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Specifying for Certification for Automotive Safety Systems

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What is innovation?

Change that creates a new dimension of performance.

– Peter Drucker

The introduction of new goods … new methods of production … the opening of new markets … the conquest of new sources of supply … and the carrying out of a new organization of any industry.

– Joseph Schumpeter

Creativity is thinking up new things. Innovation is doing new things.

– Theodore Levitt

The Schumpeterian Trilogy:
Invention, Innovation, Diffusion

- **Invention**: creation of an idea to do or make something (profitability not yet verified)
- **Innovation**: new product/ process commercially valuable i.e. successfully developed inventions.
- **Diffusion**: the spread of a new invention/innovation throughout society or at least throughout the relevant part of society.

Vehicle CPS/SW – The Landscape

Across all industries per DARPA 2011 Review (Medical, Aerospace, Naval/NASA, Automotive, Rail, et al):

- Max Complexity (100M lines of Embedded Code)
- Cost/Development Time exponential in Complexity with one exception:
  - Automotive has cut by >50% from averages of 48 months to 21-22
- Development is largely automated
- Architecture is being standardized (DBMS/Sensor Interface, Services Layer and User Interface)
  - AUTOSAR BSW (Com and Diagnostics)
  - Driven by Supply Base

Vehicle CPS/SW – Development Methodology

Embedded SW – Model Based Development Cycle (Matlab/Stateflow, Statemate/Rhapsody et al):

- Reuse – Model Level
- Requirements – User/Customer
- Systems Definition/Specification
- Application Development
- Integration with Basic SW Layer and HW
- Component Manufacturing and Test
- System Integration
- System Test
- Validation

Vehicle CPS/SW - Certification

Models for Certifying Development Methodology

- CMM/CMMi
- Pendock
- Et al

ISO 26262/Functional Safety

- New to the Industry
- Inherited from aerospace
- Executed ‘jointly’ with Supply Base

Current Automotive Efforts

Fault Tolerance

What Is Fault Tolerant Embedded Software

• Embedded Software is software that can “tolerate” faults (software design defects, or bugs)
• Fail-silent or fail-operational behavior, depending on the safety requirements
• Safety requirements derived from a hazard analysis and risk assessment (consistent with a functional safety process standard such as ISO-26262)

Why Do We Need Fault Tolerant Embedded Software

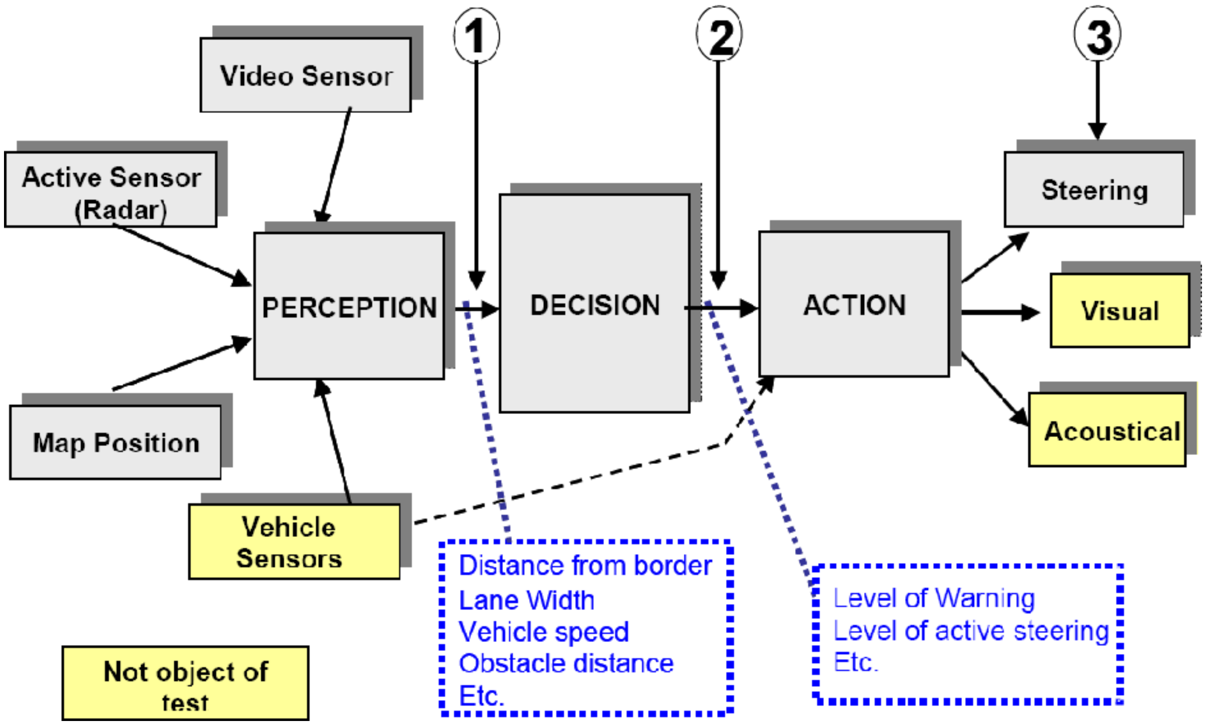
• Embedded control software is being used in the automobiles to control the motion of the vehicle with increasing levels of automation and control authority
• Long-term toward partial or even fully autonomous operation
• Increasing complexity of vehicle motion control being performed by embedded software amplifies the potential consequences of a software design fault or bug
• Software design faults must be detected and mitigated to ensure safe operation of the vehicle

Fault Tolerance

Term	Definition	Examples
Fault	Cause (mechanism) of an anomalous event	· Alpha particle bombardment · Corrosion on terminal · Metal fatigue · Incorrect test for conditional branch
Error	Incorrect state or value	· Bit-flip in a memory location or register · Wire shorted to ground · Incorrect voltage or current on a wire · Incorrect actuator position command · Incorrect result of computation
Failure	Inability of a system to perform its prescribed service	· Inadequate braking torque · Inability to steer the vehicle · Inability to open the throttle
Detection	Observation of the manifestations of an error or failure	· Sensor output shorted to ground · Invalid output torque request to actuator · Serial data message timeout · Run-time assertion violation
Identification (also called Diagnosis or Localization)	Identify the component to blame for an error or failure	· Sensor · Body Control Module · Wiring Harness · Object detection software component
Isolation (also called Fault Containment)	Prevent the fault from propagating to other parts of the system	· Error detection coding · Acceptance tests on received values · Comparison of dual-redundant values
Recovery	Mitigation action to be taken upon detection and identification	· Shut the system down · Reboot / restart the system · Switch to an active standby · Reconfigure the system

Vehicle Systems

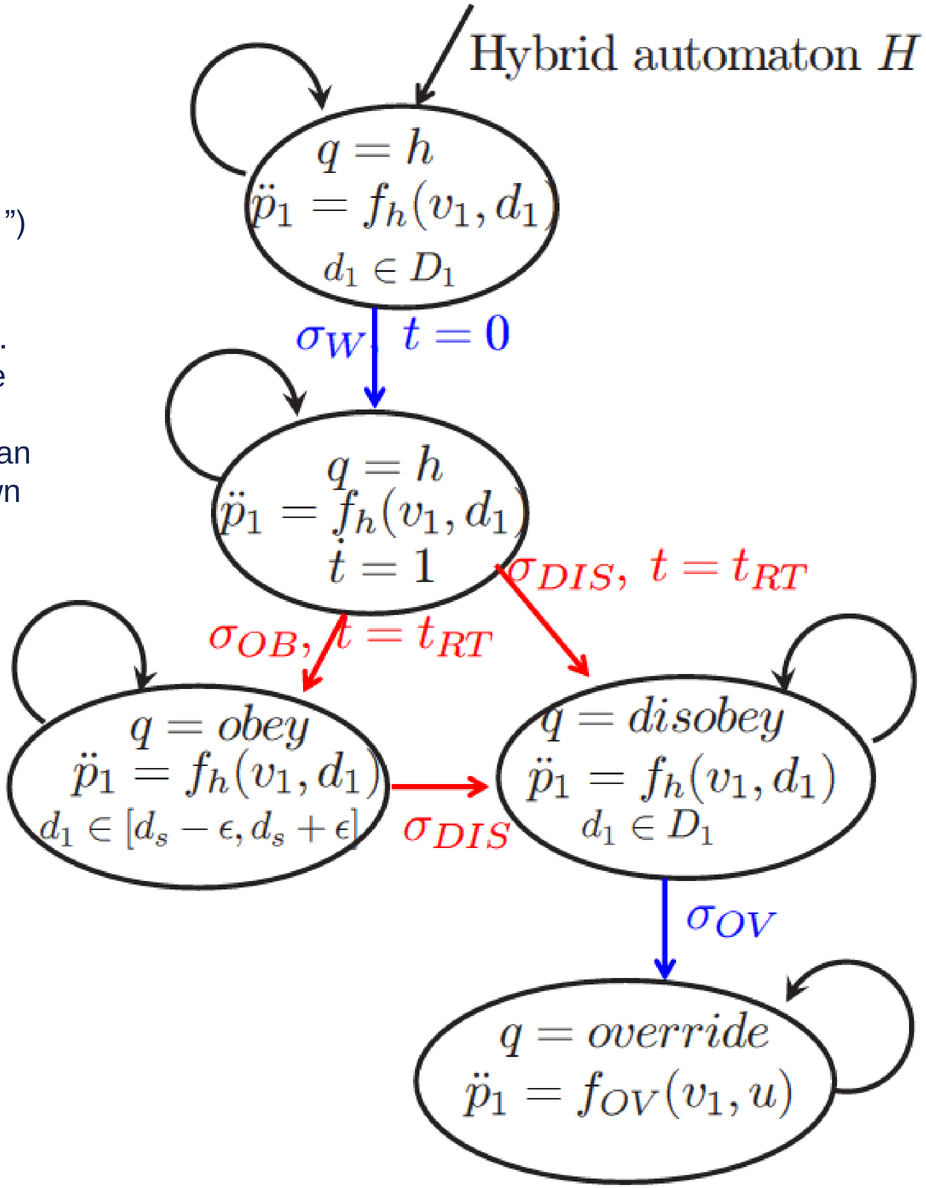
Vehicle Systems



MIT/Chrysler Virtual Analysis/Verification of Safety Systems

Hybrid automaton

- modeling a driver assistance system
- local vehicle (denoted with subscripts “1”) treats the remote vehicle(denoted with subscripts “2”) as an “enemy” to be counteracted for the worst-case scenario.
- in all modes the dynamics of the remote vehicle are given by p2 = d2 (d2 represents the human input and is free to range in a given known interval D2)



