Global lightweight vehicle developments and policy design implications

全球汽车轻量化技术的发展以及政策制定的启示

Nic Lutsey

June 5, 2014
GFEI/ICCT workshop
Beijing, China

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Presentation outline
演讲概要

- Background
- Automaker lightweighting developments (today)
- Lightweighting technology potential (2015-2025)
- Policy implications

- 背景
- 机动车轻量化发展（当前）
- 轻量化技术潜力（2015-2025）
- 政策启示

Basics on vehicle mass reduction
车辆减重／轻量化的基本信息

- Primary drivers
  - Consumer demand for acceleration performance, fuel savings, safety
  - Automaker compliance with efficiency and climate regulations
  - More cost-effective technology step before electric-drive
- Technology enablers
  - Advances in materials, manufacturing techniques (steel, aluminum, plastics)
  - Improvements in computer aided engineering (CAE) model optimization

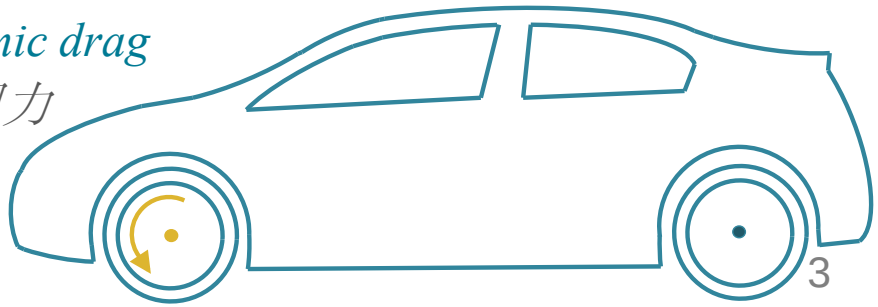
- 主要驱动力
  - 消费者对加速性能，节省燃料，安全的需求
  - 汽车制造商遵守效率/气候规定
  - 对电力传动的成本效益技术考虑
- 相关技术
  - 先进的材料和生产技术（钢制品，铝，塑料）
  - 计算机辅助工程的提高有助于模拟最优化设计

$$F_{Road} = \boldsymbol{m} \cdot a + C_{RR} \cdot \boldsymbol{m} \cdot g + \frac{1}{2} \rho \cdot C_D \cdot A_f \cdot v^2$$

