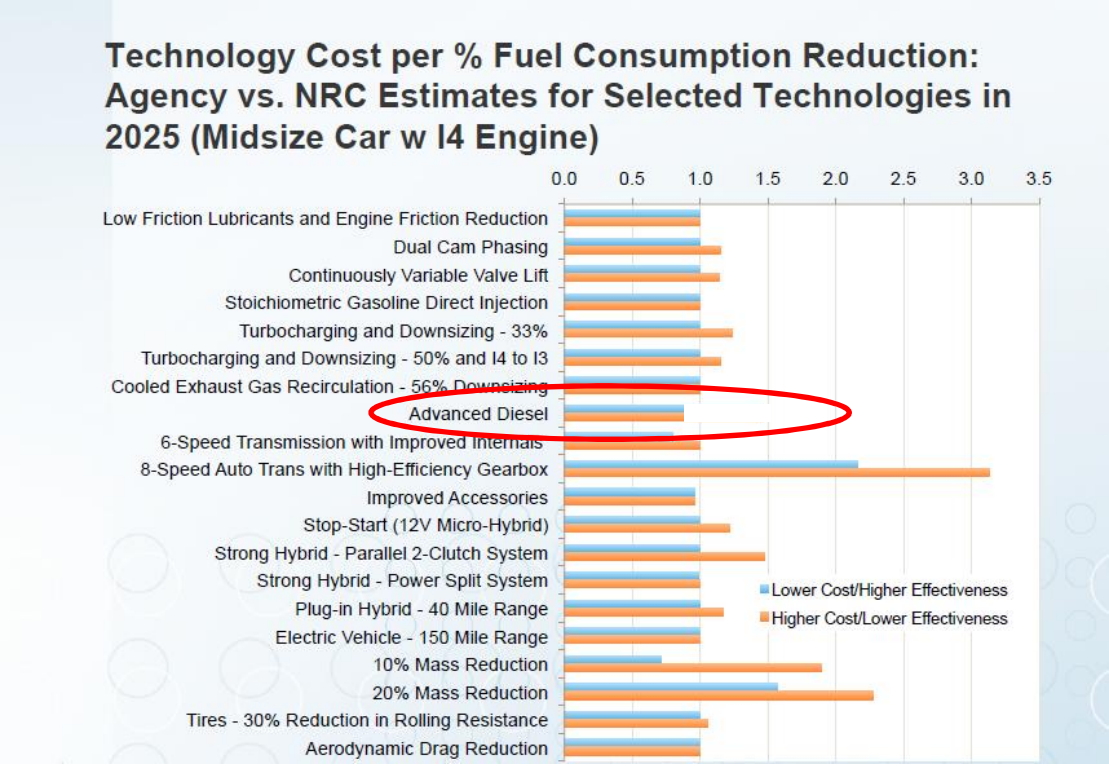
Even when assuming reduced technology burden requirements, NRC still shows a 25% cost premium over EPA.

- NRC assumes a dual stage turbocharger and a large increase in aftertreatment costs over EPA and Martec's peak PGM costed systems from 2011/2008
- Technology cost decrease from PGM alone is approximately $400 not the $602 increase in NRC
  - ➢ *This $1,000 swing is not clarified by NRC in their reporting or accounted for in their methodology*
  - ➢ *This differential is accounted for by both EPA and Martec*
- ➢ *NRC does appear to have the correct gap between Tier 2 Bin 5 and Tier 3 aftertreatment costs*
  - ➢ *~$100 in additional costs align with all parties once NRC's methodology follows the assumptions as EPA and Martec*

MARTEC

The cost of Tier III compliance for diesel engines will be insignificant by 2025 making diesel an attractive cost/benefit technology

Sample Cost/Benefit output of NRC 2015 Findings but with updated Martec Diesel Costs



With these new intelligence points we can now conclude since:

1. **Both EPA/NHTSA and NRC largely agree on efficiency improvements.**
   - NRC 2015 shows 29.5% improvement for diesel and agrees with NHTSA (29.4%)

