Technology and cost assessments for new passenger cars in China
中国近、中期乘用车节油技术路径和成本分析

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轻型汽车节能法规与技术路径国际研讨会
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Goals – three questions
项目初衷：三个问题

- Provide technical support to 2020-2025 (and possibly beyond) light-duty vehicle fuel consumption standards development
  - Stringency?
  - Technologies?
  - Costs?

- 为2020–2025年甚至以后的中期轻型车油耗标准制定提供技术依据
  - 标准定多严？
  - 采取什么技术路径？
  - 成本如何？

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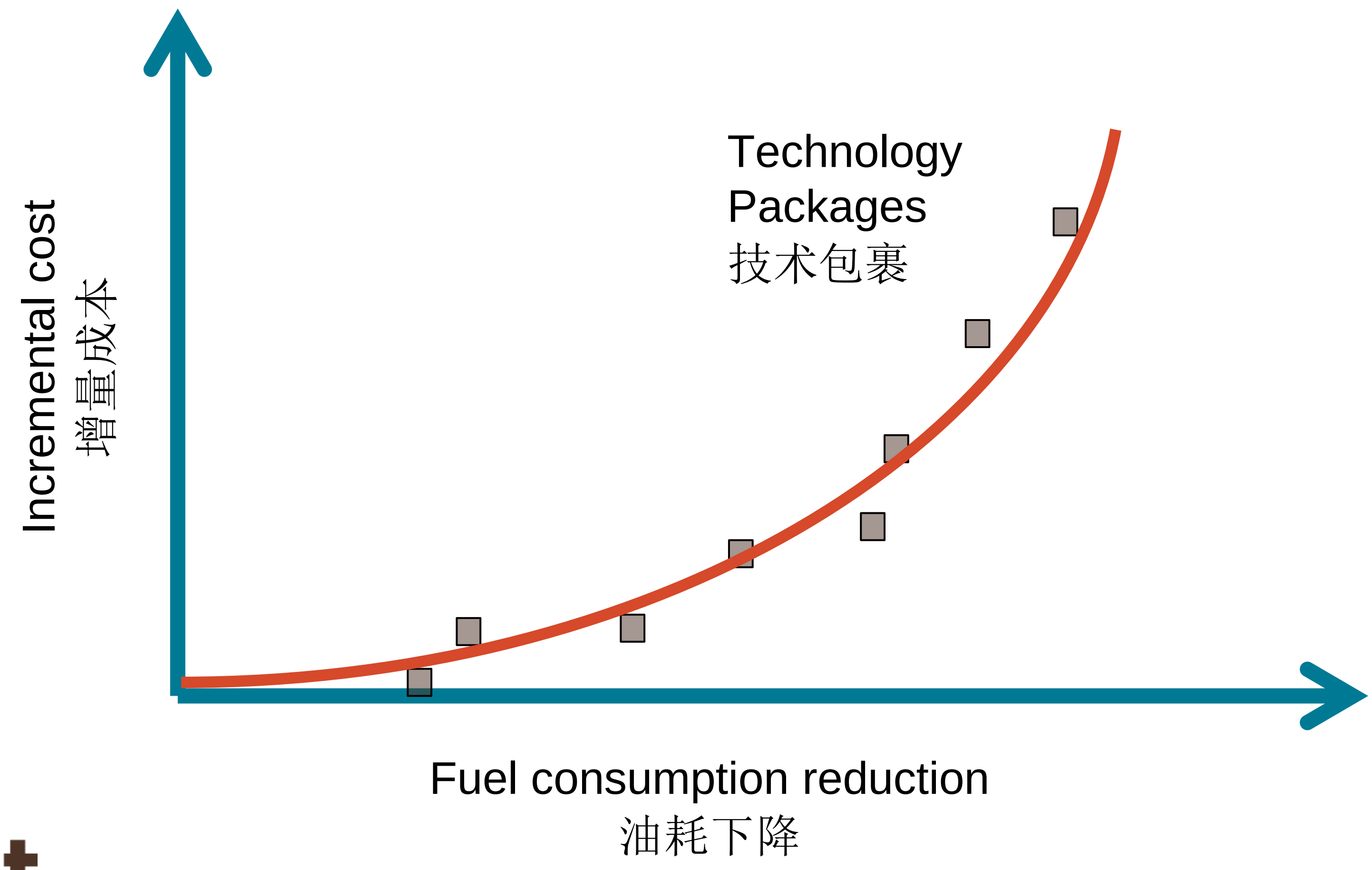
A technology cost curve for China
希望推导出中国乘用车技术成本曲线



Highlights of the project 项目特点

- A joint project between the ICCT and CATARC
- Transferred the newest US/EU methodologies to China
- Adopted new approach in assessing fuel-saving potentials of future technologies – Ricardo simulation model
- Adopted new approach in assessing the costs of these technologies – FEV tear-down analysis
- Adopted most recent assessments of mass-reduction technologies
- High-resolution adaptation to China

- ICCT与CATARC合作项目
- 将美国和欧盟最新的技术和成本评估方法论应用于中国
- 采用了Ricardo技术评估模拟，这一EPA采用的新研究方法分析各项未来技术节油潜力
- 采用了FEV开发的“技术拆解分析”法来分析新技术增量成本
- 纳入了美国和欧洲近几年轻量化技术分析结果
- 技术和成本分析过程高度本地化（中国化）

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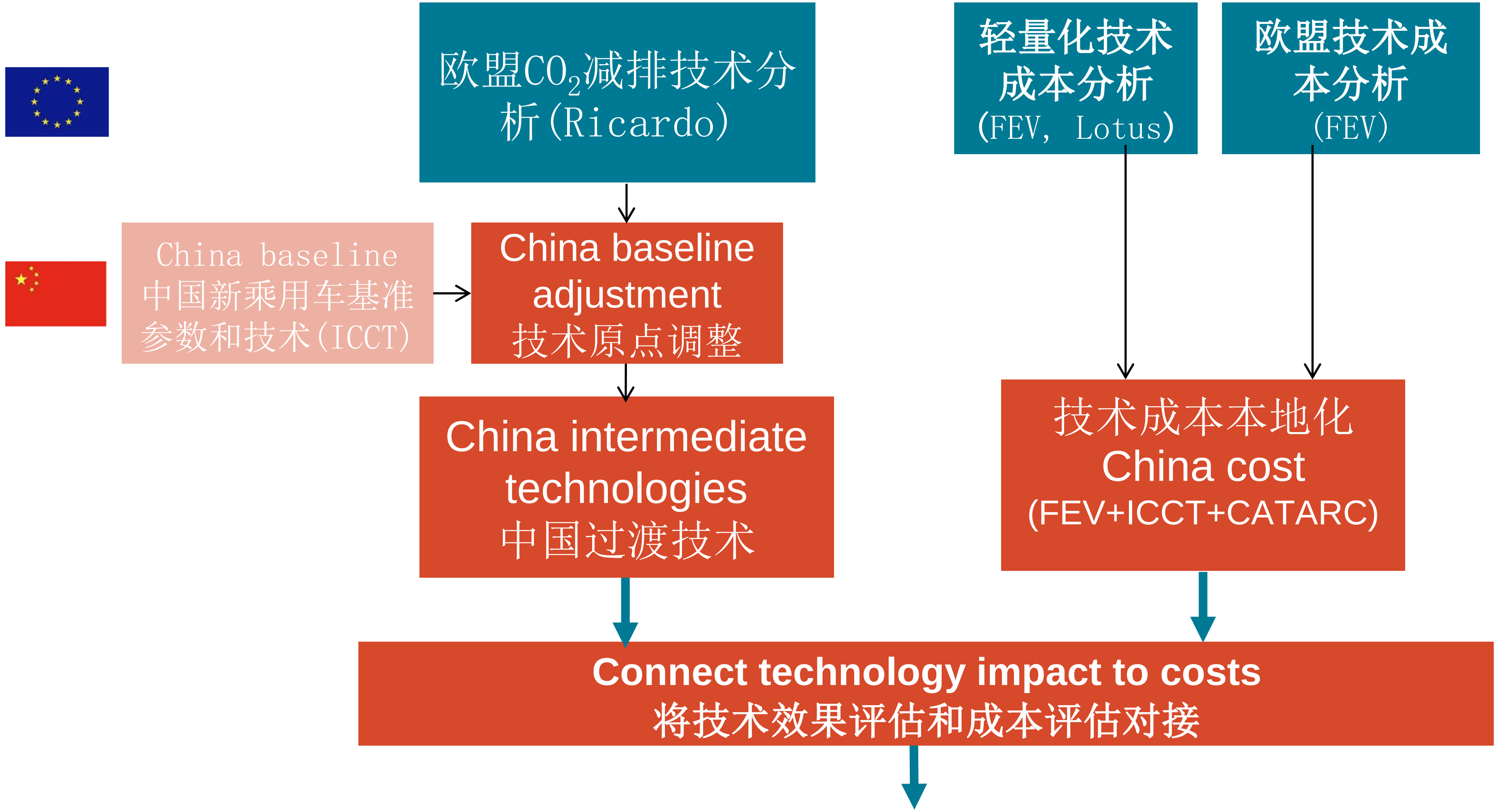
Methodology and data flow
方法论及关键步骤



