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NORMANDY MOTOR MEETINGS

Internal Combustion Engine Alive and Well in 2050

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Agenda

- Introduction
- “Local” emissions: a thing of the past?
- “Global” issue: CO_2 reduction
- The evolution of powertrain & fuels:
  - ICE gasoline & diesel
  - Hybrids
  - Full EV
  - Fuel Cell

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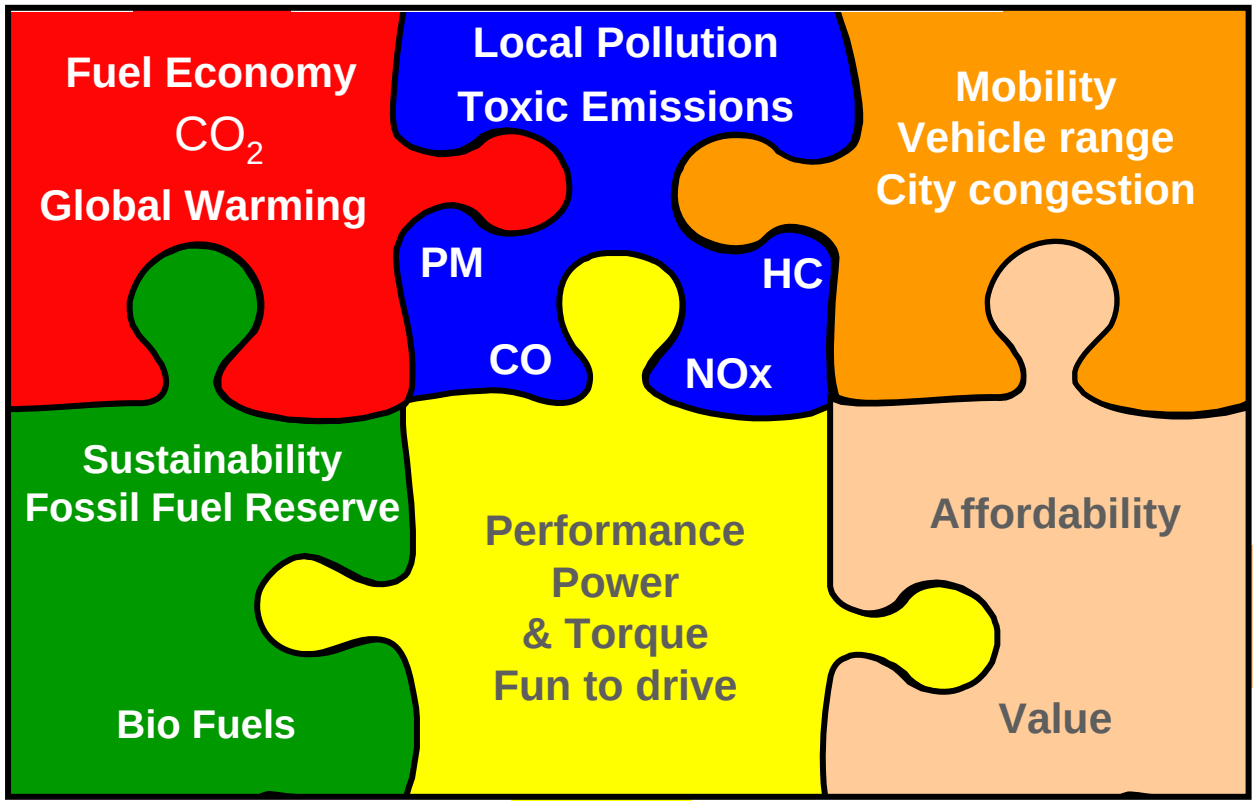
Introduction

Powertrains are used across many sectors

Examples of consumer & commercial applications

What are we trying to solve?

- A complex balance to suit all requirements
- Fuel efficiency / CO_2 and emissions regulations must be satisfied while delivering **undiminished** vehicle performance to the consumer



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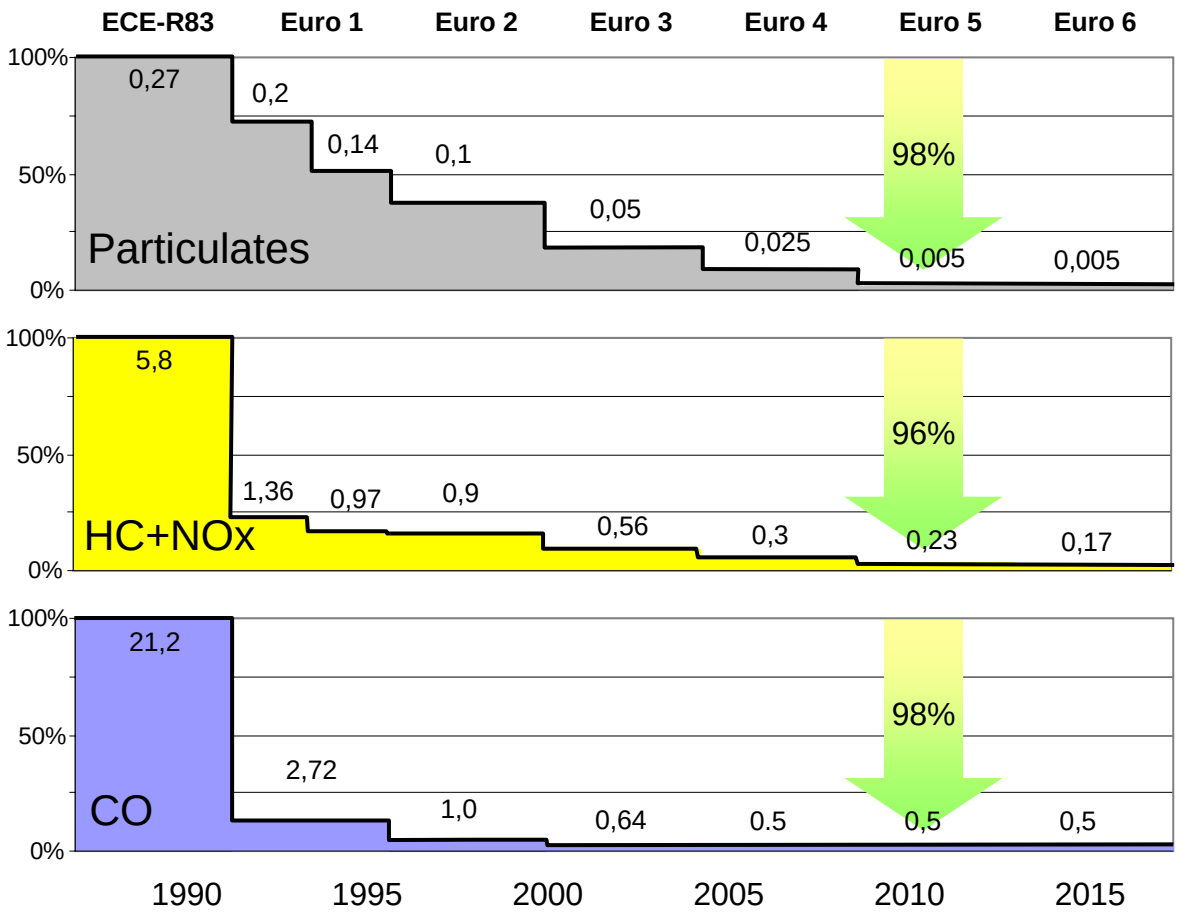
“Local” pollutants: a thing of the past?

