International Workshop

Greenhouse gas reduction potential and costs of light-duty vehicle technologies

prepared for:

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Brussels, 01.02.2012

FEV

FEV Agenda

- **FEV Introductions**
- **FEV Company Profile**
- **EPA Work Scope & Key Deliverables**
- **EPA Cost Analysis Methodology**
- **ICCT Work Scope & Key Deliverables**
- **ICCT Cost Analysis Methodology (Phase 1)**
  - Methodology Overview
  - Database Conversion Process
- **ICCT Phase 1 Project Results**
- **ICCT Phase 2 Project Work Scope**
  - Project Work Scope Overview
  - Technologies Under Evaluation

Q&A

FEV worldwide
… Turning innovative ideas into reality

Company profile

- Founded in 1978
- Independent family-owned company
- Working for major car and engine manufacturers worldwide
- Close collaboration with the Technical University in Aachen
- 2,100 employees
- > 110 engine / powertrain test cells
- Innovative: >1300 patents

Engineering services and products

- Automotive and commercial vehicles
  - Engine and powertrain
  - Vehicle integration, application and electronics
  - Test systems
- Advanced applications in aeronautics and transportations
- Clean energy, energy industry

FEV

Executive board

The FEV group is privately held and managed by a board of five chief executives.

In front:

Prof. Dr.-Ing. Stefan Pischinger
President and CEO of the FEV Group

From left to right:

Dr.-Ing. Markus Schwaderlapp
Executive Vice President

Gary W. Rogers
Executive Vice President

Rainer Paulsen
Executive Vice President

Dr.-Ing. Ernst Scheid
Executive Vice President

FEV's organizational structure
FEV´s areas of expertise

Gasoline Engines Passenger Cars

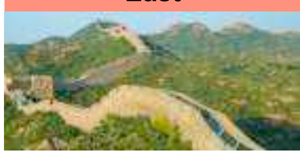
Commercial, Industrial, Large Engines

Electrics/ Electronics

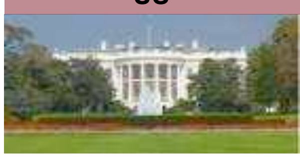
Test & Instrumentation

Business Region Europe

Business Region East



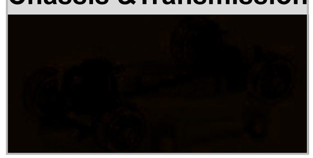
Business Region US



Business Regions	BG	BD	BC	BV	BE	BA	BT
	Business Units						
RE							
RO							
RU							

Diesel Engines Passenger Cars

Vehicle Chassis &Transmission



Advanced Applications

- We are customer and product focused
- We are the best global partner for our customer
- We have worldwide standards
- We are prepared to support all future technology needs

FEV

FEV´s areas of expertise

Vehicle Technology

Engine & transmission

Vehicle application & calibration

Demonstration cars

E-vehicle development

Powertrain testing & test facilities

FEV has emerged as one of the market leader for vehicle technology and offers today engineering services for diverse industry areas

Industry Areas

Power engineering

Marine

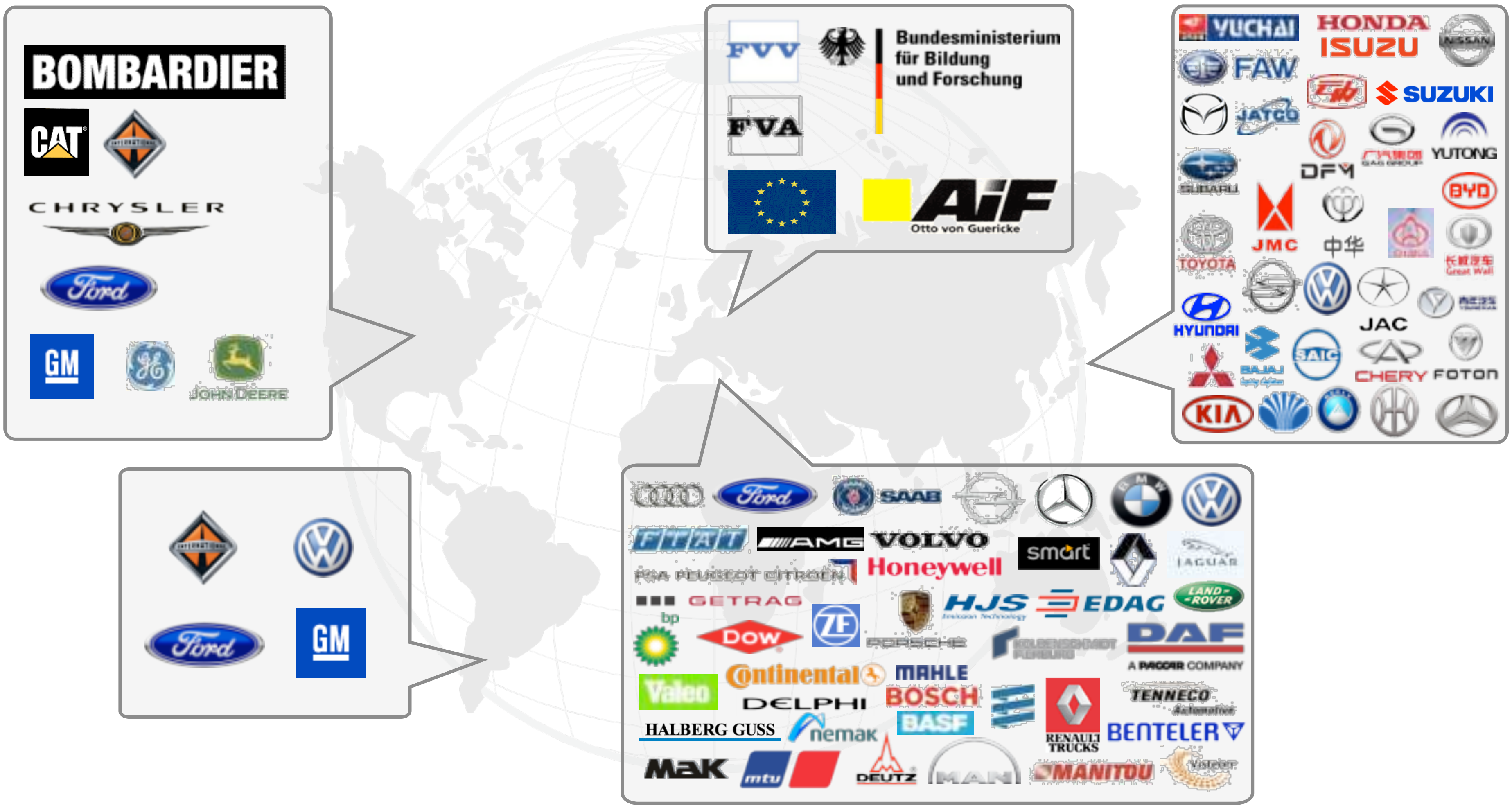
Off-Highway

Aeronautics

Rail

FEV

Powertrain development worldwide



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EPA Work Scope Definition

- The United States Environmental Protection Agency (EPA) contracted with FEV, Determine incremental direct manufacturing costs for a set of advanced light-duty vehicle technologies.

- The technologies selected are on the leading edge for reducing emissions of greenhouse gases in the future, primarily in the form of tailpipe carbon dioxide (CO2).

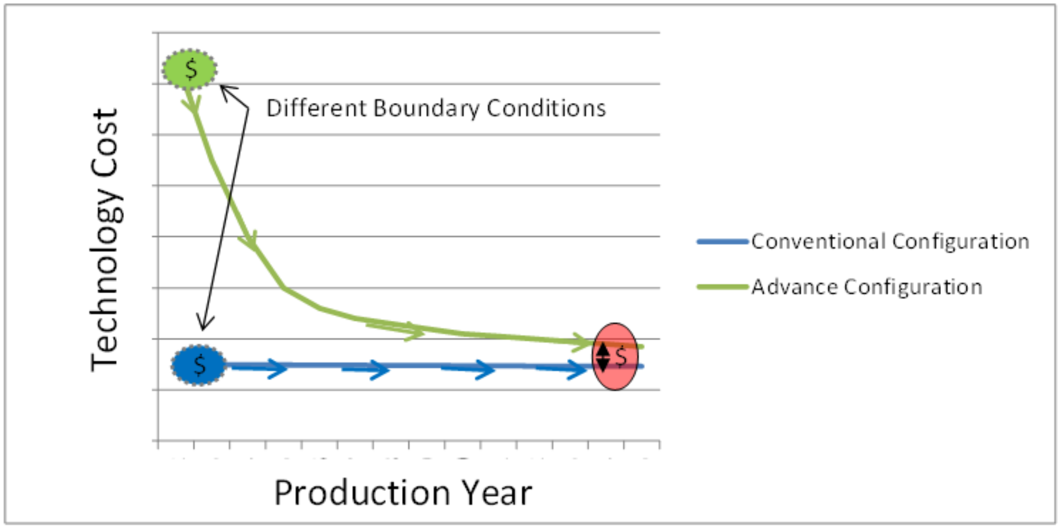
- In contrast to comparable cost analyses done in the past, which rely heavily on supplier price quotes for key components, this study is based to a large degree on teardowns of vehicles or vehicle systems.

- Each new technology configuration selected (i.e., the advance technology offering) is evaluated against a baseline vehicle technology configuration (i.e., current technology becoming the standard in the industry) having similar overall driving performance.

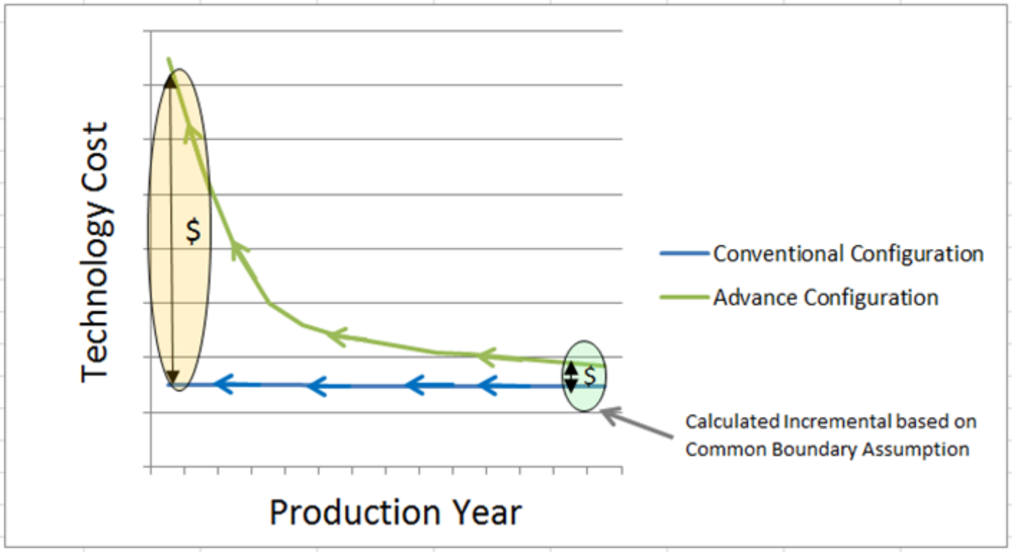
- When conducting the cost analysis for each technology configuration, a number of assumptions and boundary conditions are required upfront in the analysis prior to the start of any costing work. The same assumptions and boundary conditions are applied to both the new and baseline technology configurations establishing a consistent framework for all costing, resulting in a level playing field for comparison.

Evaluating Technology Costs

Prior Method For Evaluating Cost Differences



Revised Method For Evaluating Cost Differences



Key Objective & Deliverables

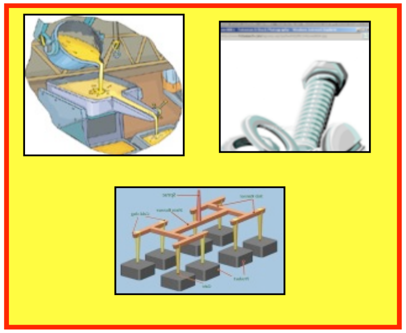
- Detailed direct manufacturing cost analysis should use tools and processes similar to those used by OEMs and suppliers in the automotive industry

- Transparency-- methodologies, assumptions, and inputs should be well documented, clearly explained, and releasable to the public, except to the extent that those essential inputs must include confidential business information.

- Sensitivity to key inputs-- the analysis shall allow subsequent adjustment of key parameters which may be highly volatile in the future (for example commodity prices such as copper, or energy inputs).