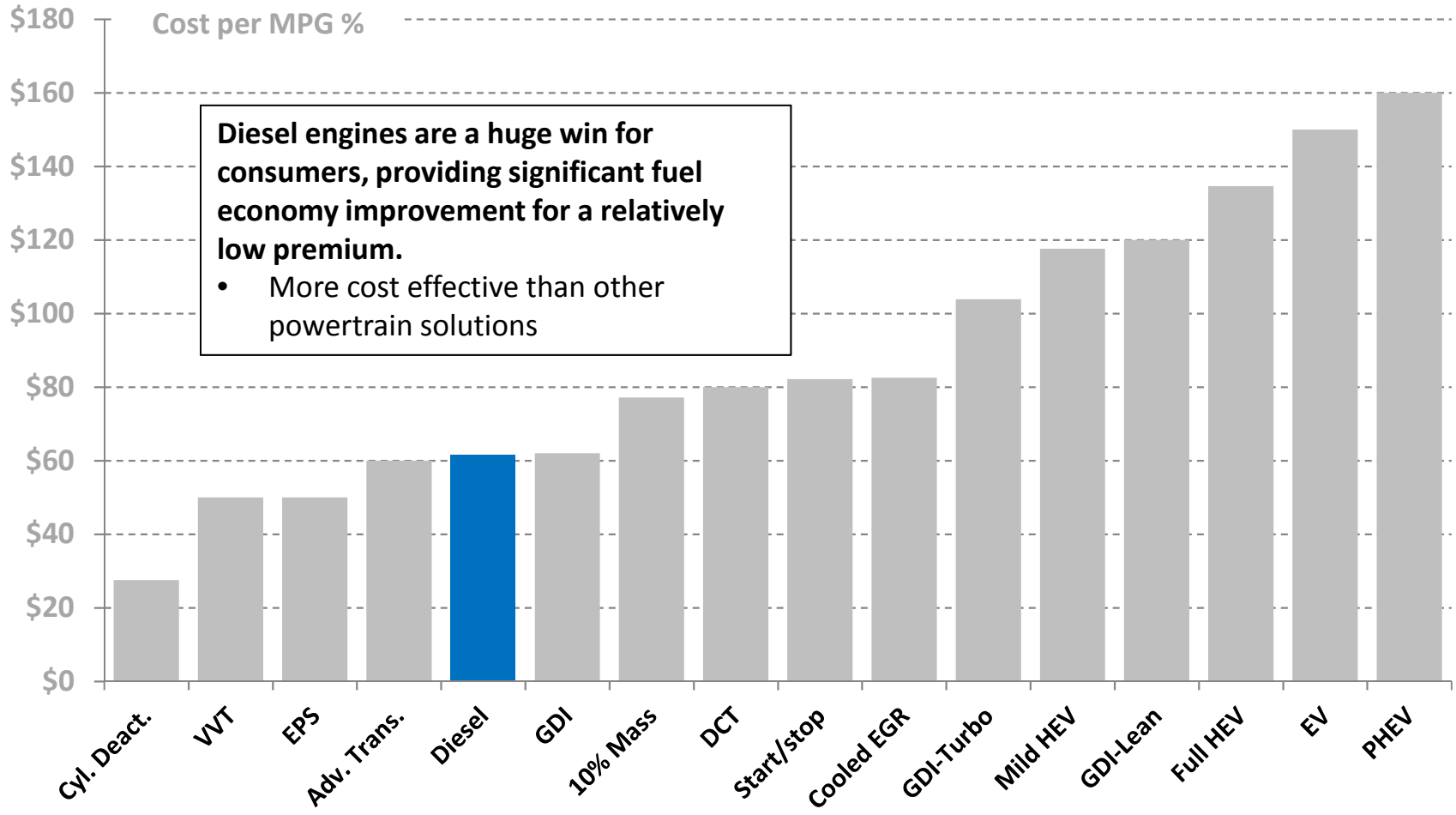
2. **Martec has determined costs for a Tier III compliant diesel is ~10-15% BELOW EPA/NHTSA current estimates and ~40% below NRC 2015.**

3. **The NRC should have concluded that the cost/benefit for diesel technology is extremely competitive.**

MARTEC

Customers see huge cost/benefit when choosing diesel.