Inertial acceleration 惯性速度

Rolling resistance 滚动阻力

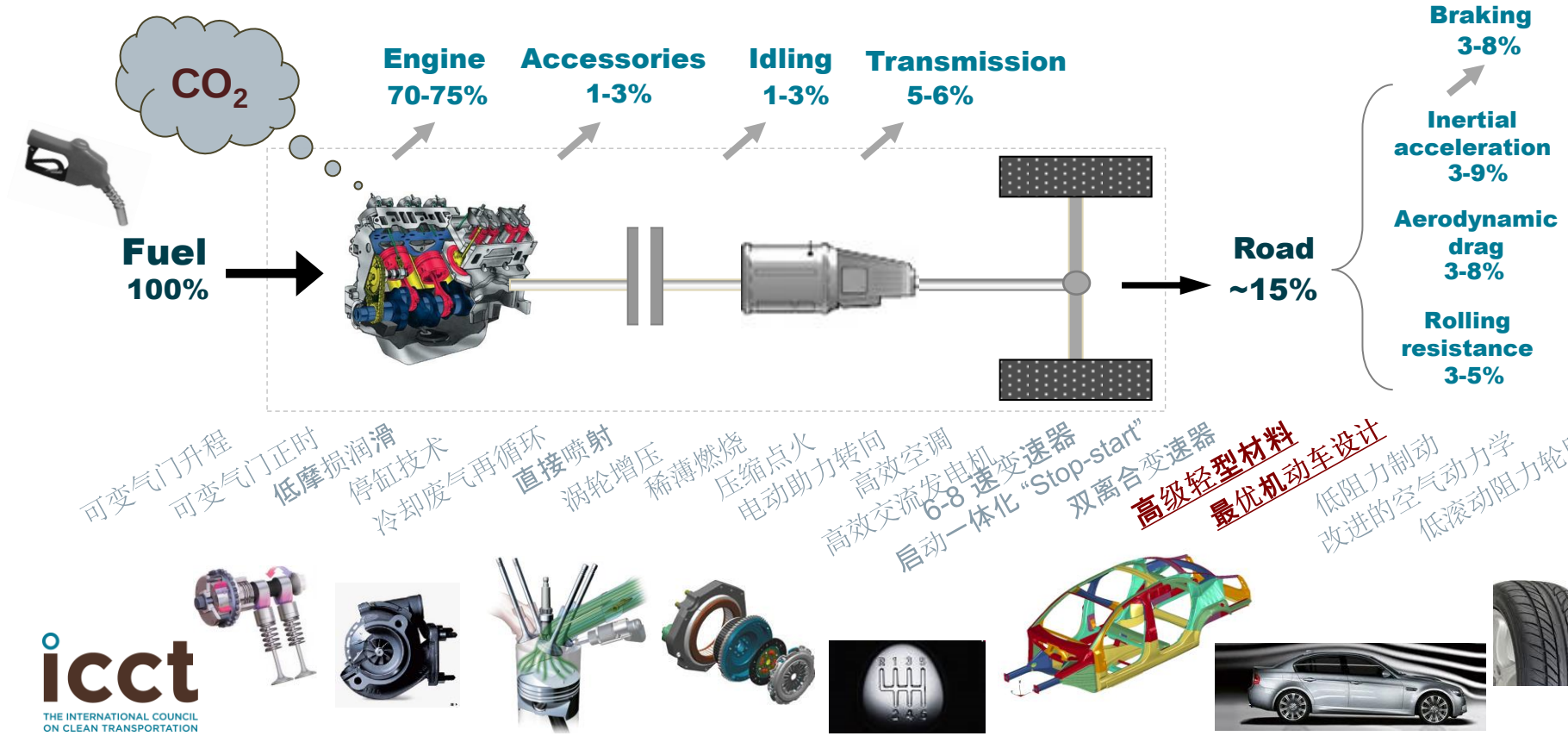
Aerodynamic drag 空气阻力



icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Background: Vehicle Efficiency
技术背景：机动车效率

- The modern car, at 15-20% efficiency, has many efficiency losses – and many efficiency opportunities
- 现代机动车效率大约为15-20%, 存在很多效率流失，同时也存在很多提高效率的机会



Sources: Lutsey, 2012; Kromer and Heywood, 2007; U.S. EPA (http://www.fueleconomy.gov/feg/atv.shtml)

Individual Technologies

Area	Technology for CO_2 reduction		Technology share, MY2013	Potential CO_2 reduction
Powertrain	Engine	Low friction lubrication	-	0.5%
		Engine friction reduction	-	2-4%
		Variable valve timing/lift	98%	4-6%
		Cylinder deactivation	8%	5-6%
		Turbocharging	15%	2-5%
		Turbo, gasoline direct injection	31%	8-15%
		Cooled EGR, turbo, GDI	-	20-25%
		Compression ignition diesel	1%	15-25%
		Digital valve actuation	-	5-10%
	Transmission	Early torque converter lock-up	-	0.5%
		Optimized shifting	-	2-6%
		6+ speed	61%	2-8%
		Continuously variable	14%	8-11%
		Dual-clutch, automated manual	-	9-13%
Vehicle	Aerodynamics		-	2-5%
	Tire rolling resistance		-	2-4%
	Accessories (steering, air cond., alternator)		-	1-4%
	Lower refrigerant emissions (low-leak, low-GWP)		-	2-10%
	Mass-reduction	**Advanced material component**	**-**	**1-5%**
		Integrated vehicle design	**-**	**5-10%**
	Hybrid systems	Stop-start mild hybrid	2%	6-8%
		Full hybrid electric system	4%	30-35%
	Plug-in electric		0.6%	50-100%

Indirect benefits: powertrain downsizing and cost reduction

相关技术

区域	CO_2减排技术		技术比重 MY2013	潜在 CO_2减排
动力系统	发动机	低磨损润滑	-	0.5%
		发动机摩擦减少	-	2-4%
		可变气门正时/升程	98%	4-6%
		停缸技术	8%	5-6%
		涡轮增压	15%	2-5%
		涡轮增压机、汽油直接喷射	31%	8-15%
		冷却废气再循环，涡轮增压机，GDI	-	20-25%
		压缩点火柴油机	1%	15-25%
		数字气门驱动	-	5-10%
	变速器	早期变矩器锁定	-	0.5%
		最优化转换	-	2-6%
		6速以上	61%	2-8%
		无段变速	14%	8-11%
		双离合，手自排变速	-	9-13%
机动车	空气动力		-	2-5%
	轮胎滚动阻力		-	2-4%
	附件(转向，空调, 交流发电机)		-	1-4%
	低制冷排放(低渗露, 低全球变暖潜力)		-	2-10%
	减重	**高级材料组件**	-	1-5%
		一体化机动车设计	-	5-10%
	混合系统	启动-停止、软性混合	2%	6-8%
		全部混合电力系统	4%	30-35%
	插入式电动车		0.6%	50-100%

间接利益:
减少动力系统尺寸
和降低成本

Automaker Response to the Vehicle Lightweighting Challenge
汽车生产商对于机动车减重挑战的回应

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Vehicle Lightweighting is a key strategy for efficiency
汽车减重是实现油耗目标的重要战略之一

- Mass reduction is expected from every automaker
  - But some will do much more (and others will do less)
- Below are some public statements, anecdotes, quotes…

