Analysis Report BAV 10-683-001_3

Light-Duty Vehicle Technology Cost Analysis
European Vehicle Market
Updated Indirect Cost Multiplier (ICM) Methodology

Prepared for:

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A. Executive Summary

The International Council on Clean Transportation (ICCT) contracted with FEV to develop a methodology and tool for calculating Indirect Cost Multipliers (ICMs) for new advance powertrain technologies in the European marketplace. The technologies selected are on the leading edge for reducing emissions of greenhouse gases (GHG) in the future, primarily in the form of tailpipe carbon dioxide (CO2). Previous Net Incremental Technology Cost assessments performed by FEV, for ICCT, utilized ICMs developed by the United States Environmental Protection Agency (EPA) for the North American Market. To assess if North American derived ICMs are universal to other regions (i.e., Europe), ICCT requested FEV develop indirect cost factors based on OEM indirect cost data specific to Europe. In addition, ICCT requested FEV make methodology modifications which would potentially improve the way ICMs were developed and/or applied to the NIDMCs.

Net Incremental Technology Cost (NITC), in the context of cost studies performed for ICCT, is the incremental cost (increase or decrease) to the final selling price of the vehicle, for converting and/or replacing baseline powertrain technologies, with advance greenhouse gas-reducing technologies. For a given production year, the NITC is the product of the Net Incremental Direct Manufacturing Cost (NIDMC), the production year ICM, and the production year learning/experience factor.

The NIDMC is the difference in direct manufacturing costs, between the new technology configuration and baseline configuration. The NIDMC includes the costs of all the components and assemblies purchased by the OEM plus any direct manufacturing costs the OEM incurs (e.g., casting, stamping, welding, engine assembly, vehicle assembly, etc.). Not included in the NIDMCs are the OEM indirect costs, which include contributors such as warranty, R&D, depreciation and amortization, maintenance and repair, corporate overhead, marketing, and dealer costs.

To account for the OEM indirect costs, the industry typically applies a retail price equivalent (RPE) factor to the direct manufacturing costs. For example, if the incremental direct manufacturing cost of a new technology over the baseline configuration was €1,000, and the assumed RPE value was 1.46, the additional selling price of the new technology by the OEM would be estimated at €1,460 (€1,000 direct manufacturing costs + €460 indirect manufacturing costs).

As stated by the US EPA, “A problem with using RPE multipliers in regulatory analysis is that some of the indirect cost components of the RPE multiplier, such as fixed depreciation costs, health care costs for retired workers, or pensions, may not be affected by all vehicle modifications resulting from regulation."[1]. Thus, the U.S. EPA developed a modified methodology for calculating the OEM indirect cost contribution for new technologies for OEMs designing, manufacturing and selling vehicles in the United States. The approach evaluates the RPE factors that contribute to indirect OEM costs, assessing the impact different complexity level technologies may have on each independent RPE factor. Not all RPE factors are included in the ICMs, nor are the magnitudes of each RPE factor the same for each technology configuration. In addition, ICMs are time dependent. For each technology complexity level (i.e., Low 1, Low 2, Medium 1, Medium 2, High 1, High 2), there are short-term and long-term ICM values. The change from short-term to long-term values address changes in indirect cost contributions as technology matures and indirect costs become fully amortized (e.g., warranty costs reduce overtime, production tooling amortization complete after "x" years).

For the Phase 1 and Phase 2 ICCT cost analyses, FEV utilized the EPA-developed ICMs in the calculation of the Net Incremental Technology Costs. The results are published in the following two reports: "Light-Duty Vehicle Technology Cost Analysis – European Vehicle Market (Phase 1)" and Phase 2 cost analysis "Light-Duty Vehicle Technology Cost Analysis – European Vehicle Market, Additional Case Studies (Phase 2)". Both reports can be found at ICCT web page http://www.theicct.org/light-duty-vehicle-technology-cost-analysis-european-vehicle-market.

A summary report of the Phase 1 and Phase 2 results is also available ("Light-Duty Vehicle Technology Cost Analysis, European Vehicle Market, Result Summary and Labor Rate Sensitivity Study"). In addition to summarizing the results of the Phase 1 and Phase 2 studies, the report also includes a more complete labor sensitivity analysis for all technologies evaluated. The sensitivity analysis reduces the labor cost factor by approximately 77%; the difference between the average direct labor rate in Germany (€33.28/hour for suppliers and €44.16/hour for OEMs) versus an average of Eastern European Country labor rates (€7.75/hour for suppliers and €10.29/hour for OEMs).

The following report provides a modified approach to the development and application of ICMs. The development of the ICMs is founded on published indirect cost data (i.e., RPE data) from OEMs conducting business in Europe. A developed ICM calculator considers technology attributes (e.g., component complexity, number of new components, ease of technology integration, ease of integration into the production line, and customer

1 RTI International and Transportation Research Institute (University of Michigan), "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," prepared for the United States Environmental Protection Agency, February 2009

notice/awareness) and their impact level to arrive at a recommend nominal ICM factor. Adjustment factors, for each contributor to the nominal ICM factor (e.g., warranty, R&D, depreciation, maintenance, corporate overhead, marketing, dealership) are independently applied to account for changes in the nominal ICM factor overtime.

For each technology configuration evaluated, a comparison between the selected EPA North American developed ICMs and FEV European developed ICMs is provided. In addition, the developed European ICMs were updated in the Phase 1 and Phase 2 cost models for both the primary Western European analyses and the Eastern European sensitivity analyses. For ease of comparison, the results are presented in a similar format as in the original Phase 1 and Phase 2 summary report ("Light-Duty Vehicle Technology Cost Analysis, European Vehicle Market, Result Summary and Labor Rate Sensitivity Study").

B. Introduction

B.1 Background

B.1.1 Phase 1 and Phase 2 Overview

FEV conducted two previous light-duty vehicle technology cost studies for the ICCT. Both studies investigated the incremental costs to update conventional light-duty vehicle technology configurations with various advanced technology configurations, aimed toward improving fuel economy and reducing greenhouse gas emissions.

The initial study, **"Light-Duty Vehicle Technology Cost Analysis – European Vehicle Market (Phase 1),"** addressed the transfer and conversion of information and results from existing advance vehicle powertrain cost analysis studies performed by FEV, based on previously completed detailed teardown and cost analysis work conducted for the U.S. Environmental Protection Agency (EPA) by FEV and its subcontractors in a North American context. Accounting for key differences in manufacturing costs (e.g., material, labor, and manufacturing overhead) and vehicle segment performance attributes (e.g., engine horsepower, torque, displacement and configuration), EPA cost models were converted into European models. The technologies studied in the Phase 1 analysis are captured below in **Table B-1**. Each new technology configuration is evaluated against a baseline technology configuration representative of the current leading conventional technology.

Table B-1: Phase 1 New Technology Configurations Evaluated

Case Study ID	Baseline Technology Configuration	New Technology Configuration
01**	Naturally Aspirated (NA), Port Fuel Injected (PFI), Gasoline Internal Combustion Engine (ICE)	Downsized (DS), Turbocharged (Turbo), Direct Injection (DI) Gasoline Internal Combustion Engine (ICE)
02**	Dual Overhead Cam (DOHC), NA, PFI, Dual-Variable Valve Timing (D-VVT), Gasoline ICE	Single Overhead Cam (SOHC), NA, PFI, Multi-Air Variable Valve Timing and Lift (VVTL), Gasoline ICE
08**	5-Speed Automatic Transmission	6-Speed Automatic Transmission
10**	6-Speed Automatic Transmission	8-Speed Automatic Transmission
09**	6-Speed Automatic Transmission	6-Speed Dual Clutch Transmission
04**	Conventional Powertrain Vehicle	Conventional Powertrain Vehicle Upgraded with a Belt Alternator Starter (BAS) Start-Stop System
05**	Conventional Powertrain Vehicle	Power-Split Hybrid Electric Vehicle
07**	Conventional Powertrain Vehicle	P2 Hybrid Electric Vehicle
06**	Mechanical Air Conditioning Compressor System	Electical Air Conditioning Compressor System

The **"Light-Duty Vehicle Technology Cost Analysis - European Market, Additional Case Studies (Phase 2)"** continued the analysis work begun in Phase 1 with new powertrain technology evaluations not studied previously as part of either ICCT or EPA work. Phase 2 was an all-new study conducted using EPA methodology and European cost values, requiring new teardowns, hardware assessments, and cost models. The same boundary conditions, costing assumptions, and general vehicle segment attributes were maintained between the Phase 1 and Phase 2 studies to provide a level playing field for comparison. The technologies studied in the Phase 2 analysis are captured below in **Table B-2**.

Table B-2: Phase 2 New Technology Configurations Evaluated

Case Study ID	Baseline Technology Configuration	New Technology Configuration
20**	Conventional Diesel Engine	Downsized Conventional Diesel Engine (e.g. I4-I3, I6-I4, V8-I6)
21**	Conventional Diesel Engine with 1800 Bar Fuel Injection Subsystem	Conventional Diesel Engine Upgraded with 2500 Bar Fuel Injection Subsystem
22**	Diesel Engine with Conventional Valvetrain Subsystem	Diesel Engine Upgraded with Discrete Variable Valve Timing and Lift (VVTL) Valvetrain subsystem
23**	Conventional Diesel Engine with a Cooled High Pressure Exhaust Gas Recirculation (EGR) Subsystem	Conventional Diesel Engine Upgraded with a High Pressure, Low Pressure Cooled High EGR Subsystem
31**	Conventional Gasoline Engine with a Uncooled Low Pressure EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem
32**	Conventional Gasoline Engine with no EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem
26**	6-Speed Manual Transmission	6-Speed Dry Dual Clutch Transmission (DCT)
30**	Conventional Powertrain Vehicle (Manual Transmission)	Conventional Powertrain Vehicle ((Manual Transmission) Upgraded with a Belt-Driven Starter Generator (BSG) Start-Stop System

The costs developed in the Phase 1 and Phase 2 analyses are based on three primary steps as summarized below. Full study details are available in the respective reports (http://www.theicct.org/light-duty-vehicle-technology-cost-analysis-european-vehicle-market)

In **Step 1**, the Net Incremental Direct Manufacturing Costs (NIDMC) are developed for each technology configuration (**Figure B-1** below). Based on detailed teardowns and subsequent assessments of component differences between the comparison technologies, component differences are costed using detailed cost modeling tools. The costing for both the new and baseline technology configurations is founded on a common set of boundary conditions, representative of established mass-production (i.e., large production volumes, same production timeframe, high product maturity, competitive marketplace).

The NIDMC includes the costs of all the components and assemblies purchased by the OEM plus any direct manufacturing costs the OEM incurs (e.g., casting, stamping, welding, engine assembly, vehicle assembly, etc.). Not included in the NIDMCs are the OEM indirect costs, which include contributors such as warranty, R&D, depreciation and amortization, maintenance and repair, corporate overhead, marketing, and dealer costs.

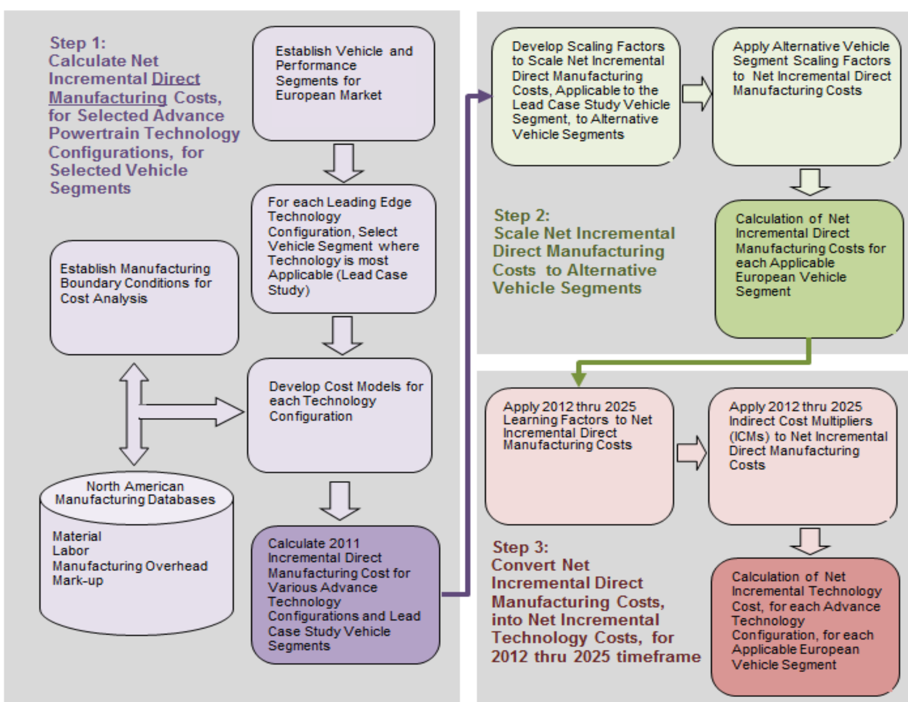


Figure B-1: Process for Developing Net Incremental Technology Costs for New Advance Powertrain Technology Configurations Relative to Conventional Technology Configurations

In **Step 2**, NIDMCs from the lead case study are scaled across multiple vehicle segments to assess the direct manufacturing cost impact to alternative vehicle segments.

In **Step 3**, the Net Incremental Technology costs are developed. Net Incremental Technology Costs are the incremental costs (increase or decrease) to the final selling price of the vehicles, for converting and/or replacing baseline powertrain technologies, with advance greenhouse gas (GHG) reducing technologies. Learning Factors (LF) and Indirect Cost Multipliers (ICMs) are applied to the NIDMCs to arrive at the Net Increment Technology Cost.

NITC (Production Year X) = NIDMC x LF(Production Year X) x ICM (Production Year X)

Learning factors are applied to the NIDMC for a given technology configuration to account for differences between the single point boundary conditions by which the cost analyses were originally conducted versus the applicable boundary condition which are changing as a function of time (i.e., difference in volume assumptions, difference in product maturity assumptions, difference in competition levels, etc.).

ICMs are applied to the NIDMC for a given technology configuration to account for the OEM indirect costs (e.g., warranty, R&D, depreciation, maintenance, corporate overhead, marketing, dealership). As discussed in the Executive Summary section of this report, ICMs are selected based on technology complexity and are variable in terms of production timeframe (i.e., short-term and long-term).

For the Phase 1 and Phase 2 studies, the LFs and ICMs were provided by the EPA. The selection of the LFs and ICMs for the technologies studied in the Phase 1 analyses was based on previous EPA studies conducted for the United States. For the Phase 2 studies (technologies specific to the European market), FEV matched best-fit EPA LFs and ICMs to each of the evaluated technology configurations.

Additional details on the application the EPA ICMs and LFs to the ICCT Phase 1 and Phase 2 studies can be found in the respective reports.

For additional details on the development of ICMs and LFs by EPA, reference EPA reports “Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers”[1] and “Joint Technical Support Document: Final Rulemaking for 2017-2025, Light-Duty

Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards."[2]

B.1.2 Phase 1 and Phase 2 Summary Report and Labor Rate Sensitivity Study

Following the release of the Phase 1 and Phase 2 reports, an Eastern Europe labor sensitivity analysis was conducted on all the technologies configurations previously evaluated. For the original Phase 1 and Phase 2 studies, manufacturing rates (material costs, labor costs and manufacturing overhead costs) were based on a Germany manufacturing cost structure. To assess the impact of lower labor costs, on new technology costs, the average Germany rates were reduced by 76.7%. The reduction represents the difference in labor costs between Germany and the average of six low-cost Eastern Europe countries (**Figure B-2**). The six countries selected produce automotive components today.

Based on the 77% rate reduction, the average labor rates used in the Eastern European sensitivity analysis were €7.75/hour for supplier labor and €10.29/hour for OEM labor.

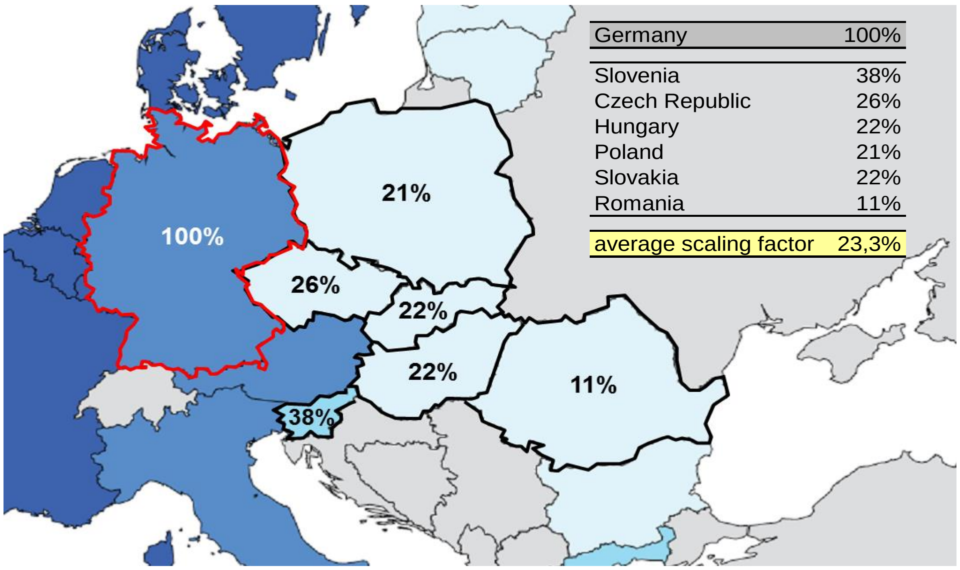


Figure B-2: Eastern Europe Labor Rate Averages Relative to Germany

Upon updating the cost models with the Eastern Europe labor rates, new NIDMCs and NITCs were calculated for the Phase 1 and Phase 2 cost studies.

[2] Environmental Protection Agency and National Highway Traffic Safety Association, "Joint Technical Support Document: Final Rulemaking for 2017-2025, Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards", Report# EPA-420-R-12-901, August 2012

The ICCT report "Light-Duty Vehicle Technology Cost Analysis, European Vehicle Market, Result Summary and Labor Rate Sensitivity Study" (Report # BAV11-683-001_2) contains a summary of the originally Phase 1 and Phase 2 results plus the Phase 1 and Phase 2 results with the Eastern European labor rate substitutions.

B.2 ICM Updates, Phase 1 and Phase 2 Cost Analysis Studies

As previously stated, the ICMs utilized in the original Phase 1 and Phase 2 cost analyses were developed by EPA based on US market data. To understand if indirect cost parameter differences exist between the US and Europe, ICCT requested FEV evaluate the indirect cost factors associated with design and developing, manufacturing, and selling light-duty vehicles in Europe. In addition, ICCT requested FEV make methodology modifications which would potentially improve the way ICMs were developed and/or applied to the NIDMCs. Acceptable modifications would be inclusive of changes required to support the differences between the US and European markets, and/or overall general cost model updates applicable to both the US and Europe. The development of the new ICMs and application methodology was led by the FEV Aachen, Germany team. Details on the development of the FEV ICM calculator for Europe are provided below in **Section C**.

