CHALMERS
UNIVERSITY OF TECHNOLOGY

DAT460 Förnyelsebar elproduktion och eltransporter lp2 HT20 (3,5 hp)

Ola Carlson, Chalmers

20201123

Hybridbilsteknik 1

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An introduction to…

Sustainable Transportation 1 (of 2)

…with focus on electrification of road transport

By: Dr. Emma Arfa Grunditz

Related intended learning outcomes

Why?

1. Describe/explain the **driving forces** for technical development towards increased electric power production from renewables as well as the **electrification of the transport sector**

How?

3. Describe the **technical characteristics and performance** of the components in the drivetrain of **electric and hybrid vehicles** and the combination of these components

4. Identify, formulate and analyze complex connections in electric power generation with renewables and electric power operation of **electric hybrid vehicles**

5. Plan and carry out calculations for electric power production with renewables and of the **electric consumption during operation with electric vehicles through modelling and simulations**

6. Make **choices of solutions** and justifications due to relevant criteria's of the problems and opportunities associated with the use of **hybrid electrical vehicles** and power production with renewable power production

9. Take part in the national and international discussion on various subjects in sustainable power production and **transportation** by reading, presenting and discussing international reports and journal papers

10. Formulate judgements that include reflecting on scientific, societal and ethical responsibilities and to achieve awareness of ethical aspects on research and development work

11. Get insight into the possibilities and limitations of technology, its role in society and the responsibility of humans for its use, including, social, economic as well as environmental and occupational health aspects

12. Continue studies in a largely self-directed and autonomous manner, and contribute to research and development

Lecture 8

- Sustainable transportation
- Emission regulations
- The weaknesses of a conventional car?!
- Degrees of electrification, types of hybrids
- Vehicle dynamics
- Vehicle energy/fuel consumption modelling and simulation
- Loads other than propulsion
- Charging
- A calculation example

} Motivation (Sustainable transportation, Emission regulations)

} How to calculate fuel/energy consumption (Vehicle dynamics, Vehicle energy/fuel consumption modelling and simulation)

Lecture 10

- Drive system components
  - Basic operation
  - Losses and efficiency
- Types of hybrid vehicles
  - Operation
  - Control

Sustainable development…

"…meets the needs of the present without compromising the ability of future generations to meet their own needs."

Report of the World Commission on Environment and Development:
***ur Common Future*, 1987**, Chairman: Gro Harlem Brundtland
http://www.un-documents.net/our-common-future.pdf

Considered to be the first definition of **sustainable** development

… now there are many more…

Transportation…




…is the need to **take people and goods from one place to another**





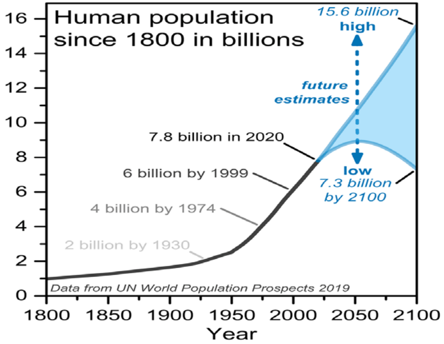




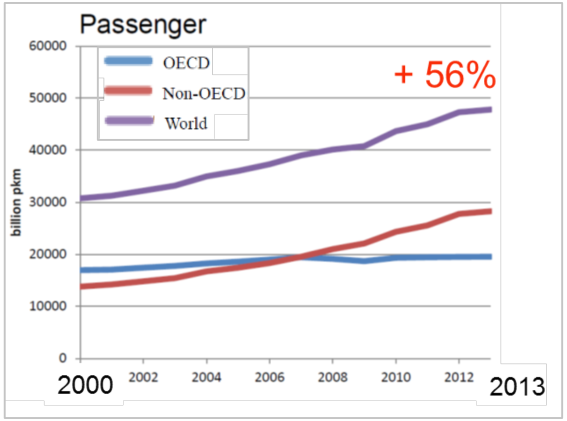

What is the current status?

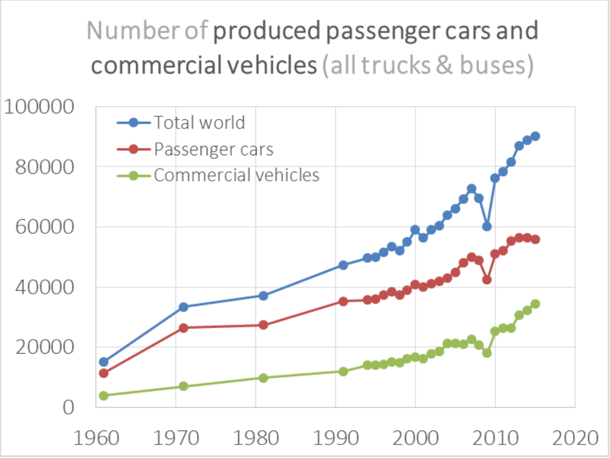
Globally increasing:

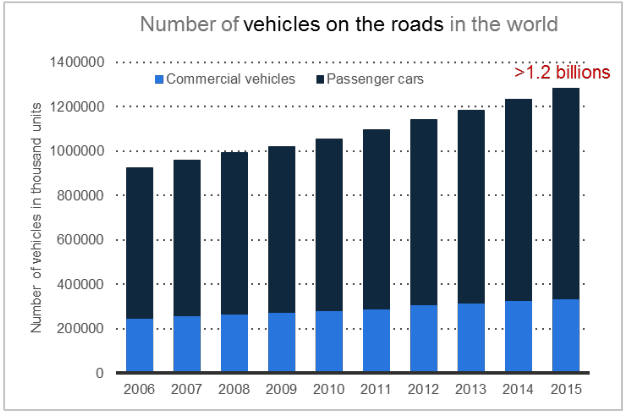
- human population
- number of vehicles produced each year
- number of vehicles in use
- transportation activity (person-km, ton-km)



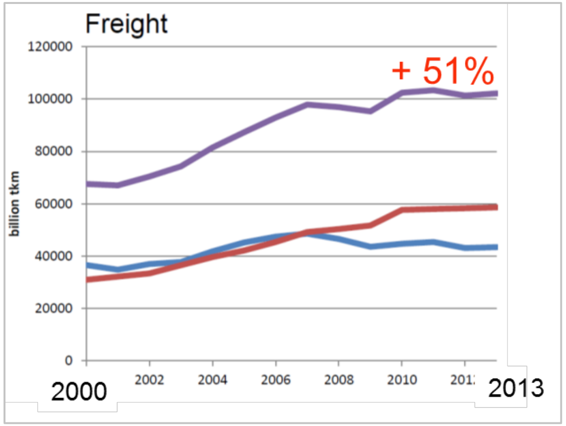
By Bdm25 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=89215845







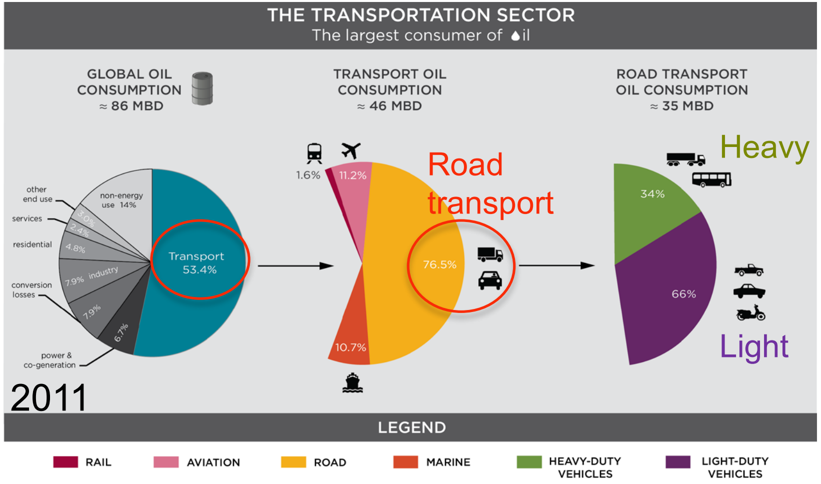
https://www.statista.com/statistics/281134/number-of-vehicles-in-use-worldwide/



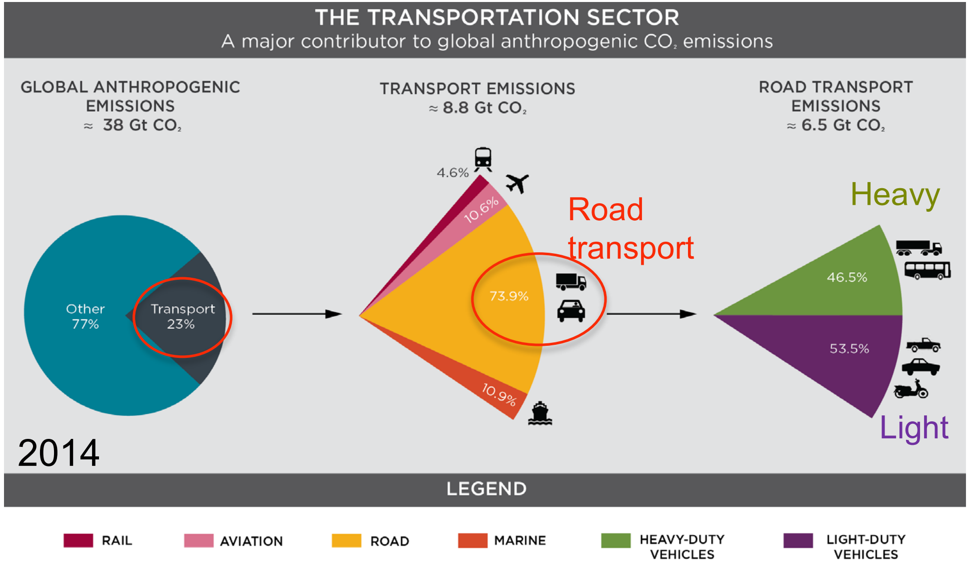
https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_23.html_mfd

https://www.iea.org/media/training/eetw2016/transport/D.1_Quantative_Transport.pdf

World oil consumption and CO_2 emission per sector



Data Source: 2011, International Energy Agency - www.iea.org/etp



Sources:
ICCT (2014). Global Transportation Roadmap Model. Available from http://www.theicct.org/global-transportation-roadmap-model
IPCC (2014). Summary for Policymakers. Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Increased numbers:
Transportation’s share of oil consumption 65.1% 2016
Transportation’s share of CO_2 emissions 24.5% 2016

http://www.theicct.org/sites/default/files/Global-oil-consumption-by-sector_2011.png
https://www.iea.org//statistics/?country=WORLD&year=2016&category=Oil&indicator=ShareOilProductsConsBySector&mode=chart&dataTable=BALANCES

http://www.theicct.org/sites/default/files/Global-transport-CO2-by-sector_1.png

Why not business as usual?