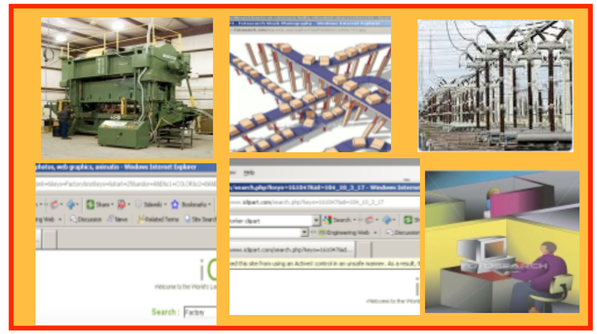
Detailed, Transparent and Flexible Cost Analysis

MATERIAL



LABOR

MANUFACTURING OVERHEAD



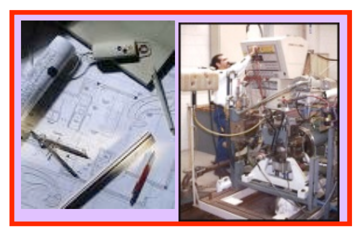
High Pressure Fuel Pump Example	Material	Labor	Burden	TMC	Scrap	SG&A	Profit	ED&T	Total Mark-up			
											1	$54.12
T1 or OEM Total Manufacturing Cost:	$16.99	$8.01	$24.95	$49.94	$0.30	$2.09	$1.64	$0.15	$4.18	→	3	$54.12
T1 or OEM Mark-Up Rates:	-----	-----	-----	-----	0.70%	7.00%	8.00%	4.00%	19.70%			
(SAC) &T1 or OEM Mark-Up Values:	-----	-----	-----	-----	$0.38	$3.79	$4.33	$2.16	$10.66			
Base Cost Impact to Vehicle:	$16.99	$8.01	$24.95	$49.94	$0.68	$5.88	$5.97	$2.32	$14.84	→		$64.79
											Packaging Cost:	$0.11
											Net Cost Impact to Vehicle:	$64.90

SCRAP

SG&A

PROFIT

ED&T



PACKAGING

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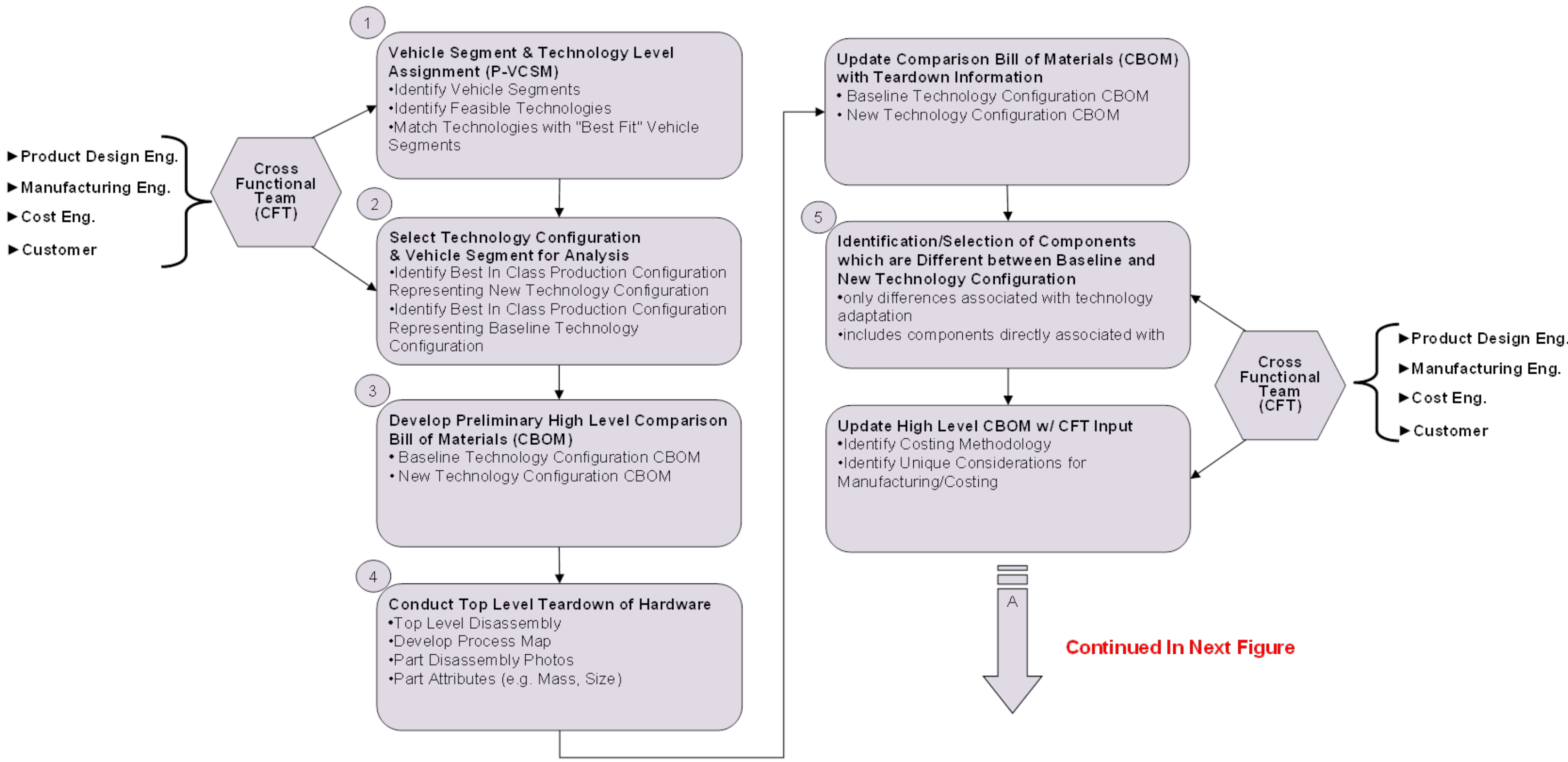
EPA Cost Analysis Methodology (Part 1 of 2)



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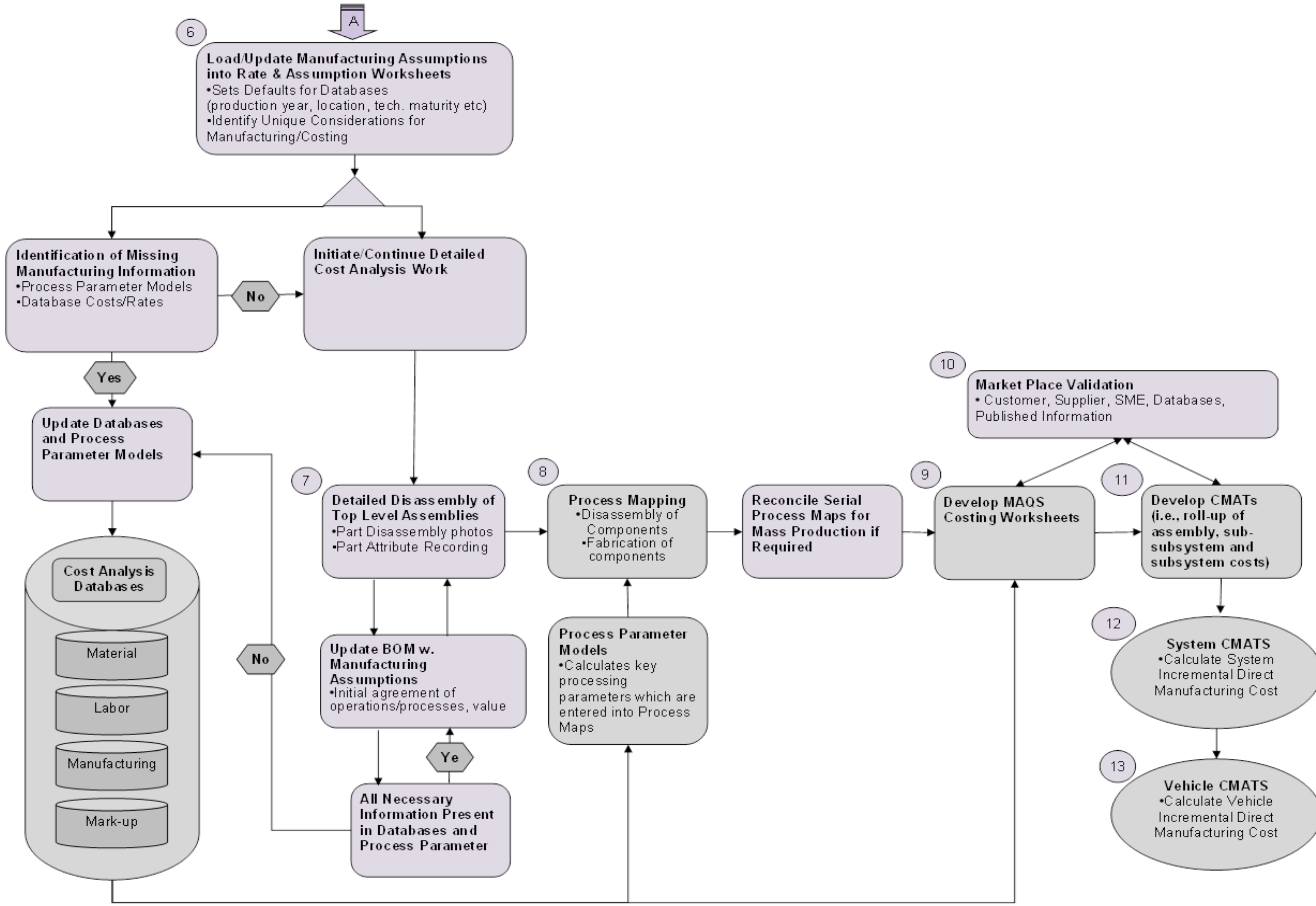
EPA Cost Analysis Methodology (Part 2 of 2)