Upon completion of the ICM calculation tools, new NITC values were derived for all technology configurations evaluated in the Phase 1 and Phase 2 studies. This was accomplished by rerunning the previously calculated NIDMCs, with the new European ICMs, in the updated Learning Factor and ICM cost models. The updated ICM results are organized in a similar fashion to the original summary and labor sensitivity study report. **Section D** below provides the Phase 1 and Phase 2 results based on the Western Europe cost analysis (i.e., Germany). **Section E** provides the Phase 1 and Phase 2 results incorporating the reduced Eastern European labor rates.

C. ICM Development

C.1 EPA Procedure for Determination of Indirect Cost Impact of Vehicle Modifications

Presented below is a very brief overview of the EPA process for developing ICMs. FEV recommends the reader reference the following two reports (listed in order of release) for greater details on EPA's methodology and tools used for developing ICMs: (1) "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers,"[1] and (2) "Joint Technical Support Document: Final Rulemaking for 2017-2025, Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards."[2]

The EPA ICM values and methodology have been revised since the initial release of the "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers" report. The values and methodology developed in this first report were used to support the 2012-2016 Final Rulemaking (FRM)[3]. Details on the revised values and methodology can be found in "Joint Technical Support Document: Final Rulemaking for 2017-2025, Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards."

C.1.1 Retail Price Equivalents

Prior to the ICM, the Retail Price Equivalent (RPE) was the standard way used by regulators to help assess the indirect cost impact of a modification to the final selling price. As shown in **Figure C-1**, the RPE is the markup factor (multiplier) used in relation to the direct manufacturing costs of that modification.

Direct manufacturing costs X RPE = Final selling price

Figure C-1: RPE in Equation to Determine Final Selling Price

The RPE multiplier calculated by the EPA is 1.46, as a weighted average of nine (9) original equipment manufacturers (OEMs) operating in the U.S. market. Using this RPE as the standard method would mean that the influence of a vehicle modification to the final selling price is 1.46 x Modification Incremental Direct Manufacturing Costs.

3 Environmental Protection Agency, "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards", Report# EPA-420-R-10-0009, April 2010

Table C-1: EPA Retail Price Equivalent (RPE) Calculation

RPE Multiplier Contributor	Relative to Cost of Sales
Direct manufacturing costs	1.00
Production overheads	0.18
Corporate overheads	0.08
Selling	0.08
Dealer costs	0.06
Net income	0.06
RPE Multiplier	**1.46**

However, EPA had a concern with using RPEs when determining the final selling price impact created by the adaptation of new advance GHG reducing technologies.

"*A concern in using the RPE multiplier in cost analysis for new technologies added in response to regulatory requirements is that the indirect costs of vehicle modifications are not likely to be the same for different technologies. For example, less complex technologies could require fewer R&D efforts or less warranty coverage than more complex technologies. In addition, some simple technological adjustments may, for example, have no effect on the number of corporate personnel and the indirect costs attributable to those personnel. The use of RPEs, with their assumption that all technologies have the same proportion of indirect costs, is likely to overestimate the costs of less complex technologies and underestimate the costs of more complex technologies*"[3].

To address the above concerns, EPA developed a modified multiplier methodology to account for the indirect costs associated with releasing new advance powertrain technologies. The modified multiplier approach was named "Indirect Cost Multiplier," or ICM.

C.1.2 EPA ICMs

The EPA ICM approach basically involves independently adjusting contributors of the RPE to account for complexity and time frame differences relative to the average RPE values. The net ICM value is the summation of the product of adjustment factors times the indirect cost contributors of the RPE (**Figure C-2**).

$$\text{ICM} = \sum \left(\text{Adjustment factor} \times \text{Indirect cost contributor of RPE} \right)$$

Figure C-2: Indirect Cost Multiplier (ICM) Calculation

The EPA team has utilized some slightly different approaches to developing RPE adjustment factors. The latest methodology (used in 2017-2025 FRM) was based on a blind survey approach (a.k.a. modified-Delphi approach) where EPA staff members with extensive automotive industry experience were asked to develop RPE adjustment factors based on a set of varying complexity technology packages. The EPA team developed adjustment factors based on both near/short-term and long-term assumptions. Based on the technologies evaluated, four primary complexity level ICMs were created (i.e., Low, Medium, High 1, and High 2). A comparison of the ICM values used in the 2012-2016 FRM versus the 2017-2025 FRM is shown below in **Table C-2**.

Table C-2: EPA Indirect Developed Cost Multipliers

	2012-2016 Rule		This Final Rule	
Complexity	Near Term	Long Term	Near Term	Long Term
Low	1.17	1.13	1.24	1.19
Medium	1.31	1.19	1.39	1.29
High 1	1.51	1.32	1.56	1.35
High 2	1.70	1.45	1.77	1.50

(Source: EPA, "Joint Technical Support Document: Final Rulemaking for 2017-2025, Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standard" Report# EPA-420-R-12-901, August 2012)

Another update to EPA ICMs was centered on the application methodology. In the 2012-2016 FRM, and similar to the general application of RPEs, the ICM and Learning Factor for a given production year were applied to the Net Incremental Direct Manufacturing Cost (NIDMC) in a multiplicative formula as illustrated below.

NITC (Production Year X) = NIDMC x LF(Production Year X) x ICM (Production Year X)

Based on this formula, the ICM factor will be directly impacted by the Learning Factor. To address this concern, the EPA team decided only warranty indirect costs should be linked to the Learning Factor. The balance of indirect costs would remain constant based on assigned short- and long-term ICM values. Therefore, indirect costs were categorized into two basic groups: warranty and non-warranty (reference **Table C-3** following). This breakout supported the multiplication of learned NIDMCs with the warranty ICM contributors and the "baseline" NIDMCs against the non-warranty ICM contributors. The term "baseline" as used in this context refers to the production year in which the developed NIDMC would be applicable, i.e., learning equals one.

Table C-3: Warranty and Non-Warranty Portions of ICMs

	Near-Term		Long-Term	
Complexity	Warranty	Non-warranty	Warranty	Non-warranty
Low	0.012	0.230	0.005	0.187
Medium	0.045	0.343	0.031	0.259
High 1	0.065	0.499	0.032	0.314
High 2	0.074	0.696	0.049	0.448

(Source: EPA, "Joint Technical Support Document: Final Rulemaking for 2017-2025, Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standard" Report# EPA-420-R-12-901, August 2012)

Shown below in **Figure C-3** is an example of the Indirect Costs and NITC calculations for the Variable Valve Lift and Timing cost analysis using the EPA ICM values and formulas. The technology configuration was studied in the Phase 2 analysis (Western European labor rates). To illustrate the calculations, production year 2013 was chosen. Same calculations apply for all production years; effective 2019 ICM values used in calculations change from short-term to long-term values.

Variable Valve Lift and Timing

NIDMC(Baseline = 2015)	€ 192.35
Learning Factor (LF) Curve	12
ICM Complexity	Medium 2 thru 2018

	ICM-Warranty		ICM-Other Indirect Costs	
	Short Term	Long Term	Short Term	Long Term
Medium2	0.045	0.031	0.343	0.259

Production Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
LF (X)	1.10	1.06	1.03	1.00	0.97	0.95	0.93	0.91	0.89	0.88
NIDMC(X)	€ 210.76	€ 204.44	€ 198.30	€ 192.35	€ 186.58	€ 182.85	€ 179.19	€ 175.61	€ 172.10	€ 168.66
Indirect Costs (X)	€ 75.31	€ 75.03	€ 74.75	€ 74.49	€ 74.23	€ 74.06	€ 73.90	€ 55.20	€ 55.09	€ 54.99
NITC (X)	€ 286.07	€ 279.46	€ 273.06	€ 266.84	€ 260.81	€ 256.92	€ 253.10	€ 230.81	€ 227.19	€ 223.64

Model Year 2013 Calculations

NIDMC (2013) = NIDMC(baseline)*LF(2103)
NIDMC (2013) = €192.35 * 1.06 = €204.44

Indirect Cost s (2013) = {Short Term ICM Warranty * NIDMC(2013)} + {Short Term ICM Other Indirect Costs * NIDMC (Baseline)}
Indirect Costs (2013) ={0.045 * €204.44} + {0.343*€192.35} = €75.03

NITC (2013) = NIDMC(2013) + Indirect Costs(2013)
NITC (2013) = €204.44 + €75.03 = €279.46

Figure C-3: Variable Valve Lift and Timing Cost Analysis Example using EPA ICM Methodology

C.2 Development and Application of European Indirect Cost Multipliers

C.2.1 Introduction

The primary objective of the ICCT ICM project was to develop ICMs for the Phase 1 and Phase 2 cost analyses: replacing the exiting ICMs developed by EPA specific for the North American market.

To meet this objective, the FEV team used the existing EPA work on ICMs as the foundation for the analysis, making methodology updates where the team felt the EPA approach might have some deficiencies; either generically or specific to the European market.

In the spirit of repeatability, transparency, and flexibility, the team strived to create an ICM calculator that would: (1) have standardized input parameters minimizing subjectivity and improving repeatability, (2) maintain transparent inputs and calculations ensuring the origin of the final ICM could be tracked, and (3) having the ability to evaluate technologies outside the Phase 1 and Phase 2 studies.

Summarized below in **Figure C-4** is the FEV approach to develop European ICMs.

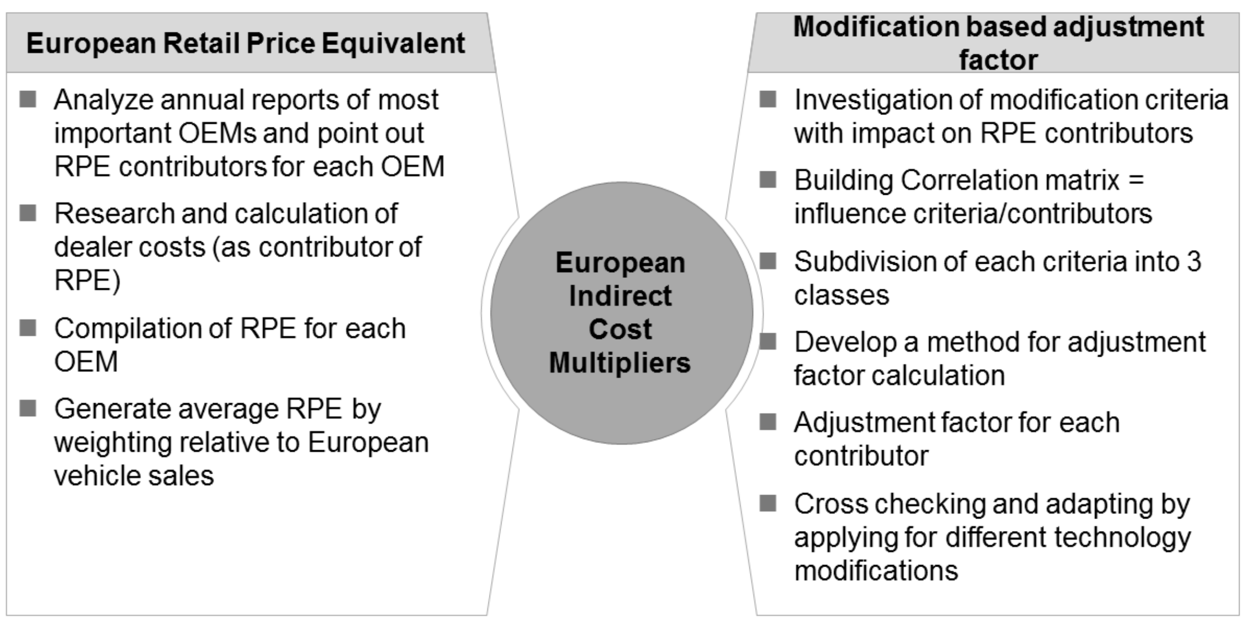


Figure C-4: FEV Approach to Developing European ICMs

C.2.2 European Retail Price Equivalent (RPE) Factor

The following section provides the details on the build-up of European RPE values along with a comparison to the RPE North American cited by EPA.

The first step in the process was to determine the OEMs that are considered major players in the European market. **Table C-4** provides the annual European car sales for 2011 along with the market share for the top nine OEMs.[4]

Table C-4: European Vehicle Sales (2011) for Calculation of Weighted European RPEs

Company	Registration of new cars in EU	Percentage
All Brands	13.111.209	100%
Volkswagen (VW, Audi, Seat, Skoda)	3.045.000	23%
PSA (Peugeot, Citroen)	1.643.160	13%
Renault (Renault, Dacia)	1.272.560	10%
GM (Opel/Vauxhall, Chevrolet, GM)	1.141.380	9%
Ford	1.046.711	8%
FIAT (FIAT, Lancia/Chrysler, Alfa Romeo, JEEP)	928.390	7%
BMW (BMW, MINI)	780.981	6%
Daimler (Mercedes, Smart)	652.790	5%
Toyota (Toyota, Lexus)	523.418	4%
Rest	2.076.819	16%

The breakdown of OEM indirect costs (2011 calendar year), reported for the top nine producers of passenger vehicles in Europe, are shown in **Table C-5** (not included in **Table C-5** are dealership cost contributions). To develop the contribution of dealership costs to overall indirect costs, FEV assumed an average dealer gross margin of 9.3% based on information gathered from the "German Federation for Motor Trends and Repairs" (Deutsches Kraftfahrzeuggewerbe). In **Table C-6** the average dealer gross margin is applied to the OEM sales figure (VW figures used in example), to arrive at the net new vehicle sales figure. In this example, 9.3% equals approximately 16.3 billion Euros (€175.675-€159.337 billion). This equates to a 0.16 factor on the direct manufacturing costs (i.e., dealer new vehicle gross profit/direct manufacturing costs).

4 Source, European Automobile Manufacturing Association (ACEA), http://www.acea.be/collection/statistics

Table C-5: Indirect Costs for Top Nine Passenger Car Producers in Europe

OEM Indirect Costs	VW	PSA	Renault	GM	FORD	FIAT	BMW	Daimler	Toyota
	[mio €]	[mio €]	[mio €]	[mio $]	[mio $]	[mio €]	[mio €]	[mio €]	[mio Y]
Cost of sales (direct manuf. costs)	100.873	42.688	27.415	108.759	98.713	41.149	42.859	68.083	13.091.646
Production overhead	28.096	6.996	6.433	21.627	14.632	9.555	11.417	12.940	2.894.137
Warranty	7.516	698	675	3.159	2.799	3.530	2.953	2.243	588.224
R&D	7.234	2.152	2.027	8.124	5.300	1.367	3.610	4.174	730.340
Depreciation and amortization	10.346	2.946	2.831	7.344	3.533	3.358	3.654	4.305	1.175.573
Maintenance. repair	3.000	1.200	900	3.000	3.000	1.300	1.200	2.000	400.000
Corporate Overhead/Expenses (e.g. Corporate Salaries, Pensions, Healthcare, etc.)	4.384	2.028	1.425	5.105	3.474	1.783	1.623	3.855	573.019
Selling Expenses (e.g. Transportation, Dealership Support, Marketing, etc.)	14.582	4.733	3.326	7.000	8.105	3.264	4.554	9.824	1.337.044
Net income	9.396	784	2.139	9.190	8.681	1.651	4.907	6.029	408.183

Table C-6: Calculation of Dealership Costs Based on VW Example

	Source/calculation	VW
OEM cost of sales (Direct Manufacturing Costs) [mio €]	Annual report	100.873
OEM sales [mio €]	Annual report	159.337
Dealer new vehicle gross margin / new vehicle sales	"Deutsches Kraftfahrzeuggewerbe" (German Federation for Motor Trades and Repairs)	9.3%
Dealer new vehicle selling cost / new vehicle sales	Assumption	8%
Dealer new vehicle net margin / new vehicle sales	Assumption	1.3%
New vehicle sales [mio €]	= OEM Sales / (1 - Dealer new vehicle gross margin)	175.675
New vehicle Sales / OEM cost of sales	new vehicle sales / cost of sales	1.74
Dealer new vehicle gross profit / OEM cost of sales	= (Dealer new vehicle gross margin / new vehicle sales) * (New vehicle sales /cost of sales)	0.16
Dealer new vehicle net profit / cost of sales	= (Dealer new vehicle net margin/ new vehicle sales) * (New vehicle sales / cost of sales)	0.02
Dealer new vehicle selling cost / cost of sales	= (Dealer new vehicle selling cost / new vehicle sales) * (New vehicle sales / cost of sales)	0.14

The same methology was used to develop dealership costs for the remaining eight OEMs considered in the analysis (**Table C-7**).

Table C-7: Calculation of Dealership Indirect Cost Contribution Factors

	VW	PSA	Renault	GM	FORD	FIAT	BMW	Daimler	Toyota	Average
OEM cost of sales (Direct Manufacturing Costs) [mio €]	100.873	42.688	27.415	108.759	98.713	41.149	43.059	68.083	13.091.646	
OEM sales [mio €]	159.337	59.912	42.628	150.276	136.264	59.559	68.821	106.540	18.993.688	
Dealer new vehicle gross margin / new vehicle sales	9.30%	9.30%	9.30%	9.30%	9.30%	9.30%	9.30%	9.30%	9.30%	
New vehicle sales [mio €]	175.675	66.055	46.999	165.685	150.236	65.666	75.878	117.464	20.941.222	
New vehicle Sales / Cost of sales	1.74	1.55	1.71	1.52	1.52	1.60	1.76	1.73	1.60	1.64
Dealer new vehicle gross profit / Cost of sales	0.16	0.14	0.16	0.14	0.14	0.15	0.16	0.16	0.15	0.15
Dealer new vehicle net profit/ cost of sales	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Dealer new vehicle sales cost / cost of sales	0.14	0.12	0.14	0.12	0.12	0.13	0.14	0.14	0.13	0.13

Dividing the indirect costs by the direct manufacturing costs for each OEM in Table C-5, contributuion factors relative to the direct manufacturing costs were established. For example, the VW production overhead indirect cost factor equals 0.28 (28.096/100.873 billion euros). These indirect cost contribution factors, along with the dealership indirect cost factors are summed to create the RPE multiplier for each OEM (**Table C-8** below). **Table C-8** also provides the average and sales weighted European RPE multipliers.