- Future availability and price of…?
  - Fossil fuels
  - Raw materials
- Need for clean air?
  - Air pollution cause the death of 3 million people/year

- Need for farming and living?
  - Global warming cause/may cause;
    - ice melting, rising sea levels, more frequent extreme weather, floods, droughts, changing ecosystems, etc. will greatly affect human food supply, water resources, health, economics, etc.

http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng.pdf
http://www.nationalgeographic.com/environment/global-warming/global-warming-effects/

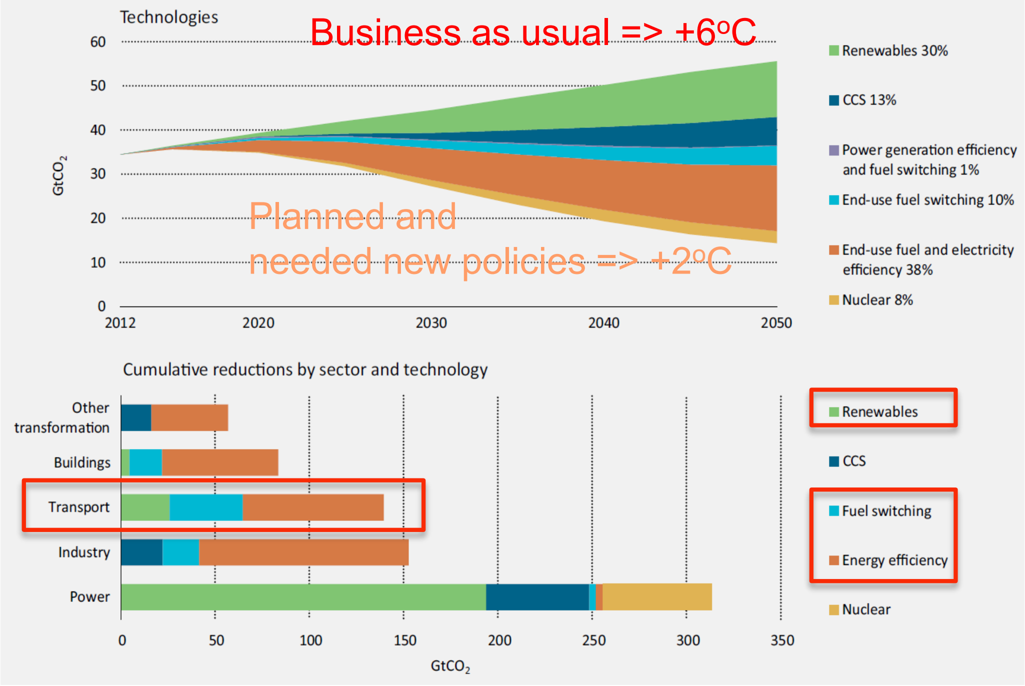
Possible mitigations

- **Decrease the need for and impact of transport**
  - community planning, to minimize the need for transport
  - avoid unnecessary travelling (video conference, lifestyle change?)
  - People can:
    - walk or bike
    - shift to public transport instead of driving car
    - car pooling
    - shift to more efficient car
  - Companies can:
    - shift to more efficient vehicle
    - plan logistic routes to minimize transport distance
    - local production, to avoid long distance freight
  - Industry can:
    - improve vehicle efficiency
      - component level
      - system level
    - shift to other fuels/energy carriers
      - biofuels
      - hydrogen
      - electricity (if renewable!)
      - etc.
    - Self driving vehicles?

In lectures and assignment
we will look into these possibilities

Estimated contribution to CO_2 reduction

International Energy Agency (IEA): Energy Technology Perspectives 2015



Very important work to be done!

http://www.iea.org/publications/freepublications/publication/ETP2015.pdf

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        - etc.
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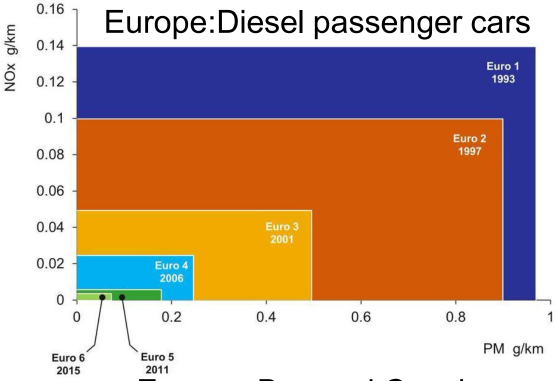
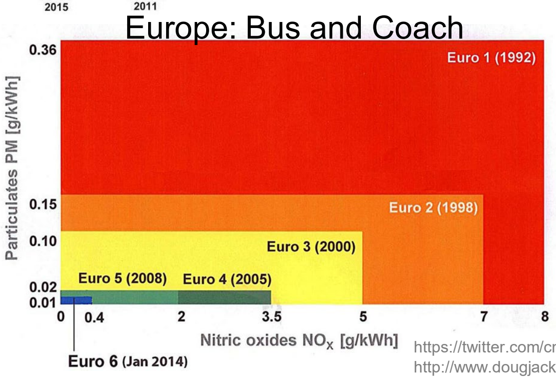
Political Policies in place

- General agreements:
  E.g. International Paris Agreement 2015
  max + 2°C compared to pre industrialization
- **Fuel taxes (on fossil fuels, carbon intense fuels)**
- **Vehicle subsidies (depending on CO_2 dependence)**
    - **Tax reliefs on carbon low vehicles**
    - **Premium on new car purchase of low emission vehicle**
- **Congestion tax in cities (e.g. Stockholm, Göteborg)**
- **Tailpipe emission regulations for new cars**
    - **Pollutants: CO, HC, NO_x, PM, etc.**
      "Must comply"-regulation, vehicle specific
      Light duty vehicles, EU: Euro 6, USA: Tier 3
      Heavy duty engines EU: Euro 6, USA: from MY 2007
    - **GHG: CO_2 or fuel consumption (gCO_2/km, L/100km, mpg)**
      "Penalty if not comply"-regulation, fleet average
      Light duty vehicles, EU >2017, USA >2017-2025
      Heavy duty vehicles, EU:not yet, USA from MY 2014

Evolution of emission regulation

According to type-approval CO_2 emissions the trend is decreasing emissions! ☺





Passenger cars CO_2

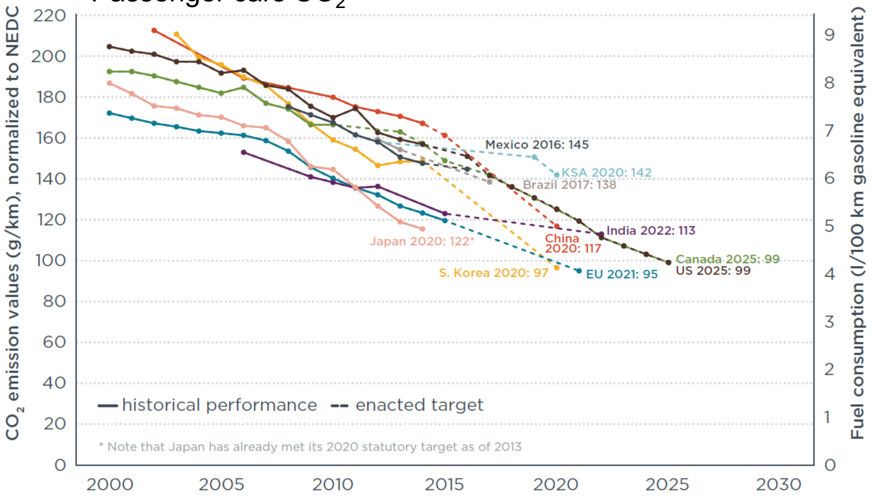
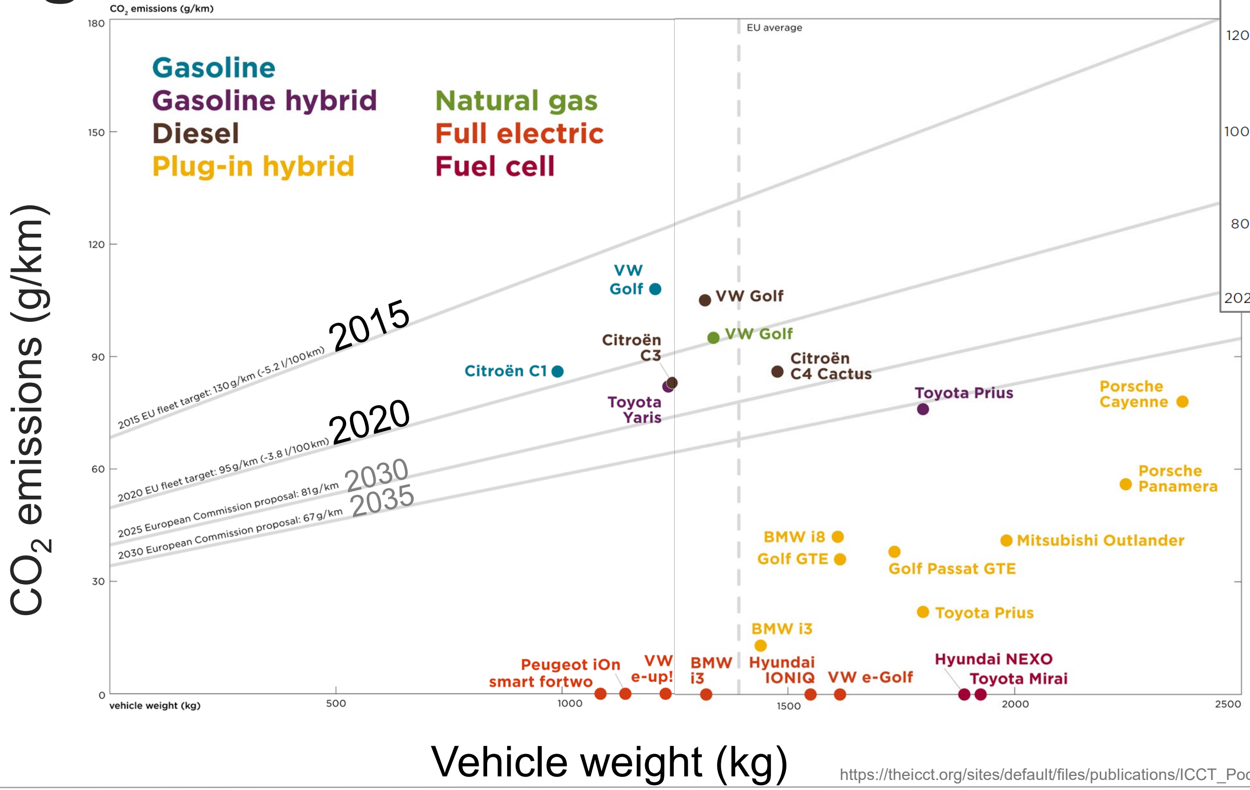


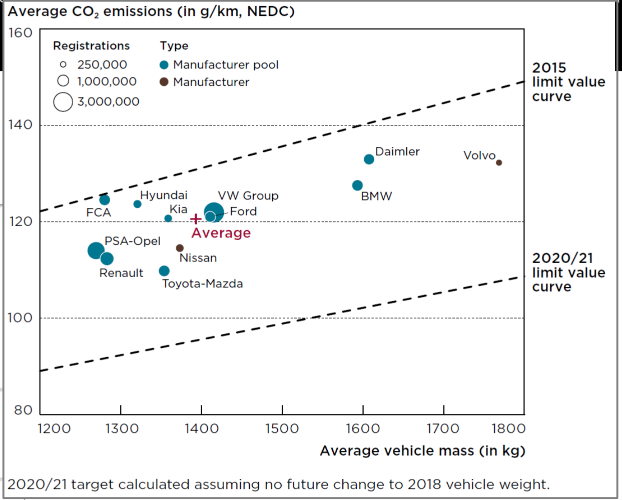
Figure 2. Historical fleet CO_2 emissions performance and current standards (gCO_2/km normalized to NEDC) for passenger cars

https://twitter.com/cmasonfisita/status/639496058217885696
http://www.dougjack.co.uk/bus-industry-euro-6-emissions-limits.html
https://www.theicct.org/sites/default/files/publications/2017-Global-LDV-Standards-Update_ICCT-Report_23062017_vF.pdf

https://theicct.org/sites/default/files/publications/European_vehicle_market_statistics_20192020_20191216.pdf

gCO_2/km - Where are we?



