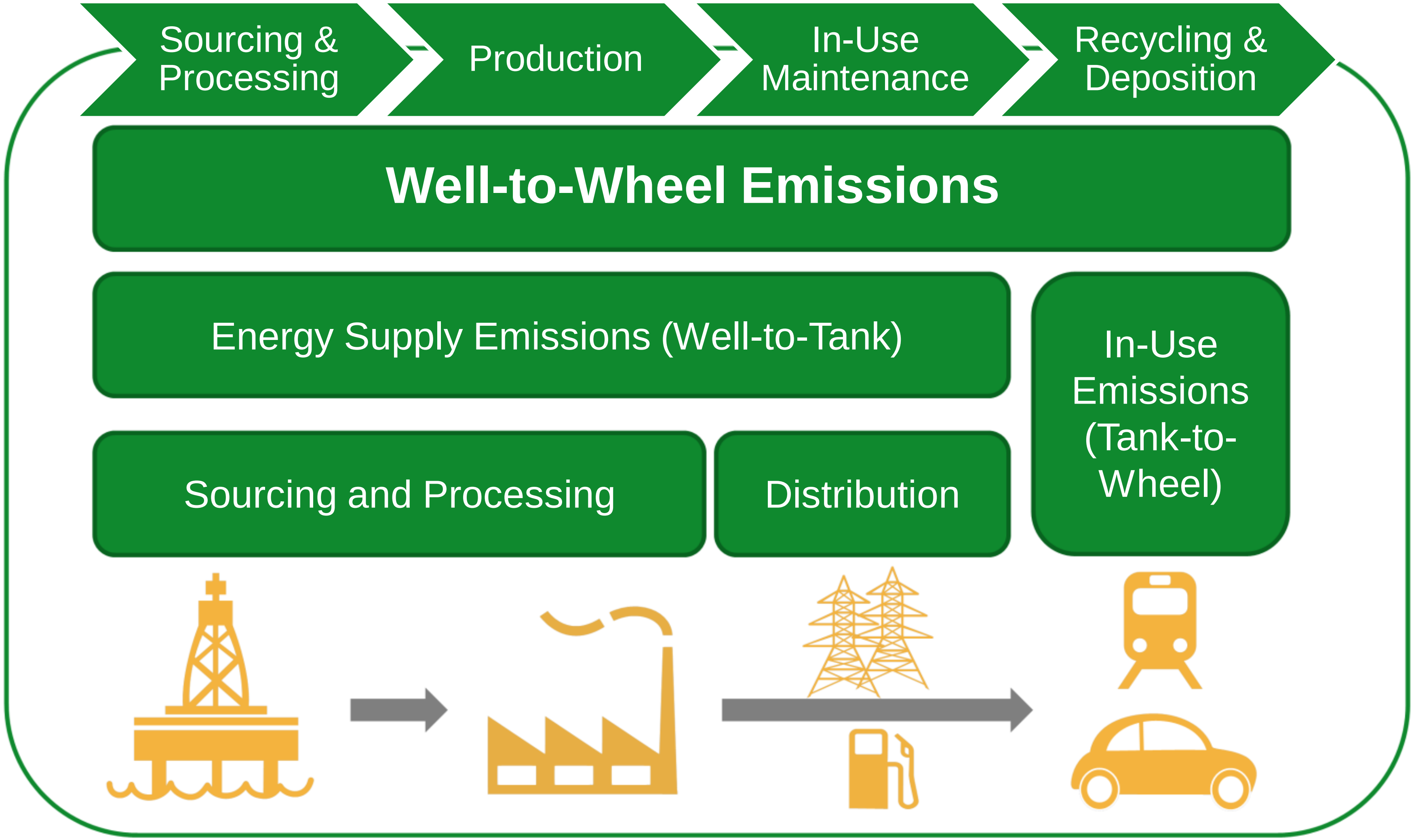
FROM T2W TO LCA – ZERO-CO_2 MOBILITY CONCEPTS AND THEIR DIFFERENT SHADES OF GREEN