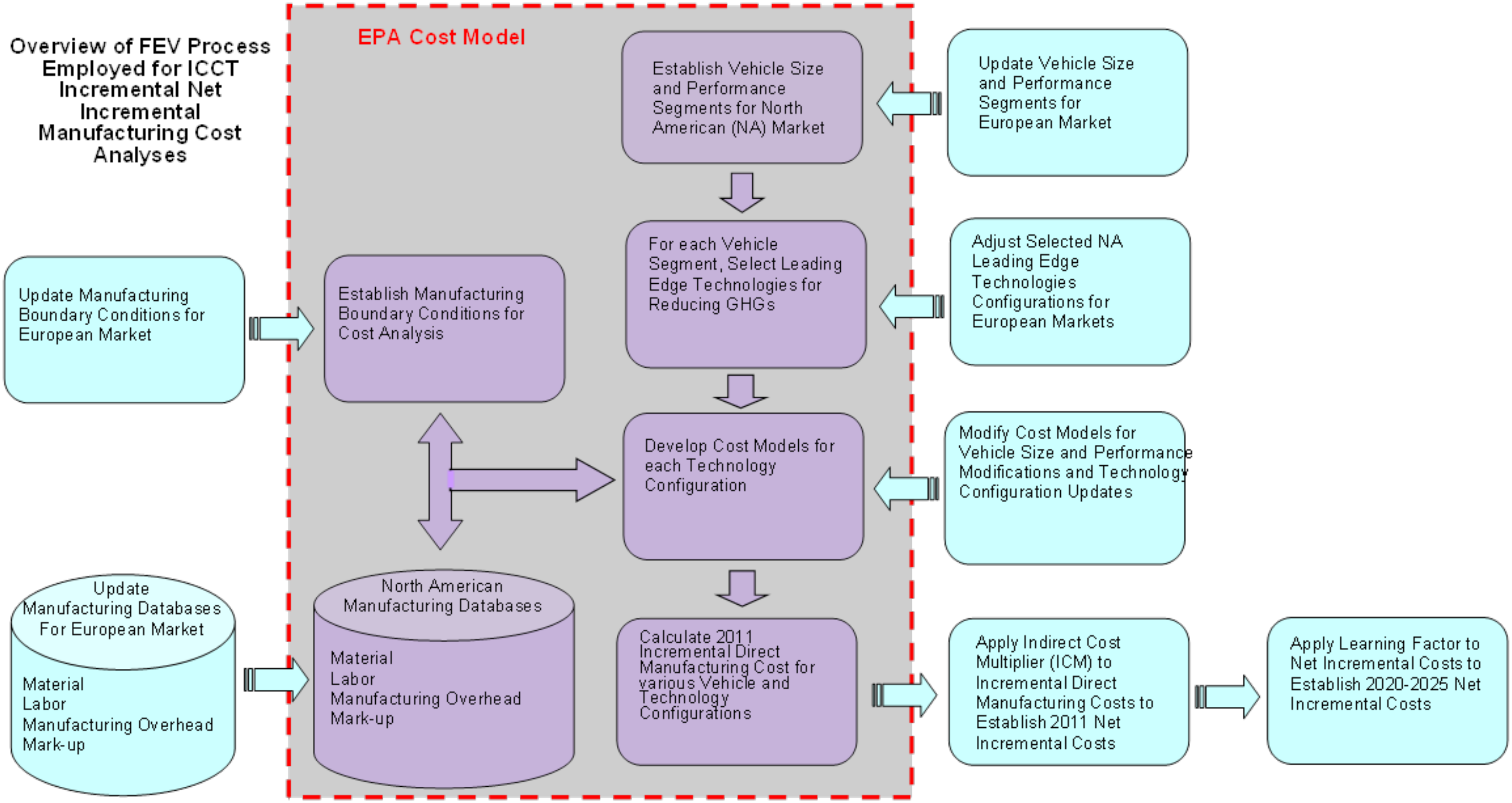


ICCT Phase 1 Work Scope Summary

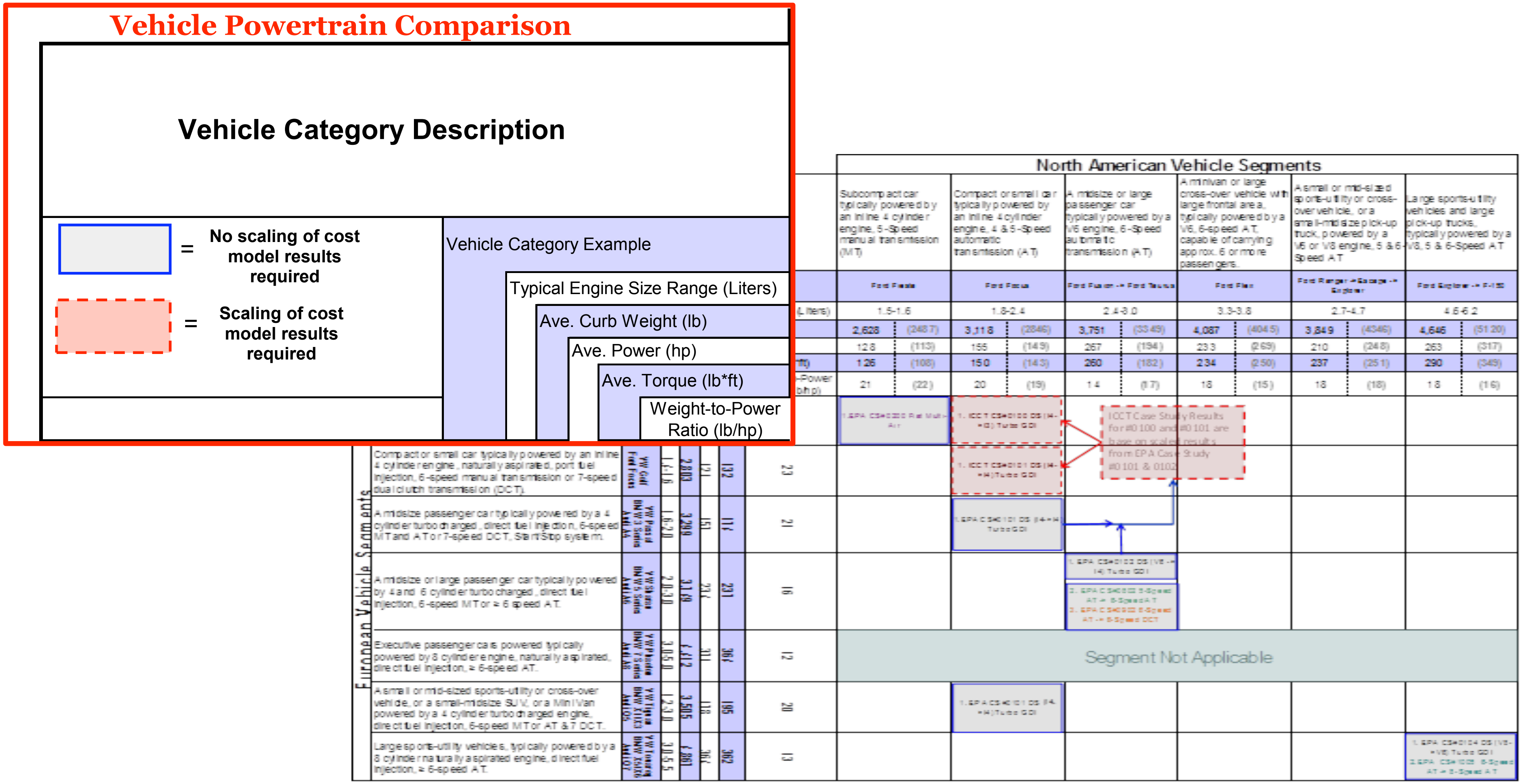
- **Transferring and conversion of information and results from existing EPA advance vehicle powertrain cost analysis studies, which were based on US market trends and manufacturing cost structures, into comparable European cost studies.**

- **This would require adjustments to the existing cost analyses relative to accounting for differences in European vehicle powertrain market trends and European manufacturing cost structures.**