Hybrid Automata – Discrete/Continuous Model and Provability

A hybrid automaton H is a tuple

H = (Q, X, U, D, ., Inv, R, f) where:

• Q is the set of discrete states or modes
• X subset Rn is the continuous state space
• U subset Rm is the continuous set of control inputs
• D subset Rp is the continuous set of disturbance inputs
• Σ = ΣU union ΣD is the set of events (ΣU are control events and ΣD are disturbance events) that trigger transitions among
Modes
• Inv = {e} are silent events, which correspond to no transition occurring
• R : X × Q × . . Q is the mode update map and
• f : X × Q × U × D . X is the vector field, which is allowed to be piecewise continuous in its arguments
• Imperfect information on the continuous state is modeled by considering a measurement map g : M mapping 2 pot X , which for a measurement y returns a set of possible continuous states compatible with such a measurement

Security and 'Provability' – USCAR/Iowa/DARPA

KEY CHALLENGES

•Creating domain-specific functional specifications with abstractions rich enough to express control algorithms, but constrained enough to enable **formal proofs of correctness**.

•Abstractions for formulating and enforcing safety and security policies geared towards the specific needs of control systems with sensory inputs, actuators to respond autonomously and instantly to an attack, and number-crunching control algorithms.

•Abstractions that allow composition of a complex high-assurance control system out of high-assurance subsystems like

- stability control
- traction control
- fuel cells
- hybrid vehicles
- powertrain control.

•Abstractions to construct and check proofs as well as reveal the obstructions to a proof.

•Designing a powerful but simple PE for use by control engineers.

High Assurance Cyber Military Systems

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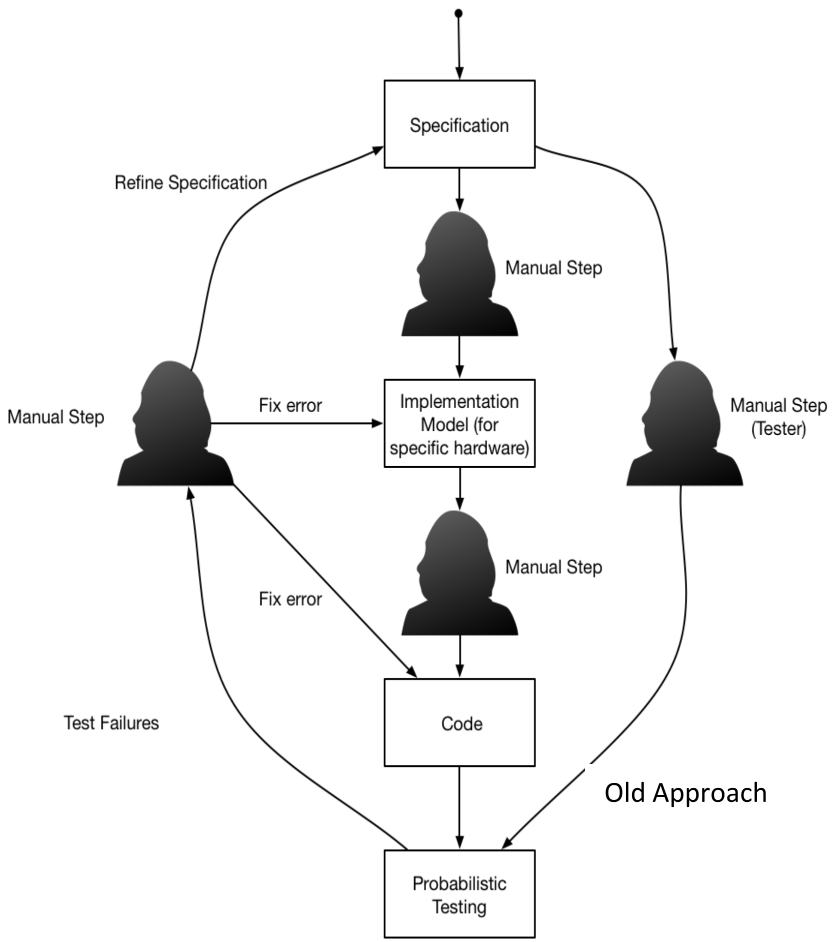
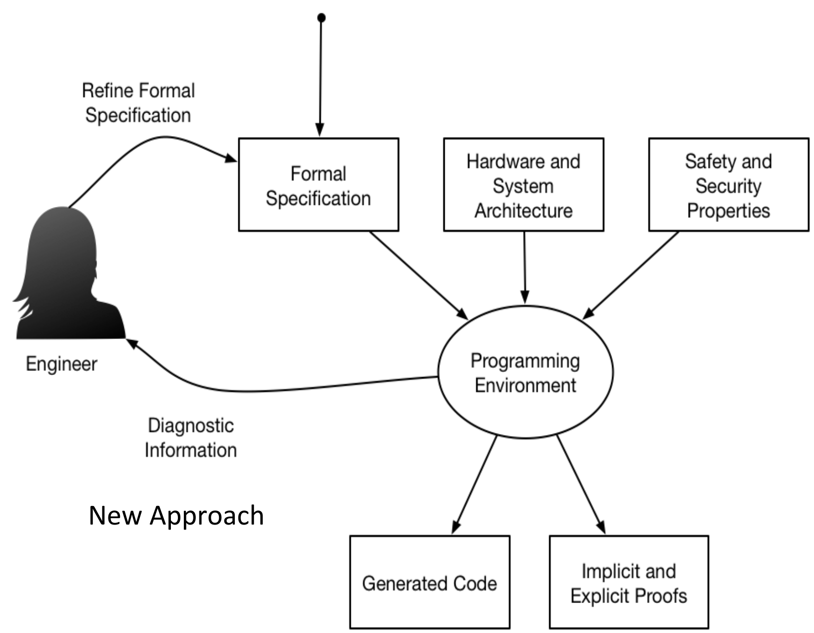
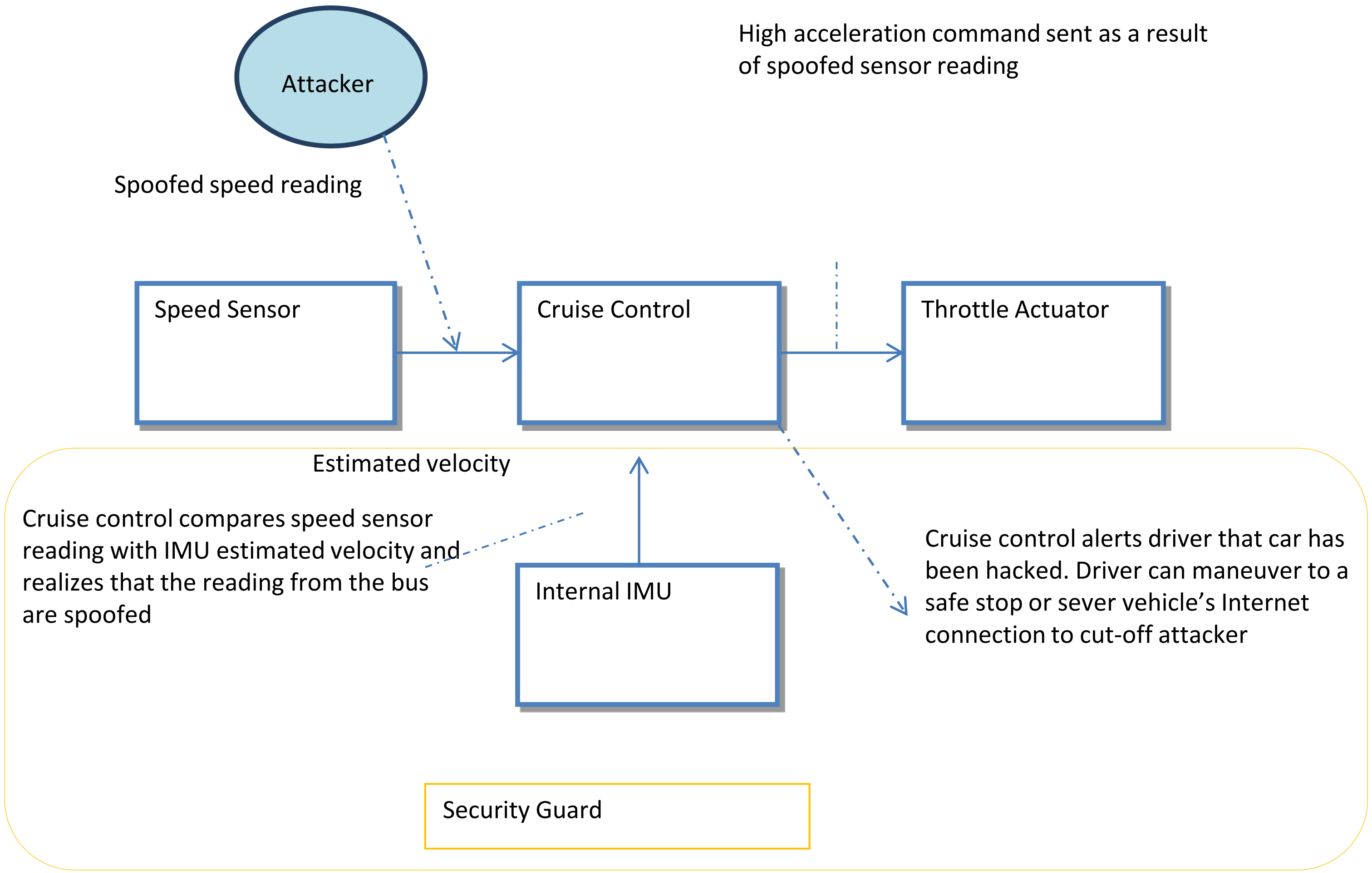