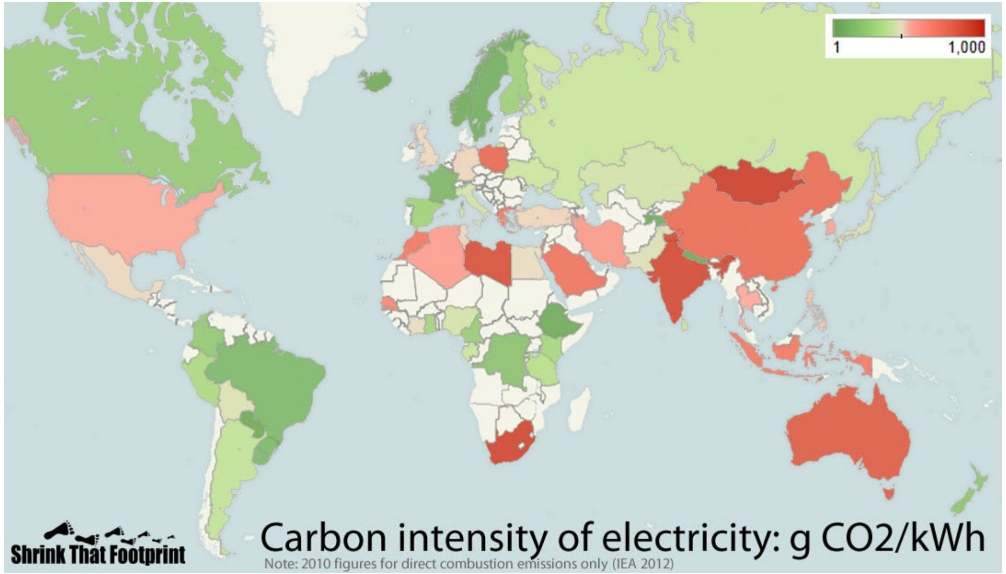


<u>For passenger cars:</u>

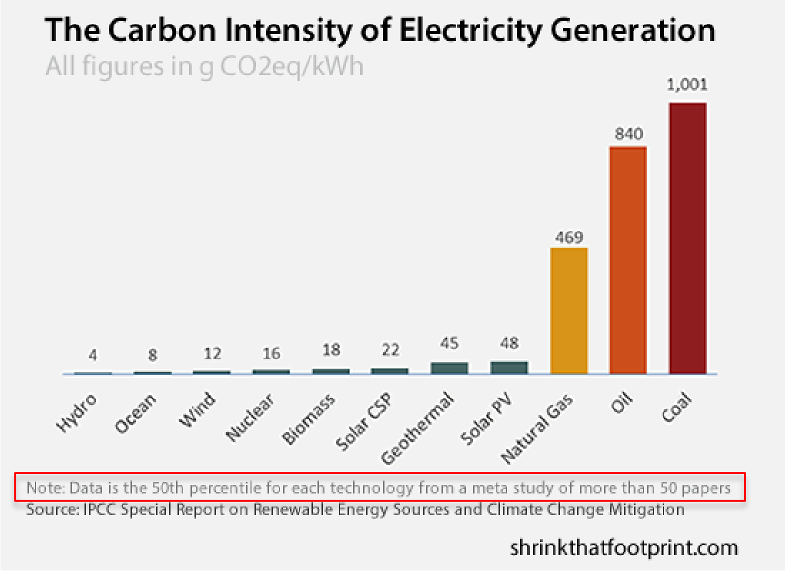
- Only the gasoline hybrid can manage the 2025 target
- Usage of energy carriers such as electricity and hydrogen cause **no tailpipe** CO_2 emissions (which is regulated here)
- Therefore Plug-in hybrids have very low CO_2 emissions, and…
- …full electric and fuel cell cars are considered ton have zero emissions…

https://theicct.org/sites/default/files/publications/ICCT_Pocketbook_2018_Final_20190408.pdf

$gCO_{2eq.}$ per produced kWh of electricity

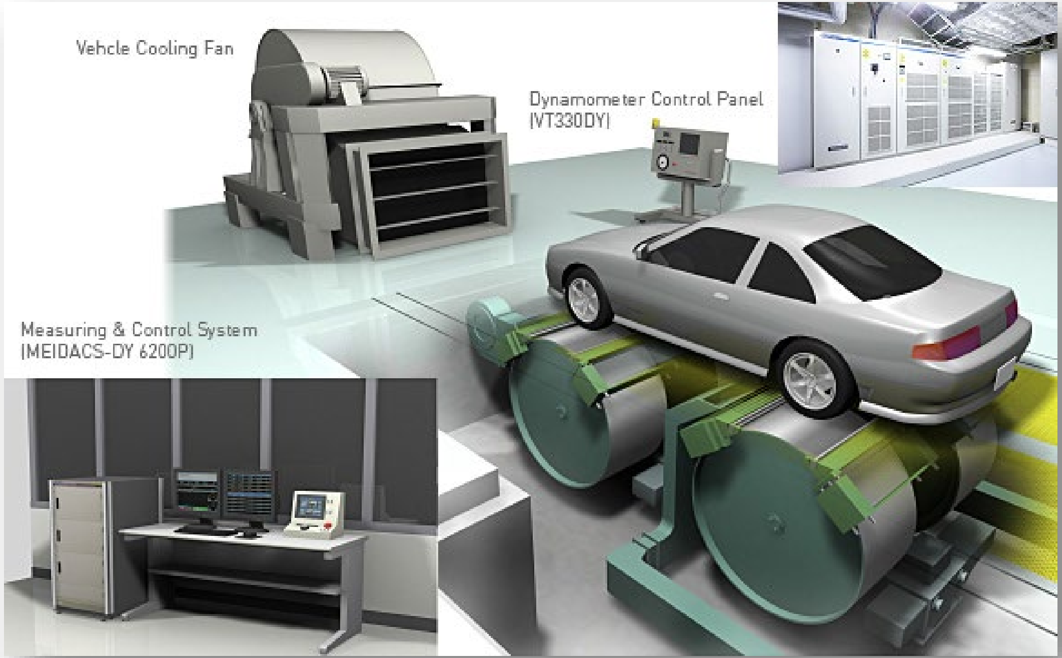


https://cleantechnica.com/2014/04/15/greenest-source-power-french-response-low-carbon-strategy/



http://www.ipcc-wg3.de/report/IPCC_SRREN_Annex_II.pdf

gCO_2/km of what?



gCO_2/km of what?

Standardized test procedures are used to measure emissions from tail pipe (g/km)

- Controlled test environment (e.g. same temperature range, flat road, no wind)
- Same predetermined driving cycle for all cars
- Driving cycle represent average driving (speed as a function of time)

In EU:

- Since 2017: WLTC (World Harmonized Light Duty Test Cycle), based on road measurements from different countries
- The previous cycle used: NEDC (New European Drive Cycle)
- Same cycle is used for measuring both toxic emissions and CO_2 emissions

In USA:

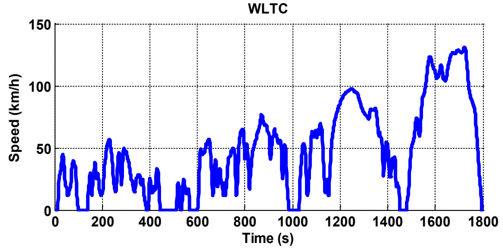
- A number of cycles (4-5) are used to measure emissions not exactly the same cycles for toxic emissions as for CO_2 emissions
- Weighting factors are used to estimate close to real emissions

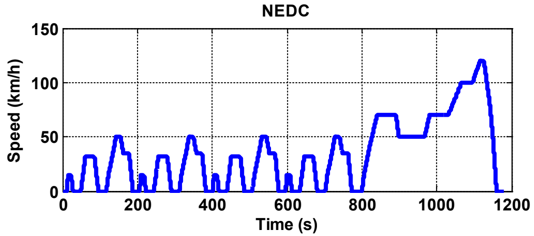
In Japan:

- They use their own cycle jp08 with both low and higher speed levels

In the rest of the world:

- Those countries that have emission regulation use one of the above standards





gCO_2/km - Where are we?

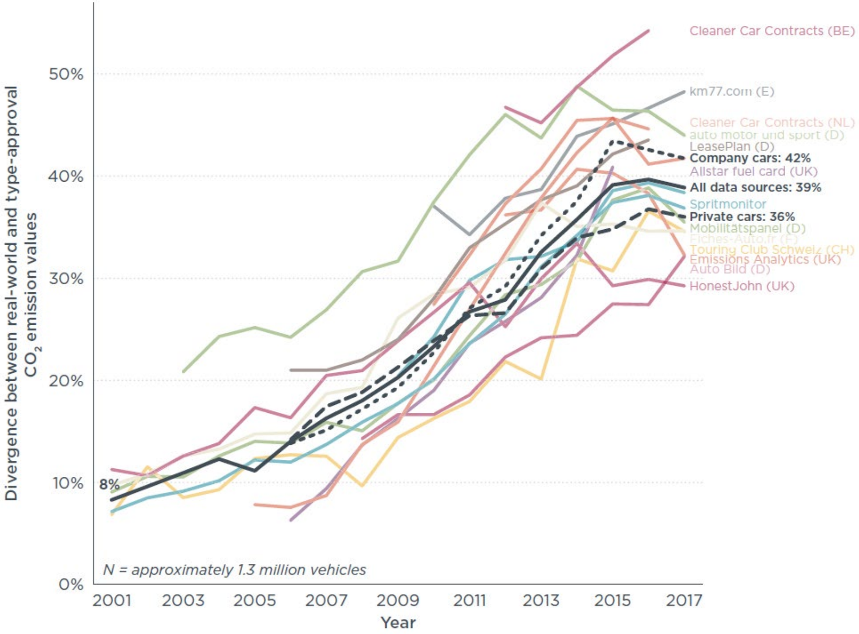


Figure 26. Divergence between real-world and manufacturers' type-approval CO_2 emission values for various on-road data sources, including average estimates for private cars, company cars, and all data sources combined.