Company	Quote, statement, or commitment	Year
Ford	• From 2011 to 2020: "Full implementation of known technology… weight reduction of 250-750 lbs" • "The use of advanced materials … offers automakers structural strength at a reduced weight to help improve fuel economy and meet safety and durability requirements • "Reducing weight will benefit the efficiency of every Ford vehicle. However, it's particularly critical to improving the range of plug-in hybrid and battery electric vehicles	2009
Toyota	• 10-30% weight reduction for small to mid-size vehicles • Up to 20% weight reduction from Toyota New Global Architecture over 2015-2025	2009 2013
Volkswagen	• "Automotive light weight solutions are necessary more than ever to reduce CO_2 emissions " • "Multi-Material Concepts promise cost effective light weight solutions "	2008
GM	• "One trend is clear - vehicles will consist of a more balanced use of many materials in the future, incorporating more lightweight materials such as nanocomposites and aluminum and magnesium." • Aims to shed 500 lb from trucks by 2016, as much as 1000 lbs in early 2020s	2010
Mazda	• Reduce each model by 220 lb by 2015; another 220 lb by 2020	2009
Nissan	• Average 15% weight reduction by 2015 • "We are… expanding the use of aluminum and other lightweight materials, and reducing vehicle weight by rationalizing vehicle body structure	2010
Renault, Peugeot	• Target of 440-lb reduction (approx. 15%) by 2018	2012

Vehicle Lightweighting is a key strategy for efficiency
汽车减重是实现油耗目标的重要战略之一

- 每个汽车制造商都希望减重
  - 但是有些会付出更大的努力 (其他的付出较少的努力)
- 以下是公开声明、承诺和引用…

公司	引用、声明和承诺	年份
Ford	• 从2011到2020年: “运用全部可知的技术…减重250-750 lbs” • “使用先进的材料…为汽车制造商提供结构强度，以减轻的重量帮助提高燃料经济性并达到安全和耐久性要求 • “减轻重量有益于每辆福特车的效率。但是，提高插入式混合和电池电力机动车的范围非常重要	2009
Toyota	• 对小型到中型机动车进行10-30%减重 • 2015至2025年丰田最新全球架构减重高达20%	2009 2013
Volkswagen	• “汽车的减重方法对于降低CO_2排放非常有必要 ” • “多种材料概念保证经济有效的减重方法”	2008
GM	• “一个清晰趋势 – 机动车在未来将均衡使用很多的材料，包含更多轻型材料，如纳米复合材料、铝、镁” • 目标在2016年之前卡车减轻500 lb，2020s初减轻1000 lbs	2010
Mazda	• 2015年之前，每个模型减轻220 lb; 2020年前另外减轻220 lb	2009
Nissan	• 2015年平均15%减重 • “我们…正在扩大铝和其他轻型材料的使用，通过车身结构合理化实现减重”	2010
Renault, Peugeot	• 2018年之前目标440 lb减重(大约15%) by 2018	2012

Vehicle lightweighting examples in production
进入量产的轻量化车型举例

Vehicle make 车型	Model year 年份	Weight reduction 减重 (kg)*	Weight reduction 减重 (%)*	Designed market 销售市场
Audi TT 3rd gen 2.0 TDI	2015	50	4%	US, EU
VW Golf TDI	2015	49	4%	EU
Lamborghini Huracan	2015	78	5%	US, EU
Acura MDX	2014	111	5%	US
Nissan Leaf	2012	80	5%	US, EU
Audi A3	2014	80	6%	US, EU
GM Cadillac CTS	2014	111	6%	US
Audi A8	2014	145	7%	US, EU
Porsche Cayenne	2012	181	8%	US, EU
Peugeot 308 SW Blue Hdi	2014	140	9%	EU
Ford F150	2015	318	14%	US
Audi Q7	2014	363	15%	US, EU
Land Rover Range Rover	2014	420	16%	US, EU
BMW i3 EV	2014	249	17%	US, EU

- *Weights are compared to each vehicle model's predecessor, except for BMW i3 EV, which is compared to the conventional steel structure.*
- *减重是相对于上一代模型的重量差距，只有BMW i3 EV是与传统的钢制结构相比较。*