Old Approach



New Approach

Security and Safety – Validation and Sensor Fusion



Economics of Safety – Standards and Innovation

Innovation Engine

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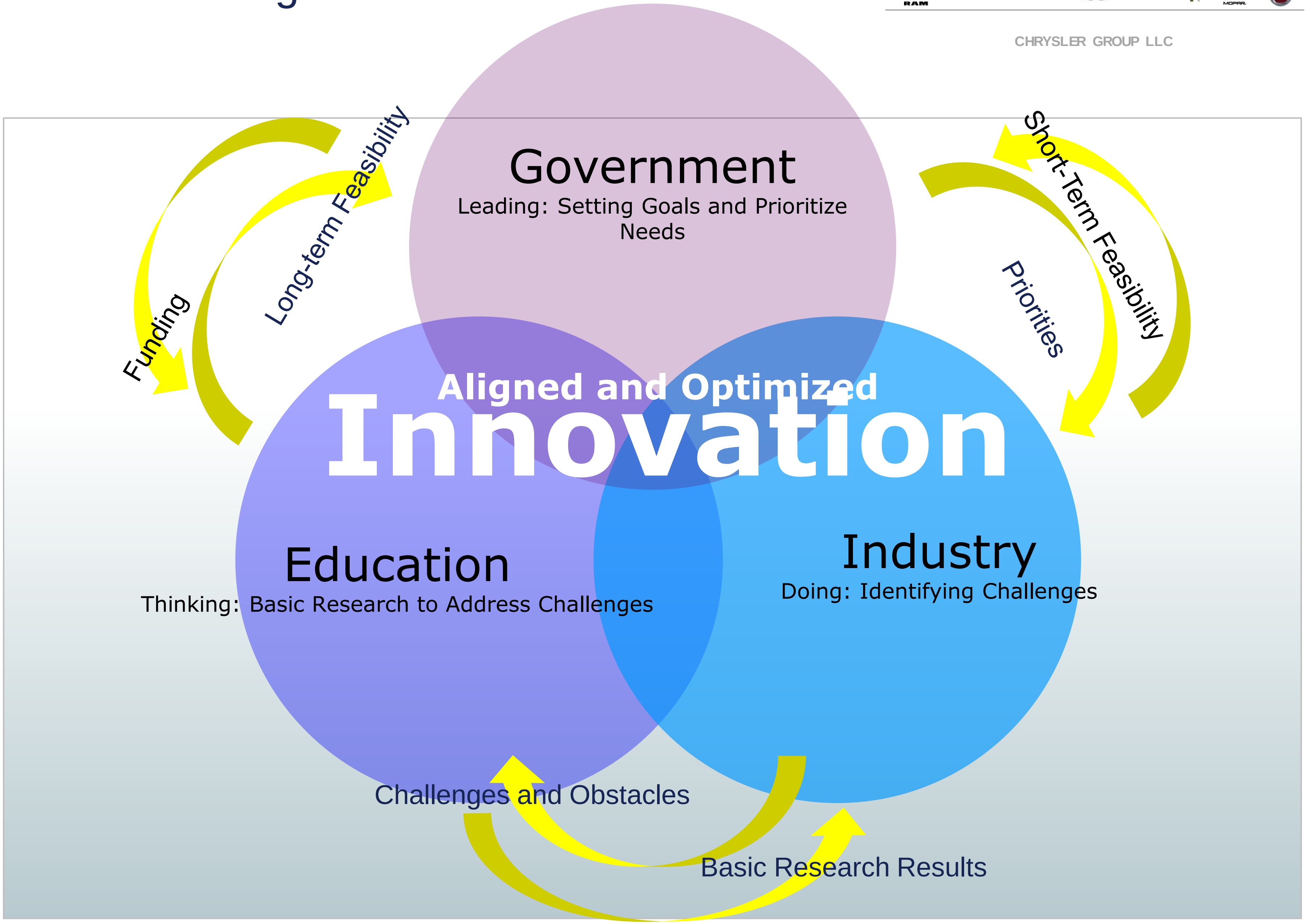

Economics of Standards

- Trends in National R&D Performance
- R&D and GDP Growth
- U.S. Business R&D   R&D by Multinational Companies
- Exports and Imports of R&D-Related Services
- Federal R&D   Federal R&E Tax Credit
- International R&D Comparisons

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Trends in National R&D Performance

- Growth in total U.S. R&D performance slowed noticeably in 2009, compared to the last several years, but the broader trend remains that R&D spending growth continues to significantly outpace growth of the U.S. economy as a whole.
- The business sector continues to account for most of both U.S. R&D performance and R&D funding.
- U.S. R&D is dominated by development activities, largely performed by the business sector. The business sector also performs the majority of applied research, but most basic research is conducted at universities and colleges and funded by the federal government.

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R&D and GDP Growth

- **Treating R&D as an investment, rather than as an expense, affects estimates of GDP growth.**
  - When R&D is treated as an investment, estimates of average annual GDP growth between 1959 and 2007 are 0.07 points higher than when R&D is treated as an expense.
  - The difference in estimated average annual growth is higher in

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International R&D Comparisons

- **The top three R&D-performing countries: United States, China—now the second largest R&D performer—and Japan represented just over half of the estimated $1.28 trillion in global R&D in 2009.**
- **Wealthy economies generally devote larger shares of their GDP to R&D than do less developed economies.**

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U.S., China, and Japan

- The United States, the largest single R&D-performing country, accounted for about 31% of the 2009 global total, down from 38% in 1999. Asian countries—including China, India, Japan, Malaysia, Singapore, South Korea, Taiwan, and Thailand—represented 24% of the global R&D total in 1999 but accounted for 32% in 2009, including China (12%) and Japan (11%).
- The pace of real growth over the past 10 years in China's overall R&D remains exceptionally high at about 20% annually.
- The European Union accounted for 23% total global R&D in 2009, down from 27% in 1999.

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Wealthy and Less Developed Countries

- The U.S. R&D/GDP ratio (or R&D intensity) was about 2.9% in 2009 and has fluctuated between 2.6% and 2.8% during the past 10 years, largely reflecting changes in business R&D spending.
- In 2009, the United States ranked eighth in R&D intensity—surpassed by Israel, Sweden, Finland, Japan, South Korea, Switzerland, and Taiwan—all of which perform far less R&D annually than the United States.
- Among the top European R&D-performing countries, Germany reported a 2.8% R&D/GDP ratio in 2008; France, 2.2%; and the United Kingdom, 1.9%.
- The Japanese and South Korean R&D/GDP ratios were among the highest in the world in 2008, each at about 3.3%. China's ratio remains relatively low, at 1.7%, but has more than doubled from 0.8% in 1999.

