Technology and cost assessment of 2020-2025 fuel efficiency technologies for light-duty vehicles in China

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International Council on Clean Transportation

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Contents

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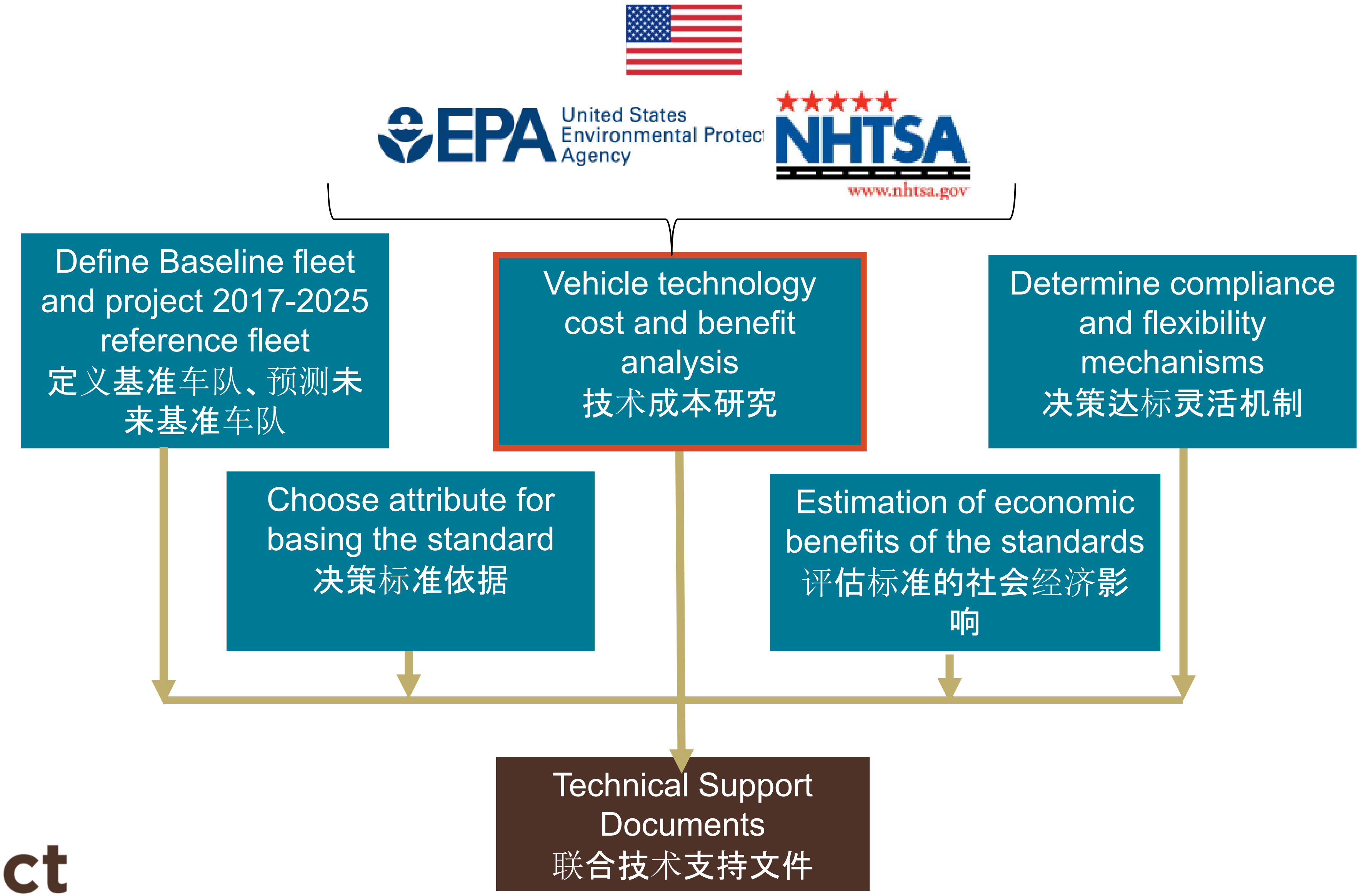
Overview of the ICCT China technology and cost assessment project

- Purpose: analyze technology pathway and associated costs to meet 5L/100km target in 2020 and equally stringent target beyond 2020
- Highlights of methodology
  - Based on years of technical work in the US and EU
  - Adopted in assessing the costs of these technologies – FEV new approach in assessing fuel-saving potentials of future technologies – Ricardo simulation model
  - Adopted new approach tear-down analysis
  - Adopted most recent assessments of mass-reduction technologies
  - High-resolution adaptation to China
- Status: Incomplete / Preliminary.
  - Current estimates presented in these slides are a mixture of Eastern European and China cost data.

The US approaches to develop fuel economy/GHG standards in general



US traditional vs. new approaches to assess vehicle efficiency technologies and costs

	Traditional approach	New approach
Technology assessment	• Interview individual manufacturers and suppliers • Internal judgment	• Interview individual manufacturers and suppliers • Internal judgment • In-depth computer simulation of vehicle technologies with peer review
Cost assessment		• Interview individual manufacturers and suppliers • Internal judgment • In-depth tear-down cost assessment of technology costs with peer review

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ICCT engagement in the US technology study

Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020-2025 Timeframe

EPA United States Environmental Protection Agency

1. INTRODUCTION

Ricardo was subcontracted by Systems Research and Applications Corporation (SRA), a wholly owned subsidiary of SRA International, Inc., under contract to the United States Environmental Protection Agency (EPA) to assess the effectiveness of future light duty vehicle (LDV) technologies on future vehicle performance and greenhouse gas (GHG) emissions in the 2020–2025 timeframe. GHG emissions are a globally important issue, and the EPA's Office of Transportation and Air Quality (OTAQ) has been chartered with examining the GHG emissions reduction potential of LDVs, including passenger cars and light-duty trucks.

SRA is a company of over 7,000 staff dedicated to solving complex problems of global significance for government organizations serving the civil government, global health, and national security markets. SRA's Air Programs and Climate Change Account works extensively with OTAQ and other EPA offices on regulatory and voluntary programs to reduce air pollution and address climate change.

SRA and Ricardo worked closely with the EPA team on nearly every technical and contractual issue.

The team at EPA OTAQ included the following staff members:

- Matt Brusstar, Director, Advanced Powertrain Center, Testing and Advanced Technology Division
- Jeff Cherry, Staff Engineer, Light Duty Vehicles and Small Engine Center, Assessment and Standards Division
- Ann Chiu, Contract Project Officer, Data Analysis and Information Center, Compliance Division
- Ben Ellies, Staff Engineer, Climate Analysis and Strategies Center, Transportation and Climate Division
- Joe McDonald, Senior Engineer, Fuels Center, Assessment and Standards Division

In addition to the SRA-Ricardo team working for EPA, other stakeholders for the program included the International Council on Clean Transportation (ICCT) and the California Air Resources Board (ARB). ICCT contributed funding for the early portion of the study in collaboration with ARB. The Advisory Committee provided advice to EPA, and included the following representatives from ICCT and ARB:

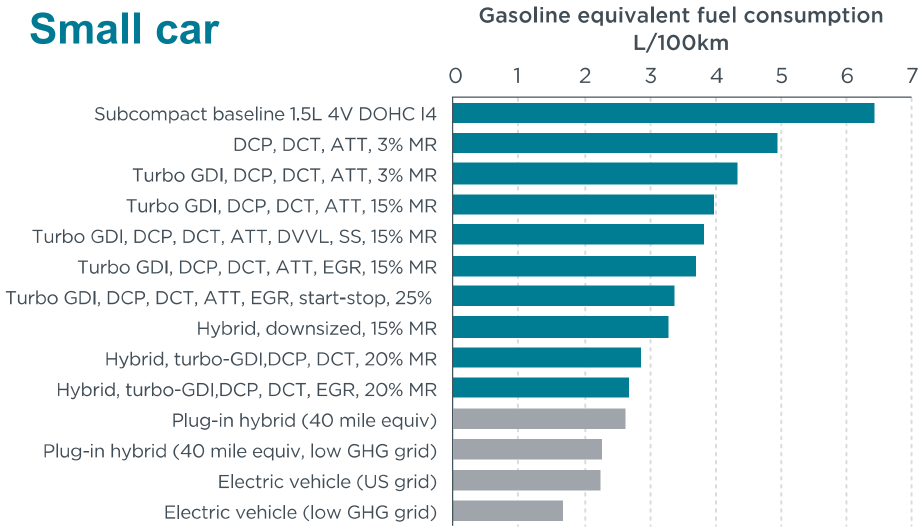
- Steven Albu, Assistant Division Chief, ARB
- Anup Bandivedakar, Senior Researcher, ICCT
- John German, Senior Fellow and Program Director, ICCT
- Paul Hughes, [illegible], ARB

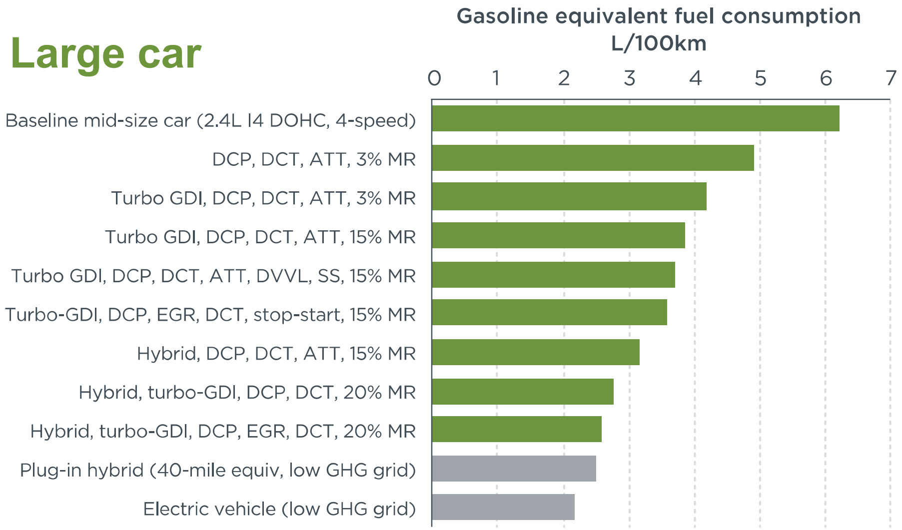
Ricardo, Inc., is the US division of Ricardo plc., a global engineering consultancy with nearly 100 years of specialized engineering expertise and technical experience in engines, transmissions, and automotive vehicle research and development. This program was performed between October 2009 and November 2011.