Emissions legislation for passenger cars

Example of European Diesel emission limits

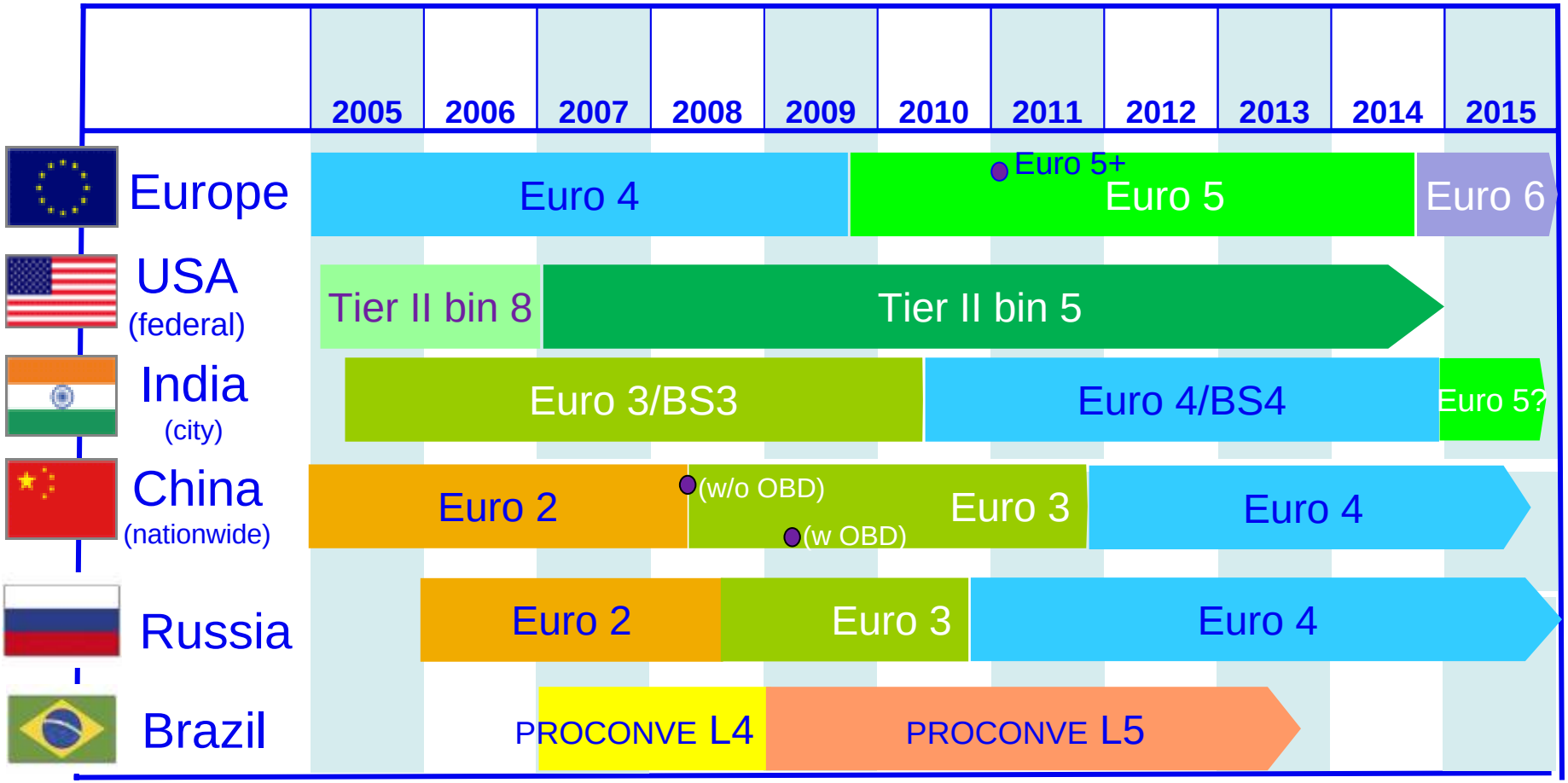


Source: European Legislation
Figures = emission limits in g/km

- **Comments**:
  - Gasoline has gone through the same drastic progression
  - Original focus was to reduce harmful/toxic emission that had a “local” impact
  - Emissions have been **dramatically cut**, typically halved every 4 to 5 years
  - Reduction by **more than 95% over 20 years**
  - Gasoline and Diesel vehicles have converging targets
  - Global regulations becoming more stringent in general
  - Many emerging nations have adopted European legislation

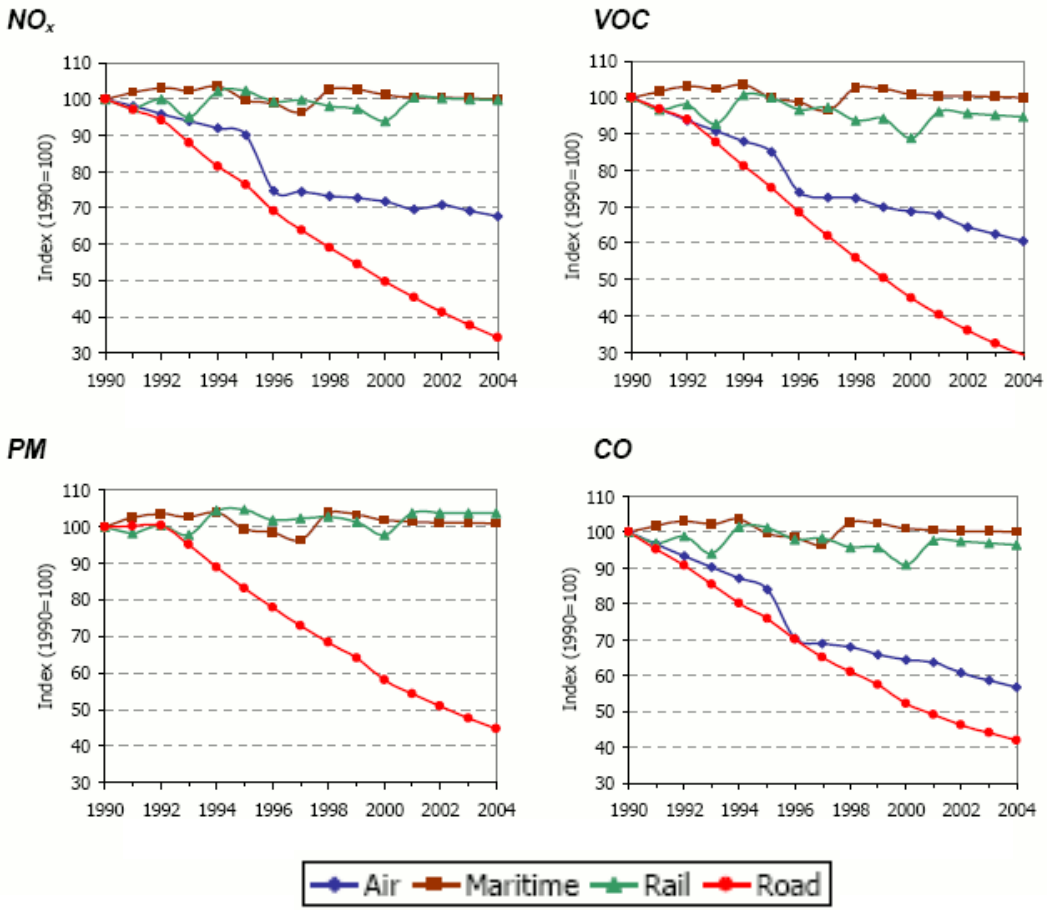
LD Emissions Legislation - Global View

- Global regulations becoming more stringent in general
- Emerging nations adopting European legislation; test cycle convergence
- CARB SULEV/PZEV will remain the most stringent



With subsequent impact on the environment

Emissions of NOx, VOC, PM and CO per passenger-km and per mode of transport in the EU15



Source: European Environment Agency

Decline based on:

- Implementation of advanced emission standards on new vehicles (previous slide)
- Proper maintenance & controls of in-use fleet
- Car parc replacement rate and end-of life incentives
- Use of clean fuels
- Despite increase of global vehicle parc

LOS ANGELES CIRCA 1970:
An air quality problem that we no longer see.