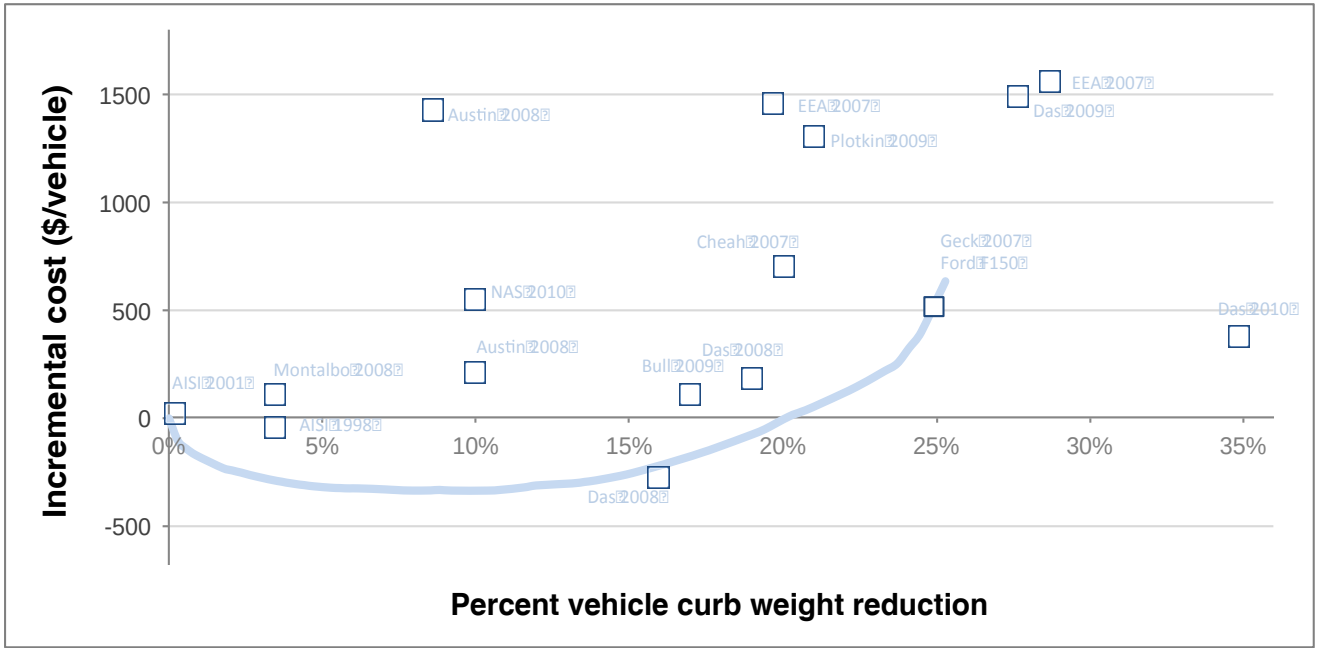
icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Lightweighting technology developments (2015-2025)
轻量化技术发展（2015-2025）

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

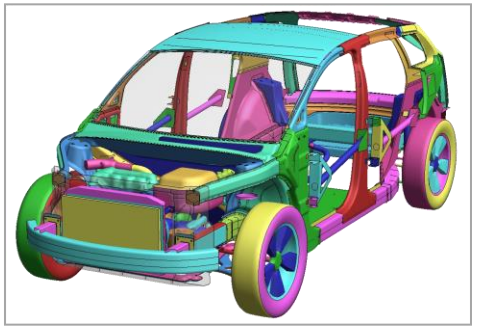
Previous vehicle lightweighting research
汽车轻量化相关研究

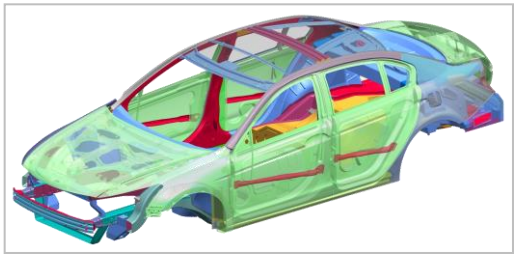
- Previous technical assessments on mass-reduction involve major studies by national US laboratories, OEM steel suppliers, OEMs with universities
  - Data plotted as vehicle cost versus percent of vehicle mass reduced
  - Each data point represents a different material/design approach to mass reduction
  - Studies vary in technical rigor, transparency, comprehensiveness, crashworthiness validation
- 关于减重的技术评估包括美国国家实验室、OEM钢铁供应商、OEM与大学所做的相关研究
  - 图中各点为机动车减重的百分比与相应的成本
  - 每个点所代表的减重方式（材料/设计）各不相同
  - 每项研究的技术精确性、透明性、综合性和防撞性验证各不相同

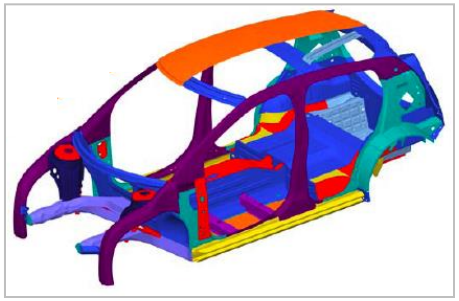


Major new vehicle lightweighting research
主要最新减重研究

- **Lotus Engineering (CARB)**
  - Cost-effective 18-32% mass reduction at < $0/vehicle for Toyota Venza
  - Includes crashworthiness safety (NHTSA FMVSS) validation
  - 2010年研究的延续(-20%, -33%重量 Toyota Venza)
  - 包括耐撞性安全(NHTSA FMVSS) 认证
  - 证明经济有效性 30%减重花费 < $0/机动车
- **FEV/EDAG (US EPA)**
  - Technical assessment of -18% mass Toyota Venza at < $0/vehicle
  - Includes crashworthiness safety (NHTSA FMVSS) validation and detailed tear-down cost assessments
  - 技术评估18%减重 Toyota Venza 花费 < $0/机动车
  - 包括耐撞性安全(NHTSA FMVSS) 认证和具体的拆解成本评估
- **EDAG / Electricore (NHTSA)**
  - Technical assessment of -22% mass-reduced Honda Accord at $319/vehicle
  - Includes crashworthiness safety (NHTSA FMVSS) validation
  - 技术评估22%减重 Honda Accord 花费 $319/机动车
- **WorldAutoSteel "Future Steel Vehicle"**
  - 12-18% mass reduction, no additional cost, with only using steels
  - 12-18%减重，仅使用钢材，无其他成本
- **George Washington University (NHTSA)**
  - 19% mass reduction from Chevrolet Silverado with advanced plastics, composites
  - 19%减重 Chevrolet Silverado使用先进塑料和复合材料