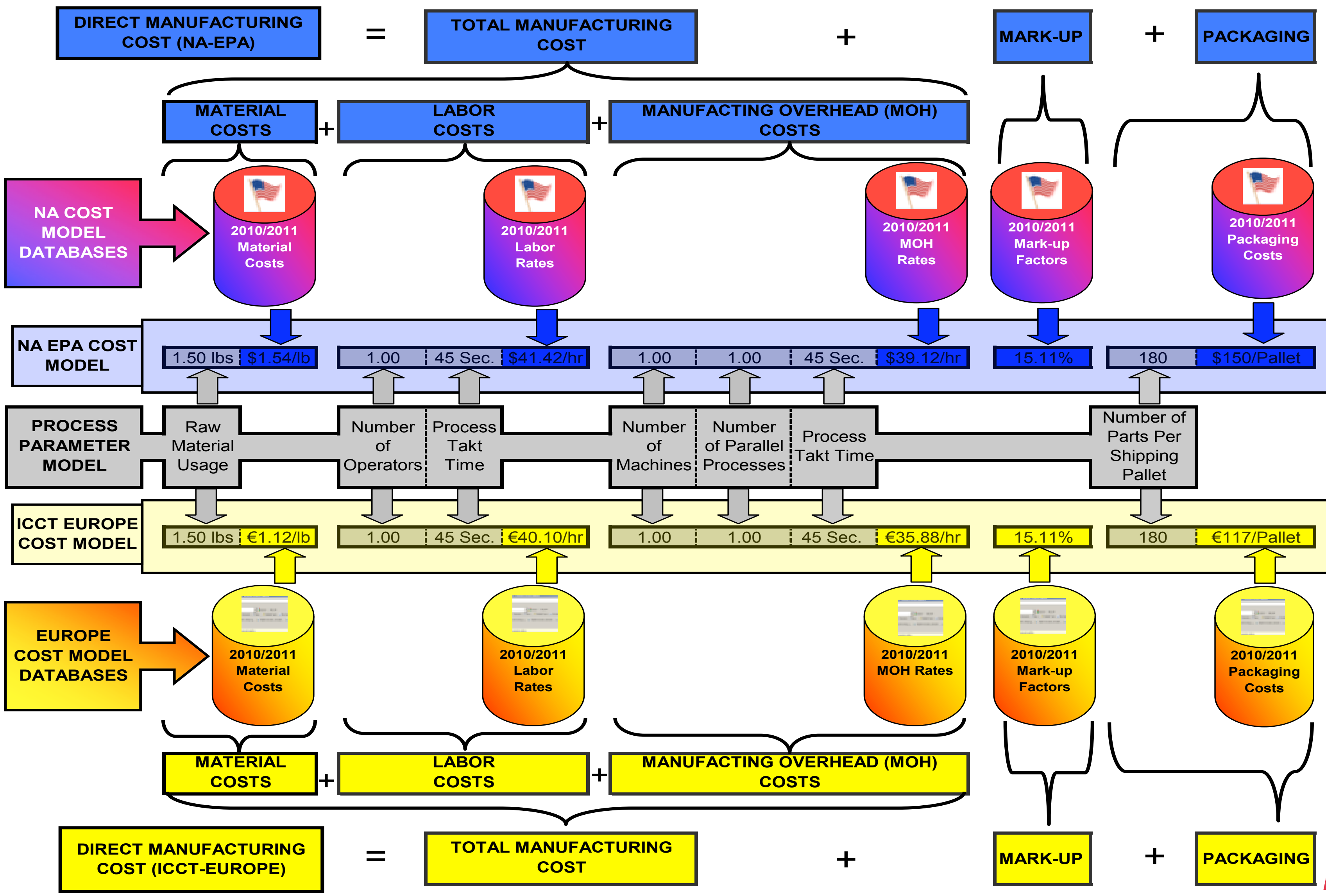
ICCT Cost Analysis Methodology



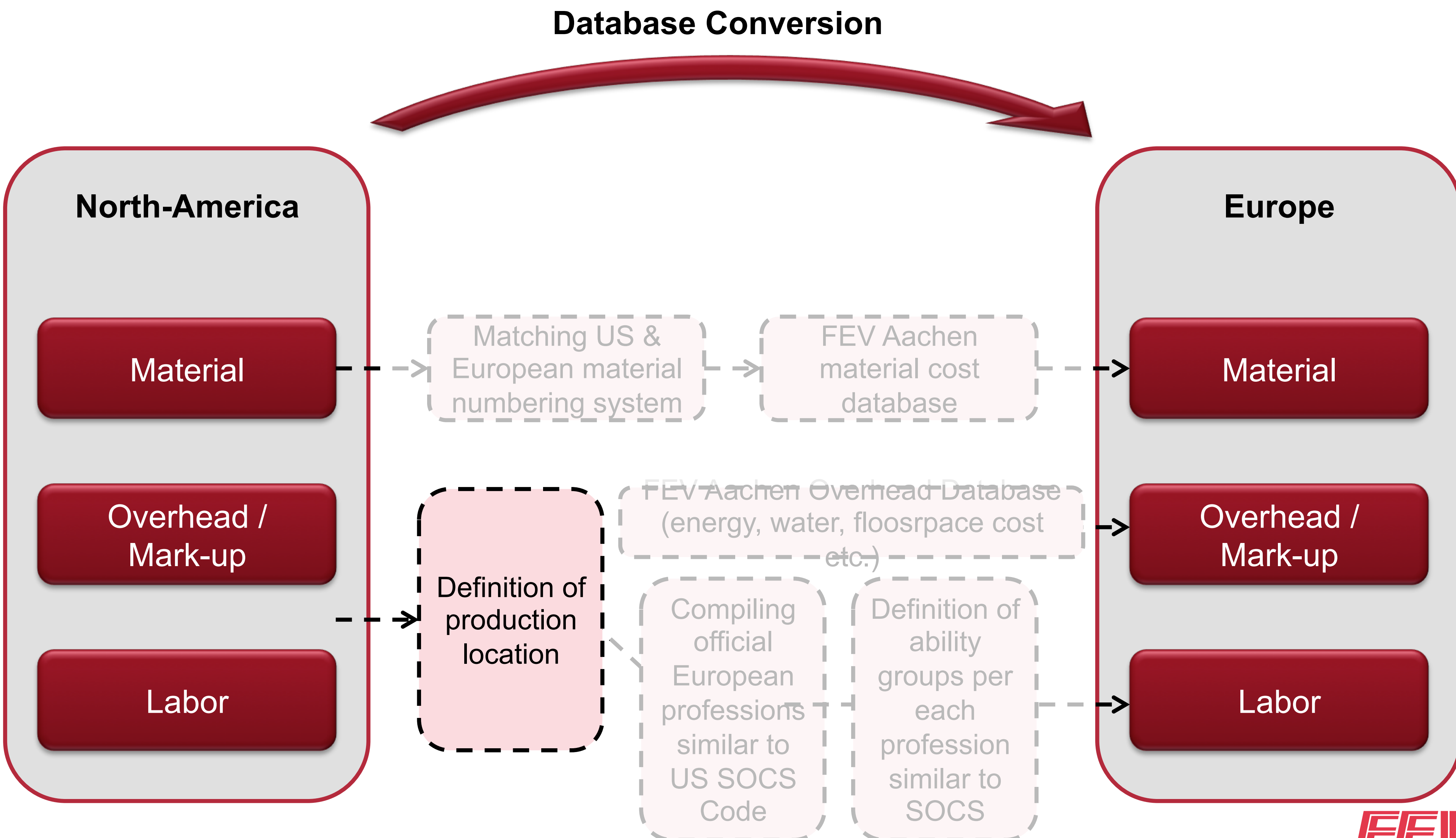
Vehicle Segment Conversion



Cost Model Conversions



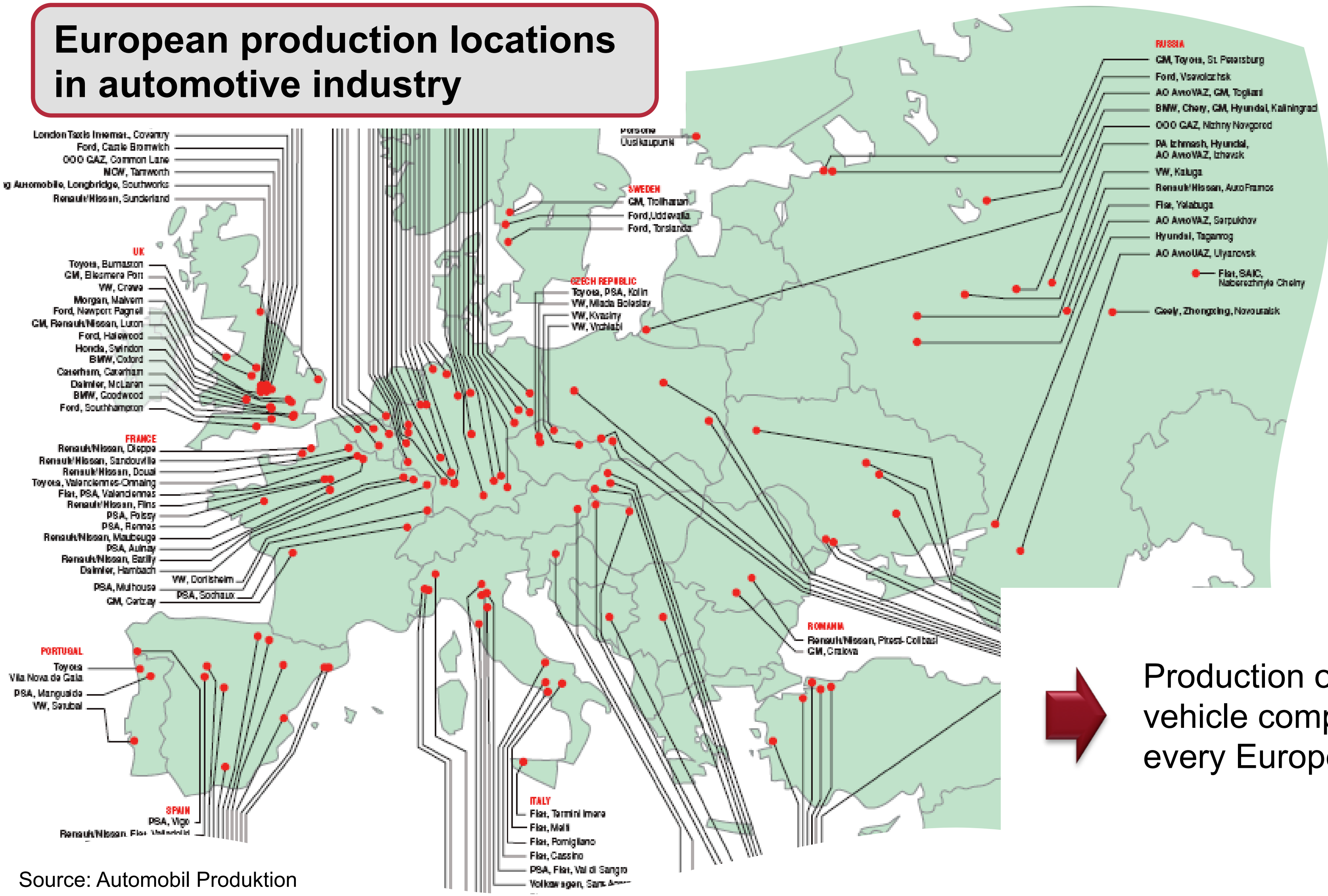
Database Conversion



SOCS = Standard Occupation Classification System

Definition of Production Location for Labor cost determination

European production locations in automotive industry



Source: Automobil Produktion

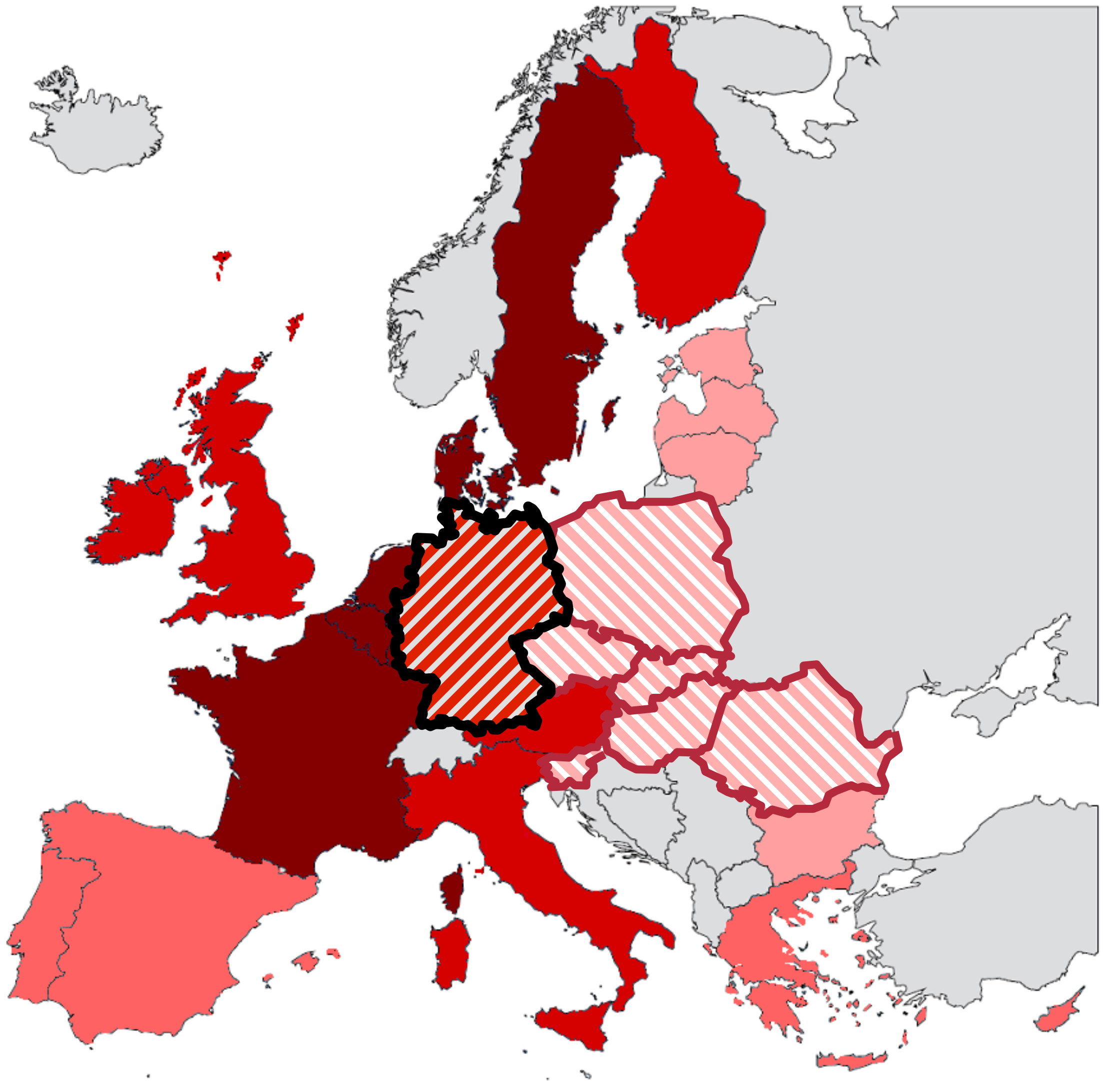
Production of vehicles and vehicle components in nearly every European country

Definition of Production Location for Labor cost determination

Labor cost in Europe

- 1 to 10 €/h
- 10 to 20 €/h
- 25 to 30 €/h
- 30 €/h and more

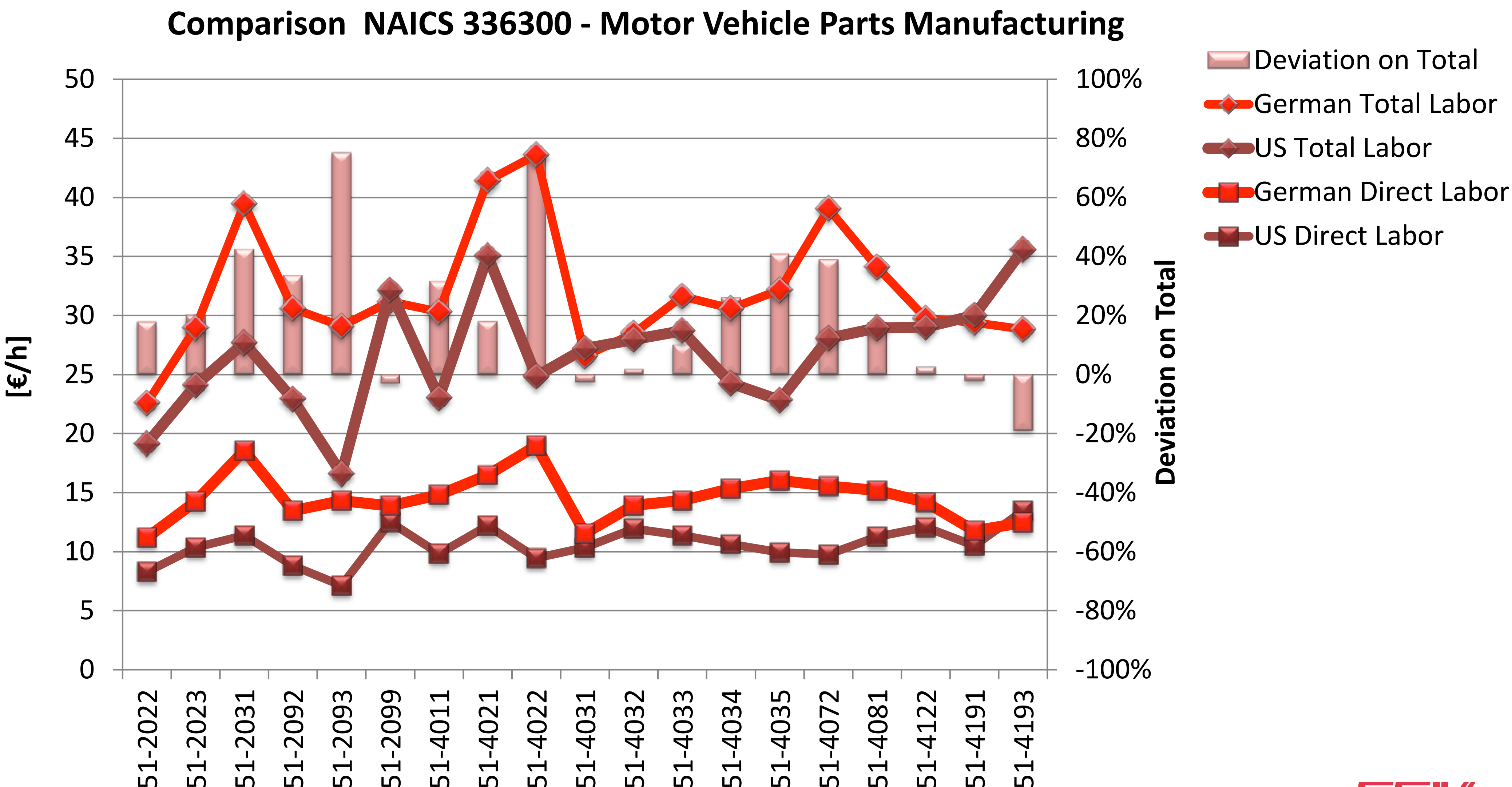
Big differences in labor costs across Europe



Approach to meet European average

- Consideration of German labor costs as representative of Western European conditions
- Definition of one percental relation between German labor costs and an average of Eastern European countries

Phase 1



Total labor = direct labor + indirect labor + maintenance & repair + fringe allocation

Summary of ICCT Phase 1 Results: Engines

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Calculated Incremental ***Direct*** Manufacturing Cost 2010/2011 Production Year	Net Incremental Manufacturing Costs (***Direct + Indirect Costs***) with Applicable Learning Applied			
								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	VW Polo	€ 230	€ 371	€ 327	€ 267	€ 237
	2	0101	1.6L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.2L, I4, 4V, DOHC, Turbo, GDI, dVVT, ICE	Compact/ Small	VW Golf	€ 360	€ 505	€ 460	€ 398	€ 367
	3	0102	2.4L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.6L, I4, 4V, DOHC, Turbo, GDI, dVVT, ICE	Midsize	VW Passat	€ 367	€ 520	€ 473	€ 407	€ 375
	4	0103	3.0L, V6, 4V, DOHC, NA, PFI, dVVT, ICE	2.0L, I4, 4V, DOHC, Turbo, GDI, dVVT, ICE	Midsize/Large	VW Sharan	€ 80	€ 245	€ 194	€ 123	€ 89
	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	€ 946	€ 854	€ 726	€ 664
	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	VW Polo	€ 107	€ 159	€ 145	€ 126	€ 117