Table C-8: Calculated RPE Values for Nine European OEMs

cost contributor	VW	PSA	Renault	GM	FORD	FIAT	BMW	Daimler	Toyota	Average	weighted Average
Cost of sales (direct manuf. costs)	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Production overhead	**0.28**	**0.16**	**0.23**	**0.20**	**0.15**	**0.23**	**0.27**	**0.19**	**0.22**	**0.21**	**0.22**
Warranty	0.07	0.02	0.02	0.03	0.03	0.09	0.07	0.03	0.04	0.04	0.05
R&D	0.07	0.05	0.07	0.07	0.05	0.03	0.08	0.06	0.06	0.06	0.06
Depreciation and amortization	0.10	0.07	0.10	0.07	0.04	0.08	0.09	0.06	0.09	0.08	0.08
Maintenance, repair	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Corporate Overhead	**0.04**	**0.05**	**0.05**	**0.05**	**0.04**	**0.04**	**0.04**	**0.06**	**0.04**	**0.05**	**0.05**
Selling	**0.14**	**0.11**	**0.12**	**0.06**	**0.08**	**0.08**	**0.11**	**0.14**	**0.10**	**0.11**	**0.11**
Dealers	**0.16**	**0.14**	**0.16**	**0.14**	**0.14**	**0.15**	**0.16**	**0.16**	**0.15**	**0.15**	**0.15**
Dealer net profit	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Dealer selling cost	0.14	0.12	0.14	0.12	0.12	0.13	0.14	0.14	0.13	0.13	0.13
Net income	**0.09**	**0.02**	**0.08**	**0.08**	**0.09**	**0.04**	**0.11**	**0.09**	**0.03**	**0.07**	**0.07**
RPE Multiplier	**1.72**	**1.48**	**1.64**	**1.54**	**1.49**	**1.54**	**1.69**	**1.64**	**1.55**	**1.59**	**1.60**

Figure C-5 provides a comparison of the average RPE contibutors for Europe as calculated by FEV and the RPE contributors for North America as calculated by EPA. Note the EPA average RPE value asssummed for 2017-2025 FRM was updated to 1.5 versus 1.46, which was assummed in the original ICM debvlopment process. The values shown below are representative of the updated 1.5 RPE. From the bar chart below it is evident that a large difference between the North American/EPA RPE and European/FEV RPE is associated with the dealership selling costs.

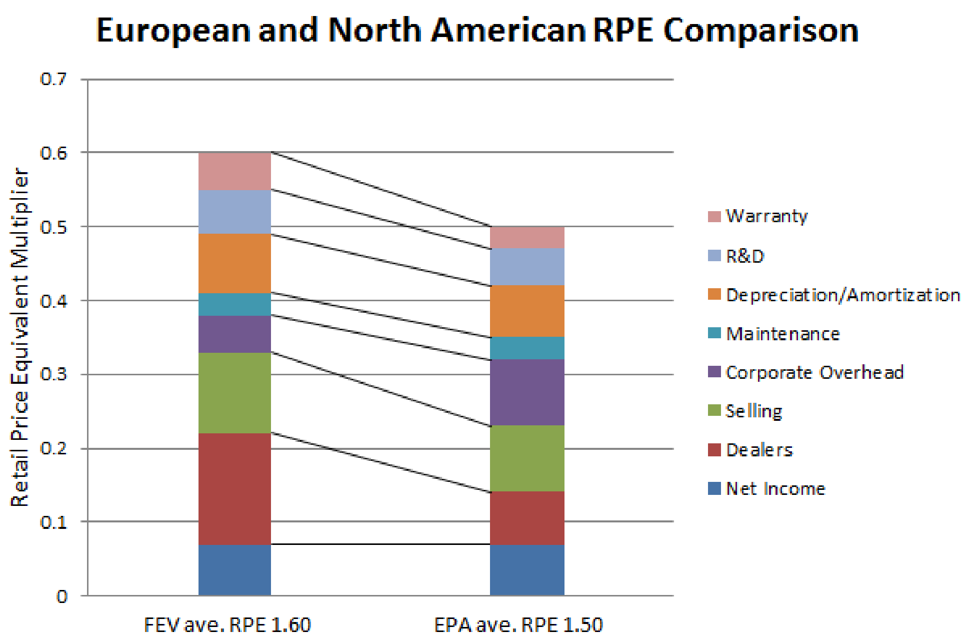


Figure C-5: Comparison of RPE Contributors - Europe and North America

C.2.3 Assessing Influential Parameters that Impact Indirect Costs

The next step in the process was to identify what technology attributes (e.g., design complexity, manufacturability, functional improvement, incremental direct manufacturing cost impact, serviceability complexity, etc.) had significant influence on the indirect manufacturing costs. Using the previous technologies evaluated as reference, the team discussed, identified, and selected the following five (5) technology attributes:

1. **Component type**

   The basis for the FEV consideration was the German Automobile Club "common breakdown causes statistic."[5] This statistic describes the percentage

5 Source: ADAC Pannenstatistik 2011, http://www.adac.de/sp/presse/meldungen/technik_umwelt/ADAC-Pannenstatistik-2011%20.aspx

influence of different parts on vehicle breakdowns. A higher breakdown probability is assumed to cause higher warranty costs. Parts with a higher probability are mostly electrical parts, while parts with a lower probability are engine or engine management parts. All other parts are responsible for only few breakdowns.

2. **Integrality in an existing production line**
   The level of integration in an existing production line could have, for instance, an influence on the magnitude of depreciation costs. If an OEM needs to buy new machines or new tools, the depreciation costs become higher than for modifications that can be machined within the old production line and which do not require new tools.
3. **Integrality in an existing product concept**
   Consideration was the fact that modifications can differ in their effort of research and development. For a completely new developed system these costs are high while only low costs are required when a modification is simple and does not require development for integration in an already existing system.
4. **Number of additional/modified components**
   The number of additional or modified components a modification consists of is assumed to have an influence on indirect costs such as R&D. An increase in new components creates higher R&D costs while a modification that consists of only one modified part requires less R&D costs.
5. **Customer notice**
   Basis for this criterion is the consideration that marketing costs are high if the customer does not recognize an improvement that accompanies a modification. If customers realize an improvement, then they will be willing to pay the higher price and no additional marketing will be necessary. Marketing costs that are required due to a modification caused by regulation are those only regarded; common marketing activities are not.

For each of indirect cost influencing attributes above, a simplistic categorization scale was developed to define the magnitude of attribute change associated with the new technology configurations. The scale is broken into three category levels (i.e., A, B, and C level). An “A” level change would result in small changes to the five attributes listed above. Conversely, a “C” level change signifies a large impact to the attributes. **Table C-9** lists the five technology attributes along with the categorization definitions developed for each level.

Table C-9: Technology Attributes and Categorization Scale

Class	A	B	C
Component type	Other parts (exhaust system, car body, transmission…)	Engine / engine management	Electrics (battery, starter, generator)
Integrability in production line	Integrable without / with low investment	Production line has to be supplemented/expanded partly (single machines)	Production line has to be expanded/supplemented (nearly) completely (new machines/tools)
Integrability in product concept	Integrable without / with low work (plug 'n' play)	Integrable with adaptions	Complete new developed system
Number of additional or modified components	Few	Several	Many
Customer notice	Customer notices high improvement according to his requirements	Customer notices medium improvement	Customer notices no improvement, he needs to be convinced to pay the higher price due to a modification

C.2.4 Adjustment Factors and ICMs

The calculated RPE includes all indirect costs that are included in the final selling price of a car. FEV felt some of the components of indirect cost are not impacted by future environmental regulations. This concerns:

- *OEM and dealer profit.* As previously explained, profit must **not** be used to evaluate the impact of modifications to the OEM and dealer costs. Producers would not be affected by regulations if profits were fully included in costs: their profits would be the same before and after the change.

- *Transportation costs which are included in selling costs.* Transportation costs are assumed to be uninfluenced by technology modifications. According to the 2011 Ford Motor Company Annual Report, selling costs can be divided into approximately 50% transportation and 50% marketing costs. This leads to a split of the selling contributor with marketing 0.06 and transportation 0.05.

The final RPE contributors selected for the ICM calculation are represented in **Table C-10**.

Table C-10: RPE Contributors Selected for ICM Calculation

Cost Contributors	RPE weighted Average	Applicable Contributors to ICM
Cost of sales (direct manuf. costs)	**1.00**	**1.00**
Production overhead	**0.22**	**0.22**
Warranty	0.05	0.05
R&D	0.06	0.06
Depreciation and amortization	0.08	0.08
Maintenance, repair	0.03	0.03
Corporate Overhead	**0.05**	**0.05**
Selling	**0.11**	**0.06**
Transportation	0.055	~~0.055~~
Marketing	0.055	0.06
Dealers	**0.15**	**0.15**
Dealer net profit	0.02	~~0.02~~
Dealer selling cost	0.13	0.13
Net income	**0.07**	~~**0.07**~~
RPE Multiplier	**1.60**	**1.46**

At this stage in the ICM development process the team has identified the baseline indirect cost factors values which are the starting point for the development of ICMs. In addition technology configuration attributes which can have significant influence on the magnitude of indirect costs have been selected. Further, for each technology attribute, a simple categorization scale defining the potential range of difference was established.

The next step was to establish the influence strength each technology configuration attribute had on each indirect cost contributor. **Table C-11** presents the findings of an investigation of correlations between technology configuration attributes and indirect cost contributors. For example, the warranty costs are highly influenced by the type of component and are lowly influenced by the class of integrality in an existing product line. On the other hand, the number of new or modified components does not necessarily have a direct influence on the depreciation costs; that is, although a modification may require a lot of new bolts that have to be integrated, new machines may not have to be bought because of the high number but only if these components are not easy to integrate in a production line.

Table C-11: Technology Configuration Attributes and Influencing Strength on Indirect Costs

	Component type	Integrability in production line	Integrability in product concept	Number of new/ modified components	Costumer notice
Warranty	+++	+	++	++	
R & D		+	+++	+++	
Depreciation		+++			
Maintenance		+++			
Corporate Overhead		++	+	+++	
Marketing					+++
Dealer			++	+	

+++ high influence ++ medium influence + low influence Empty fields: no influence

The qualitative influence described by any amount of "+" symbols in the table is not intended to describe the precise height of the corresponding factor. **Table C-12** through **Table C-16** offer descriptions specific to a criteria and its influence on each indirect cost contributor.

Table C-12: Influence of "Component Type" on Indirect Cost Contributors

Contributor	Identification of Influence
Warranty	The probability of breakdowns and so the amount of the warranty costs depends on the component type. According to the "ADAC breakdown statistic" the component type can be divided to electrics, engine / engine management parts and other mechanical parts.
R & D	An engine part can require equal R&D costs as an electrical part or a transmission. The component type does not form a clear conclusion to the height of R&D costs.
Depreciation	No correlation between amount of depreciation costs and component type assumed.
Maintenance	No correlation between amount of maintenance costs and component type assumed.
Corporate Overhead	No correlation between amount of overhead costs and component type assumed.
Marketing	No correlation between amount of marketing costs and component type assumed.
Dealer	No correlation between amount of dealer costs and component type assumed.

Table C-13: Influence of "Integration in Production Line" on Indirect Cost Contributors

Contributor	Identification of Influence
Warranty	A low level of integrability in the production line creates some warranty costs due to learning effects which come around with new production lines. This impact does not occur if a modification can be integrated easily.
R & D	The R&D costs are higher for parts which are not capable of being integrated than for parts which can be integrated in a product line easily or with low investments (e.g. tooling development etc.). The overall influence is very small.
Depreciation	Parts which are not capable of being integrated lead to acquirements of new or additional machines and equipment. Therefore the depreciation costs are higher for these parts than for parts which can be integrated easily or with low investments.
Maintenance	Maintenance costs are assumed to rise proportional to depreciation costs.
Corporate Overhead	For parts which are not capable of being integrated higher costs for production planning are assumed.
Marketing	No correlation between amount of marketing costs and class of "integration in product line" assumed.
Dealer	No correlation between amount of dealer costs and class of "integration in product line" assumed.

Table C-14: Influence of "Integration in Product Concept" on Indirect Cost Contributors

Contributor	Identification of Influence
Warranty	New developed systems cause high warranty costs because these systems are assumed to have a higher probability for breakdowns. Parts which are easy to integrate in an existing product concept are assumed to cause lower warranty costs: the interfaces to the products which are in use are already fully developed.
R & D	R&D costs are assumed to be higher for completely new developed systems than for parts which need just a few adjustments to get integrated in an existing system easily or with low investments. The influence on R&D is very high.
Depreciation	No correlation between amount of depreciation costs and kind of integration in product concept assumed.
Maintenance	Maintenance costs are assumed to be proportional to depreciation costs.
Corporate Overhead	The more difficult it is to integrate a new part in a product concept the more management/administration effort is assumed.
Marketing	No correlation between amount of marketing costs and kind of integration in product concept.
Dealer	Dealer costs are expected to be higher for new developed systems than for parts which can be integrated in an existing system easily or with low investment due to higher costs of employee training and/or additional costs for new tools/equipment.

Table C-15: Influence of "Number of New/Modified Components" on Indirect Cost Contributors

Contributor	Identification of Influence
Warranty	New components cause high warranty costs due to the lack of experience in comparison to already used components. The more new components are used for a modification the higher the warranty costs get.
R & D	The R&D costs are assumed to rise with the number of new developed or modified components. The influence of the number on R&D is very high.
Depreciation	No correlation between amount of depreciation costs and number of new/modified components.
Maintenance	Maintenance costs are assumed to be proportional to depreciation costs.
Corporate Overhead	The higher the number of new or modified components is the more administration is required.
Marketing	No correlation between amount of marketing costs and number of new / modified components.
Dealer	If the modification consists of a lot of new or modified components the dealer has higher administration costs than for more simple modifications. At the same time the dealer may need some extra equipment for these parts.

Table C-16: Influence of "Customer Notice" on Indirect Cost Contributors

Contributor	Identification of Influence
Warranty	No correlation between amount of warranty costs and kind of customer notice.
R & D	No correlation between amount of R&D costs and kind of customer notice.
Depreciation	No correlation between amount of Depreciation costs and kind of customer notice.
Maintenance	Maintenance costs are assumed to be proportional to depreciation costs.
Corporate Overhead	No correlation between amount of corporate overhead costs and kind of customer notice.
Marketing	Modifications that cause a perceived benefit at the customer are not assumed to require additional marketing activities. Modifications which do not have a direct advantage for the customer are assumed to require additional marketing to justify the price changes.
Dealer	No correlation between amount of dealer costs and kind of customer notice.

Using both the influencing strength matrix (**Table C-11**) and tables detailing technology configuration attribute influences on indirect costs (**Table C-12 - Table C-16**), the team developed weighted adjustment factors for each technology configuration attribute, at each category level, for each indirect cost contributor.

The adjustment factor development for each indirect cost are shown in **Table C-17** through **Table C-23**. The final adjustment factor for each indirect cost contibutor is based on the category level (i.e., A, B, or C) the new technology configuration falls within for each technology configuration attribute. The net adjustment factor for each indirect cost is the summation of technology configuration attribute adjustment factors. For example, in **Table C-17**, if the new technology configuration resulted in many new engine components being added/modified, requiring significant modifications to the existing engine platform, and moderate changes to the engine production line, the warranty adjustment factor would equal 2.85 (1+0.1+0.75+1).

In each of the Adjustment Factor development tables below, the Minimum and Maximum adjustment factors are provided for reference only. In addition, located underneath each table are some general points regarding the development of the adjustment factors.

Table C-17: Adjustment Factors for Warranty Indirect Costs

Characteristic	Component Type			Integrability in Production Line			Integrability in Product Concept			Number of New/ Modified Components			Minimum Adjustment Factor	Maximum Adjustment Factor
Category	A	B	C	A	B	C	A	B	C	A	B	C	AAA-combination	CCC-combination
Adjustment factor	0.5	1	1.5	0	0.1	0.2	0.5	0.75	1	0.5	0.75	1	1.5	3.7

- Warranty costs are influenced by the component type, the level of integrability in an existing production line, the level of integrability in an existing product concept, and the number of new or modified components.
- Component type has the highest amount of influence. Therefore, the values are higher than for the other categories. The other categories have a comparable influence.
- Even the minimum adjustment factor of 1.5 leads to higher warranty costs than average. This results of the lack of experience and higher risks with new modifications – even for "small" modifications.
- The maximum adjustment factor of 3.7 is a result of the low percentage of cost causer within the RPE factor. The high adjustment factor represents the warranty costs for complex new parts.

Table C-18: Adjustment Factors for R&D Indirect Costs

Characteristic	Integrability in Production Line			Integrability in Product Concept			Number of New/ Modified Components			Minimum Adjustment Factor	Maximum Adjustment Factor
Category	A	B	C	A	B	C	A	B	C	AAA-combination	CCC-combination
Adjustment factor	0.1	0.2	0.4	0.1	1	2	0.1	1	2	0.3	4.4

- R&D costs are influenced by the level of integrability in an existing production line and an existing product concept as well as by the number of new of modified components. The last two have a high influence on R&D. The first, meanwhile, has a very low influence.
- A modification which contains only few new/modified parts and which is easy to integrate in the production line as well as in the product concept is expected to have less than average R&D costs.
- A modification which contains lots of new/modified parts and which is difficult to integrate in an existing production line as well as in an existing product concept requires a lot more than the average R&D costs.

Table C-19: Adjustment Factors for Depreciation Indirect Costs

Characteristic	Integrability In Production Line		
Category	A	B	C
Adjustment factor	0	0.5	1.5

- Depreciation costs are influenced by the level of integrability in an existing production line.
- A modification which can be integrated easily in an existing production line does not need any new machines. Therefore, no costs are considered.
- If complete new machines, tools, and equipment have to be acquired, the costs will be higher-than-average costs. The RPE factor is the relation of all depreciation to all parts. If new machines have to be bought (and depreciated) due to a modification, the adjustment factor has to be higher than average.

Table C-20: Adjustment Factors for Maintenance Indirect Costs

Characteristic	Integrability In production line		
Category	A	B	C
Adjustment factor	0	0.5	1.5

- The adjustment factors for maintenance cost correspond to the ones for depreciation. If no new machines are needed, no extra maintenance and repair costs occur.
- For new tools, machines, and equipment, higher-than-average maintenance and repair costs will occur.

Table C-21: Adjustment Factors for Corporate Overhead Indirect Costs

Characteristic	Integrability in Production Line			Integrability in Product Concept			Number of New/ Modified Components			Minimum Adjustment Factor	Maximum Adjustment factor
Category	A	B	C	A	B	C	A	B	C	AAA-combination	CCC-combination
Adjustment factor	0	0.1	0.2	0	0.1	0.2	0	0.1	0.2	0	0.6

- Corporate overheads are influenced by the level of integrability in an existing production line and an existing product concept as well as by the number of new or modified components. The three categories have the same amount of influence.
- For simple modifications, nearly nothing in production planning or administration changes. The adjustment factor is zero.
- Corporate overhead will rise only a little with complex modifications due to a bit more management and administration. The amount will be less than average, which is expressed with the net maximum factor 0.6.