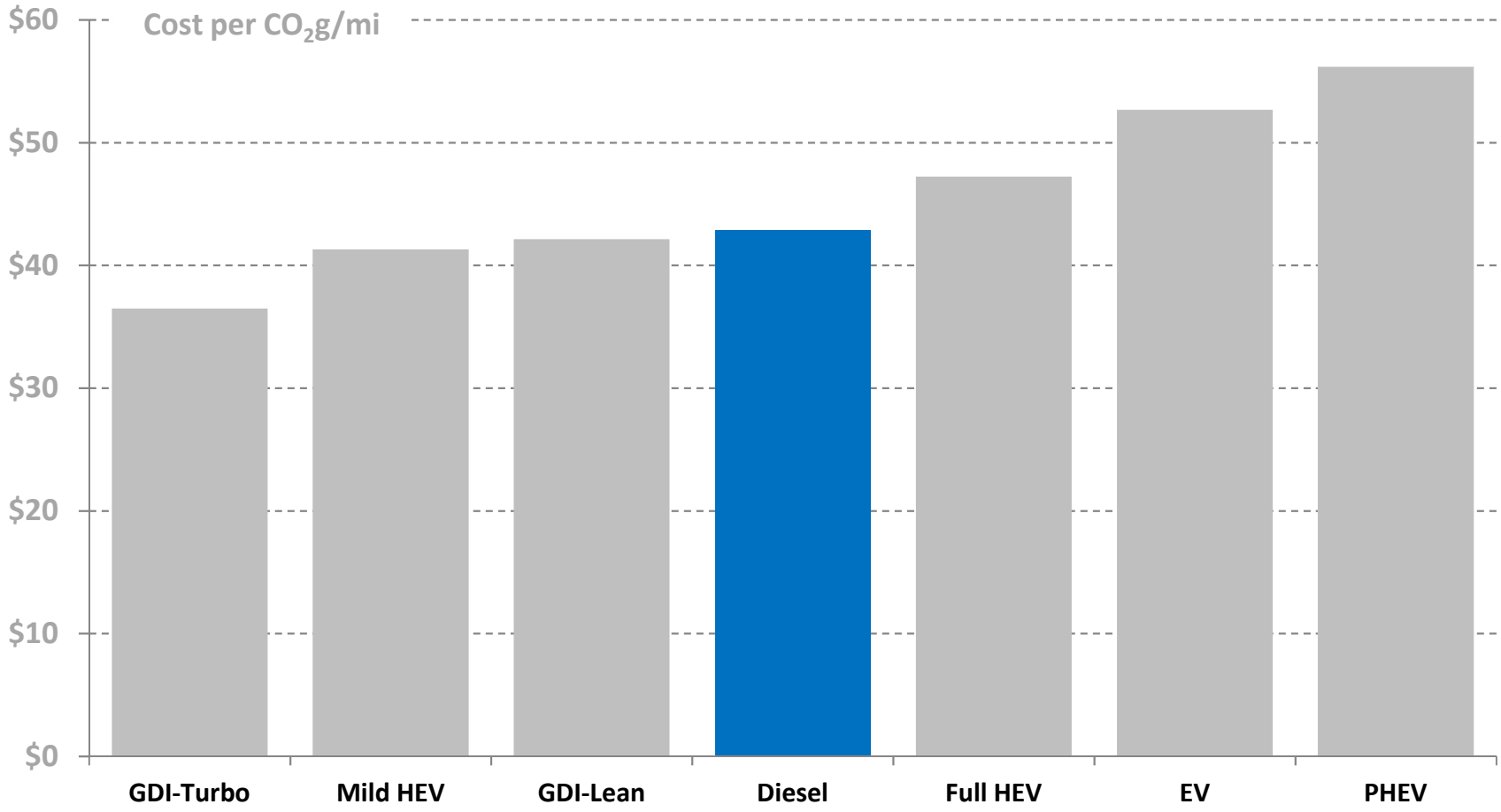
U.S. Customer Cost/Benefit: Various Technologies



MARTEC

Diesel engines still do well in GHG Cost/Benefit despite CO_2 fuel penalty

U.S. GHG Cost/Benefit: Various Technologies



Assumes average 2015 US vehicle CO_2 of 280g/mi
Assumes performance equivalency for each technology to a baseline vehicle

Does not factor in off-cycle credits
CO_2 reductions based on US FTP (Electric portion = 0g CO_2)
Fuel price $1.85/gal: March 2016

MARTEC

Conclusions

1. **The NRC 2015 Report commissioned by EPA/NHTSA incorrectly concluded significantly higher diesel engine technology costs.**
   - NRC's study indicates a 50% cost increase for diesel engines over their study from 2011 without indicating what technologies have changed or net new content
   - The 2016 analysis by Martec concludes that costs for specific components are in line with the agencies estimates for Tier 3 compliance and Tier 2 Bin 5 compliance
2. **Shifts in PGM prices have significantly and positively impacted EPA's 2007 technology package costs.**
   - ~20% reduction in overall diesel costs
   - Improvements in all components now enable reduced compliance costs as well
     - *Single VGT turbocharging, solenoid injection, reduced NVH requirements, and improved warmup characteristics have reduced the overall technology costs from the agencies original TSD (Technical Support Document)*
3. **Gasoline vehicles still have significant compliance gaps to 2025 targets.**
   - Light duty trucks/SUVs comprise ~40% of the US fleet and need >50% mpg improvement
   - Vehicles with diesel engines have a much lower compliance gap to 2025 fuel economy targets than ones with gasoline engines
4. **Light-duty diesel vehicles will remain an important strategy for CAFE compliance and customer demand**
   - Long term compliance demands for large vehicles aligning with customer needs
     - *Customers get a win/win when choosing diesel: performance and fuel economy improvement*
     - *Recent diesel product introductions have had a huge positive impact with customers due to high torque and fuel economy improvements*
       - FCA Ram 3.0L diesel sales targets have doubled
       - 50% FE improvement over 5.7L V8 gas base