Summary of ICCT Phase 1 Results: Transmissions

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Calculated Incremental *Direct* Manufacturing Cost 2010/2011 Production Year	Net Incremental Manufacturing Costs (*Direct + Indirect Costs*) with Applicable Learning Applied			
								2012	2016	2020	2025
Transmissions	1	0802	5-Speed AT	6-Speed AT	Midsize/Large	VW Sharan	(€ 79)	€ 19	€ 10	€ 1	(€ 6)
	2	0803	6-Speed AT	8-Speed AT	Large SUV	VW Touareg	€ 43	€ 59	€ 54	€ 47	€ 44
	3	0902	6-Speed AT	6-Speed Wet DCT	Midsize/Large	VW Sharan	(€ 121)	€ 47	€ 32	€ 12	€ 2

Summary of ICCT Phase 1 Results: Power-Split (4 Vehicle Segments Shown)

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Calculated Incremental *Direct* Manufacturing Cost 2010/2011 Production Year	Net Incremental Manufacturing Costs (*Direct + Indirect Costs*) with Applicable Learning Applied			
								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: 64.6kW ICE Power: 52.7kW (I4 -> I3) Traction Motor: 43.2kW Generator: 30.3kW Li-Ion Battery: 140V, 0.743kWh	Subcompact	VW Polo	€ 1,674	€ 4,235	€ 3,254	€ 2,434	€ 2,000
	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: 77.8kW ICE Power: 63.6kW (I4 - DS I4) Traction Motor: 52.0kW Generator: 36.5kW Li-Ion Battery: 162V, 0.857kWh	Compact/ Small	VW Golf	€ 1,866	€ 4,685	€ 3,609	€ 2,702	€ 2,225
	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: 101.2kW ICE Power: 82.6 kW (I4 -> DS I4) Traction Motor: 67.7kW Generator: 47.5kW Li-Ion Battery: 188V, 0.994kWh	Midsize	VW Passat	€ 2,056	€ 5,223	€ 4,009	€ 2,997	€ 2,459
	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: 151.1 kW ICE Power: 123.4 kW (V6 -> I4) Traction Motor: 101kW Generator: 70.9kW Li-Ion Battery: 211V, 1.118kWh	Midsize/Large	VW Sharan	€ 1,998	€ 5,312	€ 4,019	€ 2,985	€ 2,419

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Summary of ICCT Phase 1 Results: P2 (4 Vehicle Segments Shown)

Technology	ID	Case Study #	Baseline Technology Configuration	New Technology Configuration	European Market Segment	European Vehicle Segment Example	Calculated Incremental *Direct* Manufacturing Cost 2010/2011 Production Year	Net Incremental Manufacturing Costs (*Direct + Indirect Costs*) with Applicable Learning Applied			
								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: 64.6 kW ICE Power: 51.7 kW (I4 -> I3) Traction Motor: 12.9 kW Li-Ion Battery: 140V, 0.743kWh	Subcompact	VW Polo	€ 1,615	€ 4,143	€ 3,170	€ 2,366	€ 1,937
	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: 77.8 kW ICE Power: 62.3 kW (I4 -> DS I4) Traction Motor: 16 kW Li-Ion Battery: 162V, 0.857kWh	Compact/ Small	VW Golf	€ 1,820	€ 4,643	€ 3,559	€ 2,658	€ 2,179
	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: 101.2kW ICE Power: 80.9 kW (I4 -> DS I4) Traction Motor: 20.23 kW Li-Ion Battery: 188V, 0.994kWh	Midsize	VW Passat	€ 1,972	€ 5,092	€ 3,888	€ 2,899	€ 2,369
	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: 151.1 kW ICE Power: 120.9 kW (V6 -> I4) Traction Motor: 30 kW Li-Ion Battery: 211V, 1.118 kWh	Midsize/Large	VW Sharan	€ 1,824	€ 5,041	€ 3,768	€ 2,784	€ 2,232

ICCT Phase 2 Project Scope Review

- Advanced diesel engines with high pressure injection system (>2000 bar), variable valve lift and cam timing capable of meeting Euro 6 emission standards or better.
  - Includes Engine Downsizing
- High pressure uncooled and low pressure cooled EGR in a charge air cooling system compared with cooled high pressure EGR.
  - Includes investigation on future gasoline engine EGR system alternatives
- Dual dry clutch transmission compared with manual transmission, each with 6 gears.
- Stop-start system (including regenerative braking capability) typically used on European vehicles.
- Transferring and conversion of information and results from the EPA Toyota Venza mass-reduction and cost analysis into a comparable European mass and cost study.

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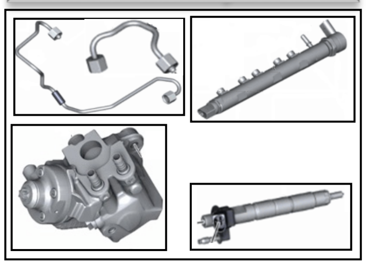
ICCT Phase 2 Project Scope Review

Advanced Diesel Engines	Injection pressure > 2000 bar
	Variable valve lift & timing
	Downsizing 4 cyl. → 3 cyl.
EGR System	HP cooled vs. HP uncooled + LP cooled
Transmission	Manual vs. dual clutch
Stop-start system	Incl. regenerative braking
Mass reduction	EPA Toyota Venza Study → European conditions

Phase 2 – Injection System Analysis: Approach

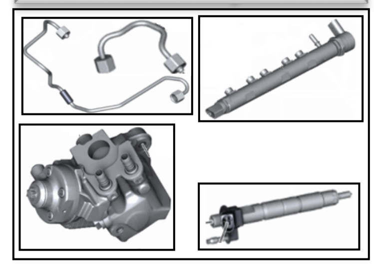
Target: Evaluation of cost difference between baseline and 2500bar system

Defined as baseline → 1800 bar system



compare

2000 bar system

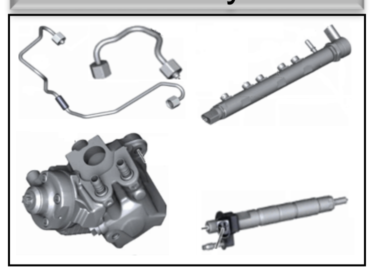


find out differences

Part 1	Part 2	Part 3	Part 4	….

Derive necessary modifications for a 2500bar system, depending on differences between both compared systems

Assumed cost difference for → 2500 bar system



Phase 2 – Injection System Analysis: Main Components

High Pressure Pump

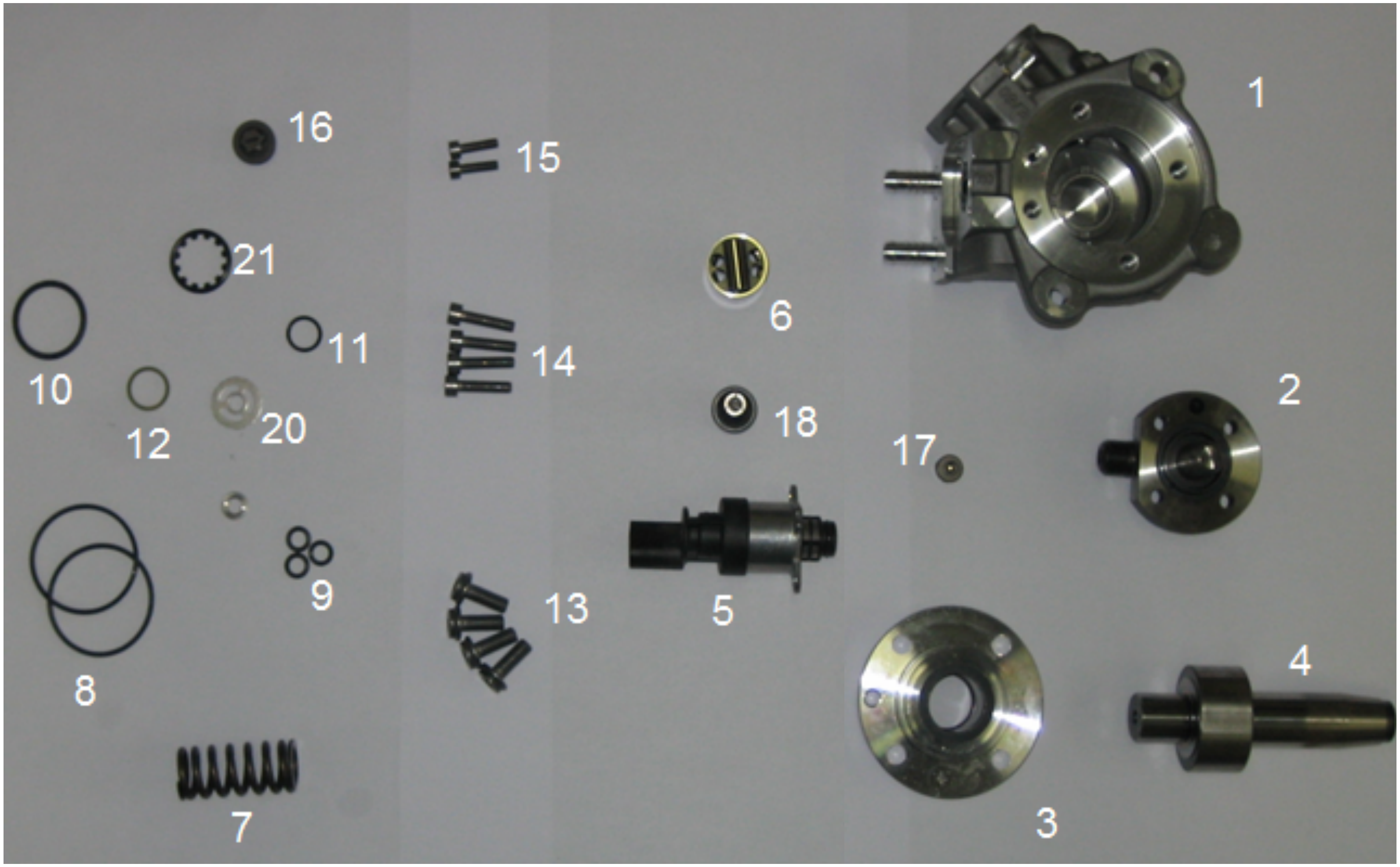
Rail

Injector

Pipe - Pump to Rail

Pipe – Rail to Injector

Phase 2 – Injection System Analysis: High Pressure Pump Teardown

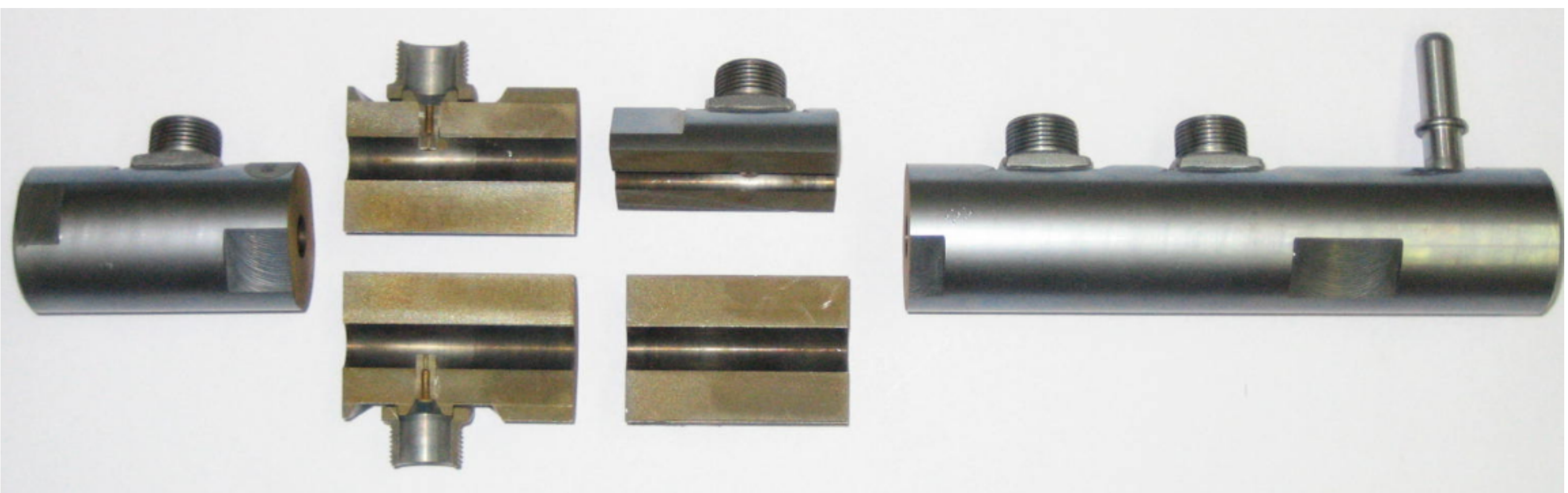


Nr.	Component
1	Pump housing
2	Cylinder head
3	Cover
4	Camshaft
5	Metering unit
6	Valve lifter
7	Coil spring
8	O-ring (cover)
9	O-ring (sealing surface of cylinder head and cover)
10	O-ring (cylinder head)
11	O-ring (pressure retention valve)
12	O-ring (screw check valve)
13	Screw (cylinder head)
14	Screw (cover)
15	Screw (metering unit)
16	Screw (check valve)
17	Check valve (cylinder head)
18	Plunger
19	Pressure retention valve
20	Disc
21	Disc