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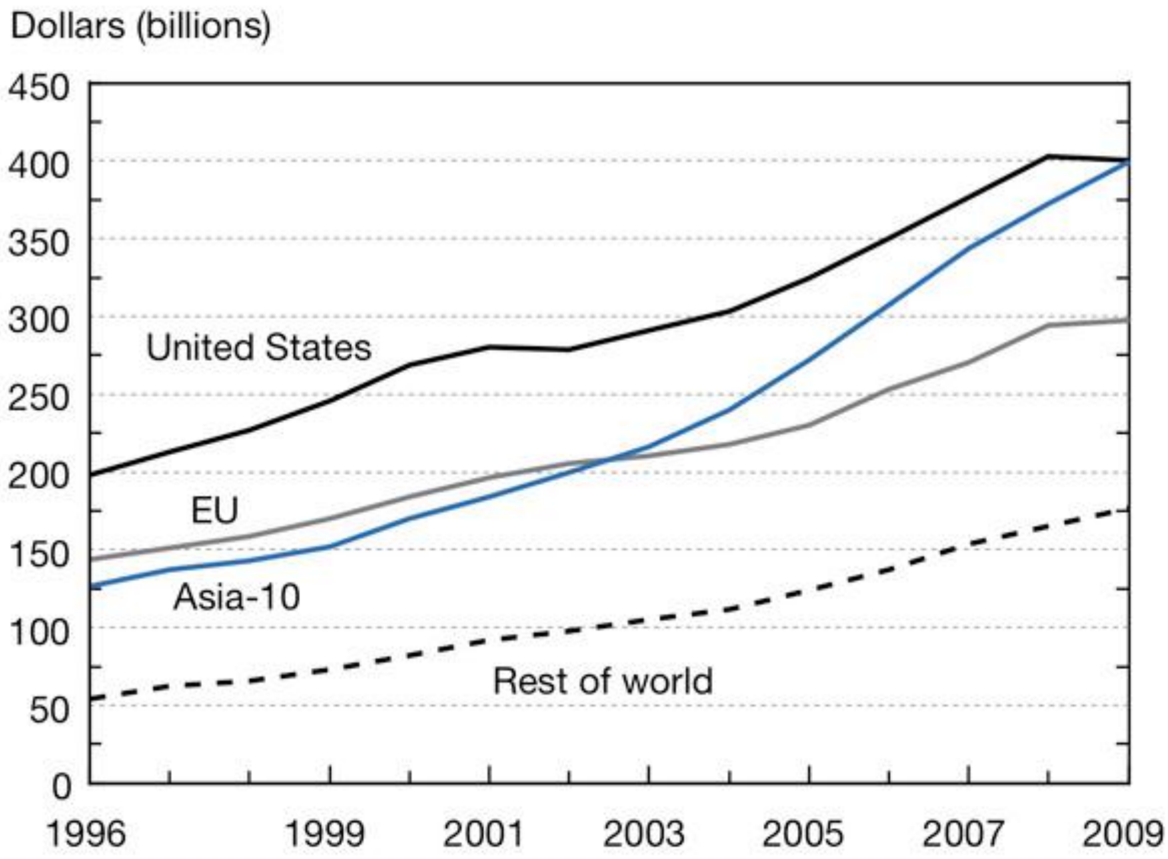
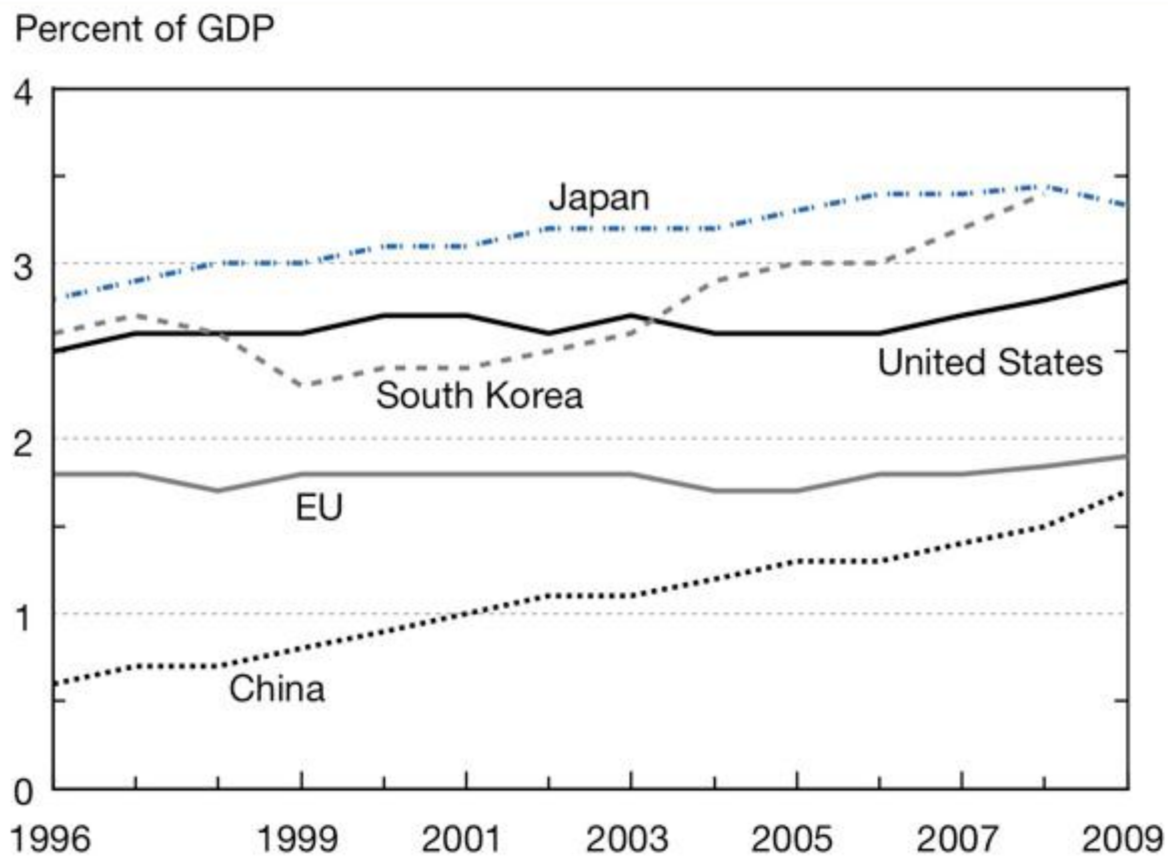
R&D expenditures for United States, EU, and 10 Asian economies: 1996–2009



Asia-10 = China, India, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Taiwan, Thailand; EU = European Union

SOURCE: National Science Board, *Science and Engineering Indicators 2012*

R&D expenditures as a share of economic output of selected regions/countries: 1996–2009



EU = European Union; GDP = gross domestic product

NOTE: 2009 data unavailable for South Korea.

SOURCE: National Science Board, *Science and Engineering Indicators 2012*

Current Complicating Factor: Connected Car

Intelligent Transportation Systems (1)

- Traditional ITS Technologies:
  - Ramp Metering
  - Transit Information
  - Electronic Payment and Credentialing
  - Transportation Management Centers

Figure 7: Los Angeles Metro Rapid Real-Time Arrival Sign (From USDOT)

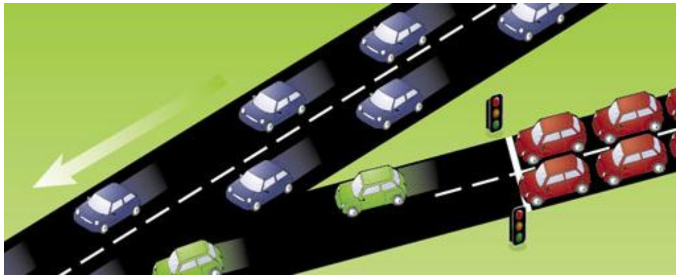


Figure 8: Ramp metering diagram (From New Zealand Transit Agency)

SOURCE: Row, S. (2009) "Future of the ITS Program" Presentation to the ITS America 2009 Annual Meeting, Plenary Session: "A New Era in Transportation – A Federal Perspective." Research and Innovative Technology Administration, USDOT. Tuesday June 2, 2009.

Intelligent Transportation Systems (2)

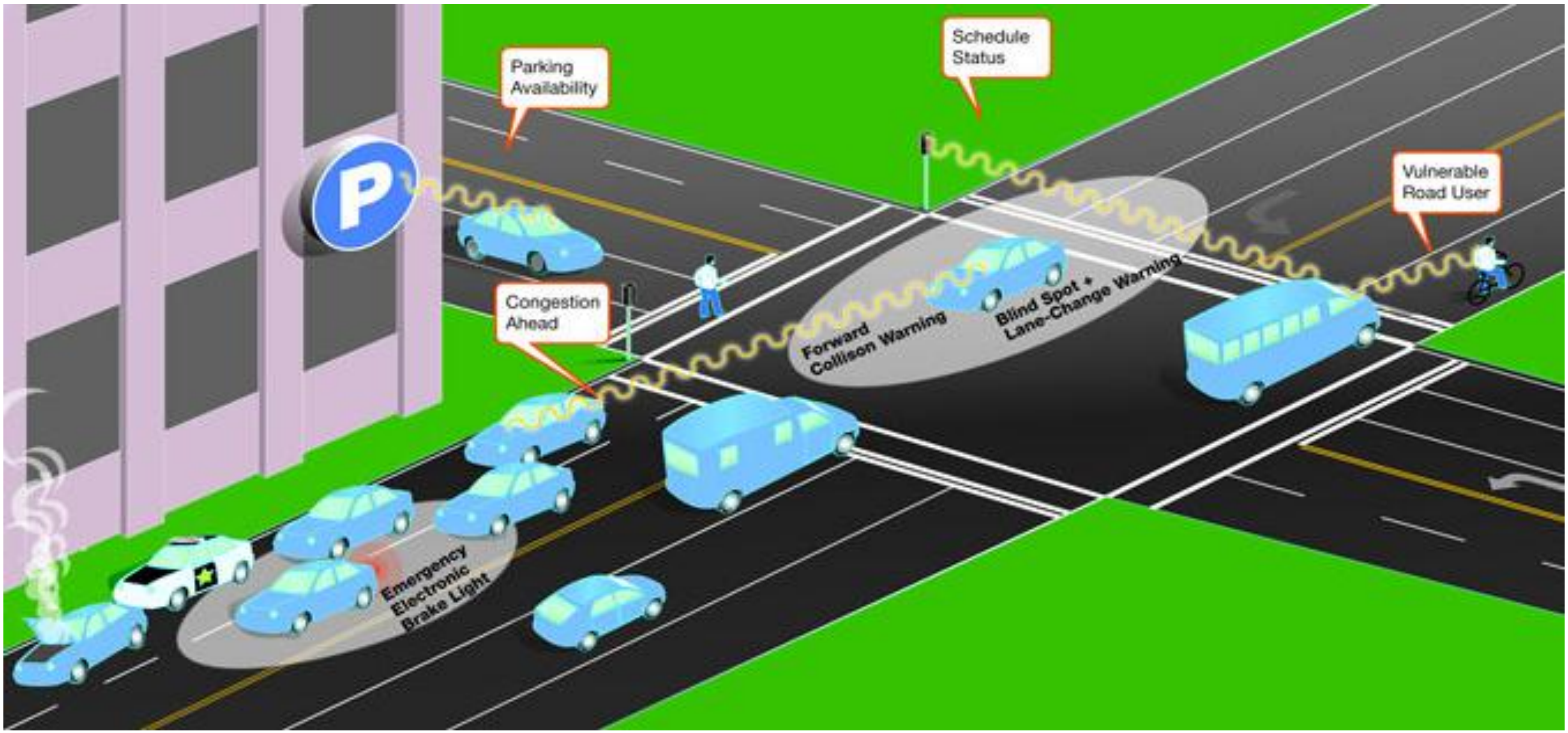


Figure 9: Intellidrive systems (formerly "Vehicle Infrastructure Integration" (VII)) consist of Vehicle to Vehicle (V2V), Vehicle to Infrastructure(V2I), and Vehicle to Device (V2D) Wireless communications.

