MEIM MASTER IN ENTREPRENEURSHIP
INNOVATION MANAGEMENT
IN COLLABORATION WITH **MIT SLOAN**

IN COLLABORATION WITH
MIT MANAGEMENT SLOAN SCHOOL

UNIVERSITÀ DEGLI STUDI DI NAPOLI
PARTHENOPE

Sustainable and Green Transportation

MEIM 2021-2022

Prof. Ivan Arsie
Energy and Propulsion Systems, Dept. of Engineering
Università degli Studi di Napoli Parthenope

Sustainable mobility

Sustainable mobility = Sustainable development applied to mobility

Transportation sustainability

Sustainable transport refers to the broad subject of transport that is or approaches being **sustainable**.

It includes **vehicles**, **energy**, **infrastructure**, **roads**, **railways**, **airways**, **waterways**, **canals**, **pipelines**, and **terminals**.

Transportation sustainability is largely being measured by transportation system **effectiveness** and **efficiency** as well as the **environmental impacts** of the system

Definition

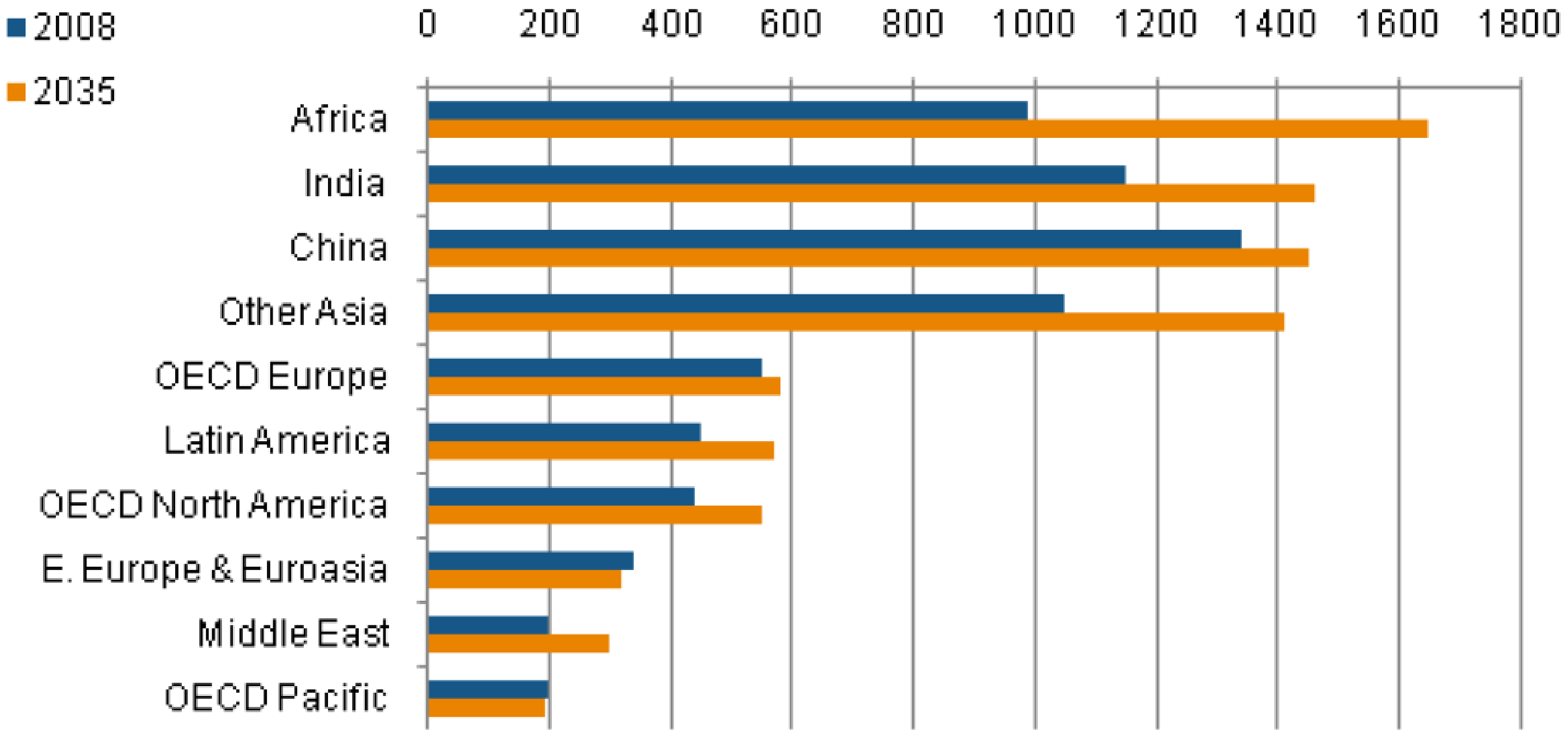
***Sustainable mobility** consists in guarantying to citizens the land accessibility and satisfy the travel and mobility freedom on short and long term, meanwhile integrating the collective interest of current and next generations.*

Economy, Energy, Environment and Society

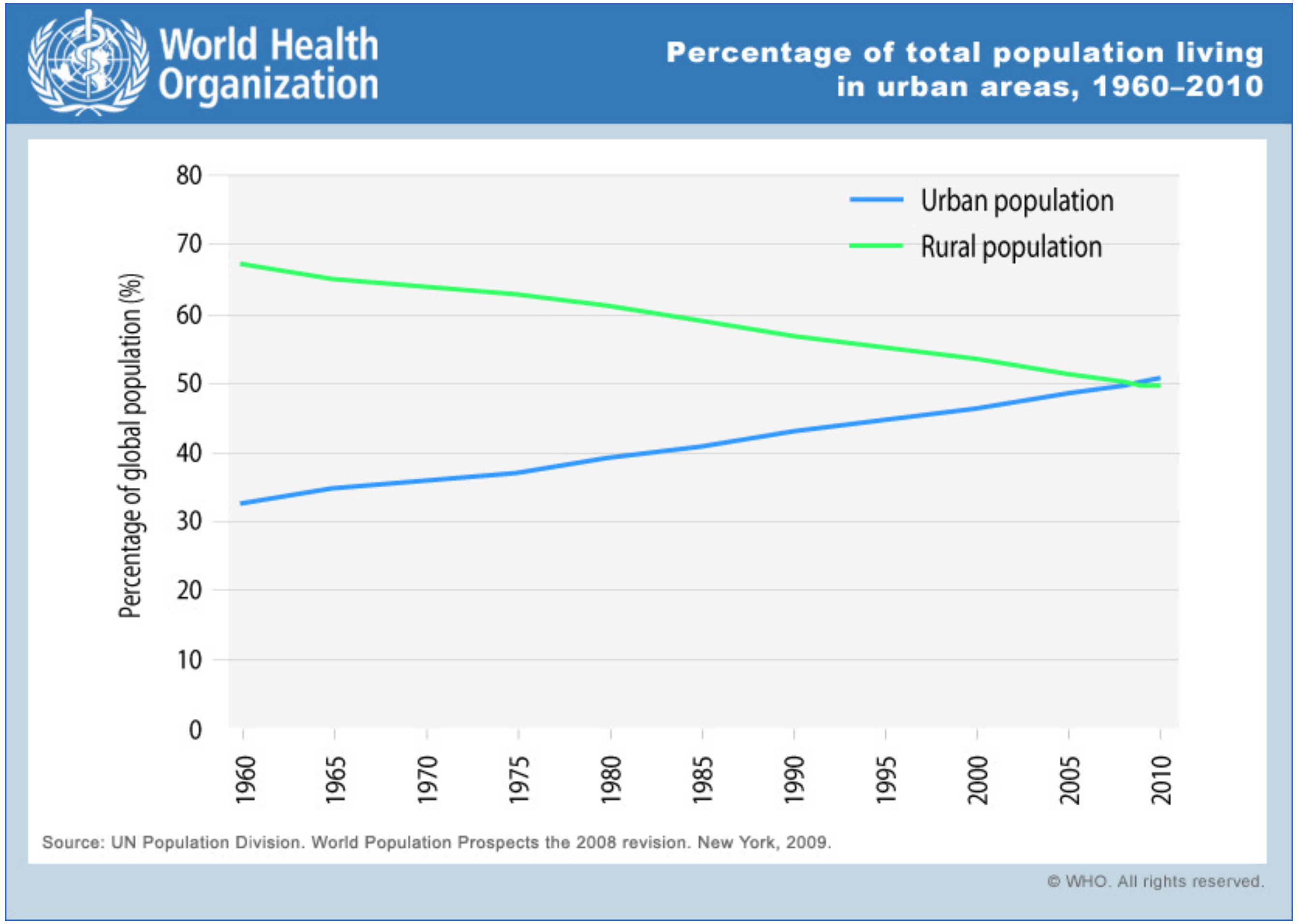
World population projections

Population by major region

Source: United Nations Population Division and World Bank databases; IEA analysis



Urban vs rural population

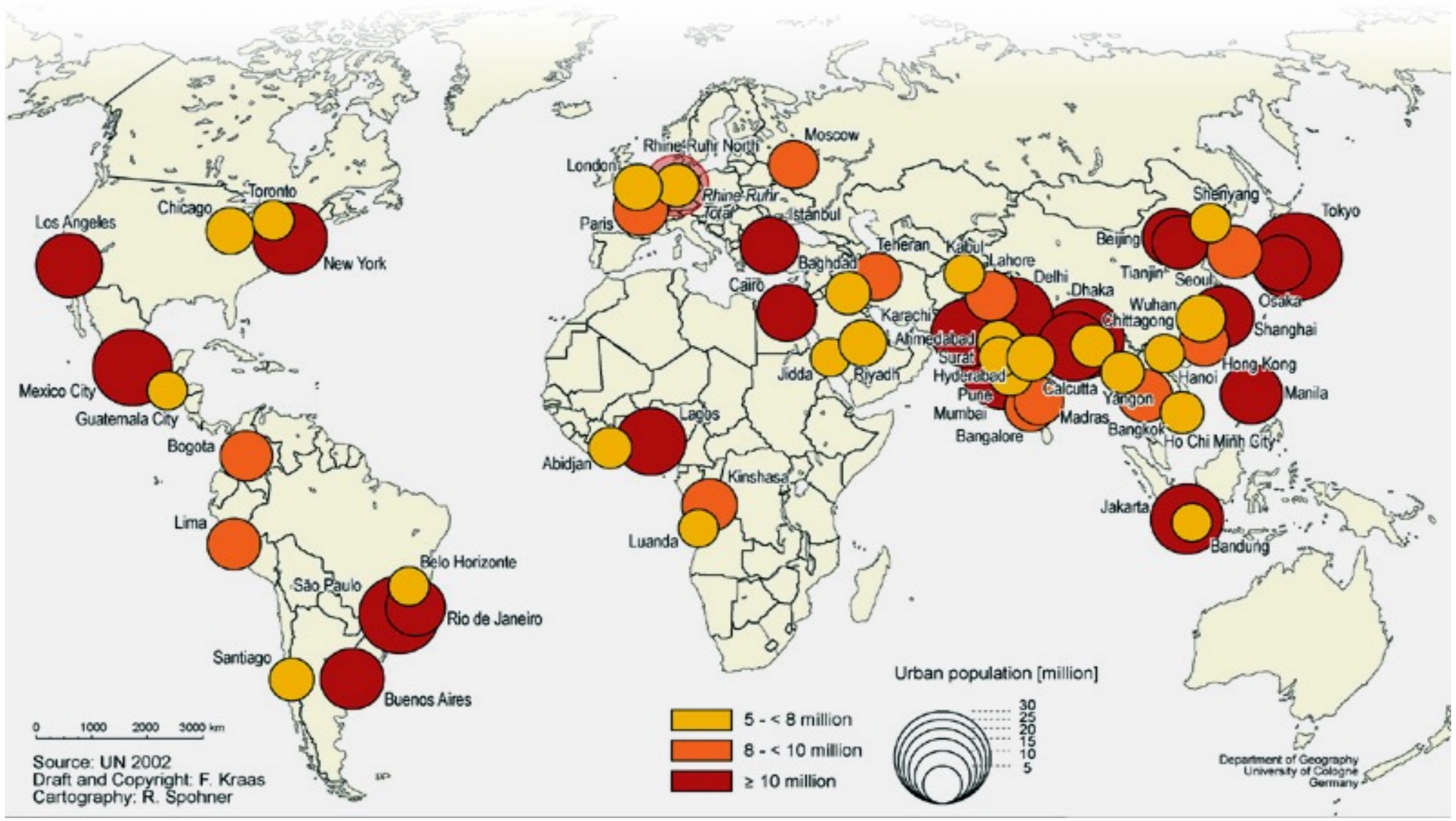


Urban population has surpassed rural population in 2009

http://apps.who.int/gho/data/node.wrapper.URBHEALTH-SITUATION?lang=en

The Emergence of Megacities

Source: GM / United Nations (2002)

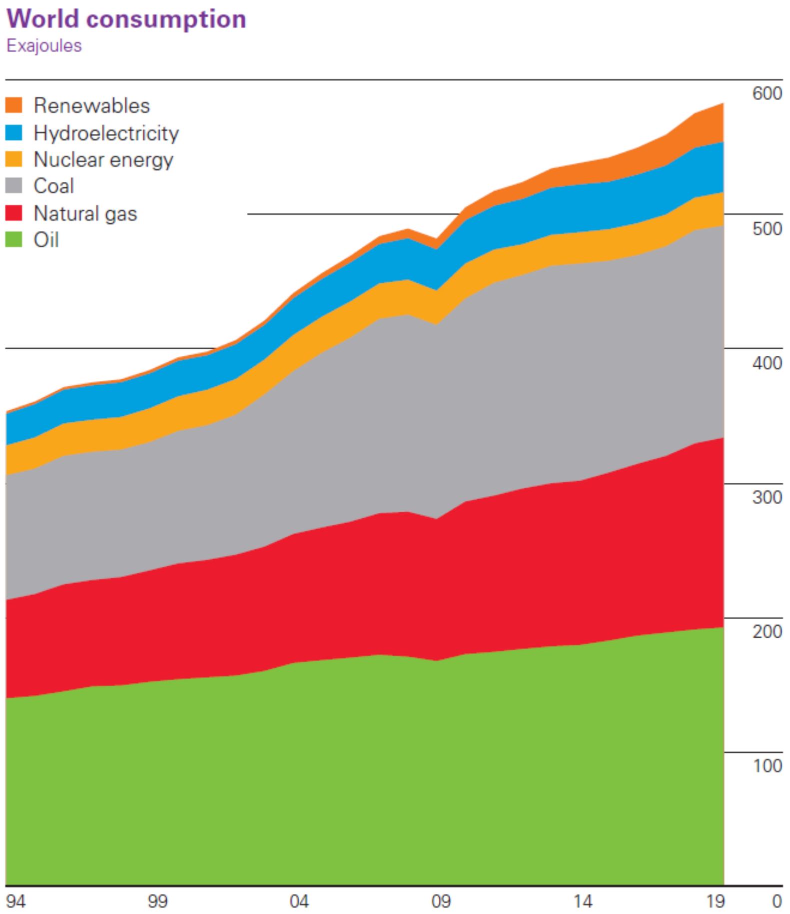


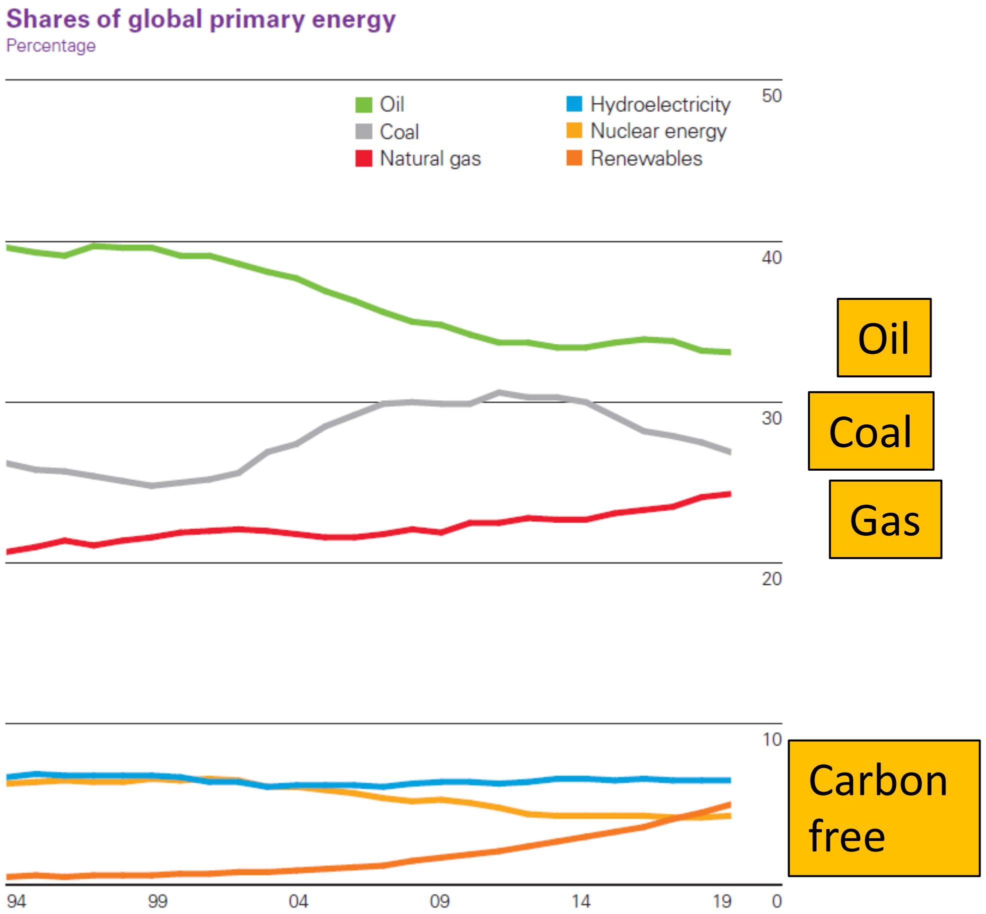
Source: UN 2002
Draft and Copyright: F. Kraas
Cartography: R. Spohner

Department of Geography
University of Cologne
Germany

- Megacities are engines of growth, rising personal income.
- Megacities produce mega-problems, such as traffic. Mobility in every megacity is unique.

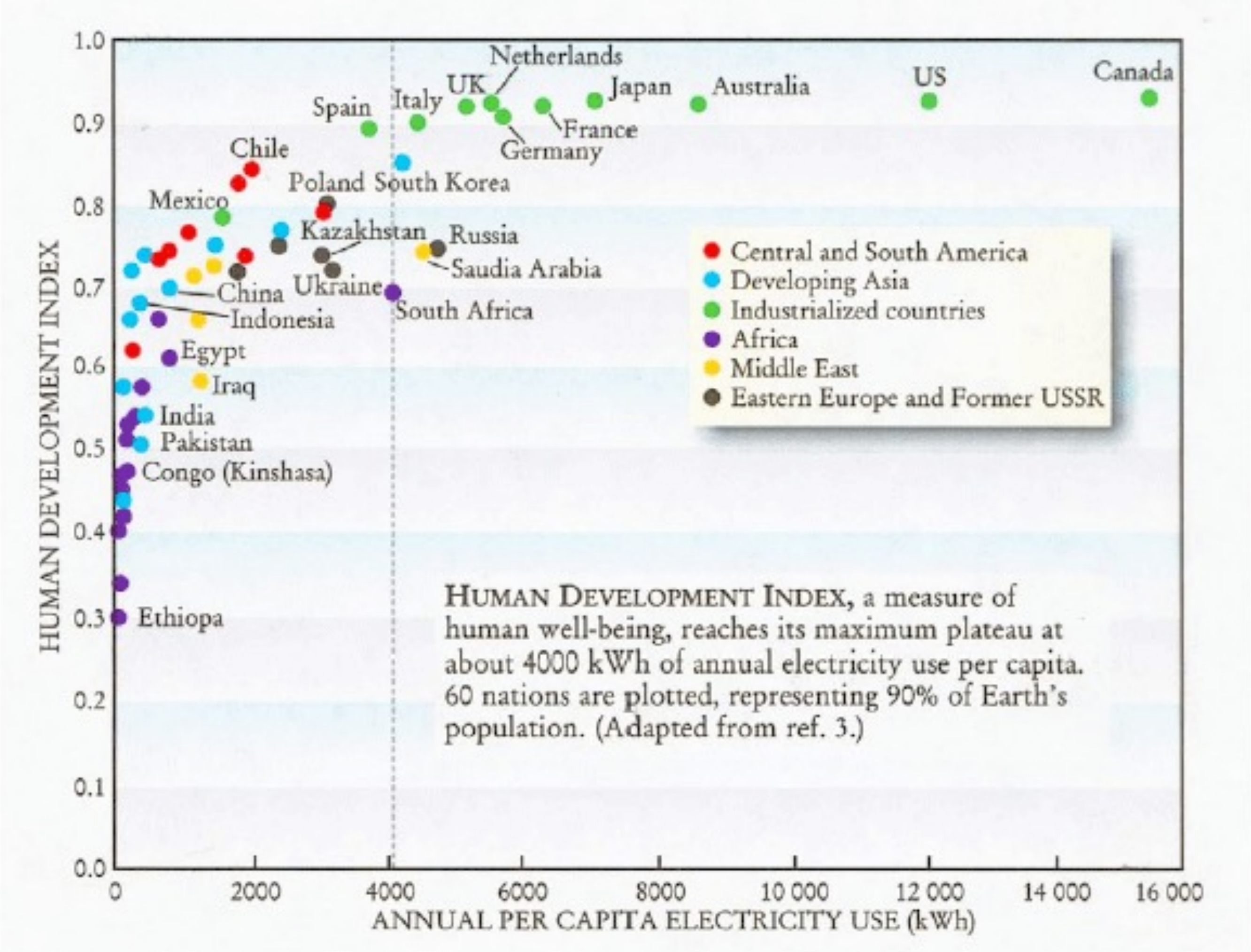
World consumption and shares of primary energy





Source: BP Statistical Review of World Energy 2020

Energy Consumption by Country



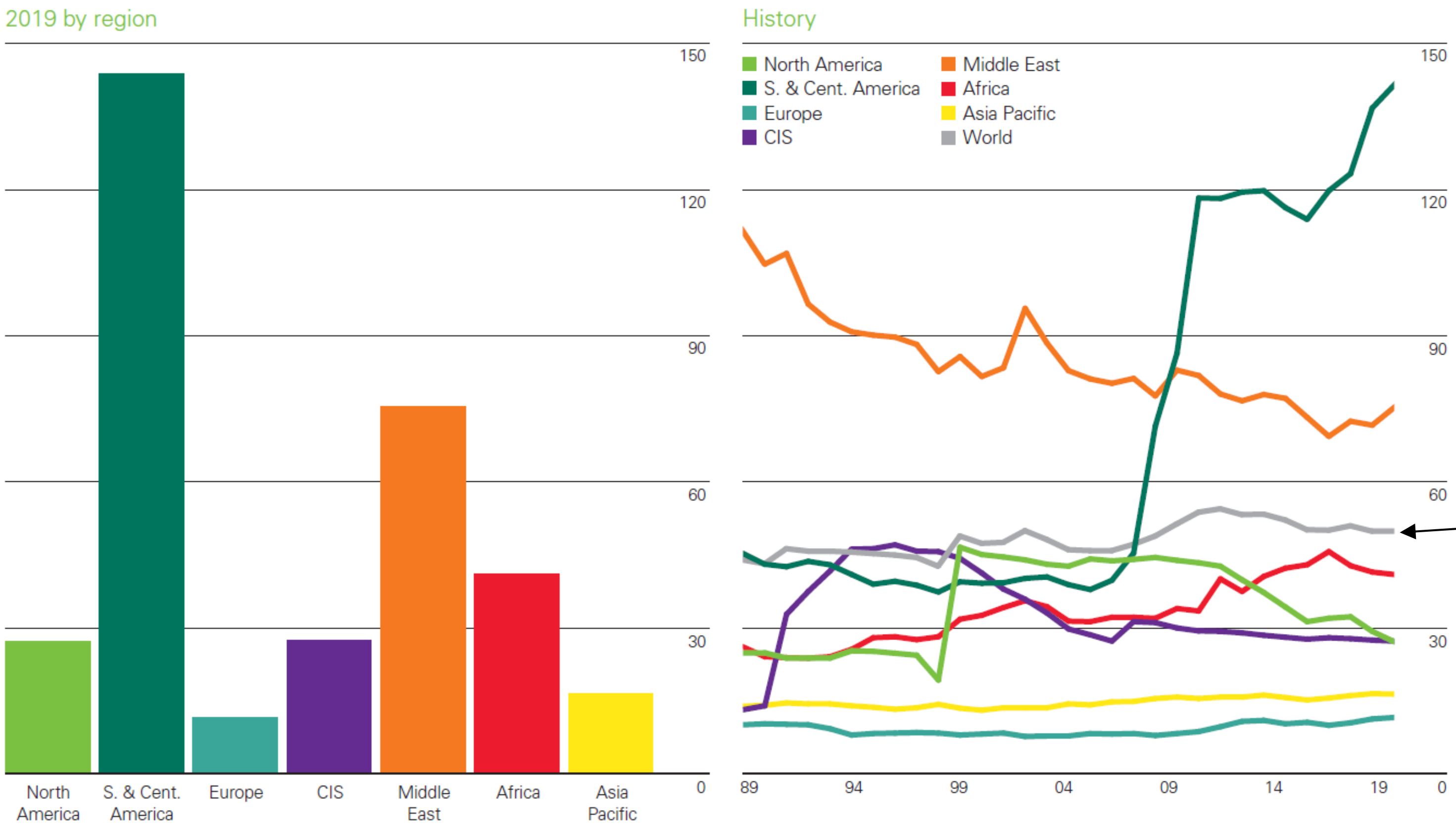
HUMAN DEVELOPMENT INDEX, a measure of human well-being, reaches its maximum plateau at about 4000 kWh of annual electricity use per capita. 60 nations are plotted, representing 90% of Earth's population. (Adapted from ref. 3.)

Human development index vs. per capita electricity use for selected countries. Taken from S. Benka, *Physics Today* (April 2002), pg 39, and adapted from A. Pasternak, Lawrence Livermore National Laboratory rep. no. UCRL-ID-140773.

Oil reserves

R/P: Ratio between proved reserves and present consumption

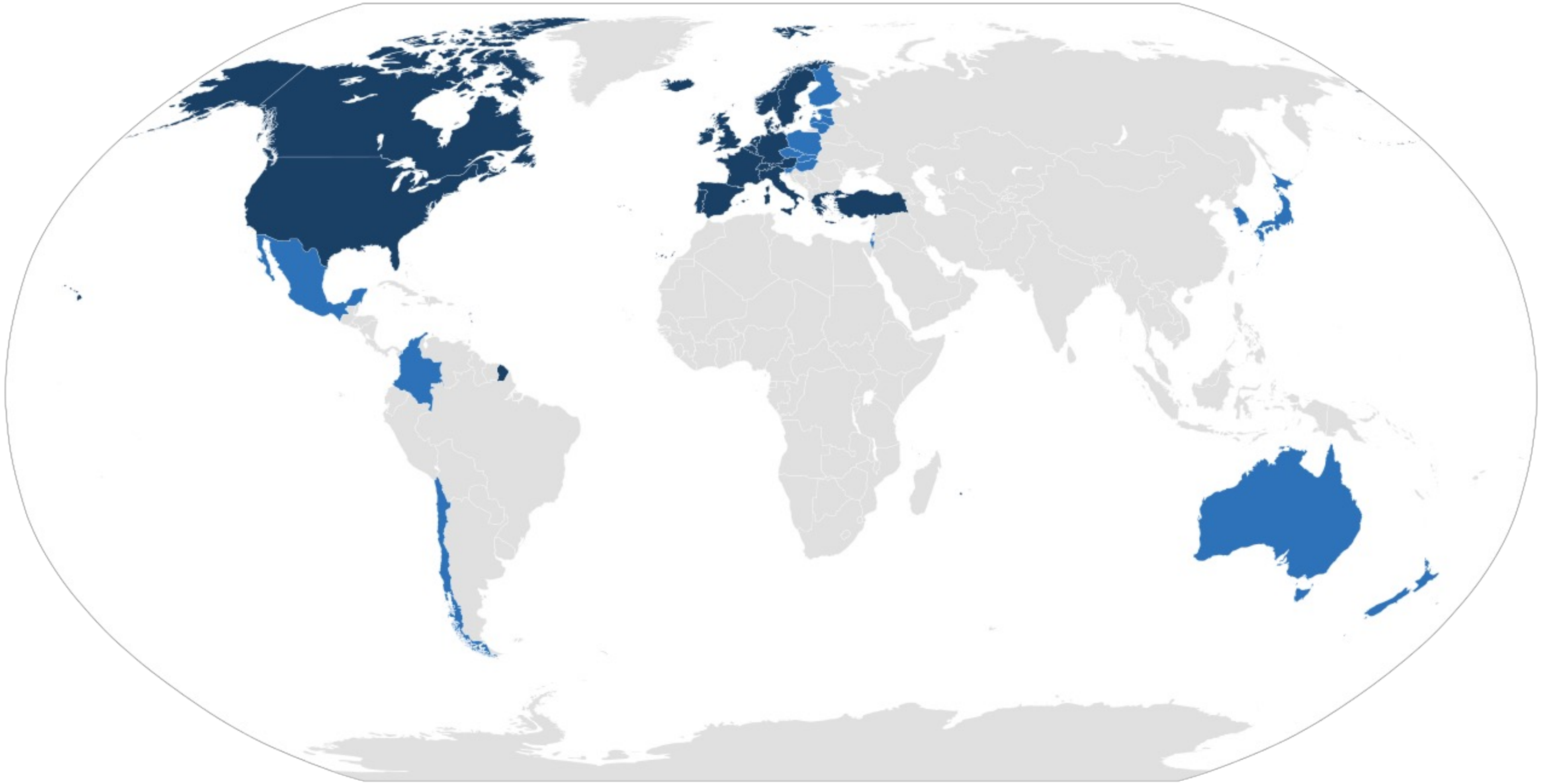
Reserves-to-production (R/P) ratios
Years



R/P at world level is about 50.

BP Statistical Review of World Energy 2020

OECD

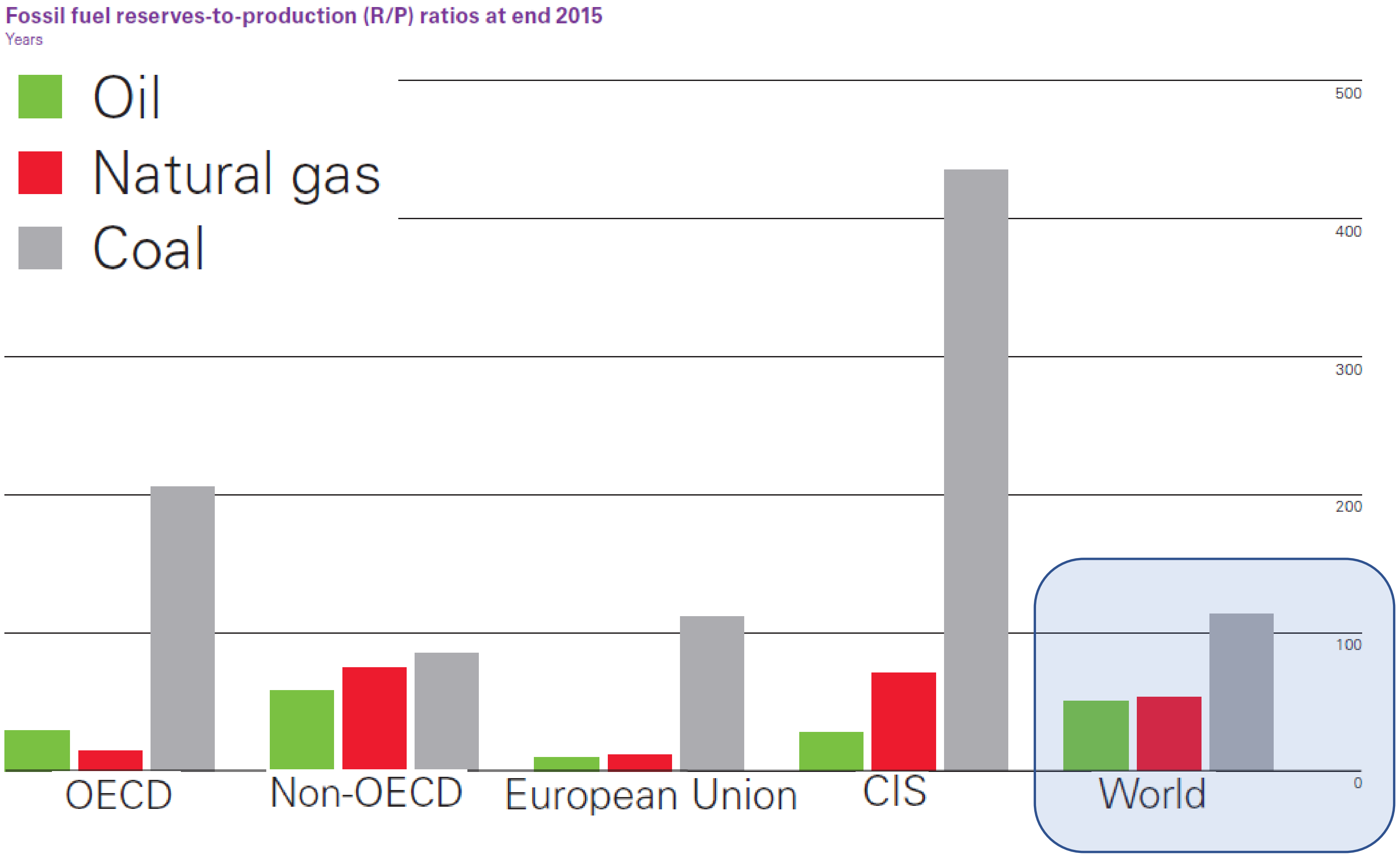


The **Organisation for Economic Co-operation and Development** (OECD) is an intergovernmental economic organisation with 37 member countries, founded in 1961 to stimulate economic progress and world trade. It is a forum of countries describing themselves as committed to democracy and the market economy,

CIS

The **Commonwealth of Independent States** (CIS) is a regional intergovernmental organization of nine (originally ten) members, plus two founding non-member, post-Soviet republics in Eurasia. It was formed following the dissolution of the Soviet Union in 1991.

Fossil fuel reserves to production (2015)



Fossil fuel reserves-to-production (R/P) ratios at end 2015

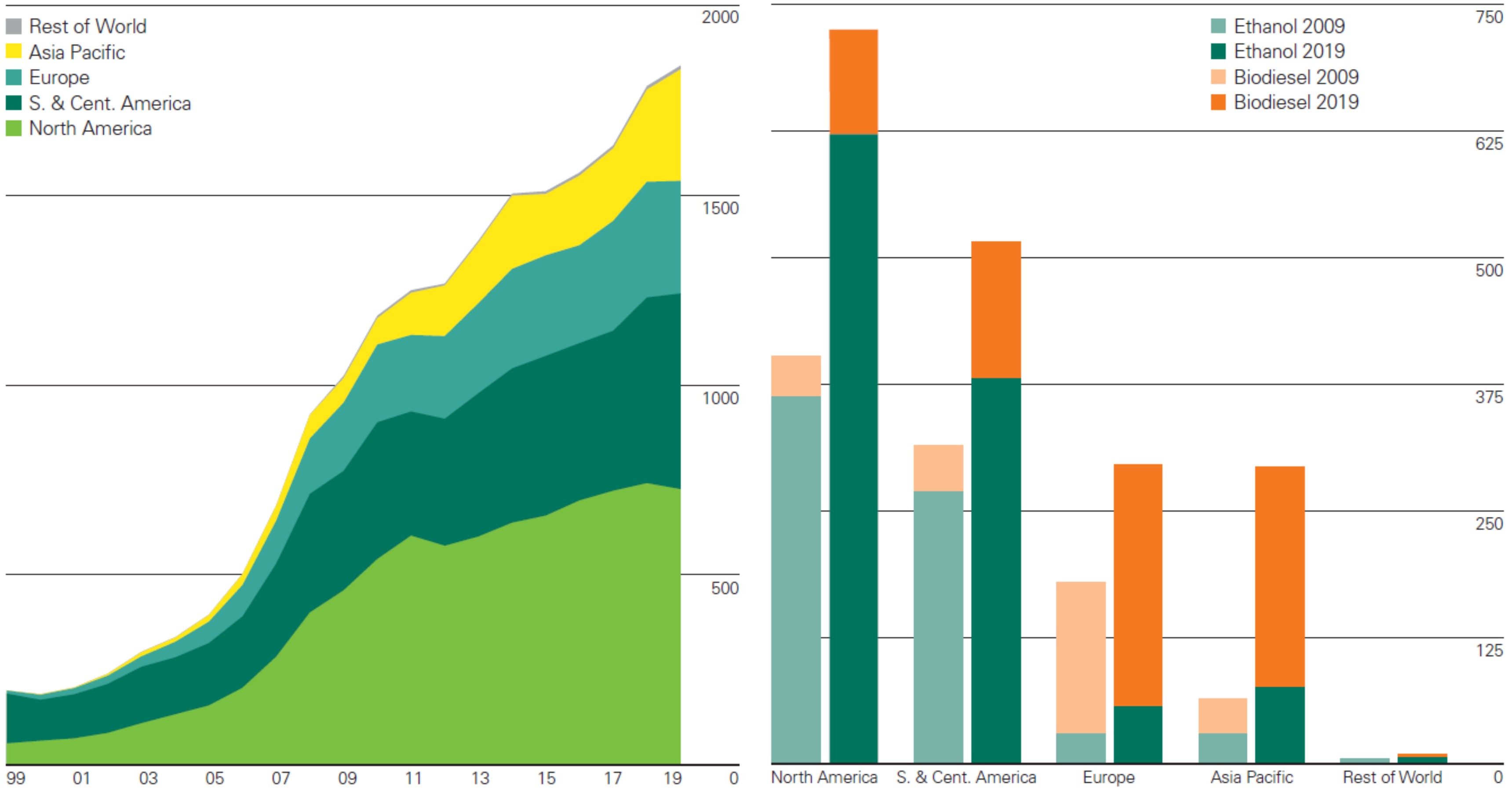
Years

Most energy known fossil reserves are represented by coal and located in ex URSS and OCSE.

BP Statistical Review of World Energy 2016

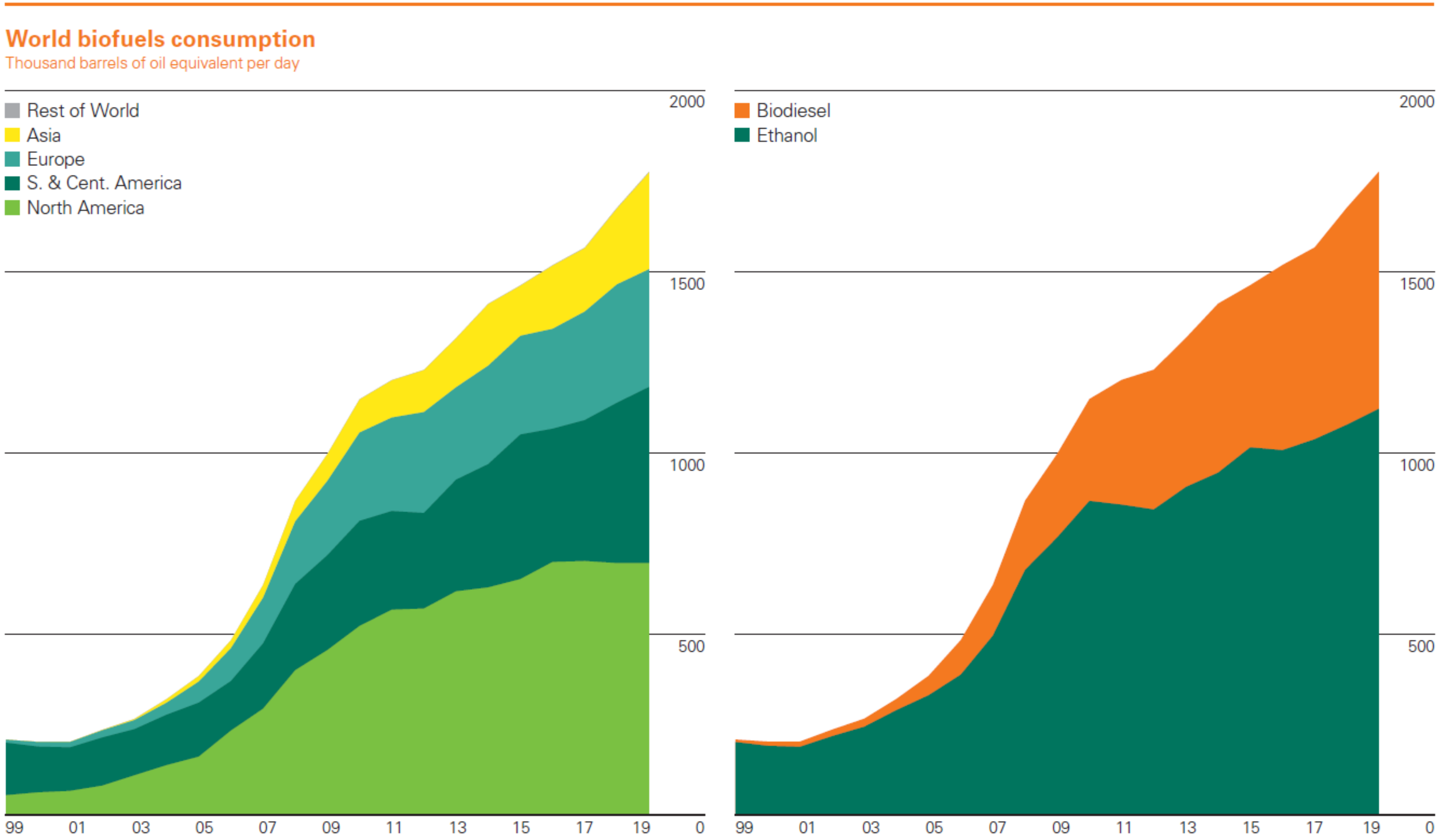
Biofuels: production

World biofuels production
Thousand barrels of oil equivalent per day



Source: BP Statistical Review of World Energy 2020

Biofuels: consumption

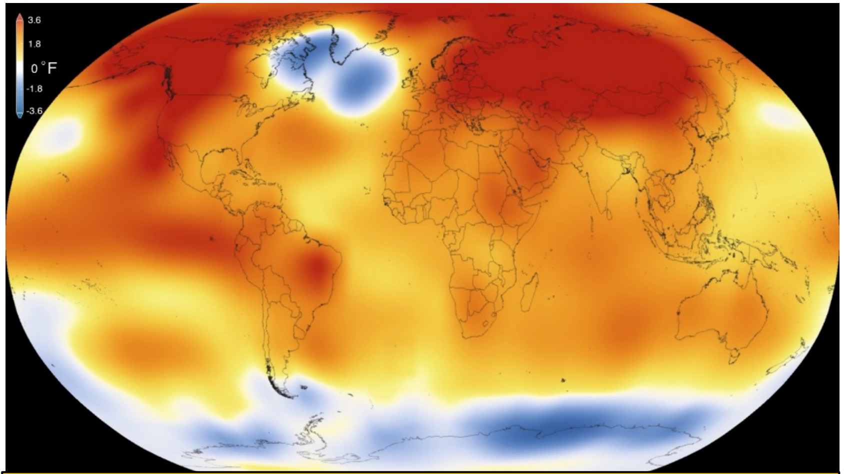


Source: BP Statistical Review of World Energy 2020

Global and Local Emissions

There are two different type of impacts of the emissions on the environment

GLOBAL

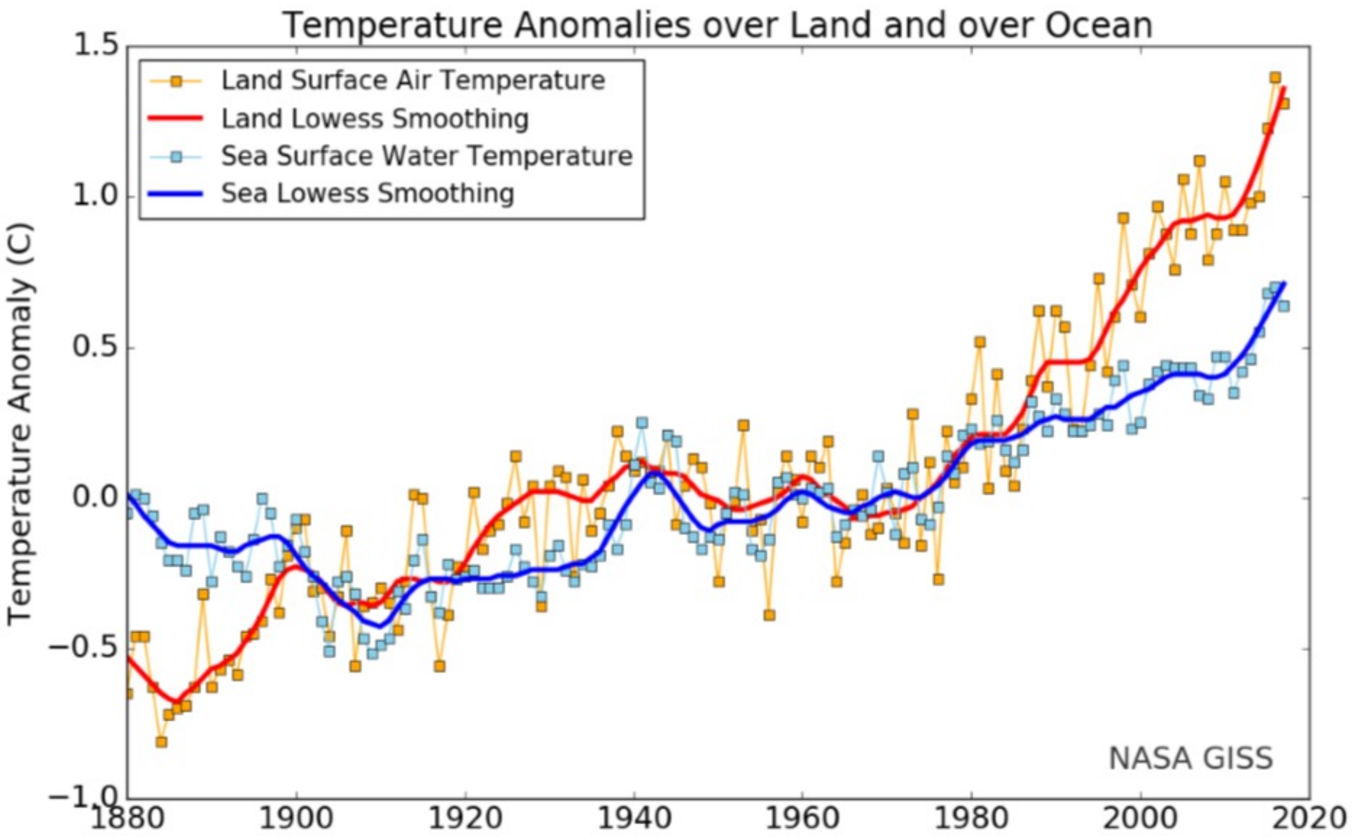


GHG (Green House Gas), as CO_2, impacting on global warming and climate changes, irrespectively of the location they were generated.

LOCAL

Gaseous emissions (CO, NOx) and PM impacting on smog, air pollution and health. They are particularly harmful in the cities.