Christof SCHERNUS, Thorsten SCHNORBUS

FEV Europe GmbH

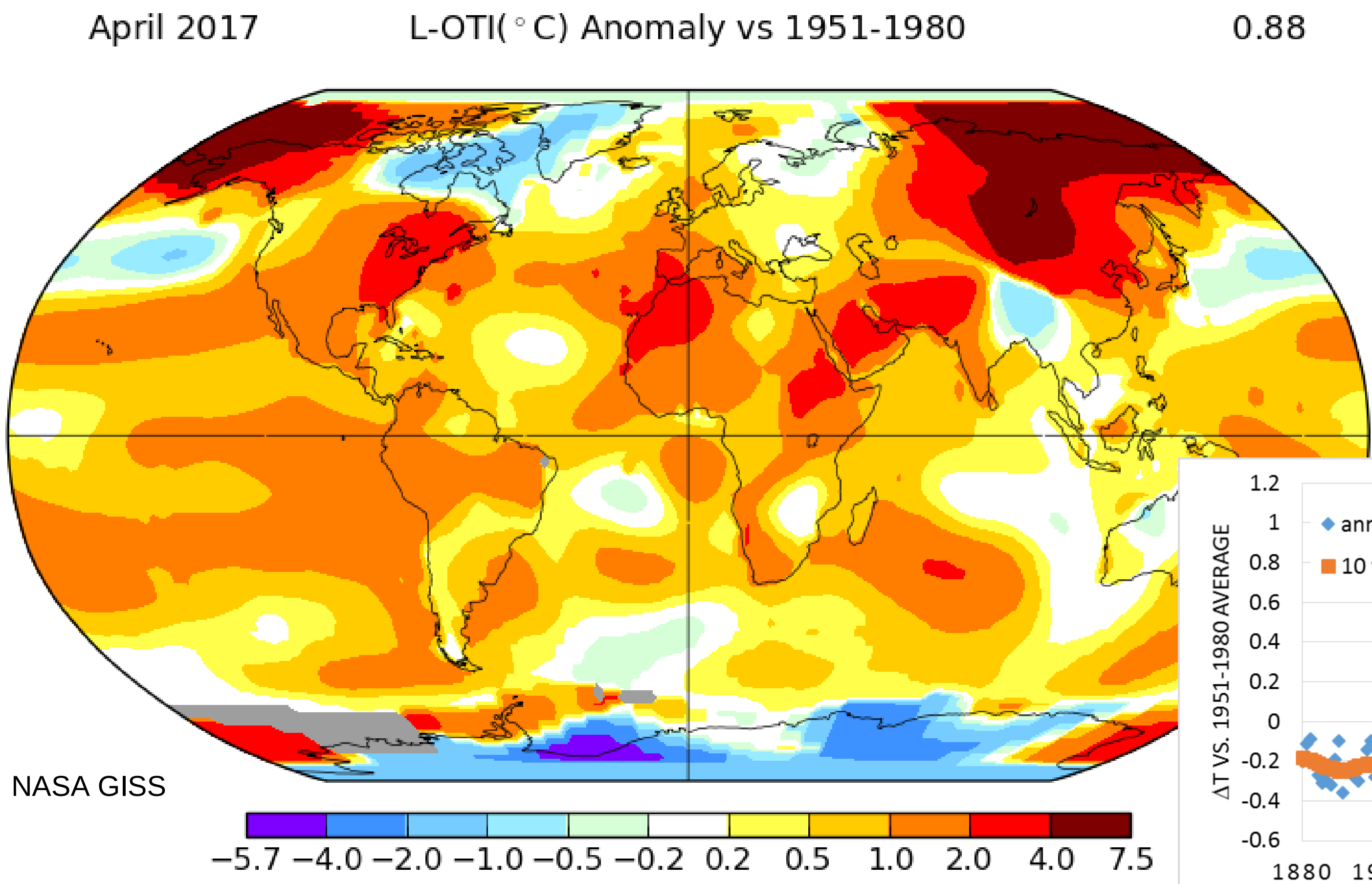
EU Tank-to-Wheel based CO2 legislation avoids the discussion about electric power sources in W2W. Though, only LCA provides the full picture.

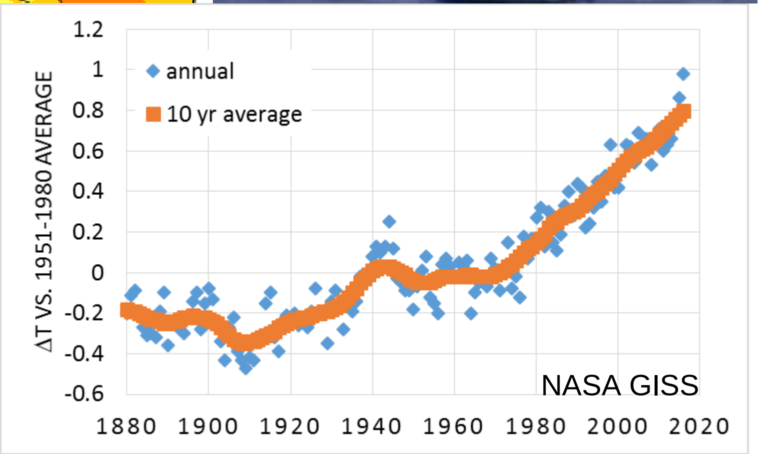


Translated from Fig. 59 in http://www.umweltbundesamt.de/publikationen/weiterentwicklung-vertiefte-analyse-der

Carbon dioxide and other GHGs promote global warming accelerated by the planet's albedo reduced by melting glaciers and dust on icefields.