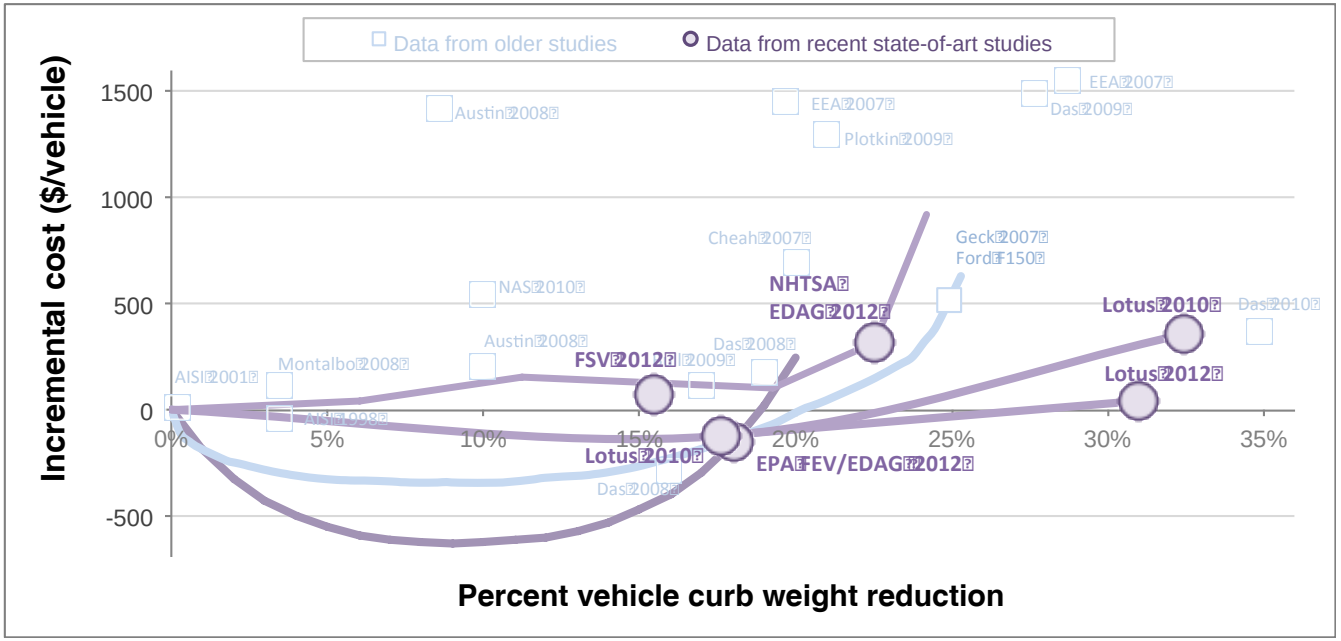






Vehicle lightweighting is highly cost-effective
汽车轻量化具有很高的经济效益性

- Major new state-of-the-art studies examine advanced materials, parts integration, system-level holistic vehicle redesign
  - High lightweighting potential, crashworthy designs, and diverse highly cost-effective approaches
  - EDAG, FEV, Lotus, and FSV lightweighting cost results are shown below
- 根据当前技术发展水平，主要研究对先进材料、零部件整合和整车系统设计改造进行验证
  - 轻量化潜力高、良好的防撞性设计，多种高经济效益的方法
  - 下图显示了EDAG, FEV, Lotus, 和FSV的轻量化成本结果