Global warming



The «precautionary principle» must be claimed

Source: NASA – Goddard Institute for Space Studies, 2018 https://data.giss.nasa.gov/gistemp

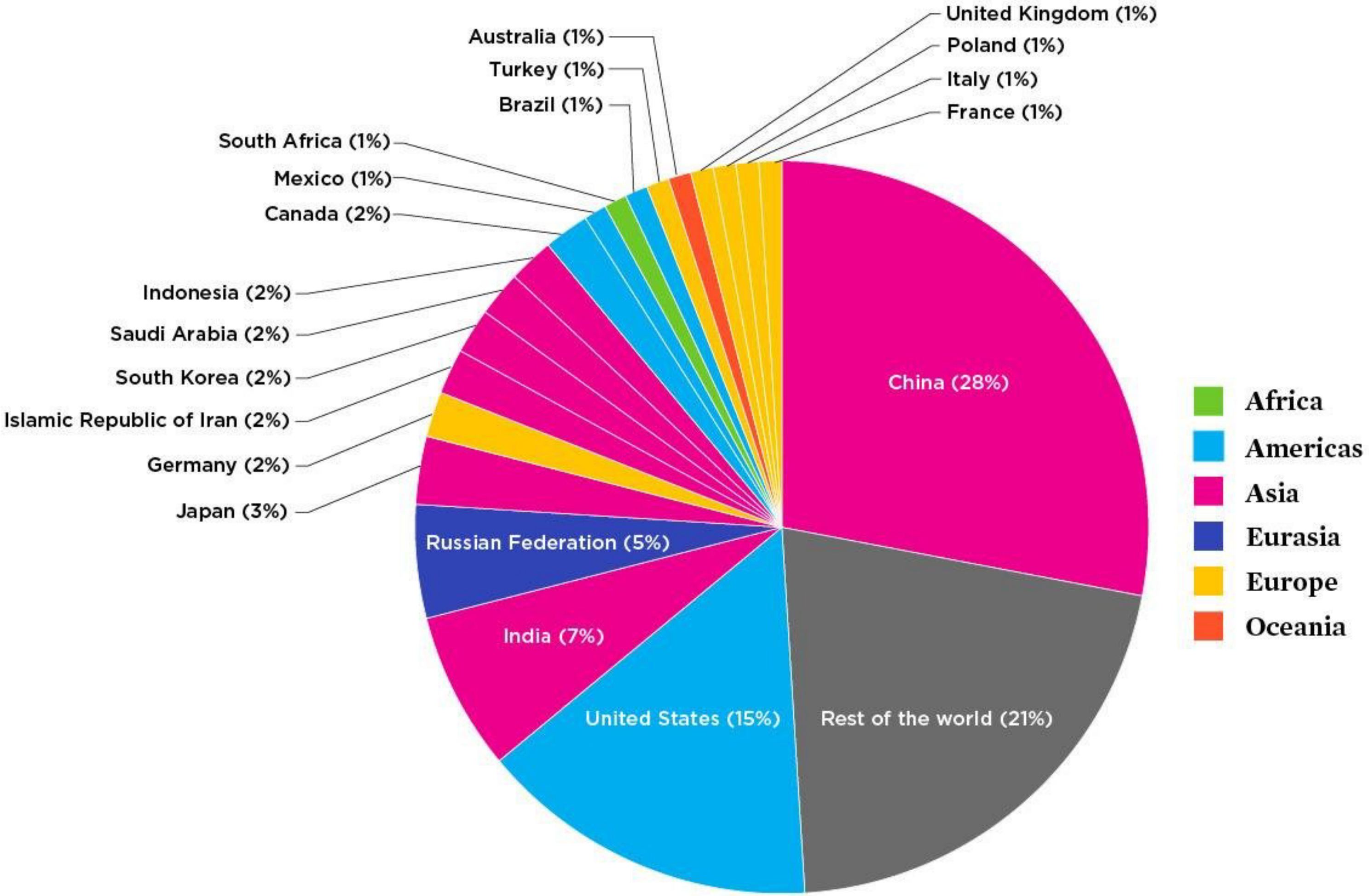
Global warming and CO2

CO2 concentration: 405,4 ppm[1], CO2 safeguard limit: 450 ppm[2]
CO2 annual growth: 1.5 ppm/Y[2]

[1] MAUNA LOA Observatory data, https://www.co2.earth/co2-monitoring

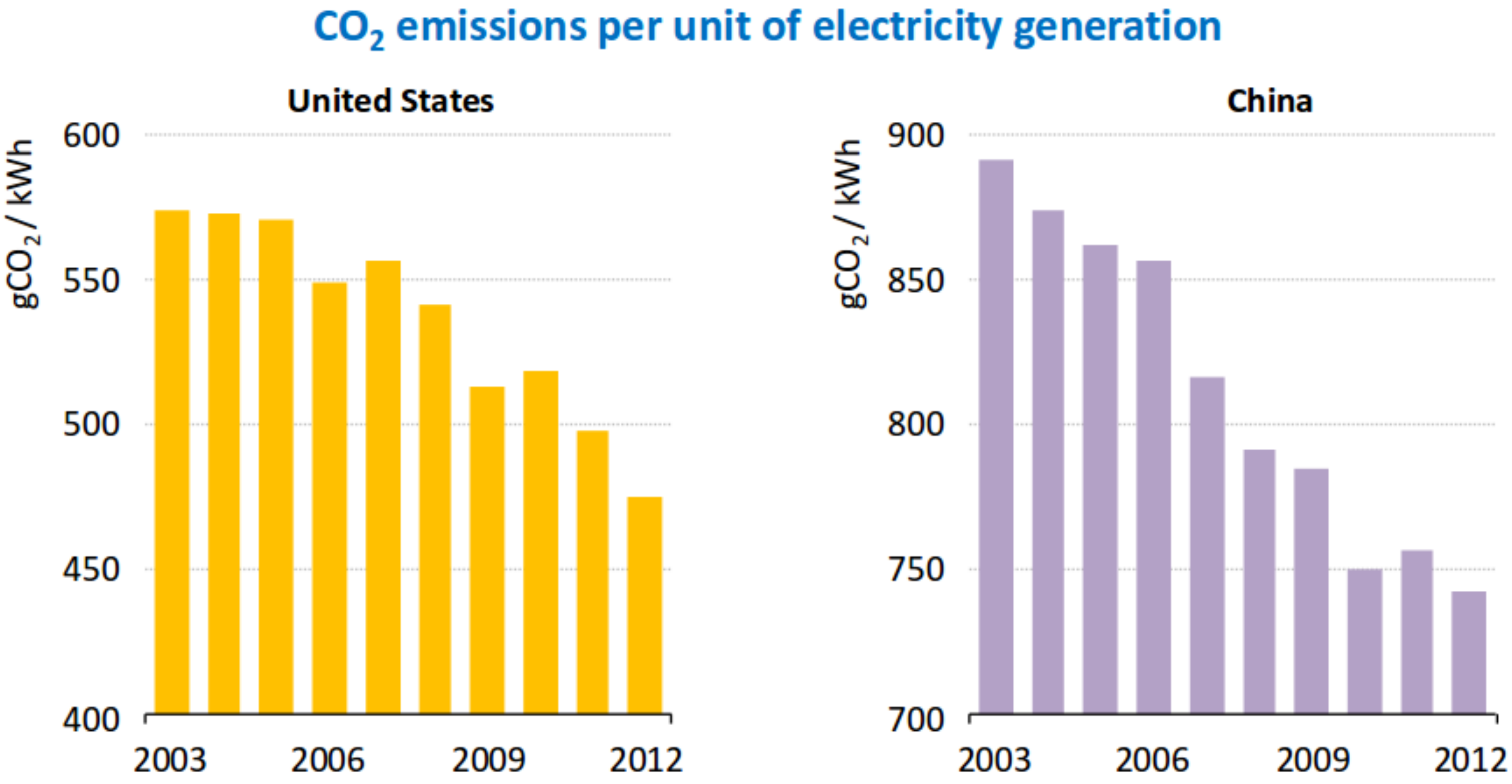
[2] IPCC Sixth Assessment Report, September 2017, https://www.ipcc.ch/

CO2 Emissions by Country



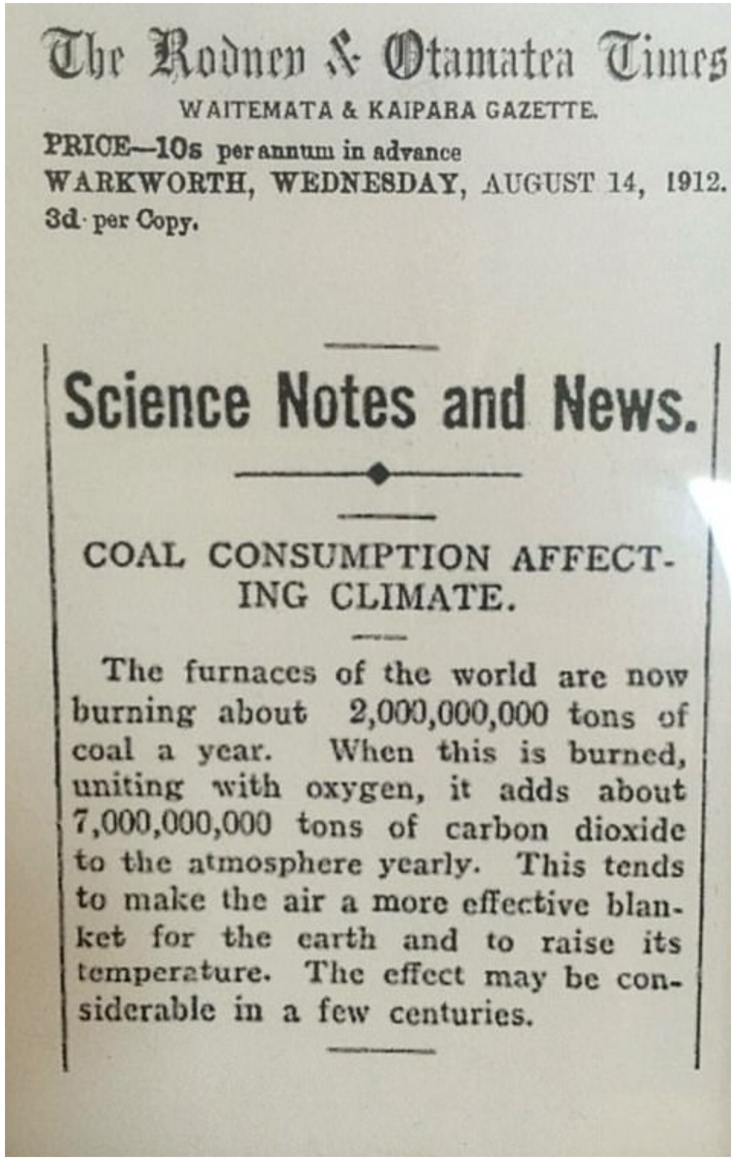
© 2020 Union of Concerned Scientists
Data: Earth Systems Science Data 11, 1783-1838, 2019

CO2 Emissions by Country



Global warming and CO2?
Nothing new!

"The Rodnen & Otamatea Time", a New Zealand newspaper, predicted global warming due to CO_2 emissions in **<u>1912</u>**!



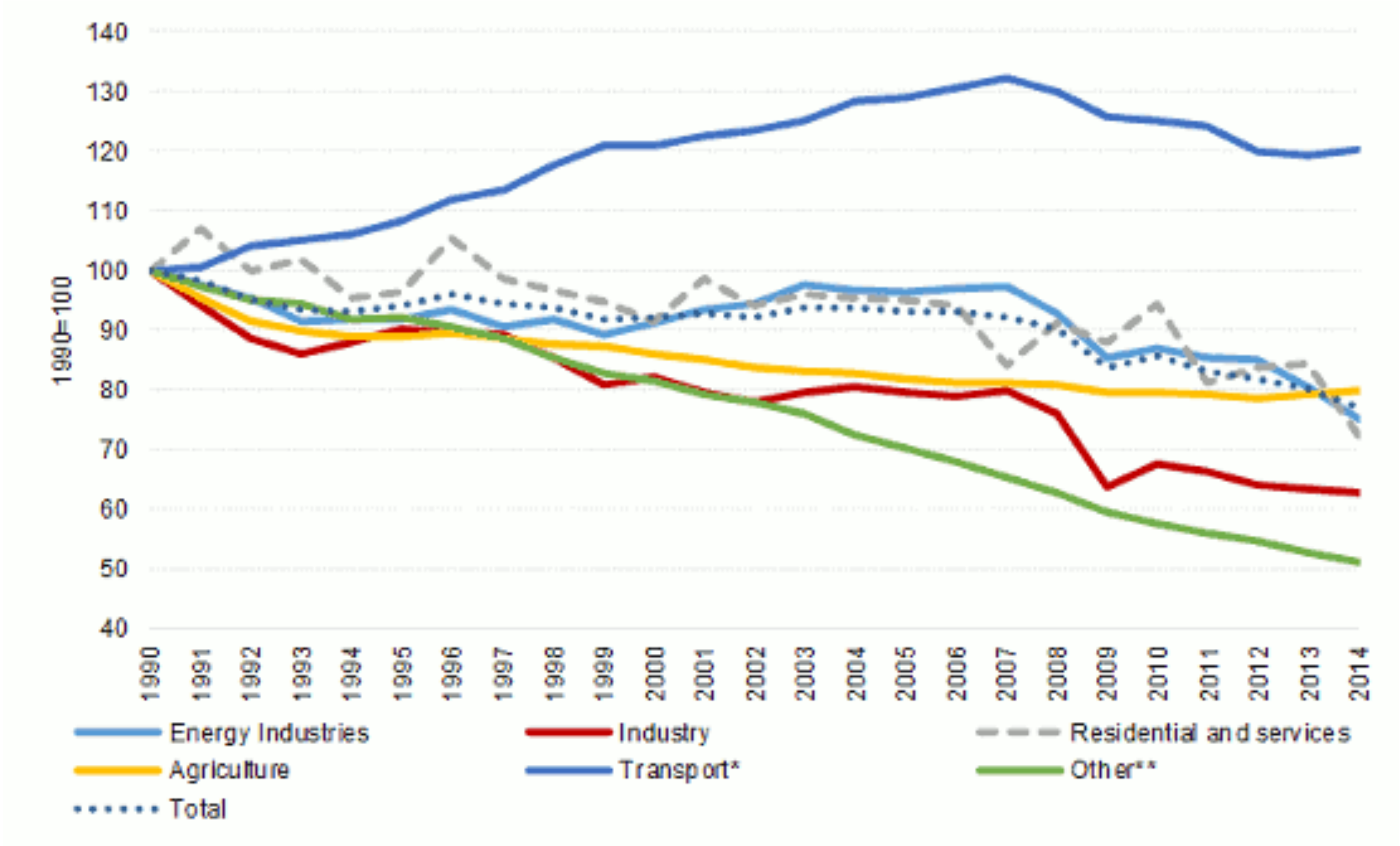
The Rodney & Otamatea Times
WAITEMATA & KAIPARA GAZETTE.
PRICE—10s per annum in advance
WARKWORTH, WEDNESDAY, AUGUST 14, 1912.
3d. per Copy.

Science Notes and News.

COAL CONSUMPTION AFFECTING CLIMATE.

The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

CO2 emissions per sectors (EU)

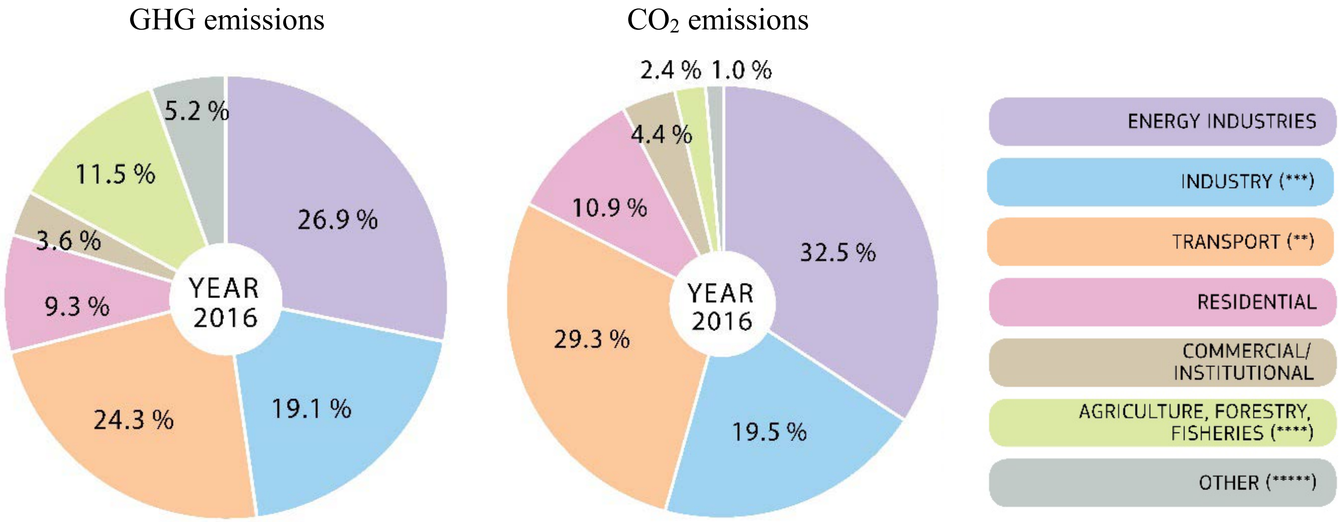


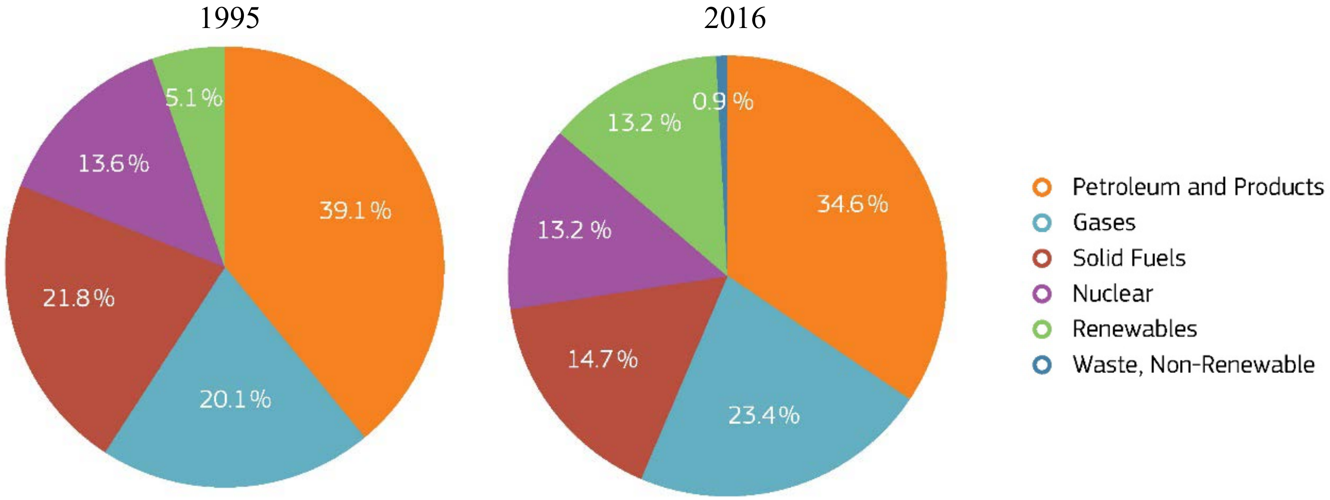
https://ec.europa.eu/clima/policies/transport_en

Transport represents almost a quarter of Europe's greenhouse gas emissions and is the main cause of **air pollution in cities**. The transport sector **has not seen the same gradual decline in emissions as other sectors**: emissions only started to decrease in 2007 and still remain higher than in 1990.

Statistics on transport related CO2

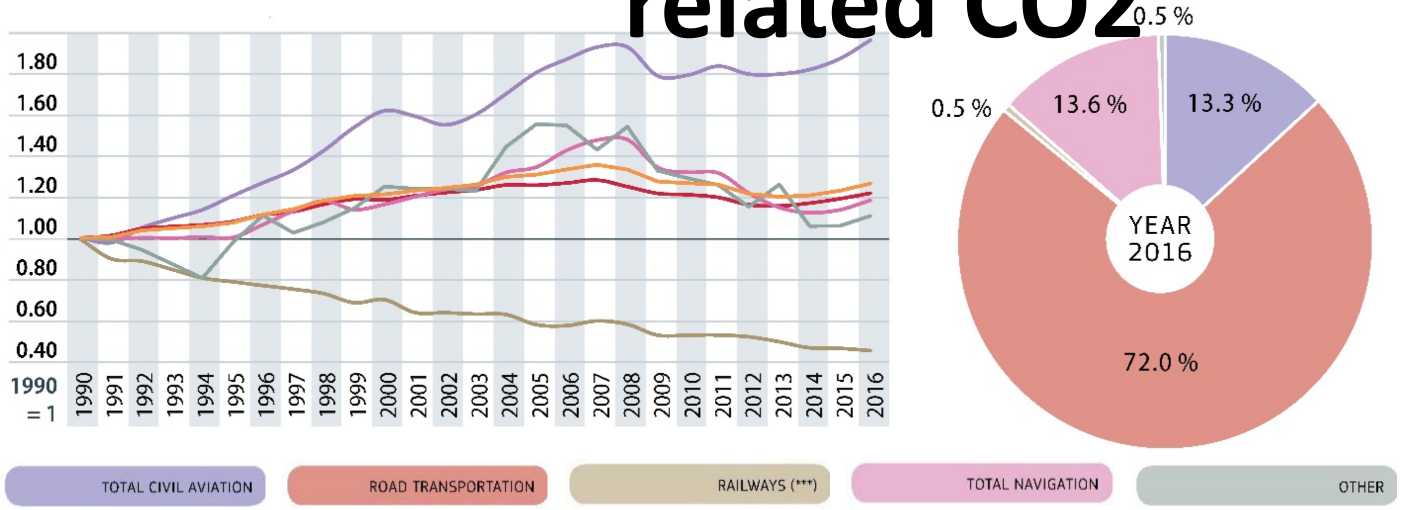
EU-28

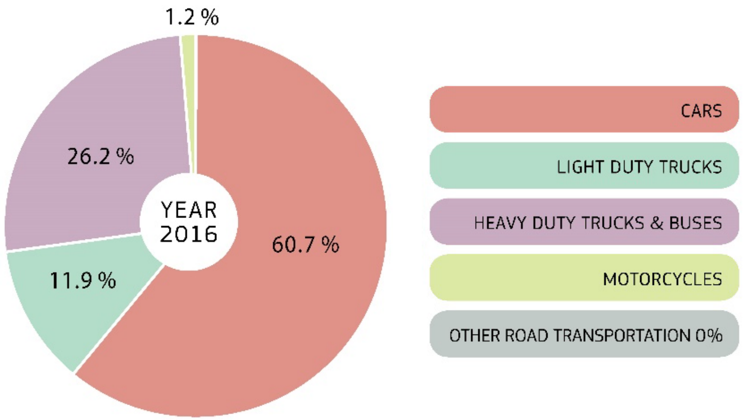


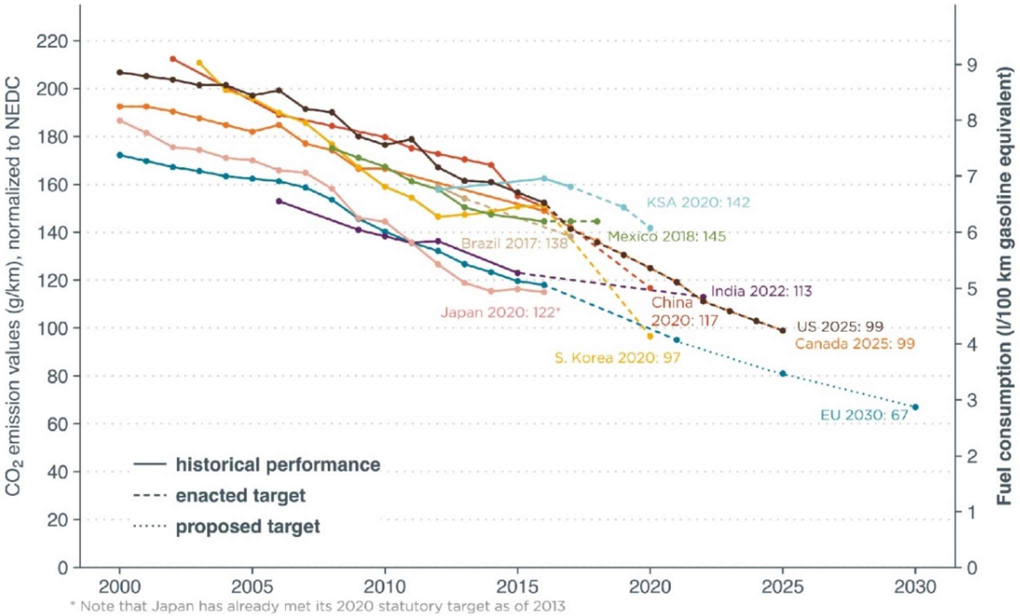


Source: European Union. EU energy in figures. Statistica. Luxembourg: Publications Office of the European Union; 2018.

Statistics on transport related CO2

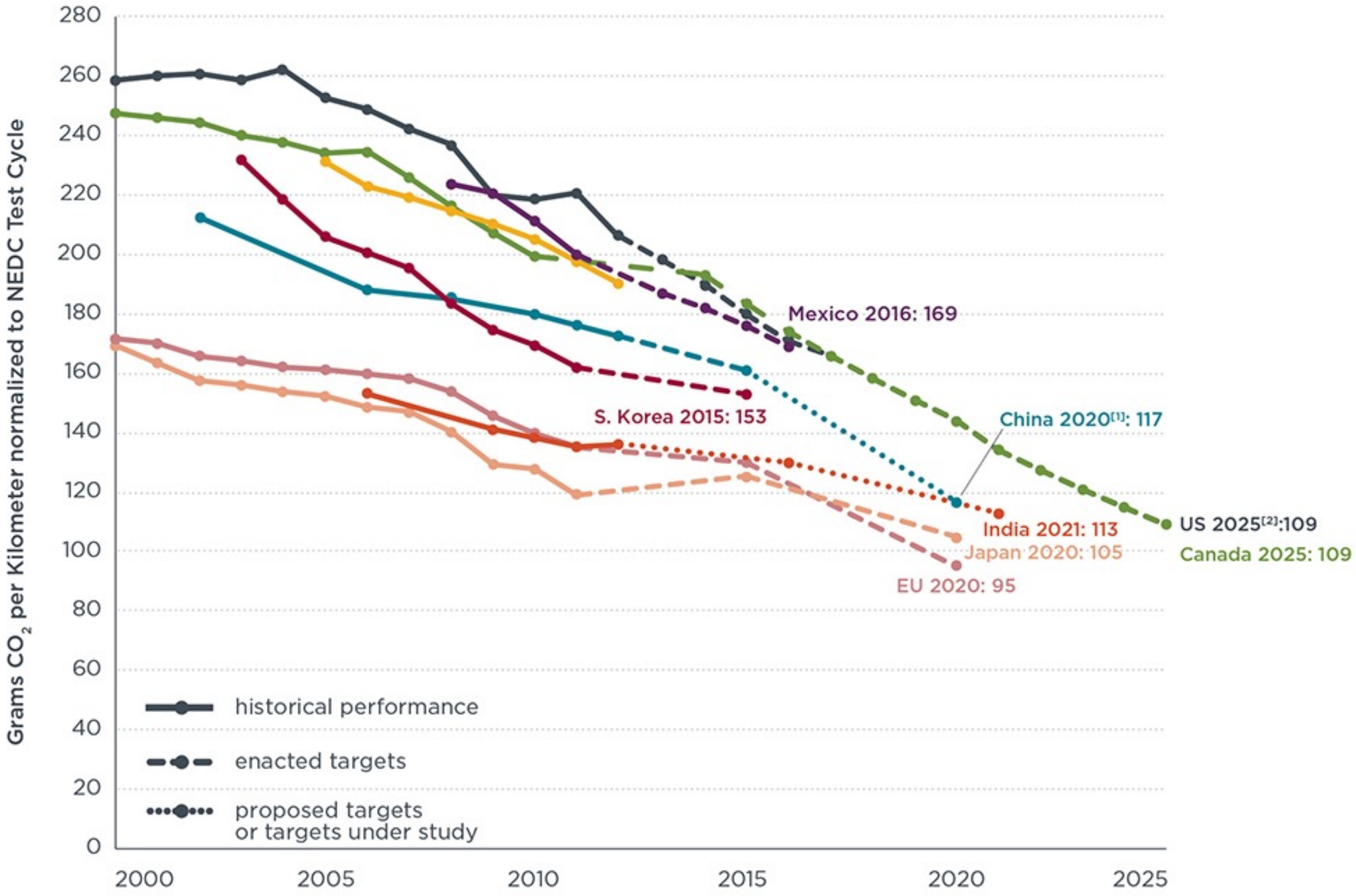






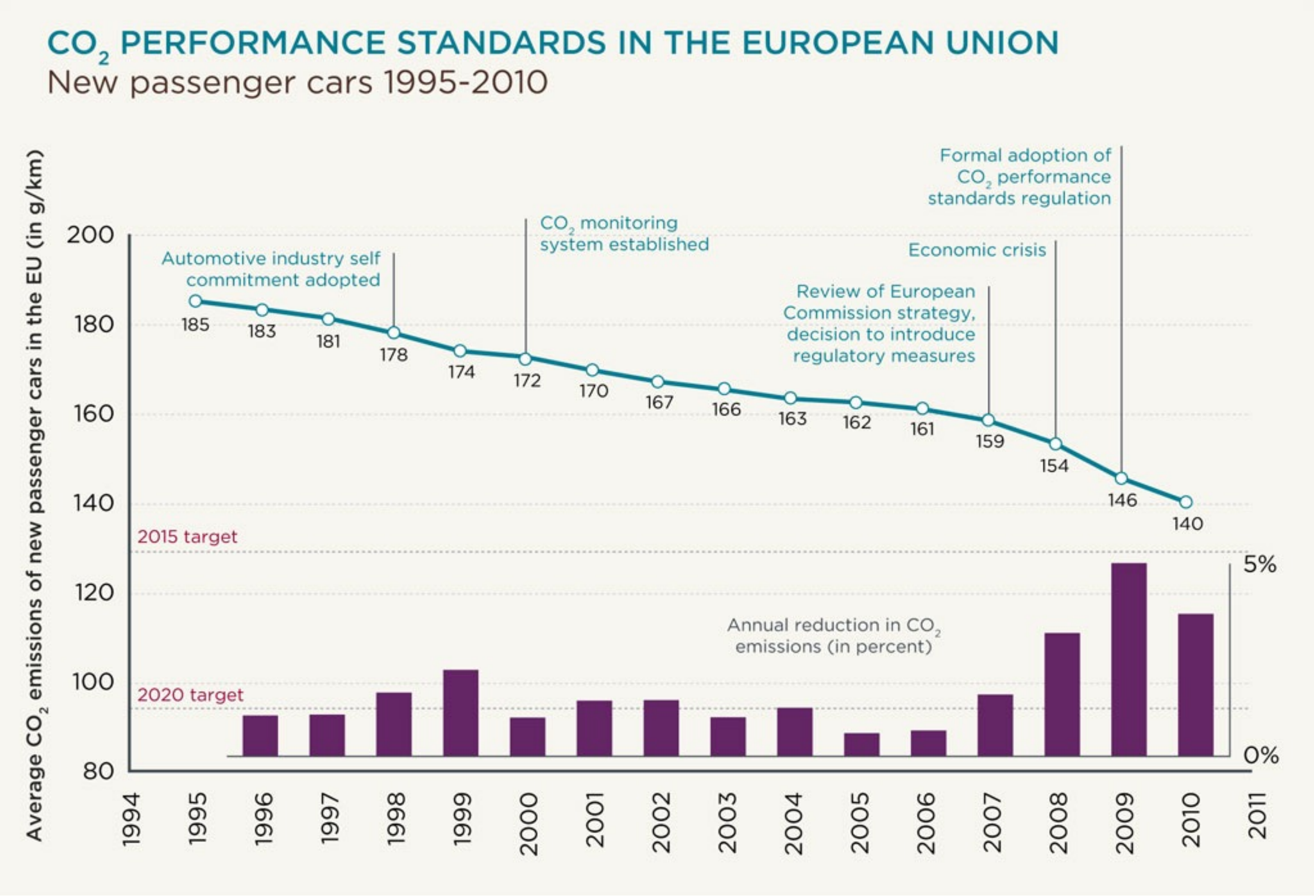
Source: European Union. EU transport in figures. Statistica. Luxembourg: Publications Office of the European
Union; 2018.

CO2 Regulations



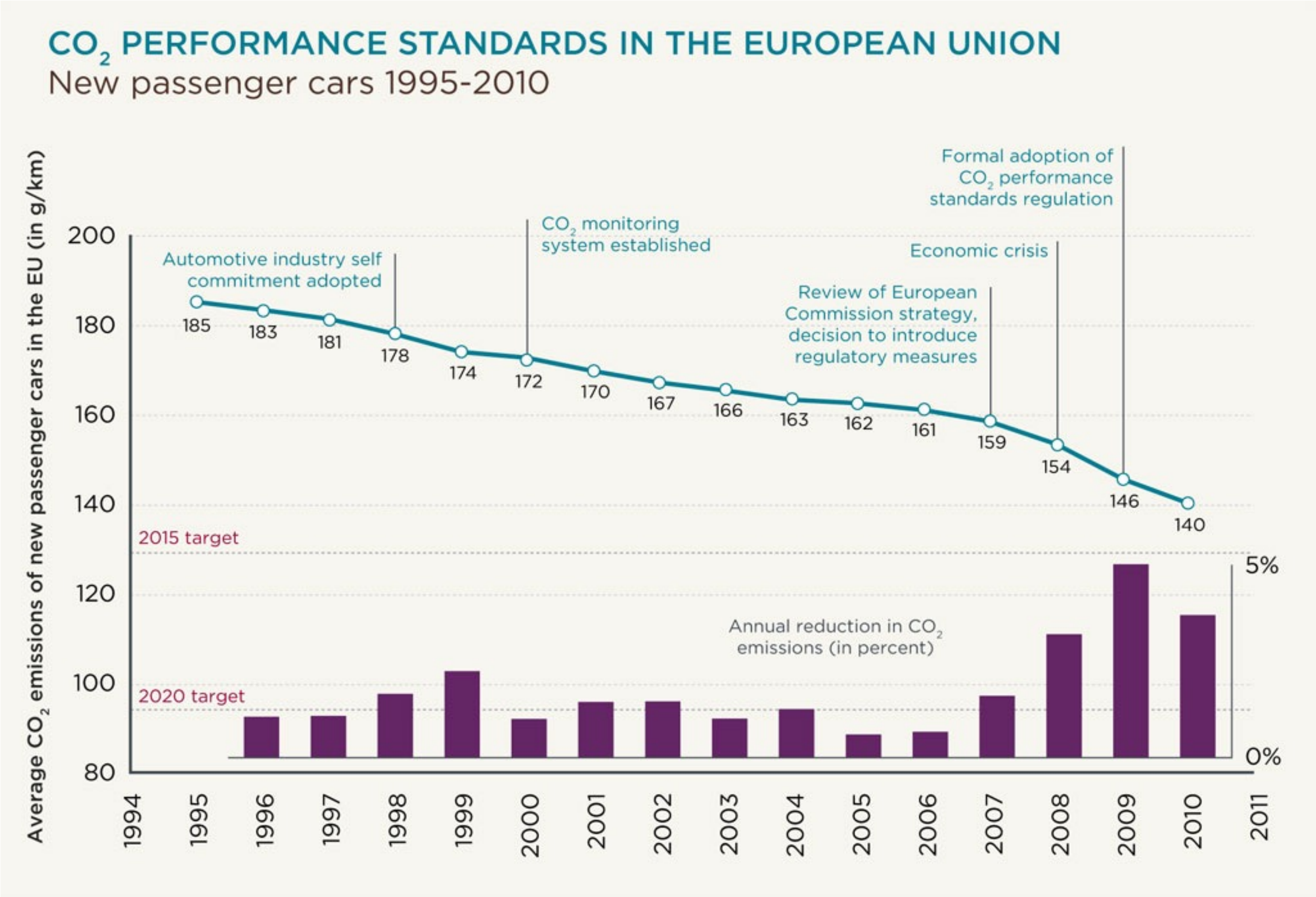
[1] China's target reflects gasoline vehicles only. The target may be higher after new energy vehicles are considered.
[2] US, Canada, and Mexico light-duty vehicles include light-commercial vehicles.
[3] Supporting data can be found at: http://www.theicct.org/info-tools/global-passenger-vehicle-standards

EU CO2 Regulations



- In 1998, the European Automobile Manufacturers' Association (ACEA), JAMA, and KAMA agreed to **reduce average CO2 emissions from new cars sold to 140 g/km by 2008**, which translated into a 25% reduction compared to the 1995 level.
- They also agreed to review the rate of progress, with a view toward making subsequent reductions —120 g CO2/km by 2012.
- But the automakers' commitment **lacked any binding burden-sharing**. The result was annual emission reductions of only 0.6 to 2.2% between 1998 and 2006.
- As it became clear that neither the 2008 target of 140 g CO2/km nor the 120 g CO2/km objective for 2012 would be met, **the European Commission announced that it would propose mandatory reductions**.
- **The regulation (EC 443/2009) setting CO2 emission performance standards for new passenger cars was adopted in April 2009**

EU CO2 Regulations



- Beginning with the Commission’s announcement, the rate of reduction in specific CO2 emissions from new passenger cars began to rise sharply: **1.6% in 2007, 3.2% in 2008 and 5.4% in 2009**.
- This suggests the **magnitude of difference regulation makes**.
- While the effects of the economic crisis and resulting incentives for new vehicle purchases offered by many EU member states potentially distort the annual emission reduction for 2009, the trend is very clear: **switching from a nonbinding voluntary industry commitment to a binding regulation spurred significant reductions in specific CO2 emissions from new passenger cars in the EU**.

Diesel/ICE ban coming?

INDEPENDENT News Politics Final Say Voices Indy/Life InFact Spor

News › World

European cities announce bans on petrol and diesel cars as green initiative spreads across continent

'It's not a human right to pollute the air for others'

Support The Guardian Subscribe Find a job

The Guardian

News Opinion Sport Culture Lifestyle

Environment ▸ Climate change Wildlife Energy Pollution

Greenhouse gas emissions

Oslo temporarily bans diesel cars to combat pollution

CNN Money Markets

Germany's second biggest ci… ban diese… …s starting to

INSIDEEVs COMPARE

Home > General > The City Of Milan's Diesel Ban Will

The City Of Milan's Diesel Ban Will Start A Chain Reaction

NEWS SPORT BUSINESS ALL SECTIONS

UK World Politics Science Education Health Brexit Royals

News

Diesel and petrol car ban: Plan for 2040 unravels as 10 new power stations needed to cope with electric revolution

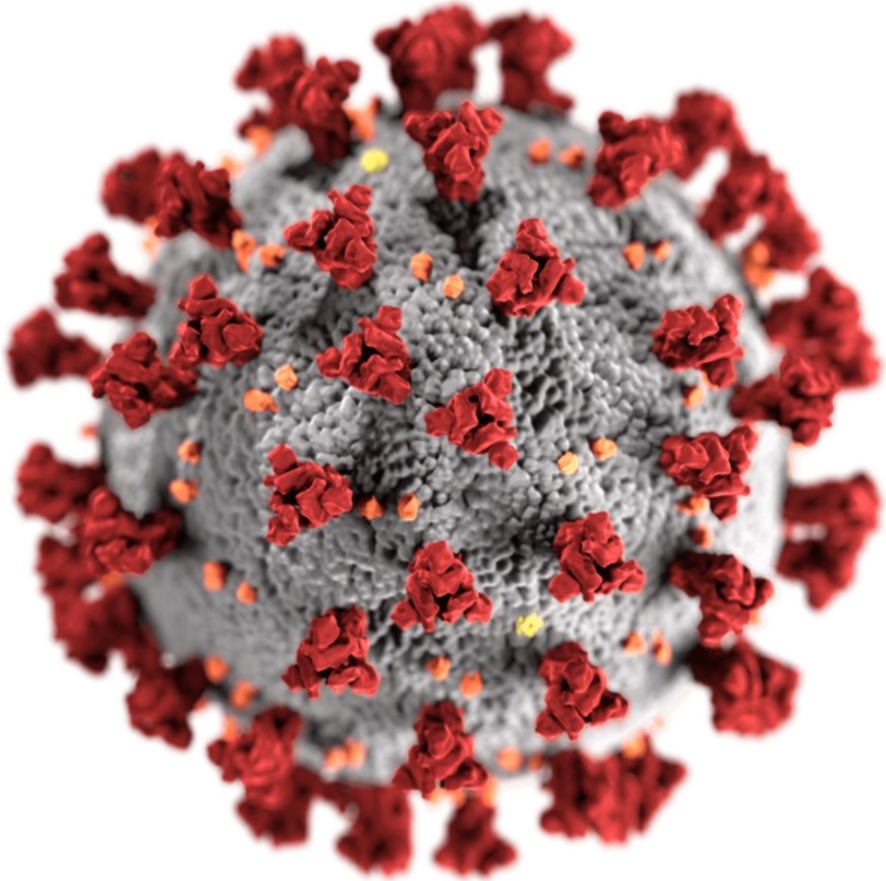
R&T NEW CARS RACING CULTURE VIDEOS REVIEWS

German Government Votes to Ban Internal Combustion Engines by 2030

The German Bundesrat has voted to ban new gasoline- or diesel-powered vehicles from EU roads starting in 2030.

After the Diesel-gate, an increasing trend toward banning of Diesel and ICE cars has been noticed

COVID Effects



Since 2020, the COVID pandemic produced their effects on road transport also

CO2 and global warming


AGI AGENZIA ITALIA

Lo scioglimento dei ghiacci potrebbe rilasciare virus di 15 mila anni fa

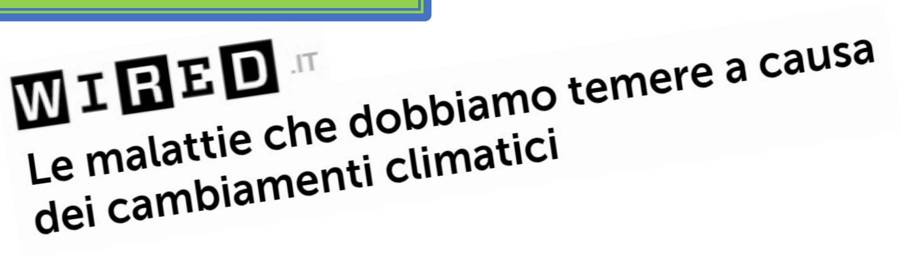

INDEPENDENT

Global warming could unleash viruses that have lain dormant for millennia, warn scientists

Global warming may have a very dangerous impact on health too


THE TIMES OF IS

Viruses expected to increase with global warming – expert


WIRED.IT

Le malattie che dobbiamo temere a causa dei cambiamenti climatici

Everybody's Health

HARVARD UNIVERSITY

COVID-19 PM2.5

A national study on long-term exposure to air pollution and COVID-19 mortality in the United States

SIMA

CORRIERE DELLA SERA

Coronavirus e polveri sottili, la conferma: il particolato atmosferico trasporta il virus

Urban pollution aggravates virus infection

WORLD ECONOMIC FORUM

The deadly link between COVID-19 and air pollution

Pittsburgh Post-Gazette

Study finds link between air pollution and COVID-19 fatalities

ANSA.it

Coronavirus: accertata presenza nel particolato atmosferico

The way we will move around

COVID-19: UIA ANNOUNCES FURTHER FORCED FLIGHT CANCELLATIONS

The New York Times

Worried About Coronavirus on the Subway? Here's What We Know

Toward increasing use of private cars for personal transportation

Coronavirus: What's the risk on public transport?

Impact of Coronavirus to new car purchase in China

Jobs and money

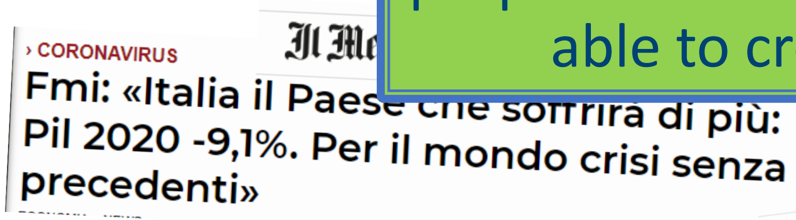

TIME

BUSINESS • COVID-19

As COVID-19 Crashes the Economy, Workers and Business Owners Wonder If Anything Can Save Them From Financial Ruin

Covid-19 may cause deepest economic crisis 'of our lifetimes' — WTO chief

Need for reasonable and affordable proposals aimed at the majority of people, able to create job opportunities


› CORONAVIRUS

Il Me

Fmi: «Italia il Paese che soffrira di più: Pil 2020 -9,1%. Per il mondo crisi senza precedenti»

The economic impact of COVID-19 (novel coronavirus)


EL PAÍS

TRIBUNA

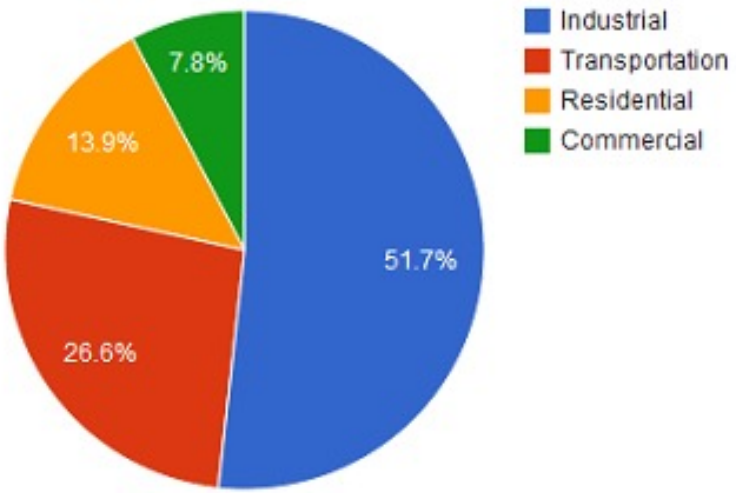
Coronavirus, crisis económica y renta básica

Transportation Energy

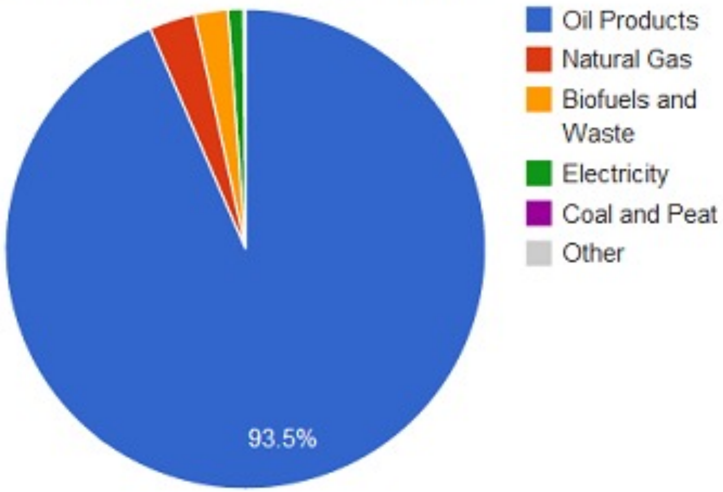
Worldwide energy use totaled **524 quads** in 2012, with **transportation using about 27%**

(A quad is a unit of energy equal to 1.055 × 10^{18} joules (1.055 exajoules or EJ) in SI units)

World Energy Consumption by Sector, 2012 (EIA Data)



World Transportation Energy by Source, 2009 (IEA data)



About 93% of transportation energy consumption comes from **petroleum** for a total of 87 million barrels per day.