The scope of the program was to execute an independent and objective analytical study of LDV technologies likely to be available for volume production in the 2020–2025 timeframe, and to develop a data visualization tool to allow users to evaluate the effectiveness of LDV technology packages for their potential to reduce GHG emissions. An assessment of the effect of these technologies on LDV cost was beyond the scope of this study.

29 November 2011 Ricardo, Inc. Page 8

The US studies are good references to China





- EPA assessed various efficiency technology packages for 19 vehicle classes
- Engine, transmission, accessory improvement and mass reduction can realize as much as 42-48% fuel reduction for small and large cars
- On average, price increase of a MY2025 car compared to a current (MY2011) car is about $2,600, or $1,700 compared to a MY2016 car to comply with the FE/GHG standards
- The incremental cost can be paid back as soon as about 3 years. Net lifetime saving is about $3400-$5000

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The ICCT has successfully converted the analysis to EU

Technology cost analysis for US (FEV)

Vehicle CO_2 reduction potential simulation for US (Ricardo)

EU vehicle market statistics (ICCT, Ökopol)

Technology cost analysis for EU (FEV)

Lightweight materials analysis (FEV, Lotus)

Vehicle CO_2 reduction potential simulation for EU (Ricardo)

FEV

Analysis Report BAV 10-449-001
May 17, 2012
Page 1

Light-Duty Vehicle Technology Cost Analysis – European Vehicle Market (Phase 1)

Analysis Report BAV 10-449-001

Prepared for:

International Council on Clean Transportation
1225 I Street NW, Suite 900
Washington DC, 20005
http://www.theicct.org/

An Assessment of Mass Reduction Opportunities for a 2017 – 2020 Model Year Vehicle Program

Prepared by: Lotus Engineering Inc.

Submitted to: The International Council on Clean Transportation

Project Report
Analysis of Greenhouse Gas Emission Reduction Potential of Light Duty Vehicle Technologies in the European Union for 2020–2025

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Van Buren Twp., MI 48111-1641
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FAX: (734) 397-6677

Prepared for: International Council on Clean Transportation (ICCT)
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CO_2 reduction cost curves for EU vehicle segments
Series of ICCT working papers describing how various elements weave together to derive cost curves
(ICCT, Meszler Engineering Services)

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Methodology for technology and cost assessment

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Technology assessment：Mechanism of Ricardo simulation

- Input data (engine maps, road load data, etc.) fed into software tool to calculate fuel consumption / CO_2 emissions over a drive cycle
- The model is validated by comparing calculated results against known data for an existing vehicle model
- Input data is changed (e.g. new engines maps) to account for future changes in technology and model is re-run
- Vehicle simulations takes interactions into account. Ricardo's vehicle simulation methodology follows closely industry-internal approach of vehicle development and was confirmed by an independent peer review

What is so special about the simulations?

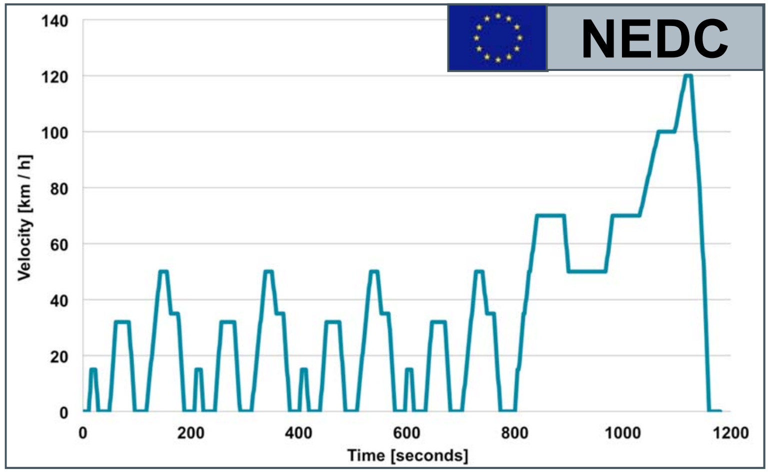
- To study future CO_2 reduction potential, technology interactions have to be accounted for → Ricardo vehicle simulations takes interactions into account by using engine maps that reflect the combined effect of the component technologies
- Ricardo's vehicle simulation methodology follows closely industry-internal approach of vehicle development and was confirmed by an independent peer review:

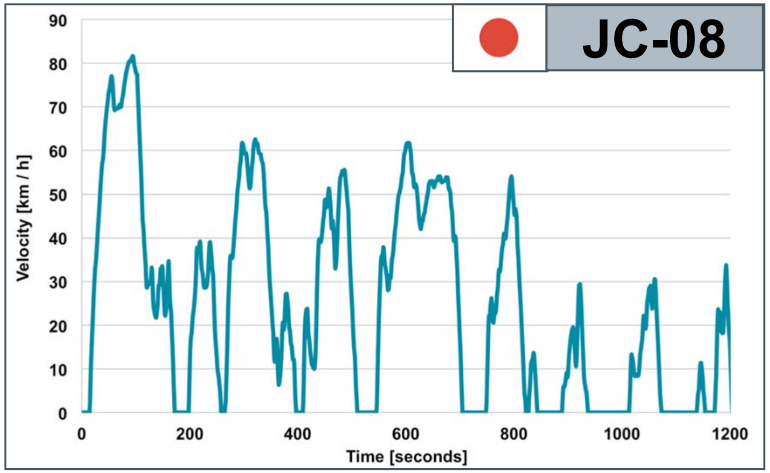
http://www.epa.gov/otaq/climate/strategies-vehicle.htm

Technology packages simulated

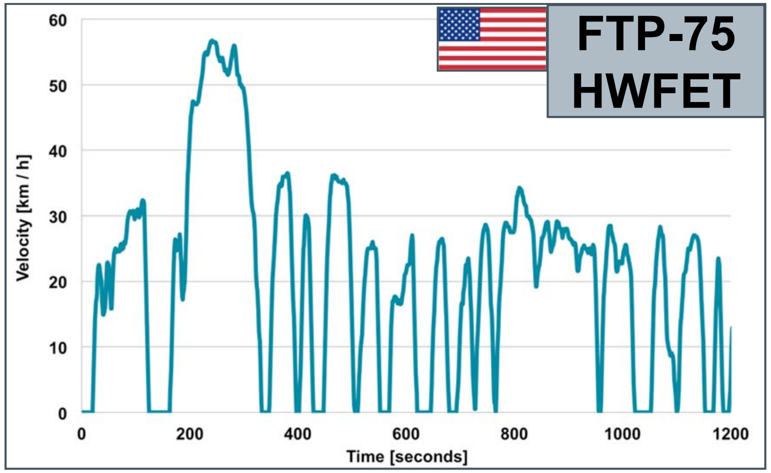
- Start-stop incl. energy-recuperation
- Gasoline direct injection (DI), turbocharging and downsizing (stoichiometric)
- Gasoline DI, turbocharging and downsizing (lean-stoich.)
- Gasoline exhaust gas recirculation (EGR) DI turbo
- Gasoline Atkinson cycle engine with cam profile switching (CPS)
- Gasoline Atkinson cycle engine with digital valve actuation (DVA)
- Gasoline P2 hybrid
- Gasoline PowerSplit hybrid
- **Diesel advanced 2020+ engine**
- Advanced transmission technologies (6/8-speed automatic, dual clutch transmission)
- **Manual transmission sensitivity analysis**

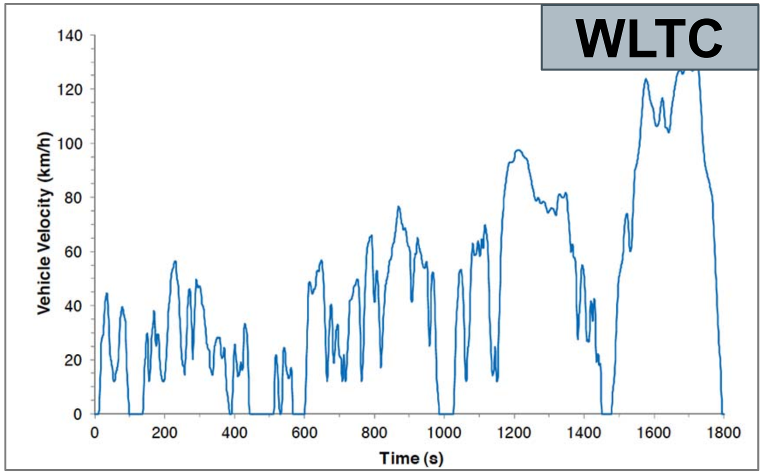
Drive cycles simulated





ICCT sponsored work to add NEDC, JC-08 and WLTP cycles





+ US 06 (Aggressive driving)

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Vehicle simulated were chosen to reflect typical models of major vehicle classes in US and EU

Toyota Yaris ✔	Toyota Camry ✔	Chrysler 300C	Saturn Vue ✔	Dodge G. Caravan ✔	Ford F150 pickup

New (C) New (large N1)