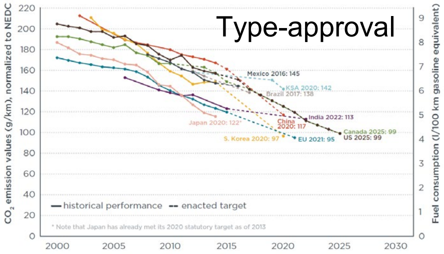
https://theicct.org/sites/default/files/publications/Lab_to_Road_2018_fv_20190110.pdf

<u>For passenger cars:</u>

According to "real world" measurements (when driving on-road under normal conditions) the deviation from type-approval CO_2 emissions has increased! ☹

<u>Reasons:</u>

- Different type of driving and load condition
  - Test cycles represent average driving
  - no AC/heater in lab-test
  - weather conditions differ
- **Manufacturers utilize tolerances and flexibilities in test procedures**



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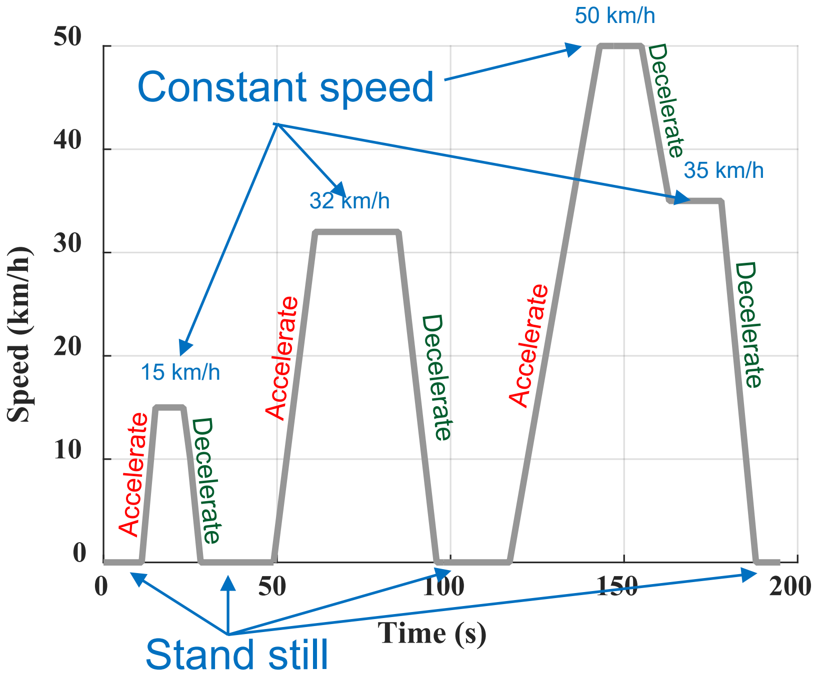
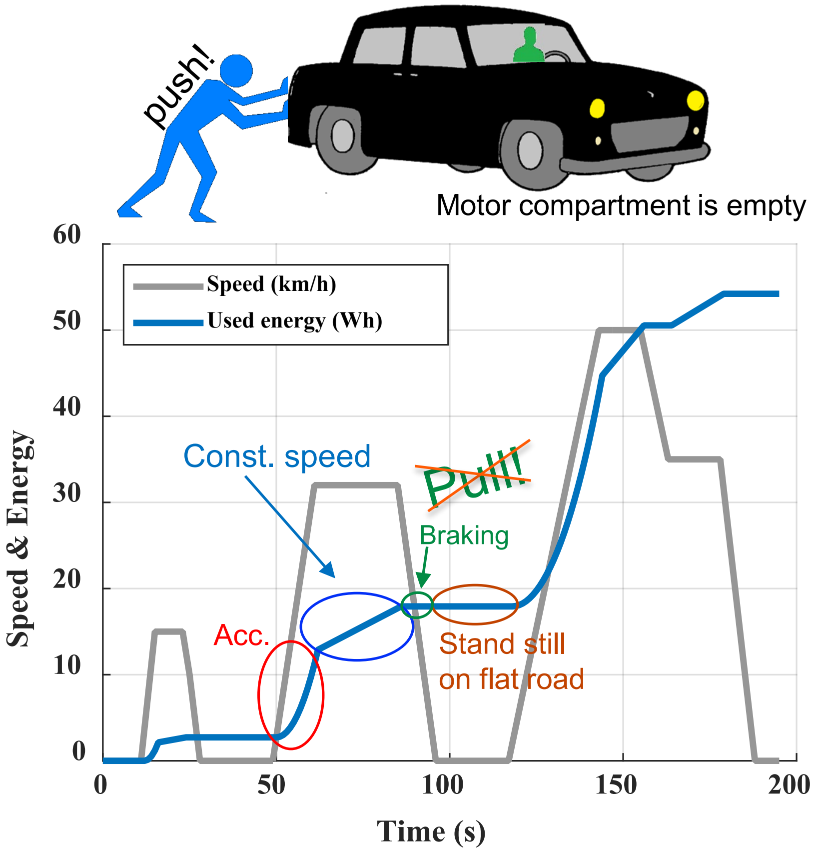
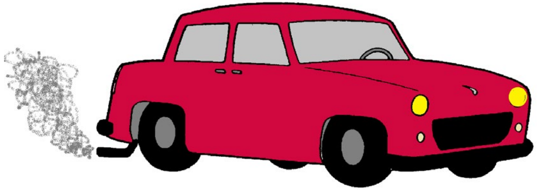
https://www.theicct.org/sites/default/files/publications/2017-Global-LDV-Standards-Update_ICCT-Report_23062017_vF.pdf

Illustrative example
- Black-box car -



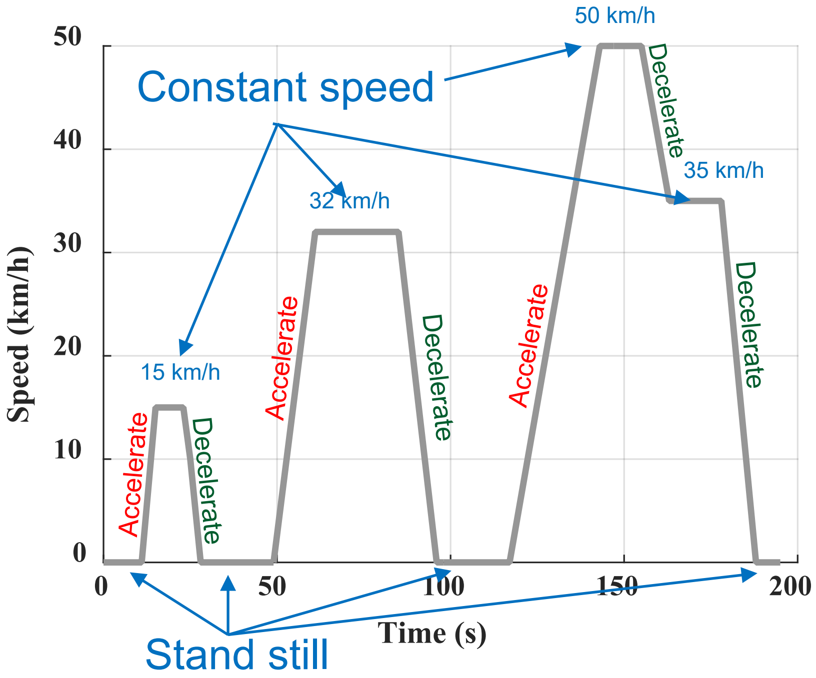


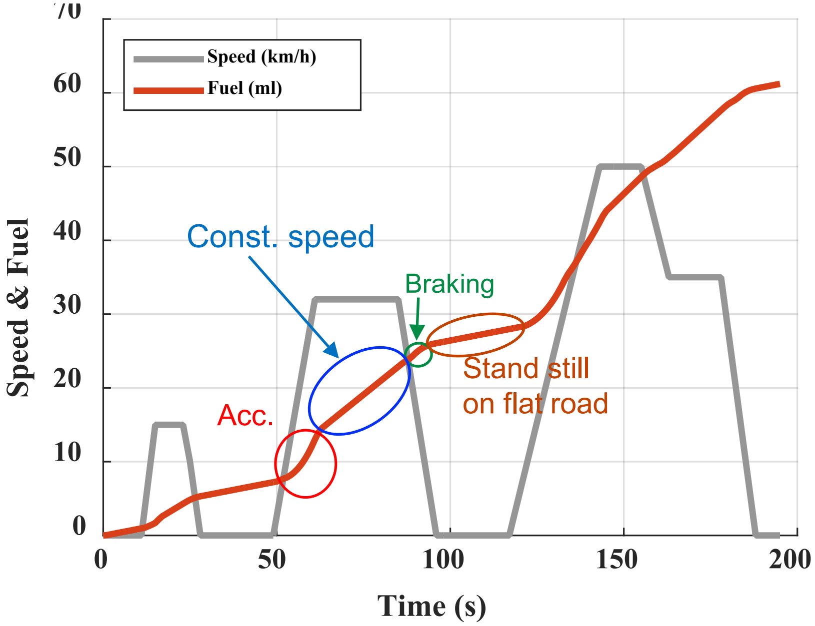
Illustrative example
- Combustion engine car -



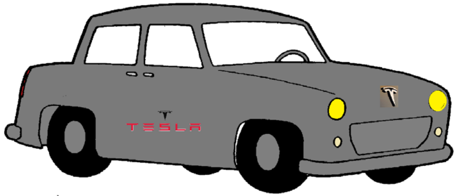
Engine also consume fuel when
- Braking
- Standing still