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Global issue: CO_2 reduction

Switching focus

Global warming concerns

Rising fuel prices

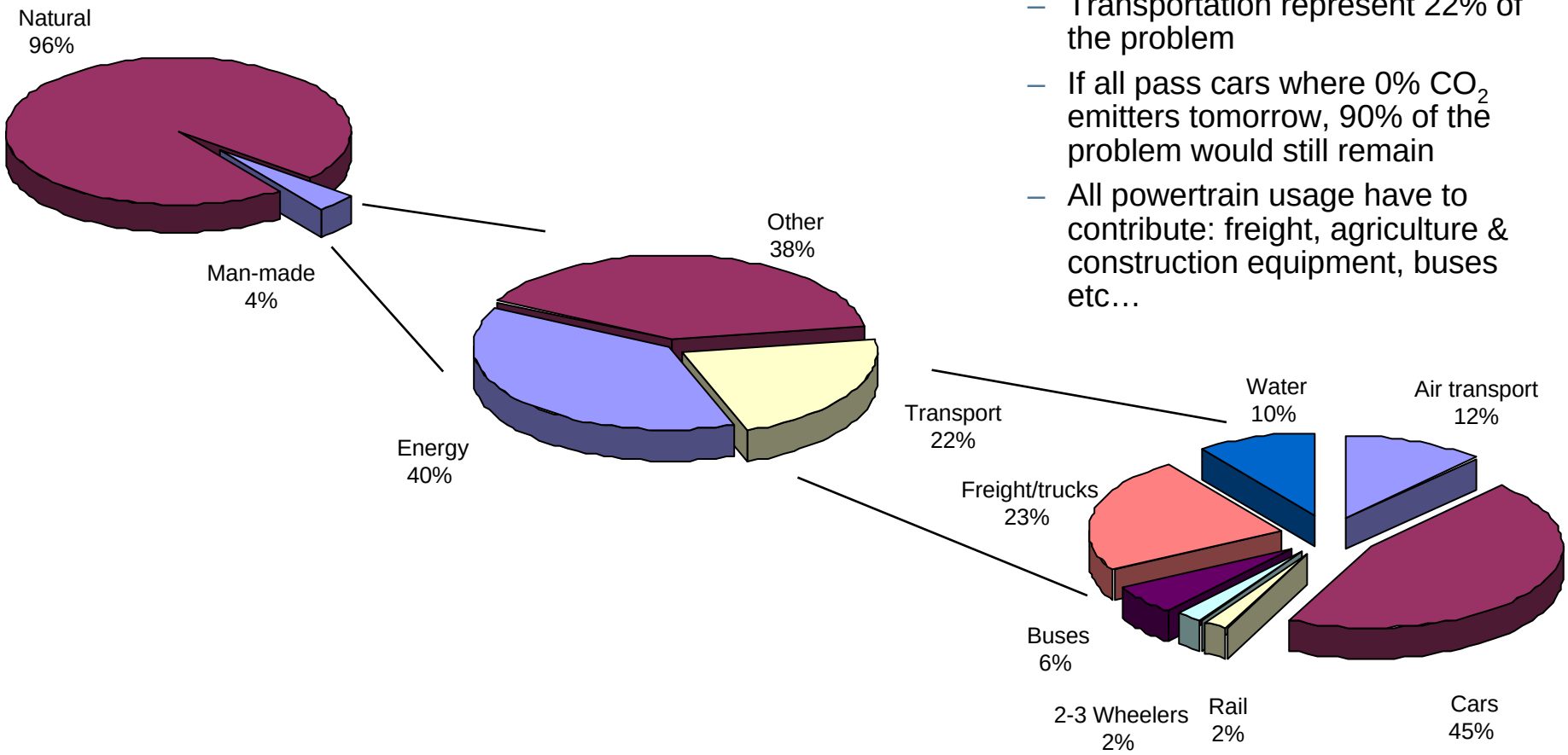
Diminishing fossil fuel reserve

The focus now shifts from the “local” to the “global” issue:

CO_2 reduction

Passenger cars are about 10% of the problem

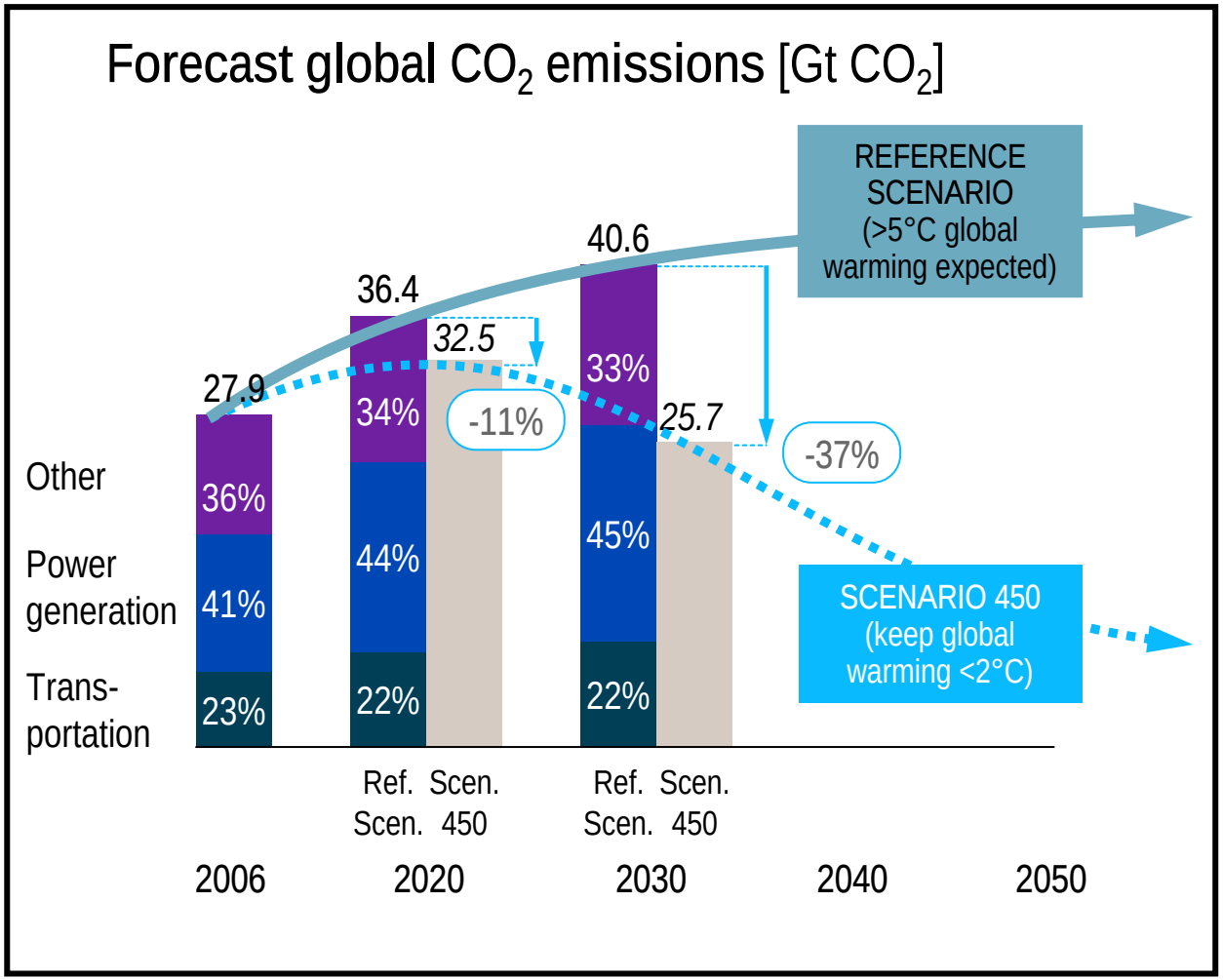
- Global CO_2 Emissions by Source



Source: Department for Environment, Food and Rural Affairs (DEFRA) 2004

- Solutions won't come from cars alone
  - Transportation represent 22% of the problem
  - If all pass cars where 0% CO_2 emitters tomorrow, 90% of the problem would still remain
  - All powertrain usage have to contribute: freight, agriculture & construction equipment, buses etc…

CO_2 reduction needed



- In order to keep global warming at 2°C by 2100, greenhouse gases have to be kept at or under 450 ppm CO_2 equivalent
- A subsequent 37% reduction in CO_2 emissions have to be achieved by 2030 compared to “natural” trend
- All sectors have to contribute
- Europe plans to move new vehicle CO_2 down to 95 gr/km, i.e. a reduction of 40% compared to 2006