A	B	C	D	E	small SUV	small N1	large N1
Peugeot 107	Toyota Yaris	VW Golf ✔	Toyota Avensis	BMW 5 series	BMW X3	Renault Kangoo	Ford Transit ✔
11%	28%	32%	11%	3%	<5%	≈50%	≈50%

C
Ford Focus ✔
32%

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Data visualization tool software

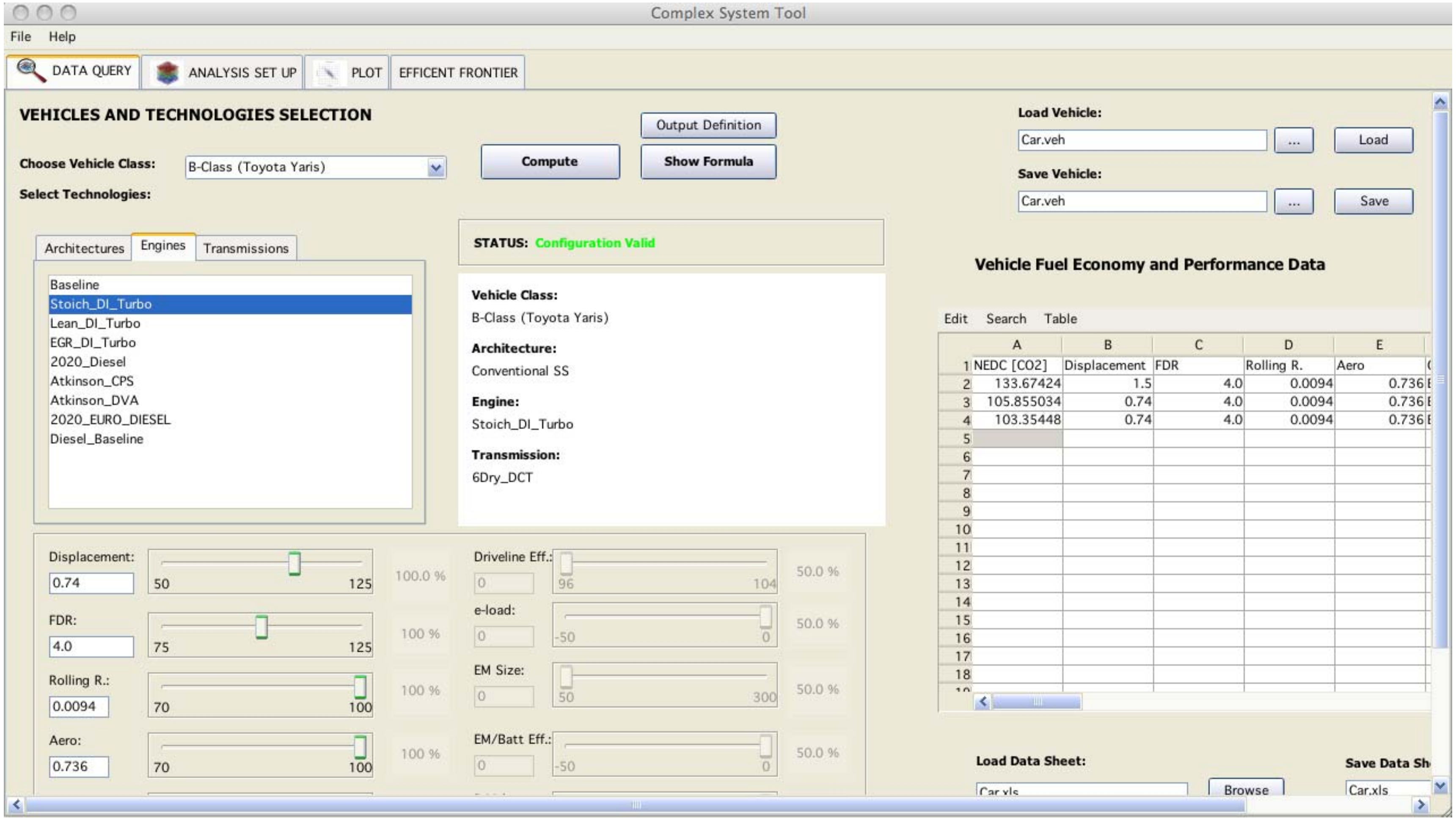

Illustration of technology assessment results

C级（汽油车）
含减低道路负载的技术

	cyl.	[l]	inj.	[kg]	trans.	[s]	[g/km]	em.	red.
EU-27 2010 average **欧盟27国平均水平**	4	1.6	PFI	1,270	5-MT	11.3	156	EU4	+12%
Ricardo baseline (start stop) Ricardo基准水平(start stop)	**4**	**1.6**	**PFI**	1,257	6-MT	9.1	139	EU5	---
STDI（start stop + 化学当量直喷+小型化） -15%减重，-10%滚动/空气阻力	**3**	**0.7**	**DI**	1,058	8-AT 8-DCT	9.0 9.1	89 87	EU6	-36% -37%
LBDI（start stop + 稀燃直喷+小型化） -15%减重，-10%滚动/空气阻力	**3**	**0.7**	**DI**	1,058	8-AT 8-DCT	9.0 9.1	87 85	EU6	-37% -39%
EGBR (start stop + 高负荷EGR直喷+小型化） -15%减重，-10%滚动/空气阻力	**3**	**0.7**	**DI**	1,058	8-AT 8-DCT	9.0 9.1	85 83	EU6	-39% -40%
阿特金森循环发动机，汽油机凸轮廓线变换系统(P2) -15%减重，-10%滚动/空气阻力	**4**	**1.6**	**DI**	1,117	8-DCT	9.1	68	EU6	-51%

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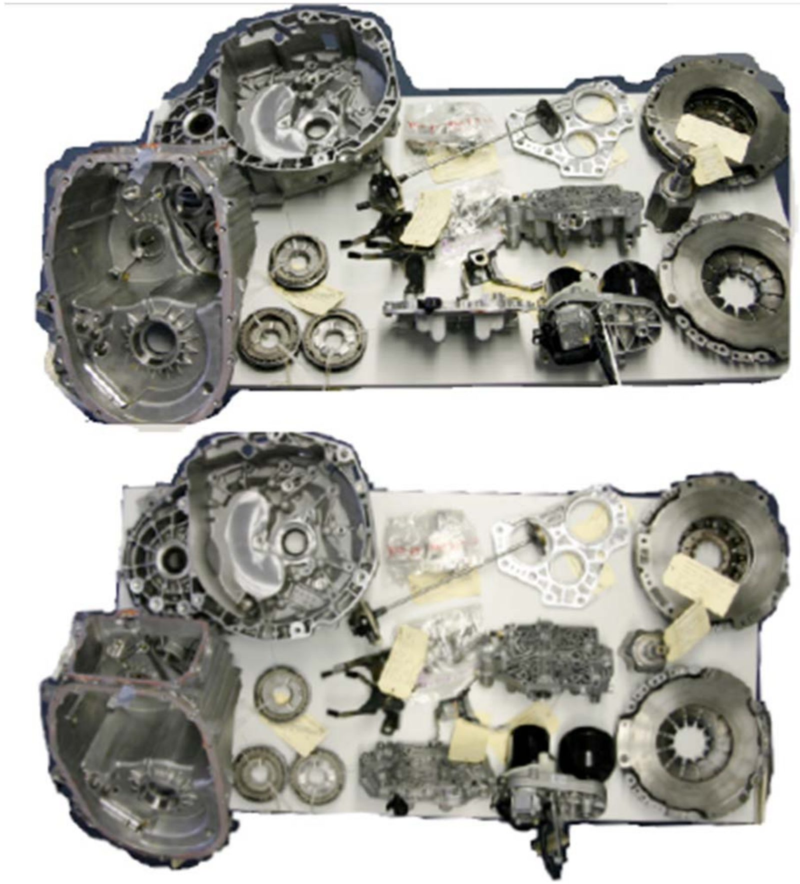
FEV Tear-down approach: tear all the way down to "nuts" and "bolts"



What's special about the tear-down approach

- Key advantages of the tear-down cost analysis approach:
  - great level of transparency
  - reduced uncertainty of results by avoiding learning factors
  - following closely industry-internal approach for costing
  - better transferability to other regions
- Downside of the approach:
  - very expensive
  - can only cost technologies in production, or variations
- Approach has been subject to independent peer-review:

  http://www.epa.gov/otaq/climate/strategies-vehicle.htm

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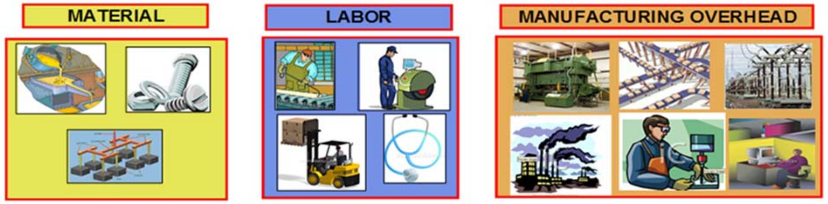
Cost components

- DMC= Material + Labor + Overhead



+ Markup of suppliers

- NIDMC = $DMC_{New} - DMC_{Base}$
- Then Learning Factor for a given year (i) will apply to NIDMC to back out high production volume cost to cost in a given year
- $NITC_i = NIDMC_i \times$ Markup factor for OEMs

DMC= Direct Manufacturing Cost, NIDMC= Net Incremental Direct Manufacturing Cost
NITC= Net Incremental Total Manufacturing Cost

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Illustration of cost analysis results for EU