Since it still operates at idling speed

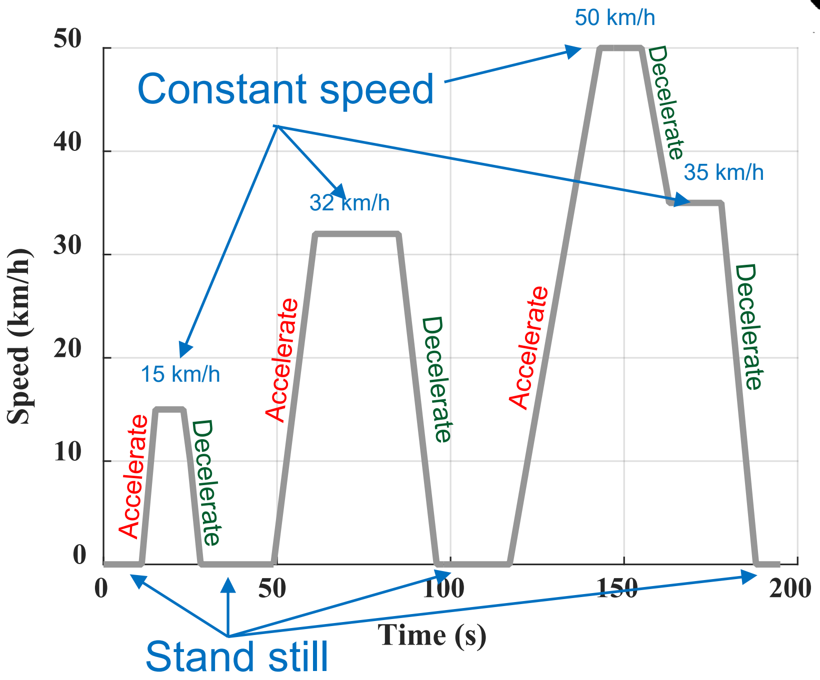


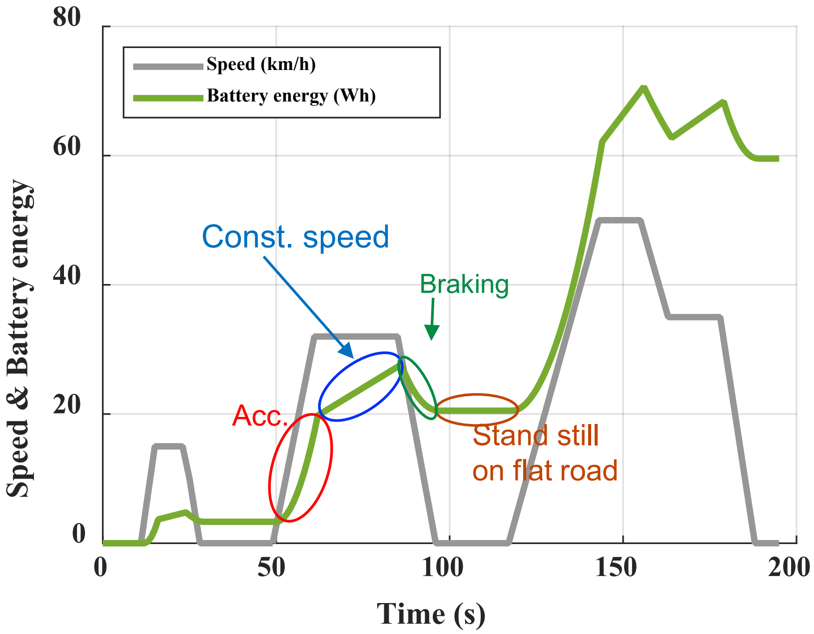


Illustrative example
- Electric car -



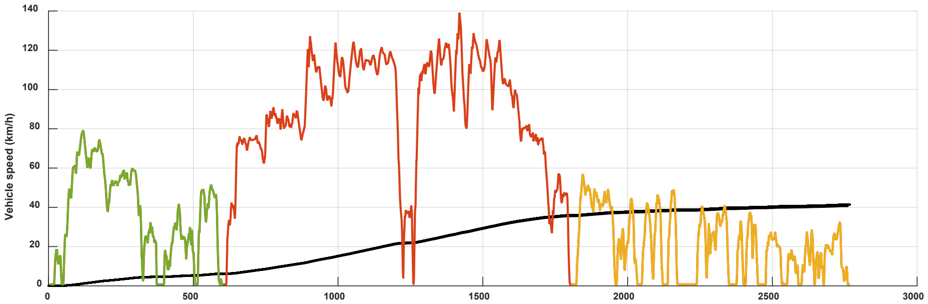
Electric car:
- can recover braking energy
- consume no energy when standing still





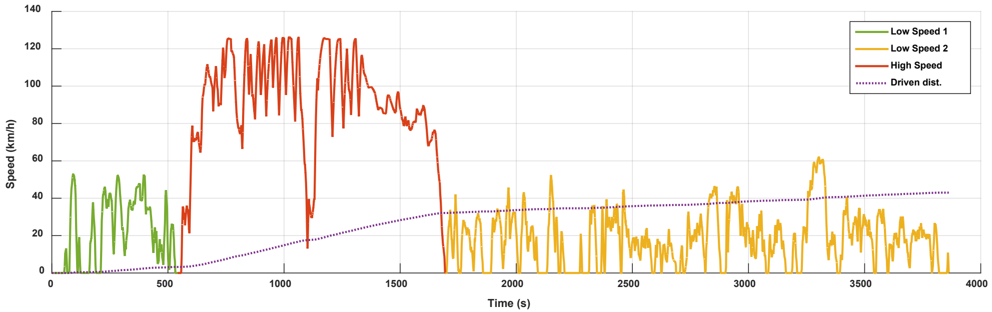
Efficiency comparison – car measurements

Large car (Fuel: E85)



	Ave speed	Fuel consumption	
Low speed 1	36 km/h	11.2 L/100km	
Low speed 2	19 km/h	14.9 L/100km	highest
High speed	89 km/h	9.7 L/100km	lowest

Medium car (Fuel: Electricity)

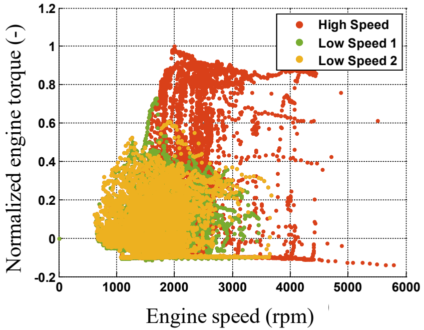


	Ave speed	Energy consumption (EM & Inverter)	
Low speed 1	21 km/h	144 Wh/km	lowest
Low speed 2	18 km/h	163 Wh/km	
High speed	90 km/h	216 Whkm	highest

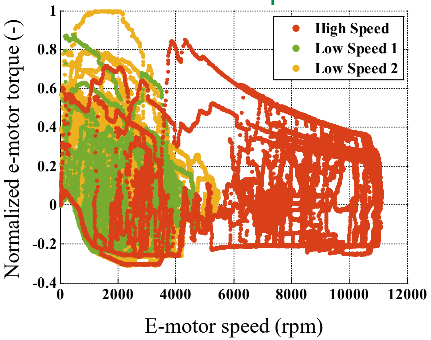
Efficiency comparison – car measurements

car measurements

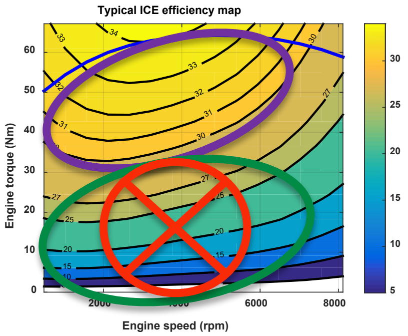
Combustion engine operation

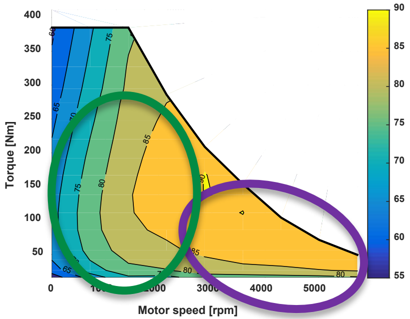


Electric motor operation



Typical simulation models





Low speed driving (roughly)

High speed driving (roughly)

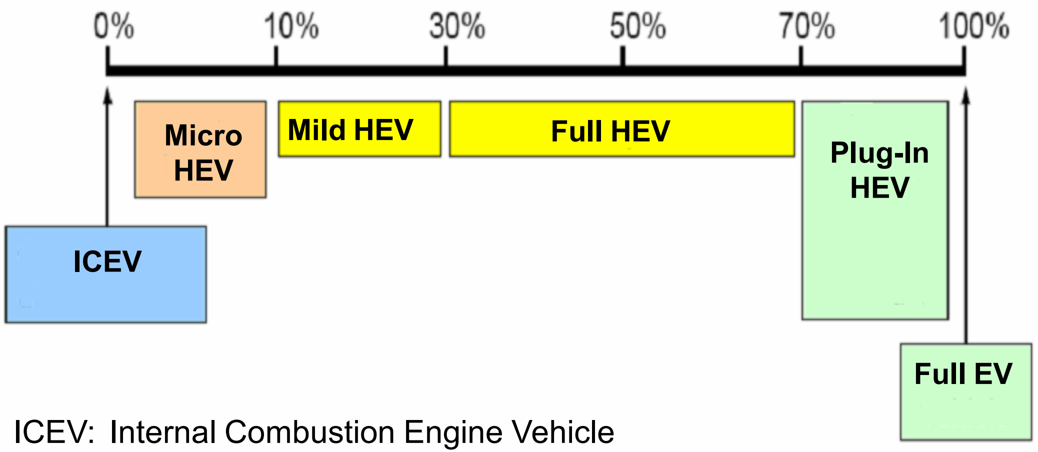
For both cars the average efficiency is

- higher during high speed driving
- lower during low speed driving

But for the **combustion engine** car

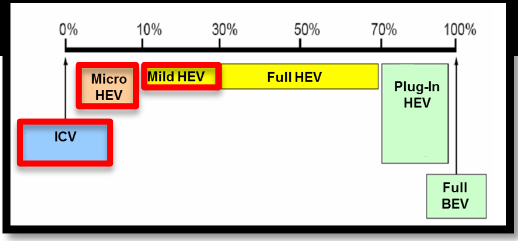
- the **efficiency is much lower during low speed driving**
- these operating points are strived to be avoided in hybrid electric vehicles
- with electric machines and “reversible” energy buffers

Degree of electrification



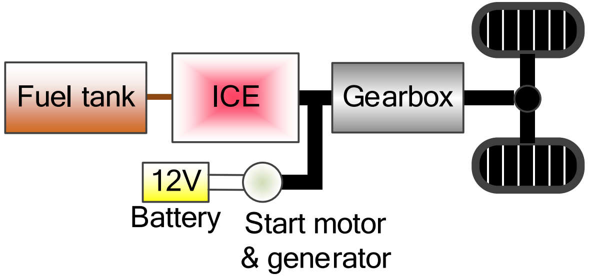
(Rough numbers just to get an idea)

ICEV: Internal Combustion Engine Vehicle
HEV: Hybrid Electric Vehicle
EV: Electric Vehicle



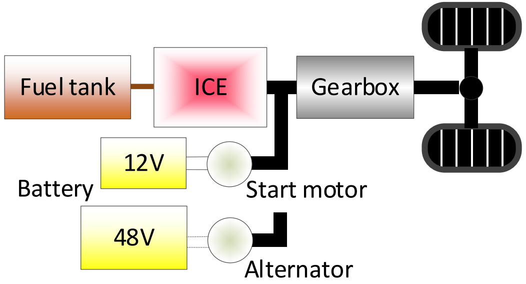
Drive system structures

Conventional combustion engine drive system



- Low average efficiency 10-20%
- Long driving range

Mild hybrid drive system

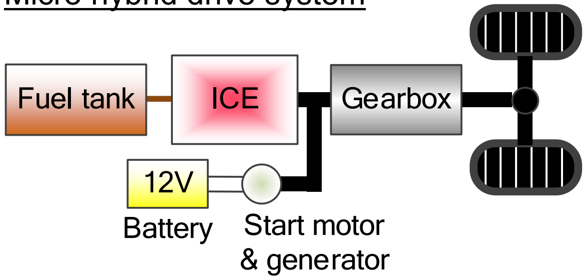


- Start/stop → no idling
- Brake energy recovery
- E-motor assist – short time

Need larger:

- Start motor (10-20 kW)
- Battery (0.5 kWh) → higher voltage?