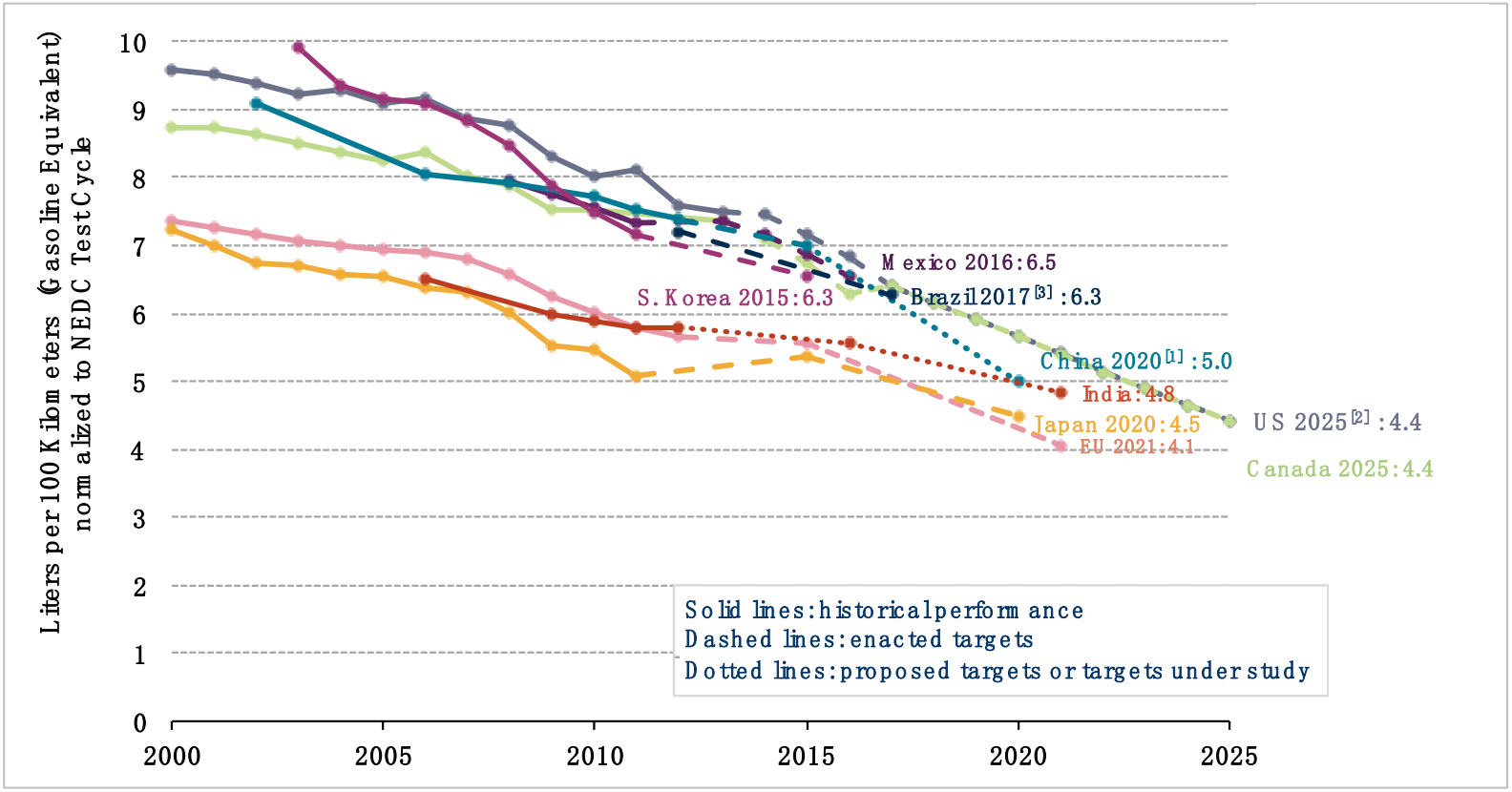


Fuel Consumption/Greenhouse Gas Standards Globally
世界燃油经济性/温室气体标准

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Global passenger car fuel consumption standards
世界乘用车油耗标准

- Standards are driving efficiency technology innovation and deployment globally
- 油耗标准驱动着全球的高效汽车的技术创新与部署



Form of standards varies widely across regions
不同地区标准的形式各不相同

Country/ Region	Regulated metric			Attribute		Form			Categories, classes, other provisions
	Fuel Economy	Fuel Consumption	CO_2/GHG	**Weight**	Footprint	Class	Continuous	Bins	
European Union#			X	**X**			X		Eco-innovations, super-credits
United States	X		X		X	X	X		2WD, AC credit, FFV/E85, alternative fuels
Japan	X			**X**				X	Averaging within bins
China		X		**X**		X		X	Transmission, per-vehicle limits → corporate average
Canada			X		X	X	X		AC credits, alternative fuels
South Korea*	X		X	**X**			X		Eco-innovations
Mexico	X				X	X	X		
India		X		**X**			X		