Cost of gasoline direct injection, turbocharging & downsizing for all classes

技术	ID	案例研究#	基线技术配置	新技术配置	欧洲市场份额	欧洲车辆市场实例	计算的增量（直接）制造成本 2010/2011 生产年度	应用适用技术的净增制造成本（直接 + 间接成本）2012	2018	2020	2026
发动机	小型化涡轮增压汽油直喷式内燃机										
	1	0100	1.4L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.0L, I3, 4V, DOHC, Turbo, GDI, dVVT, ICE	微型车	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	紧凑型/小型车	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	中型车	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	中型/大型车	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	大型运动型多用途车	VW Touareg	€ 648	€ 946	€ 854	€ 726	€ 664
	可变气门时标和升程的菲亚特Multiair系统										
	6	0200	1.4L, I4, 4V, DOHC, NA, PFI, dVVT, ICE	1.4L, I4, 4V-MultiAir, SOHC, NA, PFI, ICE	微型车	VW Polo	€ 107	€ 159	€ 145	€ 126	€ 117

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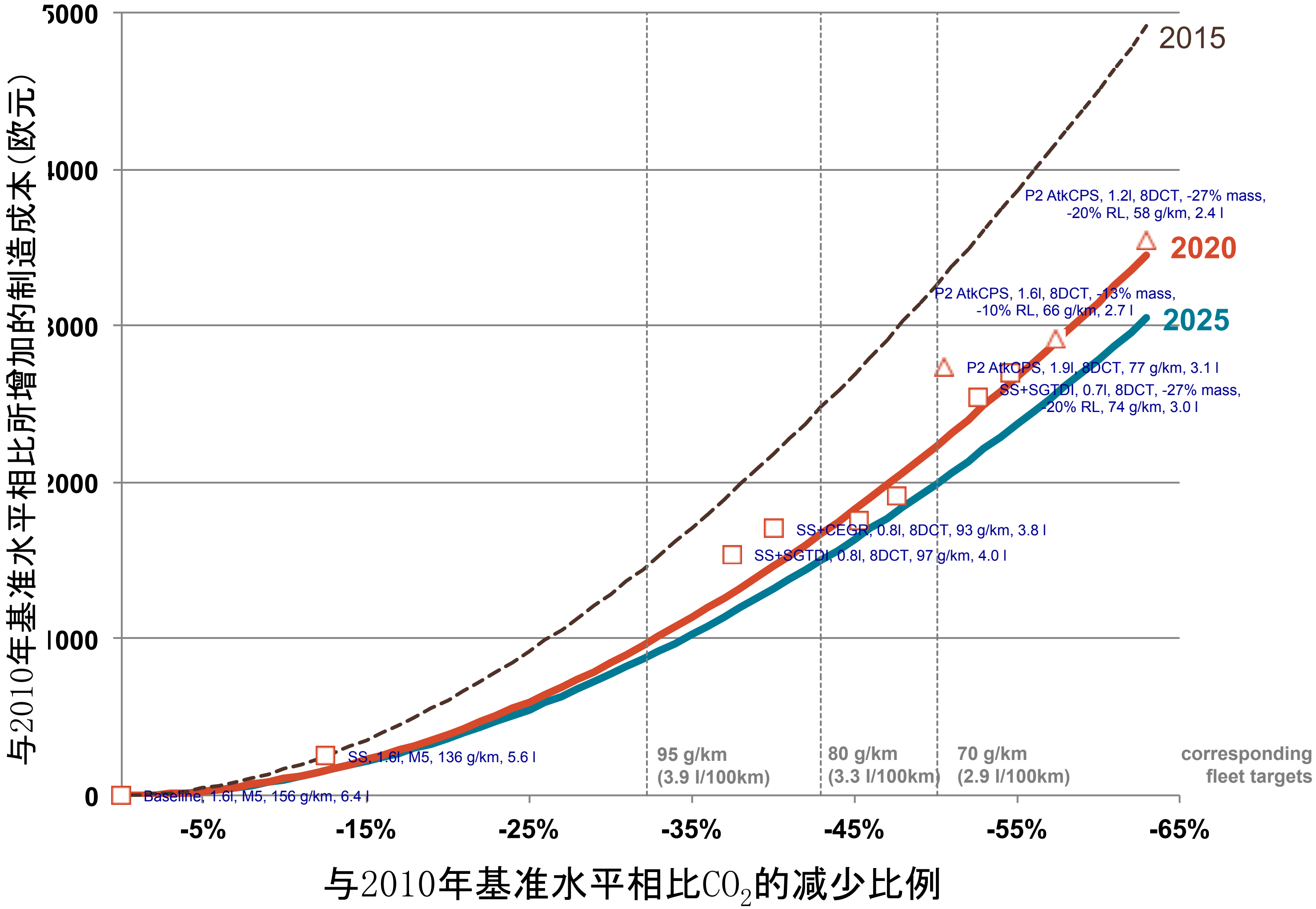
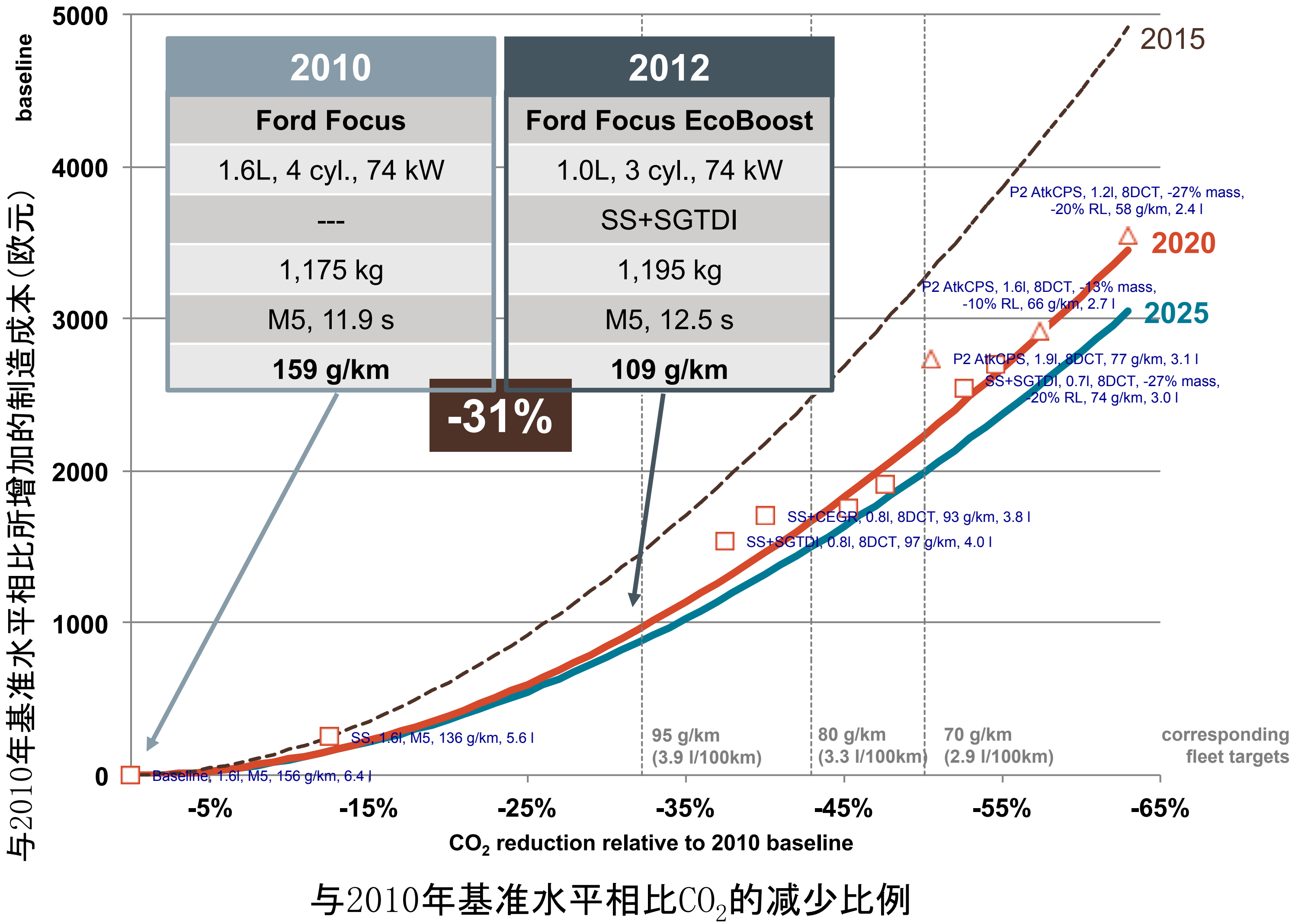
Fitting cost curves for EU

- C级汽油车



Comparing EU analytical results with vehicles on the EU market



2010	2012
Ford Focus	**Ford Focus EcoBoost**
1.6L, 4 cyl., 74 kW	1.0L, 3 cyl., 74 kW
---	SS+SGTDI
1,175 kg	1,195 kg
M5, 11.9 s	M5, 12.5 s
159 g/km	**109 g/km**

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Adaptation to China

Important Note:

Incomplete / Preliminary Data

Basis for the adaptation

- Same driving test cycle
- Similarity in key vehicle features of mainstream vehicle segments

EU 2010 data for EU-27

Segment	Mini-cars		Small		Lower medium		Medium		Upper medium		Off-road		Car-derived vans	
Market share	11%		29%		32%		11%		3%		9%		2%	
Representative model	Peugeot 107		Toyota Yaris		Volkswagen Golf		Toyota Avensis		BMW 5er series		BMW X3		Renault Kangoo	
Diesel share	7%		35%		59%		78%		81%		76%		77%	
	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
Cylinder	3.6	3.8	3.9	3.9	4.0	4.0	4.3	4.1	5.2	5.0	4.2	4.4	4.0	4.0
Displacement [L]	1.1	1.2	1.3	1.4	1.5	1.7	2.0	2.0	2.7	2.5	1.9	2.2	1.5	1.6
Power [kW]	51	51	63	61	87	83	128	109	177	144	111	123	68	67
Auto. transmission share	12%	12%	9%	3%	14%	12%	36%	21%	74%	61%	24%	37%	4%	4%
Curb weight [kg]	904	975	1105	1173	1312	1405	1514	1565	1708	1764	1450	1772	1402	1428
CO_2 [g/km] (NEDC)	118	111	136	113	156	132	178	148	200	163	182	182	178	144