Transport is a major issue for EU

63%
Oil consumption

29%
CO2 emissions

6.3%
Union's GDP

13M
People employed

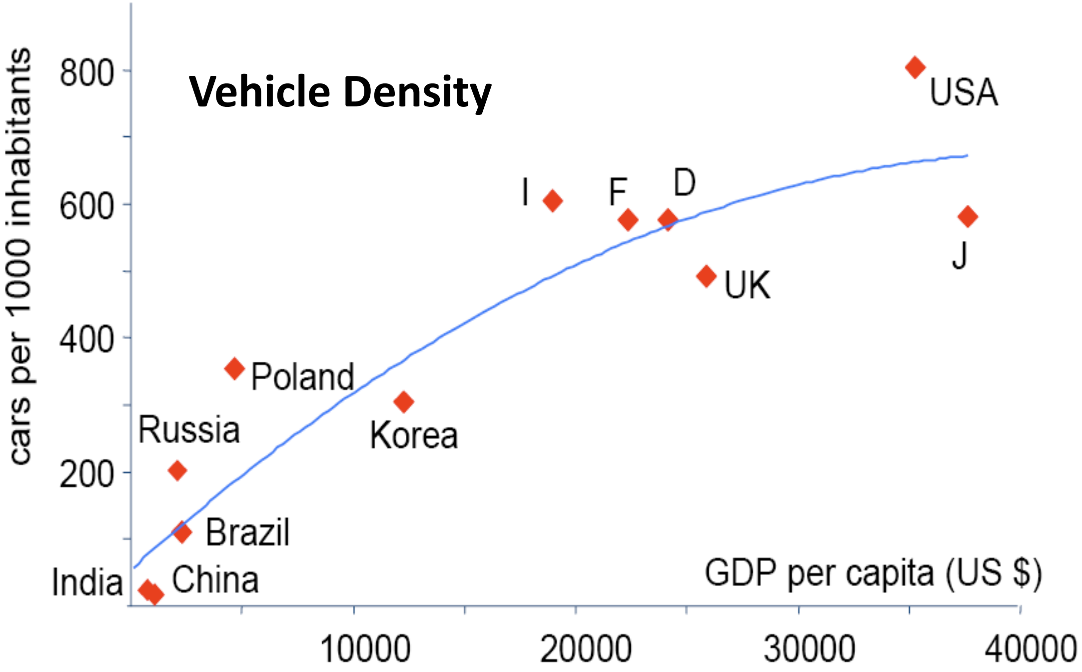
Transport

12%
CO2 emissions

2007: 159 g/km
2021: 95 g/km
CO2 targets

Passenger Cars

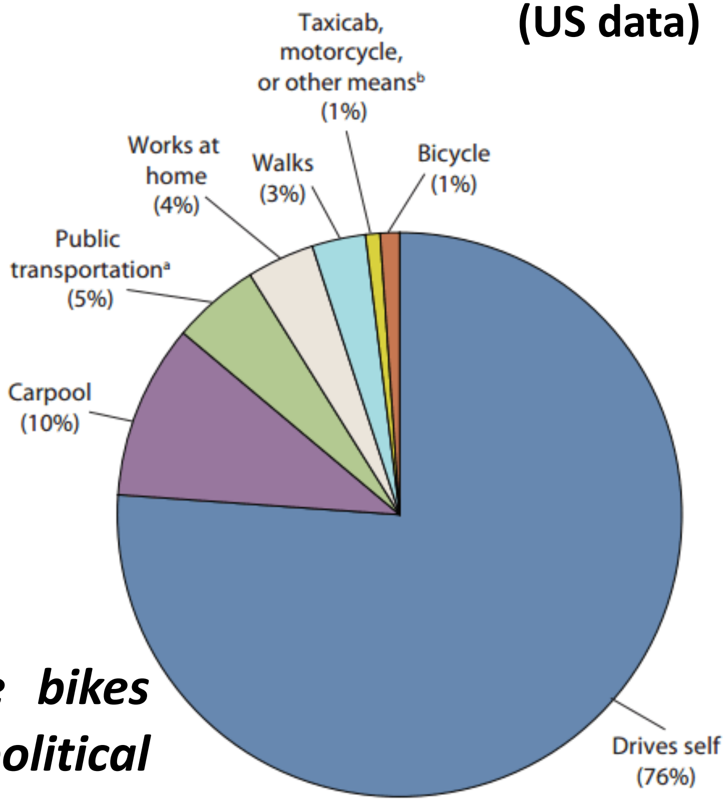
Vehicle Density and Use



Vehicle Density

Source: OECD/IEA/USDOT

How people go to work (US data)



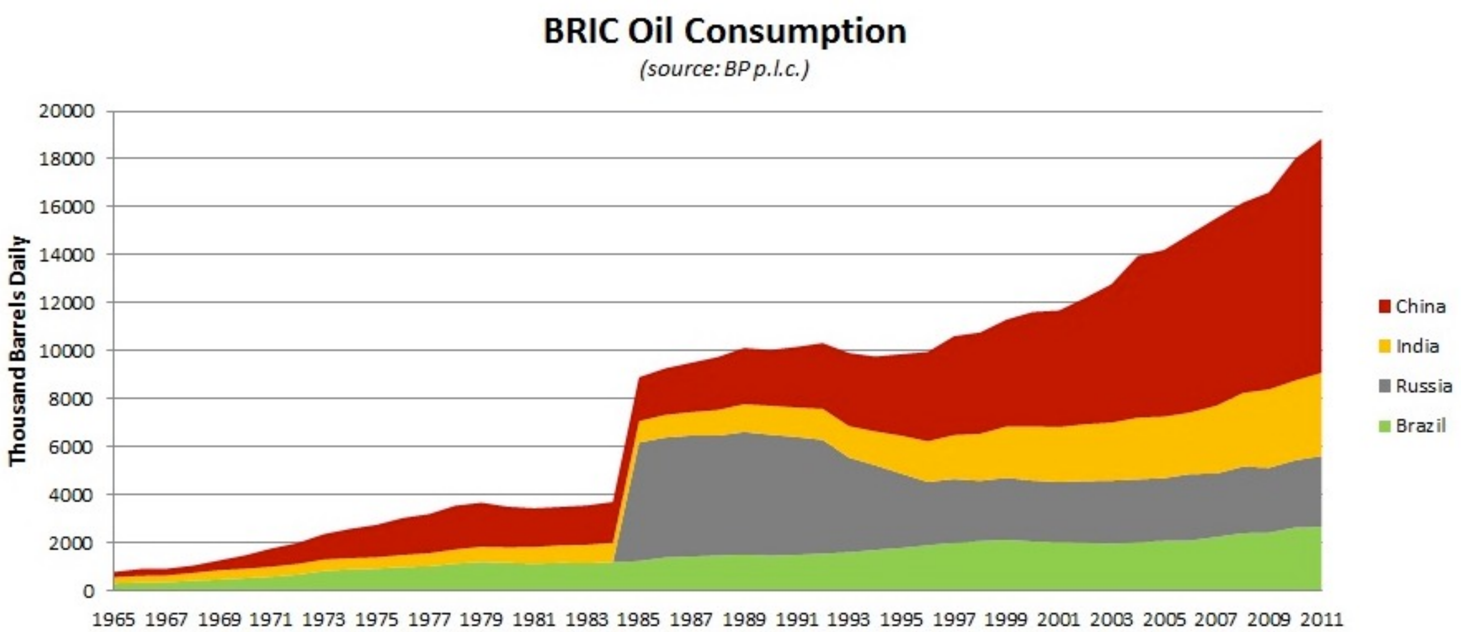
"A third of humanity doesn't want to ride bikes anymore; that has profound geopolitical implications."

Anne Korin, the co-director of the Institute for the Analysis of Global Security (May 1, 2005)

Transportation Energy

In 2011, **60%** of the total transportation energy consumption in the United States was used for **personal transportation** (passenger cars, light trucks, and motorcycles)

The **demand** for personal transportation is **rapidly growing** in the world, mostly due to the economic development of countries such as Brazil, Russia, India, China (BRIC).

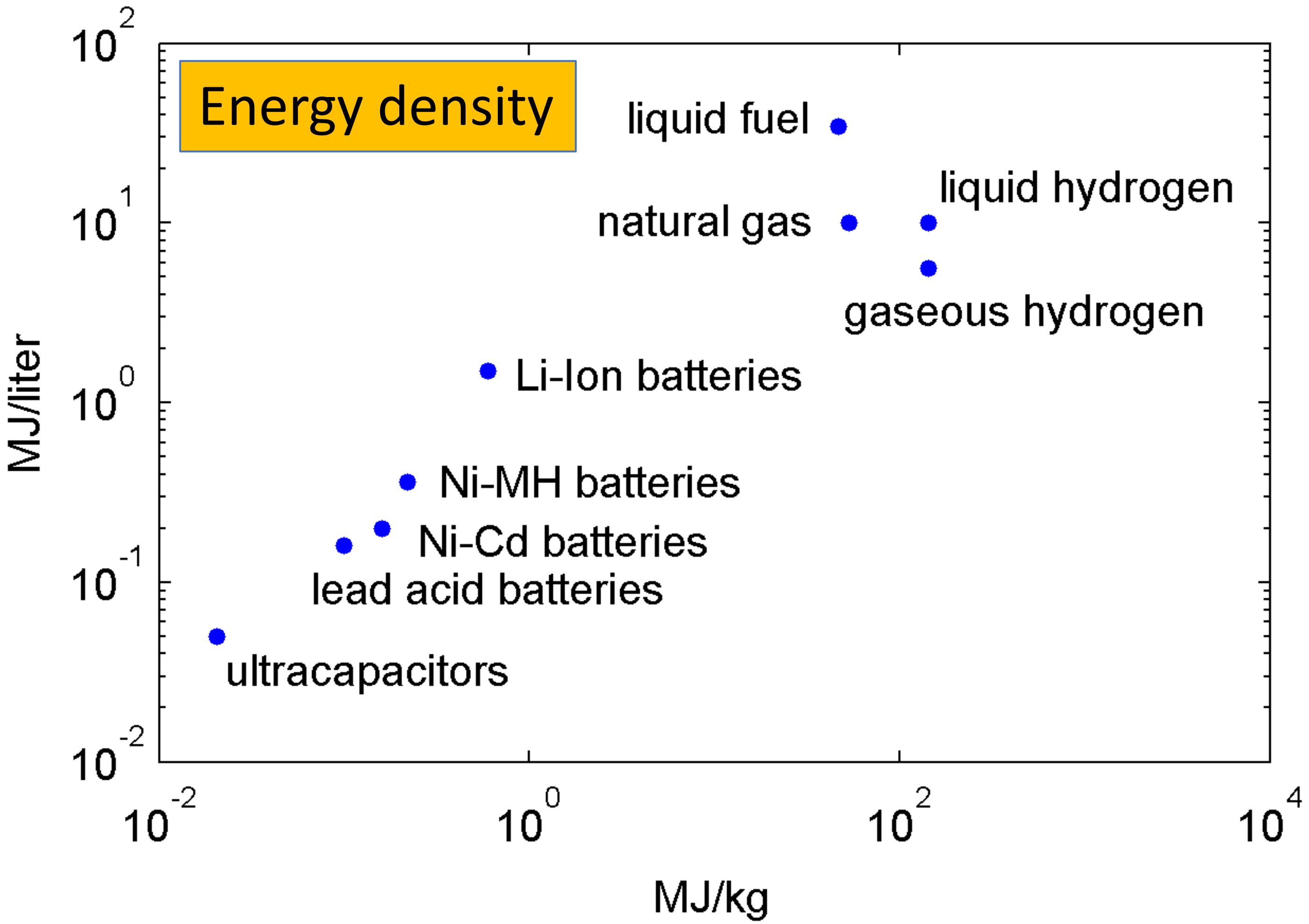


BRIC Oil Consumption

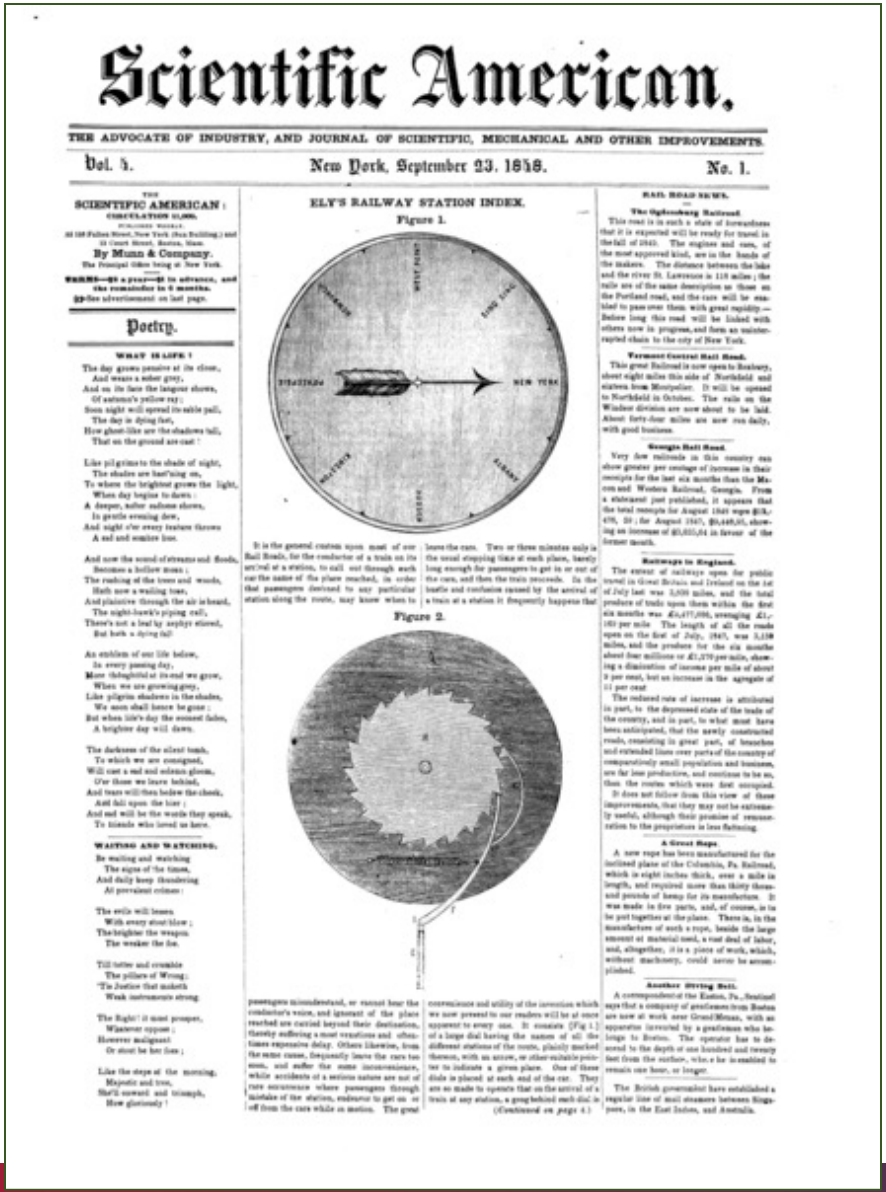
(source: BP p.l.c.)

Future Fuels?

How can we achieve petroleum independence ?



Predictions



Scientific American.

THE ADVOCATE OF INDUSTRY, AND JOURNAL OF SCIENTIFIC, MECHANICAL AND OTHER IMPROVEMENTS.

Vol. 4. New York, September 23, 1848. No. 1.

THE SCIENTIFIC AMERICAN:

By Munn & Company.

Poetry.

ELY'S RAILWAY STATION INDEX.

Figure 1.

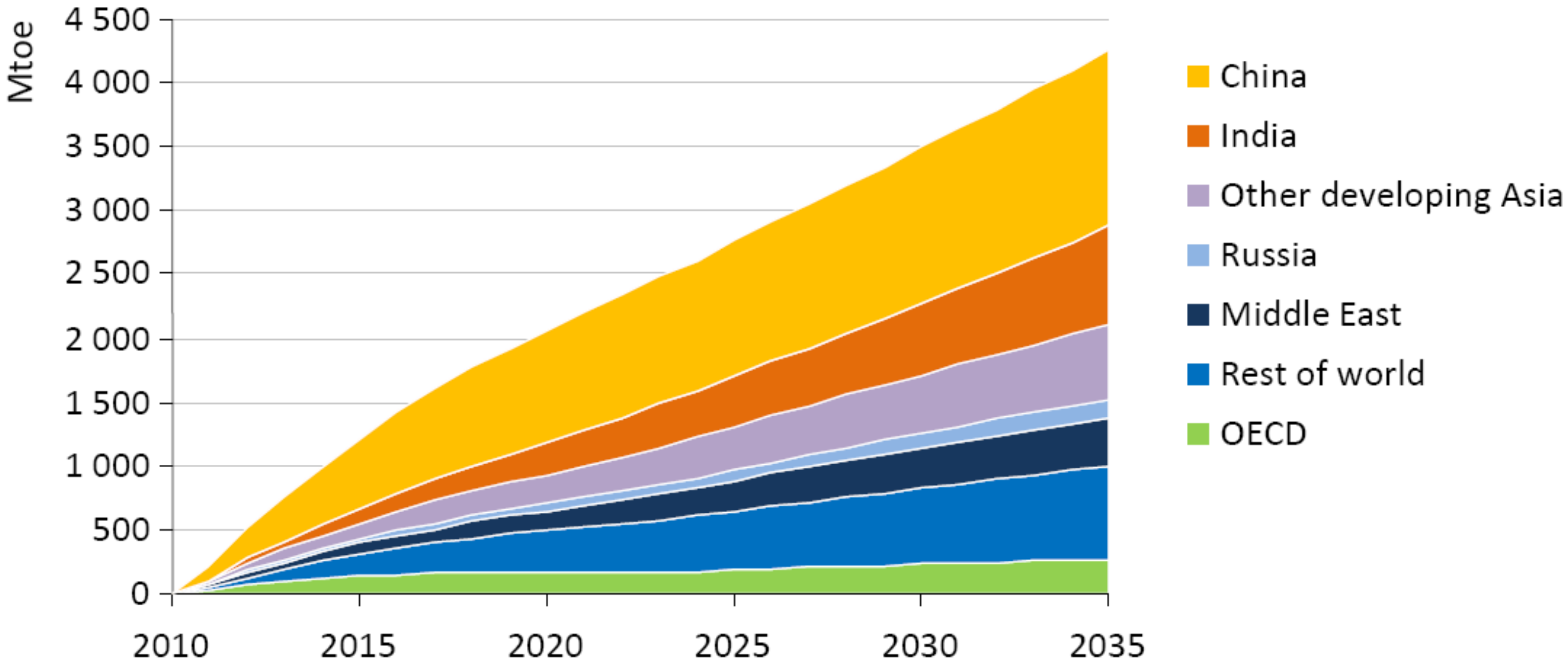
Figure 2.

*"That the **<u>automobile has practically reached the limit of its development</u>** is suggested by the fact that during the past year no improvements of a radical nature have been introduced."*

Scientific American, Jan. 2, **<u>1909</u>**

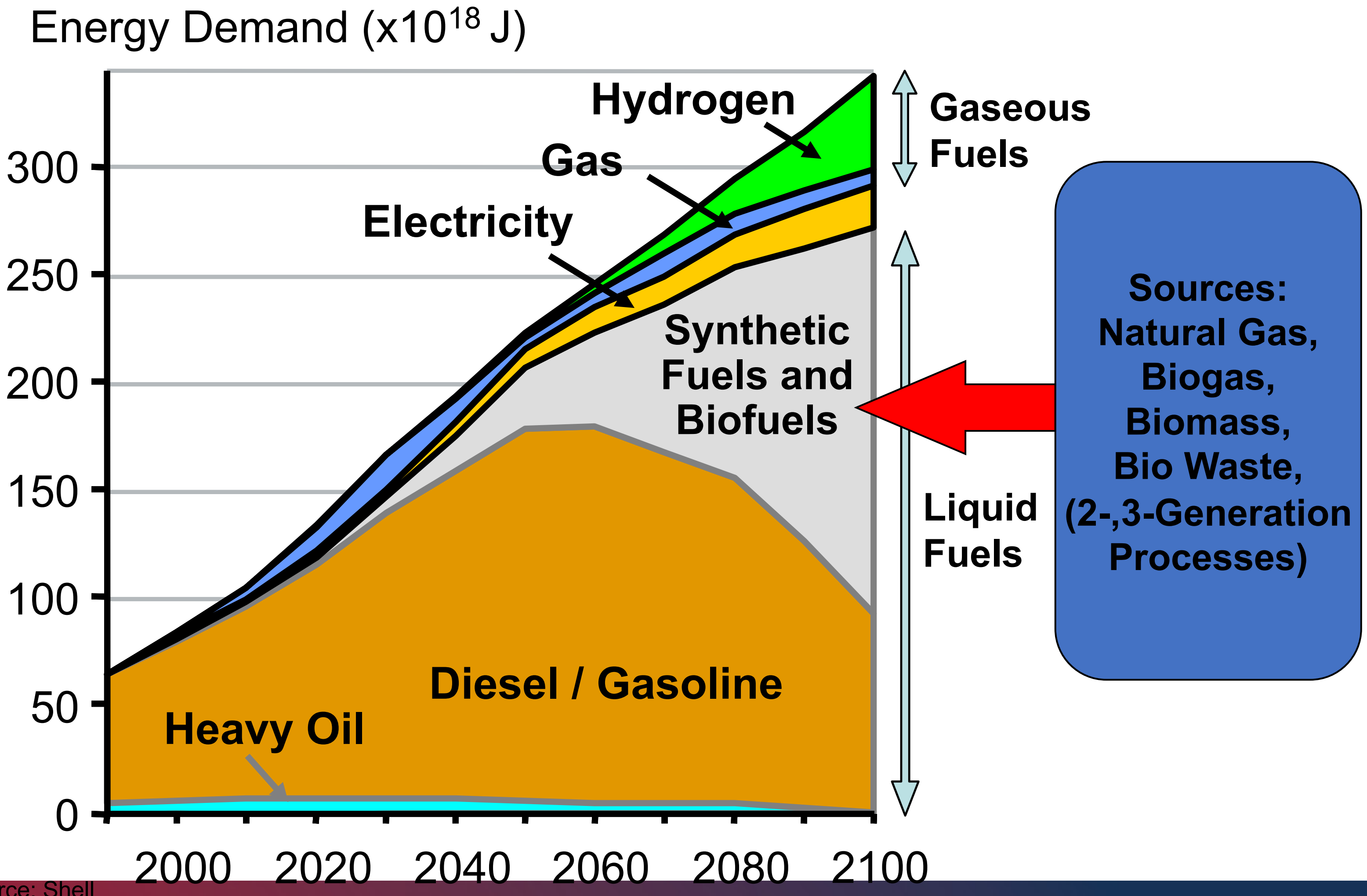
Energy Future?

Growth in primary energy demand



Global energy demand increases by one-third from 2010 to 2035, with China & India accounting for 50% of the growth

Availability of Fuels in the Future



Sources:
Natural Gas,
Biogas,
Biomass,
Bio Waste,
(2-,3-Generation Processes)

Source: Shell

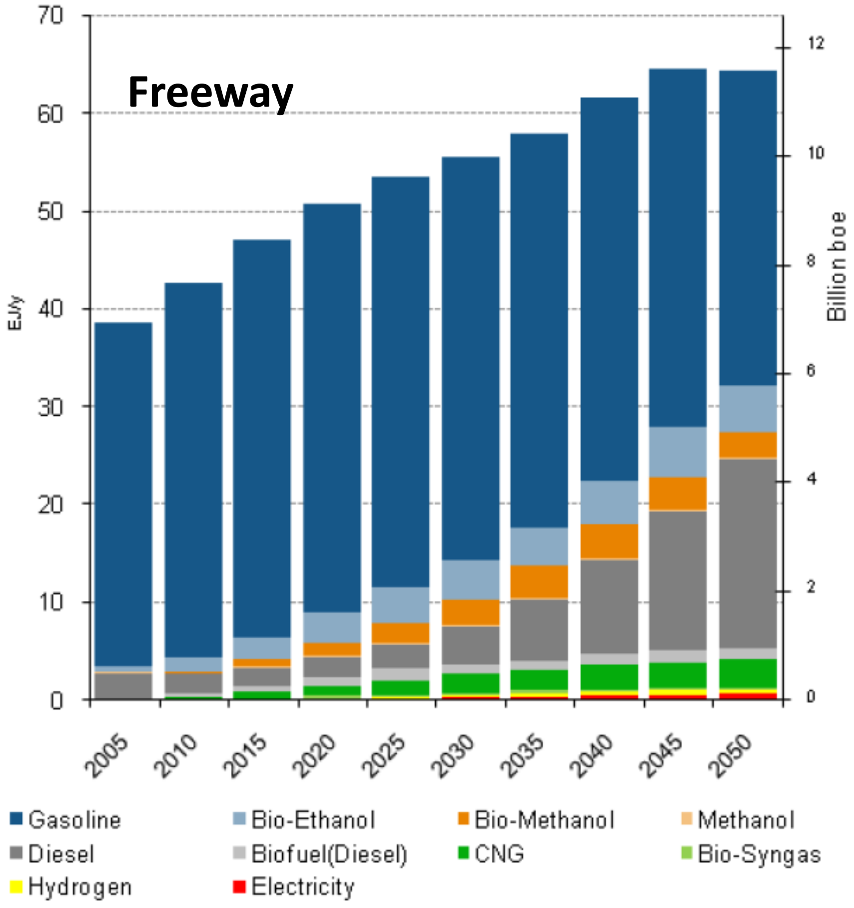
Transport scenarios

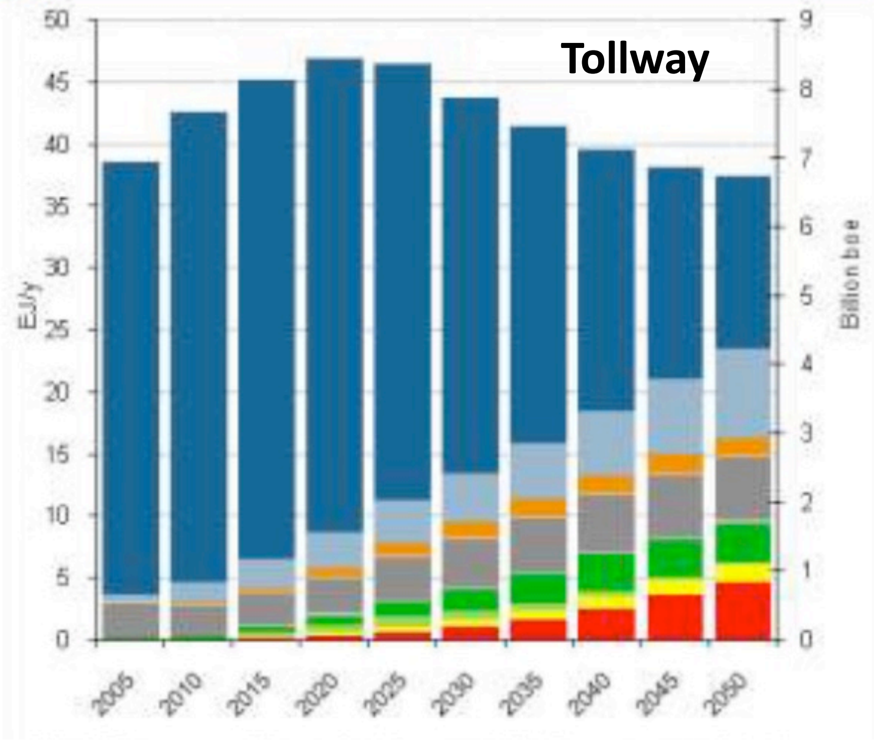
Two different scenarios have been studied by the World Energy Council:

- **Freeway**: market forces prevail to create a climate for open global competition, privatization, deregulation and liberalization.
- **Tollway:** Regulated world where governments decide to put common interests at the farefront and intervene in markets.

Fuels for LDV/cars: demand between 2010 and 2050

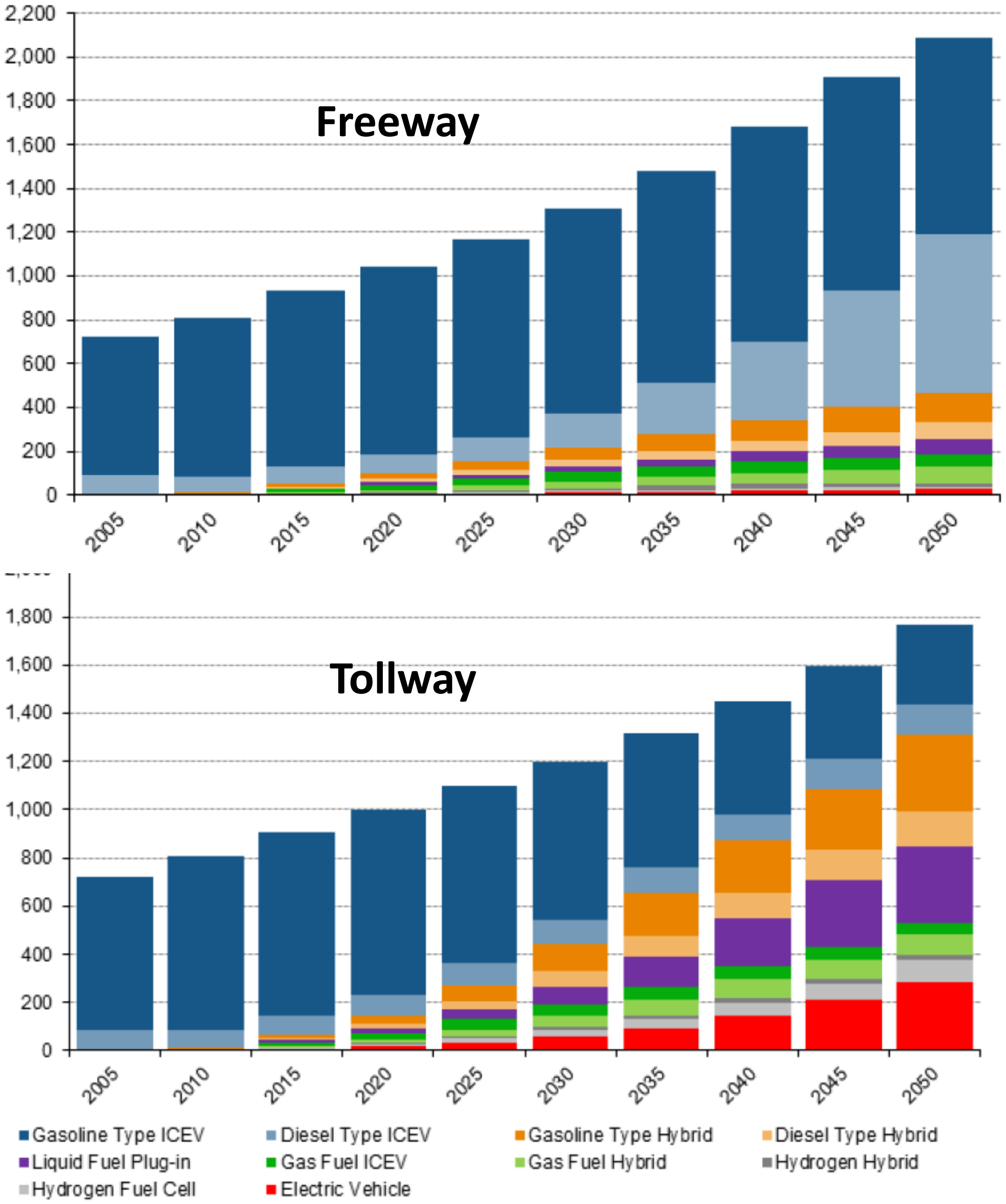
In Freeway, global fuel consumption for cars is expected to **increase by about 51%** between 2010 and 2050. The world's car fleet will still depend heavily on gasoline and diesel, which will still constitute about 80% of the fuel mix in 2050.





For Tollway, the global fuel consumption for cars is expected to **drop by about 13%** between 2010 and 2050. Car fleet will still depend on fossil fuels as gasoline and diesel will still constitute about 52% of the fuel mix in 2050

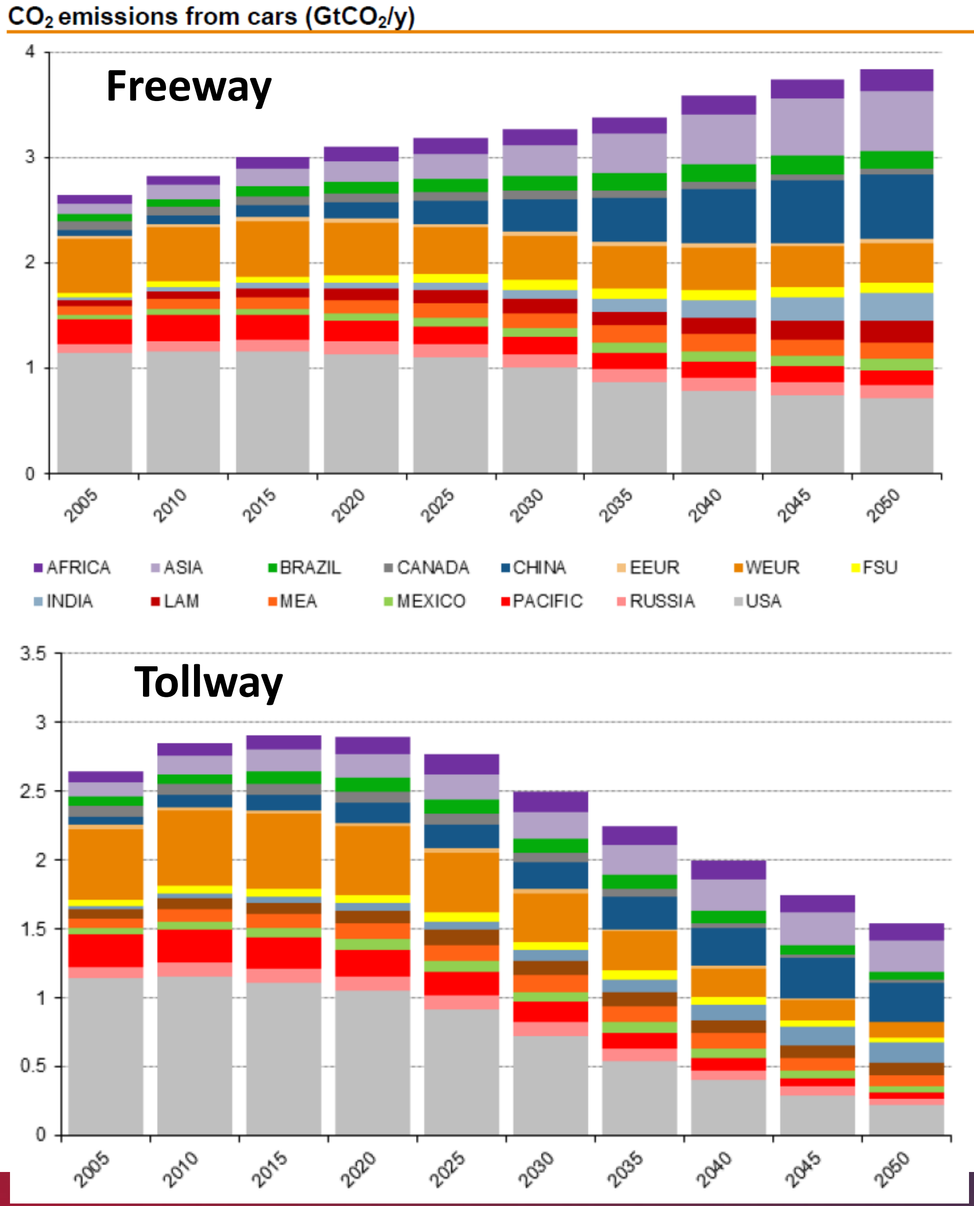
Technology mix for cars



In **Freeway** the global car fleet will still be dominated by a **78%** share for the conventional liquid fuel ICEV (43% gasoline and 35% diesel). Gasoline and diesel **hybrids** are expected to share about 11% (7% gasoline and 4% diesel). The gas ICEV and gas hybrids are expected to be about 7%. The remaining minority 6% is captured by electric, fuel cells, and plug-in vehicles.

In **Tollway**, the global car fleet in 2050 has shares of **26%** for liquid fuel conventional ICEV (19% gasoline and 7% diesel); **26% for liquid hybrids** (18% gasoline and 8% diesel); 18% plug-ins; 16% electric; 8% gas vehicles

Impact on CO2

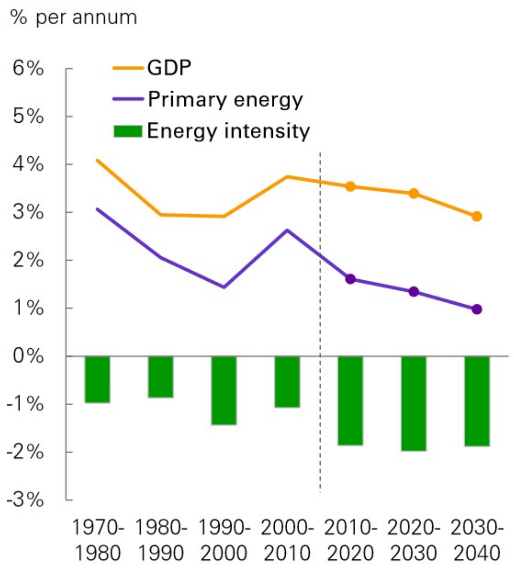


Although global fuel consumption for cars is expected to increase by about 51% between 2010 and 2050, CO2 emissions from cars are expected to **increase by 36%**. The relative drop in CO2 emissions is primarily due to engine fuel-burning improvements and changes in fuel mix, namely consuming more biofuels and CNGs.

Due to the 13% drop in global fuel consumption for cars between 2010 and 2050, CO2 emissions from cars are also expected to **drop by 46%**. As with Freeway, the relative drop in CO2 emissions is primarily due to engine fuel-burning improvements and the changes in fuel mix, namely consuming more biofuels and CNGs.

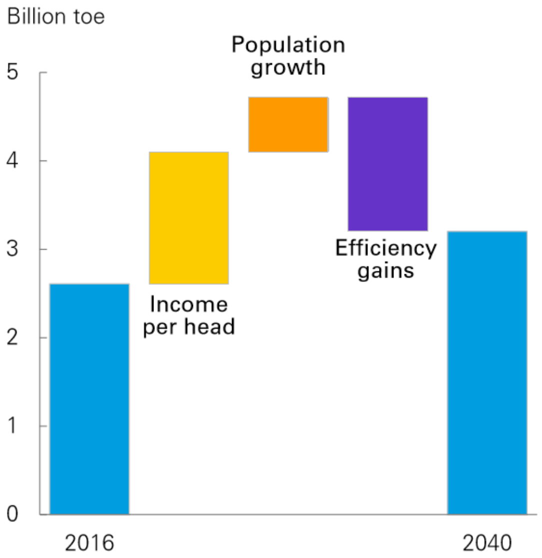
2018 BP Energy Outlook
The Evolving Transition scenario

Growth in GDP and primary energy



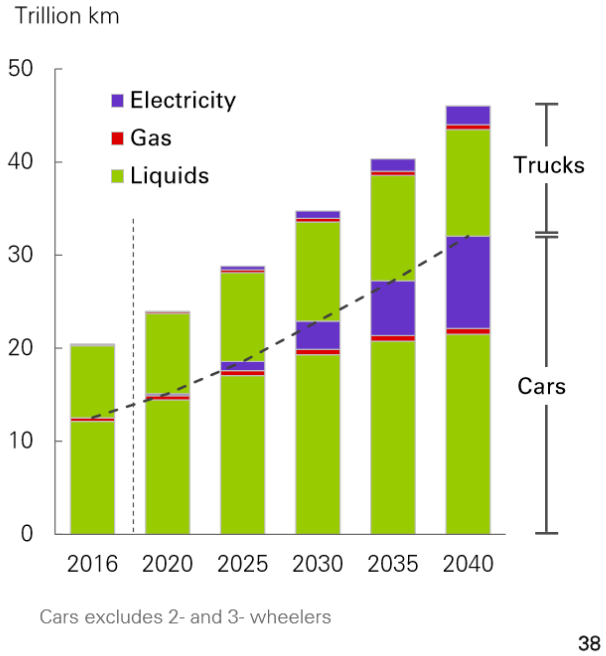
World GDP more than doubles by 2040.

Contributions to transport energy consumption growth



Slow growth in **transport energy consumption.**

Vehicle kilometres (Vkm) by fuel type

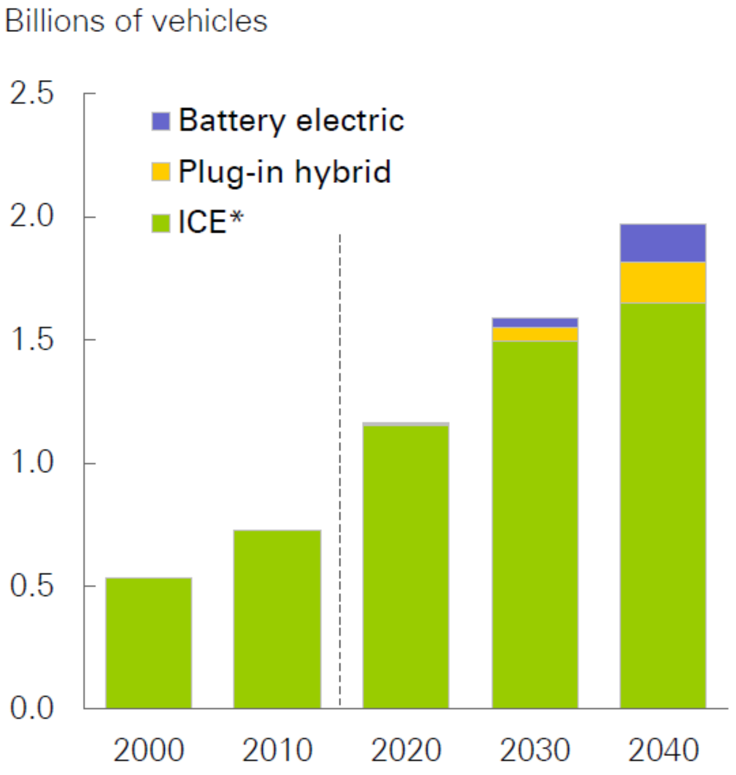


The share of vehicle kilometres **powered by electricity** increases.

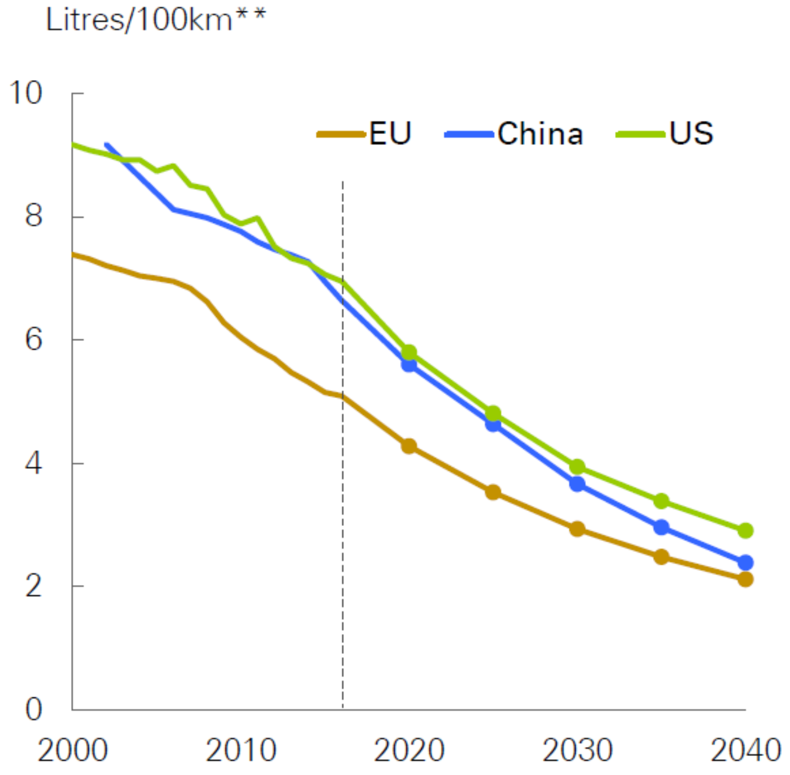
Passenger car parc growing

Evolving Transition scenario

Passenger car parc by type



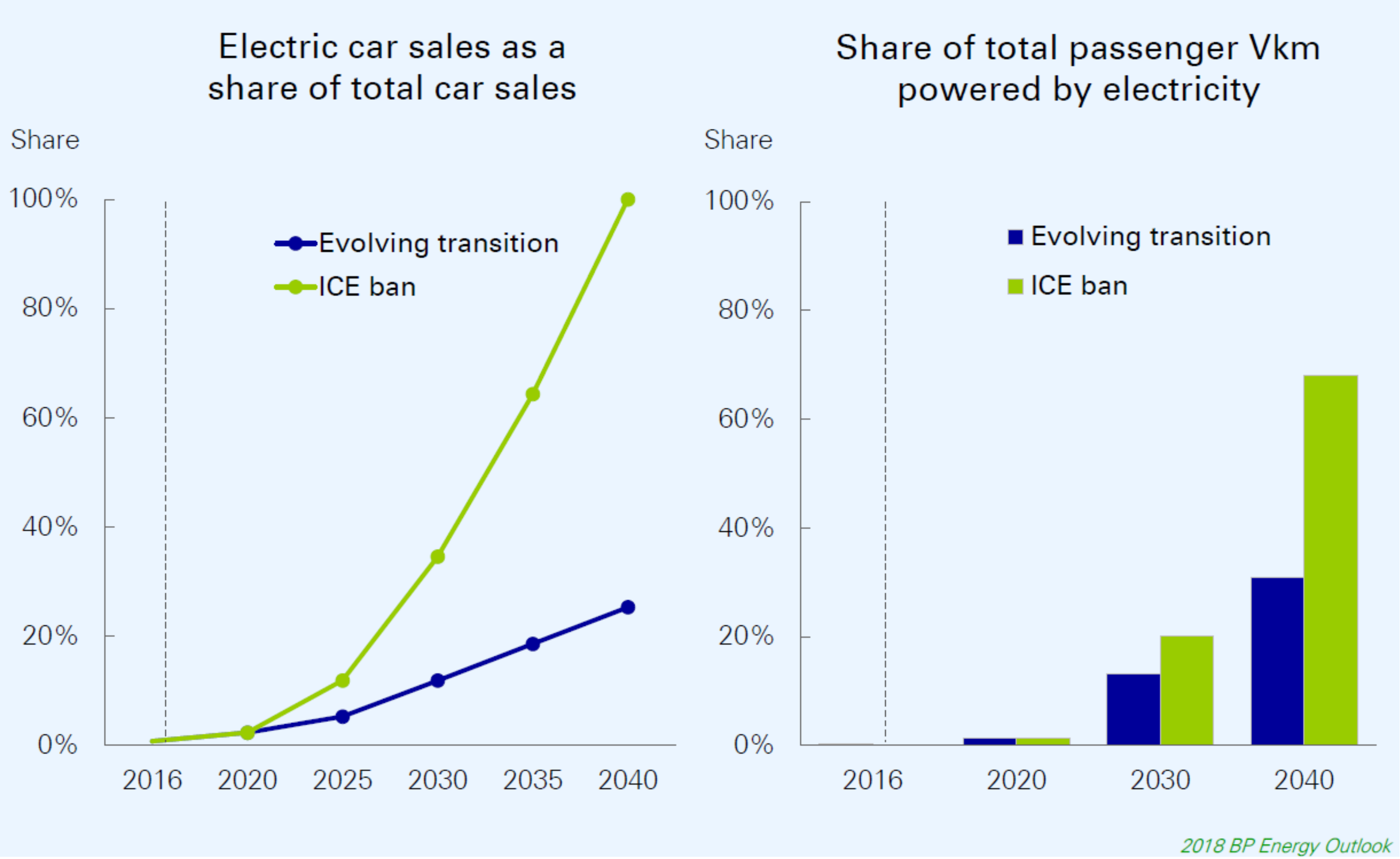
Fuel economy of new cars



*ICE vehicles includes hybrid vehicles which do not plug into the power grid
**Based on the NEDC (New European Drive Cycle), gasoline fuel

2018 BP Energy Outlook

Alternative scenario: impact of faster growth in electric



2018 BP Energy Outlook

Even in the most advanced scenario (ICE ban) the share of electric car sales would reach 50% between 2030 and 2035. In the more conservative scenario (ET) the share would be 3 times lower.