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Technology assessment based on Ricardo simulation

Ricardo对技术节油效果的仿真模拟

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About Ricardo simulation 关于仿真模拟

- Simulation models are widely adopted in the auto industry for product design and technology evaluation
- US EPA referred to Ricardo simulation results to development its 2017-2025 LDV standards
- Contracted by ICCT, Ricardo expanded the EPA simulation by adding in new technologies, vehicle classes, and test cycle
- Visualization software DVT

- 汽车行业已广泛运用、高度认可的产品开发和技术评估工具
- 美国EPA运用Ricardo仿真结果制定了2017-2025轻型车油耗标准
- ICCT雇佣Ricardo扩展了模拟内容以适用欧洲和中国的政策制定
- 用户可操作的模拟软件DVT

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Design space : major technology packages
仿真模拟的设计规模:主要动力传动系技术包

- 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

- Start-stop 包括能量回收
- 汽油直喷、涡轮增压和发动机小型化（化学当量混合）
- 汽油直喷，涡轮增压和发动机小型化（稀化学当量混合）
- 汽油的废气再循环（EGR）涡轮直喷
- 阿特金森循环发动机，汽油机凸轮廓线变换系统（CPS）
- 阿特金森循环发动机与汽油机数字式阀门驱动（DVA）
- 并联式混合动力(P2)
- 混联式混合动力(power-split)
- 先进柴油机发动机（2020 +发动机）
- 先进变速器技术（6/8速自动，双离合变速器）
- 手动变速箱的敏感性分析

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Design space : vehicle classes
模拟的车辆级别

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

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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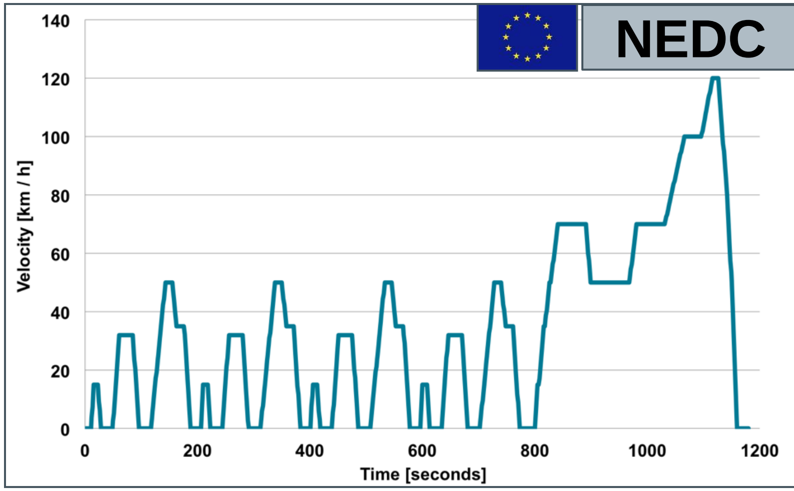
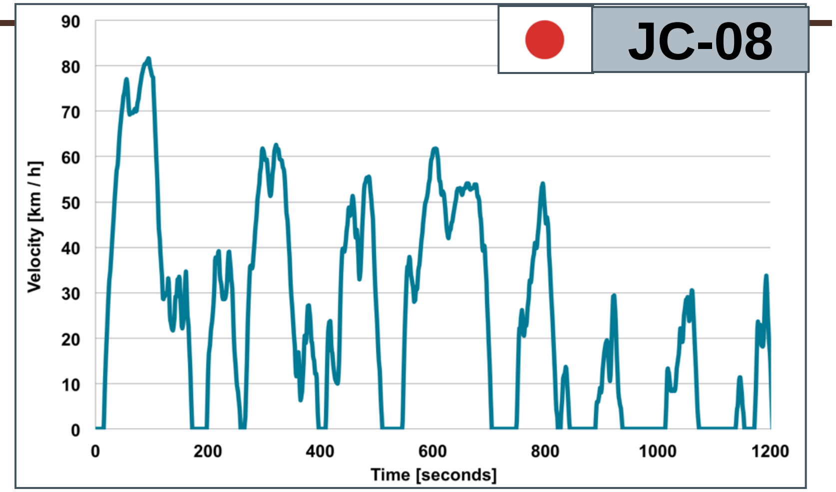
Powertrain technologies simulated or analyzed on vehicle classes
在各级别上模拟和分析的动力传动系统包裹

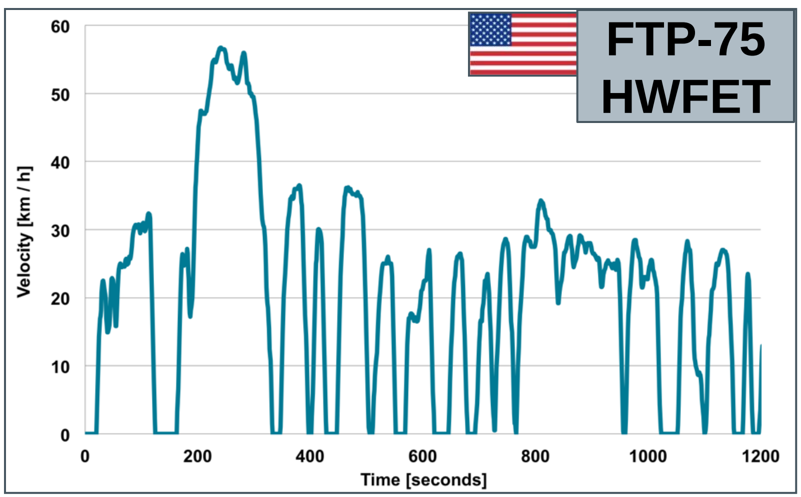
		Vehicle Class	B Class	C Class	D Class	Small CUV	N1 (Small)
		Example Vehicle	Toyota Yaris	VW Golf / VW Jetta	Toyota Camry	Saturn Vue	Ford Transit Connect
Conventional SS	Engine	Stoich DI Turbo	Yes	Yes	Yes	Yes	Yes
		Lean DI Turbo	Yes	Yes	Yes	Yes	Yes
		EGR DI Turbo	Yes	Yes	Yes	Yes	Yes
		Askinson SI	Yes	Yes	Yes	Yes	Yes
		2020 Diesel	Yes	Yes	Yes	Yes	Yes
	Transmission	6AT	Yes	Yes	Yes	Yes	Yes
		6DDCT	Yes				
		8AT		Yes	Yes	Yes	Yes
		8DCT		Yes	Yes	Yes	Yes
P2 hybrid	Engine	Stoich DI Turbo	Yes	Yes	Yes	Yes	Yes
		Lean DI Turbo	Yes	Yes	Yes	Yes	Yes
		EGR DI Turbo	Yes	Yes	Yes	Yes	Yes
		Askinson SI	Yes	Yes	Yes	Yes	Yes
		2020 Diesel	Yes	Yes	Yes	Yes	Yes
	Transmission	6DCT	Yes				
		8DCT		Yes	Yes	Yes	Yes
PowerSplit	Engine	Stoich DI Turbo	Yes	Yes	Yes	Yes	Yes
		Lean DI Turbo	Yes	Yes	Yes	Yes	Yes
		EGR DI Turbo	Yes	Yes	Yes	Yes	Yes
		2020 Diesel	Yes	Yes	Yes	Yes	Yes
	Transmission	PowerSplit	Yes	Yes	Yes	Yes	Yes

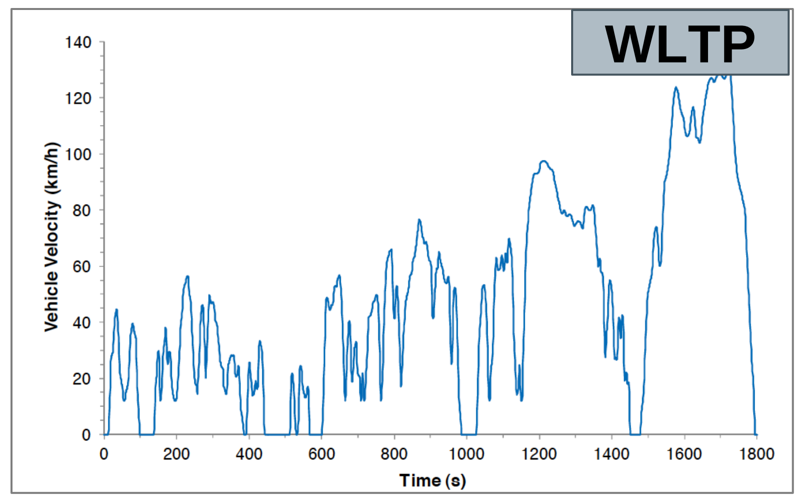
Design space : Drive cycles simulated
模拟的测试工况





ICCT出资支持了增加NEDC、JC08工况和新的WLTP工况





+ US 06 (“野蛮驾驶”)

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Input and output in simulation (DVT)
仿真模拟输入输出