China 2010 passenger car data

Segment	Mini	Small	Lower medium	Medium	Large	SUV	Minivan
Market share	6%	15%	32%	10%	4%	10%	16%
Representative model	Chery QQ3	BYD F3	Hyundai Elantra	Honda Accord	Audi A6	Honda CR-V	Wuling Zhiguang
Diesel share	0%	0%	0%	0%	1%	6%	0%
Cylinder	3.5	3.9	4.0	4.1	5.0	4.1	4.0
Displacement [L]	1.1	1.4	1.6	2.0	2.4	2.1	1.1
Power [kW]	50	71	84	112	141	110	45
Auto. transmission share	17%	26%	44%	67%	89%	50%	0%
Curb weight [kg]	918	1080	1258	1464	1684	1567	998
CO_2 [g/km] (NEDC)	150	157	173	199	211	211	178

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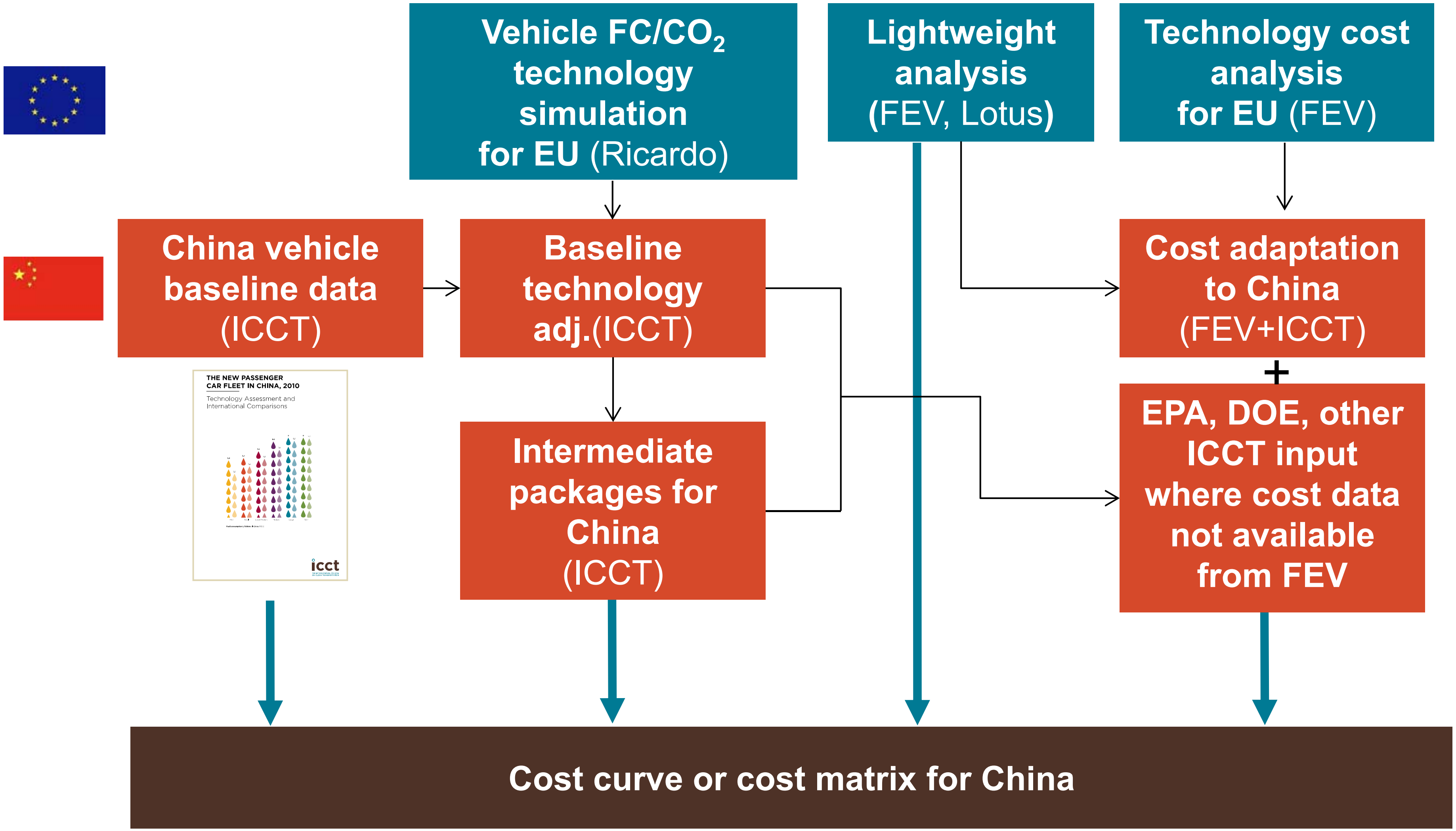
Data sources and processing



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Redefine the starting point for China

Class	B Yaris	Mini	B Yaris	Small	C Focus	LM	D Camry	Medium
Disp.	1.5	1.1	1.5	1.4	1.6	1.6	2.4	2.0
Engine Config.	I4	I4	I4	I4	I4	I4	I4	I4
Fueling:	MPFI	MPFI	MPFI	MPFI	MPFI	MPFI	MPFI	MPFI
Valve:	VVT	Fixed	VVT	Fixed	Fixed	Fixed	VVT	Fixed
Cam Config.	DOHC	DOHC	DOHC	DOHC	DOHC	DOHC	DOHC	DOHC
Transmission:	A6	M5	A6	M5	M6	M5	A6	A5
Start-Stop:	Yes	No	Yes	No	Yes	No	Yes	No
Adv. Alternator:	Yes	No	Yes	No	Yes	No	Yes	No
Alternator Regen:	Yes	No	Yes	No	Yes	No	Yes	No
NEDC L/100km:	5.6	6.4	5.6	6.7	5.7	7.4	7.3	8.5

Class	D Camry	Large	CUV Vue	SUV	B Yaris	Minivan
Disp.	2.4	2.4	2.4	2.1	1.5	1.1
Engine Config.	I4	I4	I4	I4	I4	I4
Fueling:	MPFI	MPFI	MPFI	MPFI	MPFI	TBI
Valve:	VVT	Fixed	VVT	Fixed	VVT	Fixed
Cam Config.	DOHC	DOHC	DOHC	DOHC	DOHC	SOHC
Transmission:	A6	A6	A6	M5	A6	M5
Start-Stop:	Yes	No	Yes	No	Yes	No
Adv. Alternator:	Yes	No	Yes	No	Yes	No
Alternator Regen:	Yes	No	Yes	No	Yes	No
NEDC L/100km:	7.3	9.0	8.2	9.0	5.6	7.6

	Ricardo B	Minivan
CdA (m2)	0.736	1.124
RR	0.009	0.01
Mass (kg)	1055	998

*VVT = inlet and outlet

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Define additional middle technology options for China – example of engine technologies

First Ricardo package =

ATT (Friction Reduction + VVT + DVVL + Transmission + Internal Transmission Improvements + Shift Optimization + Early TC Lockup + Advanced Alternator with Regen. + EPS)

+ Stoichiometric Turbo GDI (STGDI)

+ Start stop

− SGTDI = China Package 4

− Start Stop = China Package 2

− Start Stop − SGTDI = China Package 1

− Start Stop − SGTDI − ATT = China baseline

Costing databases updates for China

- Updates on four major databases
  - Material
  - Labor
  - Manufacturing overhead
  - Markup
- Adopt ICCT ICM
- Discuss learning factors for China

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Example of data collection in China

Item	标准职业分类体系 SOCS Code (BLS)	直接劳动 职务 Direct Labor Title (BLS)	直接劳动 工作内容 Direct Labor Description (BLS)	Currency	Active Rate 2013
tor Vehicle Manufacturing OEM - NAICS 336100					
1	51-2022	电气和电子设备装配工 Electrical and Electronic Equipment Assemblers	组装和调整电气和电子设备，比如计算机，测试设备，遥测系统，电动马达和电池Assemble or modify electrical or electronic equipment, such as computers, test equipment telemetering systems, electric motors, and batteries.	¥ CNY	
2	51-2031	发动机和其他机器装配工 Engine and Other Machine Assemblers	建造，组装或者重建机器，比如发动机，涡轮机和其他相似运用于类似行业的机器，比如建筑业，采掘业，纺织业和造纸业Construct, assemble, or rebuild machines, such as engines, turbines, and similar equipment used in such industries as construction, extraction, textiles, and paper manufacturing.	¥ CNY	
3	51-2092	团队装配工 Team Assemblers	团队作业，组装整个产品或零部件◦任务分配到团队，团队成员轮流作业，个人没有严格工作内容划分Work as part of a team having responsibility for assembling an entire product or component of a product. Team assemblers can perform all tasks conducted by the team in the assembly process and rotate through all or most of them rather than being assigned	¥ CNY	
4	51-2099	其他装配工和组装制造人员 Assemblers and Fabricators, All Other	所有未单列的装配工和组装制造人员All assemblers and fabricators not listed separately.	¥ CNY	
5	51-4011	计算机控机器工具操作人员（金属和塑料）Computer-Controlled Machine Tool Operators (Metal & Plastic)	操作计算机控制的机器或机器人用以完成一个或更多机器功能以及制造金属或塑料工件Operate computer-controlled machines or robots to perform one or more machine functions on metal or plastic work pieces.	¥ CNY	
6	51-4031	切割机，冲床和压制机的设备安装使用和维护人员，金属和塑料Cutting, Punching, and Press Machine Setters, Operators and Tenders, Metal and Plastic	安装使用以及维护机器用以切割，剪切，穿孔，开槽口，玩去，或拉直金属或塑料Set up, operate, or tend machines to saw, cut, shear, slit, punch, crimp, notch, bend, or straighten metal or plastic material.	¥ CNY	