Micro hybrid drive system



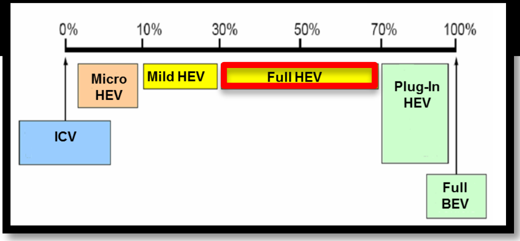
- Start/stop → no idling
- (Brake energy recovery 12V)

A larger number of stop/starts → needs higher quality:

- Start motor 2.5 kW
- Battery (larger lead acid or other chemistry)

Full hybrid drive system – configurations

- series
- parallel
- various combinations

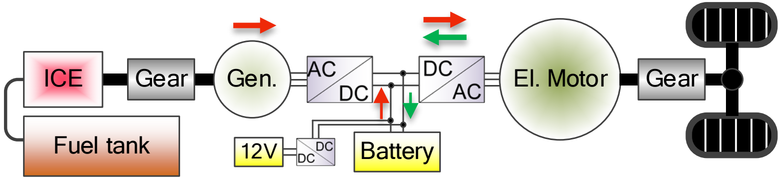


Full hybrid drive systems

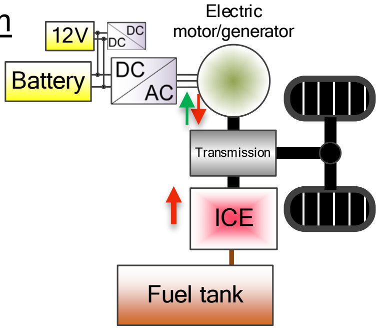
- Two power sources: combustion engine and e-motor
- Still only the fuel tank provides the energy needed for driving
- Battery energy content 1-2 kWh – used as temporary energy buffer

Series hybrid drive system

- Only electric motor propels the wheels
- ICE+Gen. power can either
  - only power the e-motor
  - power the e-motor and charge the battery



Parallel hybrid drive system

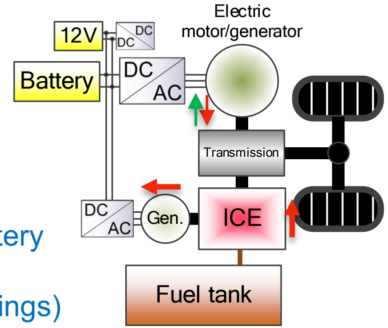


- Both ICE and e-motor can propel the wheels, either one at a time or both at the same time

Series-Parallel hybrid drive system

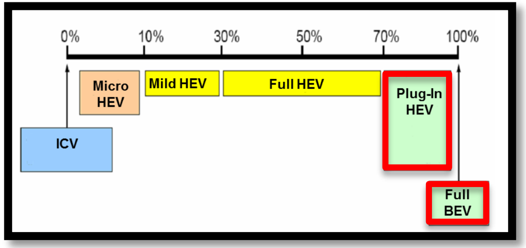
- Both ICE and e-motor can propel the wheels, either one at a time or both at the same time
- ICE power can either
  - only power the wheels
  - power wheels and charge battery
  - only charge battery

  (depending on mechanical couplings)



Plug-in hybrid, and electric drive systems

- Battery can be charged from the grid
- Braking energy can be recovered

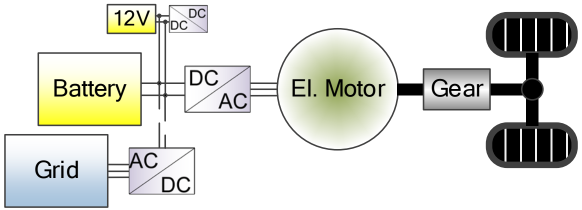


Plug-in hybrid drive system

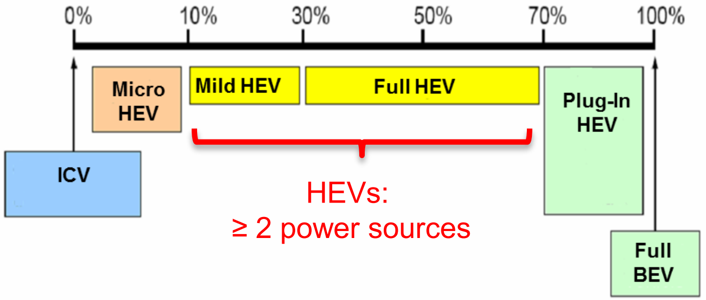
- Battery and fuel tank can provide the energy needed
- Same hybrid systems as in full hybrids + on-board charger
- Battery size in plug-in hybrids 10-20 kWh

Electric drive system

- Battery size in battery electric vehicles 15-90 kWh

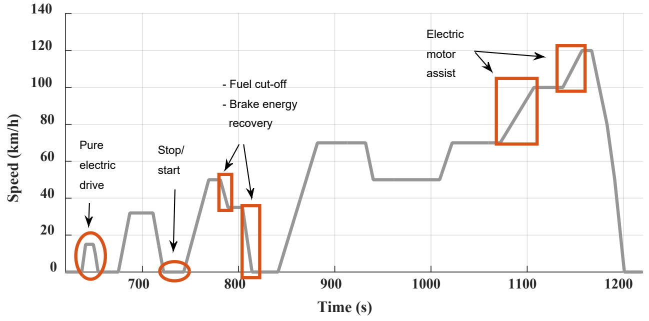


Degree of electrification
- fuel saving methods -



	ICEV	Micro HEV	Mild HEV	Full HEV	Plug-In HEV	Plug-In HEV Range Extender	Full EV
Fuel cut-off (standard today)	x	x	x	x	x		
IC engine stop/start		x	x	x	x	x	
Brake energy recovery		x	x	x	x	x	x
Electric motor assist			x	x	x		
Pure electric drive			(x)	x	x	x	x

Possible reduction implementations

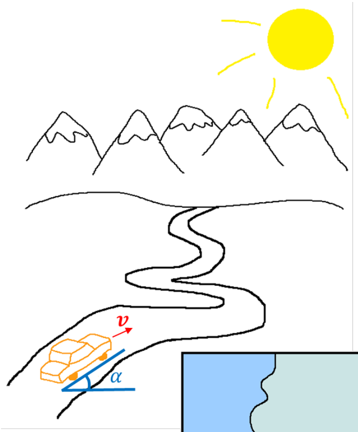


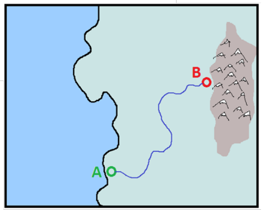
Vehicle dynamics

- for estimation of main forces and energy consumption

$$\sum F = \mathrm{m}\frac{\mathrm{dv}}{\mathrm{dt}} = m\,a$$

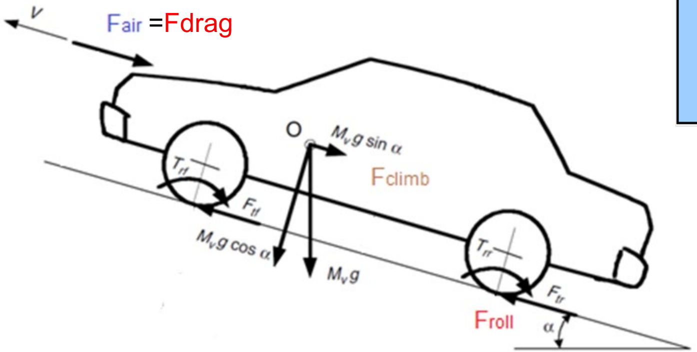
Newton's second law of mechanics
- only the longitudinal forces are considered





$$m\,a = F_{acc} = F_{traction} - F_{resistive}$$

$$m\,a = F_{acc} = F_{traction} - F_{drag} - F_{roll} - F_{climb}$$



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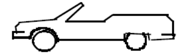
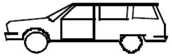
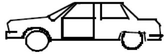
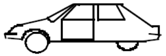
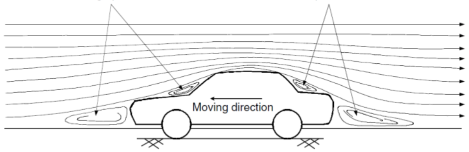
Aerodynamic drag

$$F_{drag} = \frac{1}{2}\rho C_d A \left(v_{car} - v_{head\ wind}\right)^2$$

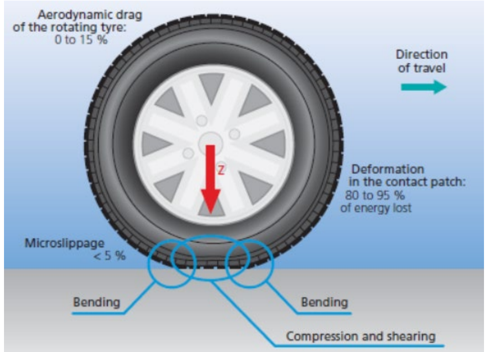
- Is the resistance of air flow around (and through) the car
- Depends on the vehicle's
  - the car's "projected" cross sectional area, A
  - shape, C_d
  - speed, v
- Is ideally estimated by assuming:
  - zero wind speed
  - atmospheric standards air density
  - only air flow straight from the front
- Fixed C_d values (which depend on car shape) taken from
  - General table (see picture to the right)
  - Manufacturers specifications
  - Wind tunnel measurements
  - CFD simulations

Vehicle Type	Coefficient of Aerodymanic Resistance
 Open convertible	0.5–0.7
 Van body	0.5–0.7
 Ponton body	0.4–0.55
 Wedge-shaped body; headlamps and bumpers are integrated into the body, covered underbody, optimized cooling air flow	0.3–0.4
 Headlamp and all wheels in body, covered underbody	0.2–0.25
 K-shaped (small breakway section)	0.23
 Optimum streamlined design	0.15–0.20
Trucks, road trains	0.8–1.5
Buses	0.6–0.7
Streamlined buses	0.3–0.4
Motorcycles	0.6–0.7

ρ_{air}	(kg/m^3)	air density, depend on temperature, humidity and pressure ($1.225 kg/m^3$ at standard atmospheric conditions)
C_d	-	coefficient of aerodynamic resistance, depend on shape of vehicle
A	(m^2)	vehicle effective frontal area
v	(m/s)	vehicle speed



https://www.ctsblog.net/2017/08/why-does-rolling-resistance-matter-in.html



Rolling resistance

$$F_{roll} = C_r m g \cos \alpha$$

- Depends on
  - mass of car
  - rolling resistance coefficient C_r
  - gravity
  - road grade
- Is caused by a combination of various physical phenomena
  - tire deflection during rotation
  - aerodynamic drag of rotating tire
  - friction between tire and road materials
- Rolling resistance coefficient, C_r dependent on
  - Tire pressure
  - Material and structure of tire and road
  - Temperature of tire and road
  - Rotational wheel speed
- Is estimated with either a fixed value for C_r (most often) or a speed dependent value
- Rolling resistance coefficient can be attained from tire measurement (seldom publically available) (low rolling resistance tires 0.005-0.009)

Rolling Resistance Coefficients

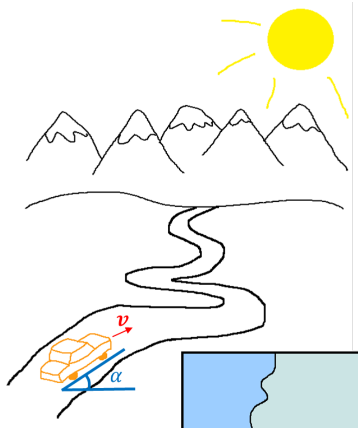
Conditions	Rolling resistance coefficient
Car tires on concrete or asphalt	0.013
Car tires on rolled gravel	0.02
Tar macadam	0.025
Unpaved road	0.05
Field	0.1–0.35
Truck tires on concrete or asphalt	0.006–0.01
Wheels on rail	0.001–0.002