Closure

Transport systems have significant impacts on the environment, accounting for **20% - 25% of world energy consumption and carbon dioxide emissions**.

Greenhouse gas emissions from transport are **increasing at a faster rate than any other energy using sector**.

Road transport is also a major contributor to **local air pollution and smog**.

Vehicles powered by **liquid fuels** will continue to play a relevant role, according to many scenarios.

Closure

Fossil fuels represent an enormous economic cost, with political, economic, and environmental risks associated to oil exploration and production

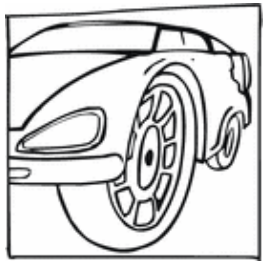
Fossil fuels are responsible for a significant **fraction of anthropogenic CO_2**: about 1/3 of total CO_2 emissions from energy consumption.

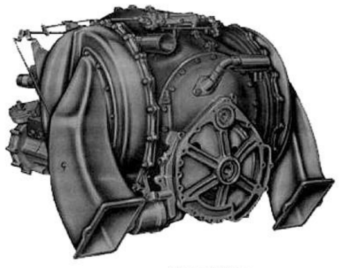
Oil dependence is becoming a **pressing issue** for many countries.

Limits of conventional vehicles and possible alternatives

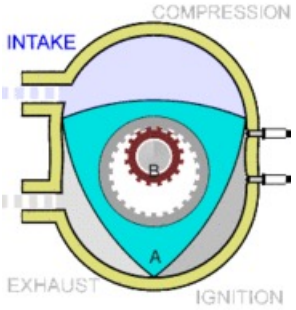
Thermal Engines

A large majority of today vehicles is moved by a thermal engine

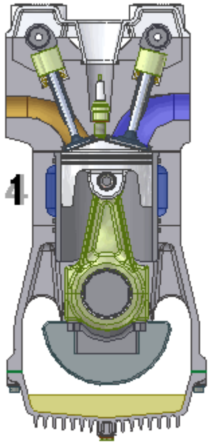


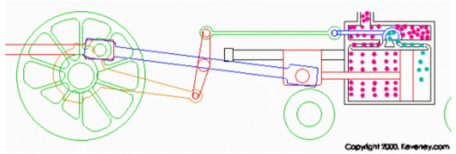


Gas Turbine

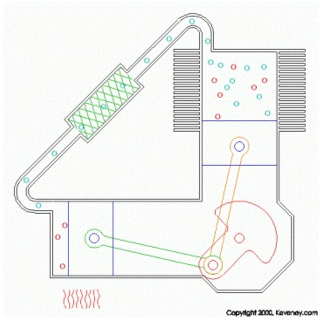


Wankel





Steam Engine



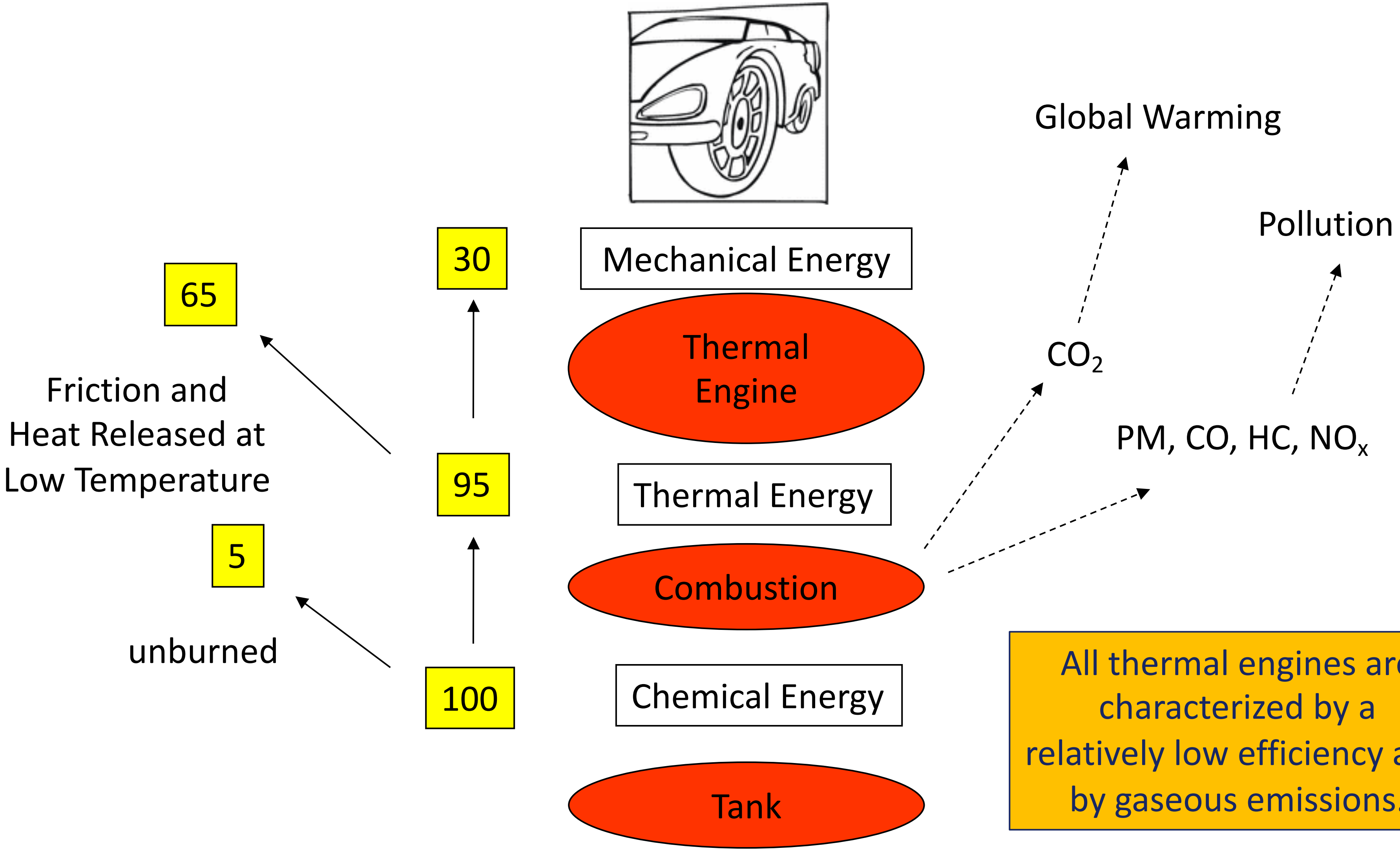
Stirling

Dynamic | Volumetric

Rotative | Reciprocating

Internal Combustion | External Combustion

Thermal Engine



Mechanical Energy

Thermal Engine

Thermal Energy

Combustion

Chemical Energy

Tank

100

95

30

5

unburned

65

Friction and Heat Released at Low Temperature

CO_2

Global Warming

PM, CO, HC, NO_x

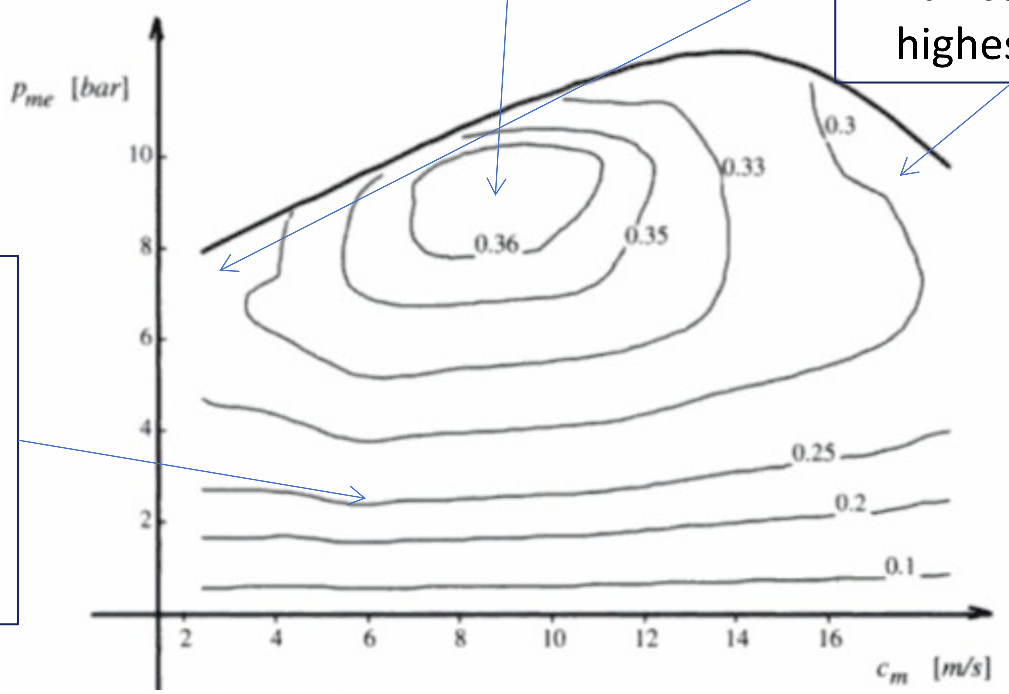
Pollution

All thermal engines are characterized by a relatively low efficiency and by gaseous emissions.

Engine efficiency map

The **engine efficiency η_g** (related to specific fuel consumption ***SFC***) depends in complex way by **engine operating variables**.

$$SFC = \frac{\dot{m}_f}{P} = \frac{1}{\eta_g LHV}$$



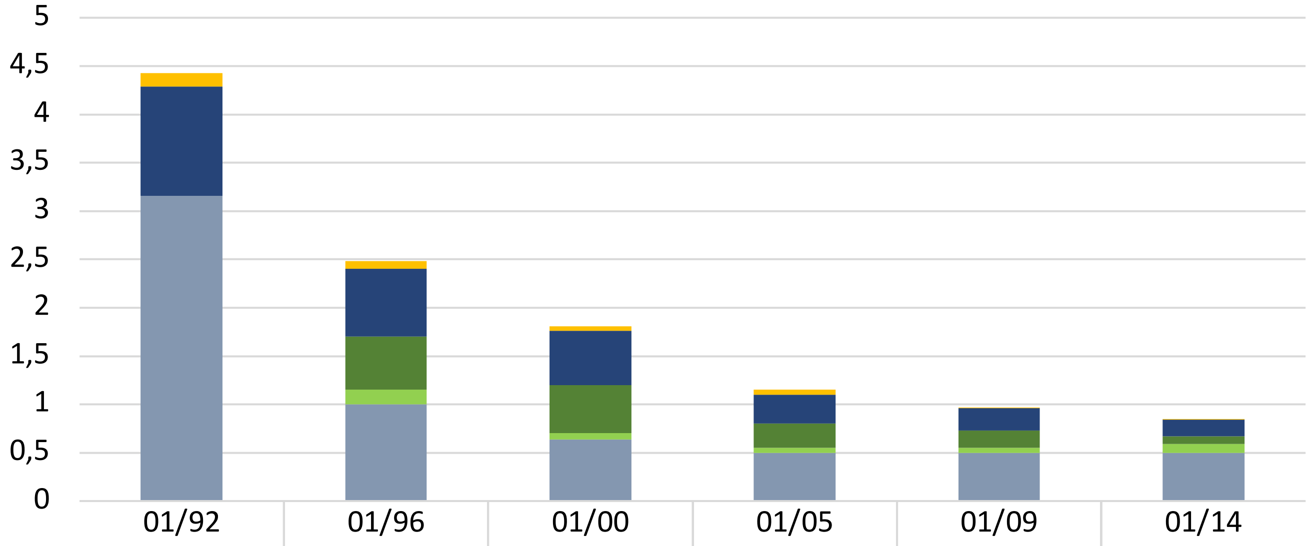
Highest efficiency can be achieved only in a limited part of the operating plane

Efficiency tends to decrease at lowest and highest rpm

At part load conditions, for instance during urban driving, engine operates at low efficiency, in particular in Spark Ignition engines (due to throttle losses).

[Source: Introduction to Modeling and Control of Internal Combustion Engine Systems]

NOx/HC/CO/PM

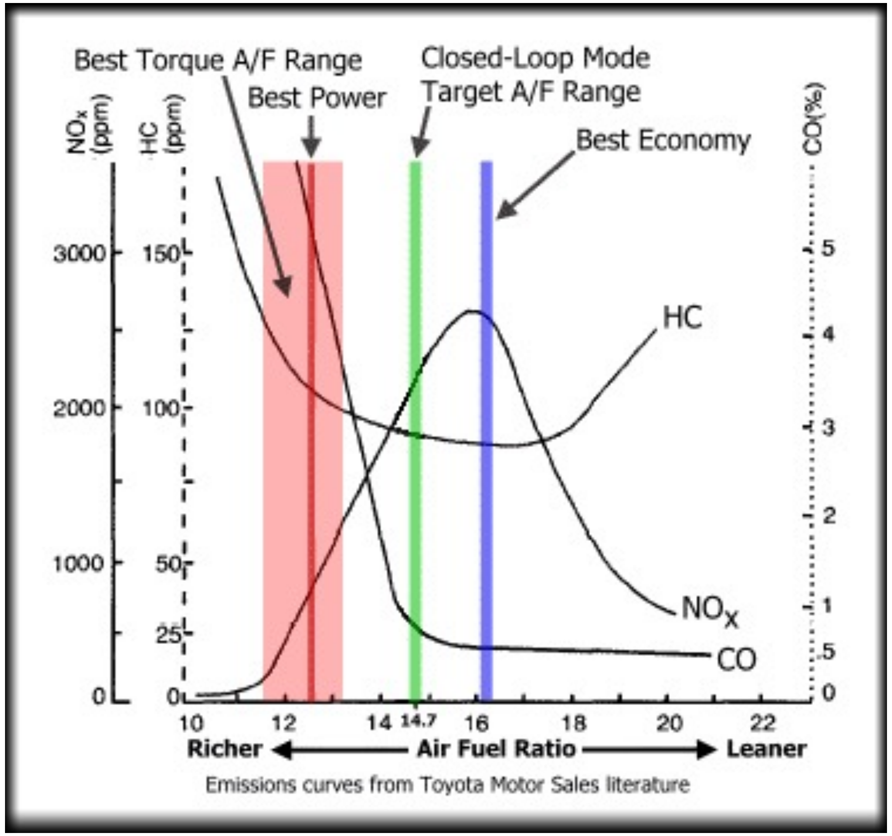


	01/92 EURO I	01/96 EURO II	01/00 EURO III	01/05 EURO IV	01/09 EURO V	01/14 EURO VI
🟨 PM [g/Km]	0,14	0,08	0,05	0,05	0,005	0,005
🟦 HC+Nox [g/Km]	1,13	0,7	0,56	0,3	0,23	0,17
🟩 Nox [g/Km]		0,55	0,5	0,25	0,18	0,08
🟩 HC [g/Km]		0,15	0,06	0,05	0,05	0,09
⬜ CO [g/KM]	3,16	1	0,64	0,5	0,5	0,5

The trend in the reduction of admitted pollutant emissions has continued until last years, both in US (EPA) and in Europe.

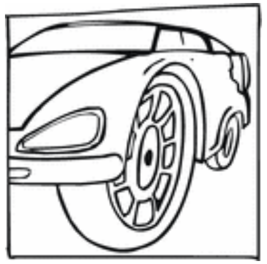
NOx/HC/CO/PM

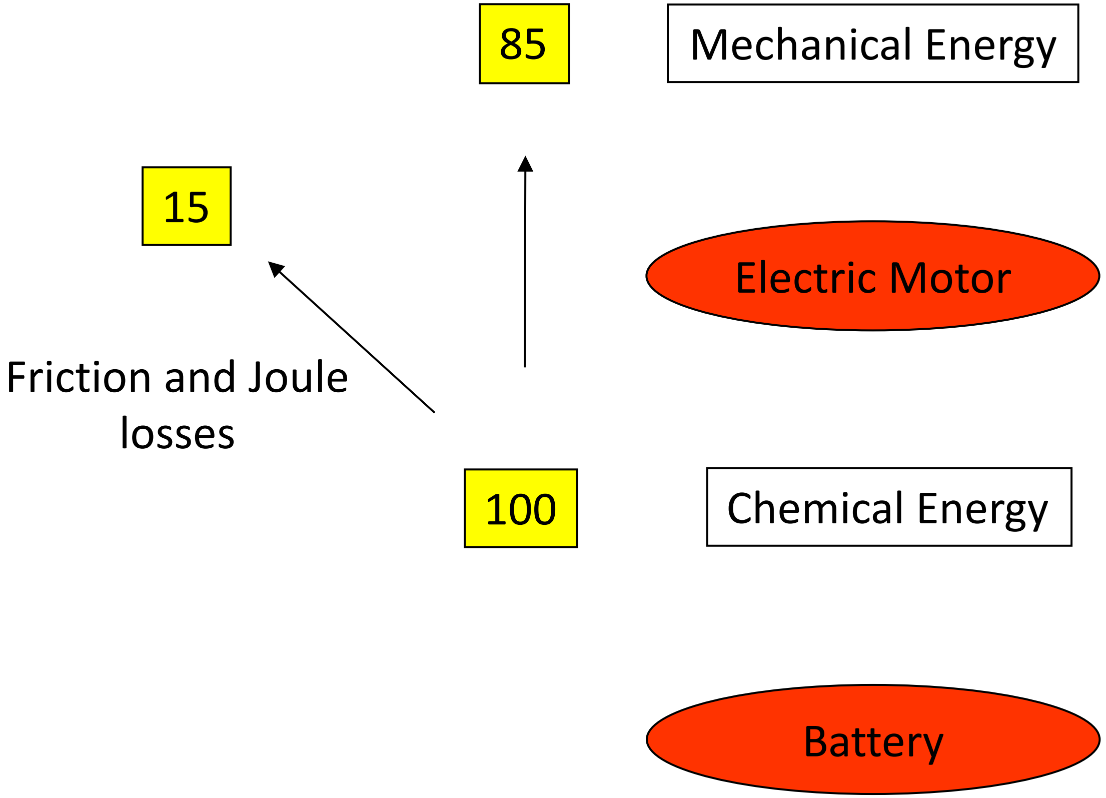
In the spark ignited engines, the need to simultaneously **oxidating** CO and HC and **reducing** NOx requires the recourse to **three-way catalysist**. The engine must work at **stoichiometric** conditions, with a **closed-loop** controlled ignition system.



Emissions curves from Toyota Motor Sales literature

Electric Motor





85

Mechanical Energy

15

Electric Motor

Friction and Joule losses

100

Chemical Energy

Battery

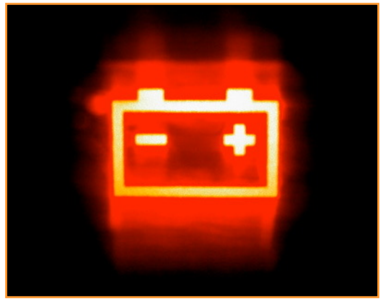
Electric motors have higher efficiency, with no gaseous and limited acoustic emissions.

Electric mobility: the problems

- There are several **issues to be solved** for the diffusion of electric mobility:
  - Lower **range** respect to conventional cars, due to lower **energy and power density** of **batteries** with respect to **liquid fuels**.
  - High **cost** of batteries, even if with a **decreasing trend**.
  - The limited diffusion of **charging infrastructure**, and the relatively **long time needed for recharging**.
  - Impact of vehicle charging on **electric infrastructure**.
  - High impact on electric consumption of power needed for **heating** and **refrigerating** the car.
- Moreover, the **CO_2** impact strongly depends on **electric generation mix**.

Energy density: batteries vs liquid fuels

	kWh/ton	%	kWh/m3	%
Liquid Fuel	11.667	*100,00*	15.556	*100,00*
Lead-Acid	30	*0,26*	50	*0,32*
Li-Ion	130	*1,11*	350	*2,25*

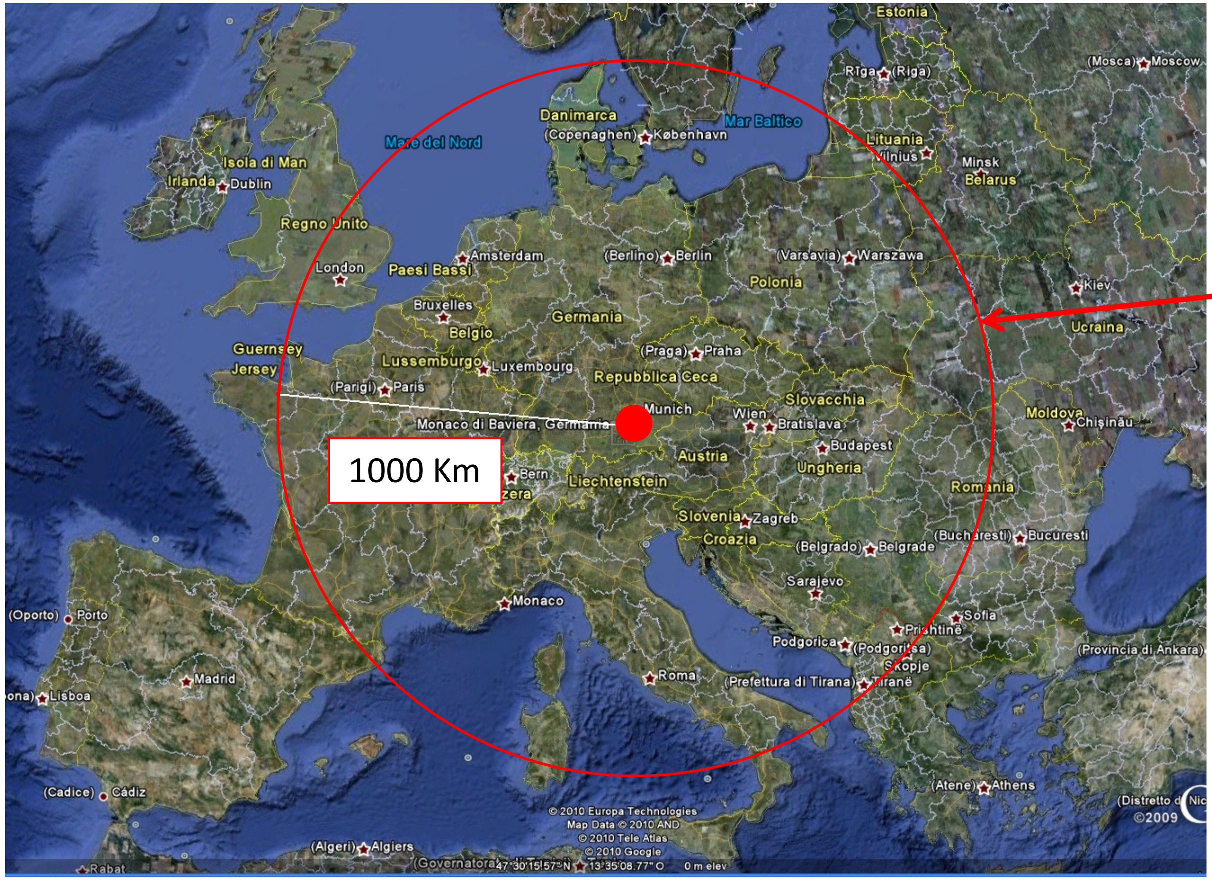


Considering that only 25% of fuel chemical energy can be converted in mechanical energy:

	kWh/ton	%	kWh/m3	%
Liquid Fuel	2.917	*100,00*	3.889	*100,00*
Lead-Acid	30	*1,03*	50	*1,29*
Li-Ion	130	*4,46*	350	*9,00*

Further increases in energy density for Lithium-Ion batteries can be achieved by adopting innovative nano-composite materials (Magasinki et al., 2010).

About the range



Almost 30 different countries and about 100.000 fuel pumps in a radius of 1000 Km (with an average density of about 0,04 pumps per Km^2)

Is a 1000 Km range <u>really</u> necessary for a car?

Charging issues

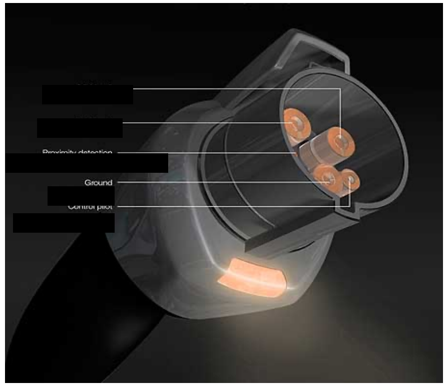
- Vehicles can be charged at **multiple power levels**:

- SAE J1772 **Standard Charge Connector**
  - Level 1 – 120VAC, 1 Phase up to 16A
  - Level 2 – 240VAC, 1 Phase up to 80A

- DC Charging (Fast Charging)– **No current standard** for charging or connector
  - Will requires different connector (A standard exists in Japan)
  - Current Japanese DC charge rate: Max 500VDC, 200A

Level 1 and Level 2 vehicle charging rates are similar to other loads within the home.

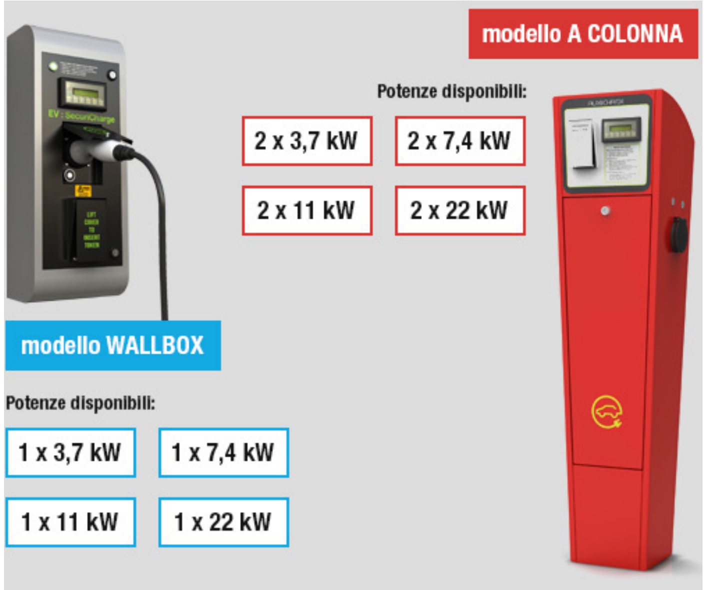
Type	Power Level	Charge Time	Reference	Grid Impact
AC Level 1 120 VAC, 12-16A	1.4 kW	PHEV–5-8hrs BEV–14-30hrs	Hairdryer	
AC Level 2 240 VAC, 15-80A	3 – 19 kW (6.6 kW typical)	PHEV–1-3hrs BEV–2-8hrs	WH, Oven, Electric Furnace	
DC Charging 3-phase, 480V	10 kW – 200kW +	PHEV–N/A BEV–15-30min	Small Comm. Bldg	



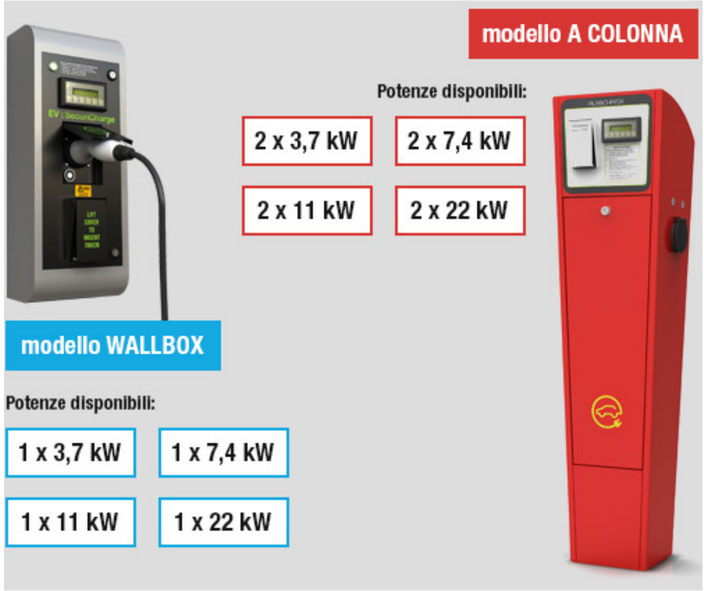
A standard charge connector SAE J1772 was adopted on January 14, 2010 by the SAE Motor Vehicle Council. The companies participating in or supporting the revised 2009 standard include GM, Chrysler, Ford, Toyota, Honda, Nissan and Tesla.

Test

- Compare the energy per unit time (i.e. the recharging power) entering into
  - i) the reservoir of a conventional car and
  - ii) the battery of a EV car.



Recharge: ICE vs EV



Power (energy per unit time) in input during «recharge»:

3.7-22 kW

Fast DC recharge:

about 100 kW

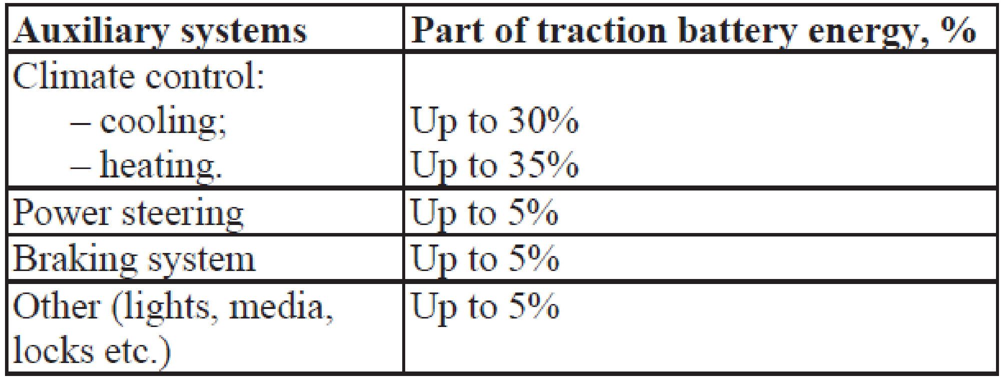
MJ/kg	42
Minutes	2
Density kg/dm3	0,75
Liters	33,33
l/s	0,28
kg/s	0,21
MW	**8,75**

Energy consumption of auxiliary systems in an EV

Energy consumption of auxiliary systems may severely impact battery consumption and range in a EV.

Cooling and **heating** may impact on traction battery energy up to 30-35%.

Heating energy is **free** in conventional cars, as well as in **hybrid cars**.



Auxiliary systems	**Part of traction battery energy, %**
Climate control: – cooling; – heating.	 Up to 30% Up to 35%
Power steering	Up to 5%
Braking system	Up to 5%
Other (lights, media, locks etc.)	Up to 5%

EV Auxiliary Systems Impacts, http://avt.inl.gov/sites/default/files/pdf/fsev/auxiliary.pdf

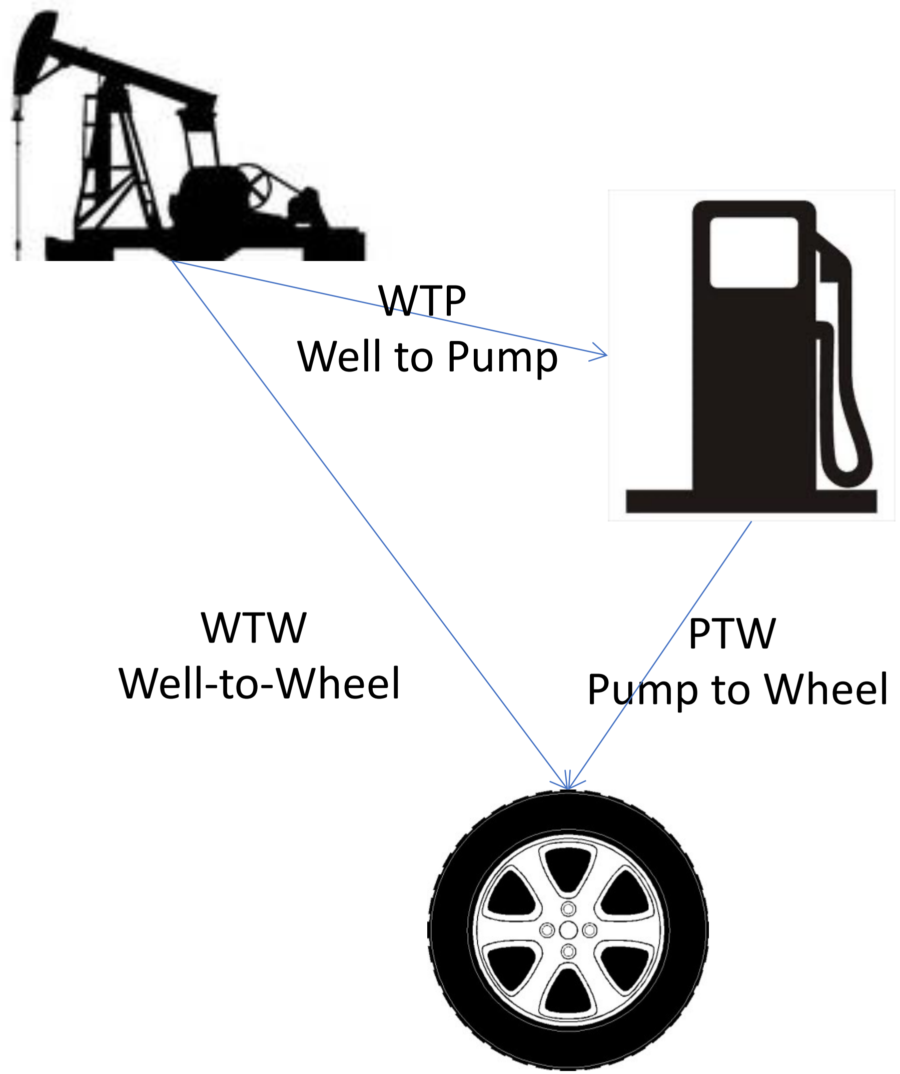
Evtimov, I., Ivanov, R., & Sapundjiev, M. (2017). Energy consumption of auxiliary systems of electric cars. Paper presented at the *MATEC Web of Conferences, , 133* doi:10.1051/matecconf/201713306002

Energy conversion schemes

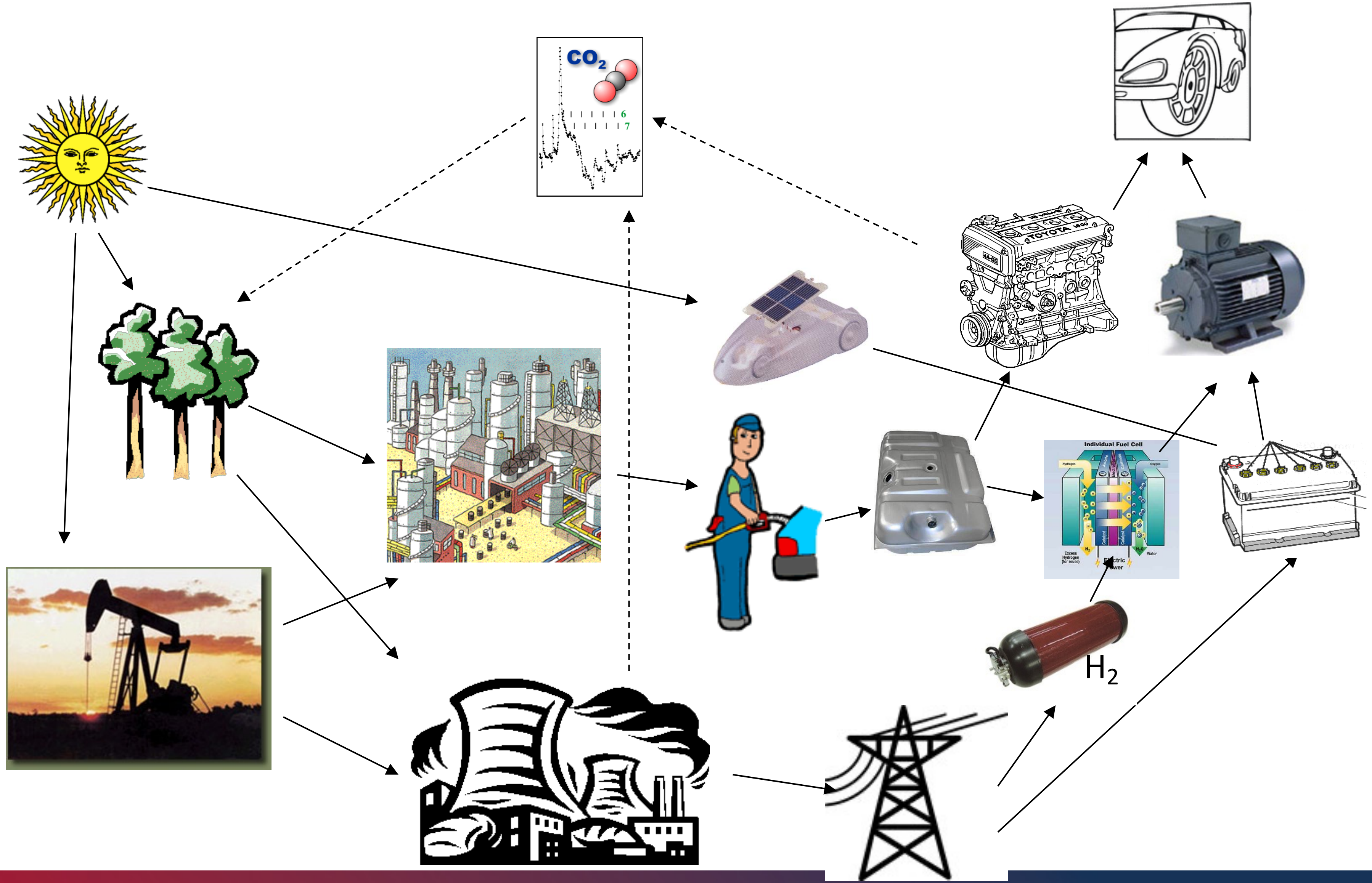
When analyzing energy conversion processes and Green House Gas Emissions for a car fueled with fossil fuels, different schemes can be considered:

- PTW Pump to Wheel
- WTP Well to Pump
- WTW Well-to-Wheel

The concept can be generalized to include bio-fuels, electricity, hydrogen, solar and other energy sources.

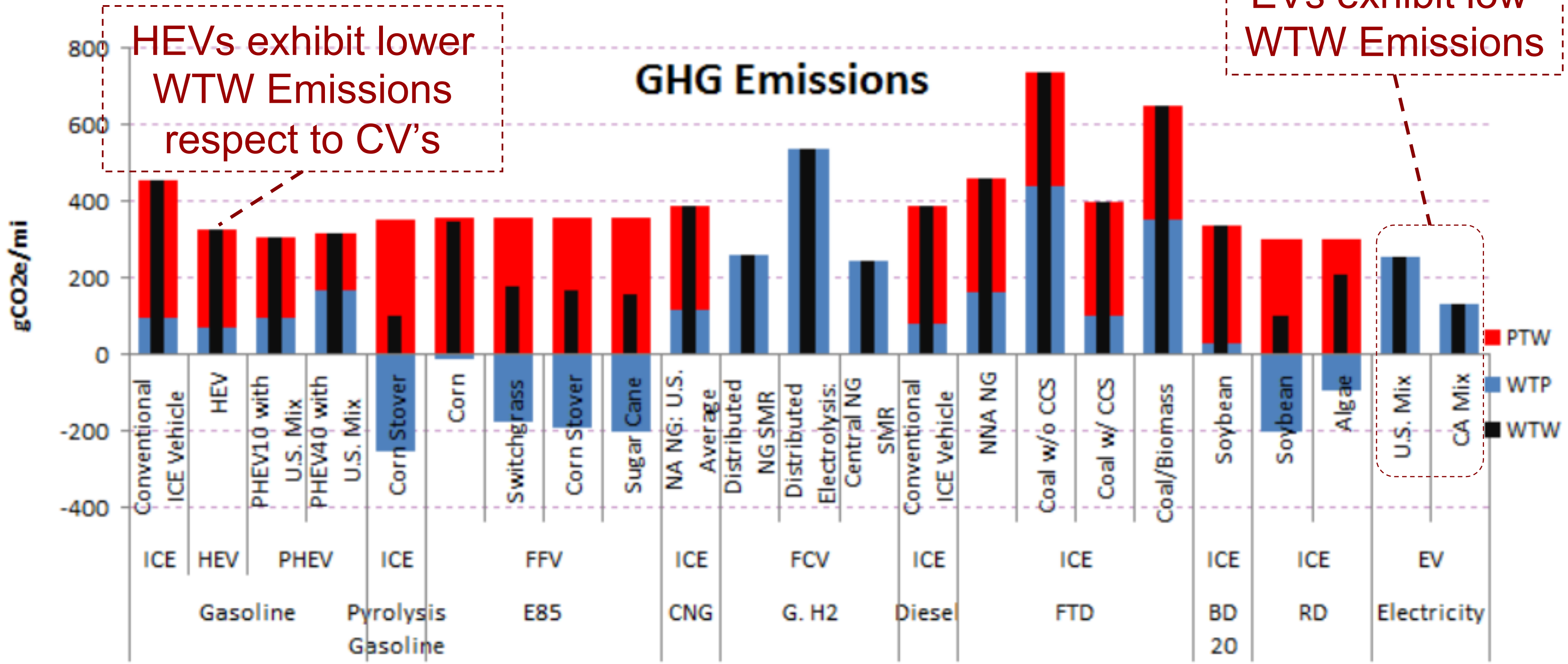


Well to wheel



Green House Gas Emissions

[Gallons of Gasoline Equivalent CO2/ mile]



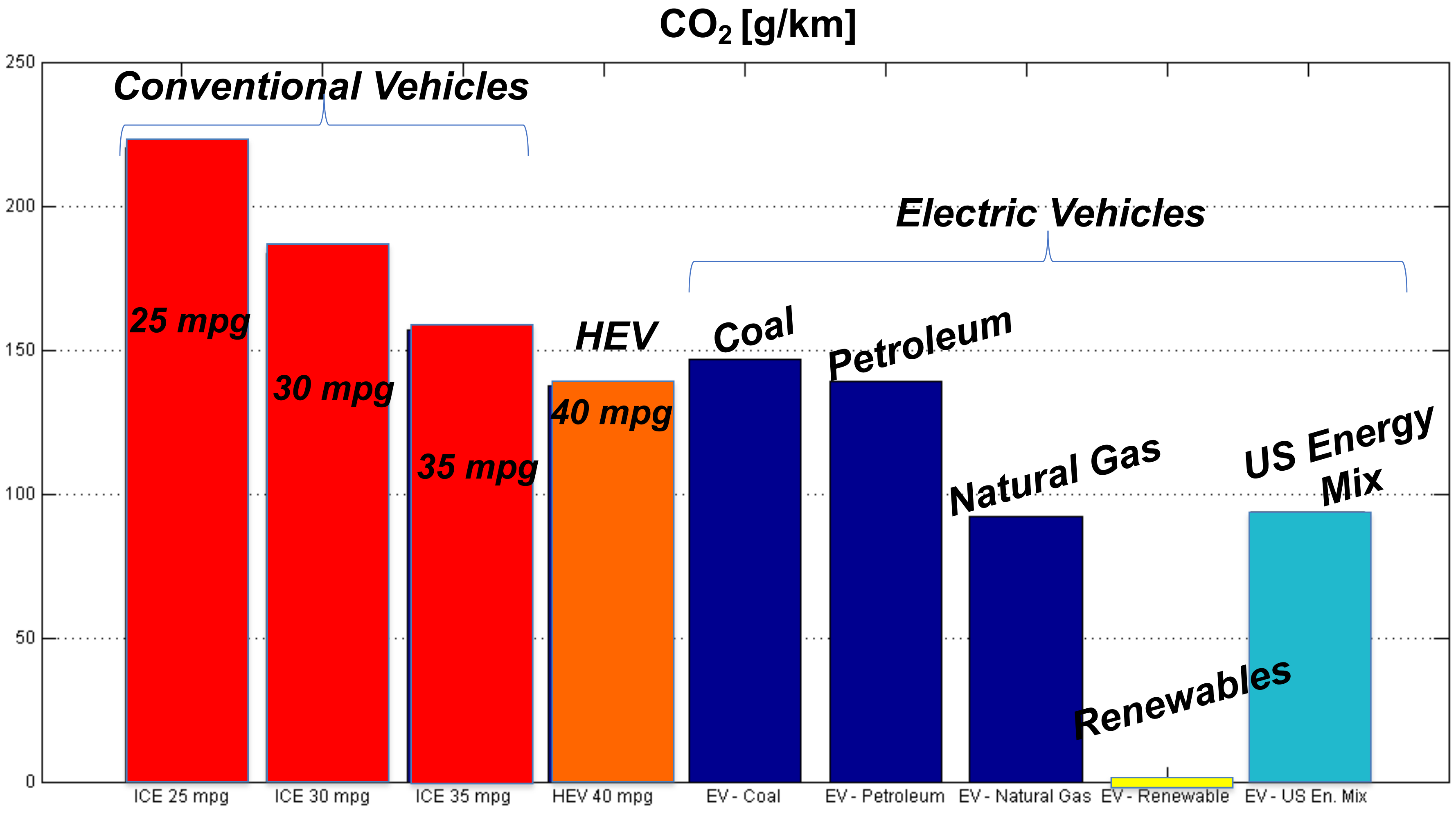
HEVs exhibit lower WTW Emissions respect to CV's

EVs exhibit low WTW Emissions

Source: GREET 2012
http://greet.es.anl.gov/

Green House Gas Emissions
PTW Pump to Wheel
WTP Well to Pump
WTW Well-to-Wheel

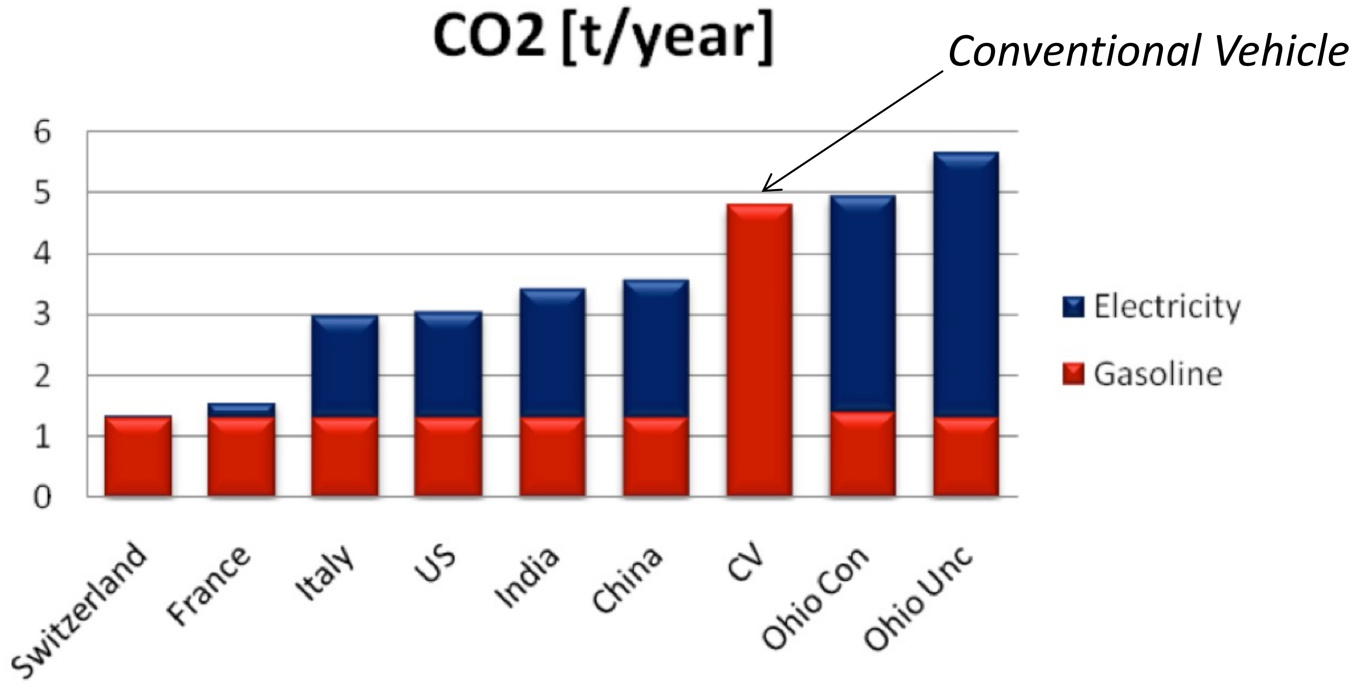
Energy Source vs. CO2 Emissions



The impact on CO_2 emissions for Electric Vehicles depends strongly on electric power generation!!