Item	中国时薪均值(元) Mean China Hourly (REF) YUAN	Hourly Wage Percentage 10%	Hourly Wage Percentage 25%	时薪中位数Median Hourly Wage	Hourly Wage Percentage 75%	Hourly Wage Percentage 90%	间接劳动比率 Indirect Labor Rate Ratio ILRR "%"	间接劳动每小时贡献额 Indirect Labor Contribution $/Hour	维护维修和运营劳动力比率MRO Labor Rate Ratio MLRR "%"	MRO Labor Contribution $/Hour	Fringe Allocation "%"	Fringe Contribution $/Hour	Total Labor Rate $/Hour
							42.11%	¥0.00	13.22%	¥0.00	160.00%	¥0.00	¥0.00
1							38%	¥0.00	11%	¥0.00	160%	¥0.00	¥0.00
2							34%					00	¥0.00
3							44%					00	¥0.00
4							38%	¥0.00	13%	¥0.00	160%	¥0.00	¥0.00
5							42%	¥0.00	12%	¥0.00	160%	¥0.00	¥0.00
6							38%	¥0.00	19%	¥0.00	160%	¥0.00	¥0.00

IMPORTANT:

Need updated values for green highlighted cell.

Yellow highlighted cells would be useful for sensitivity, but not 100% mandatory

IMPORTANT:

Left US Indirect, MRO and Fringe Ratios for reference. I would expect these to be a lot different fot China.

i.e., columns s, U and X

Code (USA)	Classification (USA)	Code (CHN)	Classification (CHN)
51-2022	Electrical Assembly-OEM	6050400	电气元件装配工
51-2031	Complex Assembly-OEM	6050300	动力设备装配工
51-2092	General Assembly-OEM	6050201	底盘装配工
51-2099	Work Cell Operator-OEM	6050201	装配钳工
51-4011	CNC Operator-OEM	6040108	数控操作工
51-4031	Cut/Punch/Forming Operator-OEM	6040400	钣金工
51-4033	Grinding/Polishing Operator-OEM	6040104	磨工
51-4122	Welding/Soldering Operator-OEM	6040201	铸工
51-9122	Painter Operator-OEM	6040502	涂装工

ICCT+CAT
ARC+FEV

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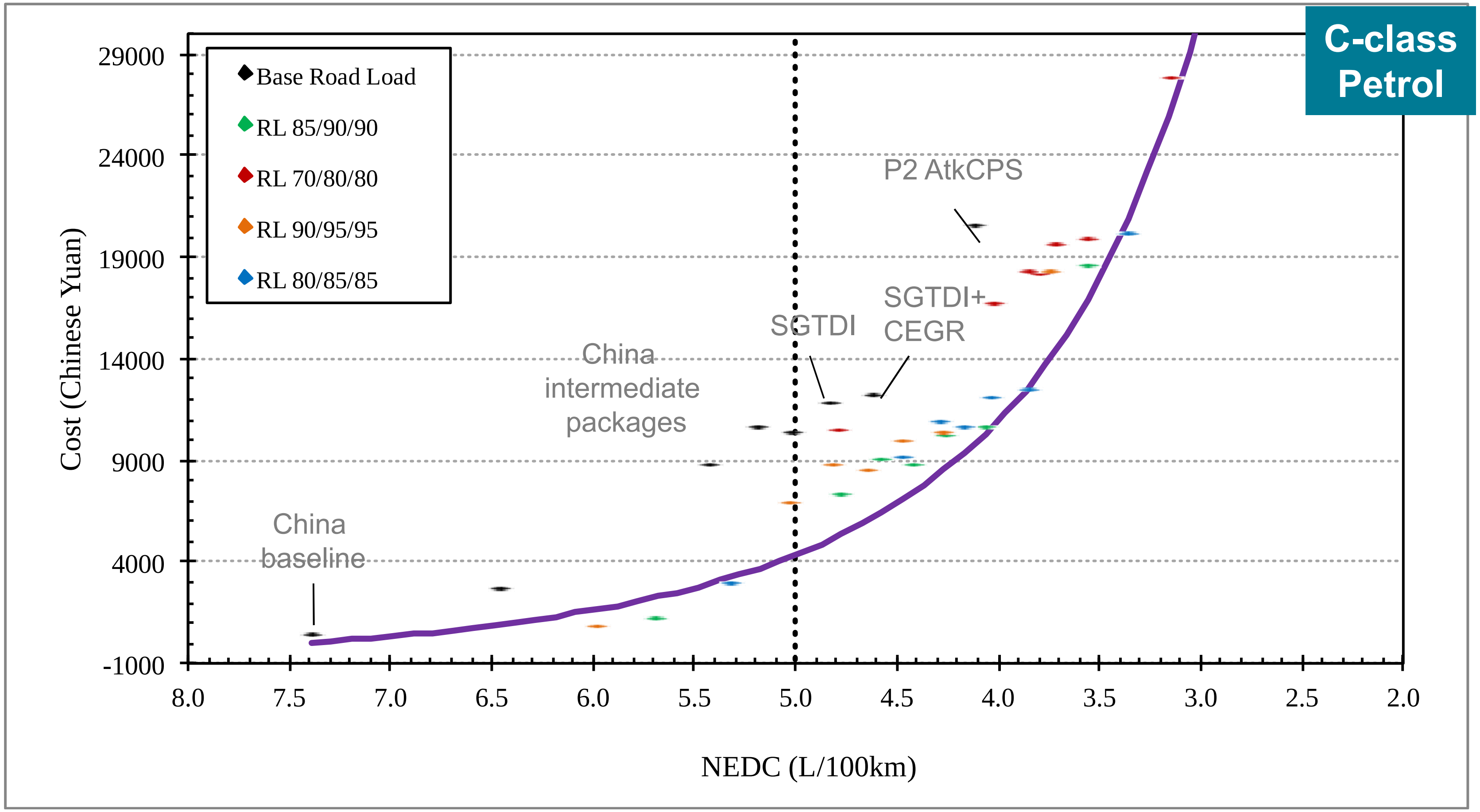
#

2020 incremental cost to OEM – Incomplete / preliminary results using Eastern EU data



- Each dot represent one tech package under certain road load scenario
- Fitted curve is determined by regressing the most cost-effective tech packages
- Temporarily based on eastern European labor rate
- Incremental cost to meet 5L/100-km for this class is less than 5,000 *Yuan*, this estimate is possibly conservative – high estimate