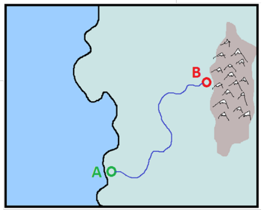
Vehicle dynamics

- for estimation of main forces and energy consumption

$$\sum F = m\frac{dv}{dt} = m\,a$$

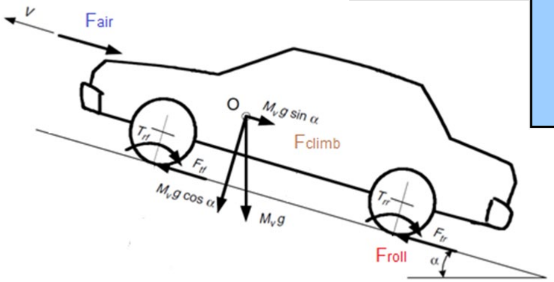
Newton's second law of mechanics
- only the longitudinal forces are considered





$$m\,a = F_{acc} = F_{traction} - F_{resistive}$$

$$m\,a = F_{acc} = F_{traction} - F_{drag} - F_{roll} - F_{climb}$$



Aerodynamic drag | Rolling resistance | Road grade | Acceleration

$$F_{trac} = \frac{1}{2}\rho C_d A\, v^2 + C_r m g \cos\alpha + m g \sin\alpha + m\frac{dv}{dt}$$

Can be positive or negative ($\sin\alpha$ and $\frac{dv}{dt}$)

$$P_{trac} = v\,F_{trac}$$

$$E_{trac} = \int_{t_A}^{t_B} P_{trac}\,dt$$

$$E_{drive\ system} = \frac{E_{trac}}{\eta_{drive\ system}} = f(\text{car size, driving, drive system efficiency, road, climate})$$

$$F_{trac} = \frac{1}{2}\rho C_d A\, v^2 + C_r mg \cos\alpha + mg \sin\alpha + m\frac{dv}{dt}$$

$$\mathrm{m}\frac{\mathrm{dv}}{\mathrm{dt}} = F_{acc} = F_{trac} - F_{resistive}$$

Controlling vehicle dynamics

There are three possible net outputs from the drive system and friction brake system to the wheel shaft:

$F_{trac} > 0$	Traction	The drive system is providing a propulsion force, controlled via the gas pedal
$F_{trac} < 0$	Braking	• Either the **friction brake** system is providing a braking force on the wheels, controlled via the brake pedal, or… • …an **electric machine** is controlled to provide a braking force, or… • …a **combustion engine** is still engaged on the wheel shaft and the internal friction in the engine and gear system provides a braking force (for example due to friction as the piston is forced to move up and down in the cylinder.) • …or other frictional forces e.g. bearings provides a small braking force
$F_{trac} = 0$	Coasting	Neither the drive system nor the brake system provides any force to the wheel shaft, (i.e. neither the gas nor the brake pedals are pressed), and the engine is disengaged from the wheel shaft via the clutch. Then the frictional forces (air drag and rolling resistance) cause the vehicle to decelerate. It is said to be *coasting.*

$$P_{trac}(t) = v(t)\, F_{trac}(t)$$

Power has the same sign as the force

$$E_{trac} = \int_A^B P_{trac}(t)\, dt$$

Integrating positive P_{trac} calculates energy flow from the drive system to the wheels
Integrating negative P_{trac} calculates energy flow from the wheels to the drive system

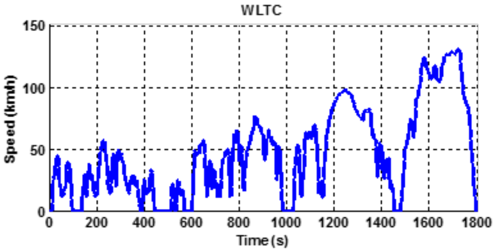
Vehicle consumption/emission modeling

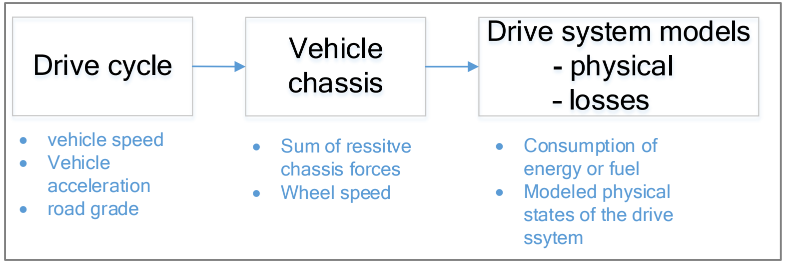
<u>In real vehicle:</u>
- Cause: driver push gas or brake pedal
- Effect: vehicle increase/decrease/hold the speed (speed and acceleration can be controlled)

<u>Often in fuel economy and emission simulations:</u>
- Cause: predetermined speed and acceleration time series (sometimes also road grade)
- Effect: calculate for each time instant, how much force and speed that must come from the drive system in order to sustain such speed and acceleration, use look-up loss maps of drive system components

- We need to link vehicle motion and drive system operation

$$F_{trac} = \frac{1}{2}\rho C_d A\, v^2 + C_r m g \cos\alpha + m g \sin\alpha + m\,\frac{dv}{dt}$$





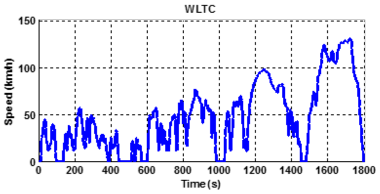
<u>Backward-looking approach</u>
- Predefined speed must be followed exactly
- **Used in our assignment**

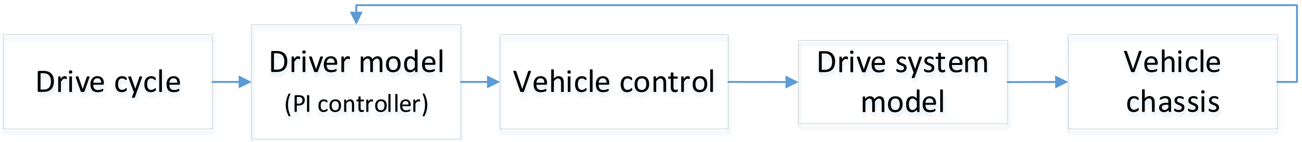
Vehicle consumption/emission modeling

Forward-looking approach

- Use a driver model
- Predefined speed is now a reference input
- Deviations from reference drive cycle is possible
- Can be used for more realistic system modelling

$$m\frac{dv}{dt} = F_{acc} = F_{trac} - F_{resistive}$$





Drive cycle
Output:
- Reference vehicle speed= *f*(time)
- (Road grade *f*(time))

Driver model (PI controller)
Output:
Pedal positions
- Gas
- Brake

Vehicle control
Output:
- Reference signals for drive system components e.g. torque and speed

Drive system model
- Model physical states of the drive system

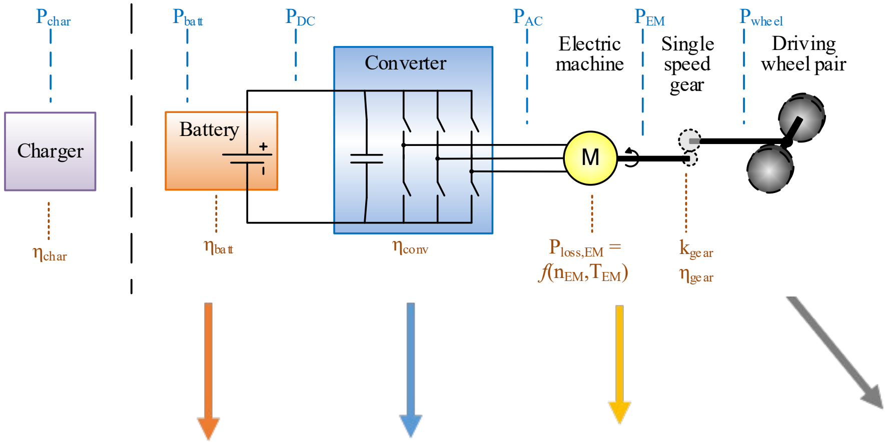
Output:
- Energy/fuel consumption
- Speed, net force, and/or power from the drive system

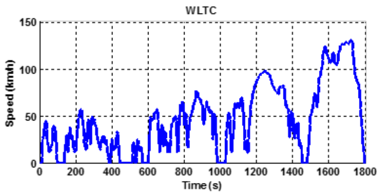
Vehicle chassis
- Vehicle dynamic model ($m\, dv/dt = F_{trac} - F_{resist}$), net force on wheel shaft will determine change in vehicle speed

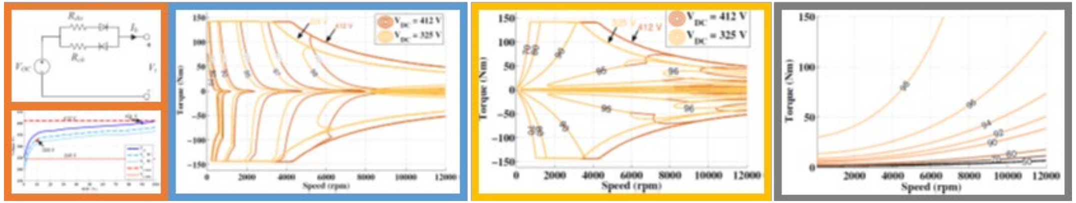
Output:
- Updated vehicle speed is fed back to driver model

Vehicle consumption/emission modeling

Drive system loss modeling - BEV example







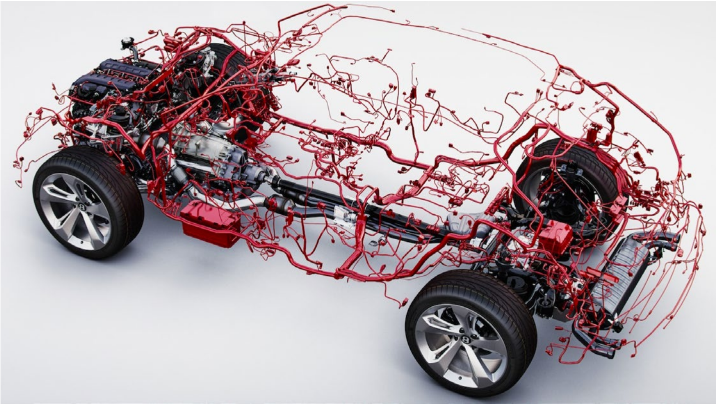
Other loads in vehicles – auxiliary loads

- **Systems for security, safety, comfort, lighting, information**

- **Air conditioning (AC) compressor**
  (conventionally driven via a belt from ICE, in HEV electrically), passenger cars ~4-6 kW, large bus up to 30kW
- **Power steering, braking systems (air compressor), heaters, pumps, fans, etc (up to 100-1500 W each)**
- **Computers/controllers (30-100 micro controllers) (up to 500W)**
- **Head lights, wipers, radio, window elevators, seat heaters etc. (up to 500 W)**

Low power loads are supplied by the 12V system

- **How much power/energy do they use?**
  - **Up to 30% of average power**
  - **During acceleration >10%**



Nielsen, F. (2016) *Automotive Climate Systems - Investigation of Current Energy Use and Future Energy Saving Measures*. Göteborg : Chalmers University of Technology (Doktorsavhandlingar vid Chalmers tekniska högskola. Ny serie, nr: 4080).