SOURCE: http://www.its.dot.gov/intellidrive/intellidrive_overview.htm

Economics: Some Evidence for ‘Convergence’

Historical fleet CO_2 emissions performance and current or proposed standards

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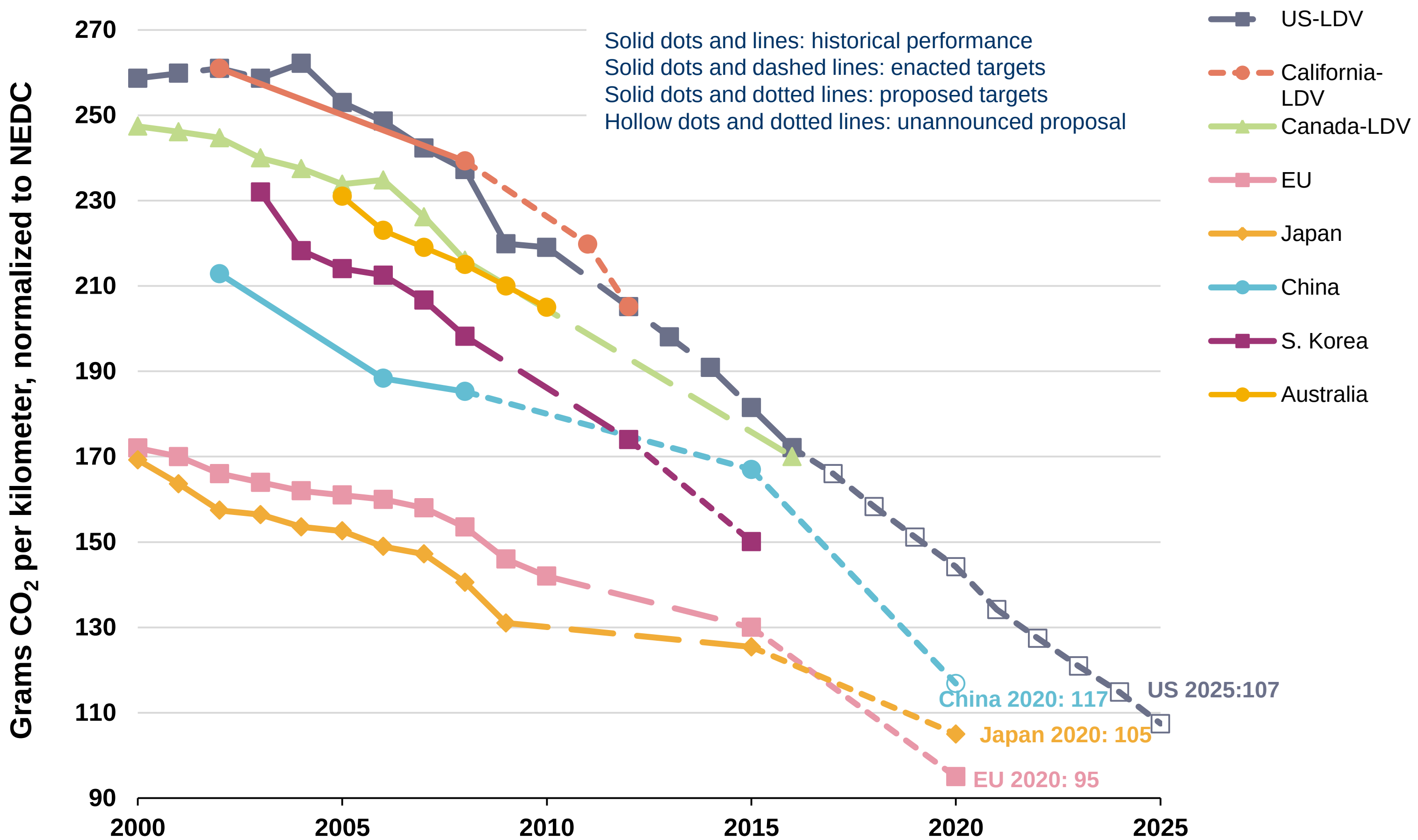
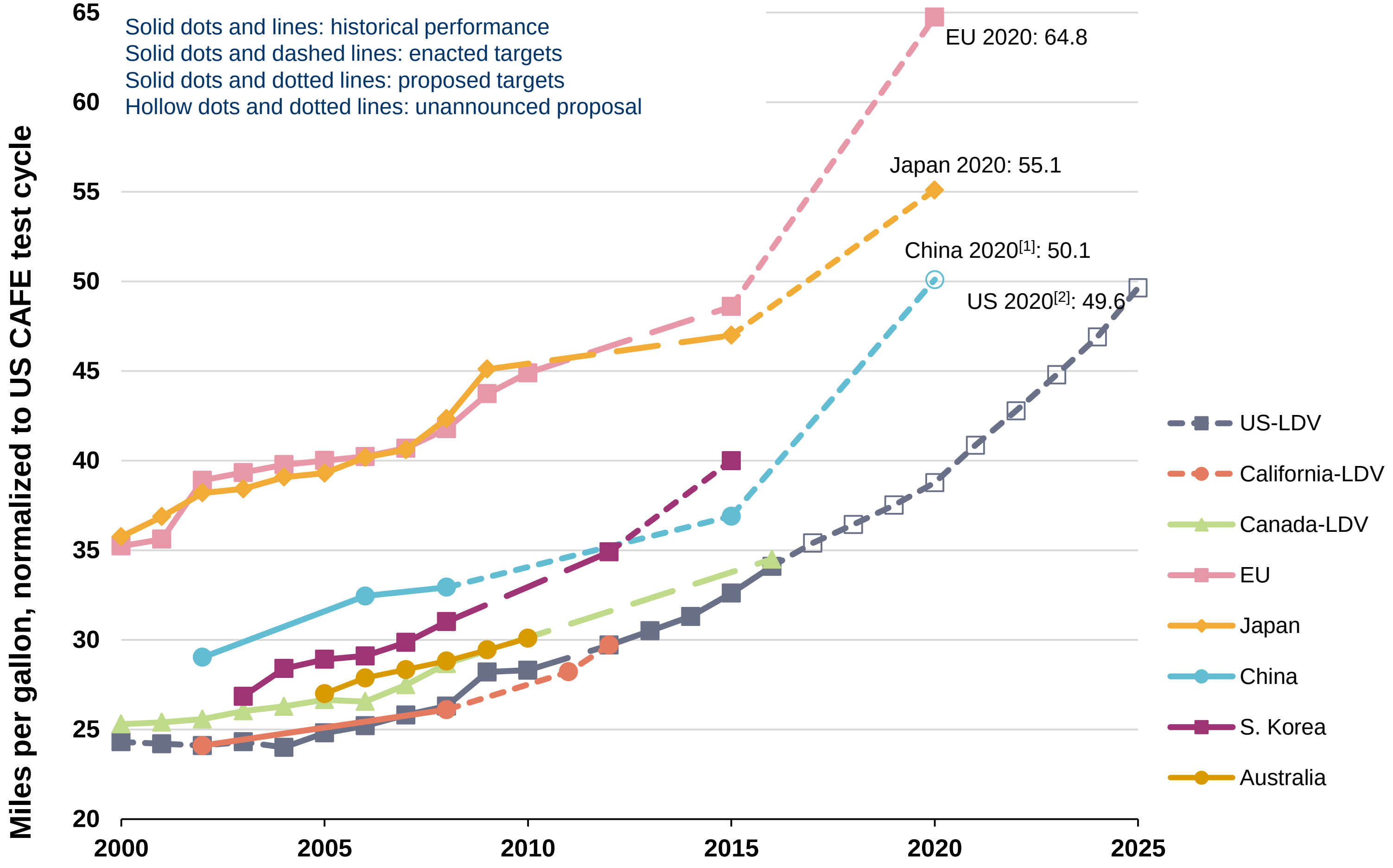


[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
[2] US and Canada light-duty vehicles include light-commercial vehicles.

Historical fleet fuel economy performance and current or proposed standards



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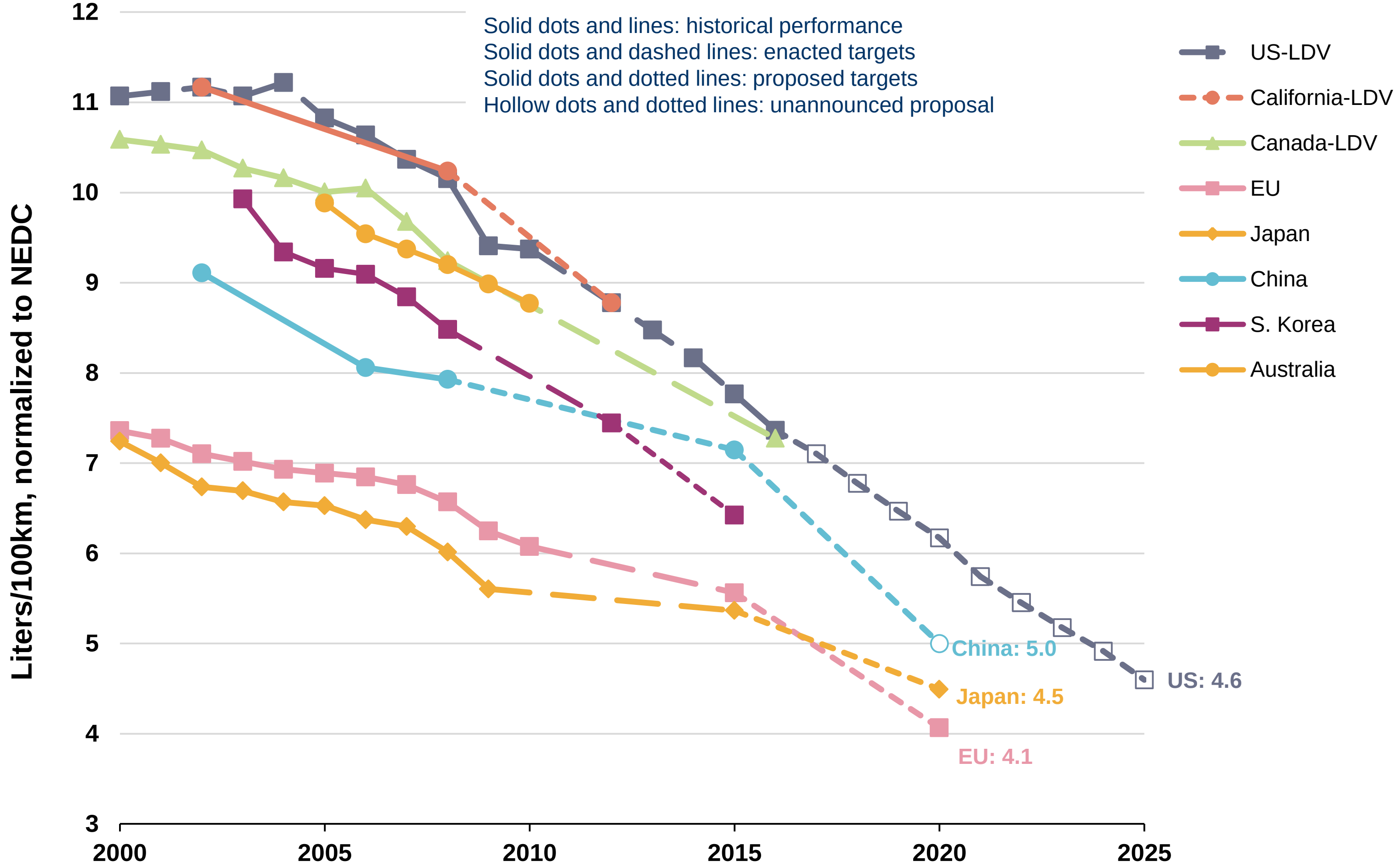