CO2 Emissions of PHEV

CO2 Emissions of Plug-In HEV in different countries

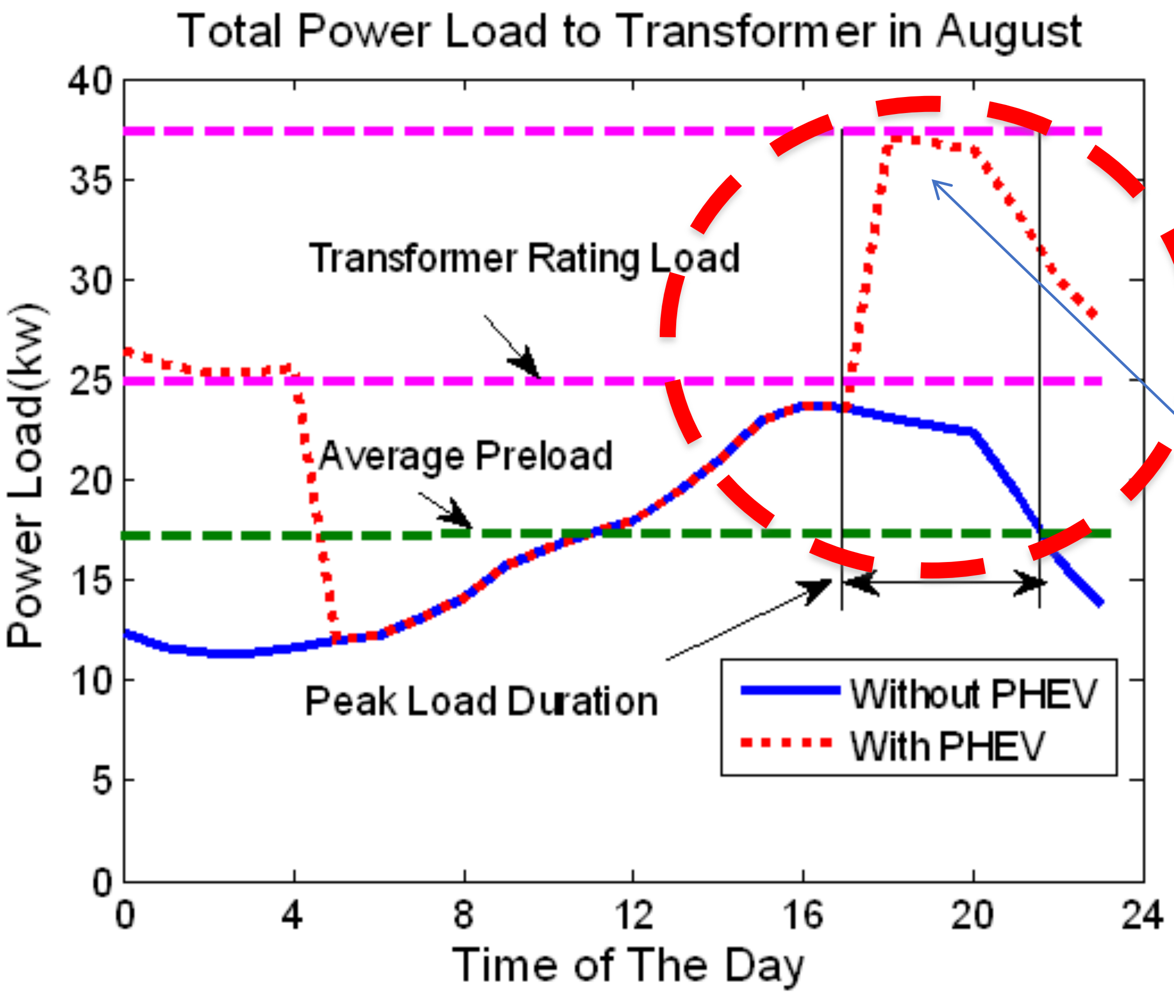


CO2 [t/year]

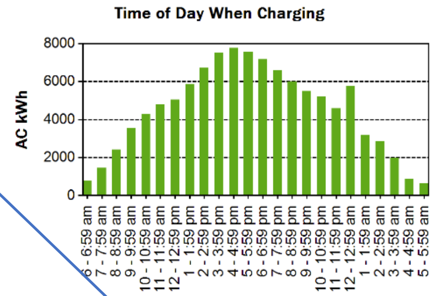
Conventional Vehicle

The benefits of PHEV with respect to conventional vehicles strongly depend on the **generation mix** of the given country. In some cases (i.e. Ohio, where coal is mostly used), the emissions of **CO_2** with PHEV's can be greater than conventional vehicles (and also **NO_x** and **SO_2** would increase)

Plugging-in…



Example:
25-kVA transformer (4-6 houses)
It is assumed that two PEVs are charged at night with Level II charging (6.6 kW)



PEVs without any intelligent control cannot guarantee that the transformer will not be overloaded for an excessive period of time

Gong Q., Midlam-Mohler S., Marano V, Rizzoni G.,"Study of PEV Charging on Residential Distribution Transformer Life", IEEE Transactions on Smart Grid 3: 1. 404-412 March, 2012

Impact of PEV Charging on Power Distribution Networks

SAMPLE STUDY

Results for 2-4-6 PEVs connected to the same 25kVA distribution transformer, considering level II charging (6.6 kW) for different charging strategies

	2 PEV	4 PEV	6 PEV
7 PM	14.41	0.0432	0.00012
12 AM	OK	0.5148	0.001
Randomized (30 min)	OK	13	2.27
Randomized (15 min)	OK	20.7	1.36
Average Charging	OK	OK	OK

Transformer time life (years)

Gong Q., Midlam-Mohler S., Marano V, Rizzoni G.,"Study of PEV Charging on Residential Distribution Transformer Life", IEEE Transactions on Smart Grid 3: 1. 404-412 March, 2012

- With poorly managed charging, **even a small number of vehicles on a single residential transformer lead to dramatic loss of insulation life**.
- **More sophisticated charging strategies can allow the same transformer to service a large number of vehicles without serious detriment to life.**

Sustainable Mobility: Possible Solutions

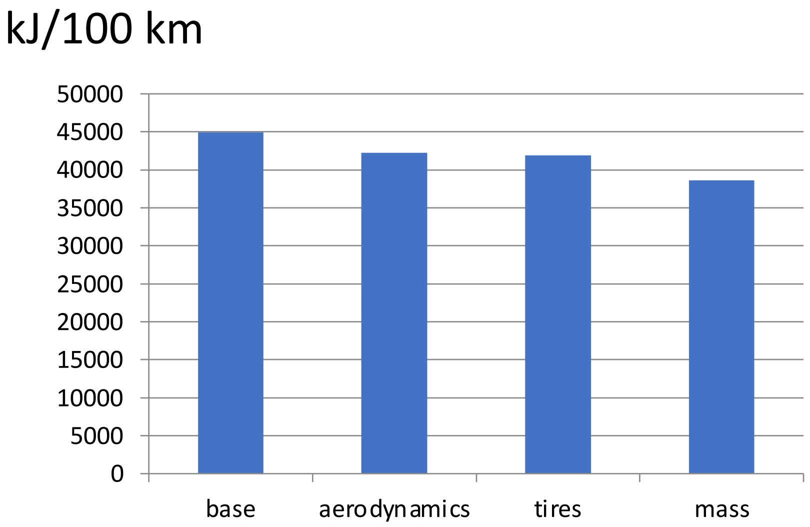
- Fuel economy improvements in conventional vehicles.
- Alternative fuels: Bio-fuel, Hydrogen, e-fuels vehicles.
- Fuel-cell vehicles.
- Hybrid Electric Vehicles.
- Plug-in Electric/Hybrid Vehicles.
- Integration with V2V/V2I communication technologies.
- Integration with solar/renewable energy.
- Fleet reconversion.

The trends

Some recent trends about the research on transportation can be sinthetized by the lines in the **Horizon 2020** Work Programme «**Smart, Green and Integrated Transport**»:

- **Mobility for Growth**
- **Green Vehicles**
- **Small Business and Fast Track Innovation for Transport**

Effects of vehicle variables on energy consumption



-----20% reduction-----

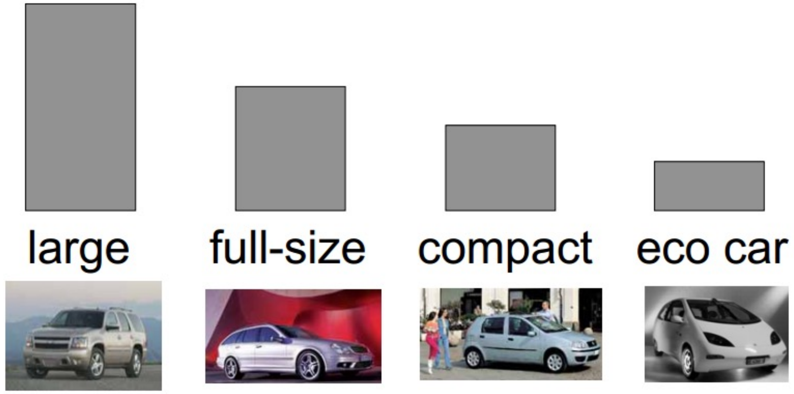
$$E \cong 19000 \cdot A_f \cdot c_w + 840 \cdot m \cdot c_r + 11 \cdot m$$

$$[kJ/100km]$$

Base values for full-size car

$A_f\ c_w$ [m^2]	0,7
c_r	0,012
m [kg]	1500

Mass has highest effects on car energy consumption!!



Source: L.Guzzella, Optimization and Control of HEV

From passive to active safety

Passive safety:
reduce the effects of accidents.

↓

Active safety:
avoid the accident.

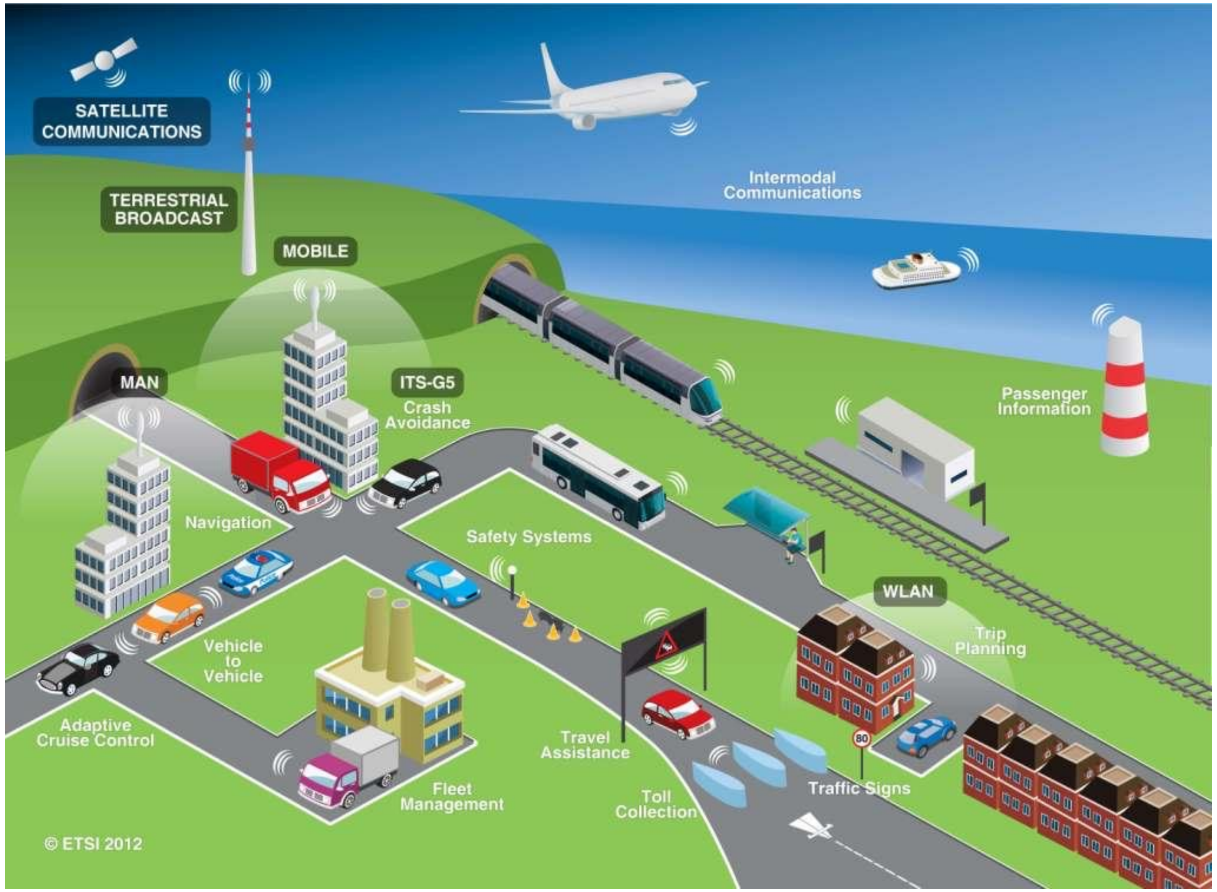
↓

Mass reduction
Energy consumption reduction

Intelligent Transport Systems

Intelligent Transport Systems (ITS) include **telematics** and all types of **communications in vehicles**, **between vehicles** (e.g. car-to-car), and **between vehicles and fixed locations** (e.g. car-to-infrastructure).

ITS are **not restricted to Road Transport** - they also include the use of information and communication technologies (ICT) for rail, water and air transport, including **navigation systems**.

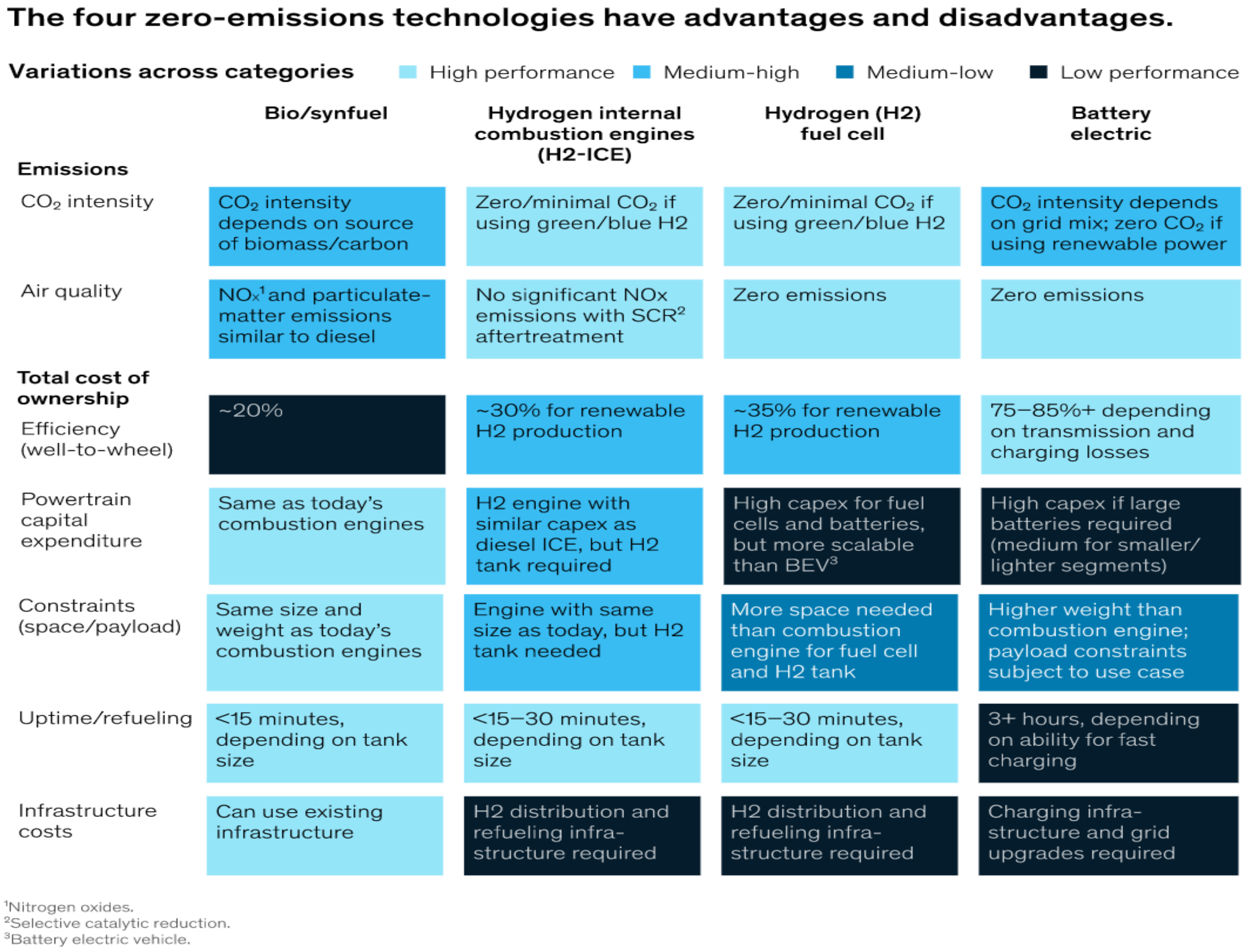


© ETSI 2012

Adoption of **ITS** can be helpful in **reducing the risk of accidents and in reducing vehicle mass**, so allowing further **energy savings**.

http://www.etsi.org/technologies-clusters/technologies/intelligent-transport

Technological solution for green vehicles



The four zero-emissions technologies have advantages and disadvantages.

Variations across categories ■ High performance ■ Medium-high ■ Medium-low ■ Low performance

	Bio/synfuel	Hydrogen internal combustion engines (H2-ICE)	Hydrogen (H2) fuel cell	Battery electric
Emissions				
CO$_2$ intensity	CO$_2$ intensity depends on source of biomass/carbon	Zero/minimal CO$_2$ if using green/blue H2	Zero/minimal CO$_2$ if using green/blue H2	CO$_2$ intensity depends on grid mix; zero CO$_2$ if using renewable power
Air quality	NO$_x$[1] and particulate-matter emissions similar to diesel	No significant NOx emissions with SCR[2] aftertreatment	Zero emissions	Zero emissions
Total cost of ownership				
Efficiency (well-to-wheel)	~20%	~30% for renewable H2 production	~35% for renewable H2 production	75–85%+ depending on transmission and charging losses
Powertrain capital expenditure	Same as today's combustion engines	H2 engine with similar capex as diesel ICE, but H2 tank required	High capex for fuel cells and batteries, but more scalable than BEV[3]	High capex if large batteries required (medium for smaller/lighter segments)
Constraints (space/payload)	Same size and weight as today's combustion engines	Engine with same size as today, but H2 tank needed	More space needed than combustion engine for fuel cell and H2 tank	Higher weight than combustion engine; payload constraints subject to use case
Uptime/refueling	<15 minutes, depending on tank size	<15–30 minutes, depending on tank size	<15–30 minutes, depending on tank size	3+ hours, depending on ability for fast charging
Infrastructure costs	Can use existing infrastructure	H2 distribution and refueling infra-structure required	H2 distribution and refueling infra-structure required	Charging infra-structure and grid upgrades required

[1] Nitrogen oxides.
[2] Selective catalytic reduction.
[3] Battery electric vehicle.

The **low-emission propulsion systems** currently considered include **BEVs** or **FCEVs**, ICEs powered with **synthetic fuels**, and ICEs powered with **hydrogen**, also in **hybrid powertrains**.

Closure

- Thermal engines convert only a limited fraction of the primary energy into mechanical energy, due to limitations of the second principle of thermodynamics.
- Moreover the combustion produces CO2 and pollutant emissions.
- Since ‘70s, the recourse to electronic control and to catalysts produced a substantial decrease in pollutant emissions.
- Electric motors have many benefits in terms of energy efficiency, noise and pollution, but car range and power recharge are now critical limiting factors for the diffusion of electric cars.
- The energy and environmental impact of vehicles must be considered in a wider perspective (LCA), not only during their operation on the road.
- Downsizing is an effective way to reduce fuel consumption in ICEs.
- Mass reduction and Intelligent Transport Systems may reduce energy demand in cars.

The 3 R’s of Sustainability

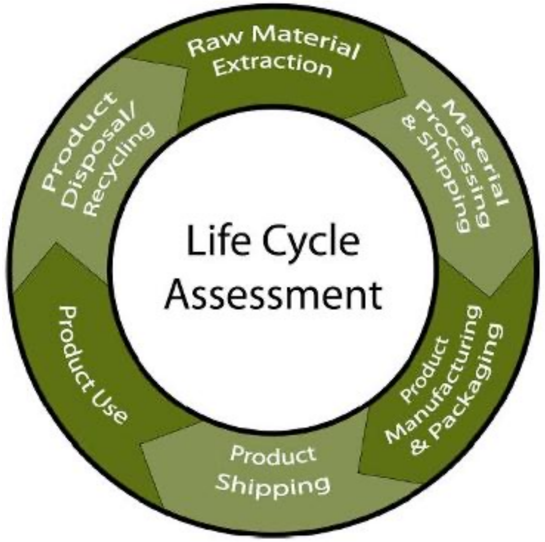
Is massive car scrapping a sustainable perspective?

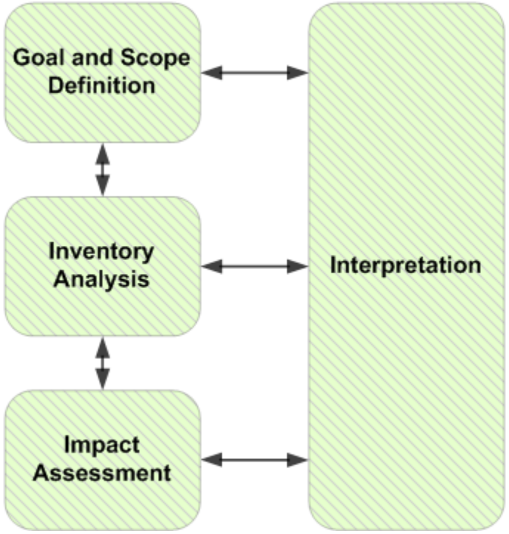
Life Cycle Assessment

Life-cycle assessment (**LCA**) is a technique to assess environmental impacts associated with **all the stages of a product's life** from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling.

The steps of LCA are:

- Compiling an **inventory** of relevant **energy and material inputs** and **environmental releases**;
- Evaluating the **potential impacts** associated with identified inputs and releases;
- Interpreting the results to help **make a more informed decision**.





The GREET Model

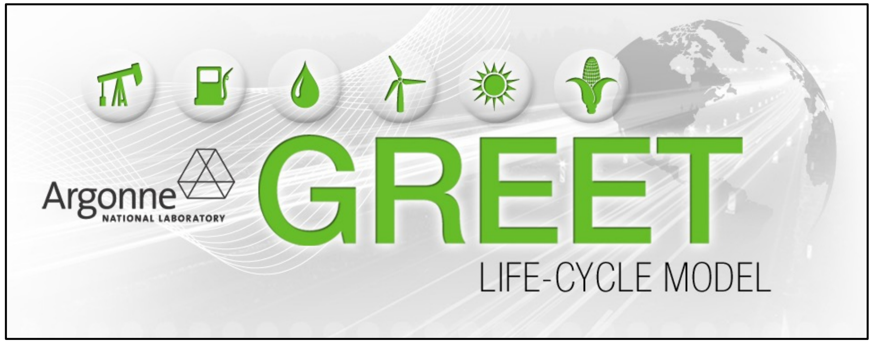
Argonne National Laboratory (U.S. Dept. of Energy) has a recognized leadership in performing LCA analyses.

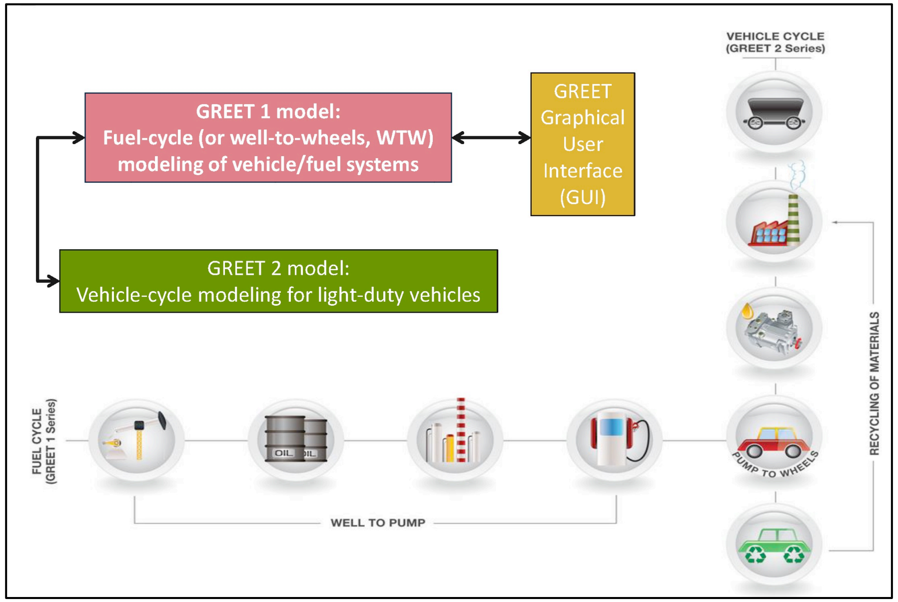
Its work led to the development of a tool, called **GREET** (**G**reenhouses gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation) model, specific for the **automotive sector**.

This software provides a comprehensive, **lifecycle based approach** to compare **energy use and emissions** of conventional (ICEVs) and advanced vehicle technologies (HEVs, PHEVs and EVs).

It takes into account **energy and environmental impact** of vehicles in three phases:

- **Fuel cycle** (Well-to-Pump)
- **Vehicle Cycle** (Assembling and junking)
- **Vehicle Operation** (Use of vehicle)




GREET 1 model:
Fuel-cycle (or well-to-wheels, WTW) modeling of vehicle/fuel systems

GREET Graphical User Interface (GUI)

GREET 2 model:
Vehicle-cycle modeling for light-duty vehicles

The scenarios

1st period

Gasoline ICE

Diesel ICE

Driving
a conventional car

2nd period

Gasoline ICE

Diesel ICE

Keep
the car

HEV

PHEV

BEV

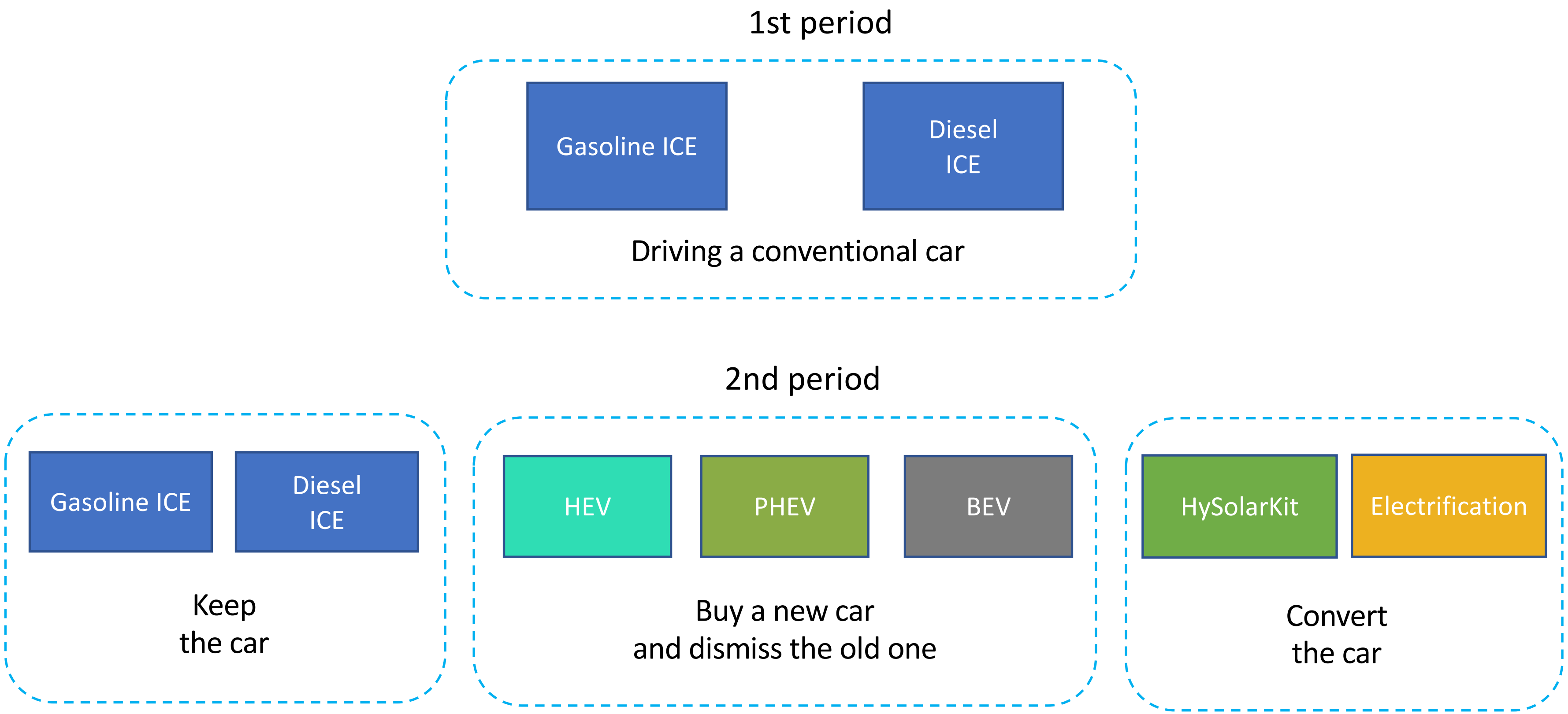
Buy a new car
and dismiss the old one

HySolarKit

Convert
the car

Francesco Antonio Tiano, Gianfranco Rizzo, Giovanni De Feo, Silvio Landolfi
Converting a Conventional Car into a Hybrid Solar Vehicle: a LCA Approach
ECOSM 2018, Changchun, Sept. 19-22, 2018.

The scenarios



1st period

Gasoline ICE

Diesel ICE

Driving a conventional car

2nd period

Gasoline ICE

Diesel ICE

Keep the car

HEV

PHEV

BEV

Buy a new car and dismiss the old one

HySolarKit

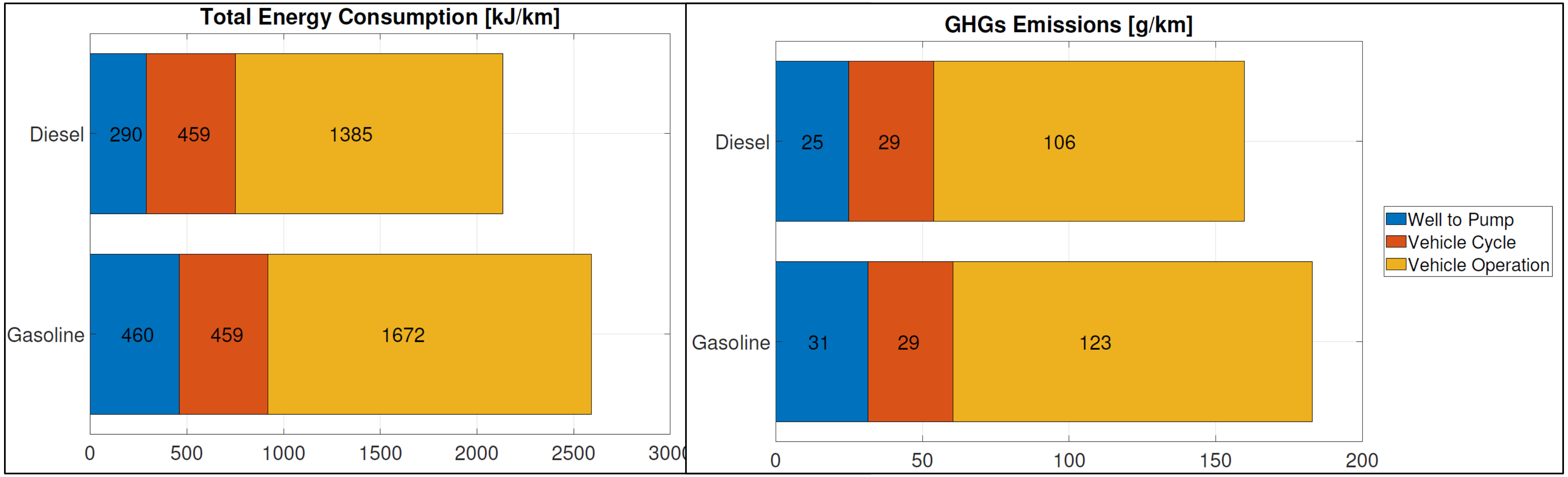
Electrification

Convert the car

Both periods have a 10 years length
50 km per day, 70% in urban driving

Tiano, F A; Rizzo, G   Life Cycle Assessment (LCA) study for different options of sustainable mobility, including vehicle conversion   *International Journal of Powertrains*, **2020**, *9(1-2)*, 122-149

1st period | Results | Energy and GHGs

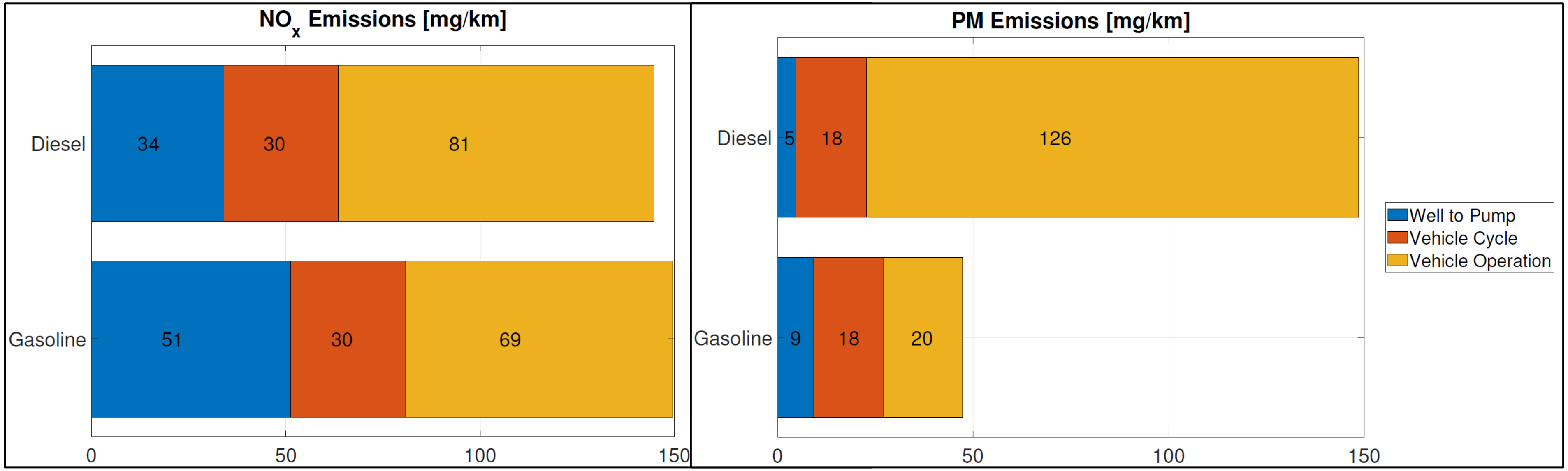


Diesel fueled vehicle shows **lower energy consumption**, in both **vehicle operation** and in **fuel cycle**.

The **same behavior** is found for GHGs emission.

These **results were expected** since diesel engines have **higher efficiency** and diesel fuel is **less refined** than gasoline.

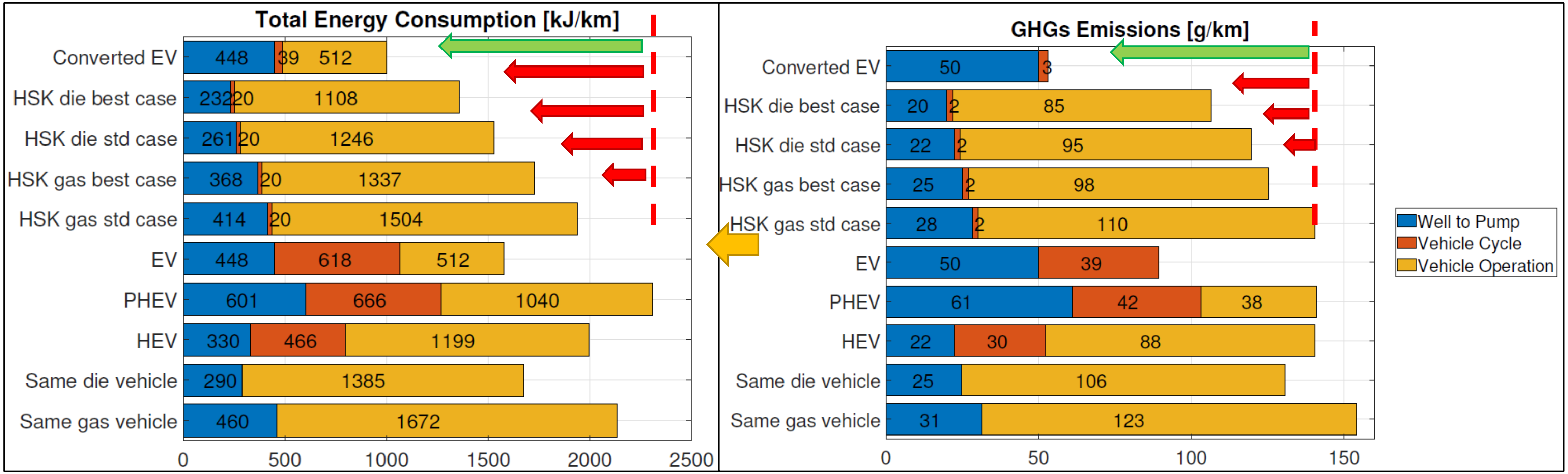
1st period | Results | NOx and PM



NOx emissions show a **not expected results**. **Diesel fueled vehicle**, although have higher emissions in vehicle operation, have an overall **slightly lower NOx emissions than Gasoline** fueled vehicle.

As expected, **PM emissions** are **largely higher** for **diesel** fueled vehicle than for **gasoline** fueled vehicle.

2nd period | Results | Energy and GHGs



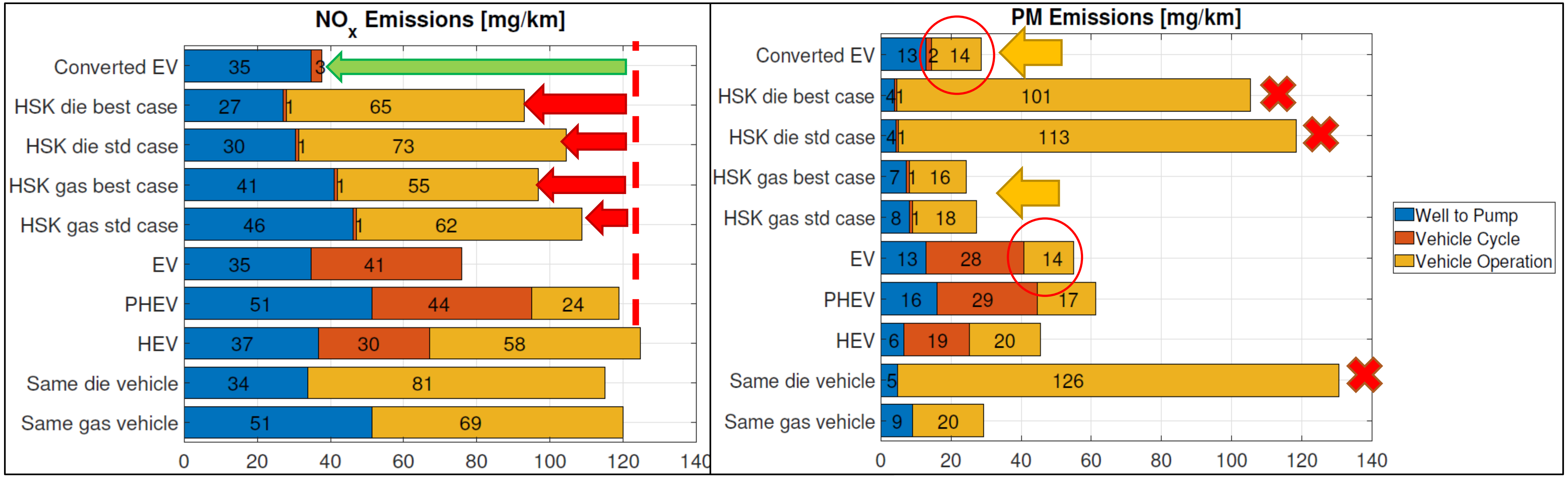
<u>**Converted vehicles**</u> have <u>**better results**</u> than new PHEVs both in terms of Total Energy and GHGs Emissions.

<u>**PHEVs have the greatest total energy consumptions**</u>.

Emissions of PHEVs and EVs strongly depends on <u>**Fuel Mix Generation of electricity.**</u>

<u>**Conversion of diesel vehicles**</u> exhibits the <u>**best results**</u> with GHGs (EVs excluded)

2nd period | Results | NOx and PM



Converted vehicles have **lower NOx emissions** than both PHEVs and HEVs.

Converted gasoline HEVs and converted EVs have the best results in NOx and PM emissions. These emissions depends on **Fuel Mix Generation of electricity.**

PM emissions of EVs during the vehicle operation are associated to **brakes** and **tyres**.

Diesel vehicles show the worse result in terms of PM emissions due to intrinsic combustion processes.

Summary of the results

	Energy Consumption (kJ/kg)				*Percent*			
	Fuel	Vehicle	Operation	Total	Fuel	Vehicle	Operation	Total
Diesel	290	459	1385	2134	*13.6%*	*21.5%*	*64.9%*	*100%*
Gasoline	460	459	1672	2591	*17.8%*	*17.7%*	*64.5%*	*100%*
PHEV	601	666	1040	2307	*26.1%*	*28.9%*	*45.1%*	*100%*
HEV	330	466	1199	1995	*16.5%*	*23.4%*	*60.1%*	*100%*
EV	448	618	512	1578	*28.4%*	*39.2%*	*32.4%*	*100%*
Diesel+HySolarKit	232	20	1108	1360	*17.1%*	*1.5%*	*81.5%*	*100%*
Gasoline+HySolarKit	369	20	1337	1726	*21.4%*	*1.2%*	*77.5%*	*100%*
Converted EV	448	39	512	999	*44.8%*	*3.9%*	*51.3%*	*100%*
Mean Value	**397**	**343**	**1096**	**1836**	***23.2%***	***17.1%***	***59.7%***	***100%***

	GHG emissions (g/km)				*Percent*			
	Fuel	Vehicle	Operation	Total	Fuel	Vehicle	Operation	Total
Diesel	25	29	106	160	*15.6%*	*18.1%*	*66.3%*	*100%*
Gasoline	31	29	123	183	*16.9%*	*15.8%*	*67.2%*	*100%*
PHEV	61	42	38	141	*43.3%*	*29.8%*	*27.0%*	*100%*
HEV	22	30	88	140	*15.7%*	*21.4%*	*62.9%*	*100%*
EV	50	39	0	89	*56.2%*	*43.8%*	*0.0%*	*100%*
Diesel+HySolarKit	20	2	85	107	*18.7%*	*1.9%*	*79.4%*	*100%*
Gasoline+HySolarKit	25	2	98	125	*20.0%*	*1.6%*	*78.4%*	*100%*
Converted EV	50	3	0	53	*94.3%*	*5.7%*	*0.0%*	*100%*
Mean Value	**36**	**22**	**67**	**125**	***35.1%***	***17.3%***	***47.6%***	***100%***

- **Vehicle operation** has a major role (59/53 % for energy consumption and GHG).
- **Fuel cycle** accounts in average for 22/27%, while **Vehicle cycle** for 19%.
- There are significant **differences** in relative weights between different options.
- **Vehicle conversion** is a good option both in terms of energy consumption and GHG emissions.

Test – Team working

Estimate the **yearly energy** required to power the **actual Italian fleet** of cars in case of **total replacement** with **electric cars**.

Use the **web** to find for the required information.

Present your **results** and **assumptions** in one or more slides or in an Excel sheet.

Choose a **name** and a **logo** for your team!

Hybrid vehicles

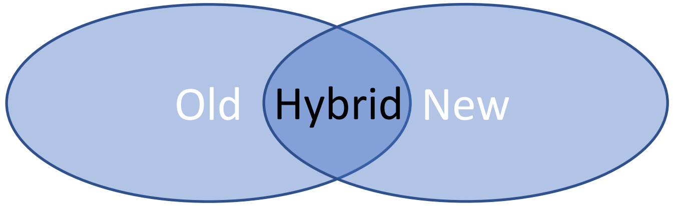
Hybrid vehicles are characterized by **two or more prime movers** and **power sources**.

Usually, the term "hybrid vehicle" is used for a vehicle combining an **engine** and an **electric motor** (**Hybrid Electric Vehicle**, HEV).

Other "hybrid" configurations have been also proposed (mechanical, pneumatic, hydraulic, solar, fuel cell).

Hybrid technologies

Hybrid propulsion occurred often in the past, when a **gradual transition** to a new technology was needed.

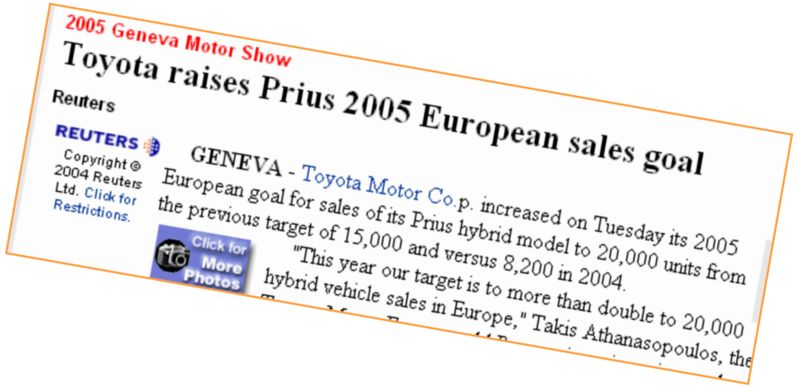


For almost a century, **ships** with **sailing** and **steam propulsions** coexisted. When reliability and mileage of steam engines improved, sailing was abandoned.

Also, first **motocycles** maintained the **pedals**, for assistance in climbing. When power increased and an efficient gear was adopted, pedals disappeared.