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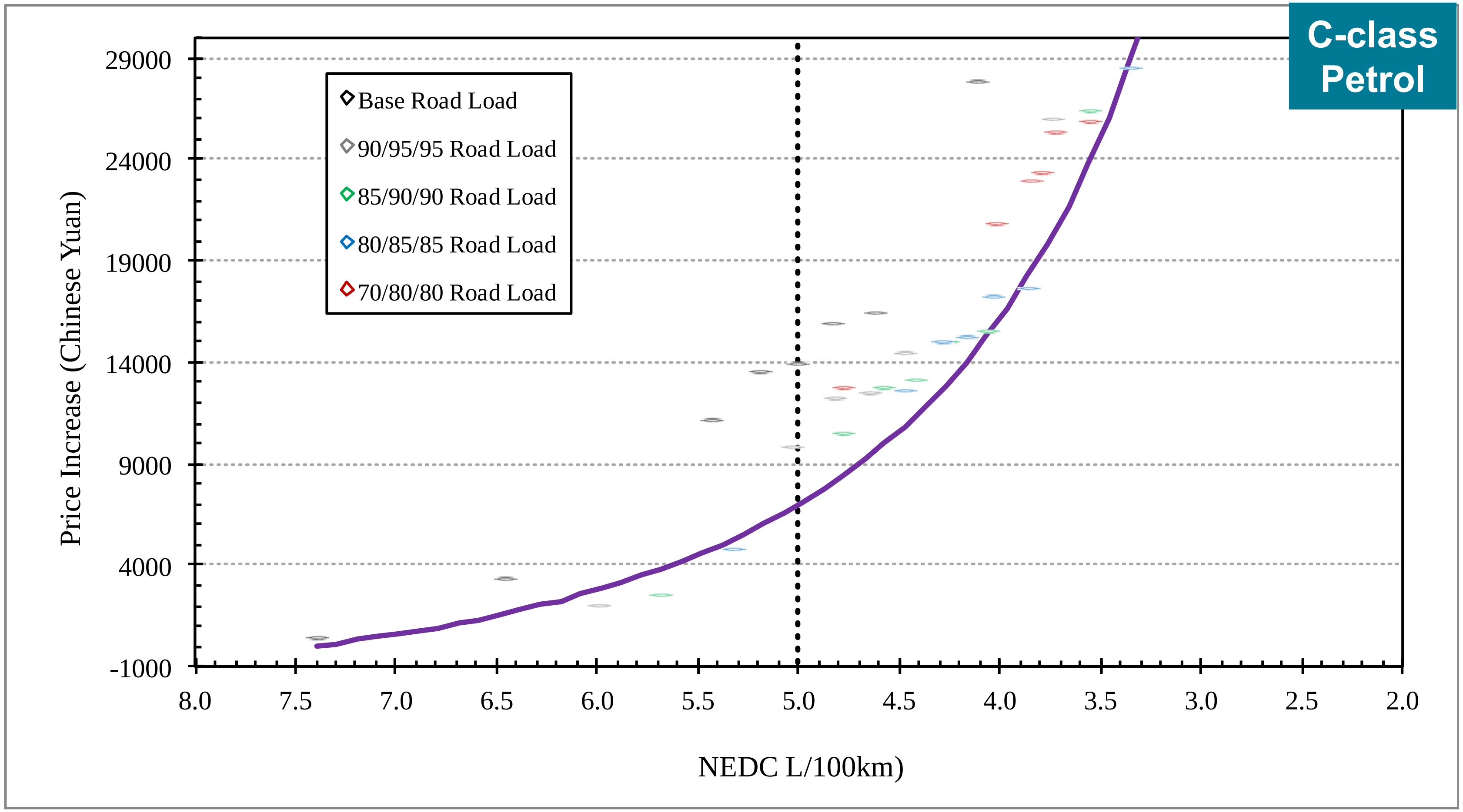
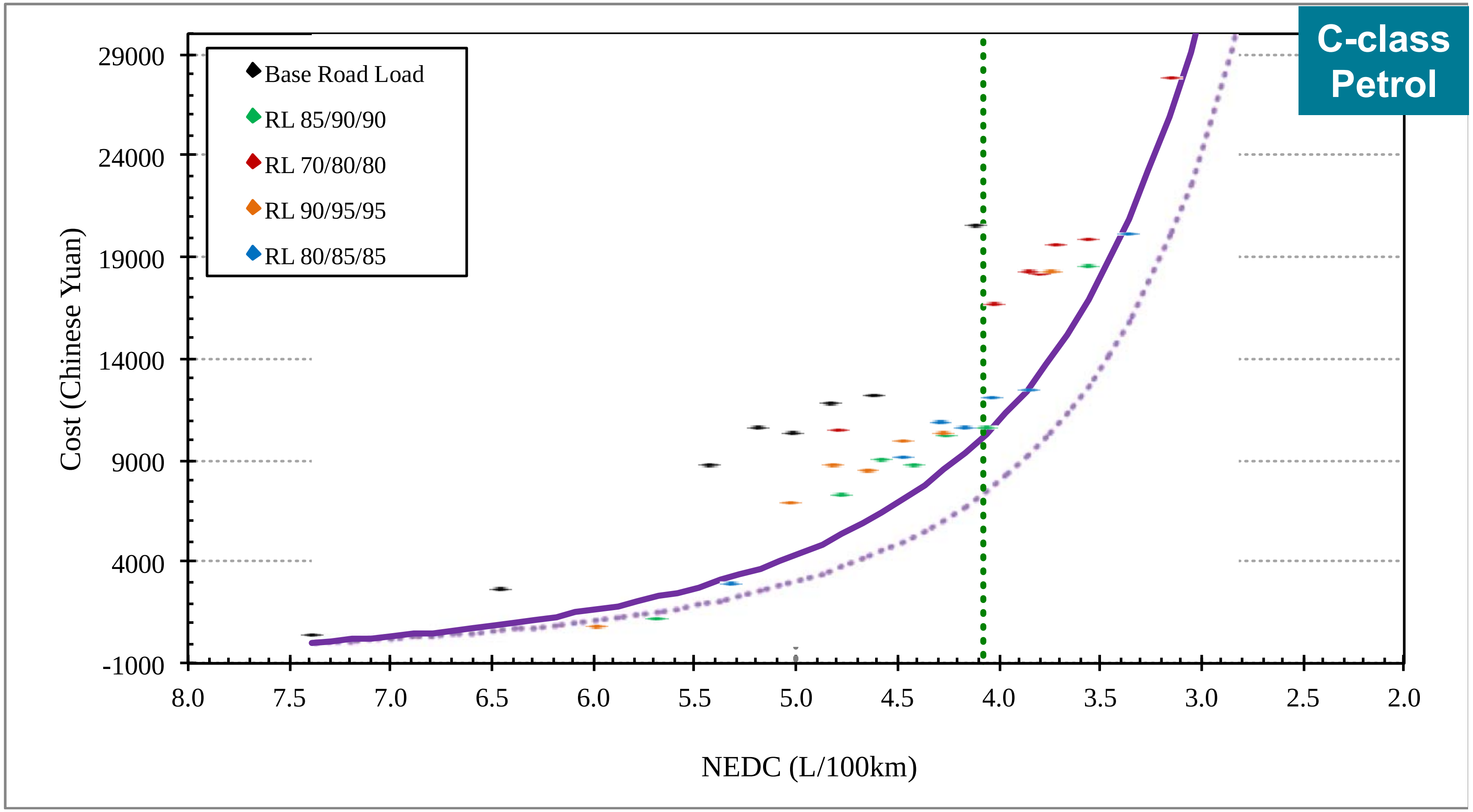
2020 price increase to consumers (total cost) – Incomplete / preliminary results using Eastern EU data



- Fitted curve is determined by regressing most cost-effective tech packages
- Temporarily based on eastern European labor rate
- Price increase to meet 5L/100-km for this class is about 7,100 *Yuan*

2025 incremental cost to OEMs – Incomplete / preliminary results using Eastern EU data



Assuming 4% annual reduction rate to get to 4.1L/100km target in 2025

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Regulatory Design Matters

Potential cost savings from mass reduction technologies

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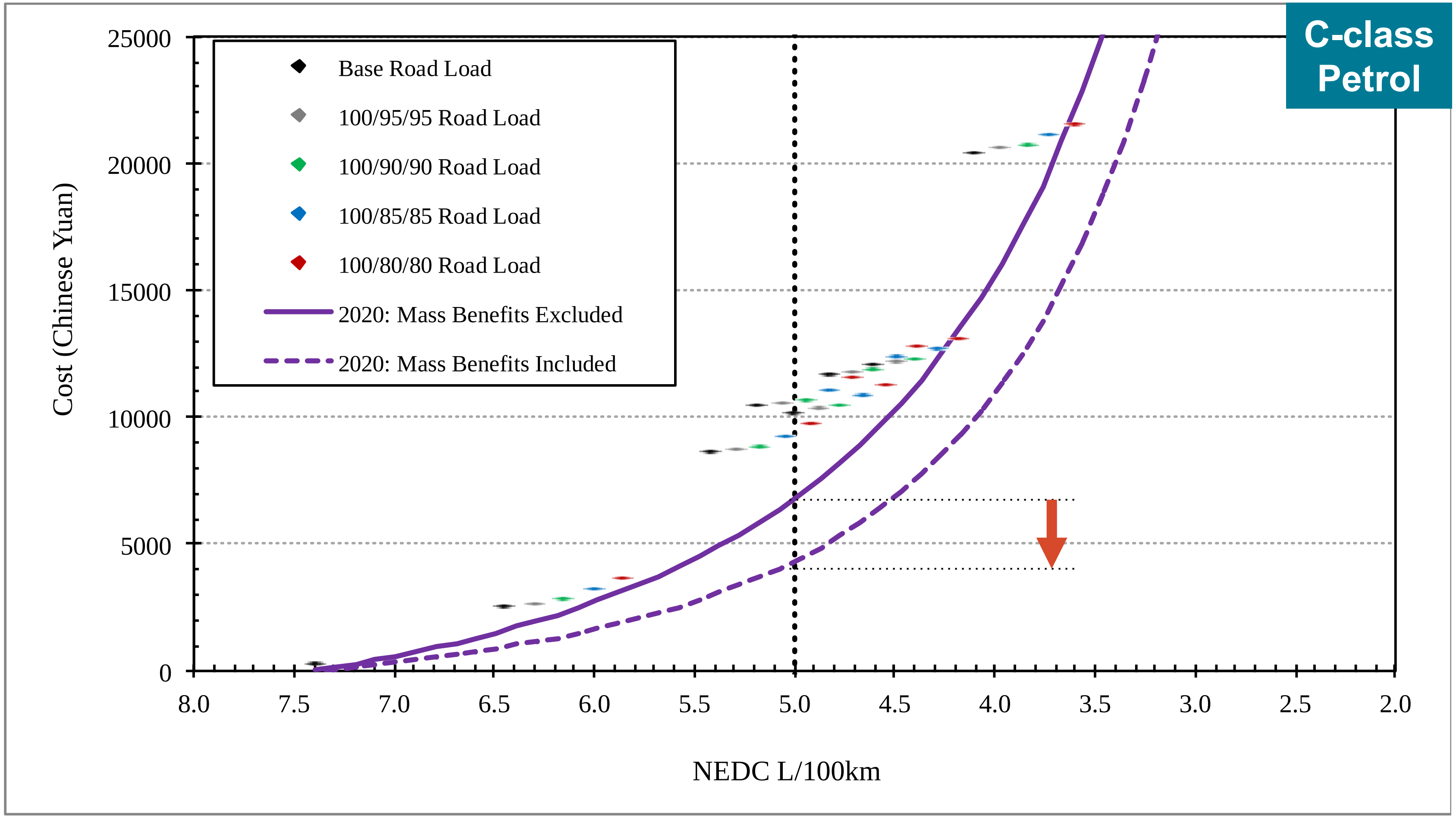
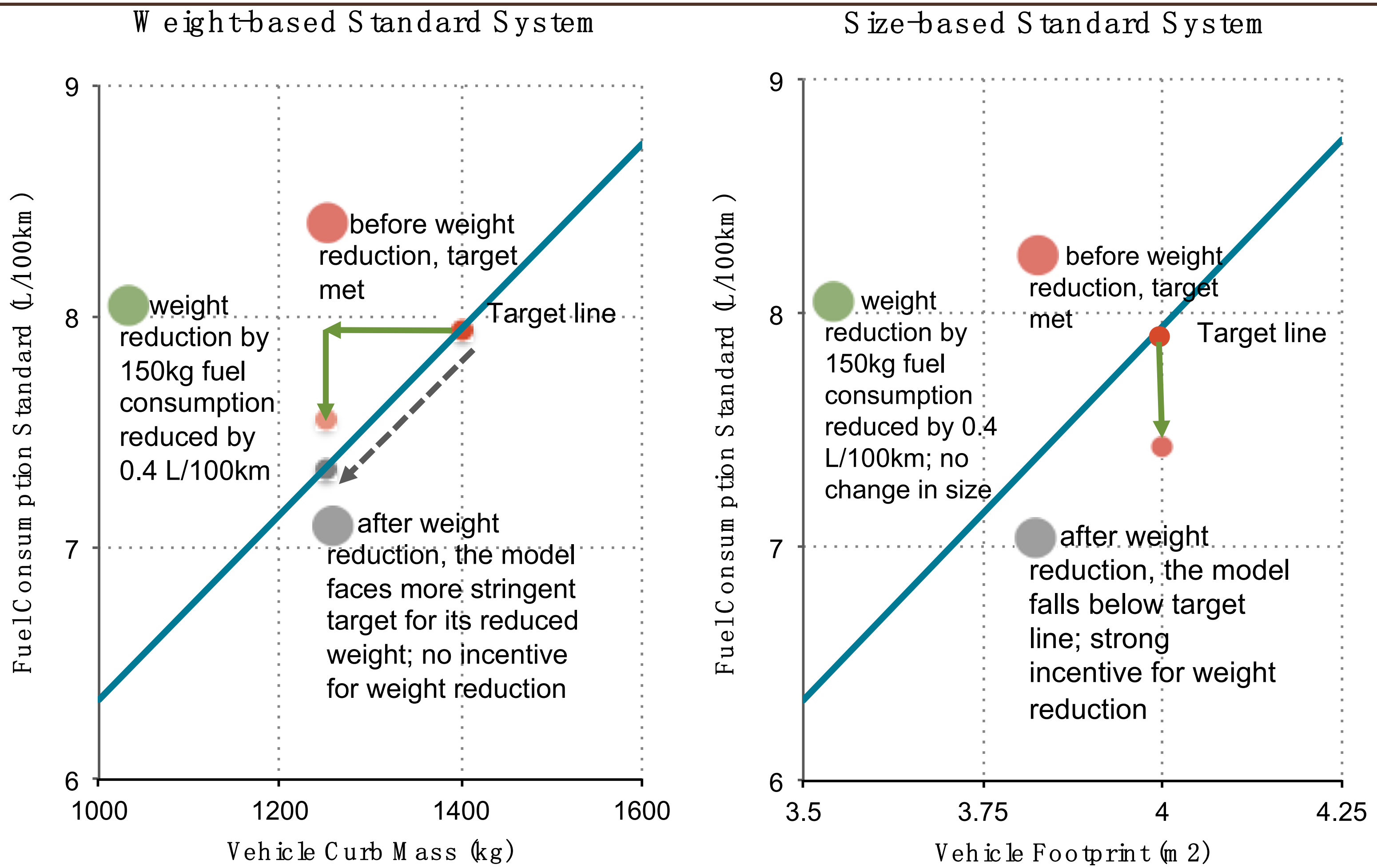
Mass reduction technologies significantly lower the compliance cost – preliminary results