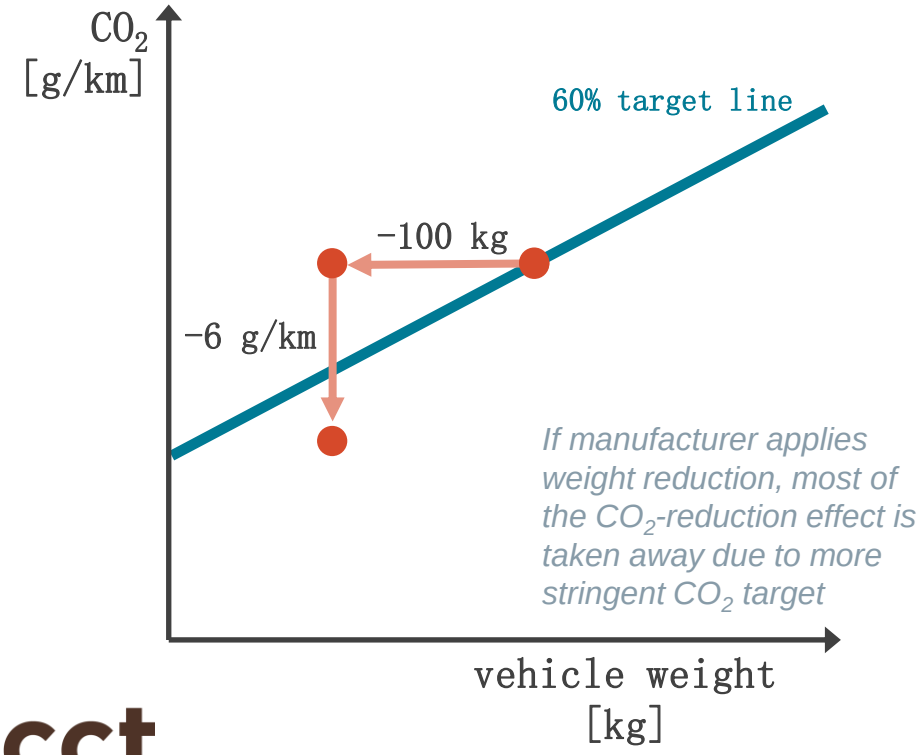
#: CO_2 standards complemented by Air-conditioning, tyre pressure monitoring, gear-shift indicators etc.
** : FE/CO_2 standards include consideration for tyre pressure monitoring, gear-shift indicators*

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

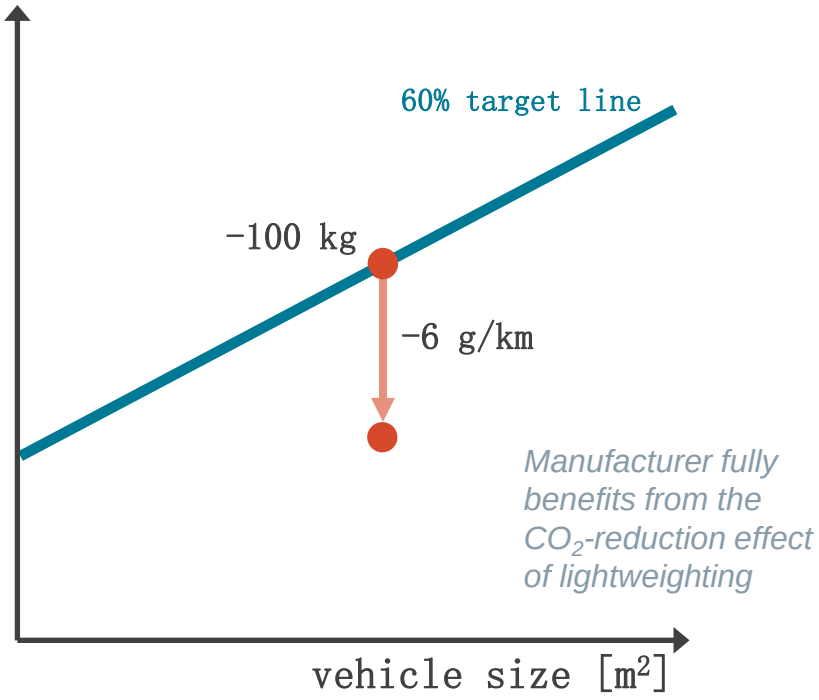
Weight vs. footprint based vehicle standards
基于质量与基于脚印面积机动车标准的比较

- Weight-based standards reduce incentive to reduce weight
- 基于质量的标准体系大大降低了减重动力，并非技术中立