Toyota Prius

- The **Toyota Prius**, first went on sale in Japan in 1997, has been the **first mass-produced hybrid vehicle**. It was introduced worldwide in 2000.
- The Prius is sold in almost 80 countries and regions, with its largest markets being those of Japan and the United States.
- Global cumulative Prius sales reached the milestone 1 million vehicle mark in May 2008, 2 million in September 2010, and passed the 3 million mark in June 2013.



2005 Geneva Motor Show

Toyota raises Prius 2005 European sales goal

Reuters

REUTERS

Copyright © 2004 Reuters Ltd. Click for Restrictions.

GENEVA - Toyota Motor Co.p. increased on Tuesday its 2005 European goal for sales of its Prius hybrid model to 20,000 units from the previous target of 15,000 and versus 8,200 in 2004.

"This year our target is to more than double to 20,000 hybrid vehicle sales in Europe," Takis Athanasopoulos, the

Source: Wikipedia

More recent HEV and PHEV


Toyota Yaris


Hyundai Ioniq

Audi Q7 e-tron


BMW 225xe

Kia Niro


Ford Mondeo Hybrid


Honda NSX


Range Rover Sport PHEV P400e

https://buglionedomenico.wordpress.com/2018/07/02/auto-ibride-2018-i-modelli-in-commercio-in-italia-prezzi-e-autonomia/

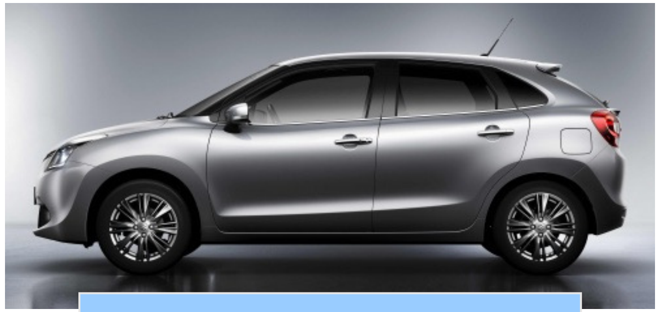
More recent HEV and PHEV

Toyota Auris Hybrid

Toyota C-HR Hybrid

Toyota RAV4 Hybrid

Volvo XC90 T8



Suzuki Baleno Hybrid

Hybrid vehicles sales

Top national markets for hybrid electric vehicles between 2007 and 2015

Country	Number of hybrids sold or registered by year								
	2015	2014	2013	2012	2011	2010	2009	2008[137]	2007[138]
Japan	633,200(1)[130]	Over 1 million[112]	679,100(1)[139]	678,000(1)[140]	316,300(1)[140]	392,200(1)[140]	334,000[141]	94,259	69,015
US	384,404[142]	452,152[16]	495,771[16]	434,498[14]	268,752[143]	274,210[144]	290,271[144]	312,386[144]	352,274[144]
France(2)	56,030[145]	41,208[145]	46,785[146]	27,730[147]	13,340[148]	9,443[149]	9,399[150]	9,137[150]	7,268[151]
UK	44,580[152]	37,215[153]	29,129[153]	24,900[154]	23,391[155]	22,127[156]	14,645[157]	15,385[157]	15,971[157]
Italy	25,240[145]	21,154[145]	14,695[158]	5,885[159]	5,244[160]				
Germany	22,529[161]	22,908[162]	24,963[163]	21,438[164]	12,622[165]	10,661[166]	8,374[166]	6,464[166]	7,591[166]
Spain	18,406[145]	12,083[145]	10,294[167]	10,030[168]	10,350[169]				
Netherlands	13,752[170]	10,341[171]	18,356[172]	19,519[173][174]	14,874[160]	16,111[175]	16,122[176]	11,837[176]	3,013[176]
Canada	Not available		~15,000[177]	~25,000[178]	Not available		16,167[179]	19,963[180]	14,828
World	Over 1.2 million	Over 1.6 million	Over 1.3 million	Over 1.2 million	-	-	740,000[181]	511,758	500,405

Notes: (1) Partial sales, includes only Toyota/Lexus sales.[140] (2) French registrations between 2011 and 2013 include plug-in hybrids

Hybrid (HEV and PHEV) sales in EU and EFTA had the highest rate of increase in last years.

Fuel Type	2018 (Q1)	2017 (Q1)	% Change	% Market Share
Total Market	4,282,134	4,256,637	0.6	100
Petrol	2,355,611	2,060,349	14.3	55
Diesel	1,603,337	1,934,374	-17.1	37.4
Alternatively Powered:	295,524	236,098	25.2	7
– ECV:	88,329	62,695	40.9	2
– – BEV	43,585	32,297	35	1
– – PHEV	44,744	30,398	47.2	1

Source: ACEA

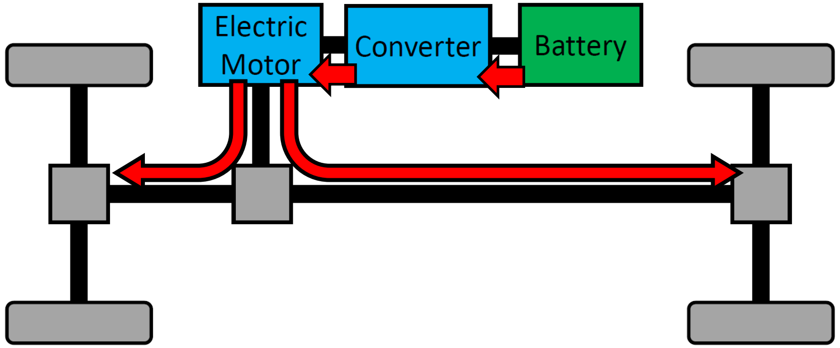
Hybrid and electric technologies

Two categories of sustainable mobility can be identified:

Electric Vehicles

Hybrid Vehicles

Battery Electric Vehicle (BEV)



Courtesy of Gianfranco Rizzo, Class of Hybrid Vehicles, Univertity of Salerno

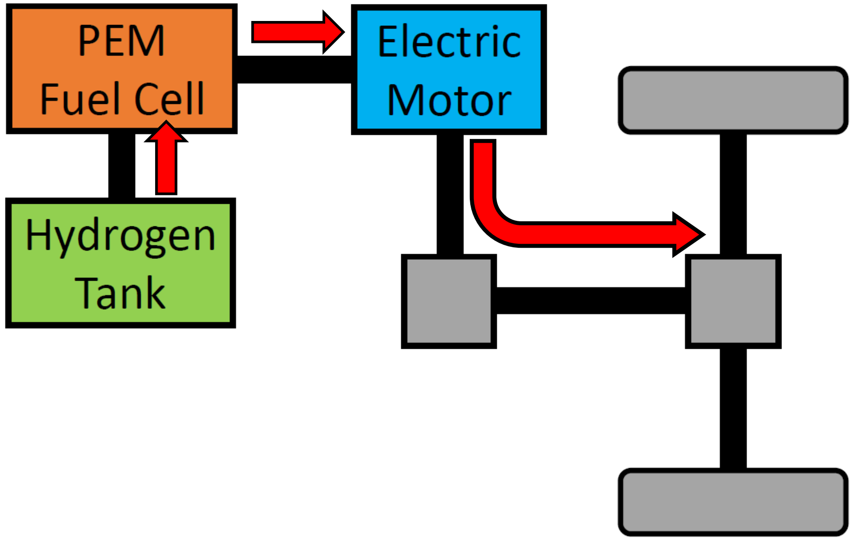
Hybrid and electric technologies

Electric Vehicles

Hybrid Vehicles

Battery Electric Vehicle (BEV)

Fuel Cell Electric Vehicle (FCEV)



PEM Fuel Cell

Electric Motor

Hydrogen Tank

Courtesy of Gianfranco Rizzo, Class of Hybrid Vehicles, University of Salerno

Hybrid and electric technologies

Electric Vehicles

- Battery Electric Vehicle (BEV)
- Fuel Cell Electric Vehicle (FCEV)

Hybrid Vehicles

👍

Pollution free
Low noise

👎

Large amount of carbon free electricity needed
Limited range
Cost and life of batteries
No free heat energy on board
Recharging issues

Courtesy of Gianfranco Rizzo, Class of Hybrid Vehicles, University of Salerno

Hybrid and electric technologies

Electric Vehicles

Battery Electric Vehicle (BEV)

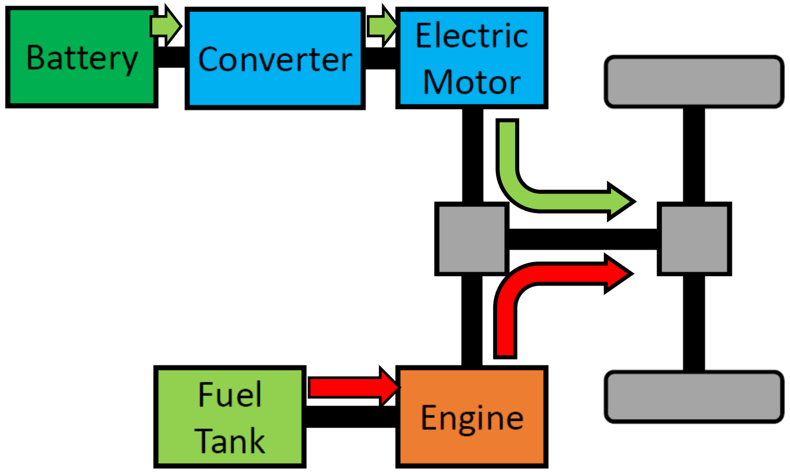
Fuel Cell Electric Vehicle (FCEV)

Pollution free
Low noise

Large amount of carbon free electricity needed
Limited range
Cost and life of batteries
No free heat energy on board
Recharging issues

Hybrid Vehicles

Parallel Cell HEV



Courtesy of Gianfranco Rizzo, Class of Hybrid Vehicles, University of Salerno

Hybrid and electric technologies

Electric Vehicles

- Battery Electric Vehicle (BEV)
- Fuel Cell Electric Vehicle (FCEV)

👍

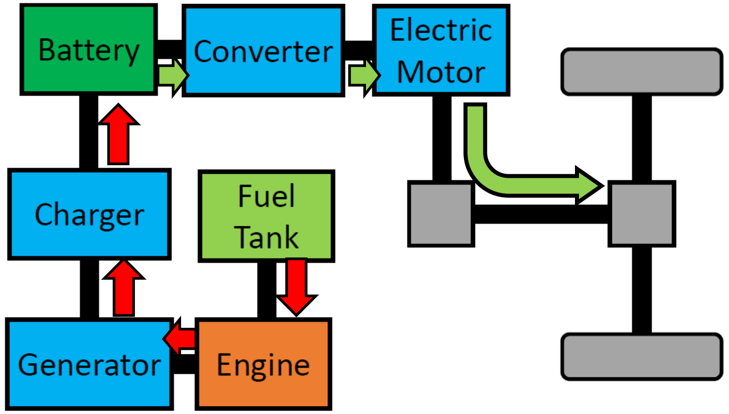
Pollution free
Low noise

👎

Large amount of carbon free electricity needed
Limited range
Cost and life of batteries
No free heat energy on board
Recharging issues

Hybrid Vehicles

- Parallel HEV
- Series HEV



Courtesy of Gianfranco Rizzo, Class of Hybrid Vehicles, University of Salerno

Hybrid and electric technologies

Electric Vehicles

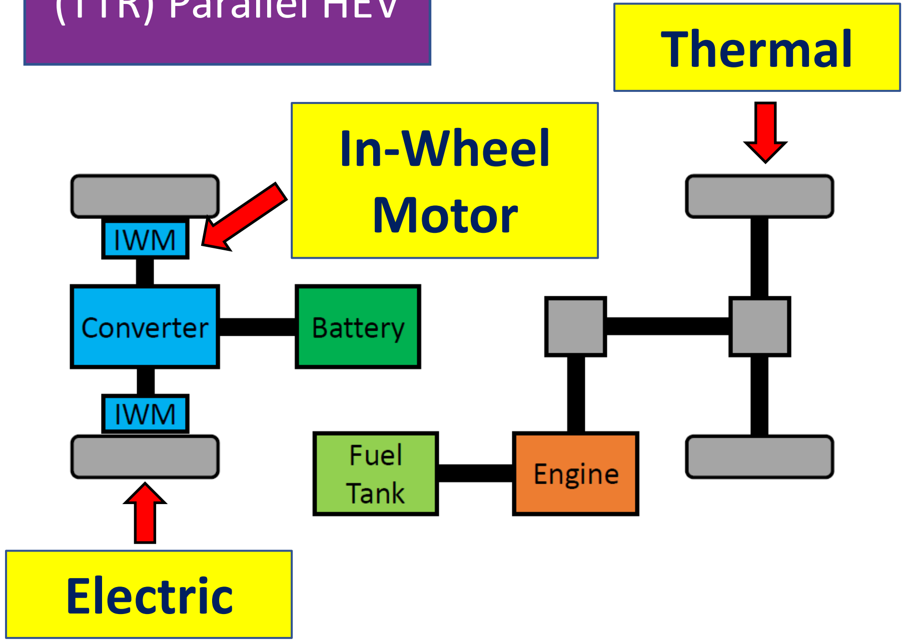
- Battery Electric Vehicle (BEV)
- Fuel Cell Electric Vehicle (FCEV)

Hybrid Vehicles

- Parallel HEV
- Combined HEV
- Series HEV
- Through-The-Road (TTR) Parallel HEV

Pollution free
Low noise

Large amount of carbon free electricity needed
Limited range
Cost and life of batteries
No free heat energy on board
Recharging issues



Courtesy of Gianfranco Rizzo, Class of Hybrid Vehicles, University of Salerno

Hybrid and electric technologies

Electric Vehicles

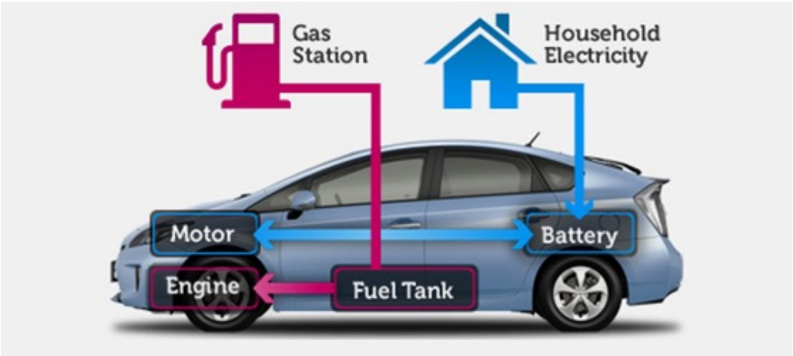
- Battery Electric Vehicle (BEV)
- Fuel Cell Electric Vehicle (FCEV)

👍 👎

👍	👎
Pollution free **Low noise**	**Large amount of carbon free electricity needed** **Limited range** **Cost and life of batteries** **No free heat energy on board** **Recharging issues**

Hybrid Vehicles

- Parallel HEV
- Combined HEV
- Series HEV
- Through-The-Road (TTR) Parallel HEV
- Plug-In HEV (PHEV)



Courtesy of Gianfranco Rizzo, Class of Hybrid Vehicles, University of Salerno

Hybrid and electric technologies

Electric Vehicles

- Battery Electric Vehicle (BEV)
- Fuel Cell Electric Vehicle (FCEV)

👍
Pollution free
Low noise

👎
Large amount of carbon free electricity needed
Hydrogen supply and storage
Limited range
Cost and life of batteries
No free heat energy on board
Recharging issues

Hybrid Vehicles

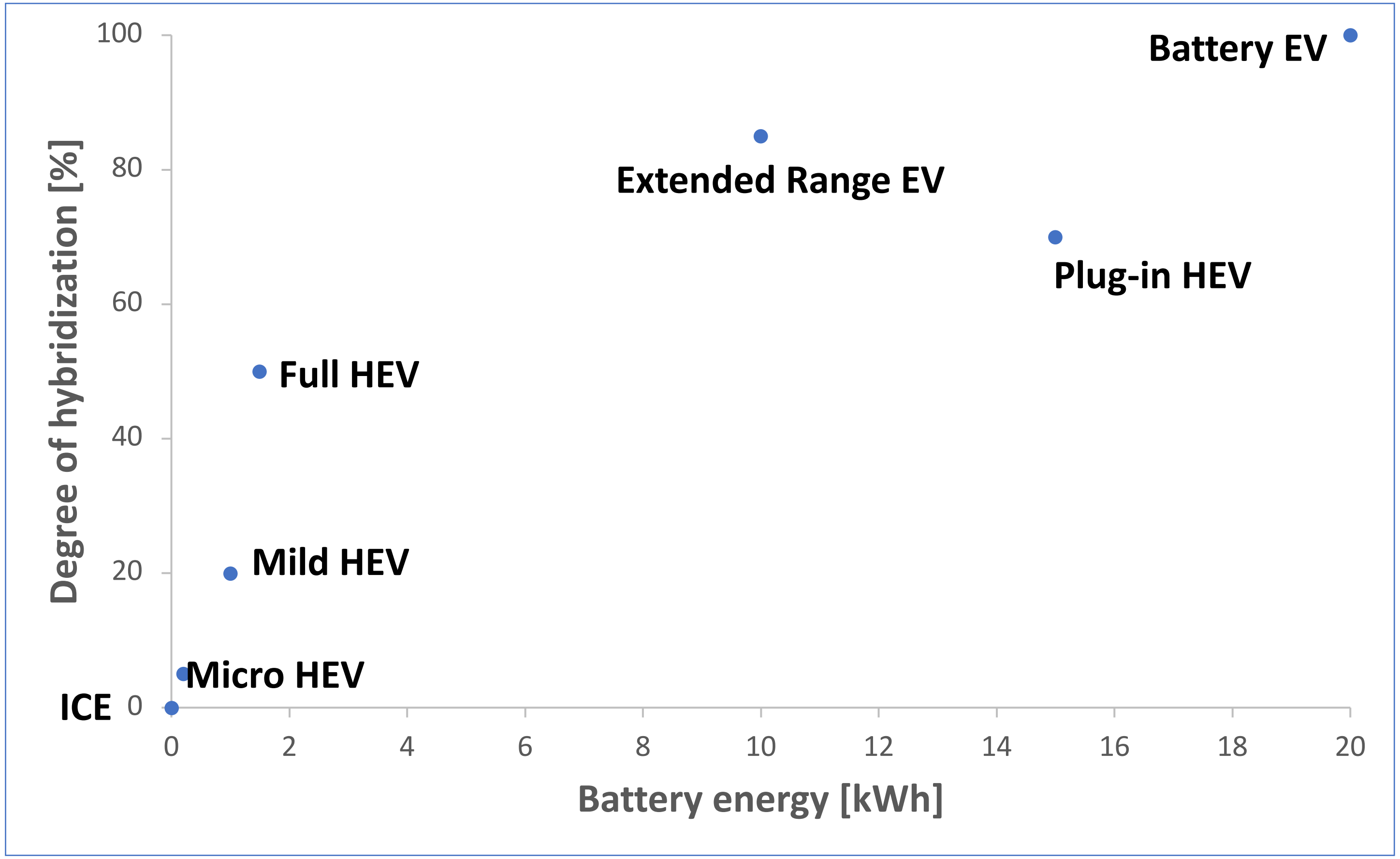
- Parallel HEV
- Combined HEV
- Series HEV
- Through-The-Road (TTR) Parallel HEV
- Plug-In HEV (PHEV)

👍
Lower emissions compared to ICEVs
Extended range

👎
Carbon free electricity needed for PHEVs
Cost and life of batteries
Recharging issues PHEVs
No zero emissions

Courtesy of Gianfranco Rizzo, Class of Hybrid Vehicles, University of Salerno

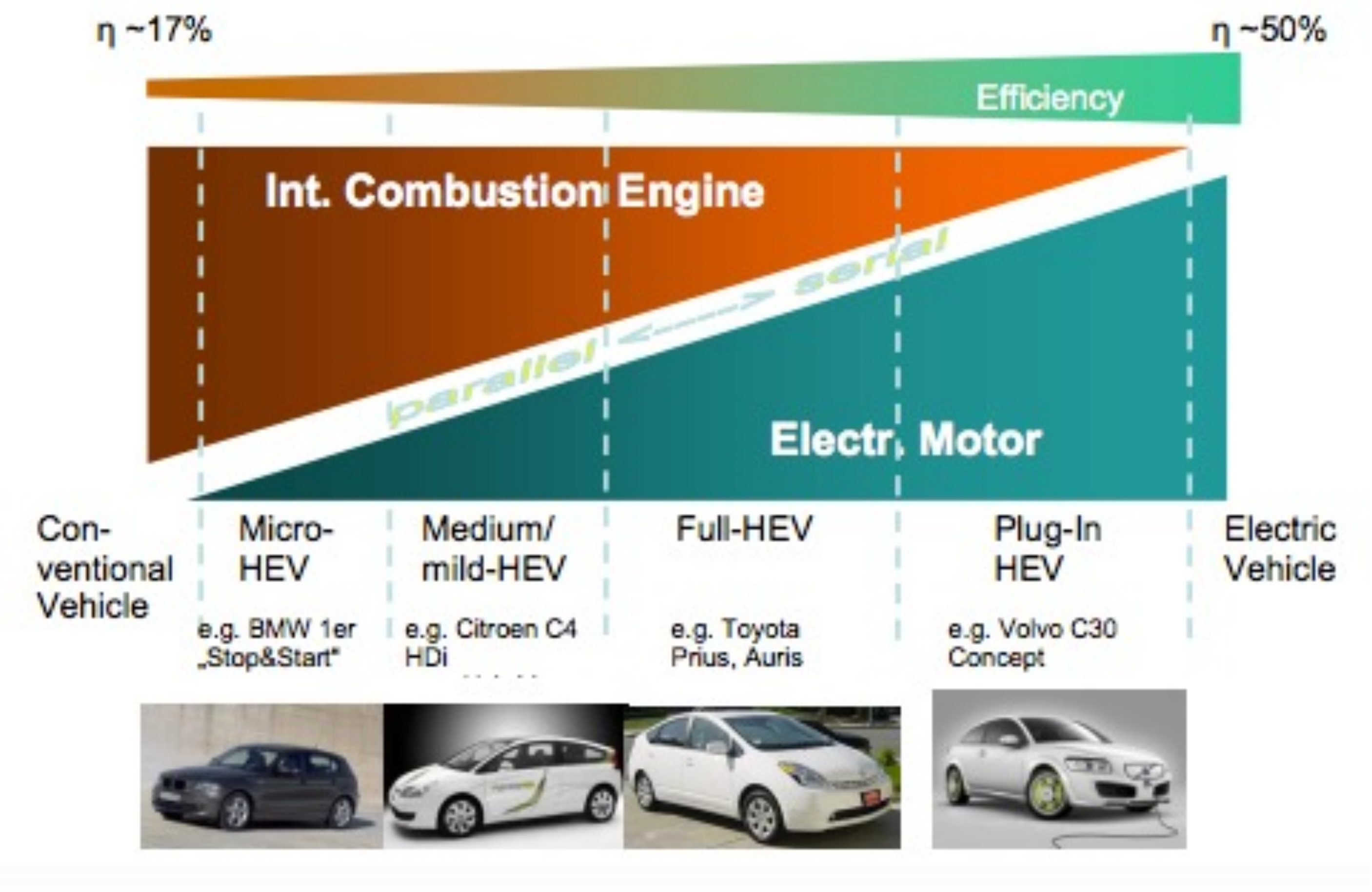
Degree of hybridization vs battery capacity



Functional classification of EV/HEVs in terms of degree of hybridization and battery capacity (typical values).

Source: L.Guzzella and A.Sciarretta (2012), Vehicle Propulsion Systems, Introduction to Modeling and Optimization, Springer

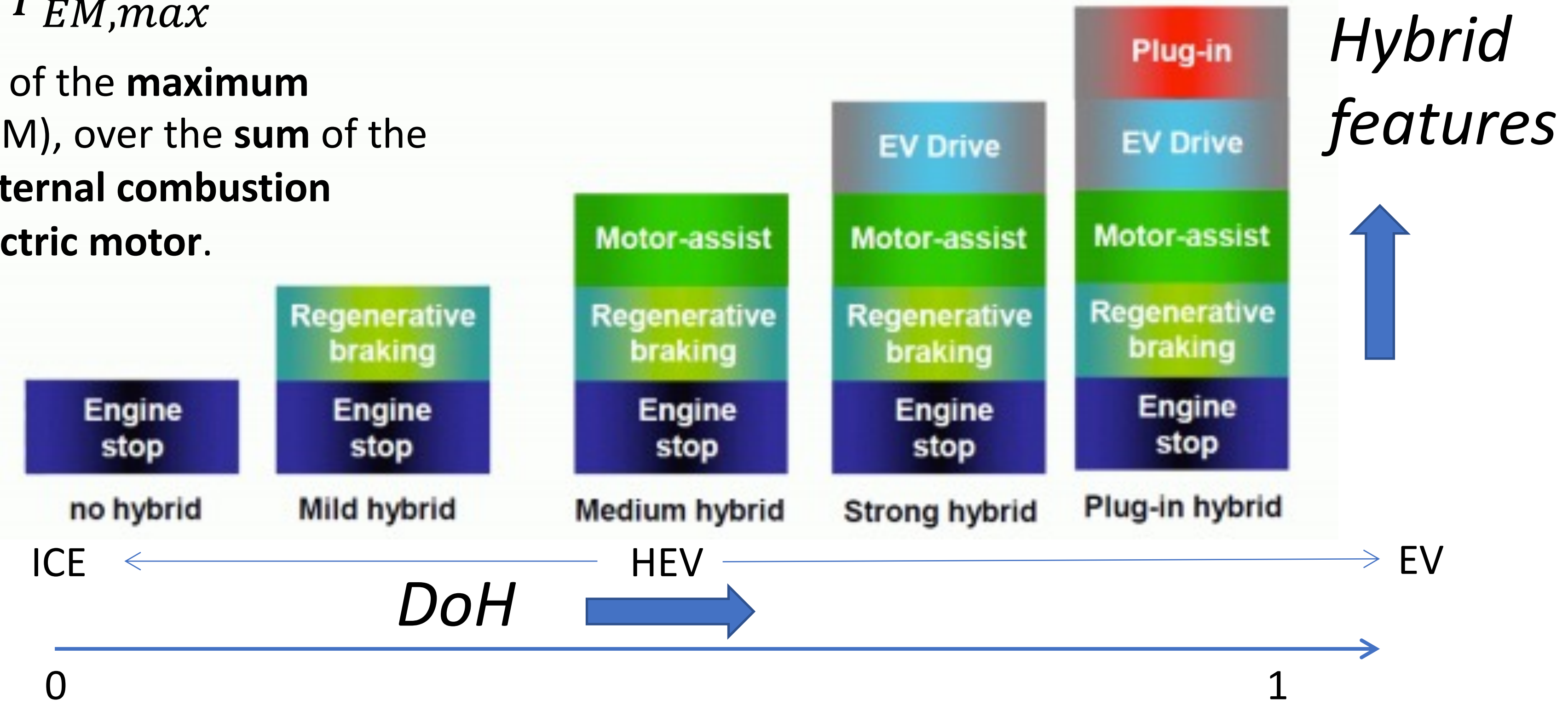
Degree of Hybridization



Hybrid and electric technologies

$$DoH = \frac{P_{EM,max}}{P_{ICE,max} + P_{EM,max}}$$

DoH is defined as the ratio of the **maximum power of electric motor** (EM), over the **sum** of the **maximum power of the internal combustion engine** (ICE) and of the **electric motor**.



Hybrid features

ICE ← HEV → EV

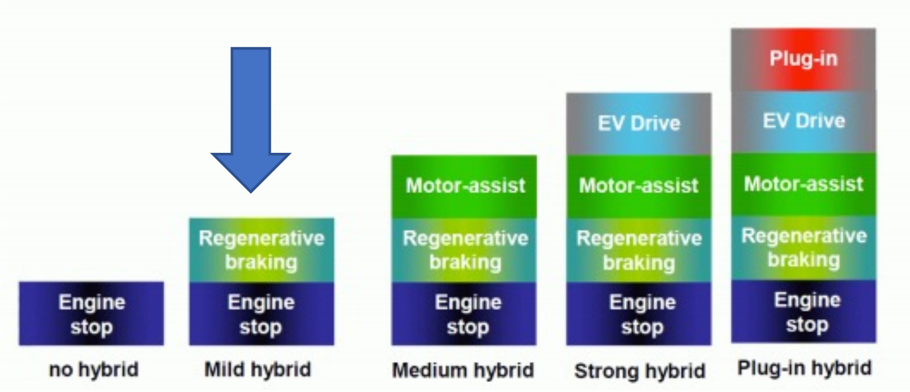
DoH →

0 → 1

Different levels of hybridization and of hybrid features can be achieved, at increasing values of the Degree of Hybridization *DoH*.

Micro Hybrids

- **Micro hybrids** (also called No-Hybrid) are essentially conventional vehicles with oversized starter motors (about 3% the power of the engine), **allowing the engine to be turned off whenever the car is coasting, braking, or stopped**, yet restart quickly and cleanly.
- During restart, the larger motor is used to spin up the engine to operating rpm speeds before injecting any fuel.
- Start& Stop allows to reduce fuel consumption of 4-5% on NEDC Cycle, and up to 8-10% in heavy traffic conditions.
- Usually, the lead-gel batteries at 12 V are used, as in conventional vehicles.
- This technology can be applied with limited modifications in short time on existing vehicles.



Mild Hybrids with BSG or ISG

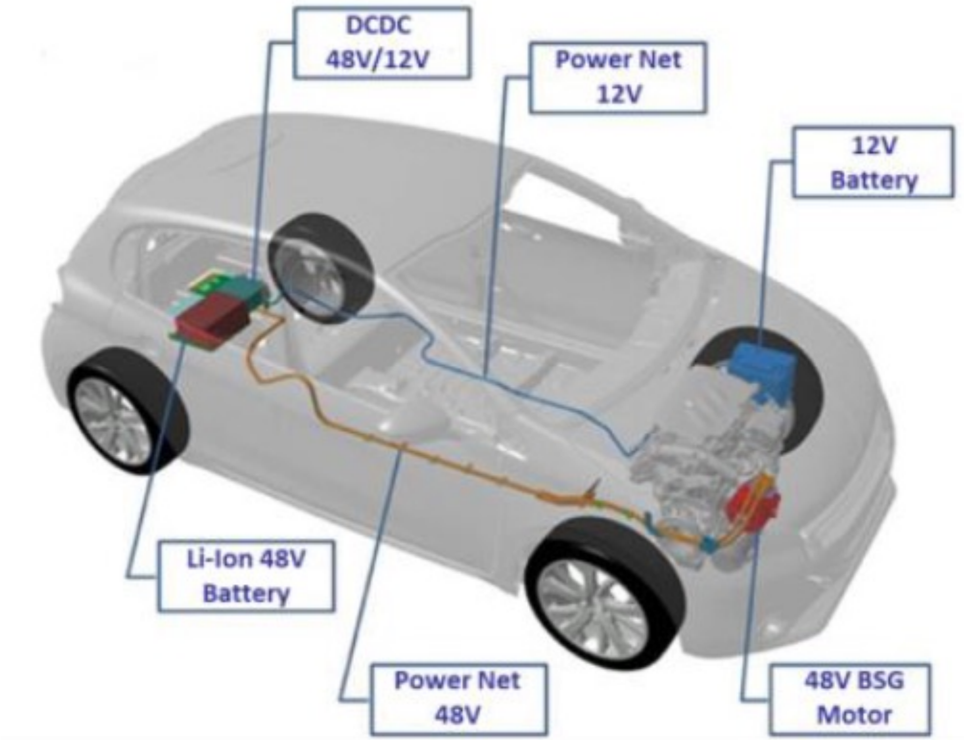
Mild hybrids are essentially conventional vehicles with oversized starter motors, **allowing the engine to be turned off whenever the car is coasting, braking, or stopped**, yet restart quickly and cleanly.

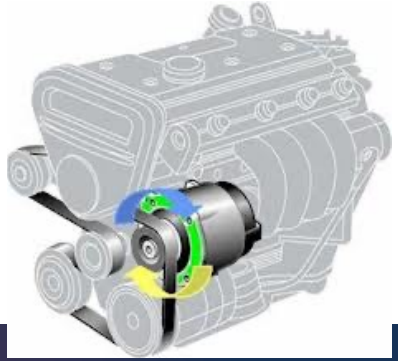
The Mild Hybrid works at higher voltage (i.e. 48 V) with a **Belt Starter Generator** (BSG) or an **Integrated Starter Generator**, up to about 15 kW.

They use two **different voltage levels** (12V and 48V), a Lithium-Ion battery of about 300-500 Wh, and a DC/DC converter for recharging the 12V battery.

A limited support to the engine during **acceleration** and some recuperation of **braking energy** can be achieved with such systems.

But there is **no EV mode at all**. Therefore, many people do not consider these to be hybrids, since there is no electric motor to drive the vehicle, and these vehicles do not achieve the fuel economy of real hybrid models.

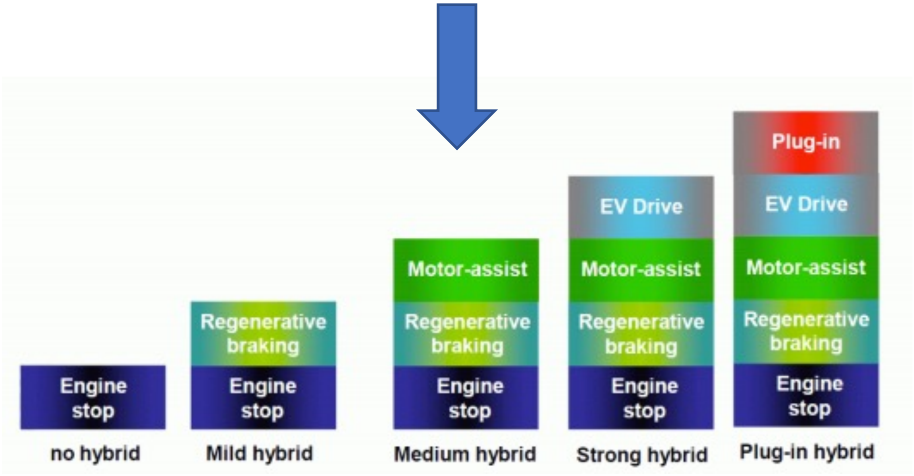




Belt Starter Generator

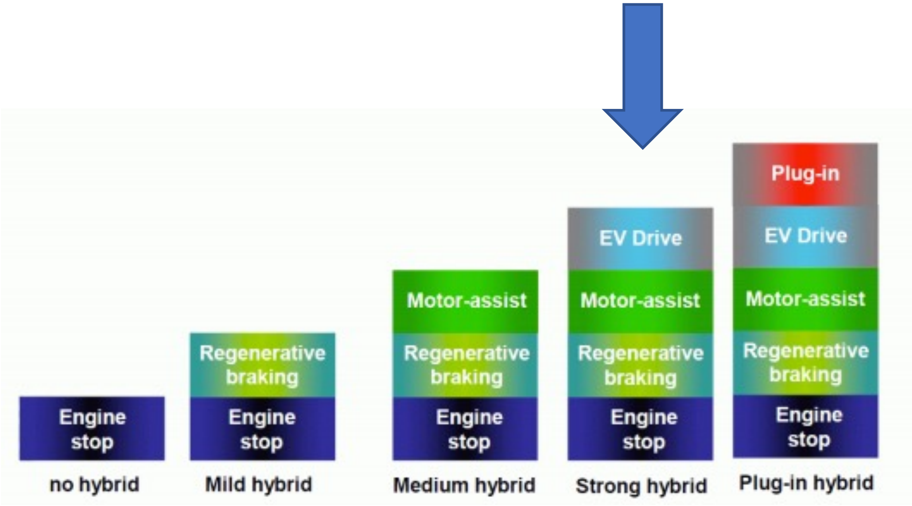
Medium Hybrid

- **Motor assist hybrids** use the engine for primary power, with a torque-boosting electric motor connected in parallel to a largely conventional powertrain.
- **EV mode is only possible for a very limited period of time**, and this is not a standard mode. Compared to full hybrids, the amount of electrical power needed is smaller, thus the **size of the battery system can be reduced**.
- The electric motor, mounted between the engine and transmission, is essentially a **very large starter motor**, which operates not only when the engine needs to be turned over, but also when the driver "steps on the gas" and **requires extra power**.
- The electric motor works as a generator during **regenerative braking**.



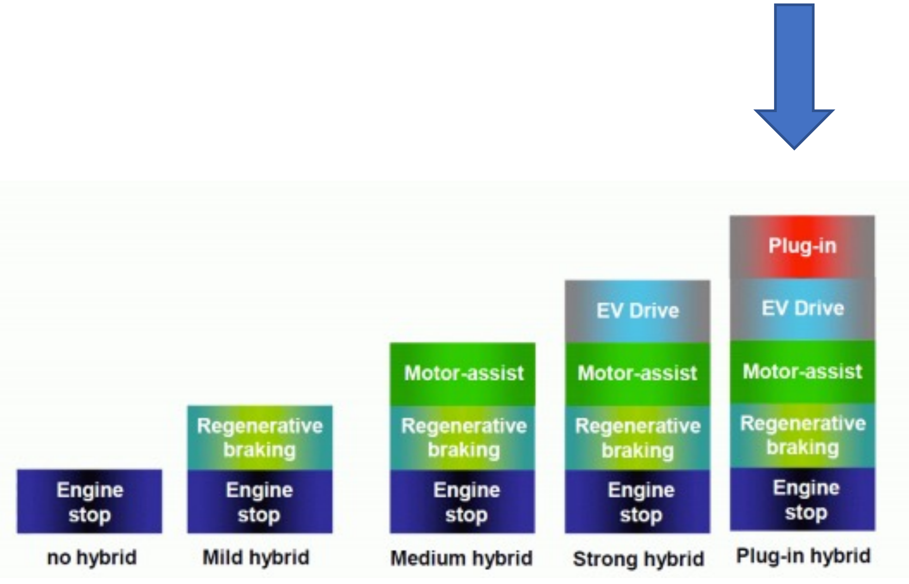
Full Hybrid

- A **full hybrid** can run on just the engine **(thermal mode)**, just the batteries **(electrical mode)**, or a combination of both **(hybrid mode)**.
- A large, **high-capacity battery pack** is needed for battery-only operation



Plug-In HEV

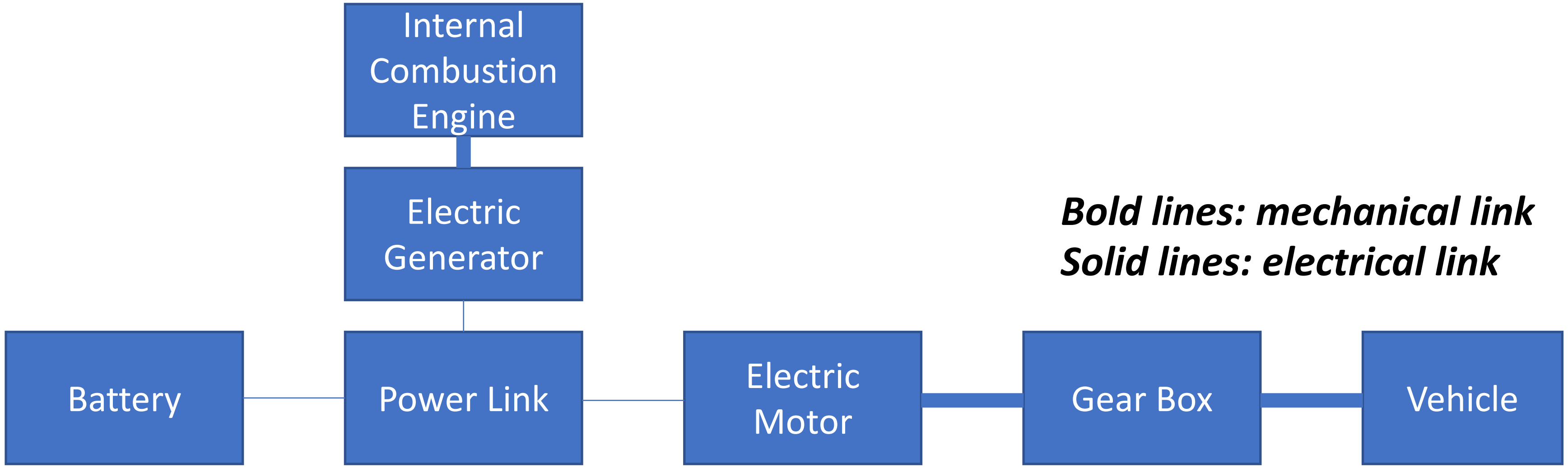
- A **plug-in hybrid electric vehicle (PHEV) is a full hybrid**, able to run in electric-only mode, with larger batteries and the ability to **recharge from the electric power grid**.
- Their main benefit is that they **can be gasoline-independent for daily commuting, but also have the extended range of a hybrid for long trips.**
- Fuel efficiency is calculated based on actual **fuel consumed by the ICE and its gasoline equivalent of the kWh of energy delivered by the utility during recharge**.
- The **"well-to-wheel" efficiency and emissions** of PHEVs compared to gasoline hybrids **depends on the energy sources used for the grid utility** (coal, oil, natural gas, hydroelectric power, solar power, wind power, nuclear power).



Series hybrid configuration

In a **Series HEV**, the **vehicle is driven only by the electric motor**.

The Internal Combustion Engine is used as an **Auxiliary Power Unit** (APU), powering an electric generator to **recharge the battery** and to **extend the range** of the vehicle.



Internal Combustion Engine

Electric Generator

Battery

Power Link

Electric Motor

Gear Box

Vehicle

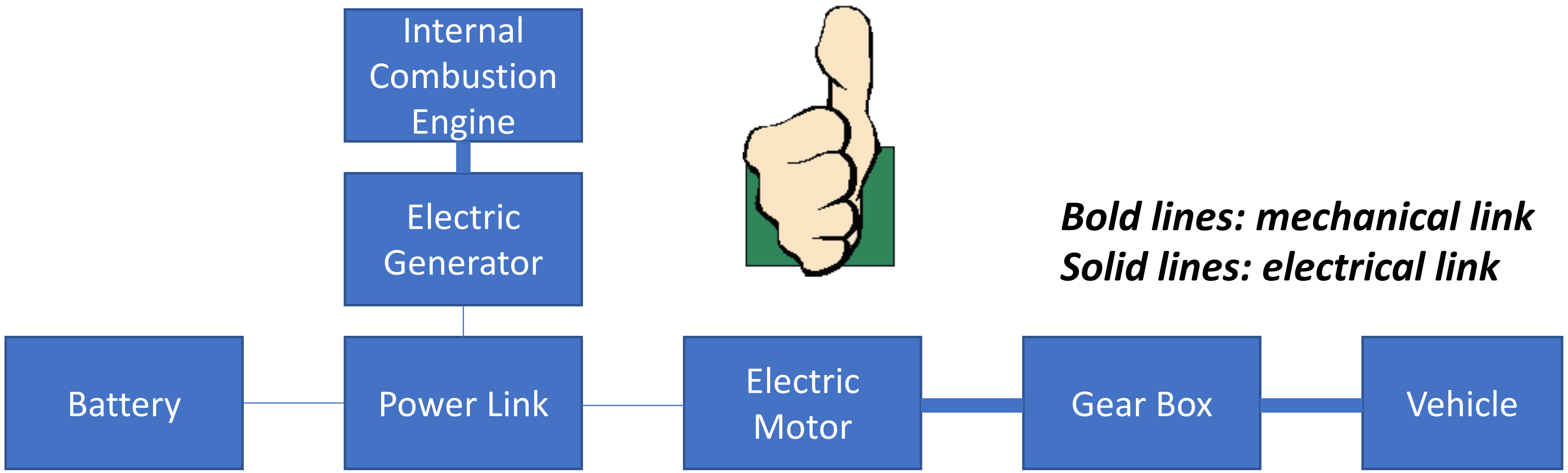
Bold lines: mechanical link
Solid lines: electrical link

Series HEV - Advantages

The engine operation is not related to the power requirements of the vehicle, thus the engine can be operated at a point with **optimal efficiency and emissions**.

The engine is mechanically decoupled from the drive axle:

- the transmission **does not require a clutch;**
- **lay-out** can be optimized;
- good **insulation** for **vibrations and noise** can be achieved, since the engine is not mechanically connected to the transmission.



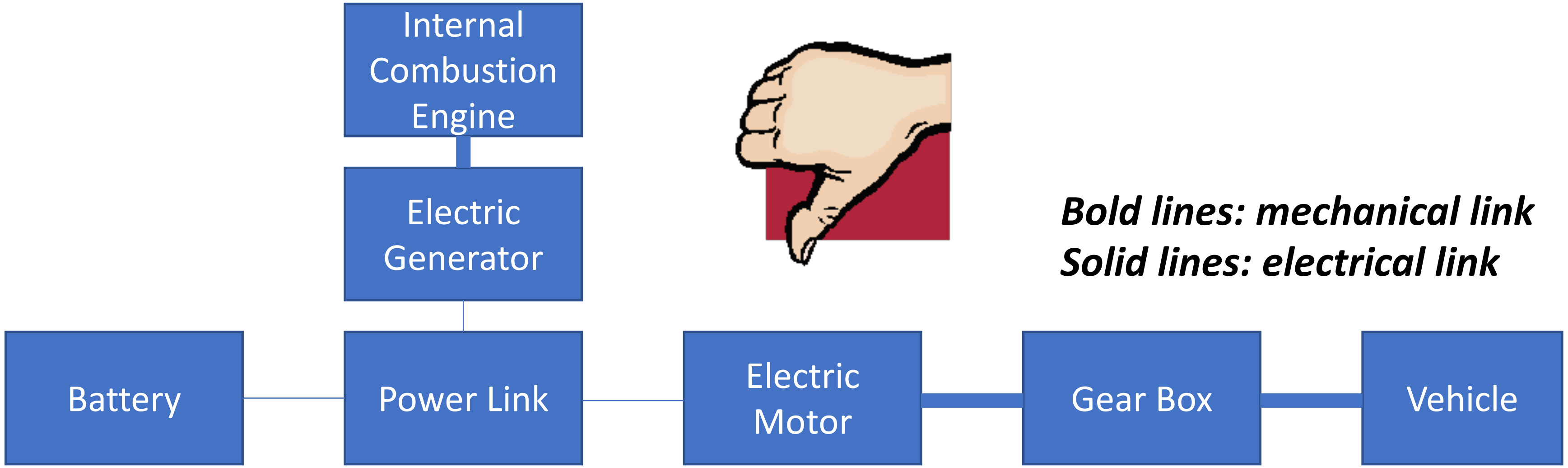
Bold lines: mechanical link
Solid lines: electrical link

Series HEV - Disadvantages

3 machines are needed: one engine, one electric generator, and one electric traction motor. This cause **additional weight and cost**.

At least the traction motor has to be sized for the **maximum power requirements** of the vehicle.

The overall tank-to-wheel efficiency is reduced due to **multiple energy conversions**.