Phase 2 – Injection System Analysis: Fuel Injector Teardown

Nr.	Component
	Nozzle module incl.
1	--Nozzle body
2	--Nozzle needle
3	--Supporting
4	--Needle bushing
5	--Nozzle spring
	Servo valve plate incl.
6	--Plate
7	--Servo valve
8	--Servo valve spring
9	Adapter plate
10	--Positioning pins
	Coupler Module incl.
11	--Tube Spring
12	--Driving piston
13	--Driven piston incl. Spring
14	--Spring driven piston
15	--Adapter plate
16	--Coupler body
17	Clamping nut
18	Adjustment plate coupler
19	Injector body
20	Piezo module
21	Edgefilter
22	Seal ring
23	Connector body incl.
24	--Return line connector
25	Thread seal

Phase 2 – Injection System Analysis: Fuel Rail Teardown

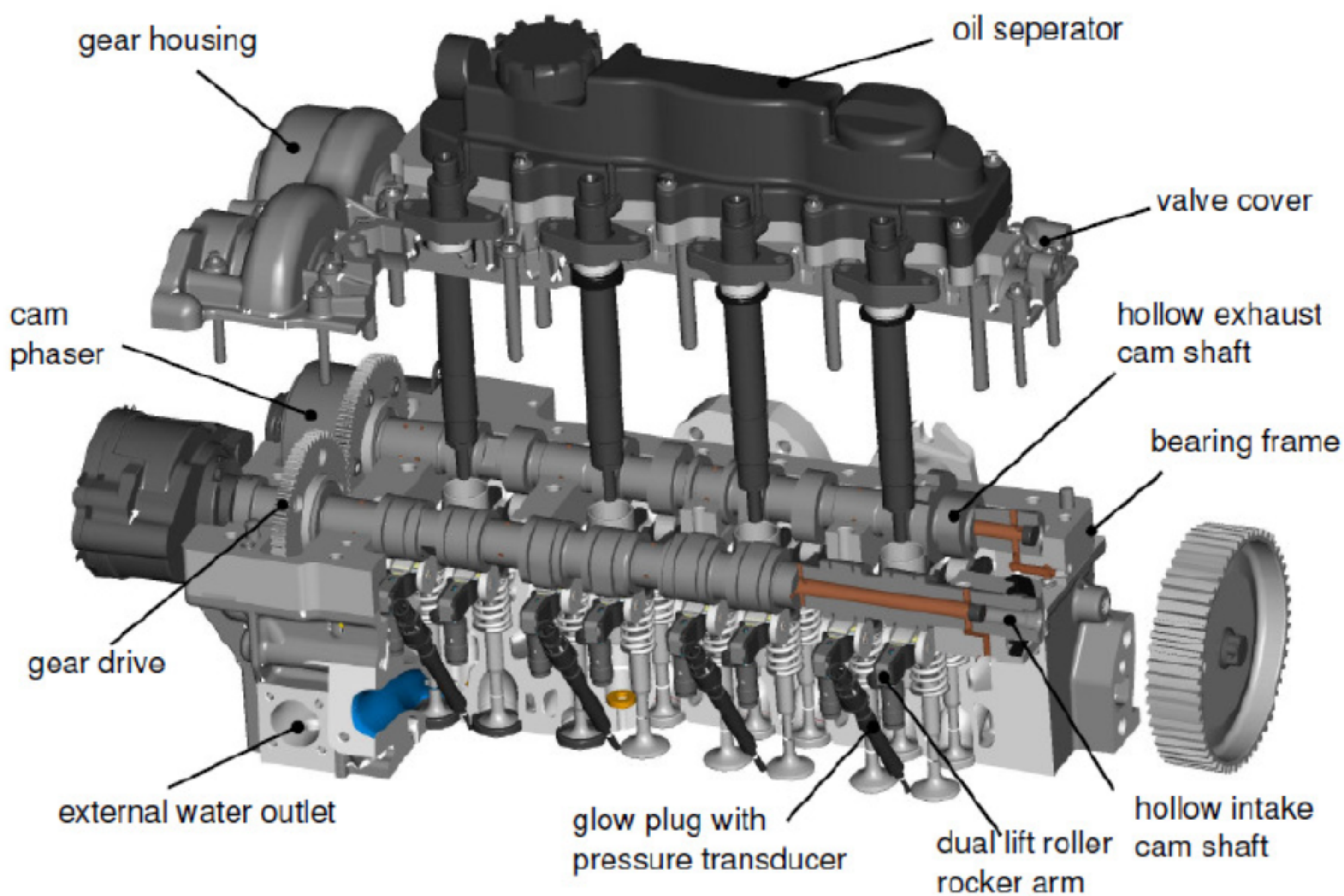


Nr.	Component
1	Rail
2	Pressure sensor
3	Pressure regulator valve

Phase 2 - Variable Valve Train Analysis: FEV HECS Concept

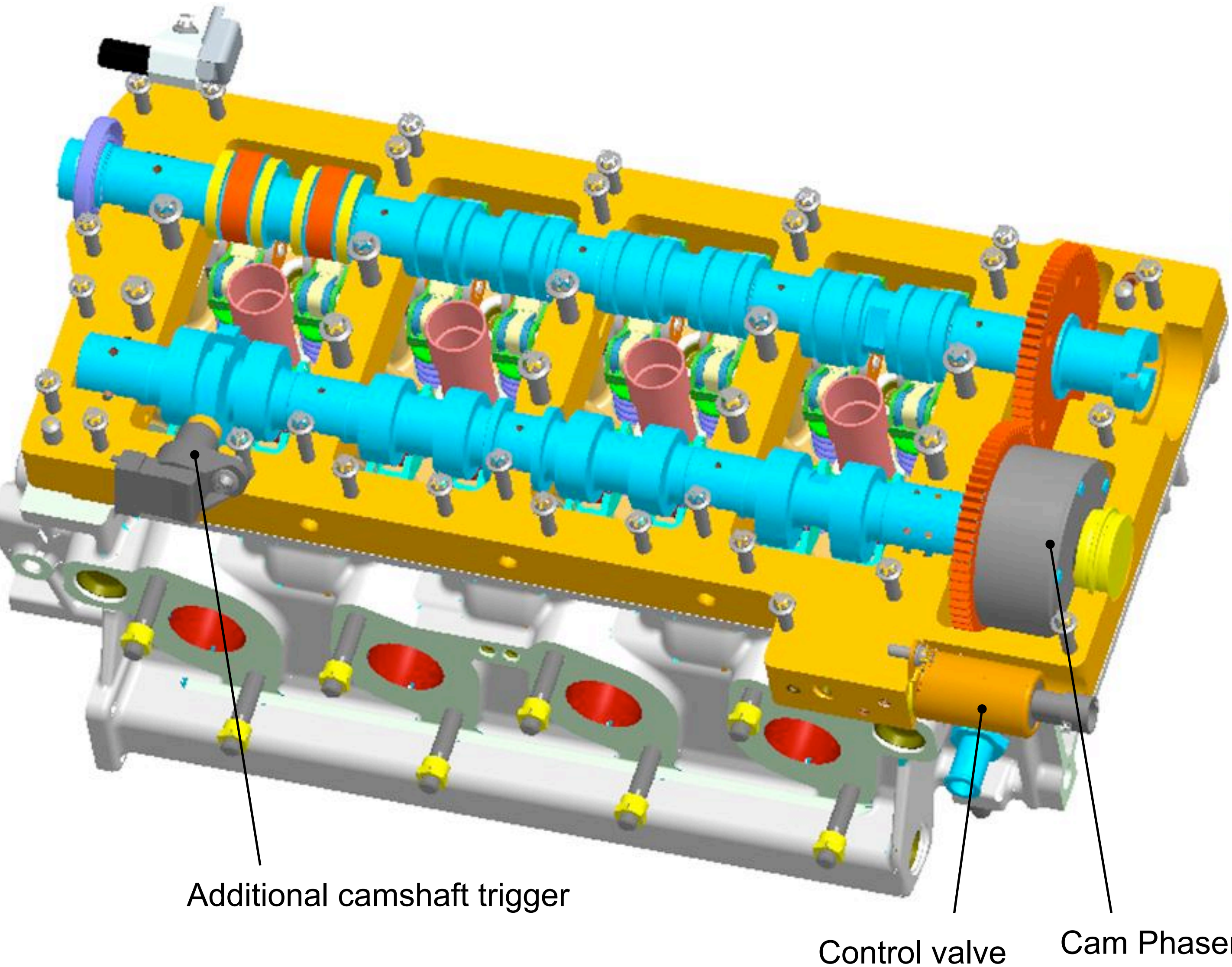
Target:

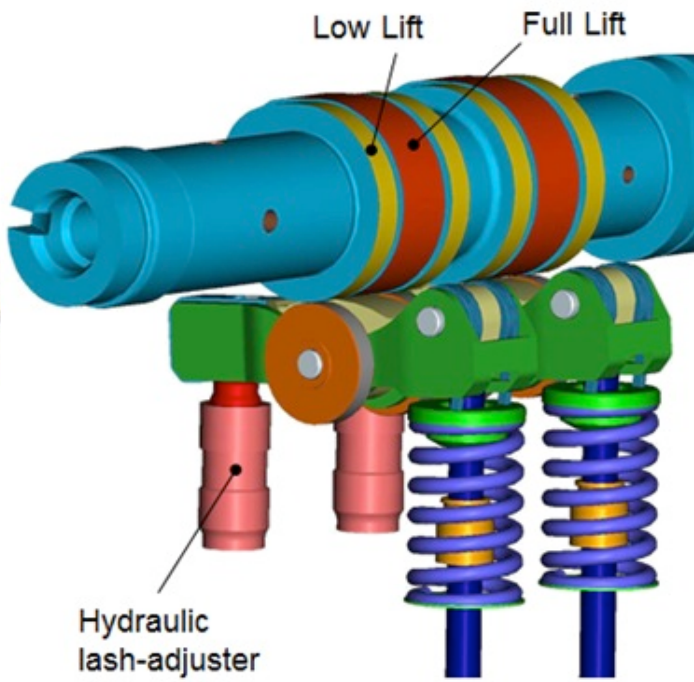
Cost Comparison of non-variable vs. variable valve train at diesel engines



Considered variable valve train concept: FEV HECS

Phase 2 - Variable Valve Train Analysis: Dual Lift Rocker





Phase 2 – Diesel Engine Downsizing Analysis

Target:

Cost Comparison of I4 Turbo Diesel engine vs. downsized I3 Turbo Diesel Engine with same power

Definition of baseline and downsized engine:

	Baseline Engine (I4)	Downsized Engine (I3)
Displacement	2 l	1,5 l
Power Output	105 kW	105 kW
Power Output per liter	52,5 kW/l	70 kW/l
Max. Torque	320 Nm	320 Nm
BMEP	20 bar	27 bar
Compression ratio	16,5	15,5
Injection System	1800 bar Piezo	2500 bar Piezo
EGR-System	HD-EGR	HD-EGR
Intercooler	Yes	Yes (10% more cooling power)
Swirl Flap Mechanism	No	Yes
Peak Firing Pressure	150 bar	180 bar
Cylinder Block Material	Aluminum	Aluminum
Cylinder Head Material	Aluminum	Aluminum