Table C-22: Adjustment Factors for Marketing Indirect Costs

Characteristic	Customer Notice		
Category	A	B	C
Adjustment factor	0	1	1.5

- Marketing costs are influenced by the level of customer notice.
- Base for the marketing adjustment factor is the assumption that the customer is willing to pay a higher price when he recognizes a benefit (e.g. higher engine power or less fuel consumption).
- If the customer does not recognize a benefit but the selling price is higher due to the modification, he needs to be convinced of the new modification by extra marketing activities.

Table C-23: Adjustment Factors for Dealer Indirect Costs

Characteristic	Integrability in Product Concept			Number of New/ Modified Components			Minimum Adjustment Factor	Maximum Adjustment Factor
Category	A	B	C	A	B	C	AAA-combination	CCC-combination
Adjustment factor	0	0.2	0.4	0	0.1	0.2	0	0.6

- Dealer costs are influenced by the level of integrability in an existing product concept and the number of new or modified components.
- There will be no additional dealer costs if a simple modification can be integrated in an existing product concept.
- For the combination of a new developed unit with lots of new or modified parts, the indirect dealer costs are expected to be a little more than half of average costs because the dealer may need new tools and additional employee training.

Table C-24 summarizes the adjustment factors discussed in the previous tables. In addition, the net min/max adjustment factors are applied to the baseline indirect cost factors to arrive at the min/max values of the Indirect Cost Multiplier (ICM).

Table C-24: Summary of Indirect Cost Adjustment Factors and Min-Max ICMs

Characteristic	Component Type			Integrability in Production Line			Integrability in Product Concept			Number of New/Modified Components			Customer Notice			Minimum Adjustment Factor	Maximum Adjustment factor	Baseline Indirect Cost Factors	Minimum ICM	Maximum ICM
Category	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	AAA-combination	CCC-combination	Direct Manufacturing Costs = 1		
Warranty	0.5	1	1.5	0	0.1	0.2	0.5	0.8	1	0.5	0.8	1	0	0	0	1.5	3.7	0.05	0.075	0.185
R&D	0	0	0	0.1	0.2	0.4	0.1	1	2	0.1	1	2	0	0	0	0.3	4.4	0.06	0.018	0.264
Depreciation	0	0	0	0	0.5	1.5	0	0	0	0	0	0	0	0	0	0	1.5	0.08	0	0.12
Maintenance	0	0	0	0	0.5	1.5	0	0	0	0	0	0	0	0	0	0	1.5	0.03	0	0.045
Corporate Overhead	0	0	0	0	0.1	0.2	0	0.1	0.2	0	0.1	0.2	0	0	0	0	0.6	0.05	0	0.03
Marketing	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.5	0	1.5	0.06	0	0.09
Dealer	0	0	0	0	0	0	0	0.2	0.4	0	0.1	0.2	0	0	0	0	0.6	0.13	0	0.078
Total Contribution to Cost of																		1.46	1.09	1.81

The assumptions and calculations were then transferred into an ICM calculator (**Figure C-6**) that could be used to calculate the ICMs for a range of new technology configurations. The operator marks the appropriate category levels for each technology configuration attribute in the "Input Table" and the ICM value is automatically calculated. In addition, an output table is displayed showing the adjustments being made to each indirect cost factor.

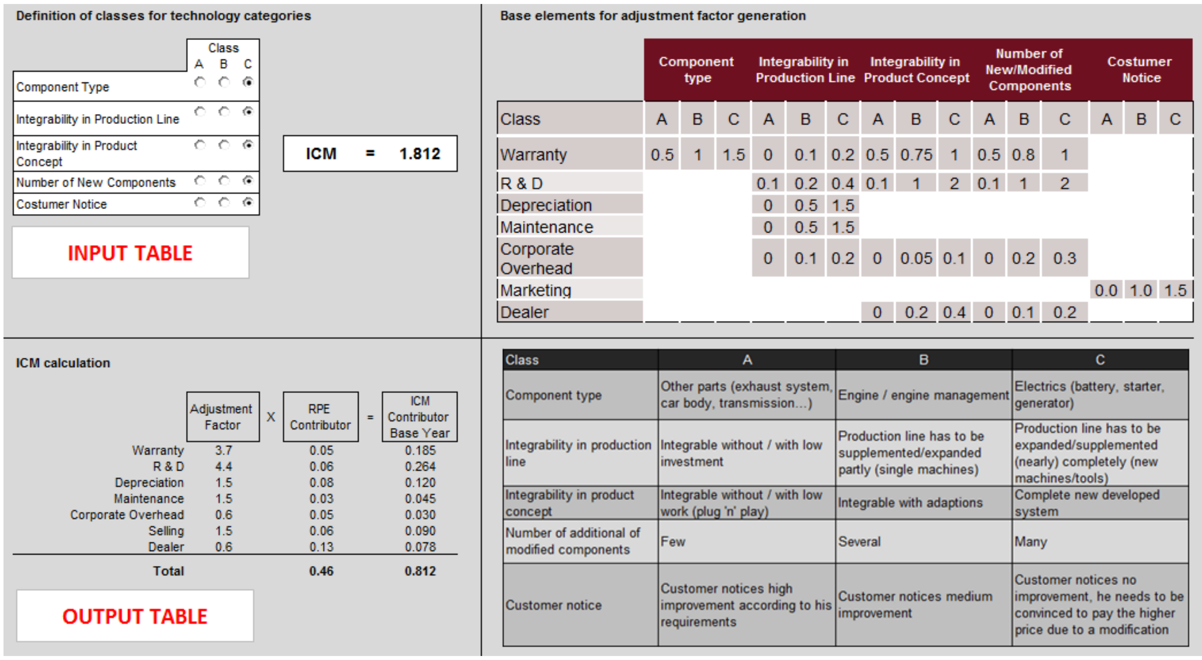


Figure C-6: ICM Calculator

C.2.5 Impact of Time on Indirect Cost Multipliers

To address the impact of time on ICMs, average time curves for every indirect cost were defined. The assumptions for each indirect cost contributor time curve is summarized below:

Warranty Costs: decrease with high rates in the first years down to warranty costs for existing parts in the future

R&D Costs: are straight-line depreciated over nine (9) years. Following the nine (9) years, no additional R&D expense is recognized

Depreciation Costs: for tooling, fixturing, gauges, etc., is defined as straight-line depreciation over eight (8) years

Maintenance and Repair Costs: are assummed to remain constant year over year

Corporate Overhead Costs: are assummed to remain constant year over year

Marketing Costs: for new technologies decrease over time (years one through eleven) eventually decreasing to zero

Dealership Costs: decline over the first six (6) years, reducing to zero in year seven and beyond.

Table C-25 and **Figure C-7** below provide the adjustment factors for each ICM as a function of time.

Table C-25: ICM Adjustment Factors as a Function of Time

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Warranty	1,00	0,80	0,63	0,50	0,40	0,33	0,29	0,27	0,26	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25
R & D	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Depreciation	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Maintenance	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Corporate Overhead	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Marketing	1,00	0,60	0,36	0,22	0,13	0,08	0,05	0,03	0,02	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Dealer	1,00	0,40	0,16	0,06	0,03	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

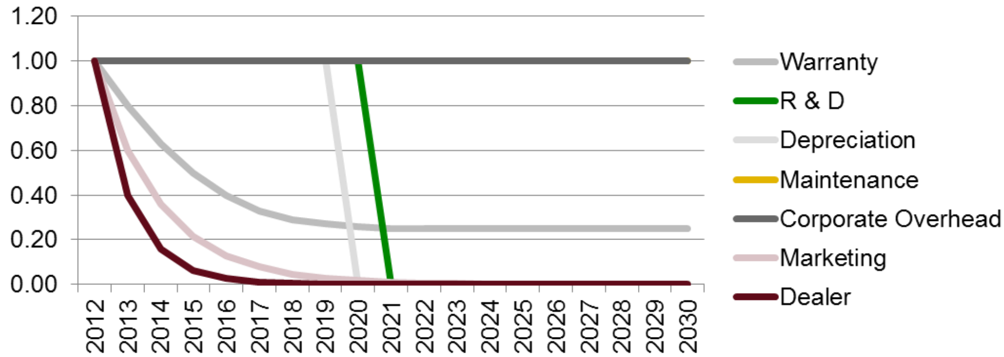
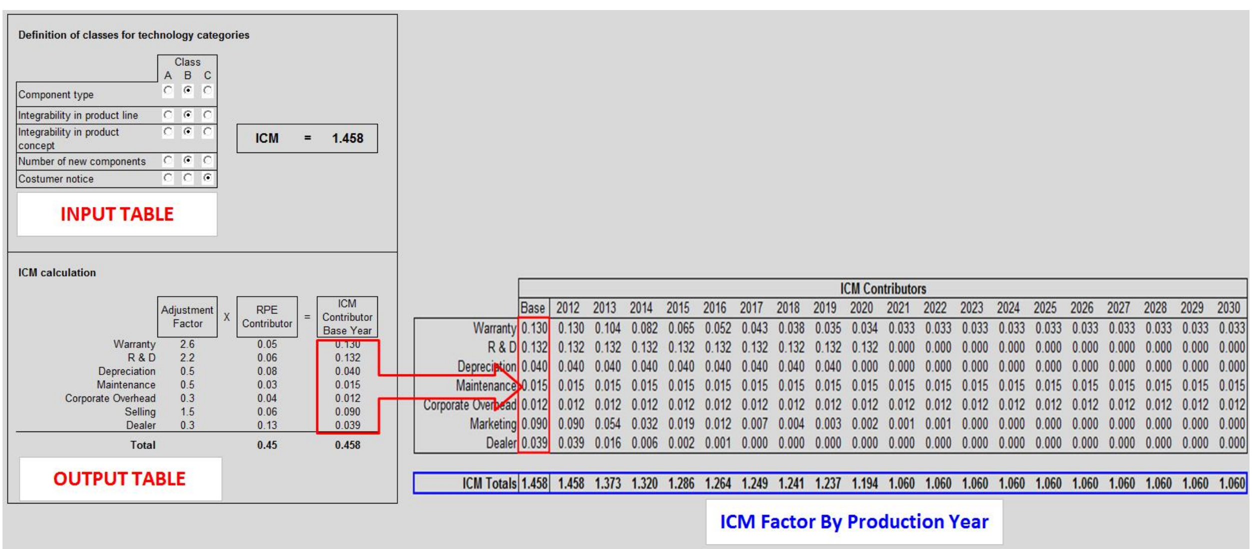


Figure C-7: Plot of ICM Adjustment Factors as a Function of Time

C.2.6 Application of ICMs

Once the ICM is calculated for the base year, adjustment factors with respect to production timing (**Table C-25**), are applied independently to the indirect cost multipliers of the ICM (e.g., warranty, R&D, Depreciation, etc.) to arrive at production year dependent ICMs. **Figure C-8** provides an example of what the calculated ICMs, by production year, would be for the Variable Valve Lift and Timing technology evaluated as part of the Phase 2 study.



Definition of classes for technology categories

	Class A	Class B	Class C
Component type	○	●	○
Integrability in product line	○	●	○
Integrability in product concept	○	●	○
Number of new components	○	●	○
Costumer notice	○	○	●

INPUT TABLE

ICM = 1.458

ICM calculation

	Adjustment Factor	X	RPE Contributor	=	ICM Contributor Base Year
Warranty	2.6		0.05		0.130
R & D	2.2		0.06		0.132
Depreciation	0.5		0.08		0.040
Maintenance	0.5		0.03		0.015
Corporate Overhead	0.3		0.04		0.012
Selling	1.5		0.06		0.090
Dealer	0.3		0.13		0.039
Total			**0.45**		**0.458**

OUTPUT TABLE

ICM Contributors

	Base	2012	2013	2014	2015	2016	2017	2018	2019	2020
Warranty	0.130	0.130	0.104	0.082	0.065	0.052	0.043	0.038	0.035	0.034
R & D	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132
Depreciation	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.000
Maintenance	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Corporate Overhead	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Marketing	0.090	0.090	0.054	0.032	0.019	0.012	0.007	0.004	0.003	0.002
Dealer	0.039	0.039	0.016	0.006	0.002	0.001	0.000	0.000	0.000	0.000
ICM Totals	**1.458**	**1.458**	**1.373**	**1.320**	**1.286**	**1.264**	**1.249**	**1.241**	**1.237**	**1.194**

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Warranty	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
R & D	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Depreciation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Maintenance	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Corporate Overhead	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Marketing	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Dealer	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ICM Totals	**1.060**	**1.060**	**1.060**	**1.060**	**1.060**	**1.060**	**1.060**	**1.060**	**1.060**	**1.060**

ICM Factor By Production Year

Figure C-8: Calculation of ICMs by Production Year

For a given technology configuration and production year (Production Year "X") the Net Incremental Technology Cost (NITC) is the summation of the Direct Manufacturing Cost (DMC), the indirect cost contribution {ICM(X) * DMC} and any adjustments made for forward or reverse learning {(1-LF(X))*DMC}. The developed methodology does not selectively apply indirect cost multipliers against the DMC and learned DMC as in the EPA methodology. Adjustments as a result of learning are accounted for in the developed ICM time curves.

Figure C-9 illustrates the application of ICMs in the Variable Valve Lift and Timing analysis. The same example used in Section C.1.2 (EPA ICMs) was used for comparison reasons. Note the application of learning factors remains the same regardless the ICM values and application methodology.

Figure C-10 provides a comparison of the indirect costs and NITCs calculated using the EPA North American ICM values and methodology versus the FEV EU ICM values and methodology. In this example, the Phase 2 variable valve lift and time technology configuration is presented. Similar trends appear in the majority of the technology configurations evaluated in the Phase 1 and Phase 2 studies. The indirect costs and NITCs are generally higher in first two years using the FEV EU ICMs; however, after these first couple years, they tend to be lower in value than when compared to the values calculated using the EPA NA ICMs.

Variable Valve Lift and Timing

NIDMC(Baseline = 2015)	€ 192.35
Learning Factor (LF) Curve	12

Production Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
LF (X)	1.10	1.06	1.03	1.00	0.97	0.95	0.93	0.91	0.89	0.88
NIDMC(X)	€ 210.76	€ 204.44	€ 198.30	€ 192.35	€ 186.58	€ 182.85	€ 179.19	€ 175.61	€ 172.10	€ 168.66
ICM(X)	0.458	0.373	0.320	0.286	0.264	0.249	0.241	0.237	0.194	0.060
Indirect Costs (X)	€ 88.10	€ 71.67	€ 61.46	€ 55.00	€ 50.72	€ 47.95	€ 46.37	€ 45.53	€ 37.38	€ 11.62
NITC (X)	€ 299.32	€ 276.48	€ 260.09	€ 247.64	€ 237.56	€ 231.05	€ 225.80	€ 221.37	€ 209.67	€ 180.34

Model Year 2013 Calculations

NIDMC (2013) = NIDMC(baseline)*LF(2103)
NIDMC (2013) = €192.35 * 1.06 = €204.44

Indirect Cost s (2013) = {ICM(X) * NIDMC (Baseline)}
Indirect Costs (2013) ={0.343*€192.35} = €71.67

NITC (2013) = NIDMC(2013) + Indirect Costs(2013)
NITC (2013) = €204.44 + €71.67 = €276.48

Figure C-9: Variable Valve Lift and Timing Cost Analysis Example using FEV ICM Methodology

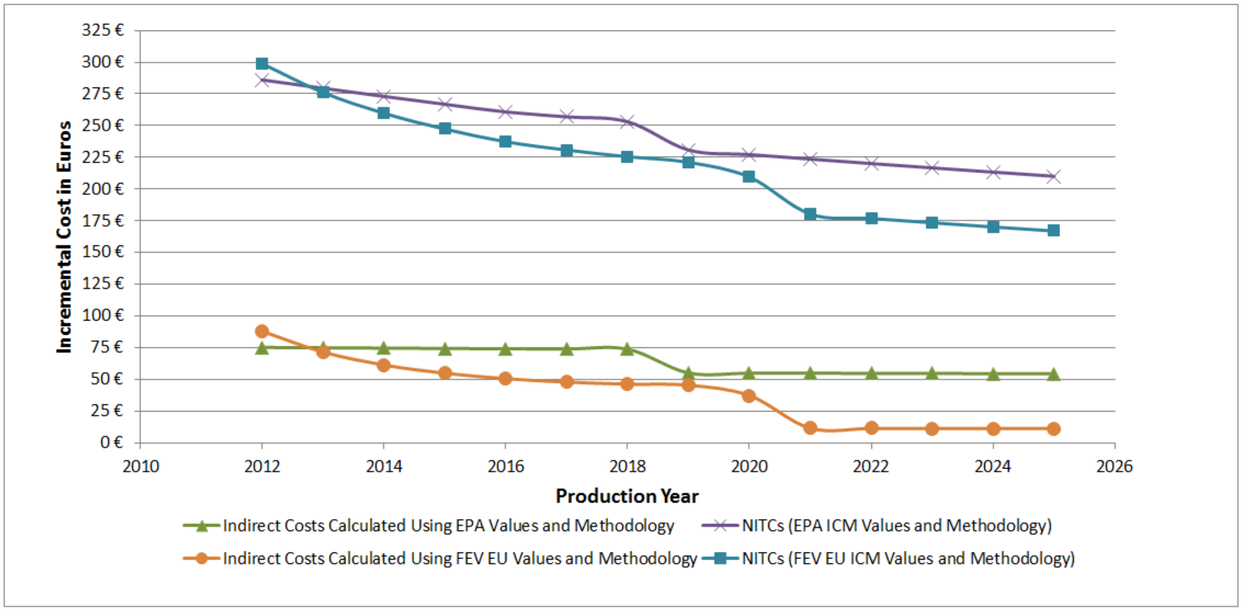


Figure C-10: Indirect Costs and Net Incremental Direct Manufacturing Costs Comparisons for Variable Valve Lift and Timing Technology Configuration

D. Phase 1 and Phase 2 Results

Table D-1 and **Table D-2** provide a summary of the EPA ICMs used in the original Phase 1 and Phase 2 cost analysis studies compared to those developed by FEV for the EU market. The EPA values shown in the table are the combination of ICM-Warranty and ICM-Other Indirect Costs, as defined by EPA. The applicable learning factors were applied to the ICM-Warranty portion to provide a fair comparison.

As stated previously, the ICMs developed using the FEV ICM model are generally higher at inception (assumed 2012 for this analysis) and significantly drop-off in comparison to the EPA values in 2025 (13 years later). This can be explained by the complete drop-off of selected indirect costs (i.e., R&D, Depreciation, Marketing, and Dealership) during years five (5) through eleven (11).