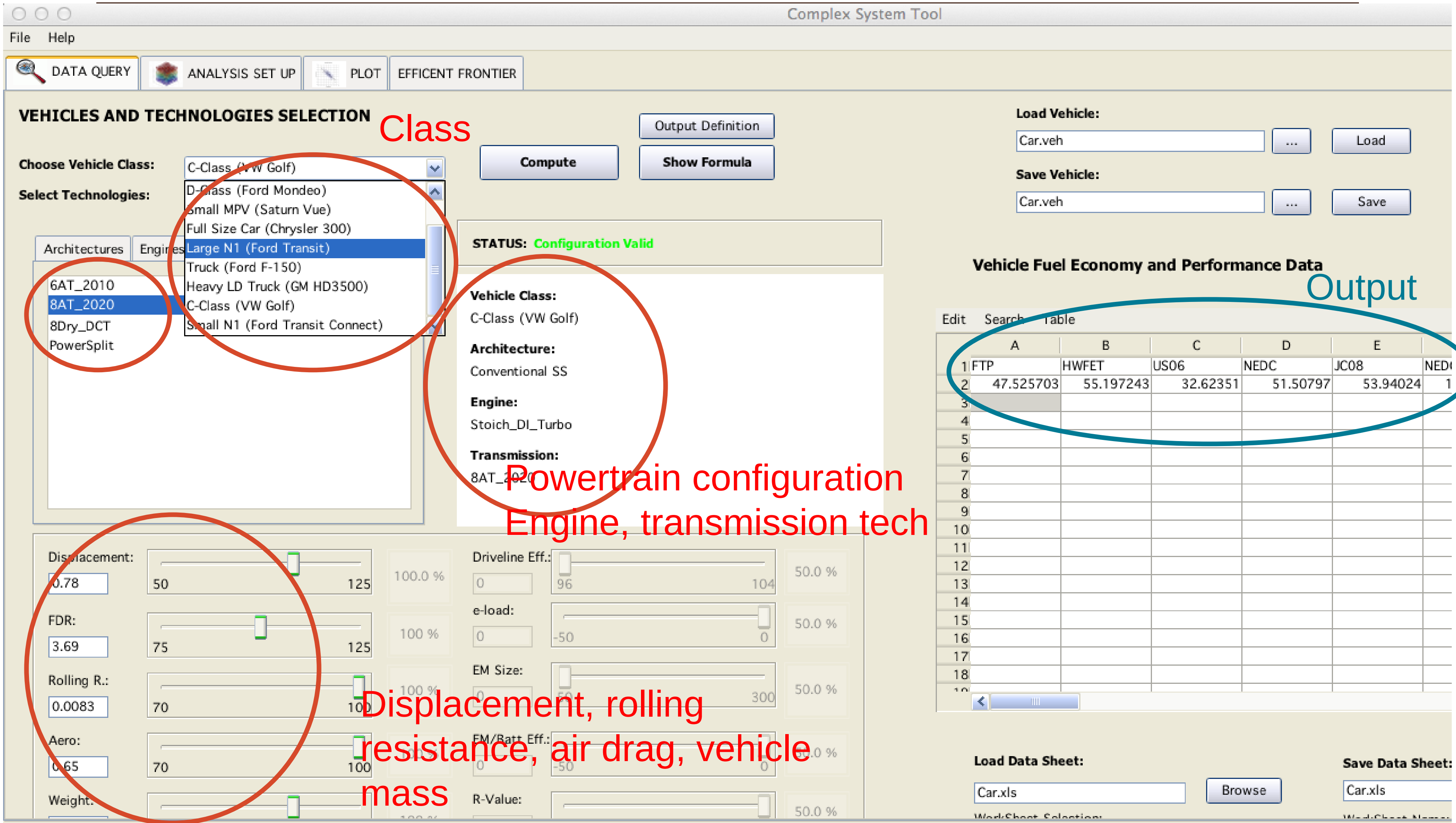
Input factors 输入

- Vehicle class 车辆级别
- Powertrain configuration 动力传动系统配置
- Engine 发动机技术
- Transmission 变速器技术
- Engine displacement 发动机参数
- Rolling resistance
- Aerodynamic drag
- Weight 整车参数

Output factors 输出

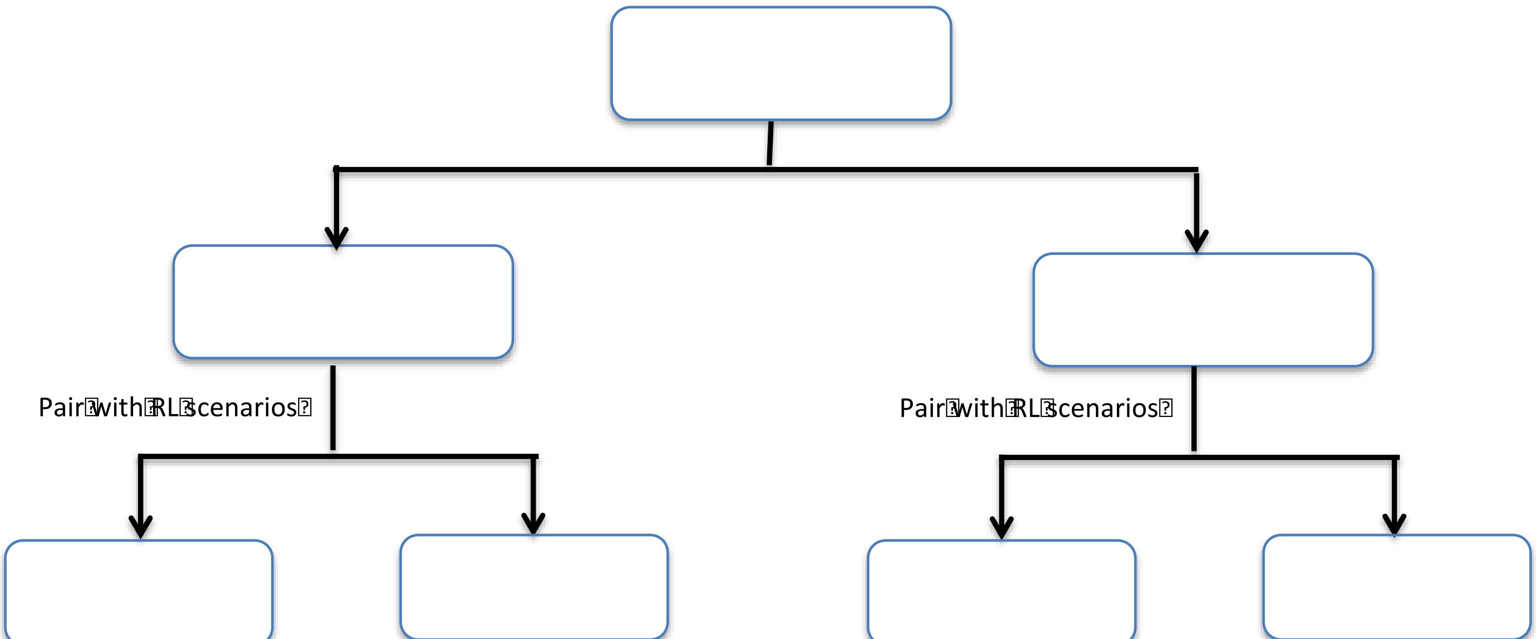
- Drive cycle fuel efficiency
  - Cycles: FTP, HWFET, CAFE, US06, NEDC, JC08, WLTP
  - Metrics: CO2, mpg
- Acceleration times
  - 0-10, 0-30, 0-50, 0-60…… mph
- Top speed
- Velocity or distance at 1.3s, 3.0s

DVT 界面功能区



Complex System Tool
File
Help
DATA QUERY
ANALYSIS SET UP
PLOT
EFFICENT FRONTIER
VEHICLES AND TECHNOLOGIES SELECTION
Class
Choose Vehicle Class:
C-Class (VW Golf)
Select Technologies:
D-Class (Ford Mondeo)
Small MPV (Saturn Vue)
Full Size Car (Chrysler 300)
Large N1 (Ford Transit)
Truck (Ford F-150)
Heavy LD Truck (GM HD3500)
C-Class (VW Golf)
Small N1 (Ford Transit Connect)
Compute
Output Definition
Show Formula
Architectures
6AT_2010
8AT_2020
8Dry_DCT
PowerSplit
STATUS: Configuration Valid
Vehicle Class:
C-Class (VW Golf)
Architecture:
Conventional SS
Engine:
Stoich_DI_Turbo
Transmission:
8AT_2020
Powertrain configuration
Engine, transmission tech
Load Vehicle:
Car.veh
Load
Save Vehicle:
Car.veh
Save
Vehicle Fuel Economy and Performance Data
Output
Edit
Table
FTP
HWFET
US06
NEDC
JC08
47.525703
55.197243
32.62351
51.50797
53.94024
Displacement:
FDR:
3.69
Rolling R.:
0.0083
Aero:
Weight:
Driveline Eff.:
e-load:
EM Size:
R-Value:
Displacement, rolling resistance, air drag, vehicle mass
Load Data Sheet:
Car.xls
Browse
Save Data Sheet:
Car.xls

Each technology package is a combination of powertrain and whole vehicle technologies
技术包裹构架：动力传动系统配合整车技术