Bold lines: mechanical link
Solid lines: electrical link

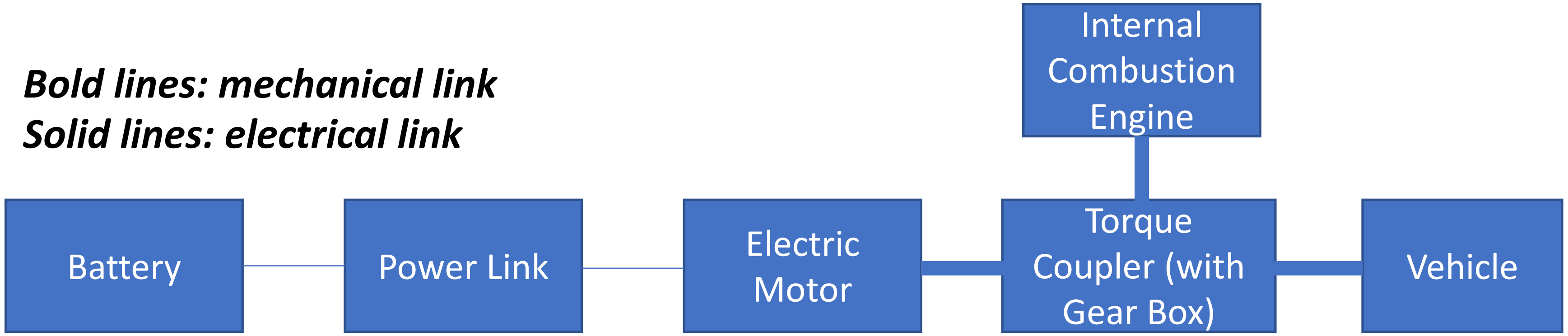
Parallel hybrid configuration

In **parallel HEVs** both the engine and the electric motor can **supply the traction power**, either **alone** or **in combination**.

The **electric motor** can **assist the engine**:

- during **accelerations** and at **high power demand**
- at **idle** (engine can be turned off)
- engine can operate at **higher efficiency** with respect to the conventional vehicle, since driver demand can be satisfied by the motor also.

Bold lines: mechanical link
Solid lines: electrical link



Internal Combustion Engine

Battery

Power Link

Electric Motor

Torque Coupler (with Gear Box)

Vehicle

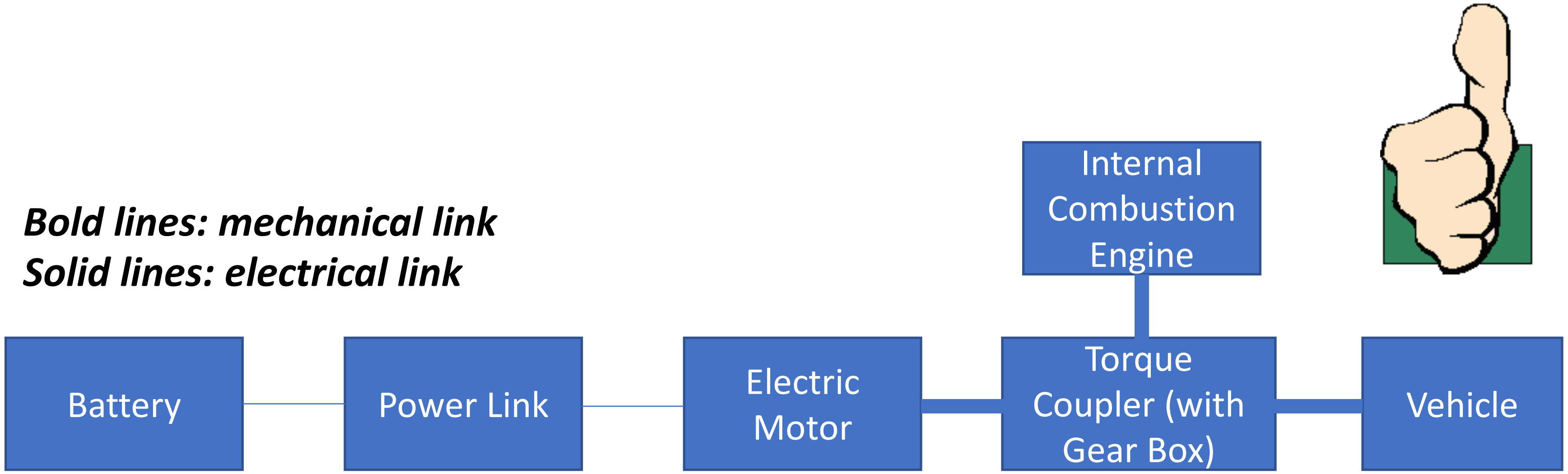
Parallel hybrid - Advantages

Power could be **optimally distributed** between electrical and thermal mover.

Both machines can be sized for a **fraction of the vehicle maximum power** → Less weight and cost with respect to series hybrid.

Engine can be **downsized**, with increased efficiency.

The overall **tank-to-wheel efficiency** is higher with respect to series hybrid, due to fewer **energy conversions**.



Bold lines: mechanical link
Solid lines: electrical link

Internal Combustion Engine

Battery

Power Link

Electric Motor

Torque Coupler (with Gear Box)

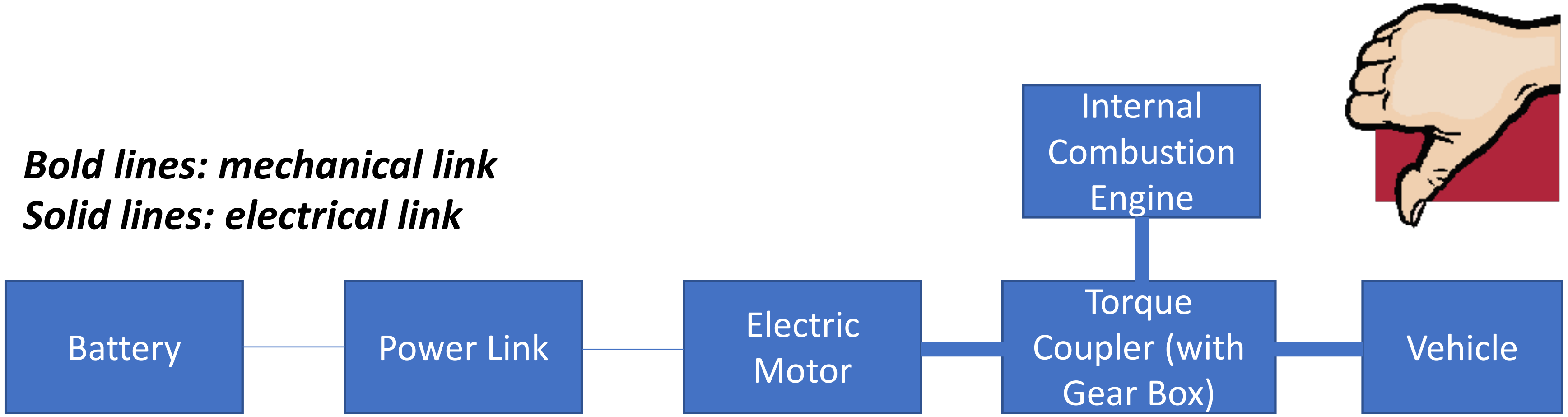
Vehicle

Parallel hybrid - Disadvantages

A **clutch** is needed, since the engine is mechanically linked to the drive train.

The engine generator is smaller, and this may **limit the recoverable braking energy**.

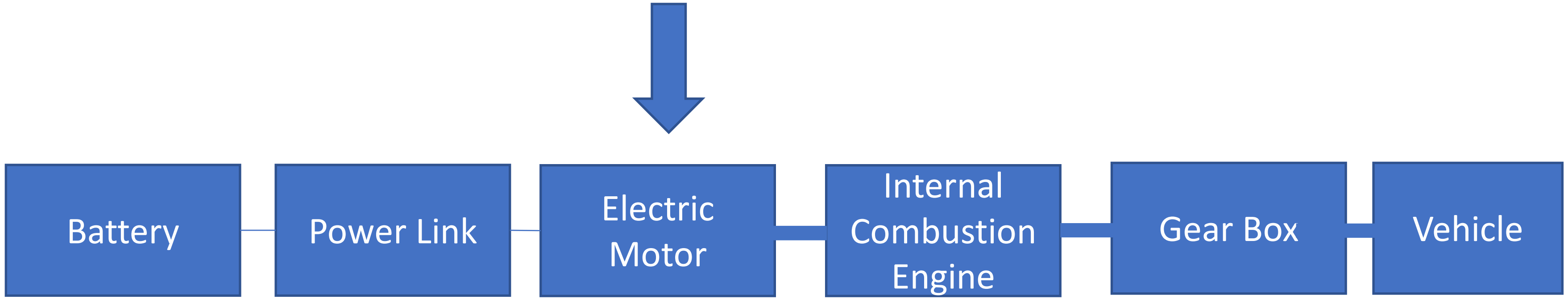
Engine operation can be somewhat optimized thanks to motor assistance, but not so effectively as in a series hybrid.



Bold lines: mechanical link
Solid lines: electrical link

Mild parallel hybrid configuration

- In **mild hybrids**, the electric machine is typically **belt-driven** and mounted on the front of the engine.
- Its speed is always **rigidly linked** to that of the engine.



Battery

Power Link

Electric Motor

Internal Combustion Engine

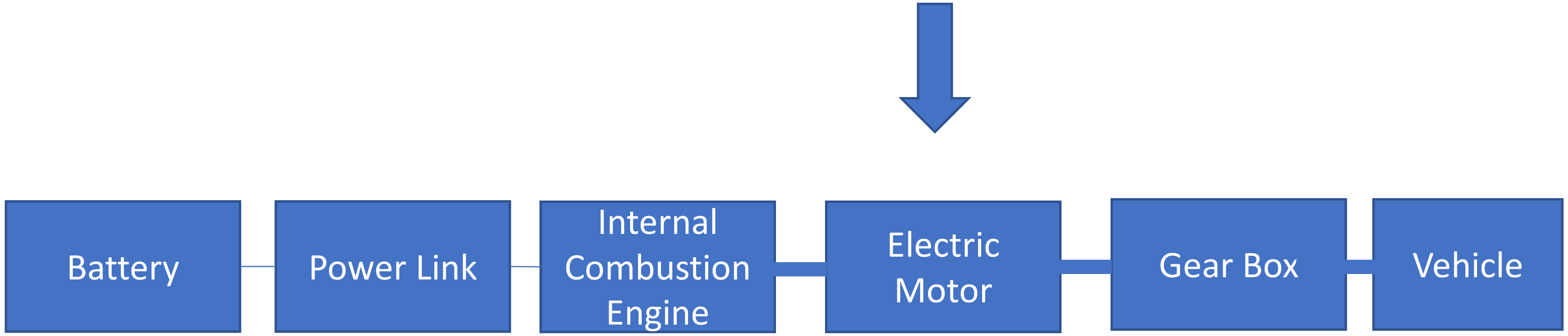
Gear Box

Vehicle

Bold lines: mechanical link - Solid lines: electrical link

Mild parallel hybrid configuration

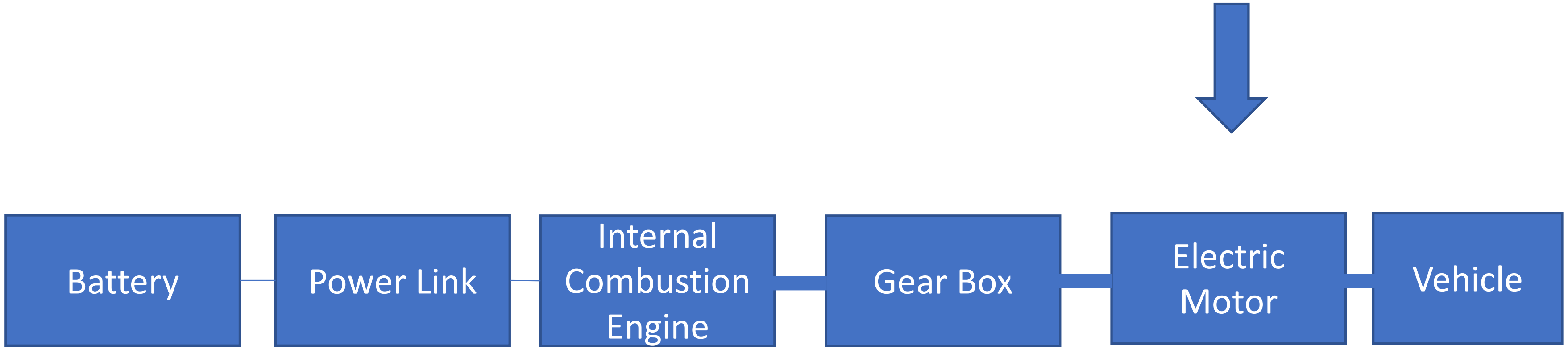
- In ***pre-transmission*** parallel hybrids, the electric machine is mounted between the engine and the gearbox.
- **The two speed levels are linked**, thus this configuration is also called ***single-shaft***.



Bold lines: mechanical link - Solid lines: electrical link

Medium parallel hybrid configuration

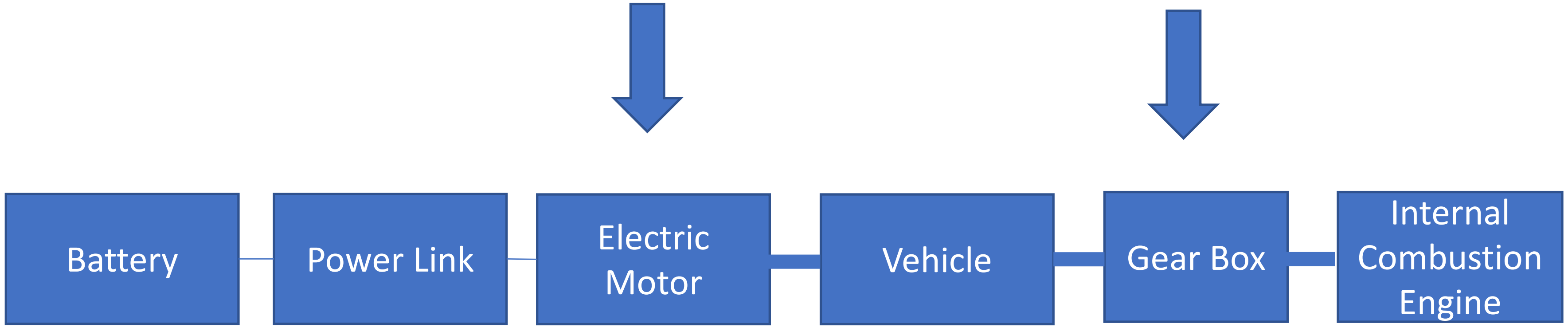
- In ***post-transmission* or *double-shaft*** parallel hybrids, the electric machine is mounted **downstream of the gearbox**, thus the two **speed levels are decoupled**.



Bold lines: mechanical link - Solid lines: electrical link

Medium parallel hybrid configuration

- In ***through-the-road*** parallel hybrids (TTR HEV), the engine and the electric machine are mounted on two separate axles, thus the mechanical link between them is only **through the road**.
- Electric motor speed is rigidly connected to vehicle speed.
- Note: the addition of **wheel-motors** to front drive conventional vehicles allows to convert them in TTR HEV.



Bold lines: mechanical link - Solid lines: electrical link

Combined hybrid configuration

The **combined hybrid configuration** is mostly a **parallel hybrid**, but it contains **some features of a series hybrid**.

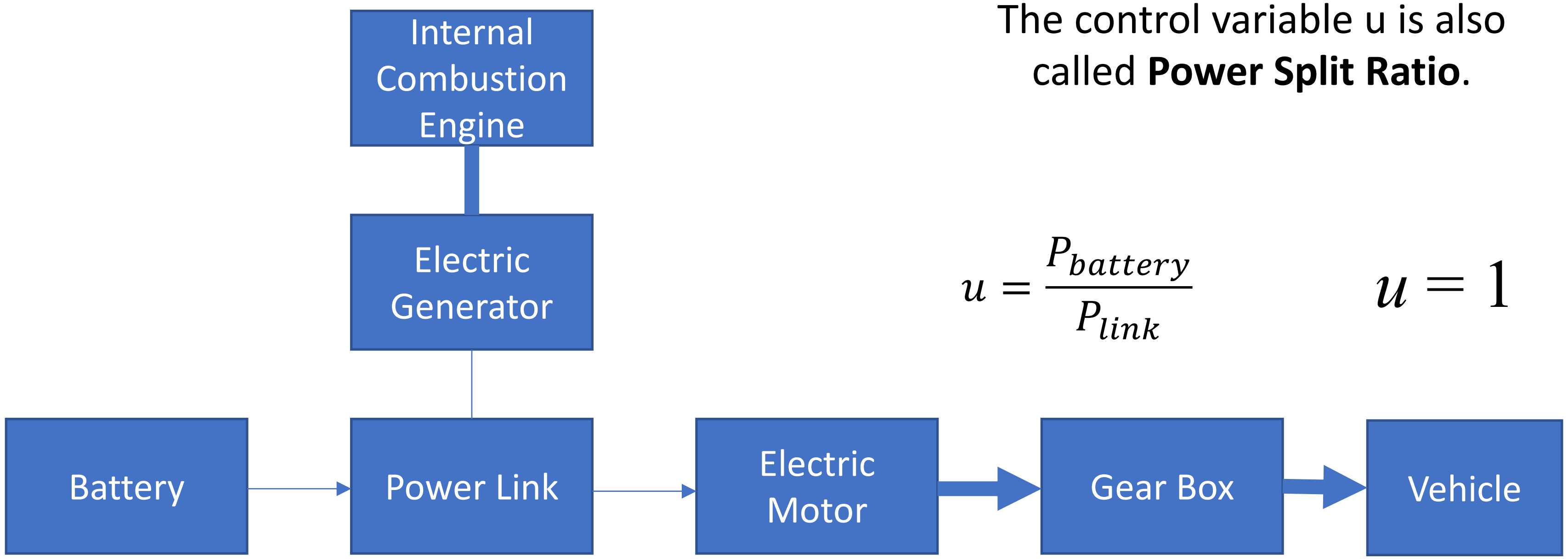
Both mechanical and electric links are present, with **two distinct electric machines**.

As in a parallel hybrid configuration, one is used as a **prime mover** or for **regenerative braking**.

The other machine acts like a **generator in a series hybrid**. It is used to charge the battery via the engine or for the stop-and-start operation.

Series hybrid vehicles 1

Pure electric driving, in zero-emission ZEV mode, can be adopted when the battery is sufficiently charged, usually in urban driving.



The control variable u is also called **Power Split Ratio**.

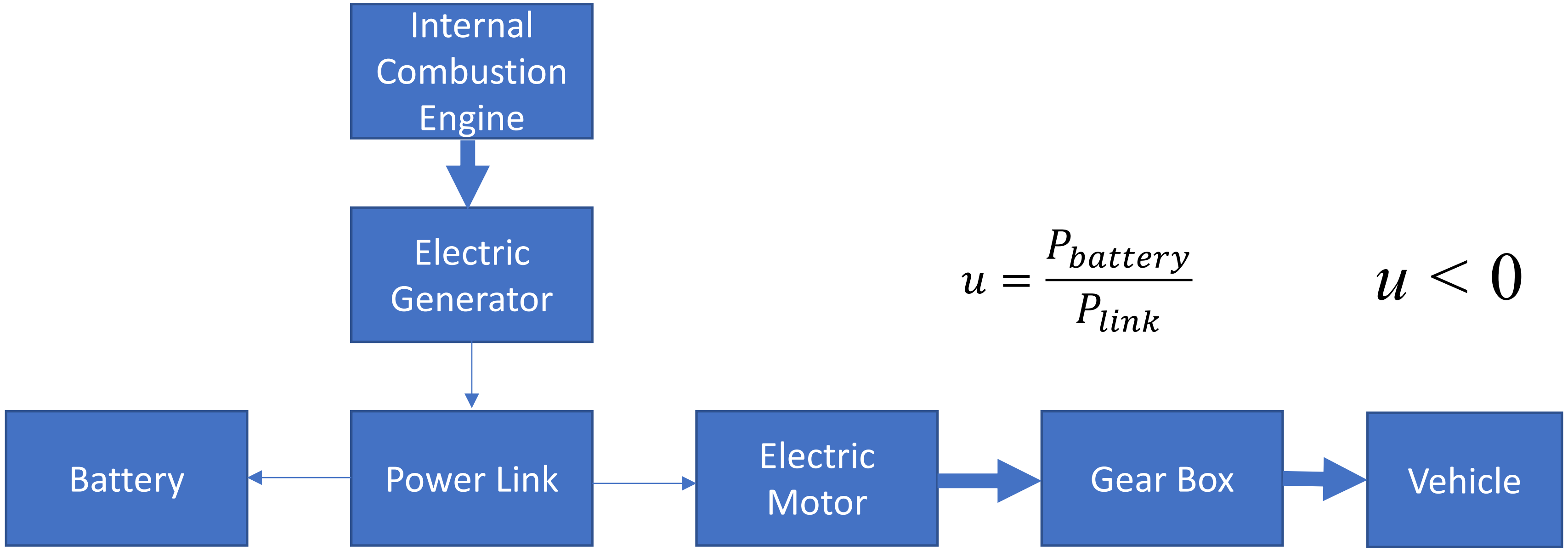
$$u = \frac{P_{battery}}{P_{link}}$$

$$u = 1$$

Series hybrid vehicles 2

When the battery charge is too low, the engine is turned on and typically set near its **maximum efficiency operating point**.

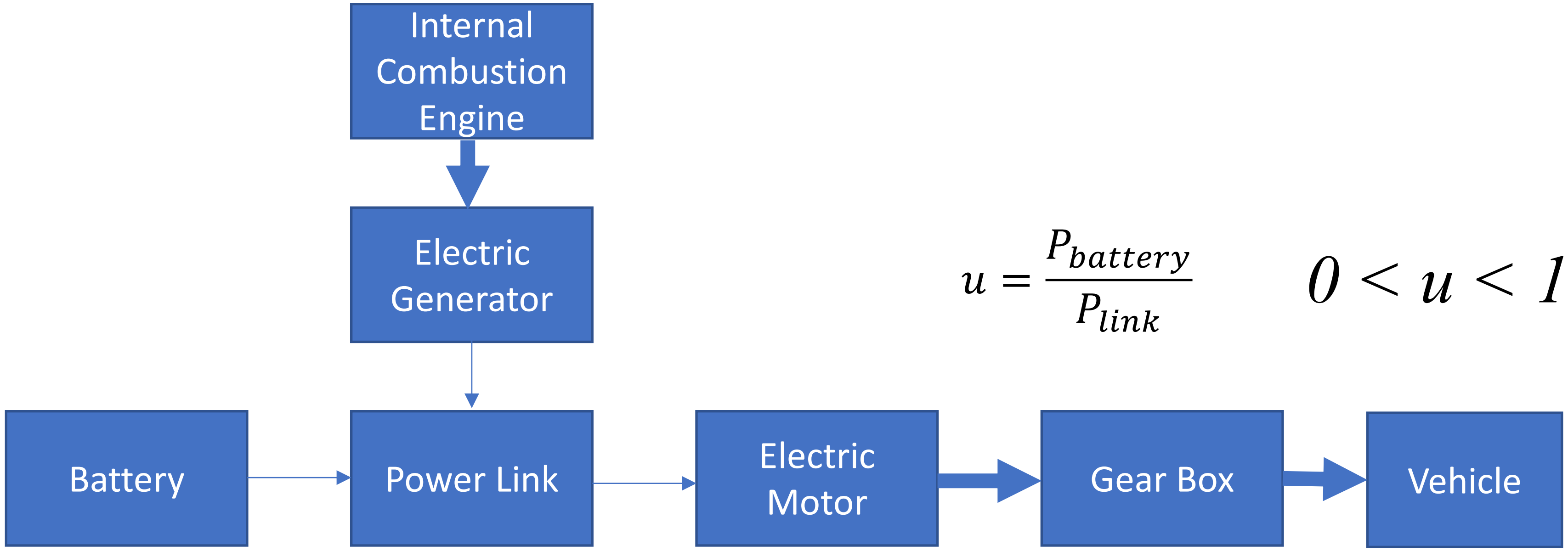
The power resulting from the difference between the engine power and the power at the link **recharges the battery** via the generator.



$$u = \frac{P_{battery}}{P_{link}} \qquad u < 0$$

Series hybrid vehicles 3

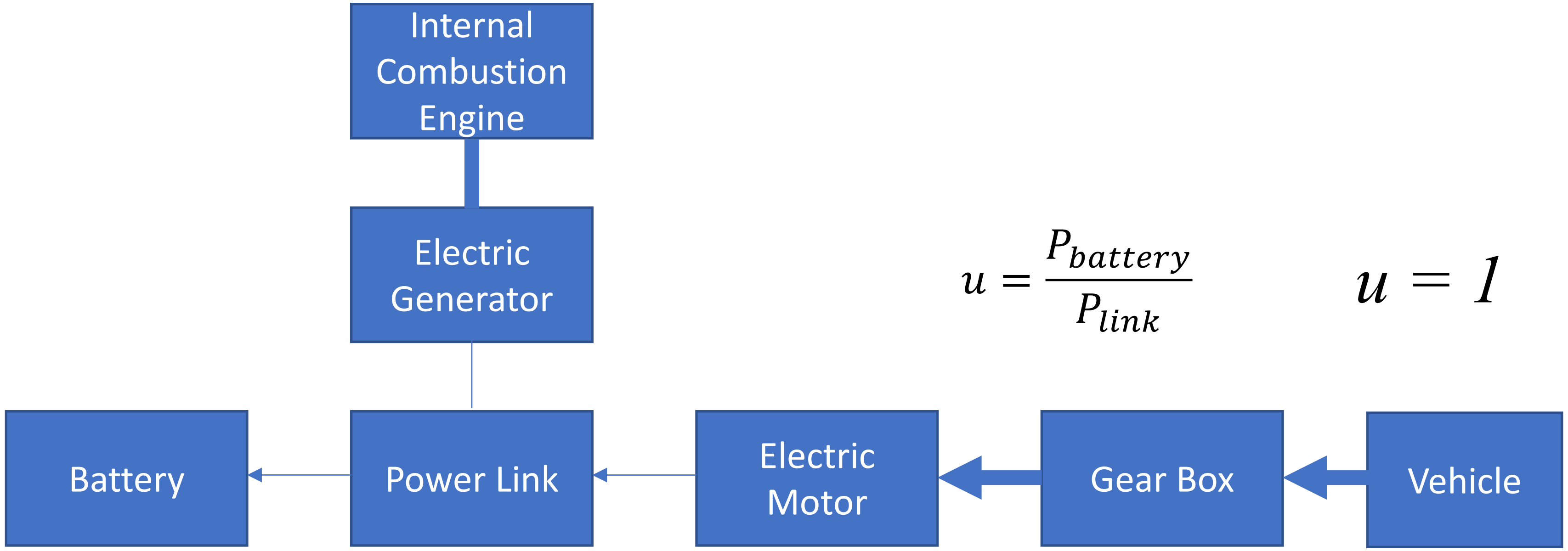
Hybrid driving: when the fuel-optimal engine power is below the power at the link, the battery could provide the **missing power**.



$$u = \frac{P_{battery}}{P_{link}} \qquad 0 < u < 1$$

Series hybrid vehicles 4

During decelerations or braking, part of the kinetic energy is recuperated in the battery by using the electric machine as **generator**.

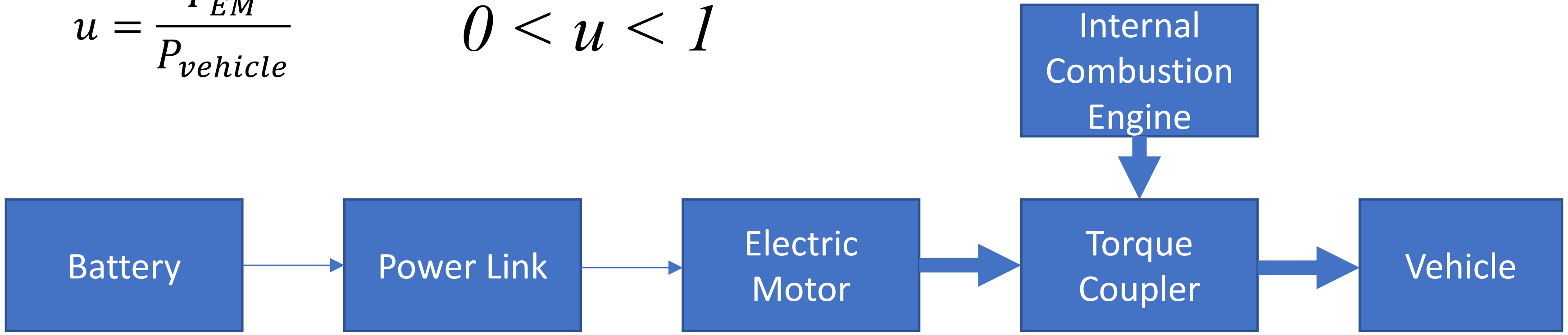


$$u = \frac{P_{battery}}{P_{link}} \qquad u = 1$$

Modes of operation of parallel hybrid vehicles: Power Assist

During **startup** or **acceleration**, the engine provides only a fraction of the total power at the coupler, while the remaining part is delivered by the motor. This operating mode is often referred to as ***power assist*** mode.

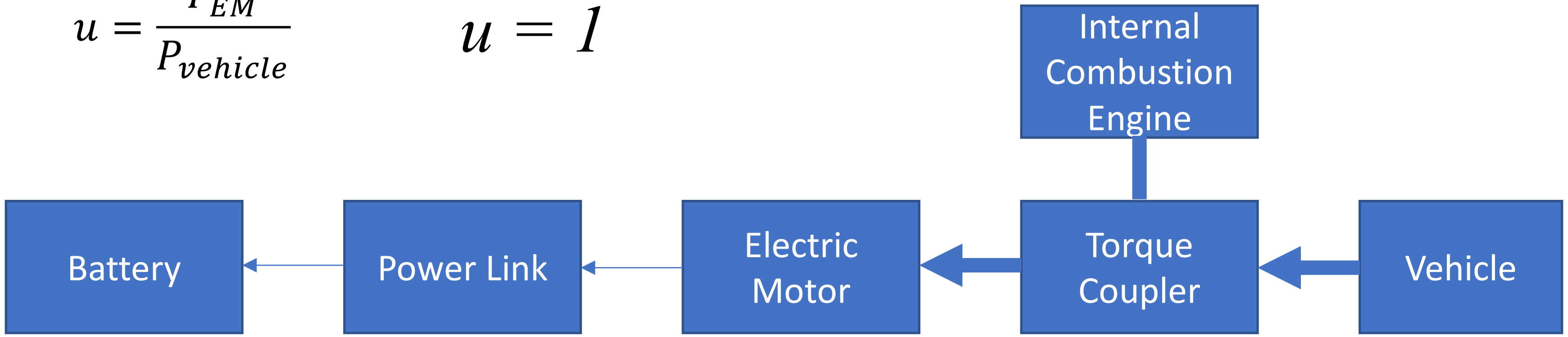
$$u = \frac{P_{EM}}{P_{vehicle}} \qquad 0 < u < 1$$



Modes of operation of parallel hybrid vehicles: Regenerative Braking

During **braking** or **deceleration**, the motor acts as generator and recuperates energy into the battery.

$$u = \frac{P_{EM}}{P_{vehicle}} \qquad u = 1$$

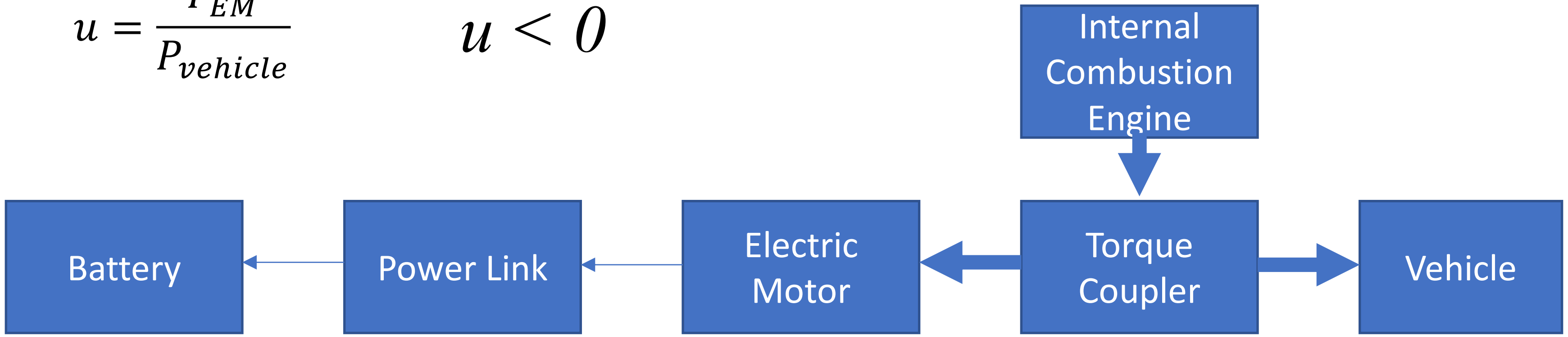


Modes of operation of parallel hybrid vehicles: Battery Recharging

It is also possible to shift the **operating point of the engine** towards **higher efficiency**.

At light load, the engine would then provide more power than strictly demanded and the extra power would be used to charge the battery via the electric machine.

$$u = \frac{P_{EM}}{P_{vehicle}} \qquad u < 0$$

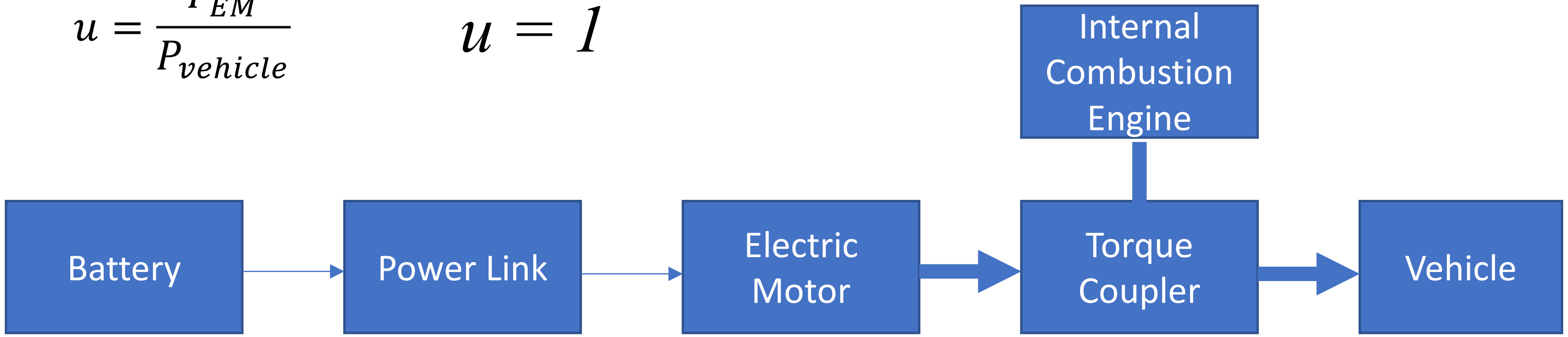


Modes of operation of parallel hybrid vehicles: Pure Electric

In pure electric mode, engine is off and **only the electric motor drivers the vehicle**.

In such way, **Zero Emission Vehicle** mode can be achieved. This is particularly useful in urban driving, when battery is enough charged.

$$u = \frac{P_{EM}}{P_{vehicle}} \qquad u = 1$$

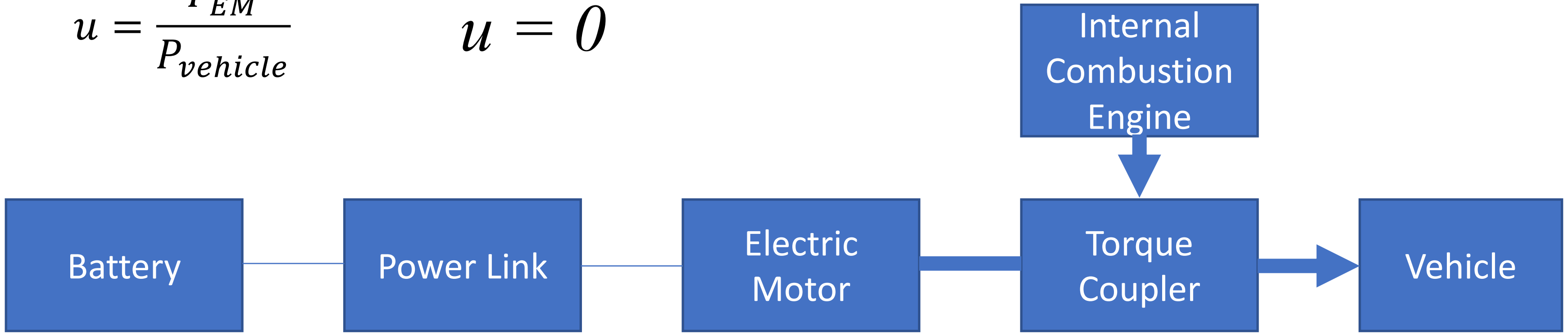


Modes of operation of parallel hybrid vehicles: Thermal Mode

In **thermal mode**, the vehicle is powered **only by the engine**, as in a conventional vehicle.

This mode may be used in extra-urban driving. Electric assistance would be necessary to reach the maximum vehicle power.

$$u = \frac{P_{EM}}{P_{vehicle}} \qquad u = 0$$



Closure

Hybrid Electric Vehicles were invented in late 1800's, but started their commercial diffusion after 1997 with Toyota Prius. Their sales are rapidly increasing in last years.

Parallel HEV is the most diffused architecture.

Series HEV's allow to optimize the engine operation, but suffer for multiple energy conversion.

Plug-in HEV (PHEV) combine the benefits of BEV and of HEV, but with higher costs and mass, increasing vehicle energy demand.

The performance and the benefits of HEV's are highly dependent on **Degree of Hybridization**. DoH is a **design variable**, fixed for every hybrid vehicle.

The operation of a HEV during different driving conditions can be analyzed considering their **Power Split** ratio, an **operating variable** changing during vehicle operation.

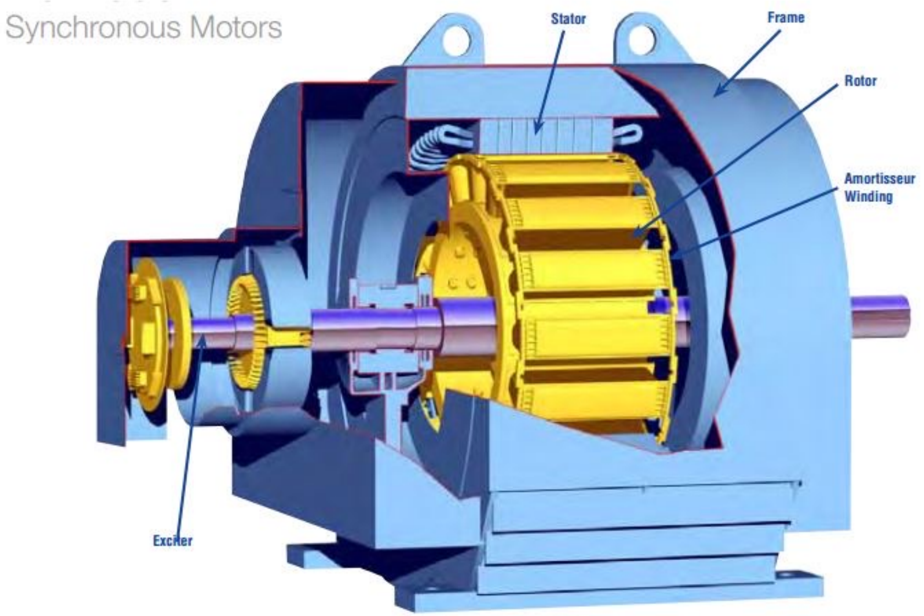
Electric Components

- Motor/Generator
- Inverter
- Battery

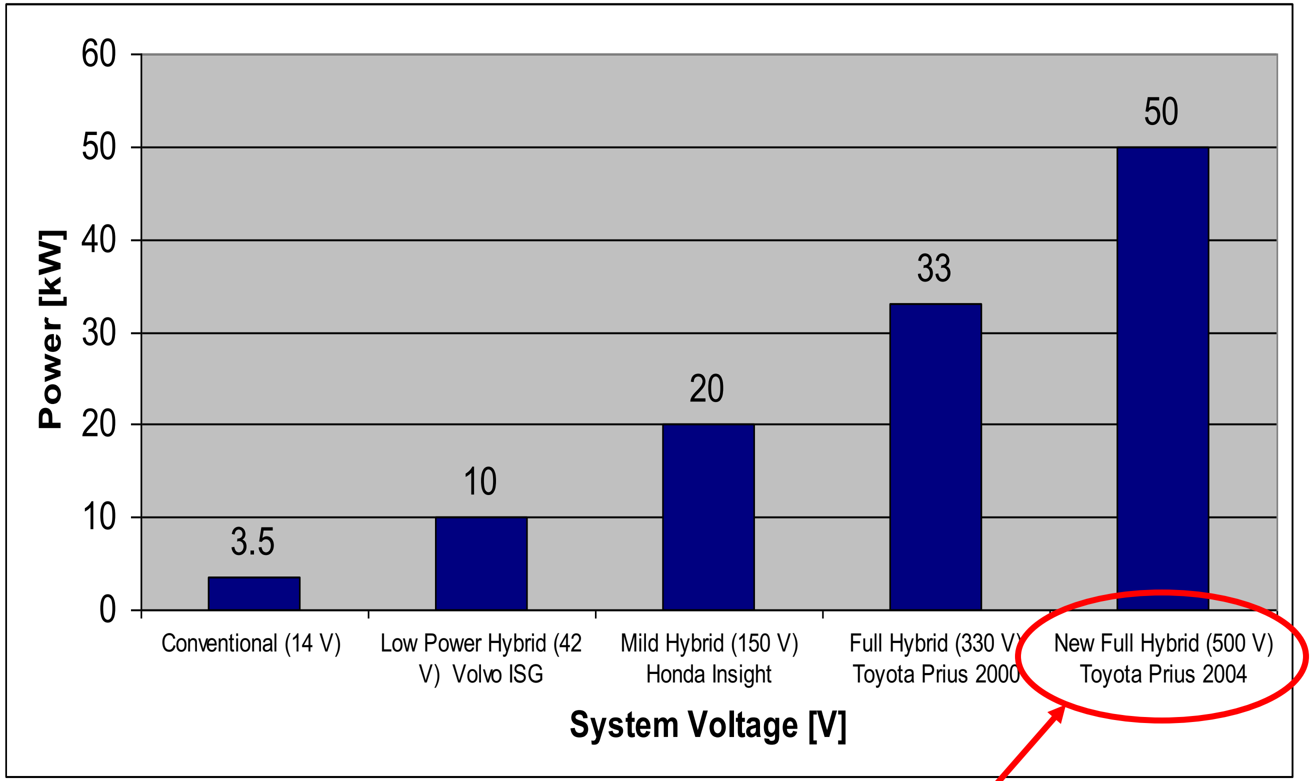
Synchronous electric motor

A **synchronous electric motor** is an AC motor in which, at steady state, the rotation of the shaft is synchronized with the frequency of the supply current; the rotation period is exactly equal to an integral number of AC cycles.

Synchronous motors contain multiphase AC electromagnets on the stator of the motor that create a magnetic field which rotates in time with the oscillations of the line current.



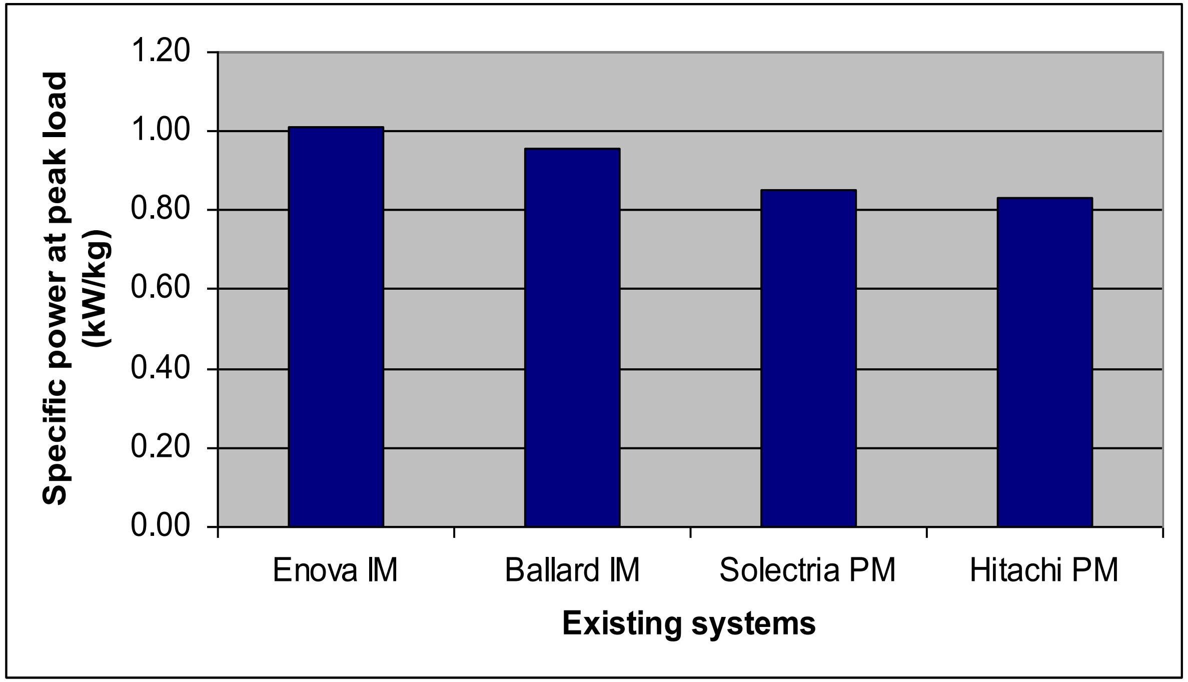
Electric drives/motors for HEV applications – Trends



High voltage allows reducing parasitic losses and, thus, increasing power density

Actual features of electric machines for HEV applications

Traction motor	Status
Specific power at peak load (kW/kg)	1.0
Volumetric power density (kW/L)	3.5
Cost per kilowatt at peak load (US $/kW)	16
Efficiency	93%



Electric machines in HEVs

- Electric machines are used both as **motors** and as **generators** in HEV’s.
- **One reversible** machine is used in parallel hybrid vehicles, while **two** separate machines are used in series hybrids and in complex hybrids.
- In parallel hybrids, a proper selection of ICE and EM can result in a **favorable torque** curve for the vehicle.

Torque-Speed curve: Electric Motor vs. I.C. Engine

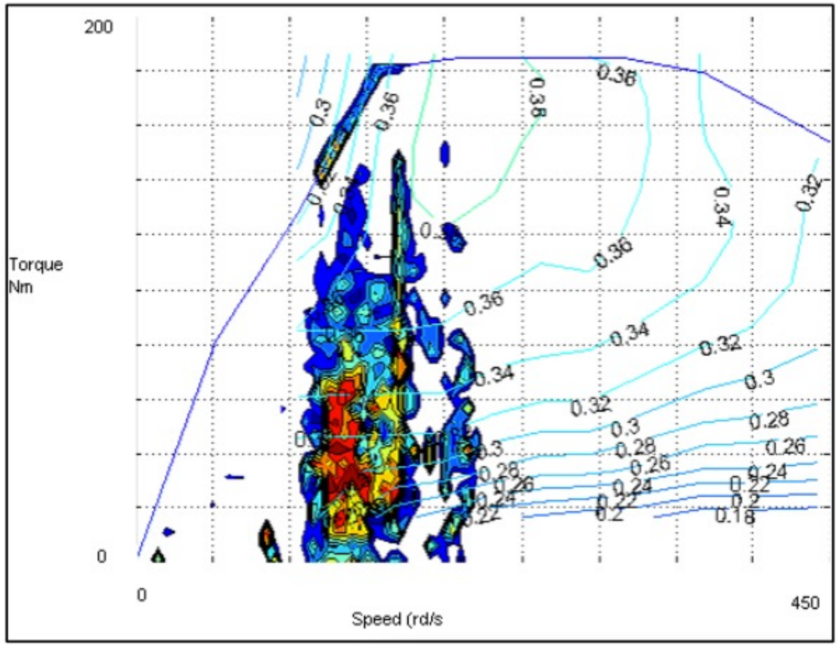
- The Electric Motor torque is limited by **maximum deliverable torque** (at low rpm) and by **maximum power**, until **maximum rpm**.