Table D-1: Comparison of FEV EU and EPA NA ICMs for Phase 1 Technologies Evaluated

Case Study ID	Baseline Technology Configuration	New Technology Configuration	FEV EU ICMs		EPA NA ICMs		ICM Ratio (FEV EU/EPA NA)	
			2012	2025	2012	2025	2012	2025
01**	Naturally Aspirated (NA), Port Fuel Injected (PFI), Gasoline Internal Combustion Engine (ICE)	Downsized (DS), Turbocharged (Turbo), Direct Injection (DI) Gasoline Internal Combustion Engine (ICE)	0.368	0.060	0.388	0.282	95%	21%
02**	Dual Overhead Cam (DOHC), NA, PFI, Dual-Variable Valve Timing (D-VVT), Gasoline ICE	Single Overhead Cam (SOHC), NA, PFI, Multi-Air Variable Valve Timing and Lift (VVTL), Gasoline ICE	0.428	0.060	0.393	0.284	109%	21%
08**	5-Speed Automatic Transmission	6-Speed Automatic Transmission	0.495	0.062	0.242	0.192	204%	33%
10**	6-Speed Automatic Transmission	8-Speed Automatic Transmission	0.525	0.062	0.387	0.282	135%	22%
09**	6-Speed Automatic Transmission	6-Speed Dual Clutch Transmission	0.726	0.103	0.387	0.290	187%	35%
04**	Conventional Powertrain Vehicle	Conventional Powertrain Vehicle Upgraded with a Belt Alternator Starter (BAS) Start-Stop System	0.383	0.046	0.412	0.282	93%	16%
05**	Conventional Powertrain Vehicle	Power-Split Hybrid Electric Vehicle	0.716	0.115	0.650	0.343	110%	34%
07**	Conventional Powertrain Vehicle	P2 Hybrid Electric Vehicle	0.585	0.080	0.650	0.343	90%	23%
06**	Mechanical Air Conditioning Compressor System	Electrical Air Conditioning Compressor System	0.585	0.080	0.564	0.338	104%	24%

Table D-2: Comparison of FEV EU and EPA NA ICMs for Phase 1 Technologies Evaluated

Case Study ID	Baseline Technology Configuration	New Technology Configuration	FEV EU ICMs 2012	FEV EU ICMs 2025	EPA NA ICMs 2012	EPA NA ICMs 2025	ICM Ratio (FEV EU/EPA NA) 2012	ICM Ratio (FEV EU/EPA NA) 2025
20**	Conventional Diesel Engine	Downsized Conventional Diesel Engine (e.g. I4-I3, I6-I4, V8-I6)	0.560	0.074	0.242	0.192	231%	38%
21**	Conventional Diesel Engine with 1800 Bar Fuel Injection Subsystem	Conventional Diesel Engine Upgraded with 2500 Bar Fuel Injection Subsystem	0.303	0.030	0.388	0.282	78%	11%
22**	Diesel Engine with Conventional Valvetrain Subsystem	Diesel Engine Upgraded with Discrete Variable Valve Timing and Lift (VVTL) Valvetrain subsystem	0.458	0.060	0.393	0.284	117%	21%
23**	Conventional Diesel Engine with a Cooled High Pressure Exhaust Gas Recirculation (EGR) Subsystem	Conventional Diesel Engine Upgraded with a High Pressure, Low Pressure Cooled High EGR Subsystem	0.458	0.060	0.388	0.282	118%	21%
31**	Conventional Gasoline Engine with a Uncooled Low Pressure EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem	0.373	0.050	0.388	0.282	96%	18%
32**	Conventional Gasoline Engine with no EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem	0.373	0.050	0.388	0.282	96%	18%
26**	6-Speed Manual Transmission	6-Speed Dry Dual Clutch Transmission (DCT)	0.535	0.068	0.388	0.282	138%	24%
30**	Conventional Powertrain Vehicle (Manual Transmission)	Conventional Powertrain Vehicle ((Manual Transmission) Upgraded with a Belt-Driven Starter Generator (BSG) Start-Stop System	0.383	0.046	0.413	0.283	93%	16%

In some cases, such as the 5-speed AT to 6-speed AT analysis and 6-speed AT to 6-speed DCT analysis, the FEV ICMs are considerably higher than the EPA NA ICMs. Although it is difficult to assess why this significant difference exists without understanding the variations in underlying assumptions which were used in development of the EPA ICMs.

The FEV ICM calculator tries to objectively define some of the basic assumptions as part of the process; though, in many cases, only scratches the surface leaving the operator subjectively embedded in the final solution. Thus, an iterative, team approach is recommended when using the FEV-developed ICM calculator.

Sections D.1 and **D.2**, which follow, provide a summary of the calculated incremental costs for each of the technologies and vehicle segments evaluated in the Phase 1 and Phase 2 analyses using the new FEV developed ICMs. The number of vehicle segments evaluated varied for each technology configuration based on customer requirements. For each cost analysis, a case study ID exists corresponding to a technology type and vehicle class.[6]

The following cost summary tables present Net Incremental Direct Manufacturing Costs (NIDMCs) and Net Incremental Technology Costs (NITCs) for production years 2012, 2016, 2020, and 2025. Restated NIDMCs are direct manufacturing costs derived with a pre-defined set of boundary conditions (volume, location, product maturity, market maturity, etc.). They do not take into account OEM indirect cost factors or reverse learning which generally increases the differential technology costs in the near-term years (i.e., 2012-2020). Over the long-run (i.e., 2020-2025) continued forward learning (design, manufacturing, commercial, etc.) generally reduces the direct manufacturing costs such that the long-term direct manufacturing costs, including OEM indirect costs and forward learning, are lower than the originally established NIDMCs. The NIDMCs with Indirect Cost Multipliers (ICMs) and Learning Factors (LFs) applied are referred to as Net Incremental Technology Costs (NITCs). The NITC is the cost the end consumer is expected to pay for a given technology in a given production year.

The format is identical to previously published ICCT report "Light-Duty Vehicle Technology Cost Analysis, European Vehicle Market, Result Summary and Labor Rate Sensitivity Study," facilitating a quick comparison of the NITCs using the EPA NA ICMs and FEV EU ICMs (the NIDMCs do not change).

D.1 Phase 1 Technologies Evaluated

A summary of the baseline and new technology configurations evaluated in the original Phase 1 analysis, and reference to the corresponding cost summary tables, is summarized in **Table D-3** through **Table D-9**.

[6] Case Study ID Number: The first two digits identify the technology (e.g., 02** = engine downsizing analysis) and the second two digits identify the vehicle segment (e.g., **00 = subcompact passenger vehicle segment). The letter following the four digit number represents one possible powertrain option in that particular vehicle segment (i.e., 0200A = engine downsizing analysis, subcompact passenger vehicle segment, I3 engine configuration). In this particular example the letter "B" would signify an I4 engine configuration for the same analysis and vehicle segment.

Table D-3: Advance Powertrain Technologies Evaluated in the Phase 1 Analysis

Case Study ID	Baseline Technology Configuration	New Technology Configuration	Cost Summary Table
01**	Naturally Aspirated (NA), Port Fuel Injected (PFI), Gasoline Internal Combustion Engine (ICE)	Downsized (DS), Turbocharged (Turbo), Direct Injection (DI) Gasoline Internal Combustion Engine (ICE)	D-4
02**	Dual Overhead Cam (DOHC), NA, PFI, Dual-Variable Valve Timing (D-VVT), Gasoline ICE	Single Overhead Cam (SOHC), NA, PFI, Multi-Air Variable Valve Timing and Lift (VVTL), Gasoline ICE	D-4
08**	5-Speed Automatic Transmission	6-Speed Automatic Transmission	D-5
10**	6-Speed Automatic Transmission	8-Speed Automatic Transmission	D-5
09**	6-Speed Automatic Transmission	6-Speed Dual Clutch Transmission	D-5
04**	Conventional Powertrain Vehicle	Conventional Powertrain Vehicle Upgraded with a Belt Alternator Starter (BAS) Start-Stop System	D-6
05**	Conventional Powertrain Vehicle	Power-Split Hybrid Electric Vehicle	D-7
07**	Conventional Powertrain Vehicle	P2 Hybrid Electric Vehicle	D-8
06**	Mechanical Air Conditioning Compressor System	Electical Air Conditioning Compressor System	D-9

Table D-4: Downsized, Turbocharged, Direct Injection Gasoline Engine & Multi-Air Variable Valve Timing and Lift Valvetrain Subsystem Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Engine	Downsized, Turbocharged, Gasoline Direct Injection Internal Combustion Engines										
	1	0100	1.4L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.0L, I3, 4V, DOHC, Turbo, GDI, dVVT, ICE	Subcompact Passenger Vehicle	VW Polo	€ 230	€ 413	€ 314	€ 259	€ 164
	2	0101	1.6L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.2L, I4, 4V, DOHC, Turbo, GDI, dVVT, ICE	Compact or Small Passenger Vehicle	VW Golf	€ 360	€ 503	€ 415	€ 366	€ 285
	3	0102	2.4L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.6L, I4, 4V, DOHC, Turbo, GDI, dVVT, ICE	Midsize Passenger Vehicle	VW Passat	€ 367	€ 524	€ 429	€ 376	€ 288
	4	0103	3.0L, V6, 4V, DOHC, NA, PFI, dVVT, ICE	2.0L, I4, 4V, DOHC, Turbo, GDI, dVVT, ICE	Midsize or Large Passenger Vehicle	VW Sharan	€ 80	€ 364	€ 226	€ 151	€ 15
	5	0106	5.4L, V8, 3V, SOHC, NA, PFI, sVVT, ICE	3.5L V6, 4V, DOHC, Turbo, GDI, dVVT, ICE	Large SUV	VW Touareg	€ 648	€ 975	€ 784	€ 679	€ 500
	Variable Valve Timing and Lift, Fiat Multiair System										
	6	0200	1.4L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.4L, I4, 4V-MultiAir, SOHC, NA, PFI, ICE	Subcompact Passenger Vehicle	VW Polo	€ 107	€ 163	€ 131	€ 116	€ 93

Table D-5: 6-Speed Automatic Transmission, 8-Speed Automatic Transmission, and 6-Speed Wet Dual Clutch Transmission Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Transmissions	1	0802	5-Speed AT	6-Speed AT	Midsize or Large Passenger Vehicle	VW Sharan	(€ 79)	(€ 40)	(€ 53)	(€ 58)	(€ 74)
	2	0803	6-Speed AT	8-Speed AT	Large SUV	VW Touareg	€ 52	€ 80	€ 64	€ 56	€ 42
	3	0902	6-Speed AT	6-Speed Wet DCT	Midsize or Large Passenger Vehicle	VW Sharan	(€ 83)	(€ 23)	(€ 40)	(€ 53)	(€ 75)

Table D-6: Belt Alternator Starter (BAS) Start-Stop System Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Start-Stop HEV	1	0402	Conventional Powertrain >I4 Gasoline ICE, 4V, DOHC, NA, PFI, VVT >4-Speed AT	Belt Alternator Starter (BAS) - HEV (Brake Regen & Launch Assist) >I4 Gasoline ICE, 4V, DOHC, NA, PFI, VVT >4-Speed AT >Electric Generator/Starter 14.5kW >Battery: 36V, 18.4Ah NiMH	Midsize Passenger Vehicle	VW Passat	€ 1,176	€ 2,289	€ 1,415	€ 1,246	€ 948

Table D-7: Power-Split Hybrid Electric Vehicle Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Power-Split HEV	1	0500	Subcompact car typically powered by an inline 4 cylinder engine, naturally aspirated, port fuel injection, 5-speed manual transmission (MT).	Power-split HEV System Power: 74.7kW ICE Power: 61.1kW (I4 -> I3) Traction Motor: 50kW Generator: 35.1kW Li-Ion Battery: 140V, 0.743kWh	Subcompact Passenger Vehicle	VW Polo	€ 1,809	€ 4,725	€ 3,402	€ 2,509	€ 1,750
	2	0501	Compact or small car typically powered by an inline 4 cylinder engine, naturally aspirated, port fuel injection, 6-speed manual transmission or 7-speed dual clutch transmission (DCT).	Power-split HEV System Power: 90kW ICE Power: 73.6kW (I4 - DS I4) Traction Motor: 60.2kW Generator: 42.3kW Li-Ion Battery: 162V, 0.857kWh	Compact or Small Passenger Vehicle	VW Golf	€ 2,012	€ 5,226	€ 3,768	€ 2,784	€ 1,943
	3	0502	A midsize passenger car typically powered by a 4 cylinder turbocharged, direct fuel injection, 6-speed MT and AT or 7-speed DCT, Start/Stop system.	Power-split HEV System Power: 117kW ICE Power: 95.6kW (I4 -> DS I4) Traction Motor: 78.3kW Generator: 55kW Li-Ion Battery: 188V, 0.994kWh	Midsize Passenger Vehicle	VW Passat	€ 2,230	€ 5,842	€ 4,203	€ 3,097	€ 2,160
	4	0503	A midsize or large passenger car typically powered by 4 and 6 cylinder turbocharged, direct fuel injection, 6-speed MT or ≥ 6 speed AT.	Power-split HEV System Power: 174.8kW ICE Power: 142.8kW (V6 -> I4) Traction Motor: 116.9kW Generator: 82.1kW Li-Ion Battery: 211V, 1.118kWh	Midsize or Large Passenger Vehicle	VW Sharan	€ 2,215	€ 5,998	€ 4,276	€ 3,117	€ 2,171
	5	0505	A small or mid-sized sports-utility or cross-over vehicle, or a small-midsize SUV, or a Mini Van powered by a 4 cylinder turbocharged engine, direct fuel injection, 6-speed MT or AT & 7 DCT.	Power-split HEV System Power: 132.6kW ICE Power: 108.3kW (I4 -> DS I4) Traction Motor: 88.7kW Generator: 62.2kW Li-Ion Battery: 199V, 1.053 kWh	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 2,336	€ 6,111	€ 4,398	€ 3,242	€ 2,262
	6	0506	Large sports-utility vehicles, typically powered by a 8 cylinder naturally aspirated engine, direct fuel injection, ≥ 6-speed AT.	n/a	Large SUV	VW Touareg	---	---	---	---	---

Table D-8: P2 Hybrid Electric Vehicle Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
P2 HEV	1	0700	Subcompact car typically powered by an inline 4 cylinder engine, naturally aspirated, port fuel injection, 5-speed manual transmission (MT).	P2 HEV System Power: 74.7kW ICE Power: 59.8kW (I4 -> I3) Traction Motor: 14.9kW Li-Ion Battery: 140V, 0.743kWh	Subcompact Passenger Vehicle	VW Polo	€ 1,704	€ 4,321	€ 2,981	€ 2,241	€ 1,593
P2 HEV	2	0701	Compact or small car typically powered by an inline 4 cylinder engine, naturally aspirated, port fuel injection, 6-speed manual transmission or 7-speed dual clutch transmission (DCT).	P2 HEV System Power: 90kW ICE Power: 72kW (I4 -> DS I4) Traction Motor: 18kW Li-Ion Battery: 162V, 0.857kWh	Compact or Small Passenger Vehicle	VW Golf	€ 1,915	€ 4,837	€ 3,340	€ 2,514	€ 1,788
P2 HEV	3	0702	A midsize passenger car typically powered by a 4 cylinder turbocharged, direct fuel injection, 6-speed MT and AT or 7-speed DCT, Start/Stop system.	P2 HEV System Power: 117kW ICE Power: 93.6kW (I4 -> DS I4) Traction Motor: 23.4kW Li-Ion Battery: 188V, 0.994kWh	Midsize Passenger Vehicle	VW Passat	€ 2,080	€ 5,311	€ 3,659	€ 2,745	€ 1,949
P2 HEV	4	0703	A midsize or large passenger car typically powered by 4 and 6 cylinder turbocharged, direct fuel injection, 6-speed MT or ≥ 6 speed AT.	P2 HEV System Power: 174.8kW ICE Power: 139.9kW (V6 -> I4) Traction Motor: 35.0W Li-Ion Battery: 211V, 1.118 kWh	Midsize or Large Passenger Vehicle	VW Sharan	€ 1,947	€ 5,280	€ 3,595	€ 2,644	€ 1,865
P2 HEV	5	0705	A small or mid-sized sports-utility or cross-over vehicle, or a small-midsize SUV, or a Mini Van powered by a 4 cylinder turbocharged engine, direct fuel injection, 6-speed MT or AT & 7 DCT.	P2 HEV System Power: 132.6kW ICE Power: 106.1kW (I4 -> DS I4) Traction Motor: 26.5kW Li-Ion Battery: 199V, 1.053kWh	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 2,164	€ 5,530	€ 3,809	€ 2,856	€ 2,028
P2 HEV	6	0706	Large sports-utility vehicles, typically powered by a 8 cylinder naturally aspirated engine, direct fuel injection, ≥ 6-speed AT.	P2 HEV System Power: 271.8kW ICE Power: 271.8 kW (No Change to V8) Traction Motor: 54.3 kW Li-Ion Battery: 269V, 1.427kWh	Large SUV	VW Touareg	€ 2,756	€ 7,040	€ 4,850	€ 3,637	€ 2,583

Table D-9: Electrical Air Conditioning Compressor Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Electrical Air Conditioning Compressor Subsystem	1	0600	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Subcompact Passenger Vehicle	VW Polo	€ 102	€ 161	€ 131	€ 117	€ 83
	2	0601	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Compact or Small Passenger Vehicle	VW Golf	€ 106	€ 168	€ 136	€ 122	€ 87
	3	0602	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Midsize Passenger Vehicle	VW Passat	€ 111	€ 177	€ 143	€ 128	€ 91
	4	0603	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Midsize or Large Passenger Vehicle	VW Sharan	€ 115	€ 183	€ 148	€ 132	€ 94
	5	0604	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 118	€ 186	€ 151	€ 135	€ 96
	6	0605	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Large SUV	VW Touareg	€ 135	€ 215	€ 174	€ 156	€ 111

D.2 Phase 2 Technologies Evaluated

A summary of the baseline and new technology configurations evaluated in the original Phase 2 analysis, and reference to the corresponding cost summary tables, is summarized below in **Table D-10**.