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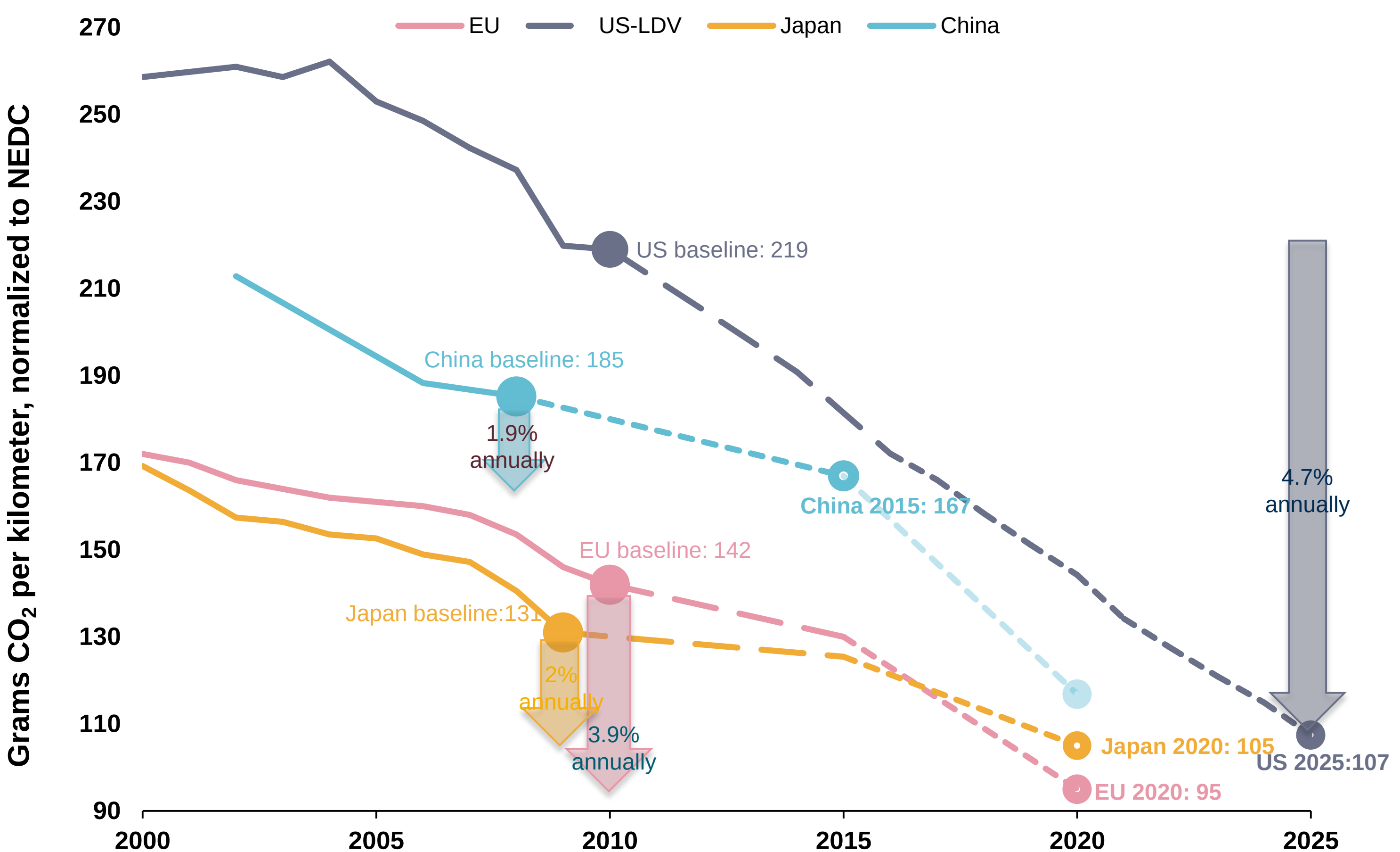
Four markets absolute and annual rate comparison



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
[2] US and Canada light-duty vehicles include light-commercial vehicles.
[3] Annual rate is calculated using baseline actual performance and target values.

Backup Slides

U.S. Business R&D

- **Domestic R&D performed by the business sector reached $291 billion in 2008.**
  - More than three-quarters of U.S. business R&D is performed in six industry groups—four in manufacturing (chemicals, computer and electronic products, aerospace and defense, and automotive) and two in services (software and computer-related products, and R&D services).

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R&D by Multinational Companies

- The majority of R&D by U.S. multinational companies (MNCs) continues to be performed in the United States. Outside the United States, R&D by U.S.-owned foreign affiliates is performed mostly in Western Europe, Canada, and Japan, followed more recently by other locations in the Asia-Pacific region.
  - In 2008, U.S. MNC parent companies and their majority-owned foreign affiliates performed $236.1 billion in R&D worldwide, according to the Bureau of Economic Analysis. This included $199.1 billion performed by the parent companies in the United States and $37.0 billion by their majority-owned foreign affiliates.
  - The share of R&D performed by Asia-located affiliates (other than in Japan) increased from 5.3% to 14.4% from 1997 to 2008. In particular, the share of U.S.-owned affiliates R&D performed in China, South Korea, Singapore, and India rose from a half percentage point or less in 1997 to 4% for China, just under 3% for South Korea, and just under 2% each for Singapore and India in 2008.
  - Majority-owned affiliates of foreign MNCs located in the United States (U.S. affiliates) performed $40.5 billion of R&D in 2008 virtually unchanged from the $41.0 billion they performed in 2007. Since 1999, the share of these companies in total business R&D has fluctuated narrowly between 13% and 15%.

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Exports and Imports of R&D-Related Services

- **Trends in cross-border transactions in research, development, and testing (RDT) services are another indicator of global linkages.**
  - In 2009, U.S. RDT exports and imports stood at $18.2 billion and $15.8 billion, respectively, for a balance of $2.5 billion.
  - In 2008, the proportion of RDT exports ($17.4 billion) to domestic U.S. business R&D performance ($290.7 billion) was 5.6%. This proportion was about 3.8% in 2001.
  - Most transactions in RDT services—around 85% of total annual RDT exports—

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Federal R&D

- **Federal spending on R&D has continued to grow, although at a slower pace, when adjusted for inflation, in the last several years. Defense continues to account for more than half of annual federal R&D spending. Health-related R&D accounts for the majority of federal nondefense R&D.**
- Eight federal agencies accounted for 97% of federal R&D spending in FY 2009: the departments of Commerce, Defense, Energy, Health and Human Services, and Homeland Security, and the National Science Foundation and National Air and Space Administration. Federal obligations for R&D have increased annually since the late 1990s. When adjusted for inflation, growth has been flatter after FY 2005.
- In FY 2009, federal obligations for R&D reached $133.3 billion and an additional $3.6 billion for R&D plant. The American Recovery and Reinvestment Act of 2009 obligated an additional $8.7 billion for R&D and $1.4 billion for R&D plant for the same fiscal year.
- In the last 10 years, federal funding for basic and applied research has grown faster in the life sciences, mathematics/computer sciences, and psychology than in other fields. In the environmental sciences, growth has not kept pace with inflation.
- Over the last two decades, the greatest change in federal R&D priorities has been the rise in health-related R&D, which currently accounts for just over half of nondefense R&D spending.