Road load scenarios simulated
模拟的道路负载（整车）技术包裹

	Nominal mass reduction	Aerodynamic Drag improvement	Rolling Resistance Improvement
Baseline (RL0)	0	0	0
Alternative Road Load 1 (RL1)	15	10	10
Alternative Road Load 2 (RL2)	30	20	20
Alternative Road Load 3 (RL3)	10	5	5
Alternative Road Load 4 (RL4)	20	15	15
Alternative Road Load 5 (NMRL1)	0	10	10
Alternative Road Load 6 (NMRL2)	0	20	20
Alternative Road Load 7 (NMRL3)	0	5	5
Alternative Road Load 8 (NMRL4)	0	15	15

To understand the impact of mass reduction technologies, we created road load scenarios with or without mass change
为理解轻量化技术的贡献，设计了两套情景分别为考虑减重和不考虑减重

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Illustration of simulation results
油耗仿真结果示例

C级(汽油车)
C Class petrol

Road Load	Engine	Transmission	Mass (lb)	Mass Change	RR	RR Change	CdA	CdA Change	0-60 mph secs	CO2 g/km	L/100km
RL0	SGTDI	A8	3250		0.0083		0.65		10.0	111.3	4.8
RL0	SGTDI	8DDCT	3250		0.0083		0.65		10.0	108.5	4.6
RL1	SGTDI	A8	2795	-14.0%	0.0075	-9.6%	0.585	-10.0%	10.0	97.0	4.1
RL1	SGTDI	8DDCT	2795	-14.0%	0.0075	-9.6%	0.585	-10.0%	10.0	94.8	4.1
RL2	SGTDI	A8	2372	-27.0%	0.0066	-20.5%	0.52	-20.0%	8.6	84.4	3.6
RL2	SGTDI	8DDCT	2372	-27.0%	0.0066	-20.5%	0.52	-20.0%	8.8	82.6	3.5
RL3	SGTDI	A8	2956	-9.0%	0.0079	-4.8%	0.618	-4.9%	10.0	102.8	4.4
RL3	SGTDI	8DDCT	2956	-9.0%	0.0079	-4.8%	0.618	-4.9%	10.0	100.4	4.3
RL4	SGTDI	A8	2665	-18.0%	0.0071	-14.5%	0.552	-15.1%	9.6	92.1	3.9
RL4	SGTDI	8DDCT	2665	-18.0%	0.0071	-14.5%	0.552	-15.1%	9.8	90.0	3.8
NMRL1	SGTDI	A8	3250	0.0%	0.0075	-9.6%	0.585	-10.0%	10.1	105.7	4.5
NMRL1	SGTDI	8DDCT	3250	0.0%	0.0075	-9.6%	0.585	-10.0%	10.0	103.3	4.4
NMRL2	SGTDI	A8	3250	0.0%	0.0066	-20.5%	0.52	-20.0%	10.0	100.6	4.3
NMRL2	SGTDI	8DDCT	3250	0.0%	0.0066	-20.5%	0.52	-20.0%	10.0	98.5	4.2
NMRL3	SGTDI	A8	3250	0.0%	0.0079	-4.8%	0.618	-4.9%	10.0	108.5	4.6
NMRL3	SGTDI	8DDCT	3250	0.0%	0.0079	-4.8%	0.618	-4.9%	10.0	105.9	4.5
NMRL4	SGTDI	A8	3250	0.0%	0.0071	-14.5%	0.552	-15.1%	9.9	103.1	4.4
NMRL4	SGTDI	8DDCT	3250	0.0%	0.007	-15.7%	0.552	-15.1%	10.0	100.7	4.3

Impact of mass reduction is reflected in the difference between RL and NMRL packages

Develop technology pathway in the Chinese context

技术路径中国化

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Basis for adapting Ricardo simulation results to China
在中国应用Ricardo分析结果的基础

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

- 中国轻型车油耗工况与欧盟相同
- 市场上主要车辆级别与欧盟接近

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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Baseline adjustment 原点回调

- The technology starting point in Ricardo is based on the US baseline technologies, therefore are too advanced for China
  - Baseline fuel consumption for C-class is 5.7 L/100km, vs 7.4L/100km in China
- Use additional (external) simulation models, literature data sources to back out the fuel efficiency impact of advanced technologies and costs

- 仿真车型最初设计为美国（或欧洲）基准车型，基准技术配置高于中国，
  - 比如紧凑型车Ricardo基准油耗是5.7 L/100km中国实际是7.4L/100km
- 需要“退回”这些先进技术，从而将技术路径的开端真正变成中国技术原点，这需要用多个外部模型和数据将这些先进技术的油耗逐一评估出来，成本也一样要“退回”

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Ricardo baseline vs China baseline
Ricardo技术基准和中国技术基准对比

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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How this is done 技术还原是如何完成的

Mini van	Ricardo Baseline	China Baseline	Adj. Factor
Transmission	A6	M5	0.96
Fuel System	MPFI	TBI	1.01
Valve System	VVT	Fixed	1.04
Engine Displacement (liters)	1.5		1
Engine Configuration	I4	I4	1
Cam Configuration	DOHC	SOHC	1.03
Valves per Cylinder	4	4	1
Start Stop System	12V BAS	No	1.11
Imp Alternator & Accessory Regen	Yes	No	1.04
VVT/DOHC Correction:			0.99019
Start Stop/Imp Alt+Regen Correction:			0.99888
Powertrain technology adj factor			1.19205

去除单项先进技术（Transmission – Imp Alternator & Accessory Regen）

避免技术交互作用重复计算（VVT/DOHC Correction; Start Stop/Imp Alt+Regen Correction）

Road load parameters are adjusted using an external tractive energy model, the output is incorporated in DVT results.

分析微客时，道路负载也须还原成中国微客的平均水平（B级车道路负载性能比微客好），但这一分析在外部模型里运算，并将运算结果纳入DVT油耗输出结果

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Baseline adjustment factors for all classes
同理得出各级车辆的技术原点校正系数

China Vehicle Class	Mini	Small	Lower	Medium	Large	SUV	Minivan
Mapped Ricardo Vehicle Class	B Class	B Class	C Focus	D Class	D Class	CUV	B Class
NEDC CO_2 (g/km)							
China Baseline	150	157	173	199	211	211	178
Unadjusted Ricardo	131.3	131.3	133.5	170.4	170.4	191.3	131.3
Baseline-Adjusted Ricardo	151	151	156.5	209	204.3	215.5	182.6
China Baseline CO_2 to Ricardo Modeled CO_2							
Unadjusted Ricardo	1.14	1.2	1.3	1.17	1.24	1.1	1.36
Baseline-Adjusted Ricardo	0.99	1.04	1.11	0.95	1.03	0.98	0.97

In all vehicle classes, backing out the technologies can explain the vast majority of differences in CO2/fuel consumption between China baseline vehicle and Ricardo baseline vehicle

基本上所有车辆级别里，将Ricardo里的先进技术退回后的油耗水平跟中国实际的基准油耗水平就很接近了。也就是说，这些技术能解释Ricardo车型和中国车型油耗差异的绝大部分。

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China intermediate technology packages
适应中国国情的过渡技术包

- Similar to the baseline adjustment, need to remove the advanced technologies from the first Ricardo technology package
- Due to the constraint of Ricardo modeling, can only subtract existing technologies from the first Ricardo package
- Therefore need to evaluate the fuel consumption impact of the removed technologies
- External models are used for the evaluation

- 核心问题和技术原点调整的原因类似，Ricardo模拟的第一个先进技术包裹对中国企业来说难以一下达到
- 由于必须依赖于Ricardo的模拟结果来分析主要未来技术包裹的节油效果，我们选择从Ricardo第一个包裹“退回”一些主要技术
- 通过外部模型和数据来分析这些“退回”的先进技术的油耗影响

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Define intermediate technology packages for China
定义符合中国国情的过渡技术包（发动机技术为例）

Ricardo第一个先进技术包=

ATT (发动机减阻+ VVT + DVVL + 变速器能效提高 + 换档优化+ 提前锁止 + 先进电机、能量回收 + EPS等不分车型的通用技术)

+ 化学平衡增压直喷(STGDI)