Source: International Energy Agency – World Energy Outlook 2008 & Roland Berger

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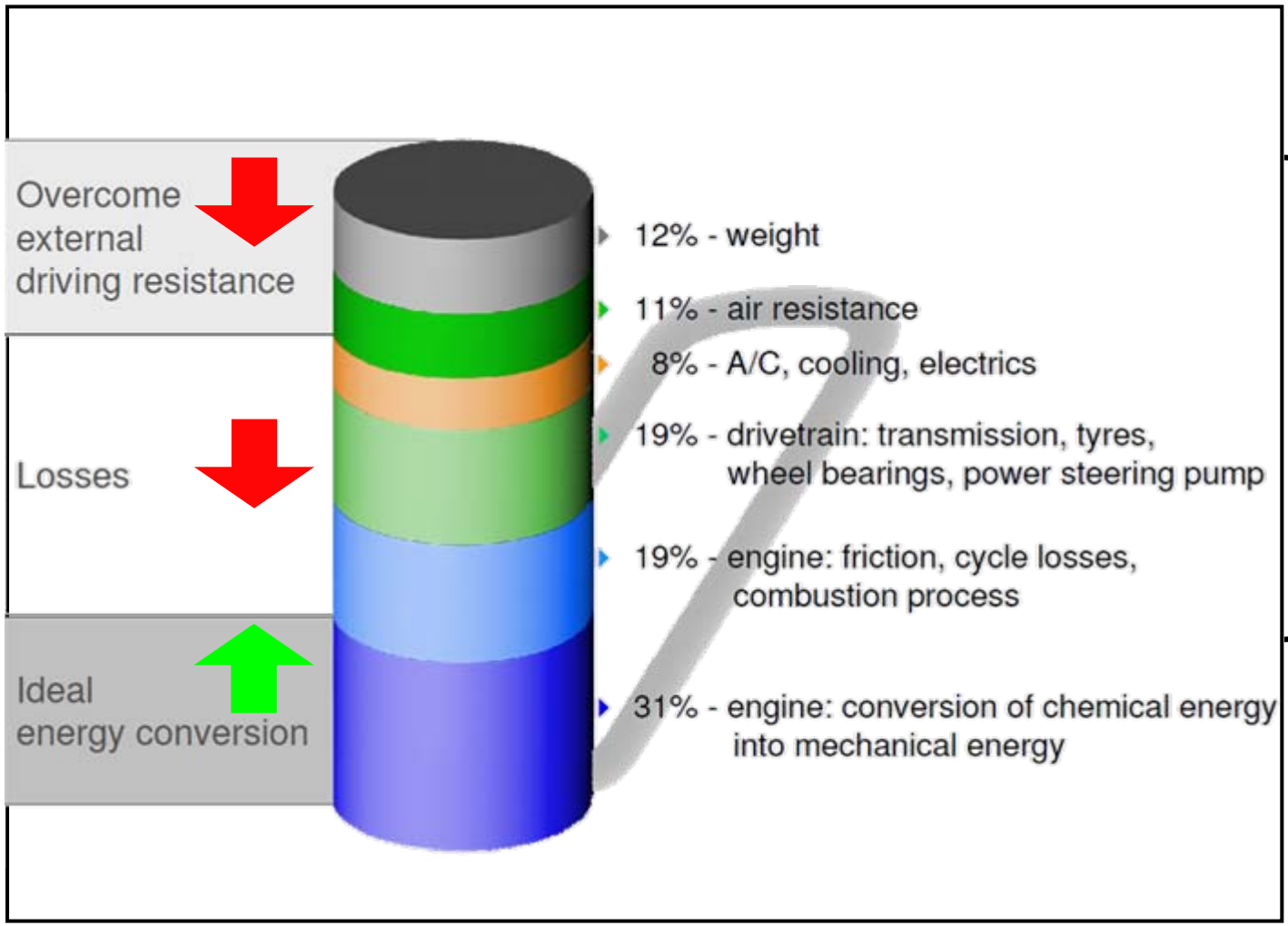
The evolution of powertrain

Only 31% of the energy is used



69%

of the energy consumption

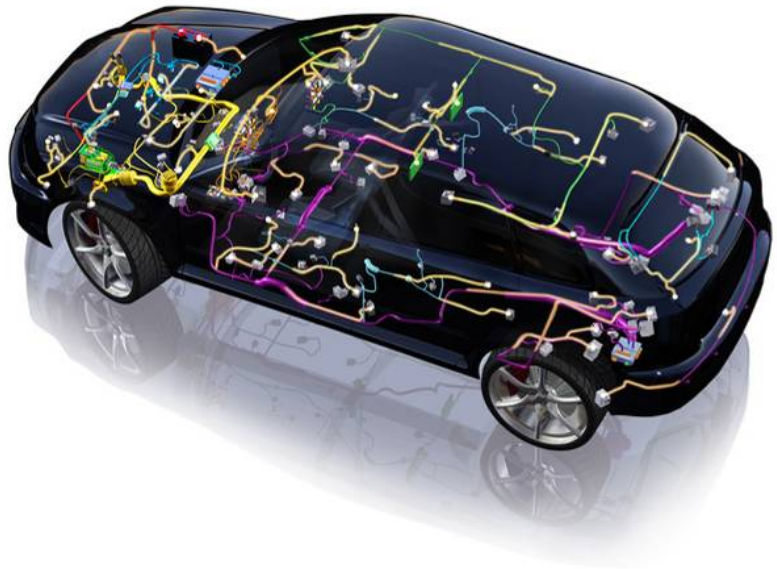
can be further optimized

Source: Audi

Vehicle level optimization

Technologies being considered:

- Weight
  - Aluminum frame & wiring
  - Composite material
- Friction
  - Air drag reduction
  - “Green” tires
- Ancillary equipment*
  - Lightning (LED)
  - Efficient HVAC
  - Adaptive cruise controls
  - Solar sunroof
  - Navigation (congestion avoidance)
- Transmission

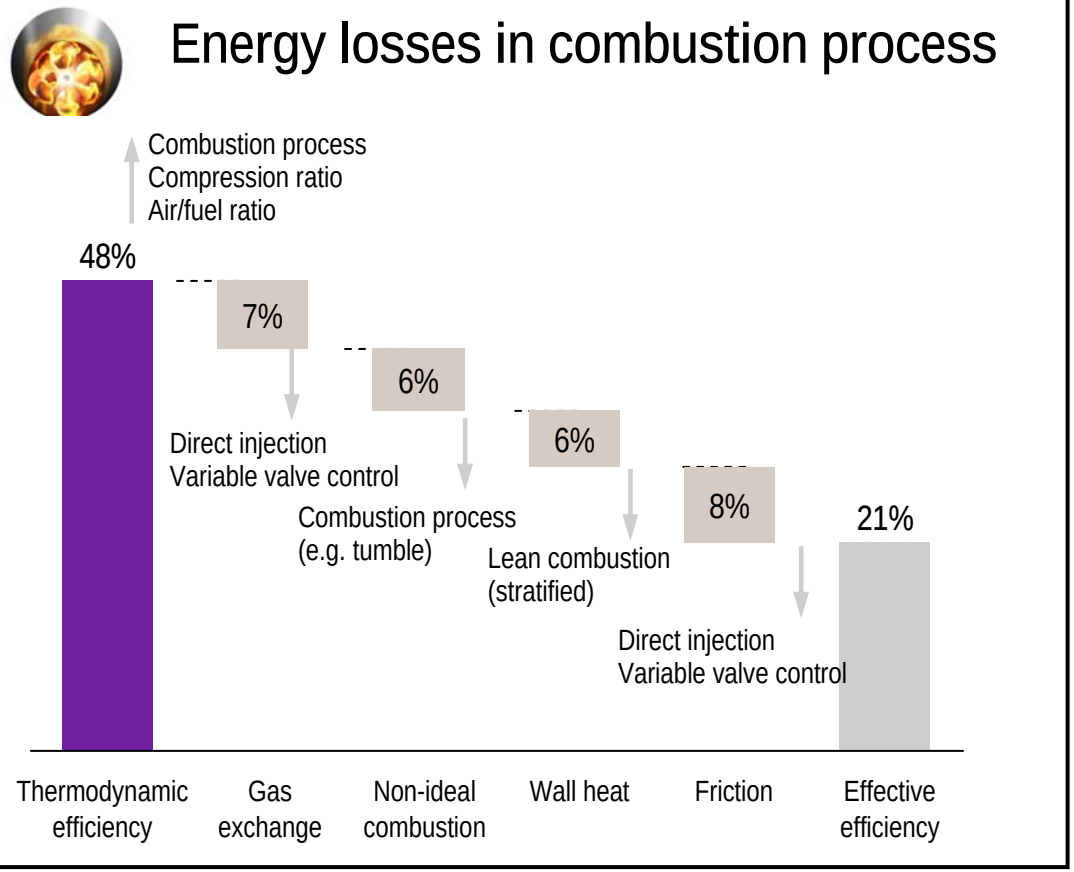


** Most equipment currently “turned off” during NEDC cycle explaining some of the gap between real life & sticker fuel consumption*