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Federal R&E Tax Credit

- **To counteract potential business underinvestment in R&D, the federal government makes available tax credits for companies that expand their R&D activities.**
- Business research and experimentation (R&E) tax credit claims were about $8.3 billion both in 2007 and in 2008.
- Five industries accounted for 75% of R&E credit claims in

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Innovation process

The innovation process

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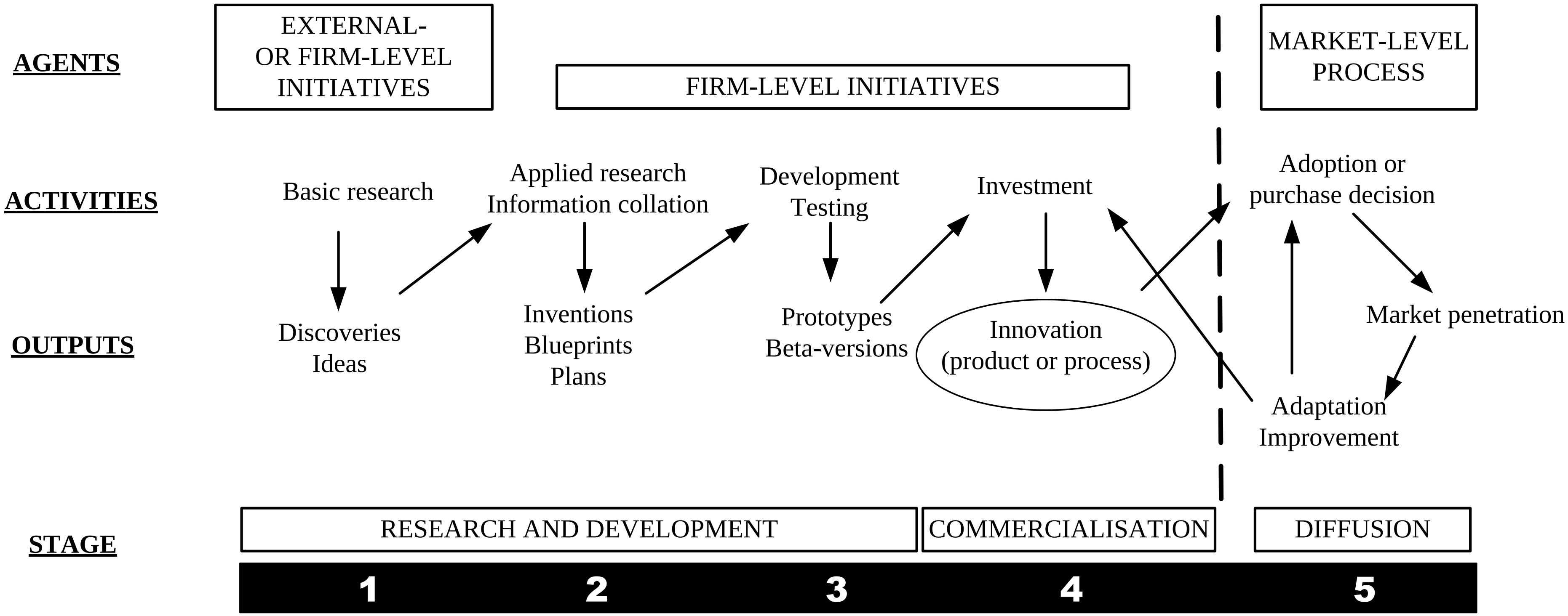


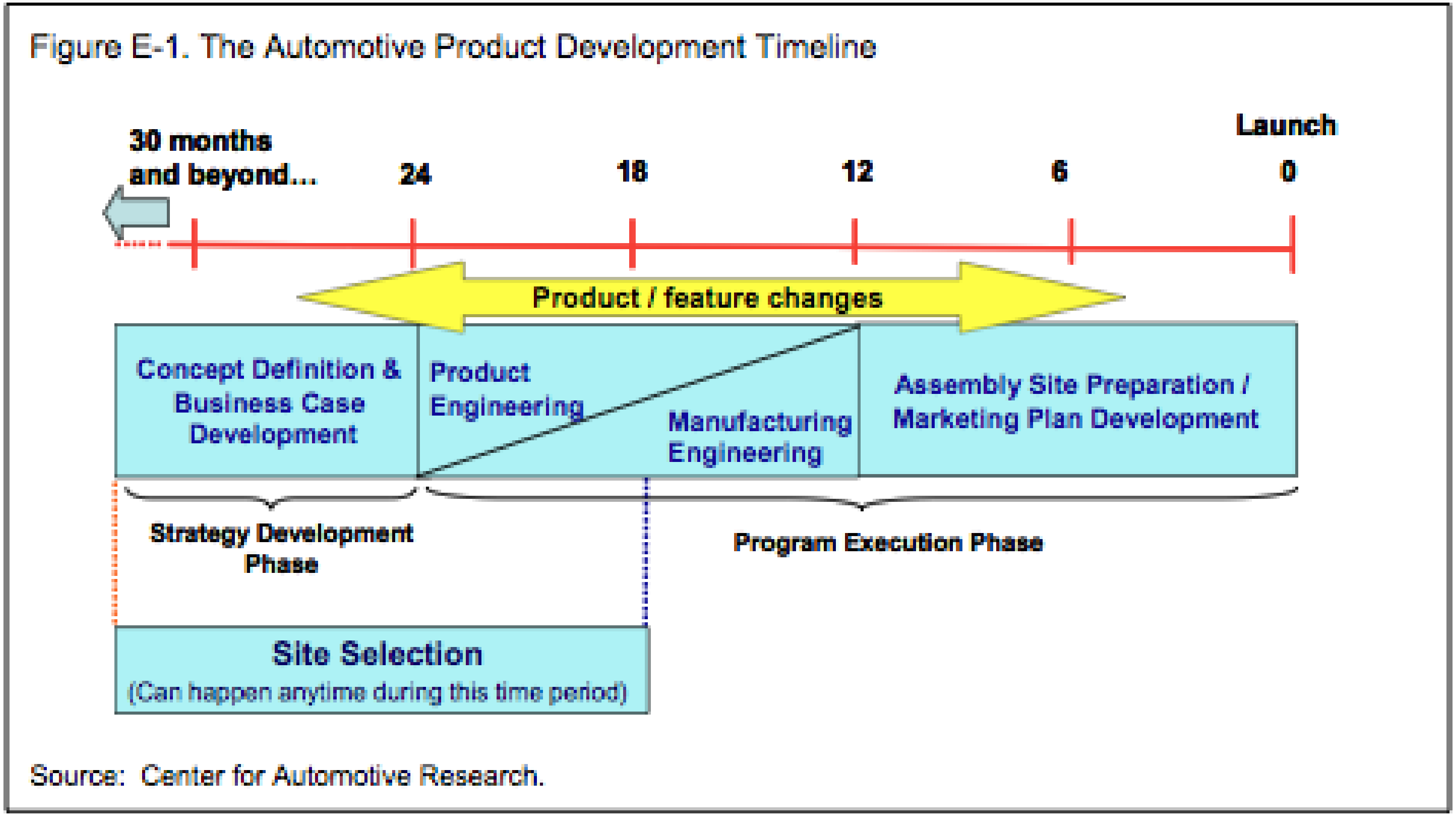
Figure 1.1 Greenhalgh and Rogers (2010)

Examples of Resource Transformations

	HUMAN	ORG.	REL.	PHYSICAL	MONETARY
HUMAN	Training	Knowledge codification, new IP	Building & developing relationships	Developing prototypes	Sales of man-hours
ORGANISATIONAL	Developing competence through use	Systems generate IP	Market intelligence	Produce By numbers	Sales of IP, processes & knowledge
RELATIONAL	Chance to build skills in relationship handling	Importing IP, processes, association with brands	Networking	Use of other company's assets	Relationship selling, preferential deals
PHYSICAL	Facilities to train with	Possible new products & know-how	Facilities build relationships	Equipment generates products	Sales of products
MONETARY	Recruitment training, conditions	Investment in brands, image and systems	Investment in building links	Investment in assets	Investment In financial instruments

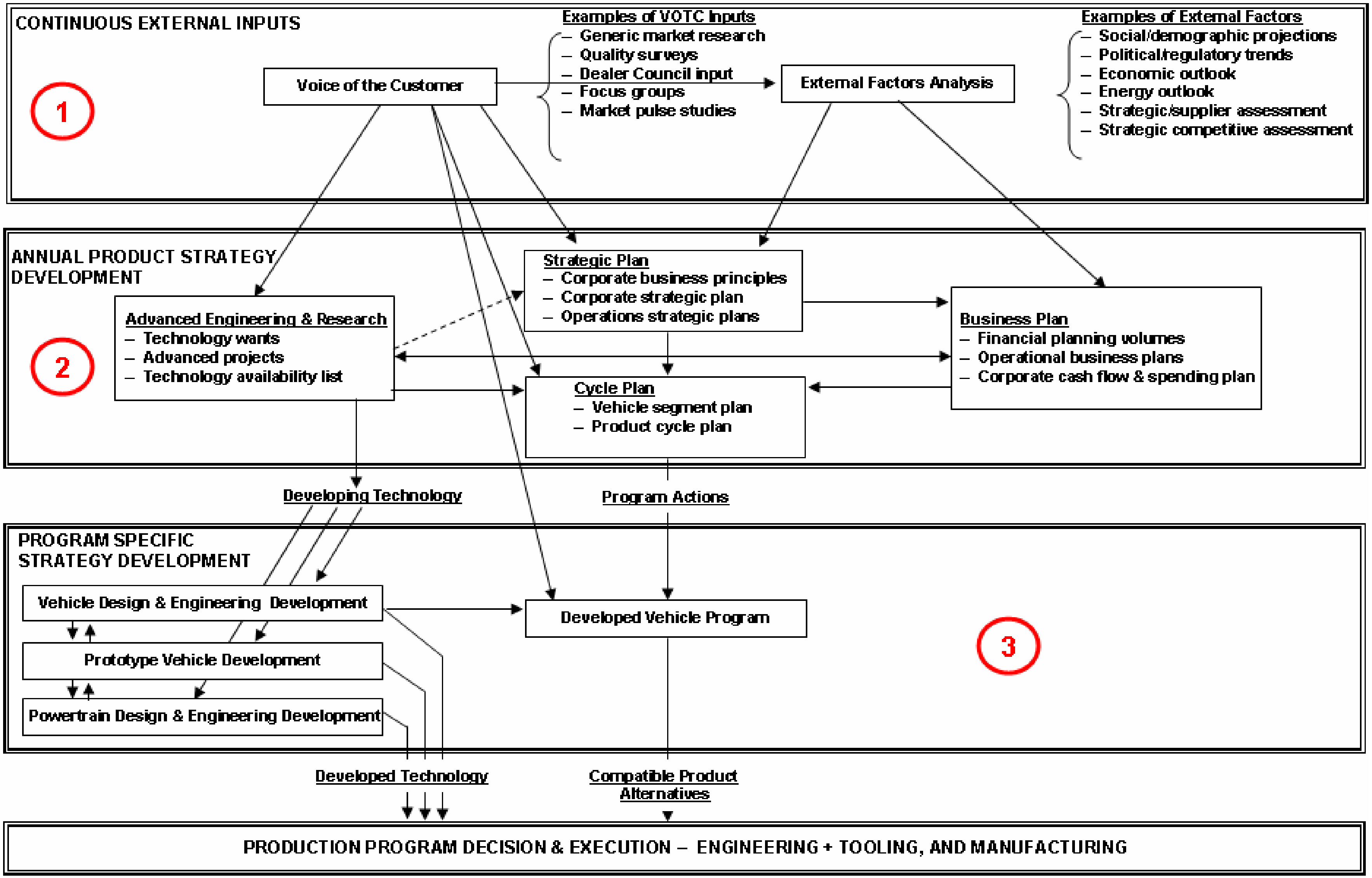
Product development process

Product development process



Automotive Business Case

FIGURE 1. A detailed look at automotive business case development



Business driver : Information economy

The Information Economy

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- Telecommunications has been seen as the foundation for "post-industrial" economies.
  - Shift from manufacturing to service focus
  - Shift from financial to knowledge capital as fundamental resource