Brusokas, L. och Rajarathinam, N. (2015) *Evaluation of Electrical Loads on 48 V Supply in Future Mild Hybrid Electric Vehicles*. Göteborg : Chalmers University of Technology

Ways to reduce energy consumption

$$E_{drive\ system} = f(\text{car size, driving, drive system efficiency, road, climate})$$

- Minimize (energy needed due to chassis)
  - Mass: smaller cars, lighter materials
  - Aerodynamic drag: small front area, stream lined design
  - Rolling friction: low friction tires
- ECO-driving
  - Smooth acceleration
  - Low speed
- Efficient drive train components
  - Minimize losses
  - Integrated components, gear & ICE, electric motor & inverter & gear
- Using the right component in the right time - maximize system efficiency ← In case of Hybrid cars
  - Power management of whole driveline

Why not just do it?!

For a manufacturer to increase vehicle efficiency it has to invest in changes to the car = **higher cost**

- Who should pay for the improvement?
- Are the customers willing to pay?

Is it possible to increase the vehicle's efficiency **and** still maintain

- performance?
- comfort?
- safety?
- reliability?
- lifetime?

https://webstore.iea.org/download/direct/2807?fileName=Global_EV_Outlook_2019.pdf

Charging

	Conventional plugs	Slow chargers	Fast chargers	
Level	Level 1	Level 2	Level 3	
Current	AC	AC	AC, Three-phase	DC
Power	≤ 3.7 kW	> 3.7 kW and ≤ 22 kW	> 22 kW and ≤ 43.5 kW	Currently < 400 kW

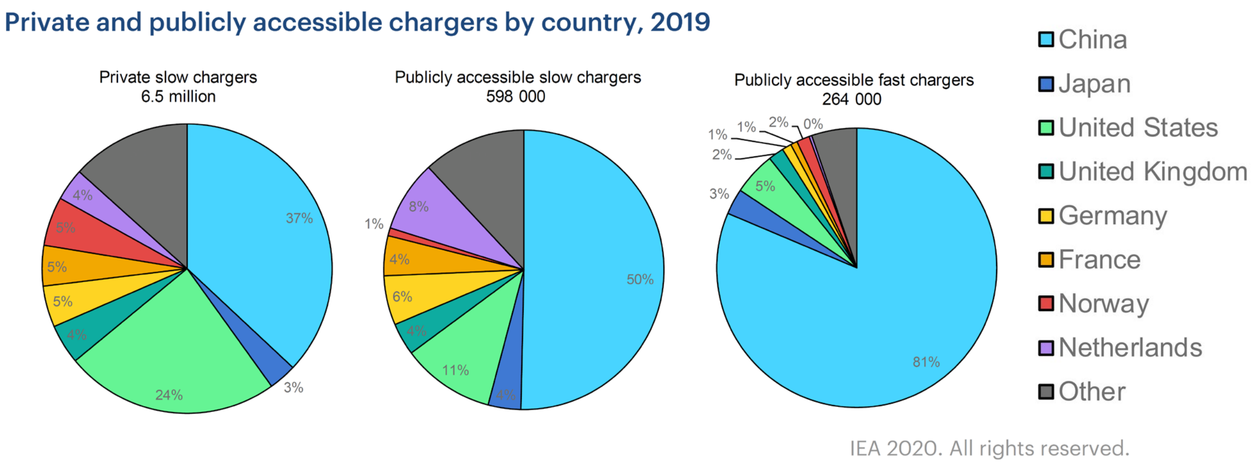
- Current method: conductive, future method: inductive (wireless)
- AC charging (Level 1 & 2, Mode 1-3)
  - On-board and external chargers regular power outlet
  - 2,0- 3.3-7.4 kW (1 phase), 11-43 kW (3 phase) – higher power = higher equipment cost
  - Charging times roughly 30 min – 8 h
- DC fast charging (Level3/Mode4) – external charger stations
  - CCS, 50-350 kW
  - CHAdeMO, 50-400 kW
  - Tesla super chargers, 120-250 kW
  - Charging times roughly 10 - 30 min
- Nominal charger efficiency ~94%
- Electric roads?! –smaller batteries on board
  - Over-head-lines – for specific type of vehicle
  - Ground tracks - accessible by any kind of road vehicle

Ongoing in Sweden, Gävle
Starting in Germany by Siemens

Ongoing in Sweden, Sthlm-Arlanda

https://www.iea.org/reports/global-ev-outlook-2020

Charging stations



Sources: IEA analysis based on country submissions, complemented by other sources. For more details, see figure 1.8 in the main report.

Sweden:
www.uppladdning.nu

Europa
https://ccs-map.eu/

World CCS/combo
https://www.plugshare.com/?combo_only=true&=SAE%20Combo%20CCS

Tesla
https://supercharge.info/

Calculation example

Useful relations:
1 J=1 Ws= 1/3600 Wh= 1/(3600 $\cdot 10^3$) kWh= 1/(3600 $\cdot 10^{12}$) TWh

How much fuel does the Swedish passenger cars consume each year?

- *Number of* passenger cars in Sweden at the end of 2015 *cars*[1]*:* ***4 669 063***
- *Total distance travelled*[2]*:* ***65 311 458 780 km****.*
- *Average gasoline consumption of Swedish car fleet 2015*[2] *:* ***8.0 liter/100km***

Estimated fuel consumption: 65 311 458 780 km/100 km ·8.0liter/100km=$\mathbf{5.22 \cdot 10^9}$ ***liter****.*
With gasoline density (820kg/m^3*) and energy density (42 MJ/kg), the energy content of this fuel is* ***50.0 TWh****.*

What if all the Swedish passenger cars were electric…how much electricity would they use during one year?

- Assume all cars are large and consume 20 kWh/k100m : 65 311 458.780/(100km) * 20 (kWh/100km) = **13.06 T Wh**

How much would the Swedish electricity production then need to increase?

- 13.06 (TWh) / 158.5 (TWh) *100 = **8.2 %**

	Per type	Share of total
Hydro	74.0 TWh	46.7%
Wind	16.6 TWh	10.5%
Nuclear	54.4 TWh	34.3%
Solar	0.1 TWh	0.06%
Other thermal	13.5 TWh	8.5%
Total production	158.5 TWh	100%

[1] *Trafik analys, Fordon 2015, Körsträckor 2015:* *http://trafa.se/sv/Statistik/Vagtrafik/Fordon/*
[2] RUS 2015: http://extra.lansstyrelsen.se/rus/Sv/statistik-och-data/korstrackor-och-bransleforbrukning/Pages/default.aspx
[3] *Elåret 2015;* http://www.svenskenergi.se/Elfakta/Statistik/Elaret/
[4] Oil, coal, natural gas and peat.

Calculation example

Useful relations:
1 J=1 Ws= 1/3600 Wh= 1/(3600 $\cdot 10^3$) kWh= 1/(3600 $\cdot 10^{12}$) TWh

What if everybody want to charge at the same time, is the **installed 40 GW** capacity enough?

- Assume 3.5 kW charging power
- 3.5 kW * 4 669 063 cars = **16.3 GW** (41% of installed capacity)

What if we use slow charging and all 24 h ?

- A typical car runs 39 km/24 h in Västar Götalandsregionen
- 2 kWh for 10 km gives 8 kWh
- 2 kW can be charged from a 10 A fuse
- Every car needs to be charge 4 h / 24 h = 1/6
- 2,0 kW * 4 669 063 cars = **9,4 GW** (23% of installed capacity)
- Equal chare of time=1/6 gives **1,6 GW** (4 % of installed capacity)

Calculation example

How much would the Swedish electricity production then need to increase?

- 13.06 (TWh) / 158.5 (TWh) *100 = **8.2 %**

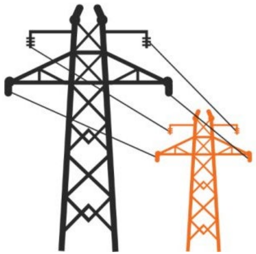


Table 3.2 Share of electricity consumption attributable to EVs by region and scenario, 2030

Country/region	2019	Stated Policies Scenario, 2030	Sustainable Development Scenario, 2030
China	1.2%	3%	3%
Europe	0.2%	4%	6%
India	0.0%	2%	3%
Japan	0.0%	1%	2%
United States	0.1%	1%	4%

Sources: Electricity demand from EVs was evaluated with the Mobility model (IEA, 2020); total final electricity consumption from (IEA, 2020) and IEA (forthcoming).

https://www.iea.org/reports/global-ev-outlook-2020

Calculation example

What if everybody want to charge at the same time, is the **installed 40 GW** capacity enough?

- Assume 3.5 kW charging power
- 3.5 kW * 4 669 063 cars = **16.3 GW** (41% of installed capacity)

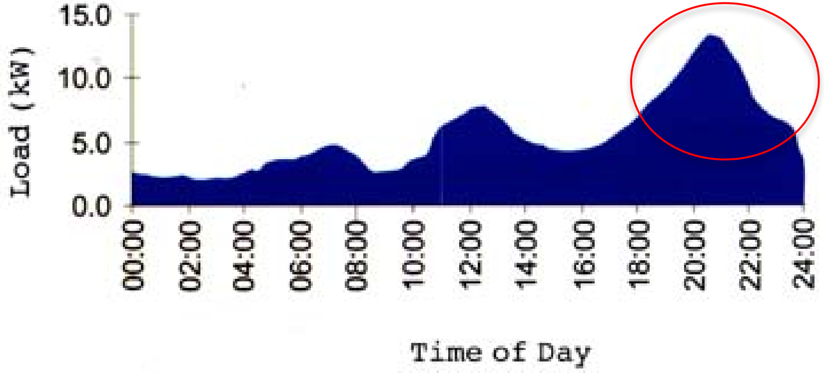
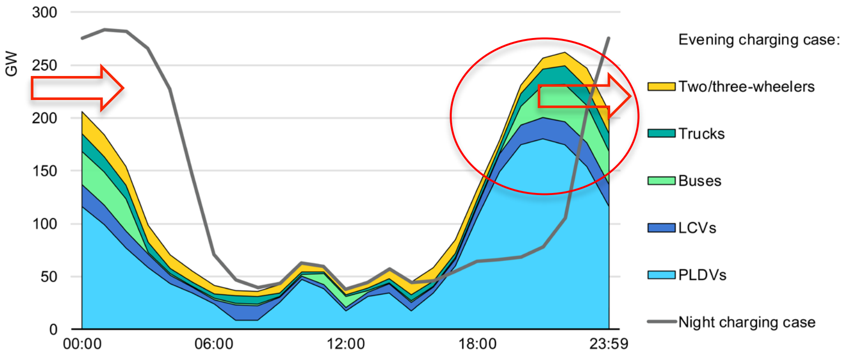


Figure 5.1 Global average weekday load profiles in an evening charging case and a night charging case by vehicle type in the Sustainable Development Scenario, 2030



Note: PLDVs = passenger light-duty vehicles; LCVs = light-commercial vehicles. EV load curves are aggregated at the global level. They are not accounting for varying time zones and might not be representative of regional patterns. They are representative of an assumed typical weekday.

https://www.iea.org/reports/global-ev-outlook-2020

Lecture 8

- Sustainable transportation
- Emission regulations
- The weaknesses of a conventional car?!
- Degrees of electrification, types of hybrids
- Vehicle dynamics
- Vehicle energy/fuel consumption modelling and simulation
- Loads other than propulsion
- Charging
- A calculation example

} Motivation

} How to calculate fuel/energy consumption

Lecture 10

- Drive system components
  - Basic operation
  - Losses and efficiency
- Types of hybrid vehicles
  - Operation
  - Control

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