+ Start stop

− **SGTDI** = **China 4 中国情景 4**

− **Start Stop** = **China 2 中国情景 2**

− **Start Stop** − **SGTDI** = **China 1 中国情景 1**

− **Start Stop** − **SGTDI** − **ATT** = **China baseline 中国基准**

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China cost curves

中国技术成本曲线

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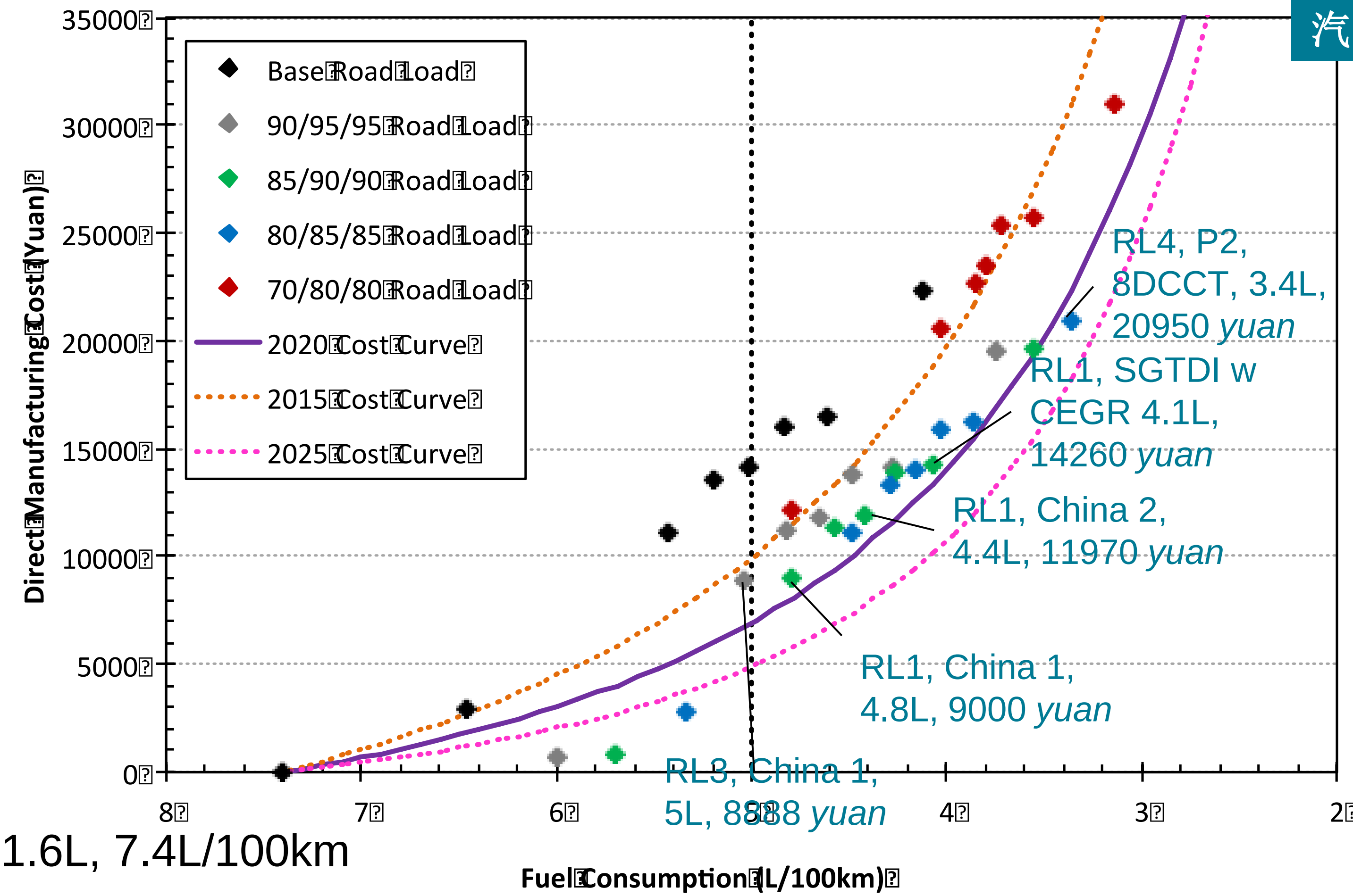
Cost Curve for C-class gasoline vehicles (direct manufacturing cost) C级直接成本曲线

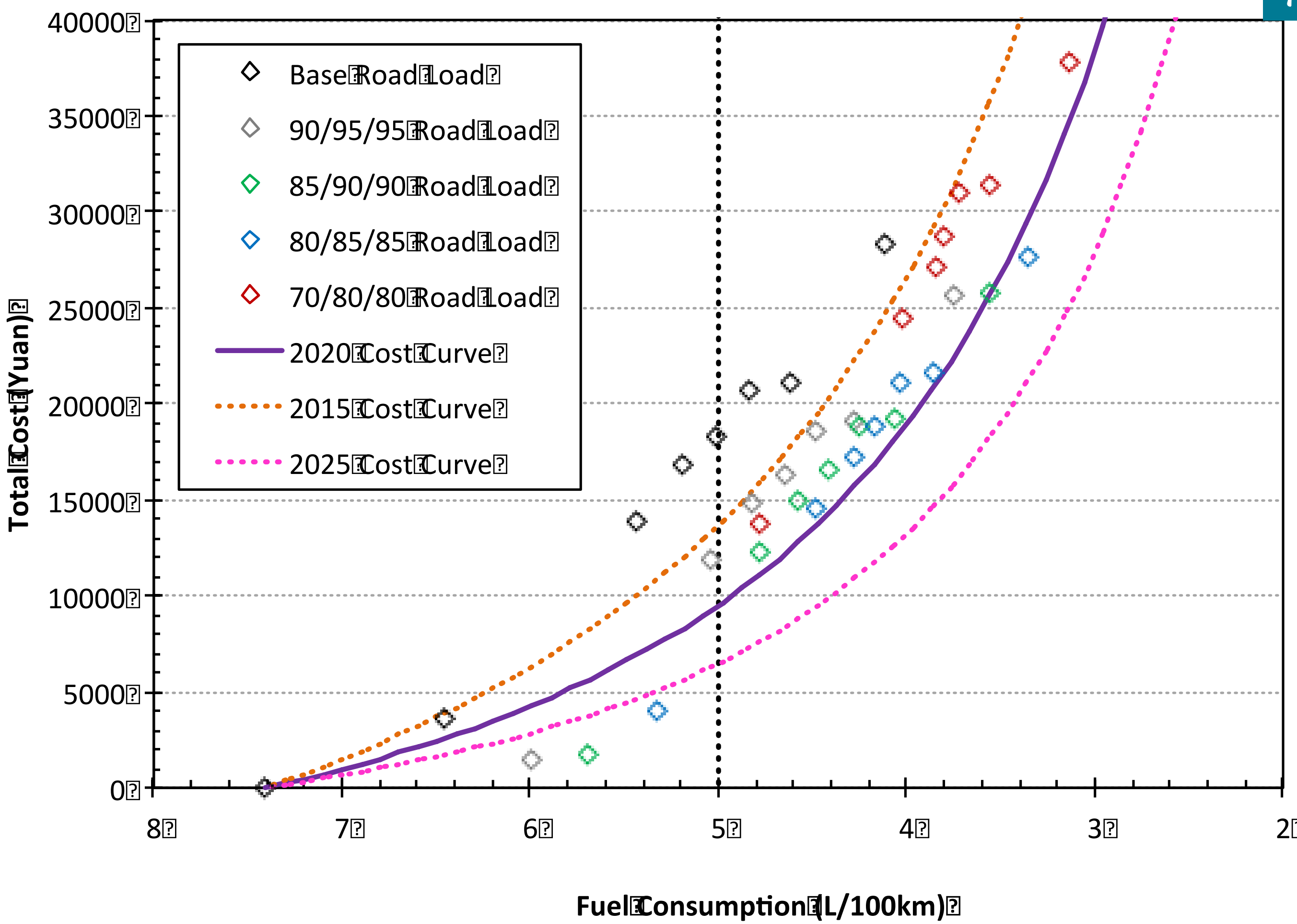
C级
汽油车



达标成本平均为7000元左右

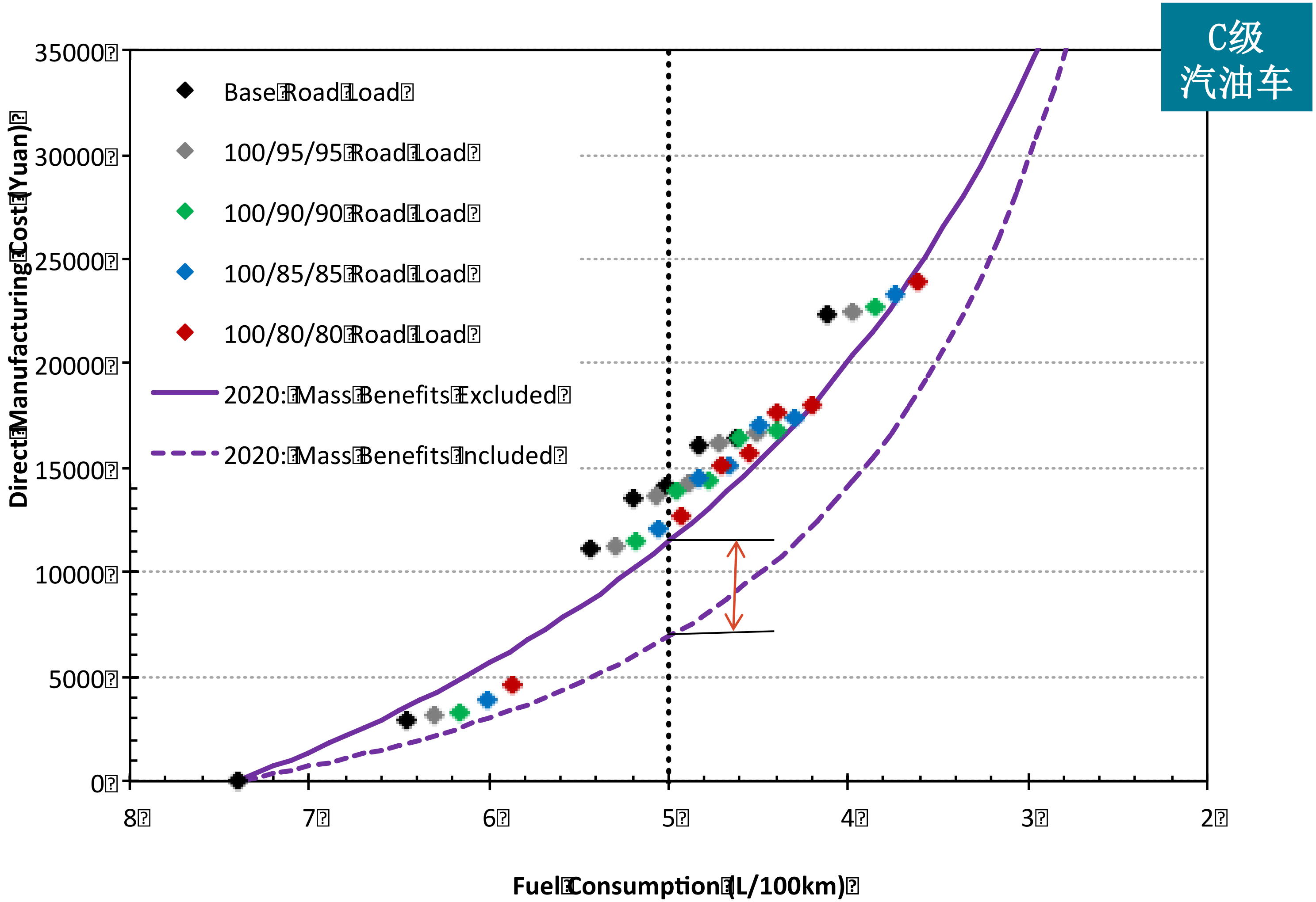
Cost Curve for C-class gasoline vehicles (direct manufacturing cost) C级总成本曲线