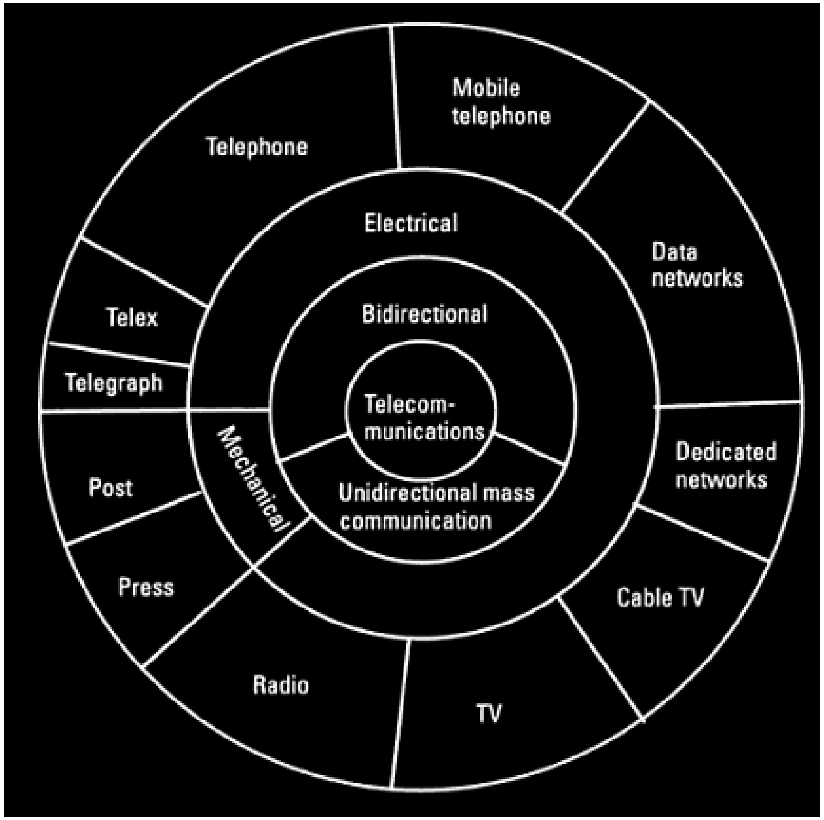

Figure 1: The Telecommunications Industry (From Anttalainen, 2003)

SOURCES:
Goddard, J., and Gillespie, A. (1986) " Advanced Telecommunications and Regional Economic Developmnet" *The Geographical Journal*., 152(3)
Anttalainen, T. (2003) *Introduction to telecommunications network engineering: 2nd Edition*.

Telecom Technology Timeline

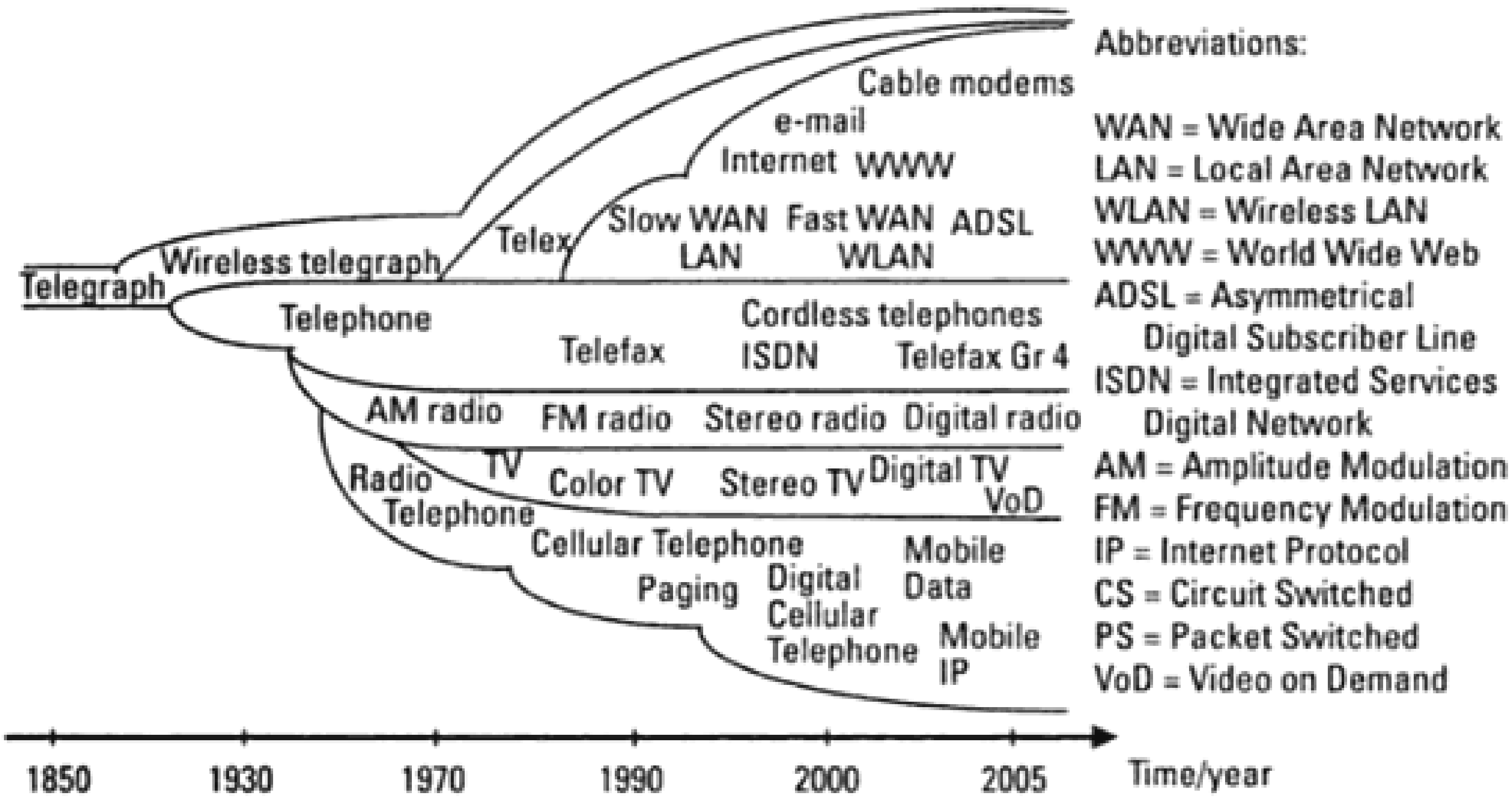

Figure 2: Development of Telecommunications Systems and Services (From Anttalainen, 2003)

Anttalainen, T. (2003) *Introduction to telecommunications network engineering: 2nd Edition*.

Business driver : GHG and fuel economy regulations

Overview of Regulation Specifications

U.S./California (enacted)	2016	Fuel economy/GHG	34.1 mpg* or 250 gCO_2/mi	Footprint-based corporate avg.	Cars/Light trucks	U.S. combined
U.S. (Supplemental Notice of Intent)	2025	Fuel economy/GHG	49.6 mpg* or 163 gCO_2/mi	Footprint-based corporate avg.	Cars/Light trucks	U.S. combined
Canada (enacted)	2016	GHG	153 (141)*** gCO_2/km	Footprint-based corporate avg.	Cars/Light trucks	U.S. combined
EU (enacted) EU (proposed)	2015 2020	CO_2	130 gCO_2/km 95 gCO_2/km	Weight-based corporate average	Cars/SUVs	NEDC
Australia (voluntary)	2010	CO_2	222 gCO_2/km	Fleet average	Cars/SUVs/light commercial vehicles	NEDC
Japan (enacted) Japan (proposed)	2015 2020	Fuel economy	16.8 km/L 20.3 km/L	Weight-class based corporate average	Cars	JC08
China (proposed)	2015	Fuel consumption	7 L/100km	Weight-class based per vehicle and corporate average	Cars/SUVs	NEDC
S. Korea (proposed)	2015	Fuel economy/GHG	17 km/L or 140 gCO_2/km	Weight-based corporate average	Cars/SUVs	U.S. combined

* Assumes manufacturers fully use A/C credit
** Proposed CAFE standard by NHTSA. It is equivalent to 163g/mi plus CO2 credits for using low-GWP A/C refrigerants.
"** In April 2010, Canada announced a target of 153 g/km for MY2016. Value in brackets is estimated target for MY2016, assuming that during 2008 and 2016 the fuel efficiency of the LDV fleet in Canada will achieve a 5.5% annual improvement rate (the same as the U.S.). This estimate is used in the accompanying charts.