Weight-based target system



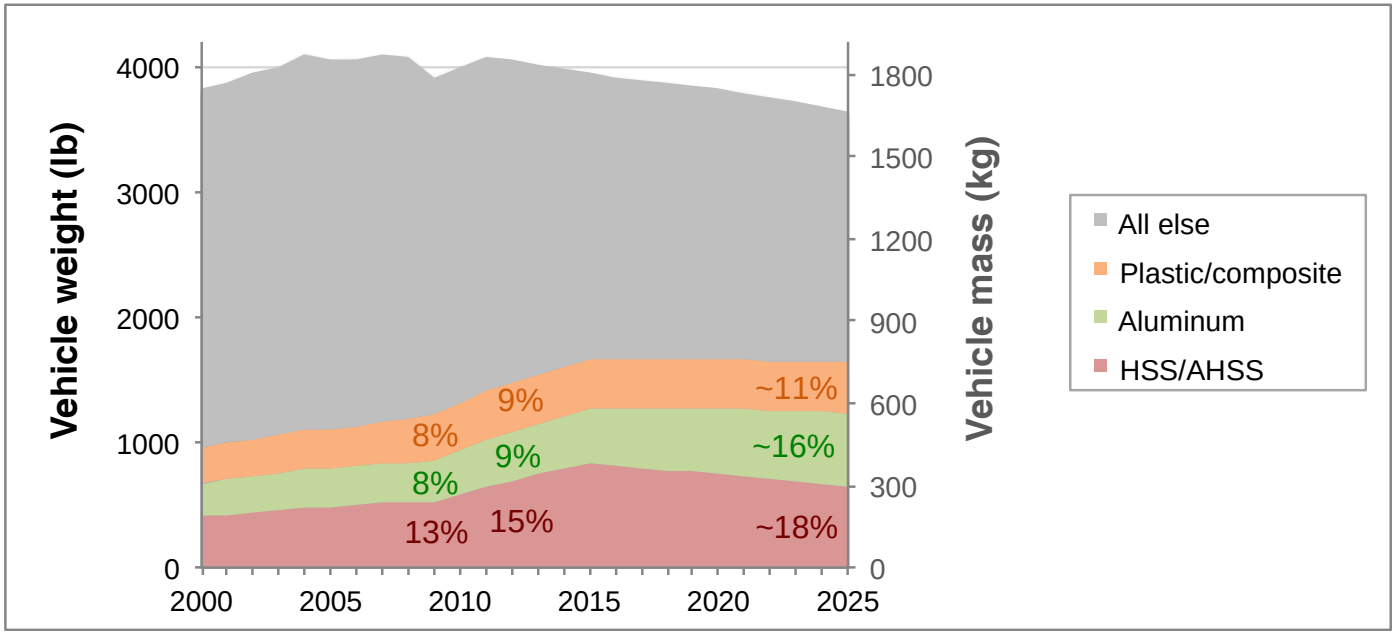
Footprint-based target system



icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Estimating lightweighting and material trends
轻量化与材料趋势预测

- US regulatory agencies are projecting a trend for ~10% average vehicle weight reduction for new vehicles in by 2025
  - Result from technology innovations (independent of fleet shifts in vehicle size)
  - OEMs using far more AHSS, aluminum, composites to achieve lightweighting goals
- 美国管理部门预测到2025年机动车平均重量将降低大约10%
  - 技术创新的结果（独立于车队尺寸的改变）
  - 厂商将使用更多的超高强度钢、铝、复合材料以达到轻量化目标



See US EPA and NHTSA 2010-2012 rulemaking analysis, Wards material trends; Ducker Worldwide steel and aluminum trends, 2010-2012; Scheps, 2011

Conclusions
结论

- Lightweighting is a mainstream, cost-effective efficiency technology
  - Innovations in materials, manufacturing, computer-aided engineering are opening up new frontiers for lightweighting to increase efficiency without compromising safety
  - Lightweighting advances are especially critical for 2020+, electric vehicles
- Regulatory design matters
  - Lightweight technology would be better promoted globally with size-based standards

- 轻量化是一个主流的、具有经济效益性的技术
  - 材料、加工工艺和计算机辅助工程的创新将允许在不影响安全的情况下通过轻量化来达到汽车效率的提高
  - 轻量化的发展对2020年之后油耗走向和电动汽车尤为重要
- 政策管理设计十分重要
  - 轻量化技术在基于尺寸的技术标准框架下会得到更好的发展

Resources and links to lightweighting studies
资料和轻量化研究相关链接

- Rulemaking / 政策制定:
  - Environmental Protection Agency (EPA) and National Highway Traffic Safety Admin. (NHTSA)
    - http://www.epa.gov/otaq/climate/regulations.htm
  - California Air Resources Board (CARB)
    - http://www.arb.ca.gov/regact/2012/leviiighg2012/leviiighg2012.htm
    - Lotus report: http://www.arb.ca.gov/msprog/levprog/leviii/leviii.htm
  - Technical lightweighting studies, peer reviews:
    - http://www.epa.gov/otaq/climate/strategies-vehicle.htm
    - FEV EDAG: http://www.epa.gov/otaq/climate/documents/420r12026.pdf
    - NHTSA EDAG: ftp://ftp.nhtsa.dot.gov/CAFE/2017-25_Final/811666.pdf
- Other resources /其他资源:
  - ICCT lightweighting links, reports
    - Lightweighting papers: http://theicct.org/vehicle-mass-reduction-resources
    - Lotus Phase 1: http://theicct.org/sites/default/files/publications/Mass_reduction_final_2010.pdf
    - World Auto Steel FSV: http://c315221.r21.cf1.rackcdn.com/FSV-EDAG_Phase2_Engineering_Report.pdf
  - Mock, 2011. Evaluation of parameter-based vehicle emissions targets in the EU
    - http://theicct.org/evaluation-parameter-based-vehicle-emissions-targets-eu
  - Lutsey, N., 2010. Review of Technical Literature and Trends Related to Automobile Mass-Reduction Technology.
    - http://pubs.its.ucdavis.edu/publication_detail.php?id=1390
  - German and Lutsey, 2010. Size or Mass? The Technical Rationale for Selecting Size as an Attribute for Vehicle Efficiency Standards
    - http://theicct.org/size-or-mass-technical-rationale-selecting-size-attribute-vehicle-efficiency-standards