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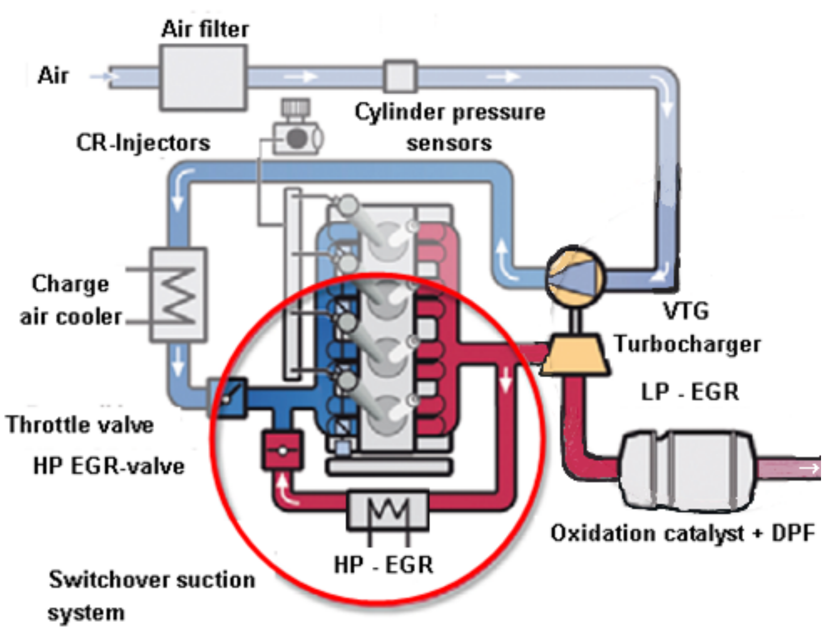
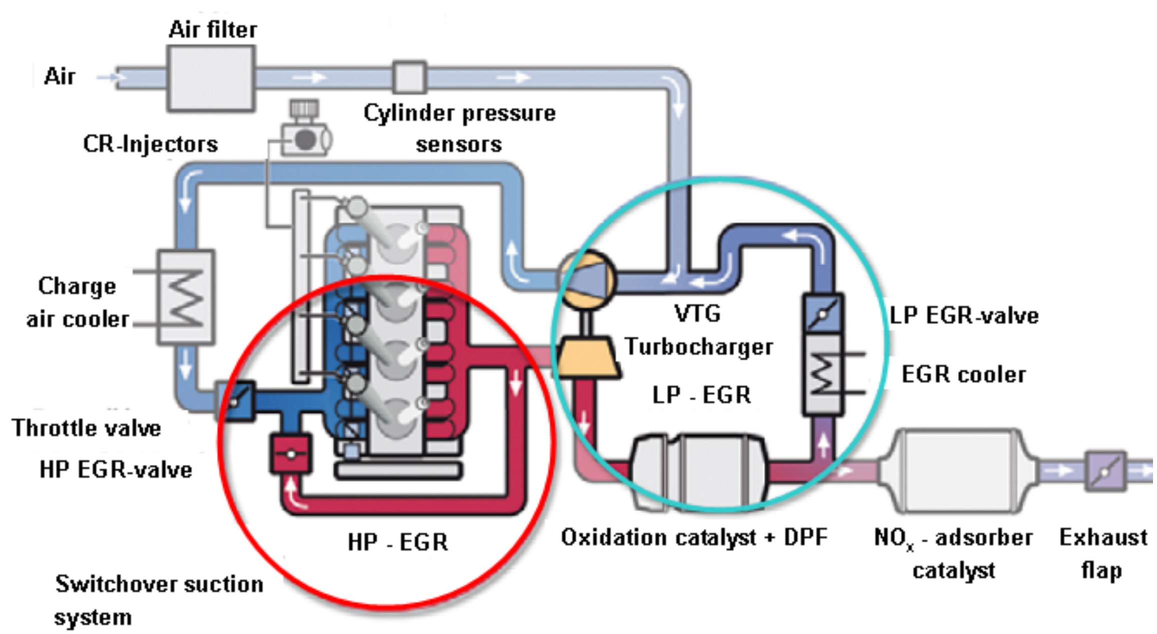
Phase 2 – EGR-System comparison

Target:

Cost Comparison of high pressure EGR vs. combined high and low pressure EGR system



High pressure EGR (cooled)

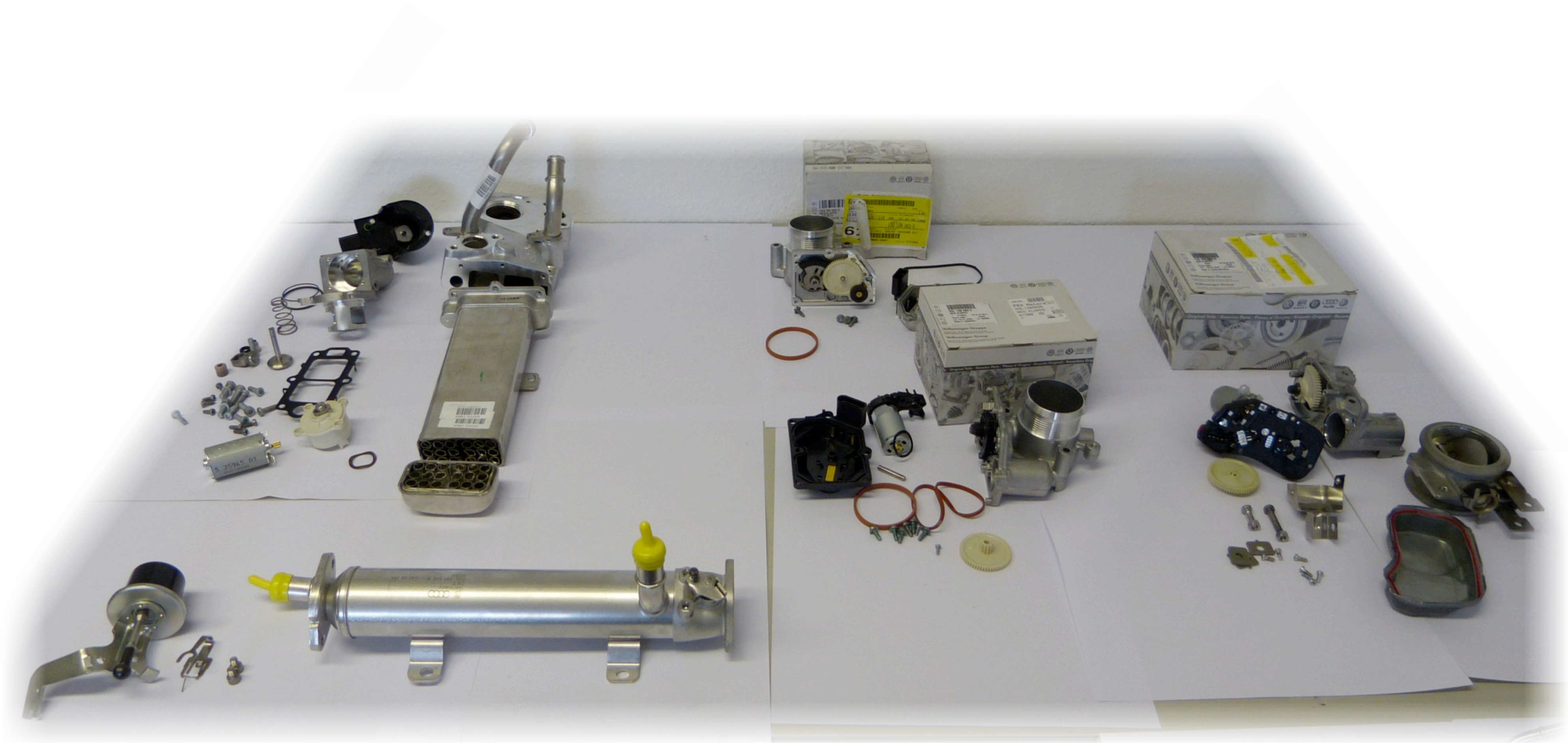


High pressure EGR (uncooled)
Low pressure EGR (cooled)

Phase 2 – EGR-System comparison: overview system hardware

Phase 2 – EGR-System comparison : Pipes

Phase 2 – EGR-System comparison: Coolers and valves



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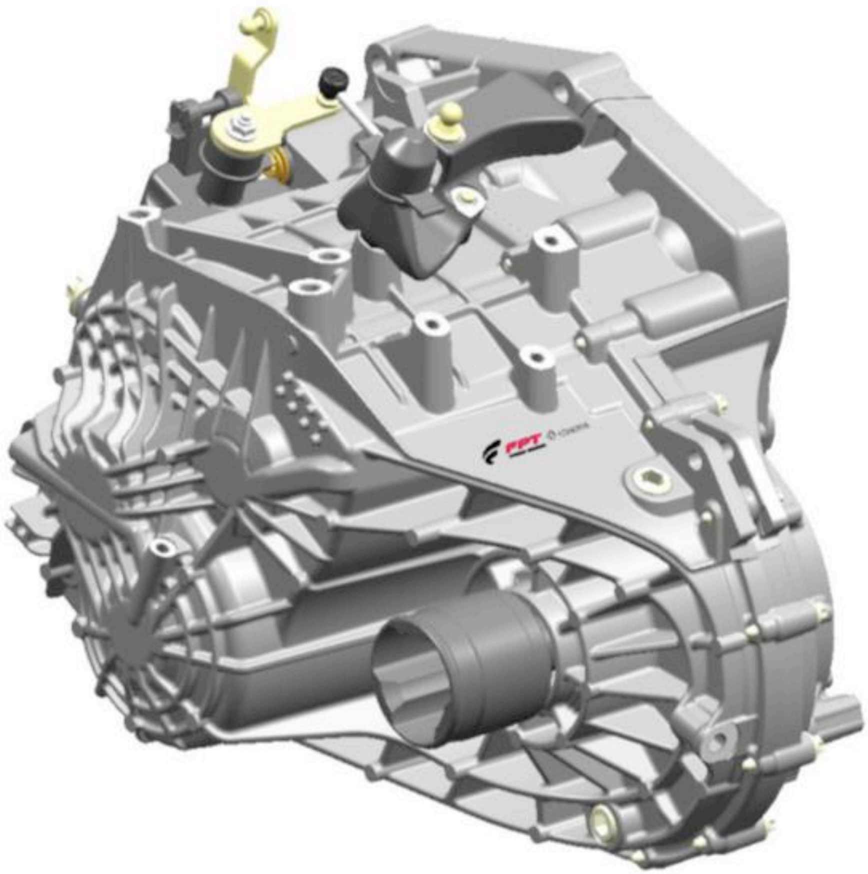
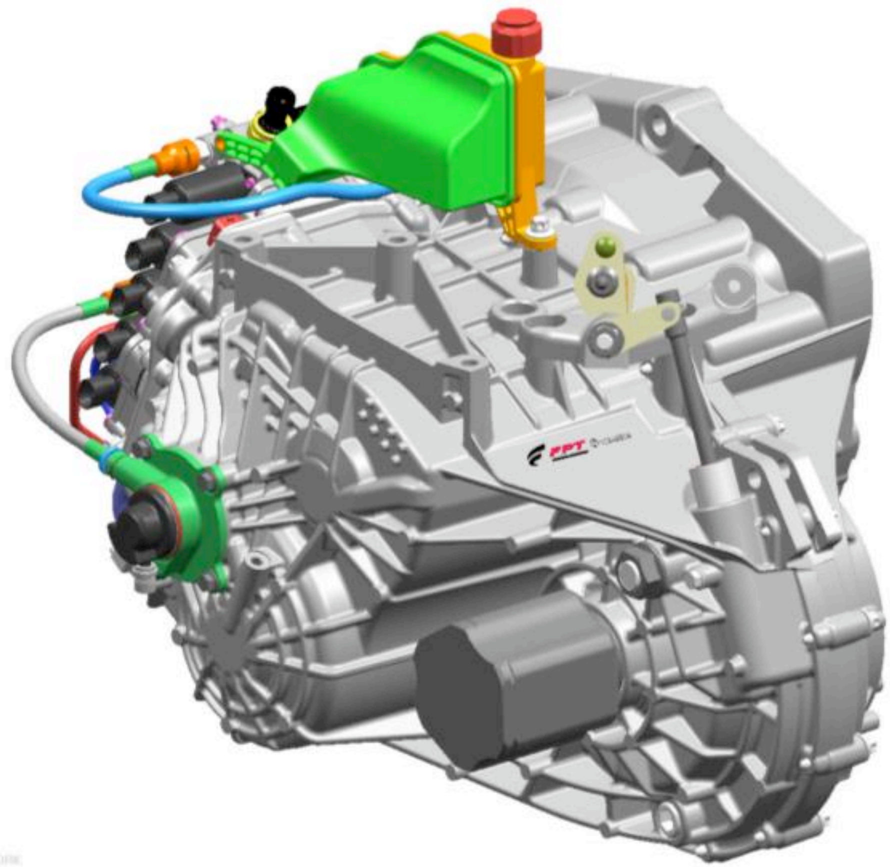
Phase 2 – Transmission Analysis

Target:

Cost Comparison of manual 6 speed vs. dual clutch 6-Speed transmission (dry clutch)