Table D-10: Advance Powertrain Technologies Evaluated in the Phase 2 Analysis

Case Study ID	Baseline Technology Configuration	New Technology Configuration	Cost Summary Table
20**	Conventional Diesel Engine	Downsized Conventional Diesel Engine (e.g. I4-I3, I6-I4, V8-I6)	D-11
21**	Conventional Diesel Engine with 1800 Bar Fuel Injection Subsystem	Conventional Diesel Engine Upgraded with 2500 Bar Fuel Injection Subsystem	D-12
22**	Diesel Engine with Conventional Valvetrain Subsystem	Diesel Engine Upgraded with Discrete Variable Valve Timing and Lift (VVTL) Valvetrain subsystem	D-13
23**	Conventional Diesel Engine with a Cooled High Pressure Exhaust Gas Recirculation (EGR) Subsystem	Conventional Diesel Engine Upgraded with a High Pressure, Low Pressure Cooled High EGR Subsystem	D-14
31**	Conventional Gasoline Engine with a Uncooled Low Pressure EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem	D-15
32**	Conventional Gasoline Engine with no EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem	D-16
26**	6-Speed Manual Transmission	6-Speed Dry Dual Clutch Transmission (DCT)	D-17
30**	Conventional Powertrain Vehicle (Manual Transmission)	Conventional Powertrain Vehicle ((Manual Transmission) Upgraded with a Belt-Driven Starter Generator (BSG) Start-Stop System	D-18

Table D-11: Diesel Engine Downsizing Case Studies

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Diesel Engine Downsizing	2	2000B	**Diesel I4 ICE** Ave. Displacement = 1.2-1.4L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Subcompact Passenger Vehicle	VW Polo	(€ 284)	(€ 125)	(€ 173)	(€ 191)	(€ 263)
	3	2001	**Diesel I4 ICE** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 5 or 6 speed MT or DCT Curb Weight: 1271kg (2803lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Compact or Small Passenger Vehicle	VW Golf	(€ 290)	(€ 127)	(€ 176)	(€ 195)	(€ 268)
	4	2002	**Diesel I4 ICE** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1496kg (3299lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Midsize Passenger Vehicle	VW Passat	(€ 303)	(€ 133)	(€ 184)	(€ 204)	(€ 280)
	5	2003A	**Diesel I4 ICE** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Midsize or Large Passenger Vehicle	VW Sharan	(€ 303)	(€ 133)	(€ 184)	(€ 204)	(€ 280)
	6	2003B	**Diesel I6 ICE** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Downsized to Diesel I4 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Midsize or Large Passenger Vehicle	VW Sharan	(€ 437)	(€ 192)	(€ 266)	(€ 294)	(€ 405)
	7	2005	**Diesel I4 ICE** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1590kg (3505lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	(€ 303)	(€ 133)	(€ 184)	(€ 204)	(€ 280)
	9	2006B	**Diesel V8 ICE** Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 8-Speed AT Curb Weight: 2207kg (4866lb)	**Downsized to Diesel I6 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Large SUV	VW Touareg	(€ 442)	(€ 194)	(€ 269)	(€ 297)	(€ 409)

Table D-12: 2500 Bar Diesel Fuel Injection System Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
High Pressure Fuel Injection, Diesel Engine	1	2100A	**Diesel I3 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 1.0L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Diesel I3 ICE Upgraded to 2500 Bar Fuel Injection System**	Subcompact Passenger Vehicle	VW Polo	€ 9	€ 11	€ 9	€ 8	€ 7
	2	2100B	**Diesel I4 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 1.2-1.4L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Diesel I4 ICE Upgraded to 2500 Bar Fuel Injection System**	Subcompact Passenger Vehicle	VW Polo	€ 11	€ 15	€ 11	€ 10	€ 9
	3	2101	**Diesel I4 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 5 or 6 speed MT or DCT Curb Weight: 1271kg (2803lb)	**Diesel I4 ICE Upgraded to 2500 Bar Fuel Injection System**	Compact or Small Passenger Vehicle	VW Golf	€ 11	€ 15	€ 11	€ 10	€ 9
	4	2102	**Diesel I4 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1496kg (3299lb)	**Diesel I4 ICE Upgraded to 2500 Bar Fuel Injection System**	Midsize Passenger Vehicle	VW Passat	€ 11	€ 15	€ 11	€ 10	€ 9
	6	2103B	**Diesel I6 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I6 ICE Upgraded to 2500 Bar Fuel Injection System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 17	€ 22	€ 17	€ 15	€ 13
	7	2105	**Diesel I4 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1590kg (3505lb)	**Diesel I4 ICE Upgraded to 2500 Bar Fuel Injection System**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 11	€ 15	€ 11	€ 10	€ 9
	9	2106B	**Diesel V8 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 8-Speed AT Curb Weight: 2207kg (4866lb)	**Diesel V8 ICE Upgraded to 2500 Bar Fuel Injection System**	Large SUV	VW Touareg	€ 22	€ 29	€ 22	€ 20	€ 17

Table D-13: Discrete Variable Valve Lift and Timing Valvetrain (Diesel Engine) Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Variable Valve Timing and Lift	1	2200A	**Diesel I3 ICE** **Conventional Valvetrain** Ave. Displacement = 1.0L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Diesel I3 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Subcompact Passenger Vehicle	VW Polo	€ 89	€ 139	€ 110	€ 97	€ 78
	3	2201	**Diesel I4 ICE** **Conventional Valvetrain** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 5 or 6 speed MT or DCT Curb Weight: 1271kg (2803lb)	**Diesel I4 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Compact or Small Passenger Vehicle	VW Golf	€ 96	€ 149	€ 119	€ 105	€ 84
	4	2202	**Diesel I4 ICE** **Conventional Valvetrain** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1496kg (3299lb)	**Diesel I4 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Midsize Passenger Vehicle	VW Passat	€ 96	€ 149	€ 119	€ 105	€ 84
	5	2203A	**Diesel I4 ICE** **Conventional Valvetrain** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I4 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Midsize or Large Passenger Vehicle	VW Sharan	€ 96	€ 149	€ 119	€ 105	€ 84
	6	2203B	**Diesel I6 ICE** **Conventional Valvetrain** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I6 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Midsize or Large Passenger Vehicle	VW Sharan	€ 112	€ 174	€ 138	€ 122	€ 97
	7	2205	**Diesel I4 ICE** **Conventional Valvetrain** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1590kg (3505lb)	**Diesel I4 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 96	€ 149	€ 119	€ 105	€ 84
	9	2206B	**Diesel V8 ICE** Conventional Valvetrain Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 8-Speed AT Curb Weight: 2207kg (4866lb)	**Diesel V8 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Large SUV	VW Touareg	€ 192	€ 299	€ 237	€ 209	€ 167

Table D-14: High Pressure, Low Pressure Cooled EGR (Diesel Engine) Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
High Pressure, Cooled Low Pressure EGR	1	2300A	**Diesel I3 ICE** **Cooled High Pressure EGR** Ave. Displacement = 1.0L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Diesel I3 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Subcompact Passenger Vehicle	VW Polo	€ 89	€ 129	€ 102	€ 90	€ 71
	3	2301	**Diesel I4 ICE** **Cooled High Pressure EGR** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 5 or 6 speed MT or DCT Curb Weight: 1271kg (2803lb)	**Diesel I4 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Compact or Small Passenger Vehicle	VW Golf	€ 89	€ 129	€ 102	€ 90	€ 71
	4	2302	**Diesel I4 ICE** **Cooled High Pressure EGR** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1496kg (3299lb)	**Diesel I4 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Midsize Passenger Vehicle	VW Passat	€ 89	€ 129	€ 102	€ 89	€ 71
	5	2303A	**Diesel I4 ICE** **Cooled High Pressure EGR** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I4 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Midsize or Large Passenger Vehicle	VW Sharan	€ 89	€ 129	€ 102	€ 89	€ 71
	6	2303B	**Diesel I6 ICE** **Cooled High Pressure EGR** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I6 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Midsize or Large Passenger Vehicle	VW Sharan	€ 89	€ 129	€ 102	€ 89	€ 71
	7	2305	**Diesel I4 ICE** **Cooled High Pressure EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1590kg (3505lb)	**Diesel I4 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 89	€ 129	€ 102	€ 89	€ 71
	9	2306B	**Diesel V8 ICE** **Cooled High Pressure EGR** Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 8-Speed AT Curb Weight: 2207kg (4866lb)	**Diesel V8 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Large SUV	VW Touareg	€ 88	€ 129	€ 102	€ 89	€ 71

Table D-15: Cooled Low Pressure EGR (Gasoline Engine) Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Gasoline, Cooled Low Pressure EGR (Compared to Uncooled Low Pressure EGR)	1	3100A	**Gasoline I3 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 1.2-1.4L Ave. Power = 74kW (100HP) Ave. Torque = 146N*m (108lb*ft) Typical Transmission Type: 5-Speed MT Curb Weight: 1084kg (2390lb)	**Gasoline I3 ICE Upgraded with Cooled Low Pressure EGR System**	Subcompact Passenger Vehicle	VW Polo	€ 43	€ 59	€ 47	€ 41	€ 34
	3	3101	**Gasoline I4 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 1.4-1.6L Ave. Power = 89kW (121HP) Ave. Torque = 179N*m (132lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1271kg (2803lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Compact or Small Passenger Vehicle	VW Golf	€ 47	€ 64	€ 51	€ 44	€ 37
	4	3102	**Gasoline I4 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 1.6-2.0L Ave. Power = 115kW (157HP) Ave. Torque = 236N*m (174lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1496kg (3299lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Midsize Passenger Vehicle	VW Passat	€ 52	€ 72	€ 57	€ 50	€ 41
	5	3103A	**Gasoline I4 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 65	€ 89	€ 71	€ 62	€ 51
	6	3103B	**Gasoline I6 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 65	€ 89	€ 71	€ 62	€ 51
	7	3105	**Gasoline I4 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 1.2-3.0L Ave. Power = 131 kW (178HP) Ave. Torque = 264N*m (195lb*ft) Typical Transmission Type: 6_Speed MT Curb Weight: 1590kg (3505lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 56	€ 77	€ 61	€ 53	€ 44
	9	3106B	**Gasoline V8 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 3.0-5.5 Ave. Power = 268 kW (364HP) Ave. Torque = 491N*m (362lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 2207kg (4867lb)	**Gasoline V8 ICE Upgraded with Cooled Low Pressure EGR System**	Large SUV	VW Touareg	€ 87	€ 119	€ 94	€ 82	€ 68

Table D-16: Cooled Low Pressure EGR Compared to ICE with No EGR (Gasoline Engine) Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Gasoline, Cooled Low Pressure EGR (Compared to ICE with no EGR)	1	3200A	**Gasoline I3 ICE** **No EGR** Ave. Displacement = 1.2-1.4L Ave. Power = 74kW (100HP) Ave. Torque = 146N*m (108lb*ft) Typical Transmission Type: 5-Speed MT Curb Weight: 1084kg (2390lb)	**Gas I3 ICE** **Upgraded with Cooled Low Pressure EGR System**	Subcompact Passenger Vehicle	VW Polo	€ 74	€ 101	€ 80	€ 70	€ 58
	3	3201	**Gasoline I4 ICE** **No EGR** Ave. Displacement = 1.4-1.6L Ave. Power = 89kW (121HP) Ave. Torque = 179N*m (132lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1271kg (2803lb)	**Gas I4 ICE** **Upgraded with Cooled Low Pressure EGR System**	Compact or Small Passenger Vehicle	VW Golf	€ 77	€ 106	€ 84	€ 73	€ 61
	4	3202	**Gasoline I4 ICE** **No EGR** Ave. Displacement = 1.6-2.0L Ave. Power = 115kW (157HP) Ave. Torque = 236N*m (174lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1496kg (3299lb)	**Gas I4 ICE** **Upgraded with Cooled Low Pressure EGR System**	Midsize Passenger Vehicle	VW Passat	€ 83	€ 114	€ 90	€ 79	€ 66
	5	3203A	**Gasoline I4 ICE** **No EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gas I4 ICE** **Upgraded with Cooled Low Pressure EGR System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 96	€ 131	€ 104	€ 91	€ 76
	6	3203B	**Gasoline I6 ICE** **No EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gas I6 ICE** **Upgraded with Cooled Low Pressure EGR System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 96	€ 131	€ 104	€ 91	€ 76
	7	3205	**Gasoline I4 ICE** **No EGR** Ave. Displacement = 1.2-3.0L Ave. Power = 131 kW (178HP) Ave. Torque = 264N*m (195lb*ft) Typical Transmission Type: 6_Speed MT Curb Weight: 1590kg (3505lb)	**Gas I4 ICE** **Upgraded with Cooled Low Pressure EGR System**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 87	€ 119	€ 94	€ 82	€ 68
	9	3206B	**Gasoline V8 ICE** **No EGR** Ave. Displacement = 3.0-5.5 Ave. Power = 268 kW (364HP) Ave. Torque = 491N*m (362lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 2207kg (4867lb)	**Gas V8 ICE** **Upgraded with Cooled Low Pressure EGR System**	Large SUV	VW Touareg	€ 117	€ 161	€ 127	€ 111	€ 92

Table D-17: 6-Speed Dry Dual Clutch Transmission Case Study Results

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Dry Dual Clutch Transmission	1	2600A	**Diesel I3 ICE** Ave. Displacement = 1.0L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1084kg (2390lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Subcompact Passenger Vehicle	VW Polo	€ 288	€ 442	€ 365	€ 328	€ 232
	3	2601	**Diesel I4 ICE** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1271kg (2803lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Compact or Small Passenger Vehicle	VW Golf	€ 291	€ 447	€ 369	€ 331	€ 235
	4	2602	**Diesel I4 ICE** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1496kg (3299lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Midsize Passenger Vehicle	VW Passat	€ 297	€ 456	€ 376	€ 338	€ 239
	5	2603A	**Diesel I4 ICE** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Midsize or Large Passenger Vehicle	VW Sharan	€ 304	€ 466	€ 385	€ 346	€ 245
	6	2603B	**Diesel I6 ICE** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Midsize or Large Passenger Vehicle	VW Sharan	€ 304	€ 466	€ 385	€ 346	€ 245
	7	2605	**Diesel I4 ICE** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1590kg (3505lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 298	€ 458	€ 378	€ 339	€ 240
	9	2606B	**Diesel V8 ICE** Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 2207kg (4866lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Large SUV	VW Touareg	€ 320	€ 491	€ 405	€ 364	€ 258

Table D-18: Belt-Driven, Starter-Generator (BSG) Start-Stop Hybrid Electric Vehicle Technology

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Start-Stop Hybrid Electric Vehicle Technology	2	3000B	**Gasoline I4 ICE Conventional Powertrain** Ave. Displacement = 1.2-1.4L Ave. Power = 74kW (100HP) Ave. Torque = 146N*m (108lb*ft) Typical Transmission Type: 5-Speed MT Curb Weight: 1084kg (2390lb)	**Gasoline I4 ICE, Manual Transmission, upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Subcompact Passenger Vehicle	VW Polo	€ 298	€ 580	€ 359	€ 316	€ 240
	3	3001	**Gasoline I4 ICE Conventional Powertrain** Ave. Displacement = 1.4-1.6L Ave. Power = 89kW (121HP) Ave. Torque = 179N*m (132lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1271kg (2803lb)	**Gasoline I4 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Compact or Small Passenger Vehicle	VW Golf	€ 311	€ 604	€ 374	€ 329	€ 250
	4	3002	**Gasoline I4 ICE Conventional Powertrain** Ave. Displacement = 1.6-2.0L Ave. Power = 115kW (157HP) Ave. Torque = 236N*m (174lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1496kg (3299lb)	**Gasoline I4 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Midsize Passenger Vehicle	VW Passat	€ 329	€ 640	€ 396	€ 349	€ 265
	6	3003B	**Gasoline I6 ICE Conventional Powertrain** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gasoline I6 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Midsize or Large Passenger Vehicle	VW Sharan	€ 352	€ 684	€ 423	€ 373	€ 283
	7	3005	**Gasoline I4 ICE Conventional Powertrain** Ave. Displacement = 1.2-3.0L Ave. Power = 131 kW (178HP) Ave. Torque = 264N*m (195lb*ft) Typical Transmission Type: 6_Speed **MT** Curb Weight: 1590kg (3505lb)	**Gasoline I4 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 337	€ 656	€ 406	€ 357	€ 272
	9	3006B	**Gasoline V8 ICE Conventional Powertrain** Ave. Displacement = 3.0-5.5 Ave. Power = 268 kW (364HP) Ave. Torque = 491N*m (362lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 2207kg (4867lb)	**Gasoline V8 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Large SUV	VW Touareg	€ 449	€ 874	€ 540	€ 476	€ 362

E. Phase 1 and Phase 2 Case Study Results Reevaluated With Average Eastern Europe Labor Rate Assumption

As discussed in **Section B.1.2**, all case studies, originally evaluated in Phase 1 and Phase 2, were reevaluated with a reduced labor rate assumption. The labor rate reduction was based on an average Eastern Europe reduction relative to Germany. In Sections **D.1** and **D.2**, the Phase 1 and Phase 2 results have been modified to account for the labor rate reduction.

E.1 Phase 1 Technologies Evaluated with Eastern Europe Labor Rate Assumption

A summary of the baseline and new technology configurations evaluated in the Phase 1, updated with the Eastern Europe labor rate assumption, is summarized below in **Table E-1**. The table, similar to the one found in **Section D.1**, has been modified with the new Cost Summary Table references.