- Engine torque is zero below **idle conditions**, due to combustion instability.
- Torque drops to zero at higher rpm, due to **mechanical losses**.
- Maximum torque is reached at lower rpm for better driveability of to high rpm for high power.

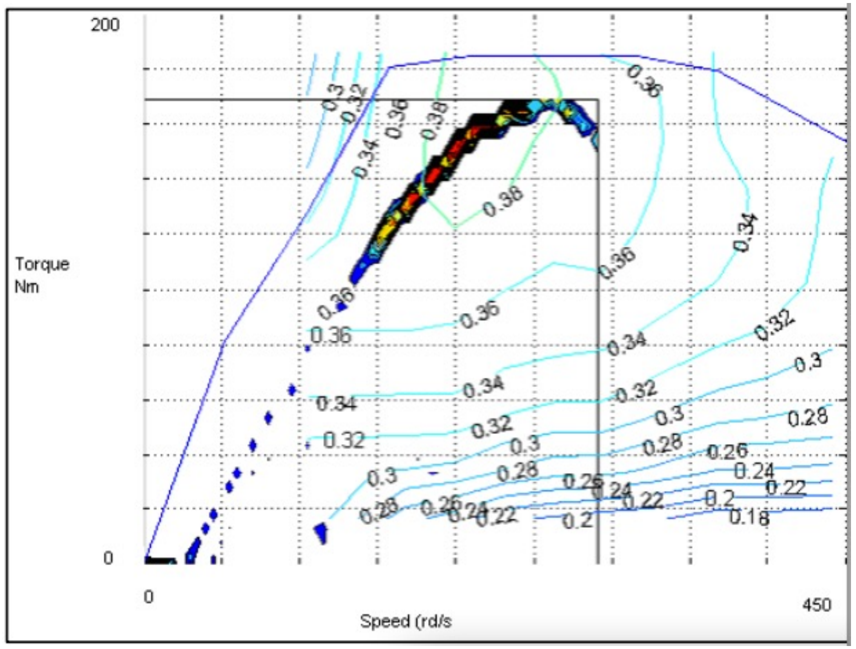
Torque-Speed curve: Parallel Hybrid Powertrain

- **Summing up** ICE and EM torque allows to optimize powertrain torque, achieving **high torque at low speed** (as electric motor) and **extending the range of higher torque**.

Engine efficiency improvement in HEV's



Conventional vehicle



Hybrid vehicle

The integration with an electric motor/generator in a hybrid electric vehicle allows thermal engine operating mostly in **higher efficiency region** with respect to a conventional vehicle.

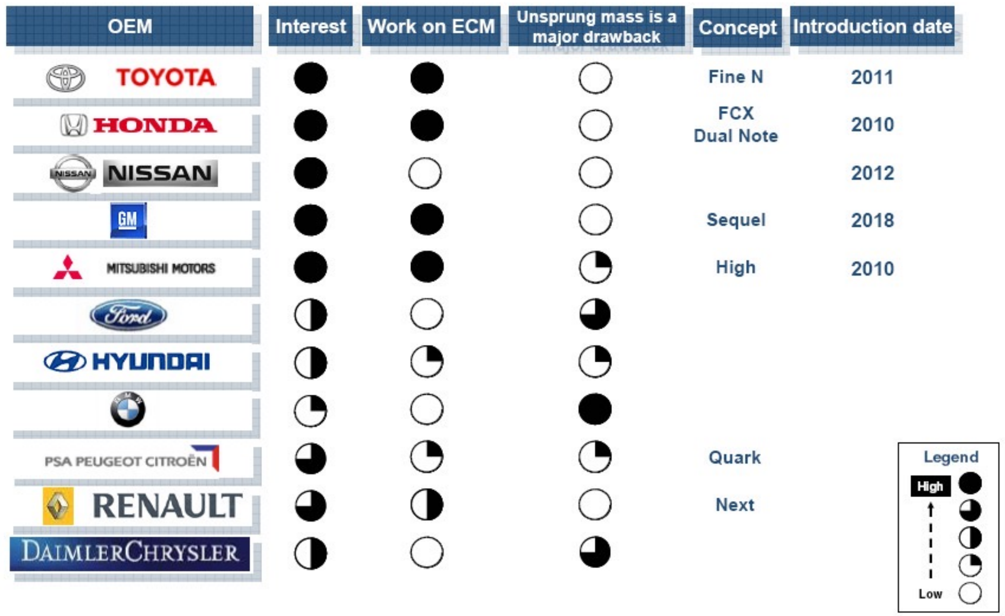
In Wheel Motors

In Wheel Motors are gaining increasing industrial interest, being strongly related to the diffusion of electric vehicles.

They may be considered as a **disruptive technology** (Murata, 2010).

Their use would also allow to **integrate drive-by-wire and advanced techniques for vehicle control** and to **expand the applicable range of vehicle control**.

An expanding market is in Asia, where IWT are being extensively used for **electrical bicycles and motorcycles**.



OEM	Interest	Work on ECM	Unsprung mass is a major drawback	Concept	Introduction date
TOYOTA	●	●	○	Fine N	2011
HONDA	●	●	○	FCX Dual Note	2010
NISSAN	●	○	○		2012
GM	●	●	○	Sequel	2018
MITSUBISHI MOTORS	●	●	◔	High	2010
Ford	◑	○	◕		
HYUNDAI	◑	◔	◔		
BMW	◔	○	●		
PSA PEUGEOT CITROËN	◕	◔	◔	Quark	
RENAULT	◕	◑	○	Next	
DAIMLERCHRYSLER	◑	○	◕		

Legend
High ●
◕
◑
◔
Low ○

© Siemens VDO Automotive AG | Bernd Gombert

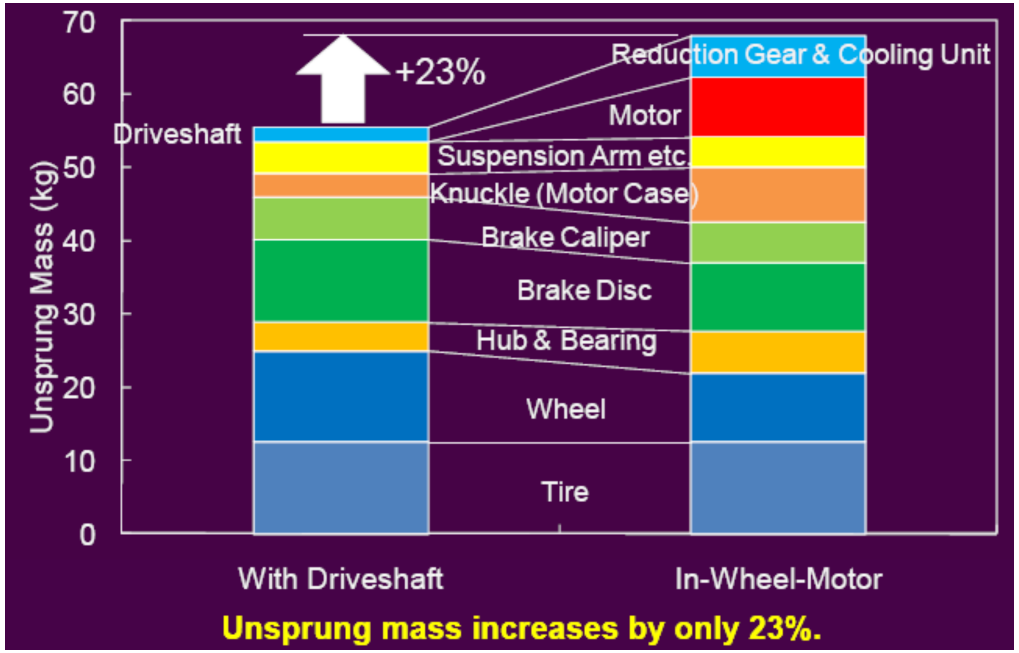
Munich Network – Mobilität "Trends auf der Straße", 28. November 2007

Interests and activities of OEM's toward in-wheel motors

In Wheel Motors: problems

The main problems of IWM are the following:

- The installation of a motor inside the wheel is made difficult by the standpoint of **space constraints**.
- Moreover, deterioration of ride comfort due to **increase in unsprung mass** occurs.
- The complexity of these problems tends to increase with **motor power**.



Satoshi MURATA, TOYOTA MOTOR CORPORATION, Innovation by In-Wheel-Motor Drive Unit, AVEC 2010.

Some In-Wheel Motors

Michelin Active Wheel

Kelly (HySolarKit)

Elaphe

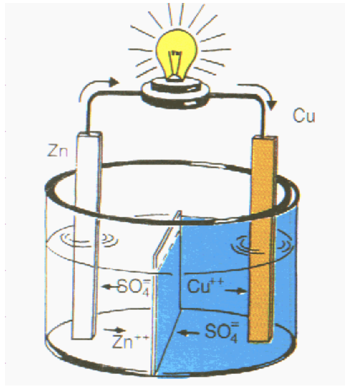
Protean Electric

Batteries: introduction

Batteries are electrochemical energy storage systems that convert directly chemical energy into electrical one (discharge) and viceversa (charge)

The first battery was developed by Alessandro Volta in 1799:

- copper and zinc diskettes
- cloth soaked with water and sulfuric acid
- two copper wires

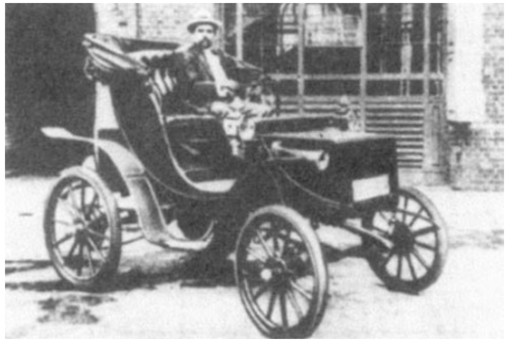


Batteries: Electrochemical Features

battery	anode	cathode	electrolyte	cell voltage
lead–acid	Pb	PbO_2	H_2SO_4	2 V
nickel–metal hydride	Metal hydride	$Ni(OH)_2$	KOH	1.2 V
lithium-ion	carbon	Li oxide	Lithiated solution	3.6 V
lithium-metal-polymer	Li	Plastic composite	Solid polymer	3.7 V
sodium–nickel chloride	Na	$NiCl_2$	Al_2O_3	2.58 V
lithium–air	Li	O_2	organic solution	3.4 V

Electrochemical features of various traction battery technologies

Batteries for automotive application



The first electric battery-powered car, the Runabout (1890).

Toyota Prius (HEV)

Tesla Model S (EV)

Toyota Auris (HEV)

Nissan Leaf (EV)

The traveling range of battery-powered vehicles will always be very limited compared to vehicles featuring combustion engines

Specific energy:

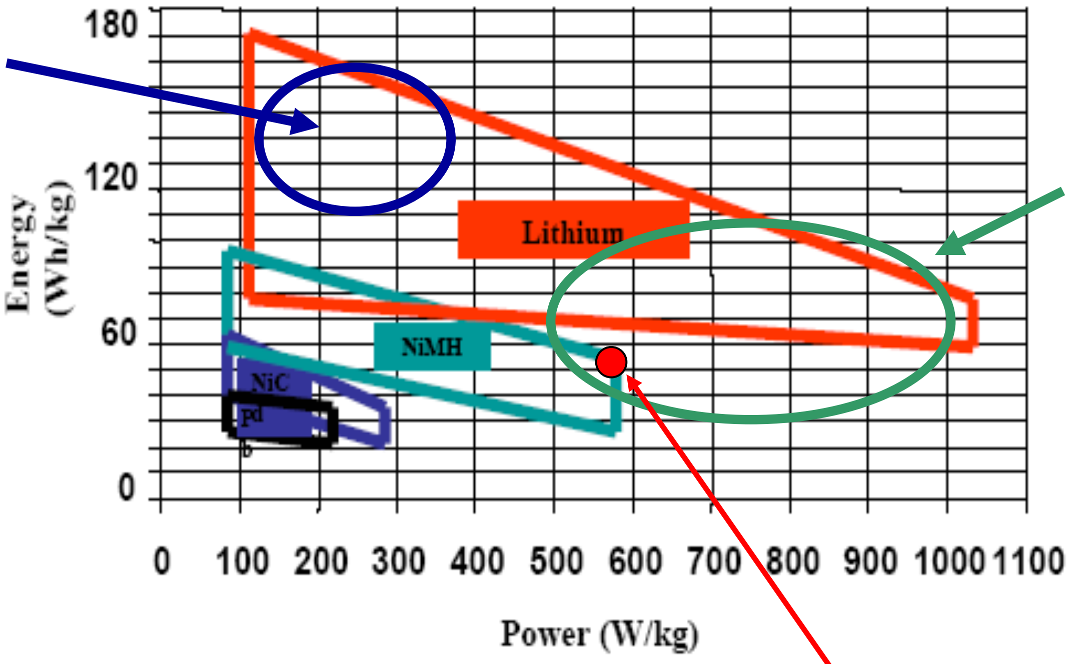
Batteries (40 to 240 Wh/kg) vs. Gasoline (12,000 to 13,000 Wh/kg)

The energy required for a medium vehicle (M1) in a combined cycle is about 140 Wh/km

Batteries for automotive application

- Making batteries lighter by significantly higher specific energy and power
- High DOD (>1000 cycles)
- High efficiency
- As maintenance free as possible without sophisticated peripheral equipment.
- No noticeable rise in price through energy consumption during use.
- Same or improved reliability compared to present products.

Comparison of battery characteristics

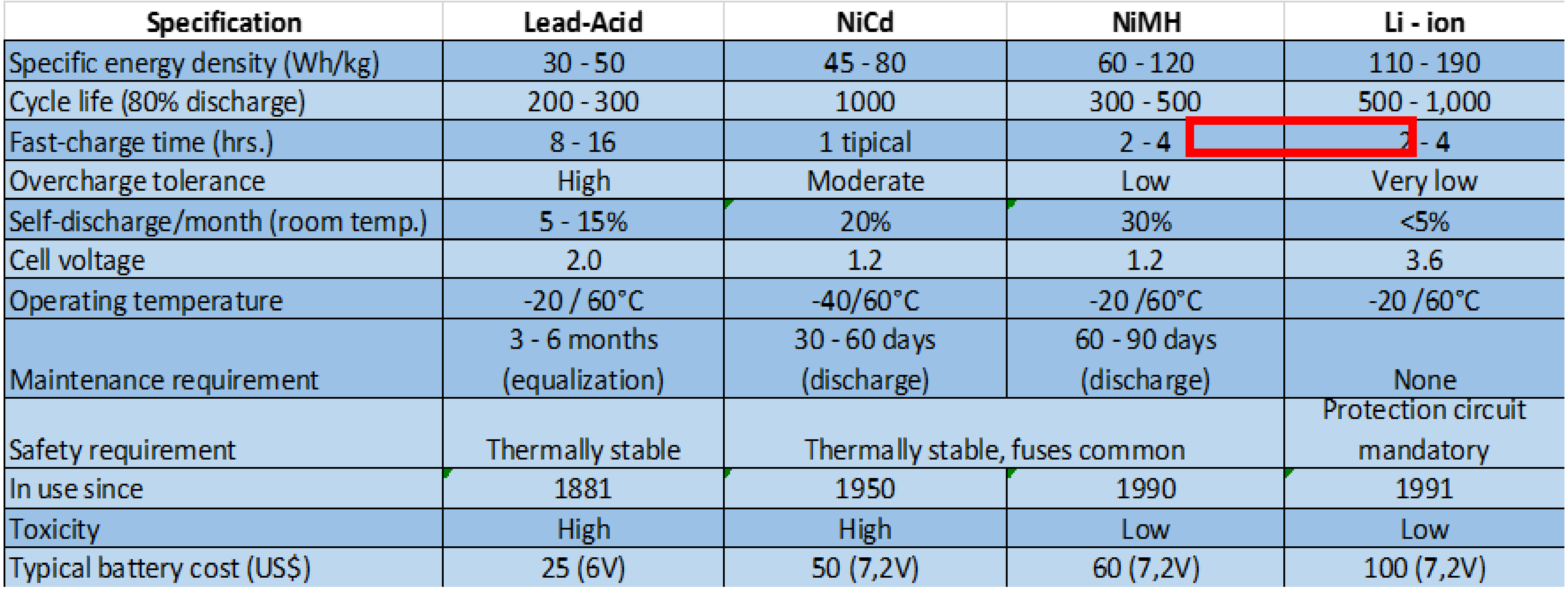


EV needs high specific energy to guarantee 100 km/day autonomy.

Series Range extender and full HEV requires higher specific power.

Toyota Prius battery pack.

Battery technologies for electric road vehicles



Specification	Lead-Acid	NiCd	NiMH	Li - ion
Specific energy density (Wh/kg)	30 - 50	45 - 80	60 - 120	110 - 190
Cycle life (80% discharge)	200 - 300	1000	300 - 500	500 - 1,000
Fast-charge time (hrs.)	8 - 16	1 tipical	2 - 4	2 - 4
Overcharge tolerance	High	Moderate	Low	Very low
Self-discharge/month (room temp.)	5 - 15%	20%	30%	<5%
Cell voltage	2.0	1.2	1.2	3.6
Operating temperature	-20 / 60°C	-40/60°C	-20 /60°C	-20 /60°C
Maintenance requirement	3 - 6 months (equalization)	30 - 60 days (discharge)	60 - 90 days (discharge)	None
Safety requirement	Thermally stable	Thermally stable, fuses common		Protection circuit mandatory
In use since	1881	1950	1990	1991
Toxicity	High	High	Low	Low
Typical battery cost (US$)	25 (6V)	50 (7,2V)	60 (7,2V)	100 (7,2V)

Toyota - Prius (HEV)

ICE

1798 (cc)	
Max power	72 kW @ 5.200 rpm
Max torque	142 Nm @ 3.600 rpm

ELECTRICAL MOTOR

Synchronous permanent magnet	
Nominal Voltage	650 V
Max Power	53 kW
Max Torque	163 Nm

BATTERY

Nickel-Metal hydride (NiMH)	
Nominal Voltage	**201,6 V**
Capacity	**6,5 Ah**
Max Energy	201,6x6,5= **1310,4 Wh**

Toyota – Auris (HEV)

ICE

1798 (cc)	
Max power	72 kW @ 5.200 rpm
Max torque	142 Nm @ 3.600 rpm

ELECTRICAL MOTOR

Synchronous permanent magnet	
Nominal Voltage	650 V
Max Power	60 kW
Max Torque	207 Nm

BATTERY

Nickel-Metal hydride (NiMH)	
Nominal Voltage	**201,6 V**
Capacity	**6,5 Ah**
Max Energy	201,6x6,5= **1310,4 Wh**

Tesla – Model S (EV)

Model S (70D)
244 kW AC synchronous electric motor
70 kWh battery (Lithium ion)
384 km range
224 km/h top speed

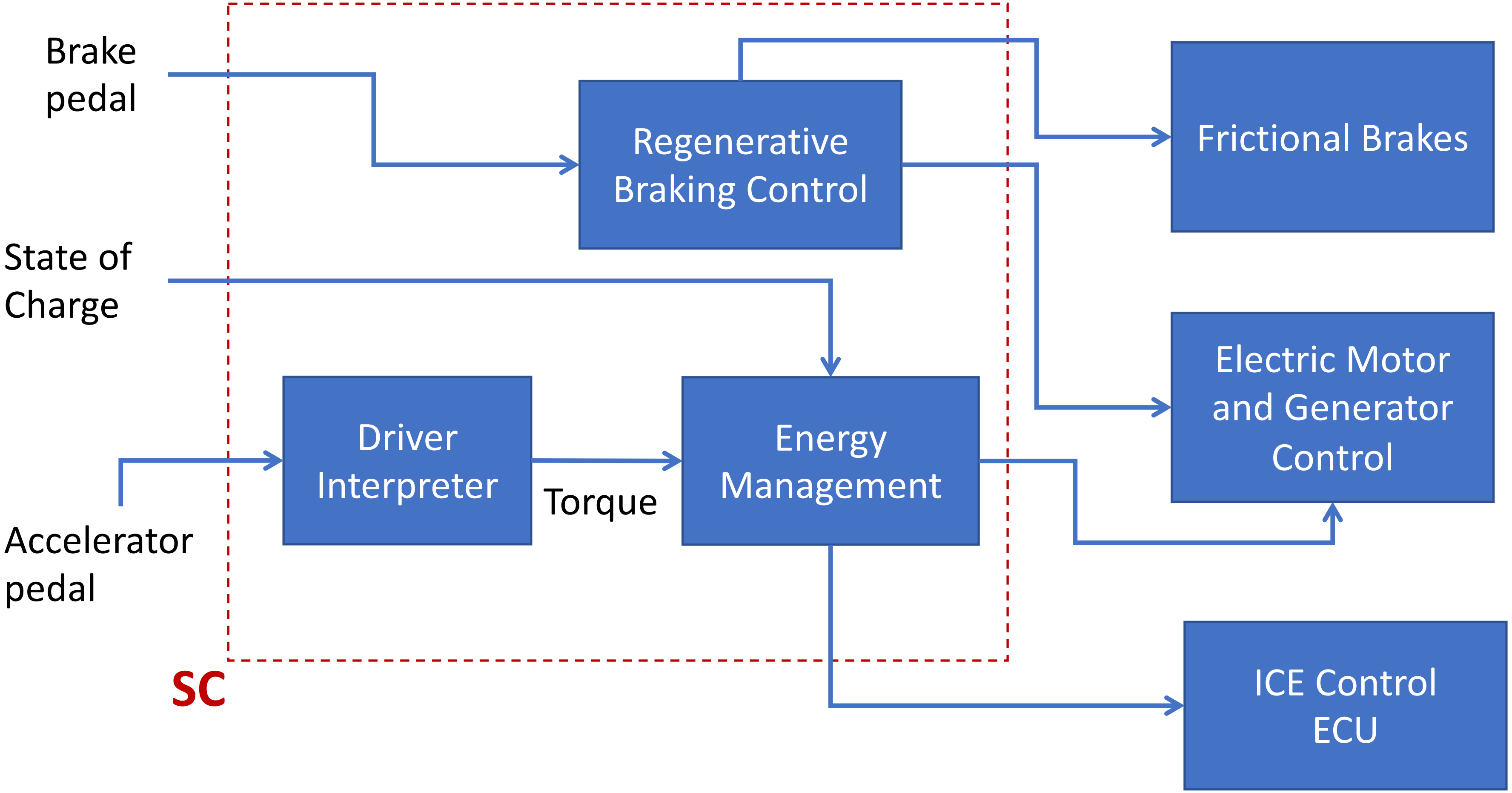
Nissan – Leaf (EV)

80 kW AC synchronous electric motor
24 kWh battery (Lithium ion)
160 km range
144 km/h top speed

Supervisory Control

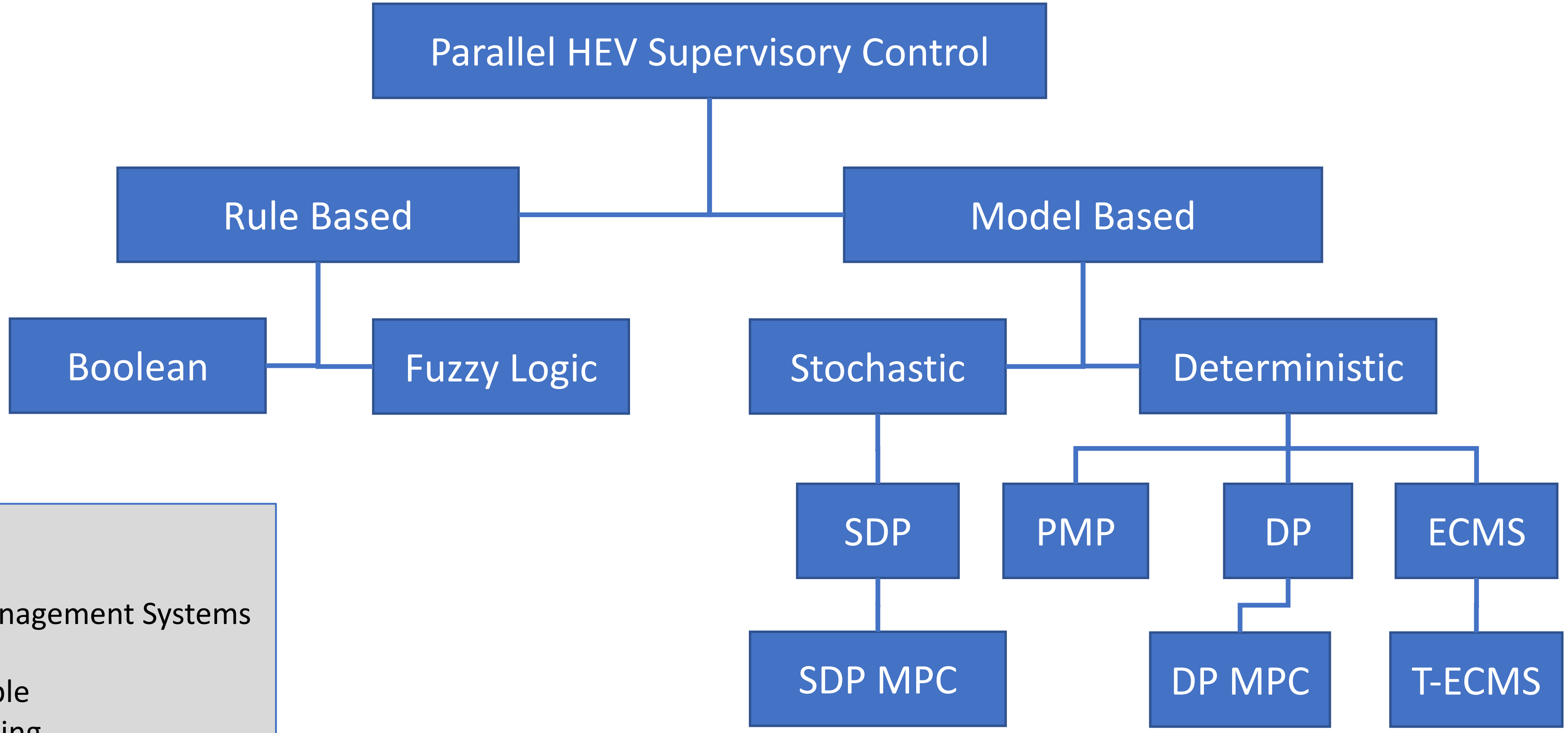
- In all types of hybrid vehicles, a **supervisory controller** (SC) must determine how the powertrain components should operate, in order to satisfy the **power demand** of the drive line in the best way.
- The main objective of the SC is **reducing the overall energy use**, typically in the presence of various **constraints** due to **emissions**, **driveability** requirements and the characteristics of the components.
- Different classification approaches can be adopted for SC:
  - Off-line vs real-time
  - Causal vs non-causal (i.e. vehicle mission known in advance)
  - Heuristic vs optimal
  - Rule based vs model based

Supervisory Control Schematics



The scheme shows the main functions and components of a **Supervisory Control** SC (also Vehicle Management Unit, VMU) for a HEV.

Supervisory Control Classification: Rule Based vs Model Based



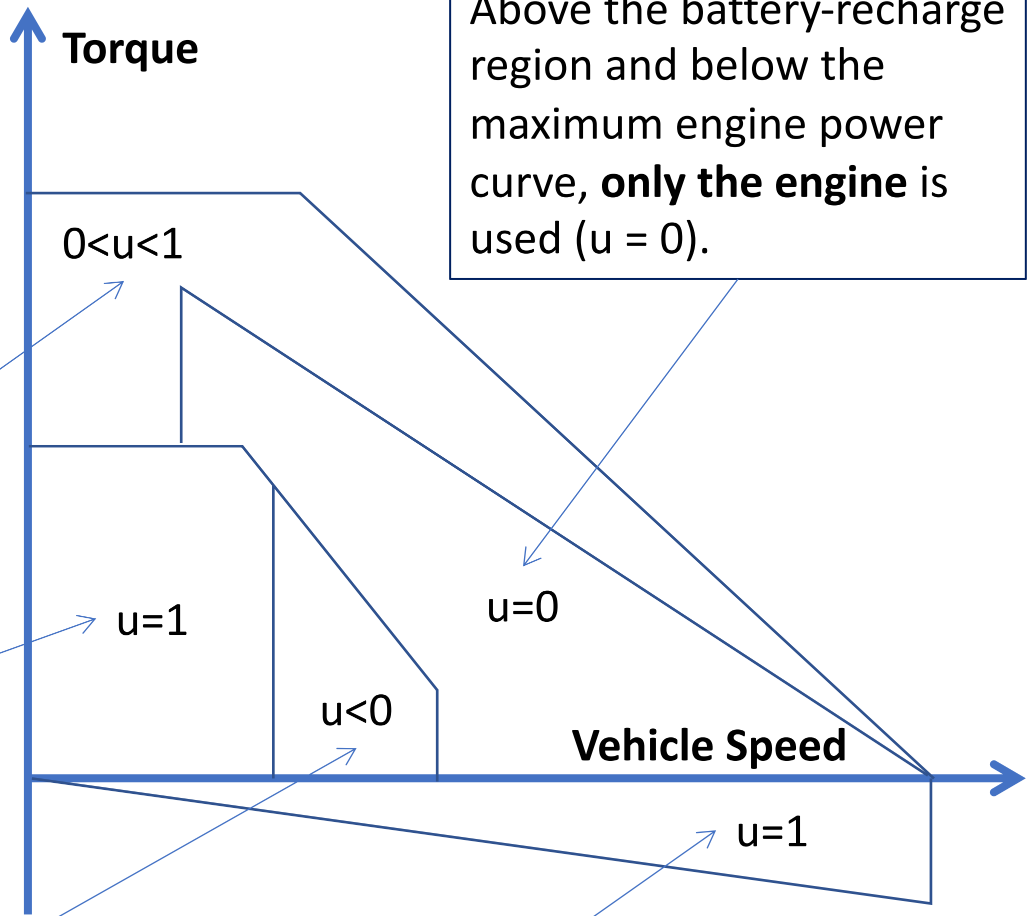
- Parallel HEV Supervisory Control
  - Rule Based
    - Boolean
    - Fuzzy Logic
  - Model Based
    - Stochastic
      - SDP
        - SDP MPC
    - Deterministic
      - PMP
      - DP
        - DP MPC
      - ECMS
        - T-ECMS

Acronyms:
DP: Dynamic Programming
ECMS: Equivalent Consumption Management Systems
MPC: Model Predictive Control
PMP: Pontryagin’s Minimum Principle
SDP: Stochastic Dynamic Programming
T-ECMS: Telemetry ECMS

Adapted from: Tae Soo Kim, Optimal Control of a Parallel Hybrid Electric Vehicle with Traffic Preview, PhD Thesis, The University of Melbourne, November 2011

Energy management in a PHEV Map based approach

In map based approach, the decisions about power split (u) for a Parallel HEV may be expressed as a function of vehicle torque and speed.



Above the maximum power of the engine, the motor is used to **assist the engine** (0 < u < 1).

Below a certain vehicle speed and a certain wheel power, **pure electric driving** is selected (*u* = 1).

For intermediate power levels, the engine is forced to deliver excess torque to **recharge the battery** (u < 0).

Above the battery-recharge region and below the maximum engine power curve, **only the engine** is used (u = 0).

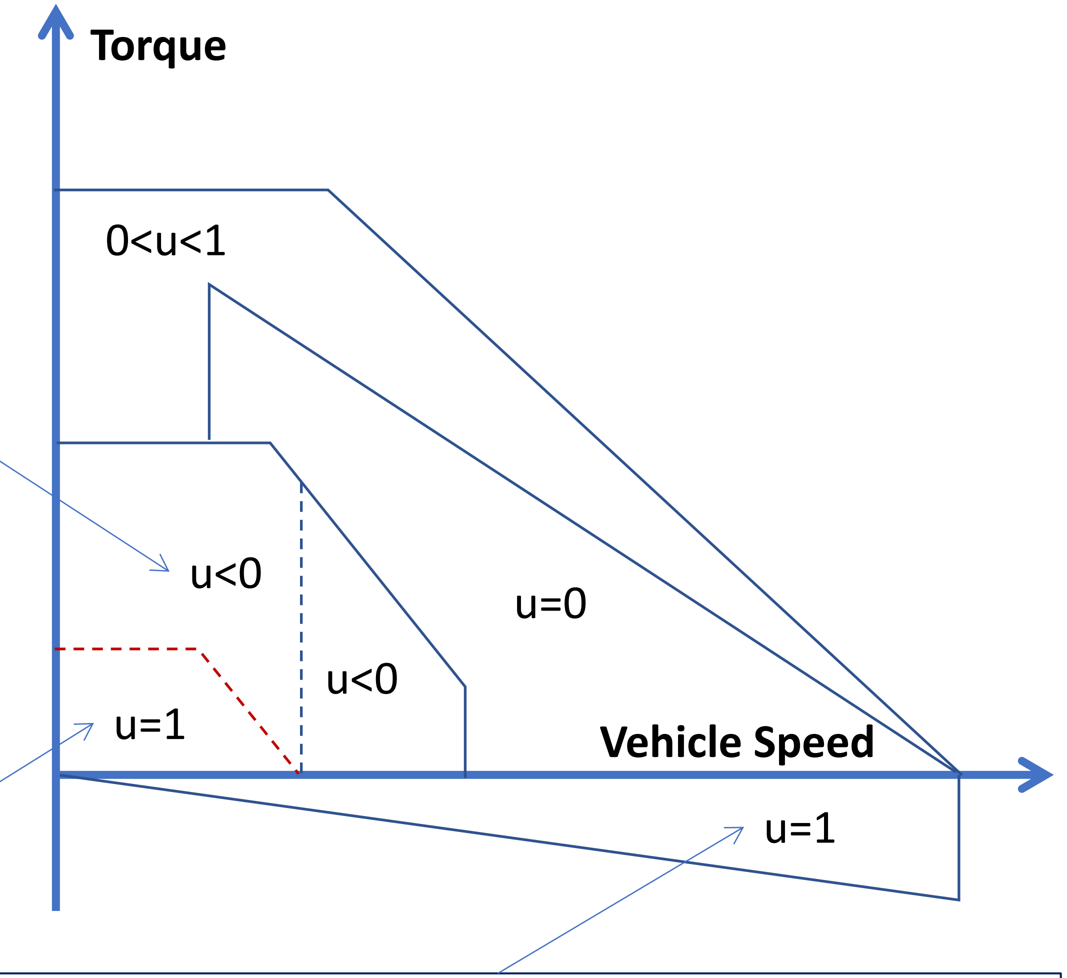
At negative torque values, **regenerative braking** is adopted

Map based approach
Effects of SoC

The extensions of certain areas depend also by the actual state of charge (SoC) of the battery.

The operating region where the engine is forced to deliver excess torque to **recharge the battery** (u < 0) is enlarged as the SoC decreases (**red line**), while it is reduced or eliminated when battery is full charged.

When SoC decreases, the area of **pure electric driving** (u = 1) is reduced also.



When battery is **fully charged**, the current coming from electric brakes **cannot be delivered to the battery**.

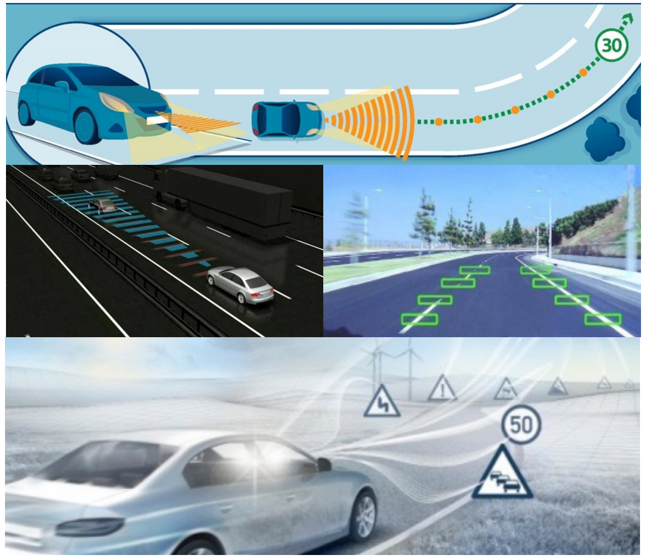
Optimal Energy Management. Off-line vs real-time strategies

Two basically different approaches can be adopted to design optimal control strategies in a HEV:

- **Off-line strategies**. The **drive cycle is assumed known a priori**. No constraints of computational power and time are given. This strategy is **not implementable**, but is useful to determine **benchmarks**, to assess the quality of implementable sub-optimal strategies.
- **On-line strategies**. In general, **drive cycle is not known**, except in particular conditions. There are also limitations in terms of computational time and power, and on reliability. **Sub-optimal strategies** are therefore often implemented.

Electronic Horizon & ADAS Maps

Advanced Driver Assistance Systems (ADAS) allow achieving benefits on safety and driver monitoring apart to improve fuel economy and environmental impact.



ADAS Maps include the information about the road ahead of the vehicle:

- Speed Limits
- Elevation and slope data
- Road length
- Signals
- Lanes number

The **Electronic Horizon (EH)** gathers together all these road information with onboard sensors and cameras data, and enables the vehicle to “see beyond the next bend”.

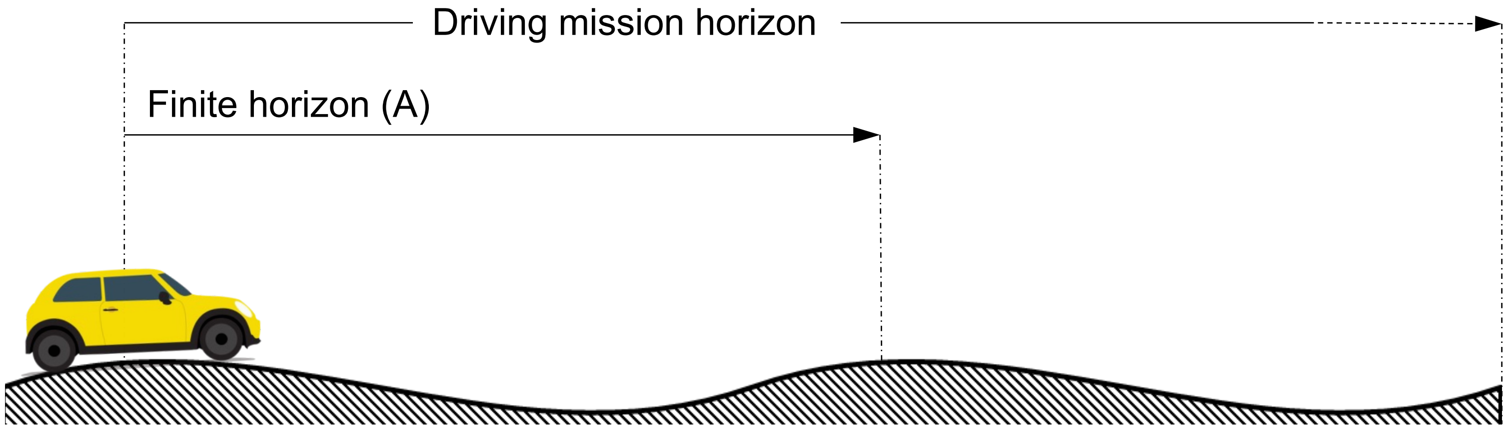
Receding Horizon Approach

Real driving scenarios are characterized by

- traffic flows
- interactions with surrounding vehicles
- traffic lights…

which can prevent the calculated optimal velocity from being tracked.

The optimal control problem is solved for a finite sliding horizon.



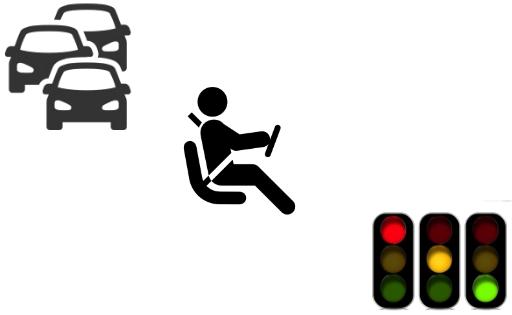
Receding Horizon Approach

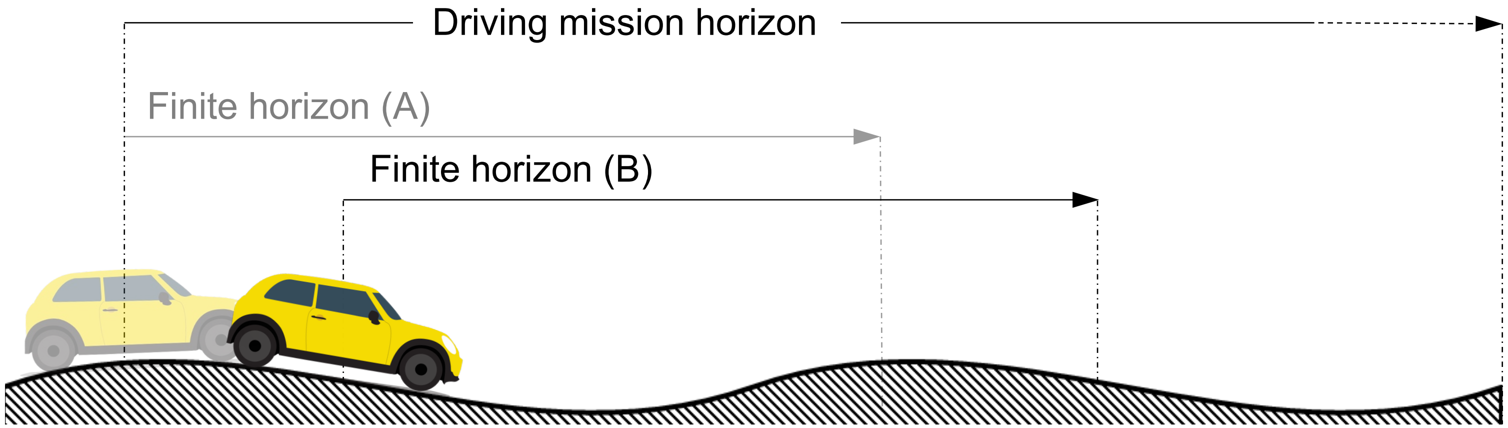
Real driving scenarios are characterized by

- traffic flows
- interactions with surrounding vehicles
- traffic lights…

which can prevent the calculated optimal velocity from being tracked.

The optimal control problem is solved for a finite sliding horizon.

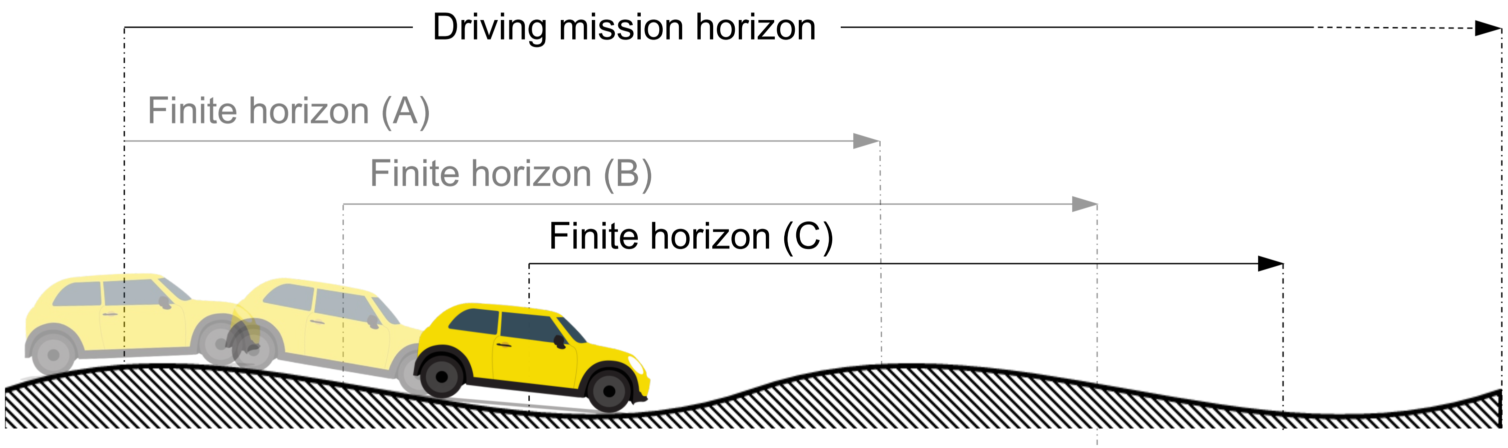




Receding Horizon Approach

Real driving scenarios are characterized by
- traffic flows
- interactions with surrounding vehicles
- traffic lights…

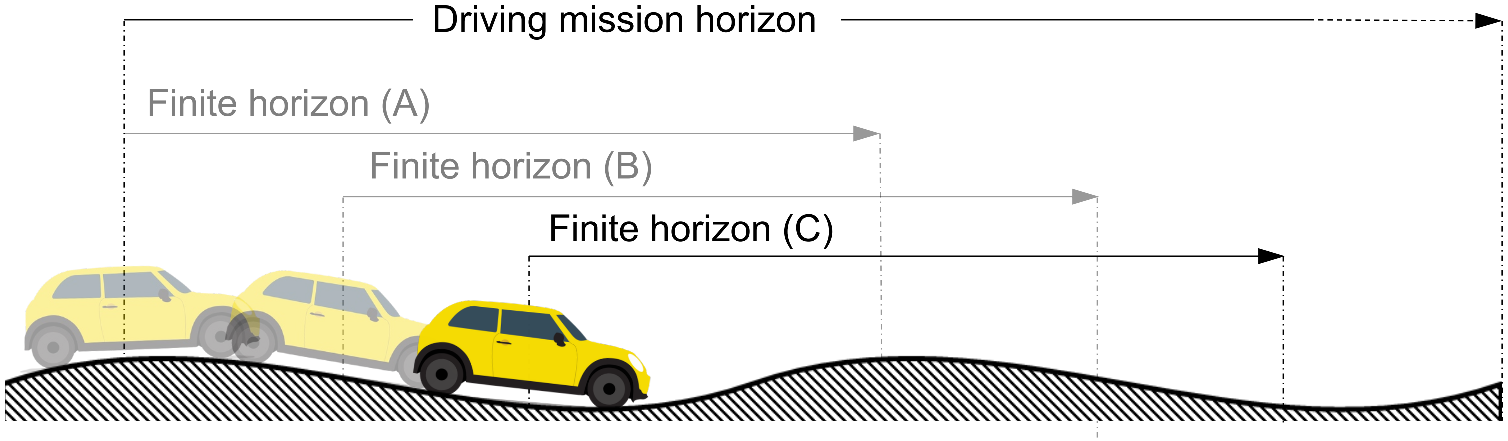
which can prevent the calculated optimal velocity from being tracked.
The optimal control problem is solved for a finite sliding horizon.



2018-01-1180

Receding Horizon Approach

- Sub-optimal solution
- Updates the optimal control law each 500 m
- Reduces the calculation time and memory usage (that are fixed)
- Adaptability to the environmental changes
- … optimization can be triggered if the vehicle drifts from the optimal reference



- Fabrizio Donatantonio, Antonio D'Amato, Ivan Arsie, and Cesare Pianese. *A multi-layer control hierarchy for heavy duty vehicles with o-line dual stage dynamic programming optimization*. Transportation Research Part C: Emerging Technologies, 92:486 503, 2018. ISSN 0968-090X. doi: 10.1016/j.trc.2018.05.006F.
- Polverino, P., Arsie, I., Pianese, C., Optimal energy management for hybrid electric vehicles based on dynamic programming and receding horizon. Energies, 2021, 14(12), 3502.

MASTER MEIM 2021-2022

Thank you for your attention