⇒ Up to 20% CO_2 reduction

Engine/combustion optimization

The effective efficiency of an engine can be increased by various measures
Mainly gas exchange and friction losses addressable



- The theoretical threshold is defined by the thermodynamic efficiency
- The **combustion cycle** (higher air/fuel ratio, higher compression) can increase this value
- Turbo-charging can shift the operating point to a more efficient region
- **Gas exchange** losses can be decreased by de-throttling (direct injection, variable valve lifting)
- **Downsizing** can be utilized to decrease mechanical losses (friction)
- **Wall heat and losses** from non-ideal combustion are difficult to control in the combustion process

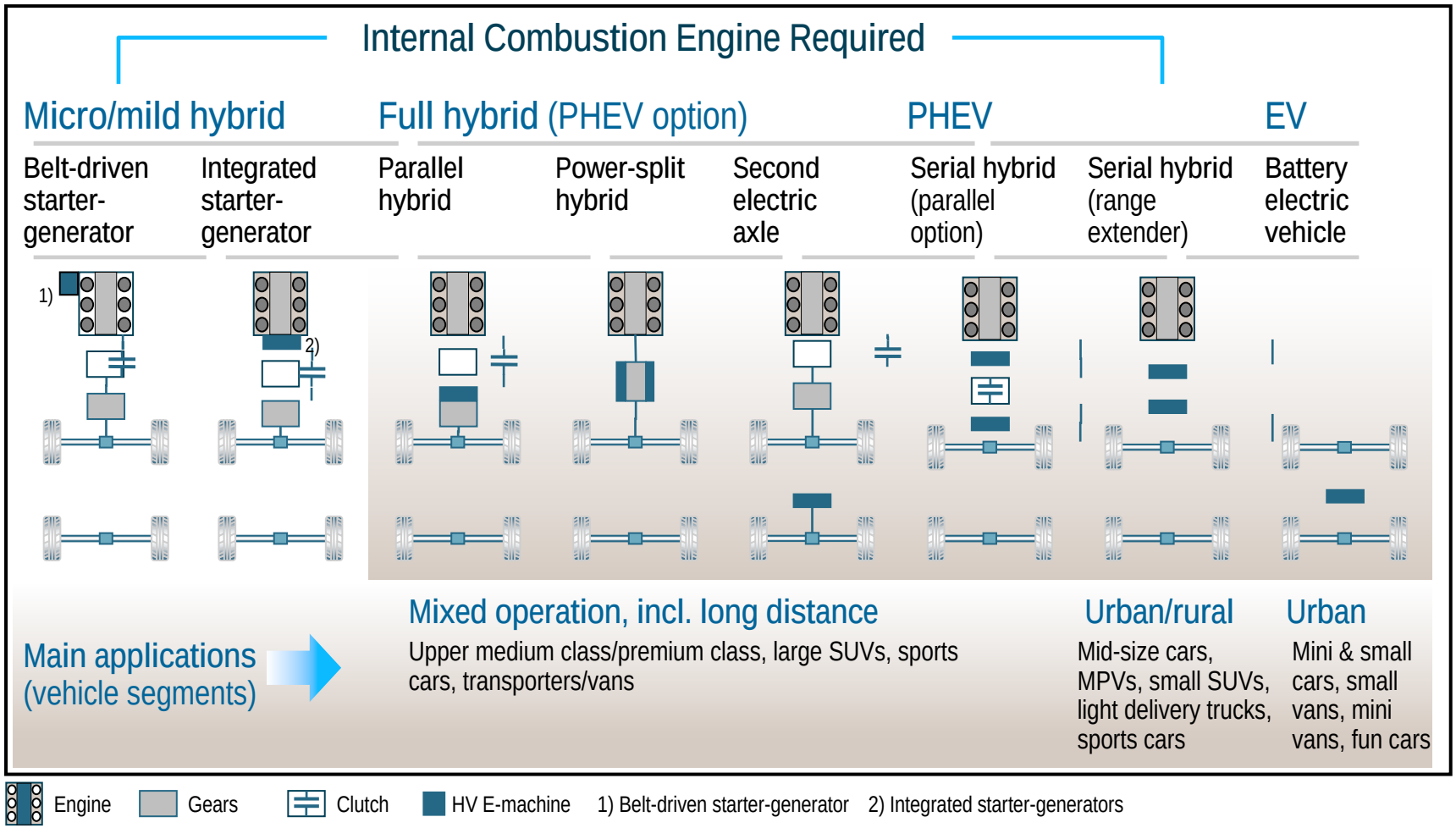
1) Typical part load operating point of naturally aspired gasoline engine (n=2000min^{-1}, p_{me}=2bar)

Source: FEV; RWTH Aachen

⇒ 25 to 35% CO_2 reduction

Hybridization

- There are different options for electrifying powertrains
- Technical layout depending on application and vehicle segment



Source: Roland Berger

⇒ 5 to 50% CO_2 reduction

Energy Density

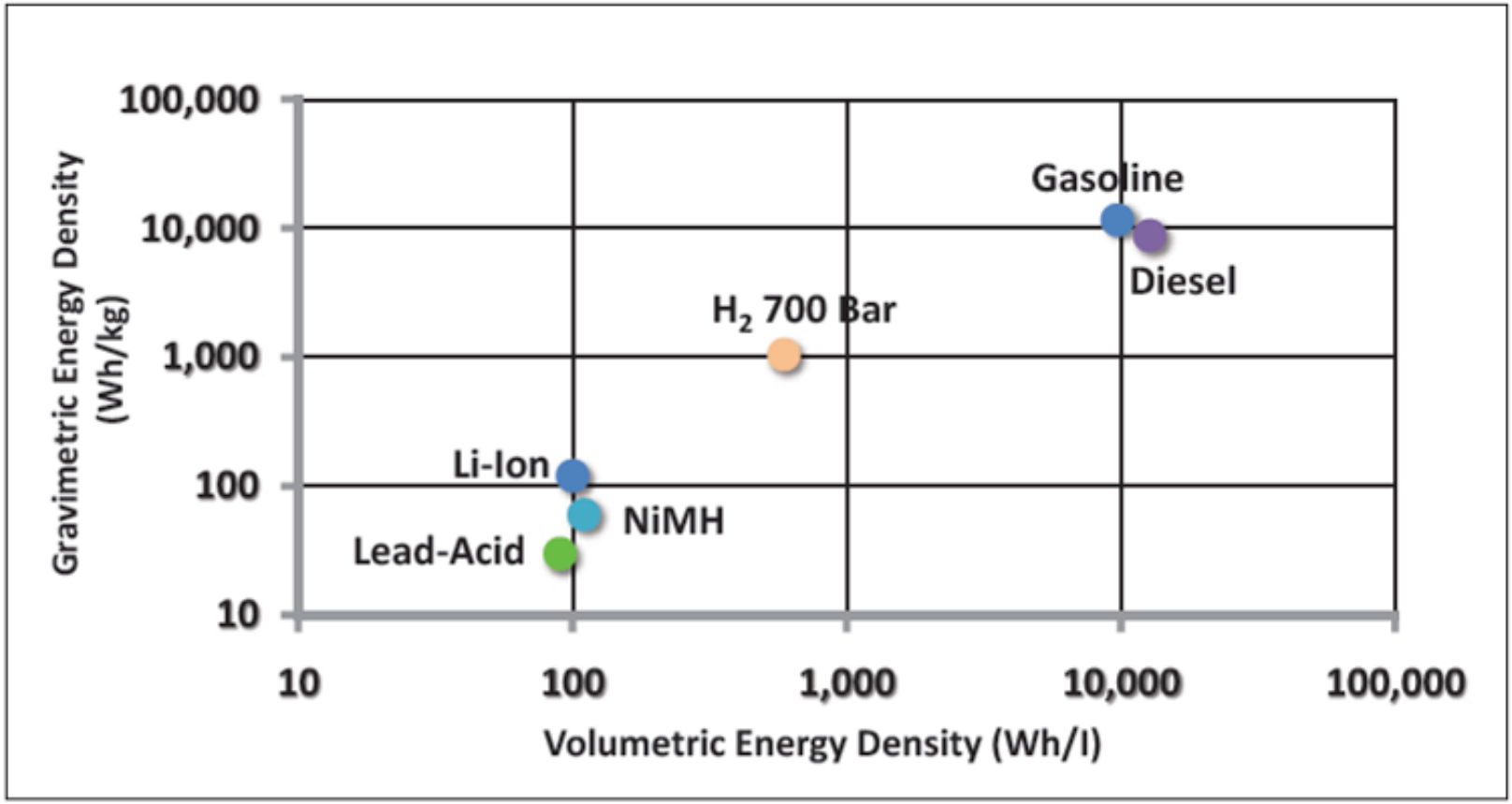


Figure 4 – Energy density of automotive fuels. The mass and the volume of the tank or battery is included)