Table E-1: Advance Powertrain Technologies, Evaluated in the Phase 1 Analysis, with Eastern Europe Labor Rate Assumption

Case Study ID	Baseline Technology Configuration	New Technology Configuration	Cost Summary Table
01**	Naturally Aspirated (NA), Port Fuel Injected (PFI), Gasoline Internal Combustion Engine (ICE)	Downsized (DS), Turbocharged (Turbo), Direct Injection (DI) Gasoline Internal Combustion Engine (ICE)	E-2
02**	Dual Overhead Cam (DOHC), NA, PFI, Dual-Variable Valve Timing (D-VVT), Gasoline ICE	Single Overhead Cam (SOHC), NA, PFI, Multi-Air Variable Valve Timing and Lift (VVTL), Gasoline ICE	E-2
08**	5-Speed Automatic Transmission	6-Speed Automatic Transmission	E-3
10**	6-Speed Automatic Transmission	8-Speed Automatic Transmission	E-3
09**	6-Speed Automatic Transmission	6-Speed Dual Clutch Transmission	E-3
04**	Conventional Powertrain Vehicle	Conventional Powertrain Vehicle Upgraded with a Belt Alternator Starter (BAS) Start-Stop System	E-4
05**	Conventional Powertrain Vehicle	Power-Split Hybrid Electric Vehicle	E-5
07**	Conventional Powertrain Vehicle	P2 Hybrid Electric Vehicle	E-6
06**	Mechanical Air Conditioning Compressor System	Electical Air Conditioning Compressor System	E-7

Table E-2: Downsized, Turbocharged, Direct Injection Gasoline Engine & Multi-Air Variable Valve Timing and Lift Valvetrain Subsystem Case Study Results
***** Eastern Europe Labor Rate Substitution *****

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Engine	Downsized, Turbocharged, Gasoline Direct Injection Internal Combustion Engines										
	1	0100	1.4L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.0L, I3, 4V, DOHC, Turbo, GDI, dVVT, ICE	Subcompact Passenger Vehicle	VW Polo	€ 169	€ 304	€ 231	€ 191	€ 121
	2	0101	1.6L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.2L, I4, 4V, DOHC, Turbo, GDI, dVVT, ICE	Compact or Small Passenger Vehicle	VW Golf	€ 265	€ 370	€ 305	€ 269	€ 210
	3	0102	2.4L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.6L, I4, 4V, DOHC, Turbo, GDI, dVVT, ICE	Midsize Passenger Vehicle	VW Passat	€ 307	€ 438	€ 359	€ 315	€ 241
	4	0103	3.0L, V6, 4V, DOHC, NA, PFI, dVVT, ICE	2.0L, I4, 4V, DOHC, Turbo, GDI, dVVT, ICE	Midsize or Large Passenger Vehicle	VW Sharan	€ 33	€ 306	€ 175	€ 105	-€ 25
	5	0106	5.4L, V8, 3V, SOHC, NA, PFI, sVVT, ICE	3.5L V6, 4V, DOHC, Turbo, GDI, dVVT, ICE	Large SUV	VW Touareg	€ 532	€ 799	€ 643	€ 557	€ 410
	Variable Valve Timing and Lift, Fiat Multiair System										
	6	0200	1.4L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.4L, I4, 4V-MultiAir, SOHC, NA, PFI, ICE	Subcompact Passenger Vehicle	VW Polo	€ 87	€ 132	€ 107	€ 94	€ 75

Table E-3: 6-Speed Automatic Transmission, 8-Speed Automatic Transmission, and 6-Speed Wet Dual Clutch Transmission Case Study Results
***** Eastern Europe Labor Rate Substitution *****

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Transmissions	1	0802	5-Speed AT	6-Speed AT	Midsize or Large Passenger Vehicle	VW Sharan	(€ 64)	(€ 32)	(€ 43)	(€ 47)	(€ 60)
	2	0803	6-Speed AT	8-Speed AT	Large SUV	VW Touareg	€ 44	€ 68	€ 54	€ 48	€ 35
	3	0902	6-Speed AT	6-Speed Wet DCT	Midsize or Large Passenger Vehicle	VW Sharan	(€ 60)	(€ 16)	(€ 29)	(€ 38)	(€ 54)

Table E-4: Belt Alternator Starter (BAS) Start-Stop System Case Study Results
*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Start-Stop HEV	1	0402	Conventional Powertrain >I4 Gasoline ICE, 4V, DOHC, NA, PFI, VVT >4-Speed AT	Belt Alternator Starter (BAS) - HEV (Brake Regen & Launch Assist) >I4 Gasoline ICE, 4V, DOHC, NA, PFI, VVT >4-Speed AT >Electric Generator/Starter 14.5kW >Battery: 36V, 18.4Ah NiMH	Midsize	VW Passat	€ 951	€ 1,851	€ 1,144	€ 1,008	€ 767

Table E-5: Power-Split Hybrid Electric Vehicle Case Study Results
*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Power-Split HEV	1	0500	Subcompact car typically powered by an inline 4 cylinder engine, naturally aspirated, port fuel injection, 5-speed manual transmission (MT).	Power-split HEV System Power: 74.7kW ICE Power: 61.1kW (I4 -> I3) Traction Motor: 50kW Generator: 35.1kW Li-Ion Battery: 140V, 0.743kWh	Subcompact	VW Polo	€ 1,556	€ 2,476	€ 1,631	€ 1,072	€ 733
								€ 1,542	€ 1,271	€ 1,077	€ 767
								€ 4,019	€ 2,902	€ 2,149	€ 1,500
	2	0501	Compact or small car typically powered by an inline 4 cylinder engine, naturally aspirated, port fuel injection, 6-speed manual transmission or 7-speed dual clutch transmission (DCT).	Power-split HEV System Power: 90kW ICE Power: 73.6kW (I4 - DS I4) Traction Motor: 60.2kW Generator: 42.3kW Li-Ion Battery: 162V, 0.857kWh	Compact/ Small	VW Golf	€ 1,732	€ 2,744	€ 1,807	€ 1,188	€ 812
								€ 1,722	€ 1,419	€ 1,202	€ 856
								€ 4,466	€ 3,227	€ 2,390	€ 1,669
	3	0502	A midsize passenger car typically powered by a 4 cylinder turbocharged, direct fuel injection, 6-speed MT and AT or 7-speed DCT, Start/Stop system.	Power-split HEV System Power: 117kW ICE Power: 95.6kW (I4 -> DS I4) Traction Motor: 78.3kW Generator: 55kW Li-Ion Battery: 188V, 0.994kWh	Midsize	VW Passat	€ 1,905	€ 3,057	€ 2,014	€ 1,323	€ 905
								€ 1,876	€ 1,547	€ 1,310	€ 933
								€ 4,933	€ 3,560	€ 2,633	€ 1,838
	4	5403	A midsize or large passenger car typically powered by 4 and 6 cylinder turbocharged, direct fuel injection, 6-speed MT or ≥ 6 speed AT.	Power-split HEV System Power: 174.8kW ICE Power: 142.8kW (V6 -> I4) Traction Motor: 116.9kW Generator: 82.1kW Li-Ion Battery: 211V, 1.118kWh	Midsize/Large	VW Sharan	€ 1,861	€ 3,325	€ 2,190	€ 1,439	€ 984
								€ 1,679	€ 1,384	€ 1,172	€ 835
								€ 5,003	€ 3,574	€ 2,611	€ 1,819
	5	0505	A small or mid-sized sports-utility or cross-over vehicle, or a small-midsize SUV, or a Mini Van powered by a 4 cylinder turbocharged engine, direct fuel injection, 6-speed MT or AT & 7 DCT.	Power-split HEV System Power: 132.6kW ICE Power: 108.3kW (I4 -> DS I4) Traction Motor: 88.7kW Generator: 62.2kW Li-Ion Battery: 199V, 1.053 kWh	Small/Midsize SUV/COV	VW Tiguan	€ 1,996	€ 3,186	€ 2,099	€ 1,380	€ 943
								€ 1,973	€ 1,626	€ 1,377	€ 981
								€ 5,160	€ 3,726	€ 2,757	€ 1,925
	6	n/a	Large sports-utility vehicles, typically powered by a 8 cylinder naturally aspirated engine, direct fuel injection, ≥ 6-speed AT.	n/a	Large SUV	VW Touareg	n/a	---	---	---	---
								---	---	---	---
								---	---	---	---

Table E-6: P2 Hybrid Electric Vehicle Case Study Results

*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
P2 HEV	1	0700	Subcompact car typically powered by an inline 4 cylinder engine, naturally aspirated, port fuel injection, 5-speed manual transmission (MT).	P2 HEV System Power: 74.7kW ICE Power: 59.8kW (I4 -> I3) Traction Motor: 14.9kW Li-Ion Battery: 140V, 0.743kWh	Subcompact	VW Polo	€ 1,467	€ 2,390	€ 1,547	€ 1,041	€ 710
								€ 1,284	€ 1,042	€ 932	€ 662
								€ 3,674	€ 2,589	€ 1,972	€ 1,372
	2	0701	Compact or small car typically powered by an inline 4 cylinder engine, naturally aspirated, port fuel injection, 6-speed manual transmission or 7-speed dual clutch transmission (DCT).	P2 HEV System Power: 90kW ICE Power: 72kW (I4 -> DS I4) Traction Motor: 18kW Li-Ion Battery: 162V, 0.857kWh	Compact/ Small	VW Golf	€ 1,637	€ 2,648	€ 1,714	€ 1,153	€ 786
								€ 1,441	€ 1,169	€ 1,046	€ 744
								€ 4,089	€ 2,884	€ 2,199	€ 1,530
	3	0702	A midsize passenger car typically powered by a 4 cylinder turbocharged, direct fuel injection, 6-speed MT and AT or 7-speed DCT, Start/Stop system.	P2 HEV System Power: 117kW ICE Power: 93.6kW (I4 -> DS I4) Traction Motor: 23.4kW Li-Ion Battery: 188V, 0.994kWh	Midsize	VW Passat	€ 1,777	€ 2,951	€ 1,910	€ 1,285	€ 876
								€ 1,530	€ 1,242	€ 1,111	€ 790
								€ 4,481	€ 3,152	€ 2,396	€ 1,666
	4	0703	A midsize or large passenger car typically powered by 4 and 6 cylinder turbocharged, direct fuel injection, 6-speed MT or ≥ 6 speed AT.	P2 HEV System Power: 174.8kW ICE Power: 139.9kW (V6 -> I4) Traction Motor: 35.0W Li-Ion Battery: 211V, 1.118 kWh	Midsize/Large	VW Sharan	€ 1,628	€ 3,209	€ 2,077	€ 1,398	€ 953
								€ 1,181	€ 959	€ 857	€ 610
								€ 4,390	€ 3,036	€ 2,255	€ 1,563
	5	0705	A small or mid-sized sports-utility or cross-over vehicle, or a small-midsize SUV, or a Mini Van powered by a 4 cylinder turbocharged engine, direct fuel injection, 6-speed MT or AT & 7 DCT.	P2 HEV System Power: 132.6kW ICE Power: 106.1kW (I4 -> DS I4) Traction Motor: 26.5kW Li-Ion Battery: 199V, 1.053kWh	Small/Midsize SUV/COV	VW Tiguan	€ 1,848	€ 3,076	€ 1,991	€ 1,339	€ 913
								€ 1,588	€ 1,289	€ 1,153	€ 820
								€ 4,664	€ 3,280	€ 2,492	€ 1,733
	6	0706	Large sports-utility vehicles, typically powered by a 8 cylinder naturally aspirated engine, direct fuel injection, ≥ 6-speed AT.	P2 HEV System Power: 271.8kW ICE Power: 271.8 kW (No Change to V8) Traction Motor: 54.3 kW Li-Ion Battery: 269V, 1.427kWh	Large SUV	VW Touareg	€ 2,345	€ 3,890	€ 2,518	€ 1,694	€ 1,155
								€ 2,021	€ 1,640	€ 1,467	€ 1,043
								€ 5,911	€ 4,158	€ 3,161	€ 2,198

Table E-7: Electrical Air Conditioning Compressor Case Study Results

*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Electrical Air Conditioning Compressor Subsystem	1	0600	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Subcompact	VW Polo	€ 100	€ 158	€ 128	€ 115	€ 81
	2	0601	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Compact/ Small	VW Golf	€ 103	€ 164	€ 133	€ 119	€ 84
	3	0602	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Midsize	VW Passat	€ 109	€ 172	€ 140	€ 125	€ 89
	4	0603	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Midsize/Large	VW Sharan	€ 113	€ 179	€ 145	€ 130	€ 92
	5	0605	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Small/Midsize SUV/COV	VW Tiguan	€ 115	€ 182	€ 148	€ 132	€ 94
	6	0606	Mechanical Air Conditioning Compressor Subsystem	Electrical Air Conditioning Compressor Subsystem	Large SUV	VW Touareg	€ 132	€ 209	€ 170	€ 152	€ 108

E.2 Phase 2 Technologies Evaluated

A summary of the baseline and new technology configurations evaluated in the Phase 2, updated with the Eastern Europe labor rate assumption, is summarized below in **Table E-8**. The table, similar to the one found in **Section D.2**, has been modified with the new Cost Summary Table references.

Table E-8: Advance Powertrain Technologies, Evaluated in the Phase 2 Analysis, with Eastern Europe Labor Rate Assumption

Case Study ID	Baseline Technology Configuration	New Technology Configuration	Cost Summary Table
20**	Conventional Diesel Engine	Downsized Conventional Diesel Engine (e.g. I4-I3, I6-I4, V8-I6)	E-9
21**	Conventional Diesel Engine with 1800 Bar Fuel Injection Subsystem	Conventional Diesel Engine Upgraded with 2500 Bar Fuel Injection Subsystem	E-10
22**	Diesel Engine with Conventional Valvetrain Subsystem	Diesel Engine Upgraded with Discrete Variable Valve Timing and Lift (VVTL) Valvetrain subsystem	E-11
23**	Conventional Diesel Engine with a Cooled High Pressure Exhaust Gas Recirculation (EGR) Subsystem	Conventional Diesel Engine Upgraded with a High Pressure, Low Pressure Cooled High EGR Subsystem	E-12
31**	Conventional Gasoline Engine with a Uncooled Low Pressure EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem	E-13
32**	Conventional Gasoline Engine with no EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem	E-14
26**	6-Speed Manual Transmission	6-Speed Dry Dual Clutch Transmission (DCT)	E-15
30**	Conventional Powertrain Vehicle (Manual Transmission)	Conventional Powertrain Vehicle ((Manual Transmission) Upgraded with a Belt-Driven Starter Generator (BSG) Start-Stop System	E-16

Table E-9: Diesel Engine Downsizing Case Studies

*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Diesel Engine Downsizing	2	2000B	**Diesel I4 ICE** Ave. Displacement = 1.2-1.4L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Subcompact Passenger Vehicle	VW Polo	(€ 229)	(€ 101)	(€ 140)	(€ 154)	(€ 212)
	3	2001	**Diesel I4 ICE** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 5 or 6 speed MT or DCT Curb Weight: 1271kg (2803lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Compact or Small Passenger Vehicle	VW Golf	(€ 234)	(€ 103)	(€ 143)	(€ 157)	(€ 217)
	4	2002	**Diesel I4 ICE** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1496kg (3299lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Midsize Passenger Vehicle	VW Passat	(€ 245)	(€ 108)	(€ 149)	(€ 165)	(€ 227)
	5	2003A	**Diesel I4 ICE** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Midsize or Large Passenger Vehicle	VW Sharan	(€ 245)	(€ 108)	(€ 149)	(€ 165)	(€ 227)
	6	2003B	**Diesel I6 ICE** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Downsized to Diesel I4 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Midsize or Large Passenger Vehicle	VW Sharan	(€ 354)	(€ 156)	(€ 215)	(€ 238)	(€ 327)
	7	2005	**Diesel I4 ICE** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1590kg (3505lb)	**Downsized to Diesel I3 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	(€ 245)	(€ 108)	(€ 149)	(€ 165)	(€ 227)
	9	2006B	**Diesel V8 ICE** Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 8-Speed AT Curb Weight: 2207kg (4866lb)	**Downsized to Diesel I6 ICE with same per Cylinder Displacement as Baseline Technology Configuration**	Large SUV	VW Touareg	(€ 357)	(€ 157)	(€ 217)	(€ 240)	(€ 331)

Table E-10: 2500 Bar Diesel Fuel Injection System Case Study Results

*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
High Pressure Fuel Injection, Diesel Engine	1	2100A	**Diesel I3 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 1.0L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Diesel I3 ICE** **Upgraded to 2500 Bar Fuel Injection System**	Subcompact Passenger Vehicle	VW Polo	€ 8	€ 10	€ 8	€ 7	€ 6
	2	2100B	**Diesel I4 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 1.2-1.4L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Diesel I4 ICE** **Upgraded to 2500 Bar Fuel Injection System**	Subcompact Passenger Vehicle	VW Polo	€ 11	€ 14	€ 11	€ 10	€ 8
	3	2101	**Diesel I4 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 5 or 6 speed MT or DCT Curb Weight: 1271kg (2803lb)	**Diesel I4 ICE** **Upgraded to 2500 Bar Fuel Injection System**	Compact or Small Passenger Vehicle	VW Golf	€ 11	€ 14	€ 11	€ 10	€ 8
	4	2102	**Diesel I4 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1496kg (3299lb)	**Diesel I4 ICE** **Upgraded to 2500 Bar Fuel Injection System**	Midsize Passenger Vehicle	VW Passat	€ 11	€ 14	€ 11	€ 10	€ 8
	6	2103B	**Diesel I6 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I6 ICE** **Upgraded to 2500 Bar Fuel Injection System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 16	€ 21	€ 16	€ 15	€ 12
	7	2105	**Diesel I4 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1590kg (3505lb)	**Diesel I4 ICE** **Upgraded to 2500 Bar Fuel Injection System**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 11	€ 14	€ 11	€ 10	€ 8
	9	2106B	**Diesel V8 ICE** **1800 Bar Fuel Injection System** Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 8-Speed AT Curb Weight: 2207kg (4866lb)	**Diesel V8 ICE** **Upgraded to 2500 Bar Fuel Injection System**	Large SUV	VW Touareg	€ 21	€ 28	€ 22	€ 20	€ 16

Table E-11: Discrete Variable Valve Lift and Timing Valvetrain (Diesel Engine) Case Study Results

***** Eastern Europe Labor Rate Substitution *****

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Variable Valve Timing and Lift	1	2200A	**Diesel I3 ICE** **Conventional Valvetrain** Ave. Displacement = 1.0L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Diesel I3 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Subcompact Passenger Vehicle	VW Polo	€ 72	€ 107	€ 98	€ 85	€ 79
	3	2201	**Diesel I4 ICE** **Conventional Valvetrain** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 5 or 6 speed MT or DCT Curb Weight: 1271kg (2803lb)	**Diesel I4 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Compact or Small Passenger Vehicle	VW Golf	€ 78	€ 116	€ 105	€ 92	€ 85
	4	2202	**Diesel I4 ICE** **Conventional Valvetrain** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1496kg (3299lb)	**Diesel I4 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Midsize Passenger Vehicle	VW Passat	€ 78	€ 116	€ 105	€ 92	€ 85
	5	2203A	**Diesel I4 ICE** **Conventional Valvetrain** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I4 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Midsize or Large Passenger Vehicle	VW Sharan	€ 78	€ 116	€ 105	€ 92	€ 85
	6	2203B	**Diesel I6 ICE** **Conventional Valvetrain** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I6 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Midsize or Large Passenger Vehicle	VW Sharan	€ 91	€ 135	€ 123	€ 107	€ 99
	7	2205	**Diesel I4 ICE** **Conventional Valvetrain** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1590kg (3505lb)	**Diesel I4 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 78	€ 116	€ 105	€ 92	€ 85
	9	2206B	**Diesel V8 ICE** Conventional Valvetrain Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 8-Speed AT Curb Weight: 2207kg (4866lb)	**Diesel V8 ICE Upgraded with Discrete Variable Valve Timing and Lift**	Large SUV	VW Touareg	€ 155	€ 231	€ 211	€ 184	€ 170