Manual

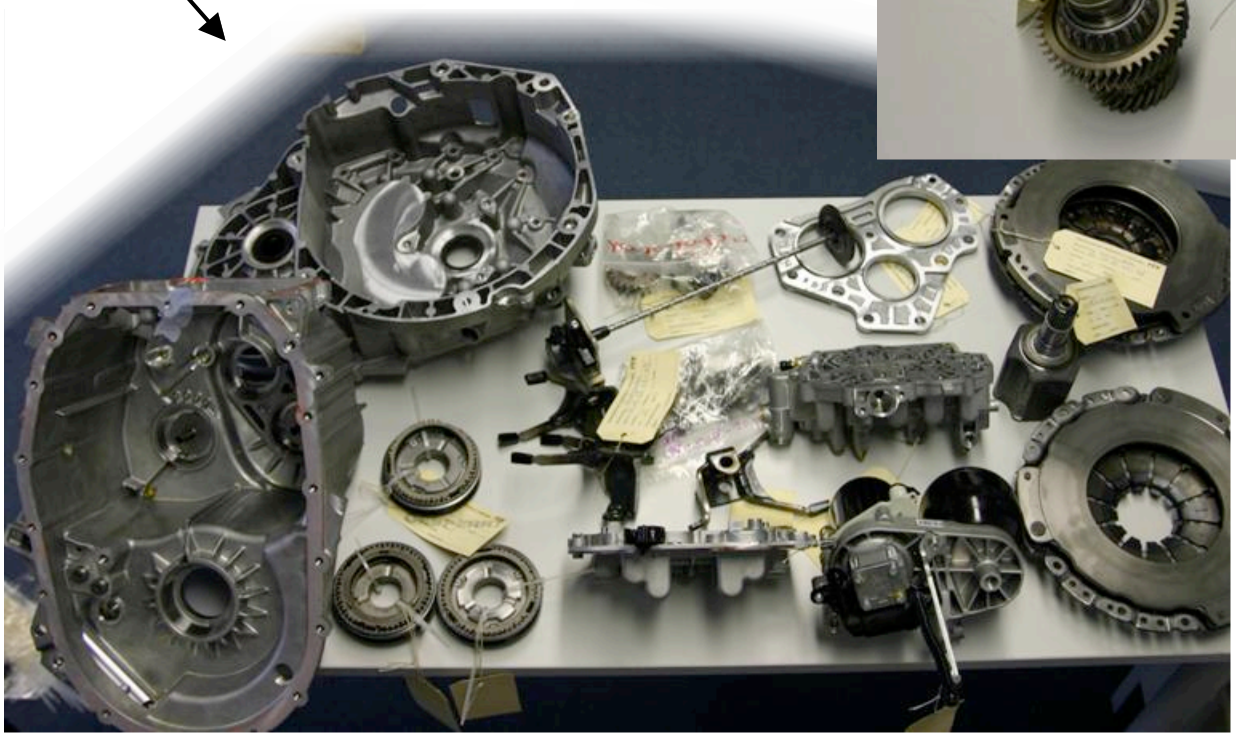


Dry DCT

Phase 2 – Transmission Analysis

Gears, Shafts →

Housing, Clutches,
Actuation System



Phase 2 – Start-Stop Vehicle Technology

Commonly found start-stop system in European Market:

1. Belt Driven starter generator
2. Enhanced starter
3. Direct Starter
4. Integrated Starter Generator

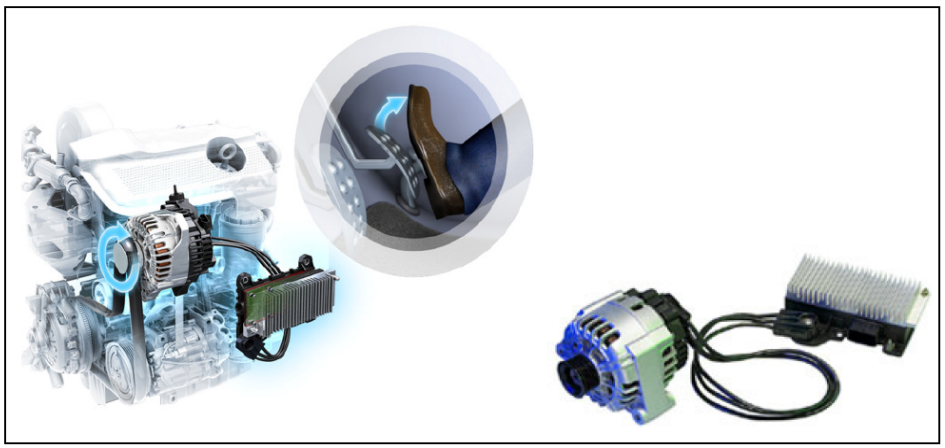


Figure: Start-Stop System i-StARS of Valeo

Manual

Mercedes-Benz A 150 Blue Efficiency (Compact Car)

Starter/Generator Type / Supplier:	Belt-Driven /Valeo (StARS)
Functional Scope	StARS Micro-Hybrid System Stop in neutral, keep brake pedal pushed (Driver-Detection) step off brake pedal starts the engine again Engine off below 8kph
Battery System	AGM-Battery (Varta)
Additional Sensors	
Modified Compo-nents	
Engine	I-4 1.2 **Diesel**, 1991 cm^3, 60 kW I-4 1.5 **Gasoline**, 1498 cm^3, 70 kW I-4 1.8 **Diesel**, 1699 cm^3, 85 kW
Transmission	5-speed, manual
SOP	2009

Phase 2 - Toyota Venza Mass-Reduction and Cost Analysis

- The primary objective of this contract is continue the design concepts of the 2010 Lotus report of the Low Development concept vehicle with 20% vehicle mass reduction along with other recent relevant studies

- The contractor should continue the work started on Lotus's research building on the original assessments to prove concept, cost effectiveness, manufacturing feasibility, and crashworthiness that can, at minimum, meet the performance functions of the original baseline vehicle (2009 Venza) while controlling for both variable and in-direct cost to maintain affordability (10% Max Cost Increase @ 20% Mass Reduction)

- Specifically, the contractor shall use advanced design, material and manufacturing processes that will likely be available in the time frame of the 2017 model year and beyond for the Low Development concept vehicle to optimize and develop an engineering design with sufficient details such that computer modeling can be performed to demonstrate crashworthiness of the vehicle concept in addition to detailed incremental cost estimate for the design, ...

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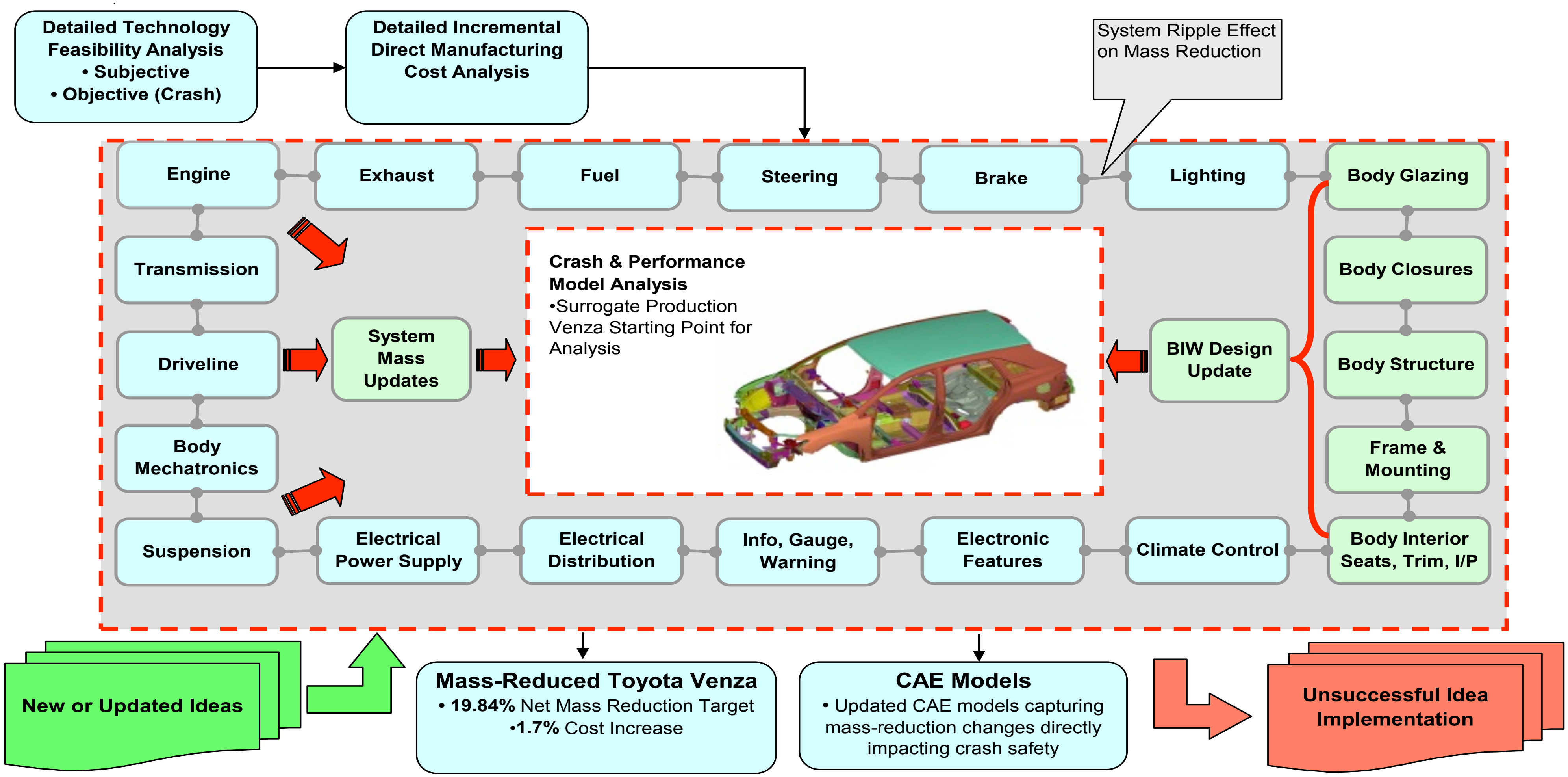
Phase 2 – Venza Mass Reduction and Cost Analysis

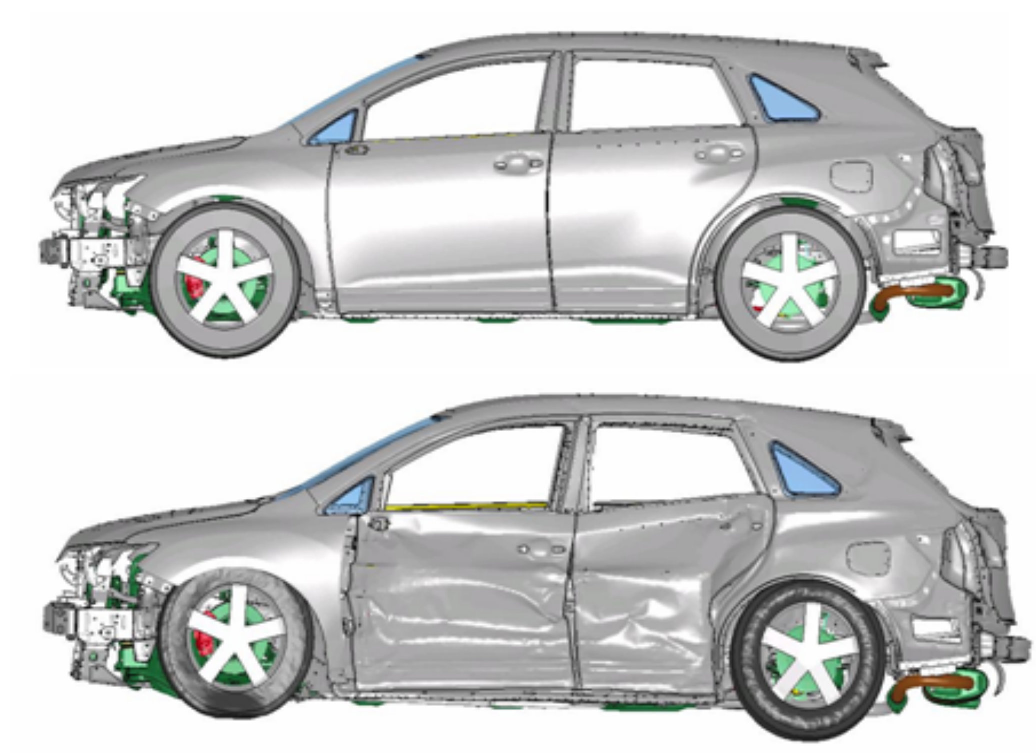


Phase 2 - FMVSS 214 Side Impact BASELINE Results

- ❑ Comparisons of Deformed Shape

Test Results - NHTSA No: MB5128

CAE Analysis Results



Q & A Time

This concludes the FEV portion of the workshop.

FEV would like to thank you for your time.