Source: General Motors – Dr U. Grebe

Biofuels: life cycle & implementation questions

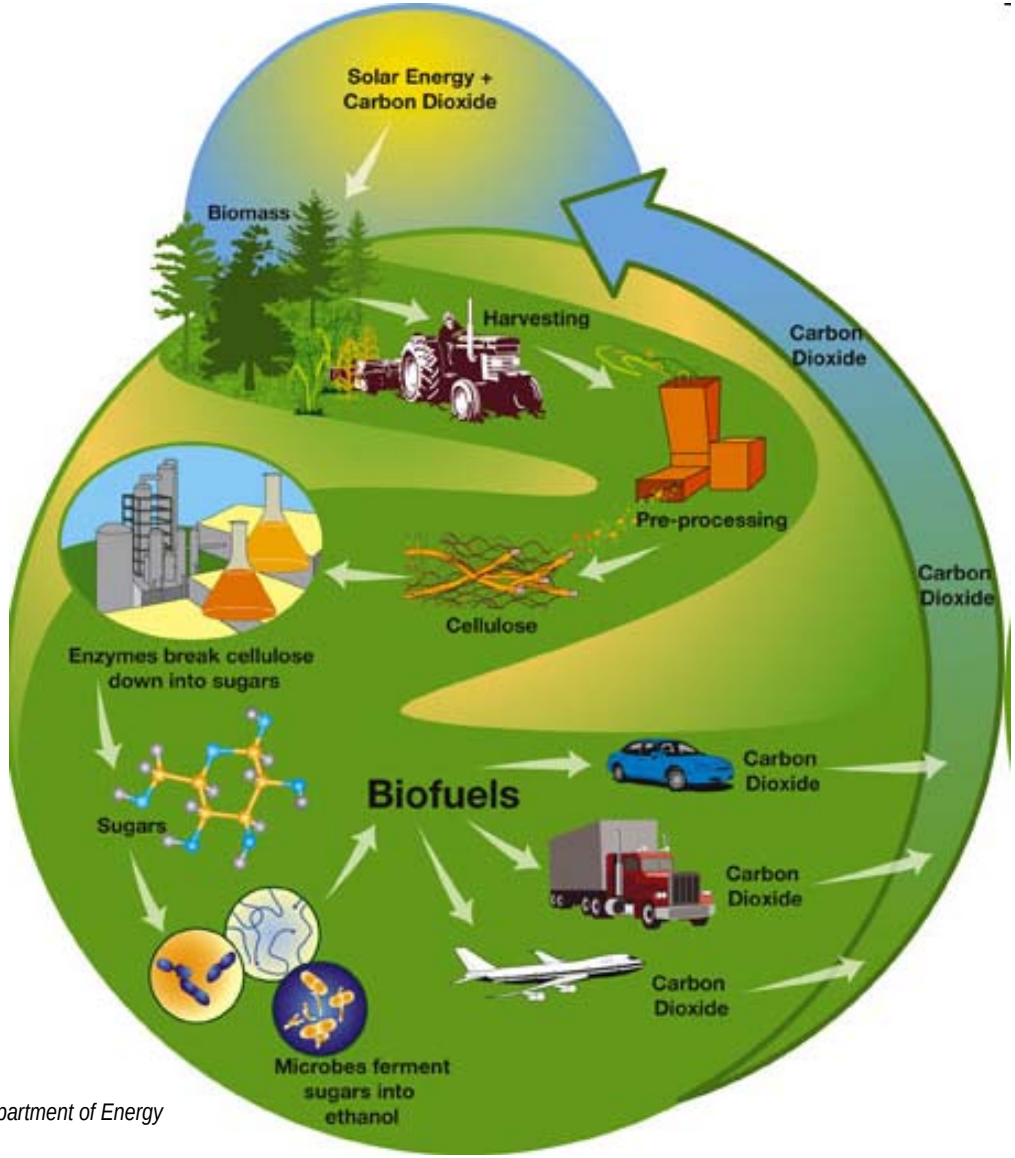
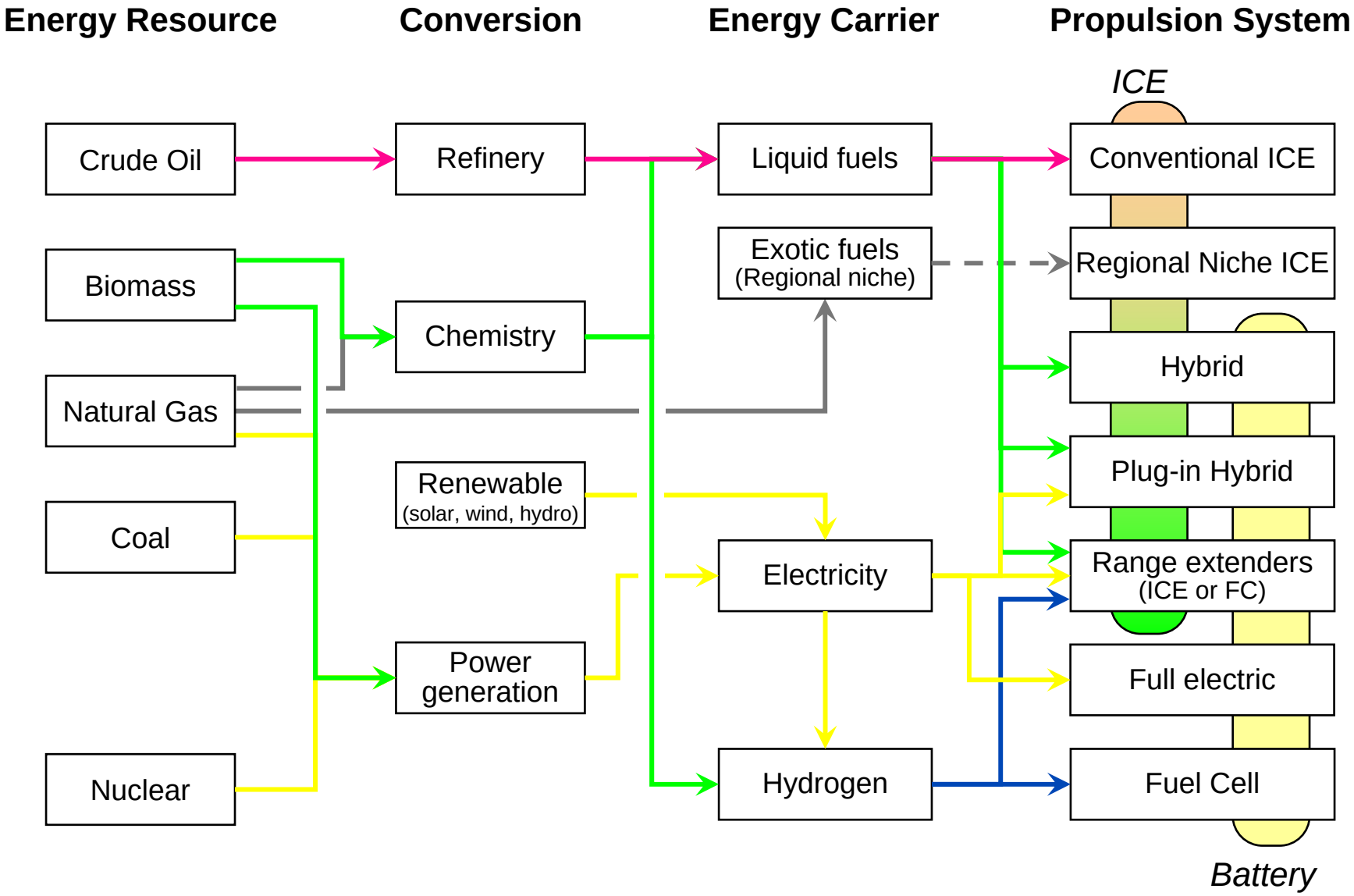
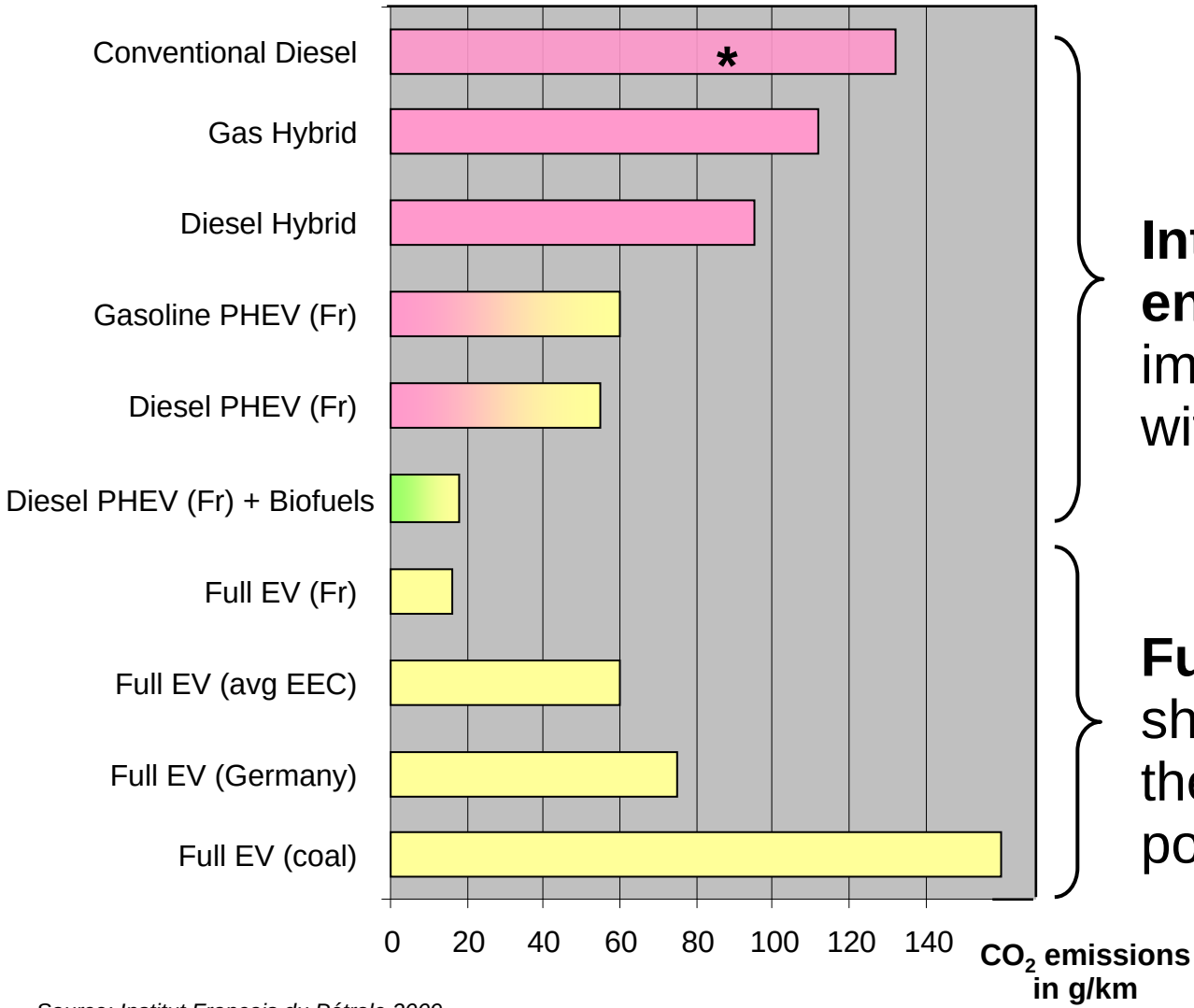