C级
汽油车



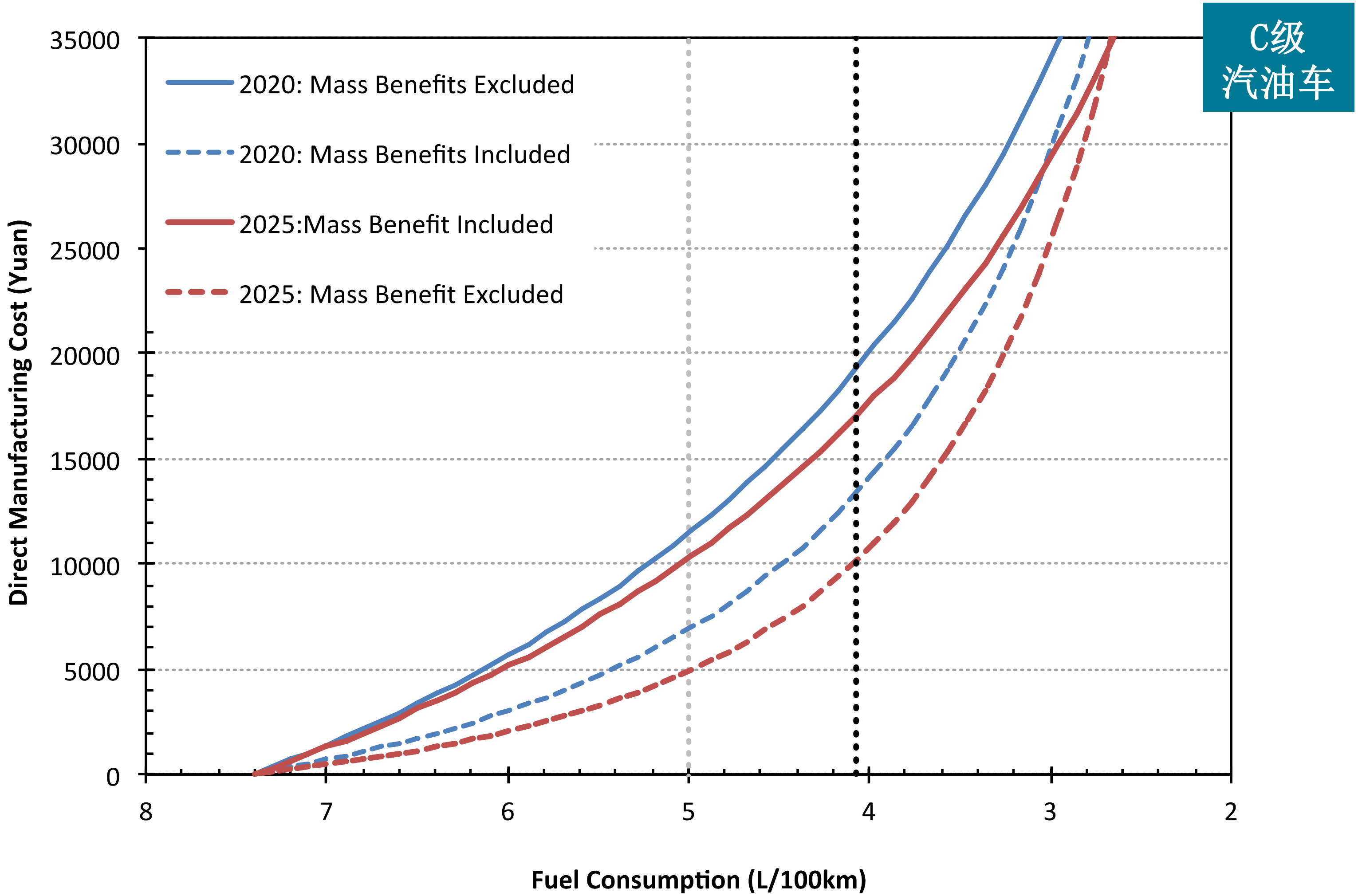
达标价格增量平均为10000元左右

Impact of mass reduction
减重技术的影响



More than 1/3 of cost saving
可节省超过1/3的成本

2025 Scenario 2025年情景



假设2025年标准在2020年基础上每年加严4%，达到4.1L/100km，成本增量在1000元左右

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Customized costs 定制技术路线成本

技术清单

定制市场份额

Road Load	Tech Package	Trans-mission	Mass (lbs)	Mass Change	RR	RR Change	CdA	CdA Change	Disp	RL Disp Change	FC L/100km	0-60 mph secs	2020 Direct Cost	2025 Direct Cost	2020 Total Cost	2025 Total Cost	**2020 Market Share**	**2025 Market Share**
RL0	"Unadjusted Baseline"	M5	2892.465		0.0079		0.65		1.6		7.402653	9.3	0	0	0	0	0.0%	0.0%
RL0	Standardized Baseline	M5	2892.465		0.0079		0.65		1.6		6.462443	9.3	2963.626	2564.003	3554.626	2811.634	0.0%	0.0%
RL0	SGTDI	A8	2892.465		0.0079		0.65		0.772		4.93891	9.1	16429.17	14671.65	21151.46	17130.01	**40.0%**	**30.0%**
RL0	SGTDI	8DDCT	2892.465		0.0079		0.65		0.78		4.831049	9.1	16045.88	14318.93	20686.79	16756.67	0.0%	0.0%
RL0	China 1 (EvoTech)	A8	2892.465		0.0079		0.65		1.6		5.57646		11490.54	10577.66	14426.57	12503.64	0.0%	0.0%
RL0	China 1 (EvoTech)	8DDCT	2892.465		0.0079		0.65		1.6		5.431503		11093.13	10212.12	13944.75	12116.57	0.0%	0.0%
RL0	China 2 (EvoTech+STGDI)	A8	2892.465		0.0079		0.65		0.772		5.144199		14482.07	12999.61	18821.59	15357.72	0.0%	0.0%
RL0	China 2 (EvoTech+STGDI)	8DDCT	2892.465		0.0079		0.65		0.78		5.014041		14094.18	12642.94	18351.42	14980.19	0.0%	0.0%
RL0	China 4 (EvoTech+SS)	A8	2892.465		0.0079		0.65		1.6		5.312702		13913.45	12658.3	17325.79	14709.02	0.0%	0.0%
RL0	China 4 (EvoTech+SS)	8DDCT	2892.465		0.0079		0.65		1.6		5.193436		13516.05	12292.76	16843.97	14321.95	0.0%	0.0%
RL0	LBGTDI	A8	2892.465		0.0079		0.65		0.772		4.757411	9.1	16429.17	14671.65	21151.46	17130.01	0.0%	0.0%
RL0	LBGTDI	8DDCT	2892.465		0.0079		0.65		0.78		4.647033	9.1	16045.88	14318.93	20686.79	16756.67	0.0%	0.0%
RL0	SGTDI wCEGR	A8	2892.465		0.0079		0.65		0.772		4.716009	9.1	16832.84	15036.53	21619.92	17561.29	0.0%	0.0%
RL0	SGTDI wCEGR	8DDCT	2892.465		0.0079		0.65		0.78		4.616199	9.1	16450.56	14684.73	21156.43	17189.03	0.0%	0.0%
RL0	P2 AtkCPS	8DDCT	3055.607		0.0079		0.65		1.943399		4.114668	9.1	22316.14	19458.82	28296.97	21588.06	**40.0%**	**50.0%**
RL1	Standardized Baseline	M5	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	1.407	-12.1%	5.69555		802.2456	-577.364	1710.633	-172.94	0.0%	0.0%
RL1	SGTDI	A8	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	0.679	-12.0%	4.346513	9.1	14251.98	11513.68	19284.18	14126.05	0.0%	0.0%
RL1	SGTDI	8DDCT	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	0.686	-12.1%	4.257119	9.1	13867.29	11159.73	18817.81	13751.38	0.0%	0.0%
RL1	China 1 (EvoTech)	A8	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	1.407	-12.1%	4.914744		9440.064	7531.538	12713.01	9619.312	0.0%	0.0%
RL1	China 1 (EvoTech)	8DDCT	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	1.407	-12.1%	4.786949		9042.659	7165.997	12231.19	9232.247	0.0%	0.0%