Table E-12: High Pressure, Low Pressure Cooled EGR (Diesel Engine) Case Study Results
*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
High Pressure, Cooled Low Pressure EGR	1	2300A	**Diesel I3 ICE** **Cooled High Pressure EGR** Ave. Displacement = 1.0L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 5-Speet MT Curb Weight: 1084kg (2390lb)	**Diesel I3 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Subcompact Passenger Vehicle	VW Polo	€ 72	€ 104	€ 82	€ 72	€ 57
	3	2301	**Diesel I4 ICE** **Cooled High Pressure EGR** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 5 or 6 speed MT or DCT Curb Weight: 1271kg (2803lb)	**Diesel I4 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Compact or Small Passenger Vehicle	VW Golf	€ 72	€ 104	€ 82	€ 72	€ 57
	4	2302	**Diesel I4 ICE** **Cooled High Pressure EGR** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1496kg (3299lb)	**Diesel I4 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Midsize Passenger Vehicle	VW Passat	€ 72	€ 104	€ 82	€ 72	€ 57
	5	2303A	**Diesel I4 ICE** **Cooled High Pressure EGR** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I4 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Midsize or Large Passenger Vehicle	VW Sharan	€ 72	€ 104	€ 82	€ 72	€ 57
	6	2303B	**Diesel I6 ICE** **Cooled High Pressure EGR** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT or DCT, or 8-Speed AT Curb Weight: 1700kg (3749lb)	**Diesel I6 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Midsize or Large Passenger Vehicle	VW Sharan	€ 72	€ 104	€ 82	€ 72	€ 57
	7	2305	**Diesel I4 ICE** **Cooled High Pressure EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT or 8-Speed AT Curb Weight: 1590kg (3505lb)	**Diesel I4 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 72	€ 104	€ 82	€ 72	€ 57
	9	2306B	**Diesel V8 ICE** **Cooled High Pressure EGR** Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 8-Speed AT Curb Weight: 2207kg (4866lb)	**Diesel V8 ICE** **Upgrade with High Pressure, Cooled Low Pressure EGR**	Large SUV	VW Touareg	€ 72	€ 104	€ 82	€ 72	€ 57

Table E-13: Cooled Low Pressure EGR (Gasoline Engine) Case Study Results
*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Gasoline, Cooled Low Pressure EGR (Compared to Uncooled Low Pressure EGR)	1	3100A	**Gasoline I3 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 1.2-1.4L Ave. Power = 74kW (100HP) Ave. Torque = 146N*m (108lb*ft) Typical Transmission Type: 5-Speed MT Curb Weight: 1084kg (2390lb)	**Gasoline I3 ICE Upgraded with Cooled Low Pressure EGR System**	Subcompact Passenger Vehicle	VW Polo	€ 35	€ 48	€ 38	€ 33	€ 28
	3	3101	**Gasoline I4 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 1.4-1.6L Ave. Power = 89kW (121HP) Ave. Torque = 179N*m (132lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1271kg (2803lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Compact or Small Passenger Vehicle	VW Golf	€ 38	€ 52	€ 41	€ 36	€ 30
	4	3102	**Gasoline I4 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 1.6-2.0L Ave. Power = 115kW (157HP) Ave. Torque = 236N*m (174lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1496kg (3299lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Midsize Passenger Vehicle	VW Passat	€ 42	€ 58	€ 46	€ 40	€ 33
	5	3103A	**Gasoline I4 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 53	€ 72	€ 57	€ 50	€ 41
	6	3103B	**Gasoline I6 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 53	€ 72	€ 57	€ 50	€ 41
	7	3105	**Gasoline I4 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 1.2-3.0L Ave. Power = 131 kW (178HP) Ave. Torque = 264N*m (195lb*ft) Typical Transmission Type: 6_Speed MT Curb Weight: 1590kg (3505lb)	**Gasoline I4 ICE Upgraded with Cooled Low Pressure EGR System**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 45	€ 62	€ 49	€ 43	€ 36
	9	3106B	**Gasoline V8 ICE** **Uncooled Low Pressure EGR** Ave. Displacement = 3.0-5.5 Ave. Power = 268 kW (364HP) Ave. Torque = 491N*m (362lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 2207kg (4867lb)	**Gasoline V8 ICE Upgraded with Cooled Low Pressure EGR System**	Large SUV	VW Touareg	€ 87	€ 119	€ 94	€ 82	€ 68

Table E-14: Cooled Low Pressure EGR Compared to ICE with No EGR (Gasoline Engine) Case Study Results

*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Gasoline, Cooled Low Pressure EGR (Compared to ICE with no EGR)	1	3200A	**Gasoline I3 ICE** **No EGR** Ave. Displacement = 1.2-1.4L Ave. Power = 74kW (100HP) Ave. Torque = 146N*m (108lb*ft) Typical Transmission Type: 5-Speed MT Curb Weight: 1084kg (2390lb)	**Gas I3 ICE Upgraded with Cooled Low Pressure EGR System**	Subcompact Passenger Vehicle	VW Polo	€ 60	€ 82	€ 65	€ 57	€ 47
	3	3201	**Gasoline I4 ICE** **No EGR** Ave. Displacement = 1.4-1.6L Ave. Power = 89kW (121HP) Ave. Torque = 179N*m (132lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1271kg (2803lb)	**Gas I4 ICE Upgraded with Cooled Low Pressure EGR System**	Compact or Small Passenger Vehicle	VW Golf	€ 62	€ 86	€ 68	€ 59	€ 49
	4	3202	**Gasoline I4 ICE** **No EGR** Ave. Displacement = 1.6-2.0L Ave. Power = 115kW (157HP) Ave. Torque = 236N*m (174lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1496kg (3299lb)	**Gas I4 ICE Upgraded with Cooled Low Pressure EGR System**	Midsize Passenger Vehicle	VW Passat	€ 67	€ 92	€ 73	€ 64	€ 53
	5	3203A	**Gasoline I4 ICE** **No EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gas I4 ICE Upgraded with Cooled Low Pressure EGR System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 77	€ 106	€ 84	€ 73	€ 61
	6	3203B	**Gasoline I6 ICE** **No EGR** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gas I6 ICE Upgraded with Cooled Low Pressure EGR System**	Midsize or Large Passenger Vehicle	VW Sharan	€ 77	€ 106	€ 84	€ 73	€ 61
	7	3205	**Gasoline I4 ICE** **No EGR** Ave. Displacement = 1.2-3.0L Ave. Power = 131 kW (178HP) Ave. Torque = 264N*m (195lb*ft) Typical Transmission Type: 6_Speed MT Curb Weight: 1590kg (3505lb)	**Gas I4 ICE Upgraded with Cooled Low Pressure EGR System**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 70	€ 96	€ 76	€ 66	€ 55
	9	3206B	**Gasoline V8 ICE** **No EGR** Ave. Displacement = 3.0-5.5 Ave. Power = 268 kW (364HP) Ave. Torque = 491N*m (362lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 2207kg (4867lb)	**Gas V8 ICE Upgraded with Cooled Low Pressure EGR System**	Large SUV	VW Touareg	€ 95	€ 130	€ 103	€ 90	€ 75

Table E-15: 6-Speed Dry Dual Clutch Transmission Case Study Results

*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC)			
								2012	2016	2020	2025
Dry Dual Clutch Transmission	1	2600A	**Diesel I3 ICE** Ave. Displacement = 1.0L Ave. Power = 62.5kW (85HP) Ave. Torque = 201N*m (148lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1084kg (2390lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Subcompact Passenger Vehicle	VW Polo	€ 233	€ 357	€ 295	€ 265	€ 188
	3	2601	**Diesel I4 ICE** Ave. Displacement = 1.6L Ave. Power = 78.6kW (107HP) Ave. Torque = 246N*m (181lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1271kg (2803lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Compact or Small Passenger Vehicle	VW Golf	€ 235	€ 361	€ 298	€ 268	€ 190
	4	2602	**Diesel I4 ICE** Ave. Displacement = 2.0L Ave. Power = 104kW (141HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1496kg (3299lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Midsize Passenger Vehicle	VW Passat	€ 240	€ 369	€ 304	€ 273	€ 193
	5	2603A	**Diesel I4 ICE** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Midsize or Large Passenger Vehicle	VW Sharan	€ 246	€ 377	€ 311	€ 279	€ 198
	6	2603B	**Diesel I6 ICE** Ave. Displacement = 2.0L Ave. Power = 148.5W (202HP) Ave. Torque = 416N*m (306lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Midsize or Large Passenger Vehicle	VW Sharan	€ 246	€ 377	€ 311	€ 279	€ 198
	7	2605	**Diesel I4 ICE** Ave. Displacement = 2.0-3.0L Ave. Power = 117.6W (160HP) Ave. Torque = 336N*m (248lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1590kg (3505lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 241	€ 370	€ 305	€ 274	€ 194
	9	2606B	**Diesel V8 ICE** Ave. Displacement = 3.0 -4.2L Ave. Power = 213kW (290HP) Ave. Torque = 623N*m (460lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 2207kg (4866lb)	**Upgrade with 6-Speed Dry Dual Clutch Tranmission**	Large SUV	VW Touareg	€ 258	€ 397	€ 327	€ 294	€ 208

Table E-16: Belt-Driven, Starter-Generator (BSG) Start-Stop Hybrid Electric
*** Eastern Europe Labor Rate Substitution ***

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Net Incremental Direct Manufacturing Cost (NIDMC)	Net Incremental Technology Cost (NITC) 2012	2016	2020	2025
Start-Stop Hybrid Electric Vehicle Technology	2	3000B	**Gasoline I4 ICE Conventional Powertrain** Ave. Displacement = 1.2-1.4L Ave. Power = 74kW (100HP) Ave. Torque = 146N*m (108lb*ft) Typical Transmission Type: 5-Speed MT Curb Weight: 1084kg (2390lb)	**Gasoline I4 ICE, Manual Transmission, upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Subcompact Passenger Vehicle	VW Polo	€ 241	€ 469	€ 290	€ 255	€ 194
	3	3001	**Gasoline I4 ICE Conventional Powertrain** Ave. Displacement = 1.4-1.6L Ave. Power = 89kW (121HP) Ave. Torque = 179N*m (132lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1271kg (2803lb)	**Gasoline I4 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Compact or Small Passenger Vehicle	VW Golf	€ 251	€ 488	€ 302	€ 266	€ 202
	4	3002	**Gasoline I4 ICE Conventional Powertrain** Ave. Displacement = 1.6-2.0L Ave. Power = 115kW (157HP) Ave. Torque = 236N*m (174lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1496kg (3299lb)	**Gasoline I4 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Midsize Passenger Vehicle	VW Passat	€ 266	€ 517	€ 320	€ 282	€ 214
	6	3003B	**Gasoline I6 ICE Conventional Powertrain** Ave. Displacement = 2.0-3.0L Ave. Power = 172kW (234HP) Ave. Torque = 321N*m (237lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 1700kg (3749lb)	**Gasoline I6 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Midsize or Large Passenger Vehicle	VW Sharan	€ 284	€ 553	€ 342	€ 301	€ 229
	7	3005	**Gasoline I4 ICE Conventional Powertrain** Ave. Displacement = 1.2-3.0L Ave. Power = 131 kW (178HP) Ave. Torque = 264N*m (195lb*ft) Typical Transmission Type: 6_Speed **MT** Curb Weight: 1590kg (3505lb)	**Gasoline I4 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Small or Midsize SUV/COV or Mini Van	VW Tiguan	€ 273	€ 530	€ 328	€ 289	€ 220
	9	3006B	**Gasoline V8 ICE Conventional Powertrain** Ave. Displacement = 3.0-5.5 Ave. Power = 268 kW (364HP) Ave. Torque = 491N*m (362lb*ft) Typical Transmission Type: 6-Speed MT Curb Weight: 2207kg (4867lb)	**Gasoline V8 ICE, Manual Transmission, Upgraded with Belt-Driven, Starter-Generator (BSG) System.**	Large SUV	VW Touareg	€ 363	€ 707	€ 437	€ 385	€ 293

E.3 Eastern Europe Labor Rate Sensitivity Analysis Comparison

In summary, a 77% percent labor rate reduction in the Phase 1 and Phase 2 analyses resulted in a Net Incremental Technology Cost change for most studies in the 15-20% range. The reduction in the labor rate had essentially the same impact to NITCs for the studies initially completed with the EPA NA ICMs and subsequently with the FEV EU ICMs. The average difference for each technology configuration evaluated in the Phase 1 and Phase 2 analysis, is shown below in **Table E-17** and **Table E-18,** respectively. The percent difference for each technology configuration is directly related to the labor contribution in the total manufacturing cost (i.e., total manufacturing cost = material + labor + manufacturing overhead) and associated mark-ups, a factor of the total manufacturing cost. For technologies where labor contribution was low comparatively to the material contribution, the effect of the lower labor rate was minimal. For example in the mechanical versus electrical air conditioning compressor analysis, the cost of the more traditional compressor components (e.g. housings, shafts, fasteners, seals, etc.) were cost neutral in comparison. The added incremental costs were largely associated with low and high voltage electronic components and assemblies with significant material costs. In the cost models, material costs include raw materials and commodity purchased component costs (e.g., circuit boards, passive electronic components, active electronics components).

Table E-17: Average Percent Reduction in Net Incremental Technology Costs with Average Labor Rate reduced by 77%, Phase 1 Technology Configurations

Case Study ID	Baseline Technology Configuration	New Technology Configuration	Average NITC Reduction Assuming Average Eastern European Labor Rate	Average Percent NITC Reduction Assuming Average Eastern European Labor Rate
01**	Naturally Aspirated (NA), Port Fuel Injected (PFI), Gasoline Internal Combustion Engine (ICE)	Downsized (DS), Turbocharged (Turbo), Direct Injection (DI) Gasoline Internal Combustion Engine (ICE)	€ 85	20.9%
02**	Dual Overhead Cam (DOHC), NA, PFI, Dual-Variable Valve Timing (D-VVT), Gasoline ICE	Single Overhead Cam (SOHC), NA, PFI, Multi-Air Variable Valve Timing and Lift (VVTL), Gasoline ICE	€ 24	18.8%
08**	5-Speed Automatic Transmission	6-Speed Automatic Transmission	-€ 11	-19.1%
10**	6-Speed Automatic Transmission	8-Speed Automatic Transmission	€ 9	15.6%
09**	6-Speed Automatic Transmission	6-Speed Dual Clutch Transmission	-€ 13	-28.0%
04**	Conventional Powertrain Vehicle	Conventional Powertrain Vehicle Upgraded with a Belt Alternator Starter (BAS) Start-Stop System	€ 282	19.1%
05**	Conventional Powertrain Vehicle	Power-Split Hybrid Electric Vehicle	€ 556	15.1%
07**	Conventional Powertrain Vehicle	P2 Hybrid Electric Vehicle	€ 506	14.4%
06**	Mechanical Air Conditioning Compressor System	Electrical Air Conditioning Compressor System	€ 3	2.3%

Notes: [1] Negative percentage indicates reduced savings as the base technology is less expensive to manufacture in the low cost country (i.e., Eastern Europe)

Table E-18: Average Percent Reduction in Net Incremental Technology Costs with Average Labor Rate reduced by 77%, Phase 2 Technology Configurations

Case Study ID	Baseline Technology Configuration	New Technology Configuration	Average NITC Reduction Assuming Average Eastern European Labor Rate	Average Percent NITC Reduction Assuming Average Eastern European Labor Rate
20**	Conventional Diesel Engine	Downsized Conventional Diesel Engine (e.g. I4-I3, I6-I4, V8-I6)	-€ 43	-19.2%
21**	Conventional Diesel Engine with 1800 Bar Fuel Injection Subsystem	Conventional Diesel Engine Upgraded with 2500 Bar Fuel Injection Subsystem	€ 1	5.3%
22**	Diesel Engine with Conventional Valvetrain Subsystem	Diesel Engine Upgraded with Discrete Variable Valve Timing and Lift (VVTL) Valvetrain subsystem	€ 25	19.2%
23**	Conventional Diesel Engine with a Cooled High Pressure Exhaust Gas Recirculation (EGR) Subsystem	Conventional Diesel Engine Upgraded with a High Pressure, Low Pressure Cooled High EGR Subsystem	€ 19	19.2%
31**	Conventional Gasoline Engine with a Uncooled Low Pressure EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem	€ 11	19.2%
32**	Conventional Gasoline Engine with no EGR Subsystem	Conventional Gasoline Engine Upgraded with a Cooled Low Pressure EGR Subsystem	€ 18	19.2%
26**	6-Speed Manual Transmission	6-Speed Dry Dual Clutch Transmission (DCT)	€ 68	19.2%
30**	Conventional Powertrain Vehicle (Manual Transmission)	Conventional Powertrain Vehicle ((Manual Transmission) Upgraded with a Belt-Driven Starter Generator (BSG) Start-Stop System	€ 83	19.2%

Notes: [1] Negative percentage indicates reduced savings as the base technology is less expensive to manufacture in the low cost country (i.e., Eastern Europe)

As discussed in more detail in ICCT report "Light-Duty Vehicle Technology Cost Analysis, European Vehicle Market, Result Summary and Labor Rate Sensitivity Study", a cleansheet cost modeling approach would be required to assess the actual impact of manufacturing selected components in low-cost Eastern European countries versus Western indutrialized nations. Though the values above represent a rough order of magnitude of the potential cost differences which may be applicable if the components are suitable for manufacturing in low cost countries.

F. Conclusion

For many of technology configurations evaluated, the FEV developed baseline European ICMs were very similar to those developed by EPA for North America (NA). As shown in **Table D.1** and **D.2** many of baseline ICM values, where the timing curve factor equals one (i.e., production year 2012) were within +/- 10% of the EPA NA values). In some cases, such as the 5-speed AT to 6-speed AT analysis and 6-speed AT to 6-speed DCT analysis, the FEV ICMs are considerably higher than the EPA NA ICMs. Although as stated in **Section D**, it is difficult to assess why this significant difference exists without understanding the variations in underlying assumptions which were used in development of the EPA ICMs. This validates the need for more detailed, transparent models where assumptions can logged and evaluated in subsequent reviews. The FEV EU ICM model takes a step in this direction, though acknowledges that the model can be further expanded minimizing the need for users to make broad based assumptions resulting in user to user repeatability issues. Expanding the model with more finite choices would also help improve on the transparency as fewer user dependent assumptions are being made.

For all technology configurations evaluated there is a significant reduction in the NITCs for the later production years. This can be explained by the complete drop-off of selected indirect costs (i.e., R&D, Depreciation, Marketing, and Dealership) during years five (5) through eleven (11). In contrast the EPA NA ICM methodology maintains “long-term” indirect contributions” in the later production years; generally for production years 2018 through 2030. The impact of timing on indirect costs is a complicated topic. Based on the assumed boundary conditions, the results can be significantly different. The developed methodology provides another means of evaluating indirect costs over the long-term, though acknowledges this methodology can be expanded to include consideration to variations in assumed boundary conditions.