Image from US Department of Energy

Main Fuel Pathways



Well-to-wheel CO_2 emission by vehicle/fuel type

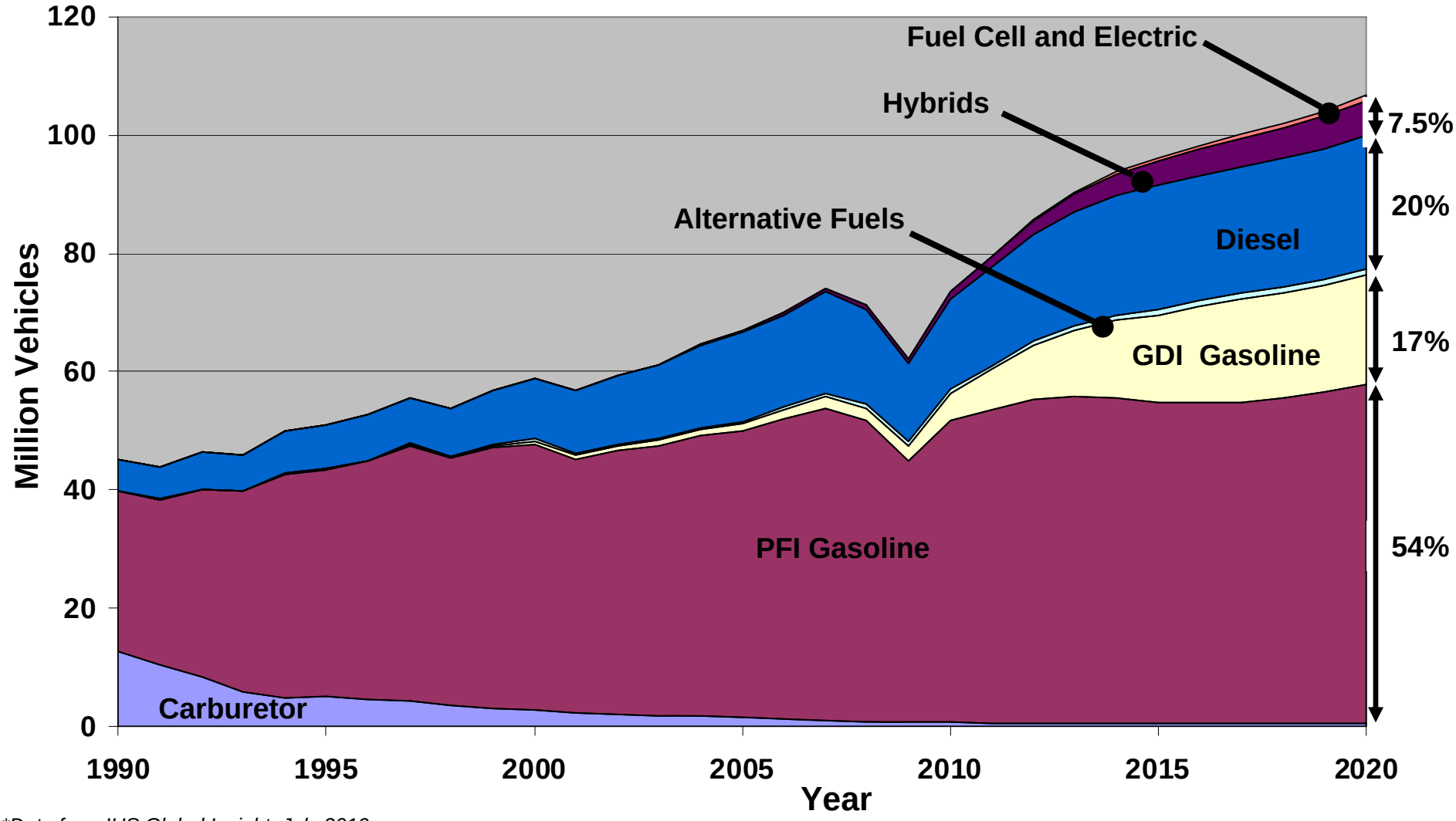


Internal combustion engines have significant improvement potential with hybrids & biofuels