RL1	China 2 (EvoTech+STGDI)	A8	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	0.679	-12.0%	4.533771		12358.32	9887.527	17018.26	12402.41	0.0%	0.0%
RL1	China 2 (EvoTech+STGDI)	8DDCT	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	0.686	-12.1%	4.419035		11969.61	9530.125	16547.08	12024.08	0.0%	0.0%
RL1	China 4 (EvoTech+SS)	A8	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	1.407	-12.1%	4.682243		11752.07	9516.936	15479.52	11723.74	0.0%	0.0%
RL1	China 4 (EvoTech+SS)	8DDCT	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	1.407	-12.1%	4.577158		11354.66	9151.395	14997.7	11336.68	0.0%	0.0%
RL1	LBGTDI	A8	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	0.679	-12.0%	4.200887	9.1	14251.98	11513.68	19284.18	14126.05	0.0%	0.0%
RL1	LBGTDI	8DDCT	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	0.686	-12.1%	4.100809	9.1	13867.29	11159.73	18817.81	13751.38	0.0%	0.0%
RL1	SGTDI wCEGR	A8	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	0.679	-12.0%	4.151915	9.1	14643.89	11867.93	19738.99	14544.77	0.0%	0.0%
RL1	SGTDI wCEGR	8DDCT	2502.247	-13.5%	0.0071	-10.1%	0.585	-10.0%	0.686	-12.1%	4.066325	9.1	14260.08	11514.78	19273.65	14171.04	0.0%	0.0%
RL1	P2 AtkCPS	8DDCT	2632.319	-13.9%	0.0071	-10.1%	0.585	-10.0%	1.631299	-16.1%	3.558246	9.1	19608.32	15733.55	25774.41	17990.51	0.0%	0.0%
RL2	Standardized Baseline	M5	2112.028	-27.0%	0.0063	-20.3%	0.52	-20.0%	1.212	-24.3%	4.788233		12175.66	6894.564	13776.93	7709.341	0.0%	0.0%
RL2	SGTDI	A8	2112.028	-27.0%	0.0063	-20.3%	0.52	-20.0%	0.675	-12.6%	3.795943	7.9	25731.88	19076.89	31477.76	22105.03	0.0%	0.0%
RL2	SGTDI	8DDCT	2112.028	-27.0%	0.0063	-20.3%	0.52	-20.0%	0.675	-13.5%	3.720301	7.9	25337.43	18714.31	30999.46	21721.1	0.0%	0.0%
RL2	China 1 (EvoTech)	A8	2112.028	-27.0%	0.0063	-20.3%	0.52	-20.0%	1.212	-24.3%	4.131791		20925.54	15099.69	24913.4	17603.59	0.0%	0.0%
RL2	China 1 (EvoTech)	8DDCT	2112.028	-27.0%	0.0063	-20.3%	0.52	-20.0%	1.212	-24.3%	4.024388		20531.09	14737.11	24435.1	17219.65	0.0%	0.0%
RL2	China 2 (EvoTech+STGDI)	A8	2112.028	-27.0%	0.0063	-20.3%	0.52	-20.0%	0.675	-12.6%	3.901656		23840.52	17452.72	29214.59	20383.48	0.0%	0.0%
RL2	China 2 (EvoTech+STGDI)	8DDCT	2112.028	-27.0%	0.0063	-20.3%	0.52	-20.0%	0.675	-13.5%	3.797393		23449.02	17093.08	28738.68	20002.33	0.0%	0.0%
RL2	China 4 (EvoTech+SS)	A8	2112.028	-27.0%	0.0063	-20.3%	0.52	-20.0%	1.212	-24.3%	3.936384		23125.49	16988.86	27545.82	19606.02	0.0%	0.0%

成本输出

	2020	2025
	4.5	**4.4**
	19373	**17664**
	24724	**19916**

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结论

- 本研究使用了由美国EPA主导开发又应用于欧盟的新研究方法：Ricardo车辆技术模拟和FEV拆解成本分析法。
- 具有高度客观性和透明性，并接近汽车企业内部的分析方法，因而可以作为中国现有的对车辆技术潜力和成本分析的有益的补充。
- 结果显示可以以合理的增量成本在2020年达到5L/100km目标，以及在2025年达到更严格的要求。
- 主要技术路径为改善发动机、变速器、附件能效和车辆轻量化，不必须依赖于昂贵的电动技术、或柴油技术。
- 选择适当的、技术中立的、可充分鼓励轻量化技术的标准评价体系对降低达标成本非常重要。

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Thank you!

Questions?

Contact: hui@theicct.org

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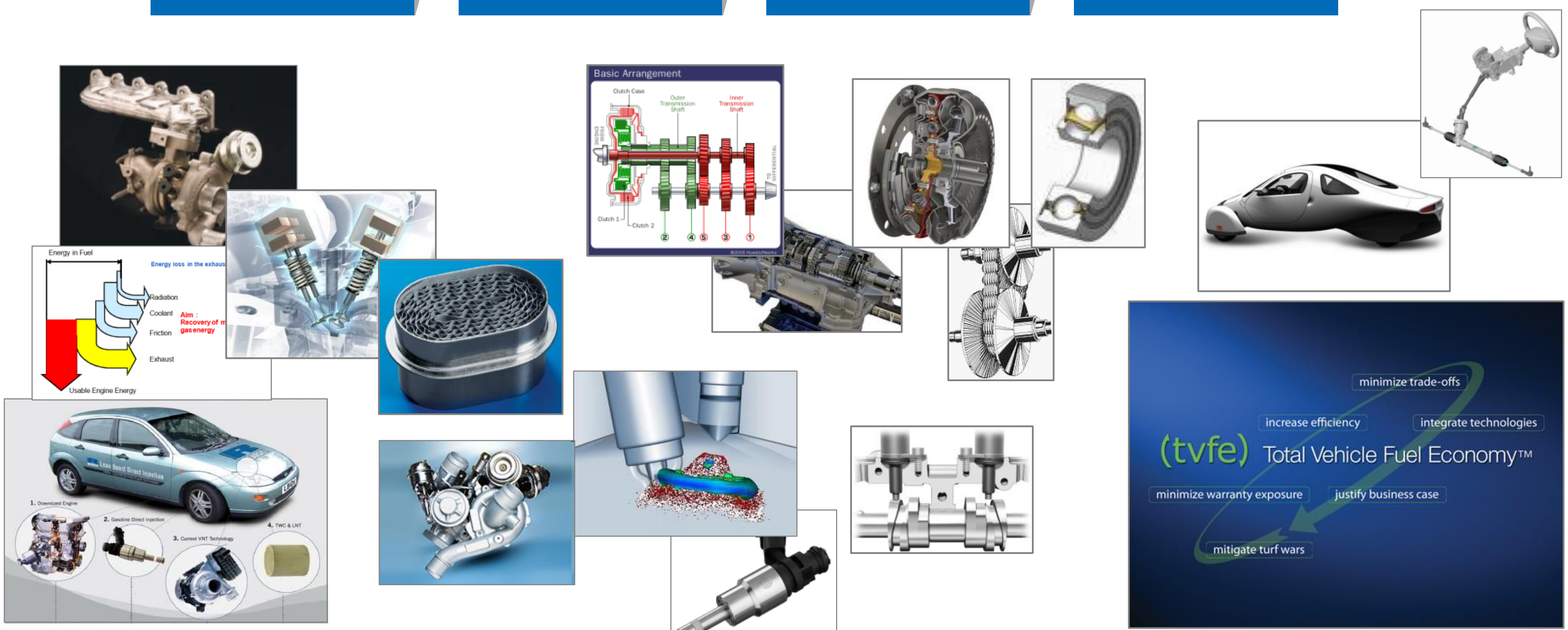
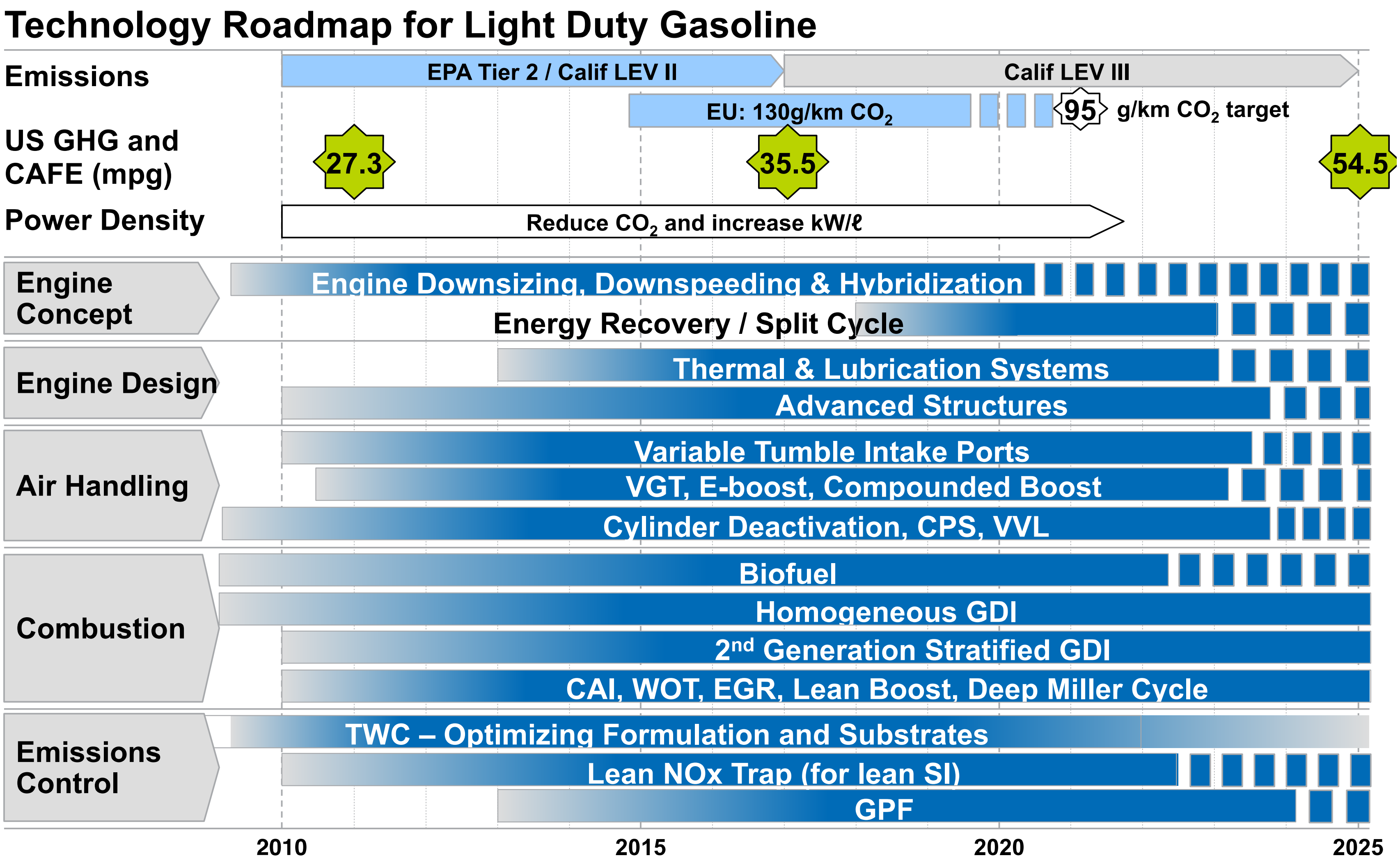
Technology package development procedures