Nearly 2500 *Yuan* cost reduction, or over 35% cost saving, to OEMs with mass reduction technologies

Regulatory design matters



- Weight-based standard always assigns a penalty to mass reduction
- Footprint-based standard fully awards mass reduction technologies

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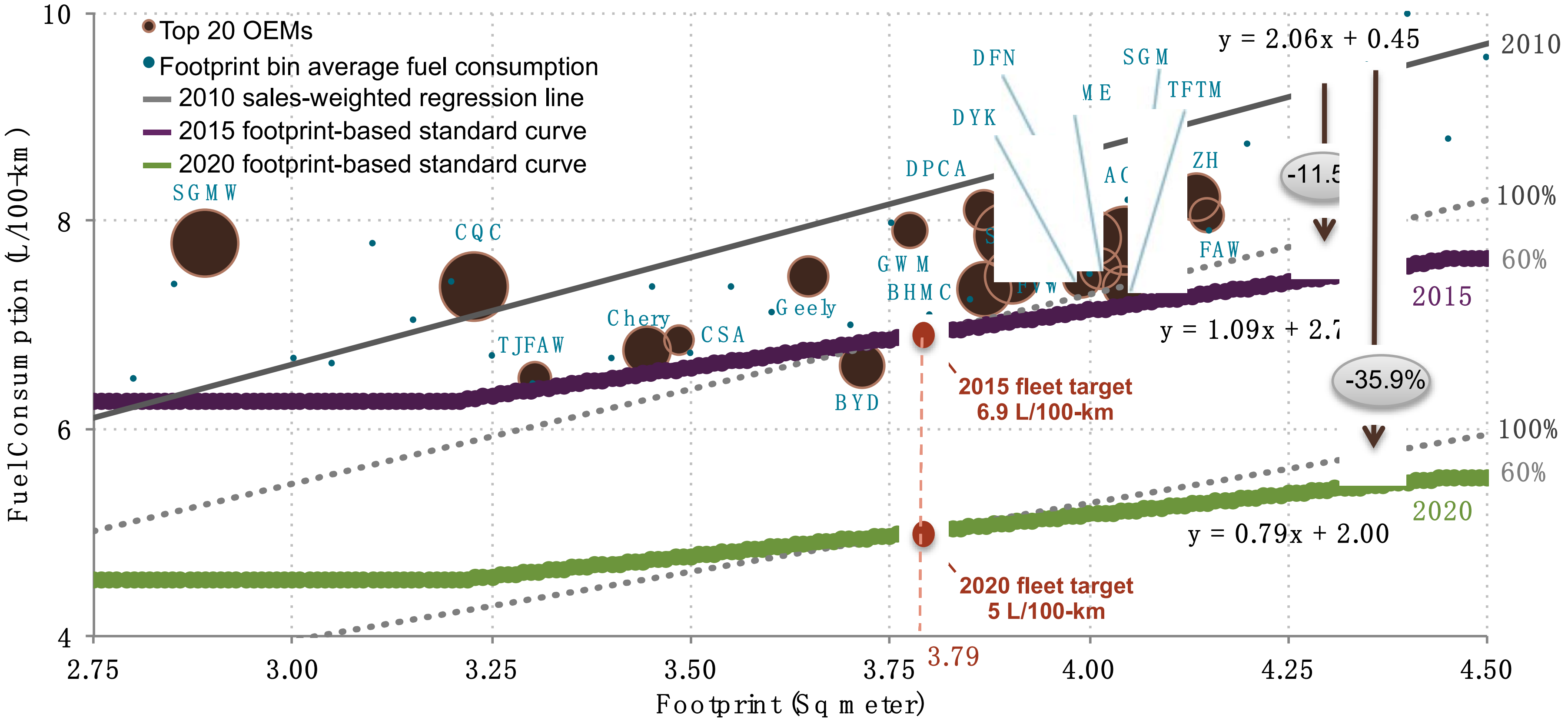
A footprint-based fuel consumption standard for China



…that does not change the overall fleet fuel consumption targets for 2015 and 2020, and can significantly lower the compliance cost

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Conclusions

- New approach to technology and cost assessment (Ricardo simulation and FEV tear-down cost) offer good complement to existing studies in China.
- Benefits of new approach: data driven, transparent assumptions, and similar to approach used by industry to redesign vehicles.
- Our preliminary cost estimates (though still lacking important Chinese data) suggest that the 5l/100km target can be met at reasonable cost.
- Importantly, preliminary results suggest 5l/100km standard will not require the most expensive technologies such as full hybridization or electrification.
- Compliance costs could be substantially lower if China modified its current regulatory design to shift from mass- to size-based scaling factor.

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Thank you!

谢谢！

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Publications

- Ricardo: “Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020-2025 Timeframe", Dec. 2011.
  - Computer simulations of 6 baseline vehicles, gasoline direct injection with turbocharging, boosted EGR, Atkinson cycle (for hybrids), both parallel (P2) and powersplit hybrid systems, 6/8 speed advanced automatic transmissions, and dual-clutch automated manual transmissions (DCT).
  - http://www.epa.gov/otaq/climate/documents/420r11020.pdf
- Ricardo: “Analysis of GHG Emission Reduction Potential of Light Duty Vehicle Technologies in the European Union for 2020–2025”, May 2012
  - Added NEDC and JC08 test cycles, added C class vehicle (Golf/Focus) and small commercial van (Ford Transit), updated diesel engine map, compared manual transmission to DCT efficiency
  - http://www.theicct.org/ghg-emission-reduction-potential-ldv-technologies-eu-2020-2025
- FEV: “Light-Duty Vehicle Technology Cost Analysis – European Vehicle Market (Phase 1)”, May 2012.
  - Created and used European materials, labor, overhead, and mark-up to translate US cost estimates to Europe for: Downsized turbocharged GDI; 6- and 8- speed auto transmission; 6 speed wet DCT; Variable valve timing (VVLT); Powersplit hybrid; P2 hybrid; Electrical air compressor
  - http://www.theicct.org/light-duty-vehicle-technology-cost-analysis-european-vehicle-market
- FEV: ”Light-Duty Vehicle Technology Cost Analysis – European Vehicle Market, Additional Case Studies (Phase 2)”, Sept. 2012.
  - Diesel engine downsizing; 2500 bar diesel injection systems; Diesel VVLT; Two stage Diesel EGR; Cooled and uncooled low-pressure gasoline EGR; 6-spd dry DCT; start-stop system evaluation
  - http://www.theicct.org/light-duty-vehicle-technology-cost-analysis-european-vehicle-market
- ICCT: “Initial processing of Ricardo vehicle simulation modeling CO2 data”, July 2012.
  - http://www.theicct.org/initial-processing-ricardo-vehicle-simulation-modeling-co2-data
- ICCT: “Summary of the EU cost curve development methodology”, November 2012.
  - http://www.theicct.org/eu-cost-curve-development-methodology