Full electric vehicles shift the CO_2 issue from the vehicle to the powerplant

Source: Institut Français du Pétrole 2009

Today‘s and Future Distribution of the different Propulsions on the Worldwide Market



*Data from IHS Global Insight, July 2010

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Delphi’s View

Delphi: Committed to the Kind of Innovation that Will Keep Our Planet Green and Its Occupants Safer and More Connected

People Megatrends

- Natural Growth
- People Live Longer
- Generations X & Y
- Increased Concern about Safety, Security and Privacy
- Health Care
- 8/5 > 12/6 > 24/7

World Megatrends

- World Turmoil
- Globalization
- Higher Cost of Natural Resources
- Increasing Environmental Awareness/ Regulations

Technological Megatrends

- Information Explosion
- Wireless World

Consumer wants:

Safe

- More cars, more congestion and more distractions create demand for sophisticated safety systems

Green

- Fast growing economies: more fuel for mobile platforms
- Demand for electrical energy and related conventional resources far exceeds current capabilities

Connected

- Global demand for broadband access will continue to grow

Delphi: Portfolio of Green Solutions

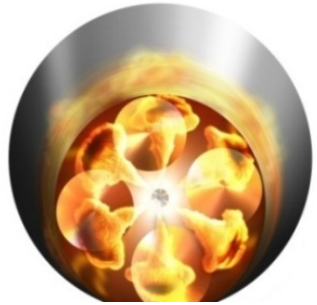
- **Fuel Economy and Performance Technologies**
  - Cylinder Deactivation System
  - Two-step Valve Train with Dual Independent Cam Phasers
- Reman ECM/PCM
- Universal Reflash Tool
- **Alternative Fuel Systems/Components**
  - Fuel System for Dimethyl Ether
- **Evaporative Emissions Canisters**
- **Diesel Fuel Injection Systems and Aftertreatment**
- **Gasoline Direct Injection**
- Next Generation Energy Efficient A/C
- HVAC Compressors
- HVAC Systems for Alternative Refrigerants
- **Diagnostic Systems**

- Electric HVAC Systems
- **Hybrid and Electric Vehicle Technologies**
- Power Conversion Products
- High Voltage Battery Pack System
- **Ammonia, Planar Oxygen & Battery IVT Sensors**
- Electronics Packaging
- Halogen-free Cable
- Aluminum Cable
- Miniaturization
- Navigation
- Ultra Light Radio

Powertrain Products in Bold

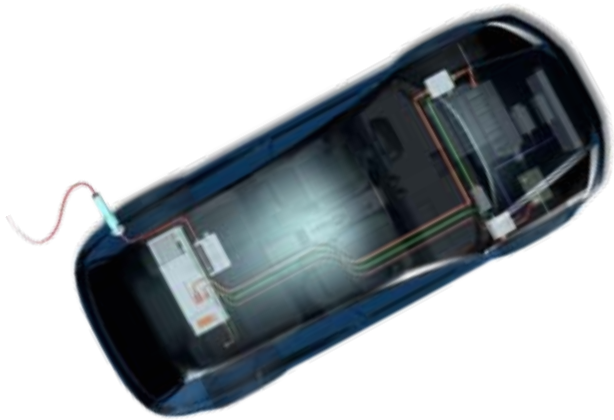
The future will be diverse

- ICE is alive and well in the foreseeable future
  - Further combustion improvements: turbo-charging, downsizing…
  - Bio fuels will further enhance CO_2 equation



- Hybridization/electrification
  - Increasing levels of hybridization will extend life of ICE
  - Offer new pathways for ICE optimization

- Full electric vehicles
  - Low energy density, by mass & volume
  - Battery costs, new business model required?
  - Most electricity generation still emits CO_2
  - Range, infrastructure limitation



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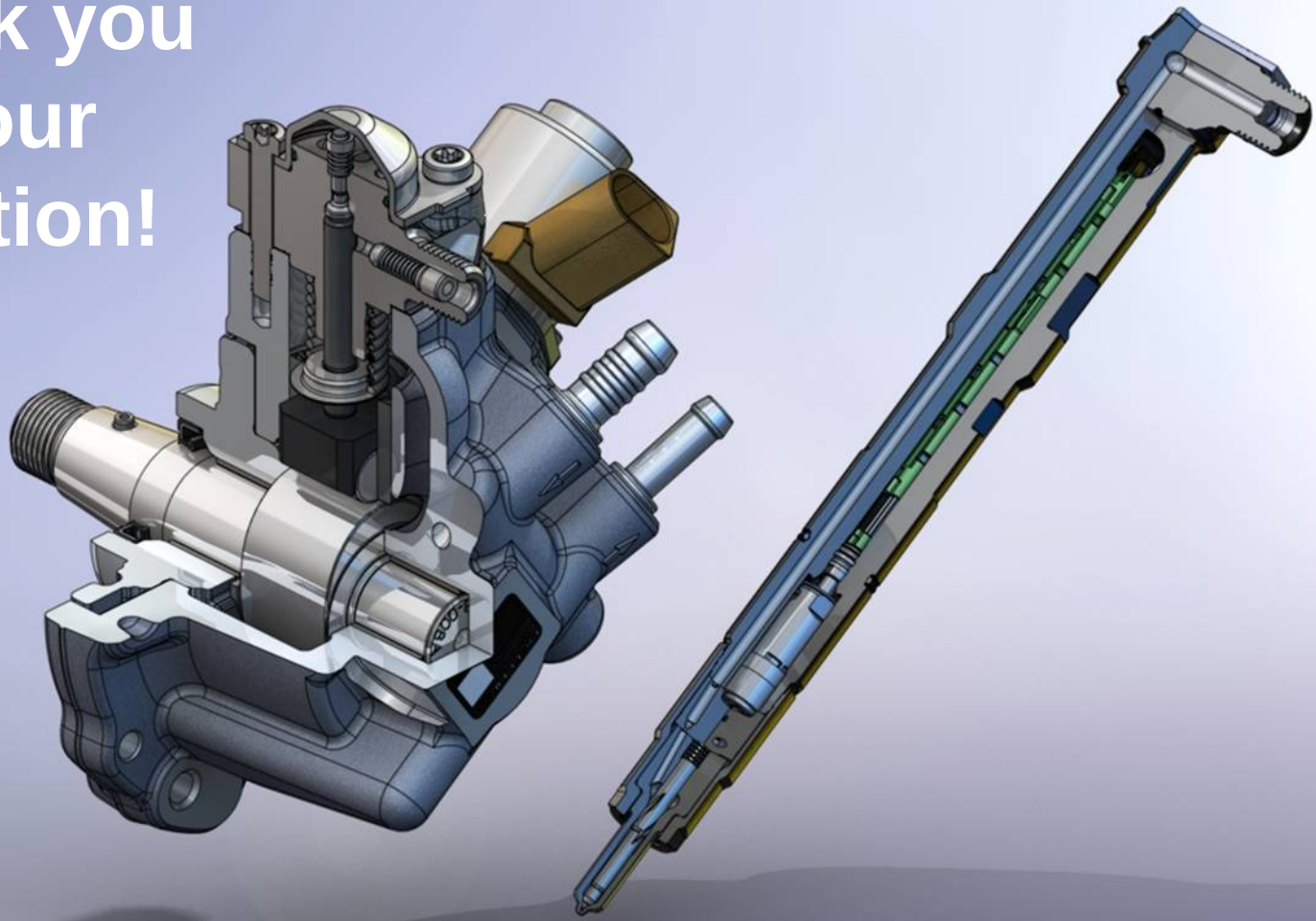

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Innovation for the Real World

Glossary

- SI = Spark Ignition = gasoline
- CI = Compression Ignition = Diesel
- DI = Direct Injection
- HCCI = Homogenous Charge Compression Ignition
- EV = Electric Vehicles = Full or Pure Electric vehicles
- HEV = Hybrids (Electric Vehicles)
- PHEV = Plug-in Hybrid Electric Vehicles
- FC = Fuel Cells (often HFCV = Hydrogen FC Vehicles)