Technology Identification → Ricardo Subject Matter Expert Assessment → EPA Review & Technology Discussion → Technology Package Selection



Source: Ricardo

Technology roadmap after SME evaluation



Source: Ricardo

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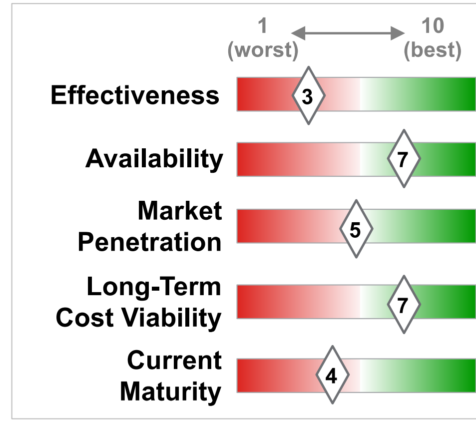
Sample advanced technology evaluation

Technology and Status

- **Concept:** Improvements in air handling through a suite of boosting technologies either standalone or in combination
- **Base Functioning:** Provision of higher specific torque and power to enable downsized engines. Technologies include eBoost (e-machine in CHRA or electrical separation by e-Turbine and e-Compressor); supercharging (advances to avoid variable drive); variable nozzle compressor
- **CO_2 Benefit:** 2% (more if engine downsized for equivalent performance)
- **Costs:** Increase in turbocharger air system matching and development time, increased complexity in engine controller. Variable cost of turbocharger doubles plus additional air cooling requirement, sensors and actuators

Ratings of Technology



Technology Applicability

- Technology applicable to all sectors of diesel application
- Highway benefits – improved transient response from engine allows downsizing. More air allows improved emission performance for NOx and PM control giving leeway for CO_2 reduction.
- City benefits – much improved transient performance allowing downsizing. Operation in more efficient area of turbocharger map gives more noticeable CO_2 benefit in city driving
- In conjunction with enhanced EGR allows for premixed or homogeneous combustion in part load operation for very clean emissions. Design can facilitate the use of pre-TC catalyst for quick aftertreatment light-off

Visualization

Picture: http://honeywellbooster.com

Source: Ricardo

Ricardo Technologies and Assumptions

Table 5.1: Engine technology package definition.

Engine	Air System	Fuel Injection	EGR	Valvetrain CPS	Valvetrain DVA
2010 Baseline	NA	PFI	No	No	No
Stoich DI Turbo	Boost	DI	No	Yes	No
Lean-Stoich DI Turbo	Boost	DI	No	Yes	No
EGR DI Turbo	Boost	DI	Yes	Yes	No
Atkinson with CPS	NA	DI	No	Yes	No
Atkinson with DVA	NA	DI	No	No	Yes
Diesel	Boost	DI	Yes	Yes	No

Source:
Ricardo Inc., "Project Report, Analysis of Greenhouse Gas Emission Reduction Potential of Light Duty Vehicle Technologies in the European Union for 2020-2025," 2012.

Table 5.2: Hybrid technology package definition.

Function	Powertrain Configuration: 2010 Baseline	Stop-Start	P2 Parallel	Powersplit
Engine idle-off	Yes	Yes	Yes	Yes
Launch assist	No	No	Yes	Yes
Regeneration	No	No	Yes	Yes
EV mode	No	No	Yes	Yes
CVT (Electronic)	No	No	No	Yes
Power steering	Belt	Electrical	Electrical	Electrical
Engine coolant pump	Belt	Belt	Electrical	Electrical
Air conditioning	Belt	Belt	Electrical	Electrical
Brake	Standard	Standard	Blended	Blended

Table 5.3: Transmission technology package definition.

Transmission	Launch Device	Clutch
Baseline Automatic	Torque Converter	Hydraulic
Advanced Automatic	Multidamper Control	Hydraulic
Dry clutch DCT	None	Advanced Dry
Wet clutch DCT	None	Advanced Damp

Blanket 3.5% improvement in fuel consumption coming from a combination of friction improvements in future engines

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Accelerating technology introduction
新技术的使用正在加速

	汽油缸内直喷	涡轮增压	6档自动变速
2009	4.2%	3.6%	25%
2010	8.3%	3.5%	38%
2011	13.7%	7.4%	52%

Source: 2011 EPA Fuel Economy Trends Report
数据来源：2011年EPA燃油经济性趋势报告

2010	2012	2010
Ford Focus	**Ford Focus EcoBoost**	**C-class diesel avg.**
1.6L, 4 cyl., 74 kW	1.0L, 3 cyl., 74 kW	1.7L
---	SS+DI+turbo	
1,175 kg	1,195 kg	
M5	M5	
14.6 km/l	**21.4 km/l**	**17.4 km/l**

+47%

2010	2012
Audi A3	**Audi A3**
1.6L, 4 cyl., 75 kW	1.2L, 4 cyl., 77 kW
---	SS+DI+turbo+7DCT
1,185 kg	1,150 kg
M5	7DCT
14.4 km/l	**20.1 km/l**

+40%

New powertrains introduced in Europe
新动力总成系统在欧洲出现

Pace of Technology Innovation is Accelerating
技术创新的步伐也在加快

技术种类	来源	能效提高	成本
涡轮增压，发动机小型化（不减少气缸数）	2001 NRC 报告	5-7%	$250-400
	RIA-18bar报告	12-15%	$342
	RIA-24bar报告	16-20%	$550
	RIA-含增压废气循环报告	20-25%	$967
4-6档自动变速	2001 NRC 报告	3-4%	$150-$300
	RIA	3-4%	($15)
自动变速双离合	RIA	4-6%	($154-223)

2倍能效

新技术，2倍能效

成本从增到减

新技术，能效更高，成本更低

- 成本为直接制造成本
- NRC Report is Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, 2002
- Draft RIA is for NHTSA/EPA proposed standards for 2017-25 light-duty vehicles

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