April 2017 was the third record temperature month in a row – again.





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

Counterfeiting rapid climate change requires dramatic reduction of GHG emissions in all sectors: transport, power, industry, household, farming

Decarbonisation Targets

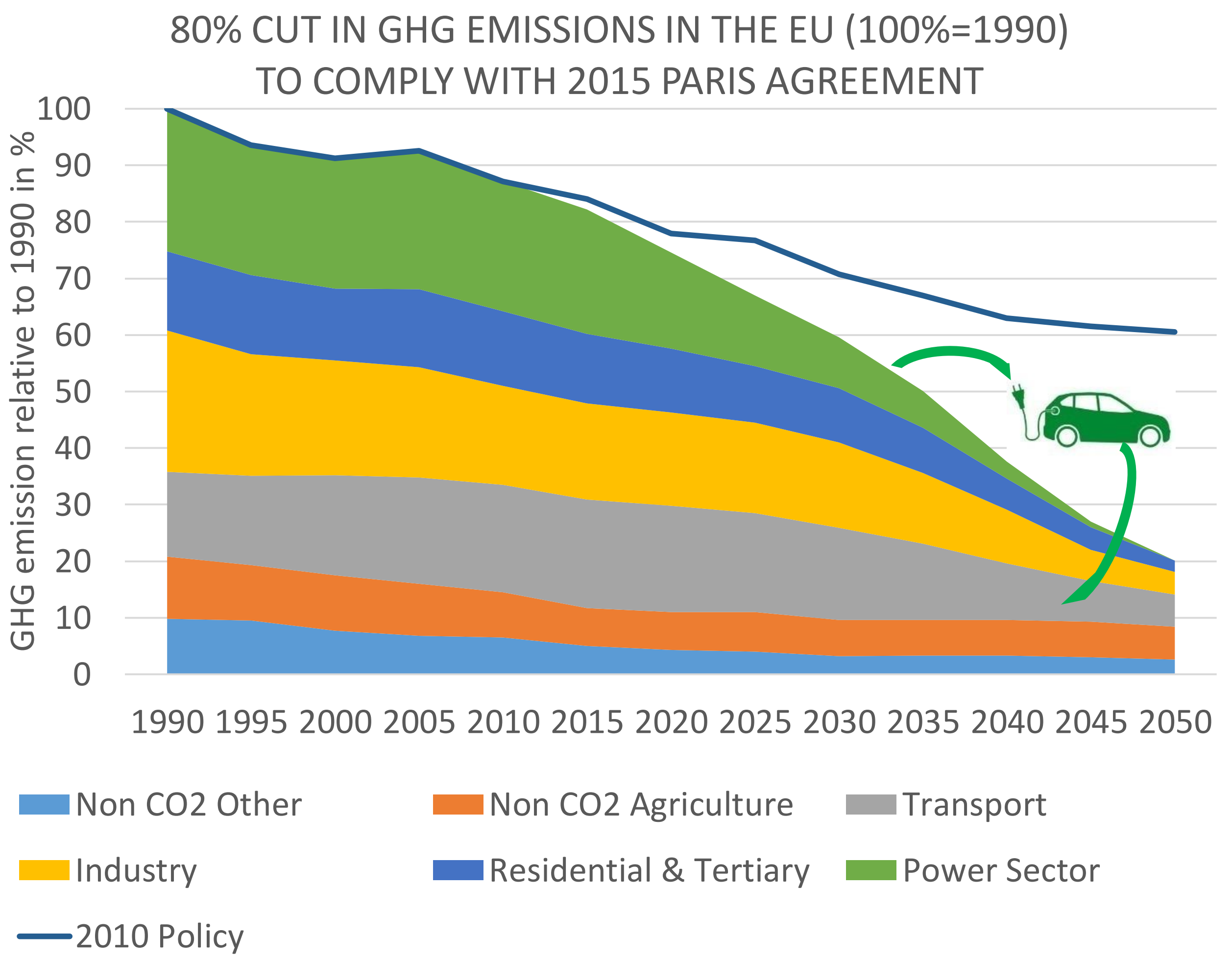
Total GHG emission reduction

- 80% until 2050,
- 40% until 2030

Sector Targets 2050

- almost all electric power from regenerative sources (97%)
- Transport GHG -60%
- Industry, transport and household decarbonisation by using renewable energy (simply thinking: regen. electricity)

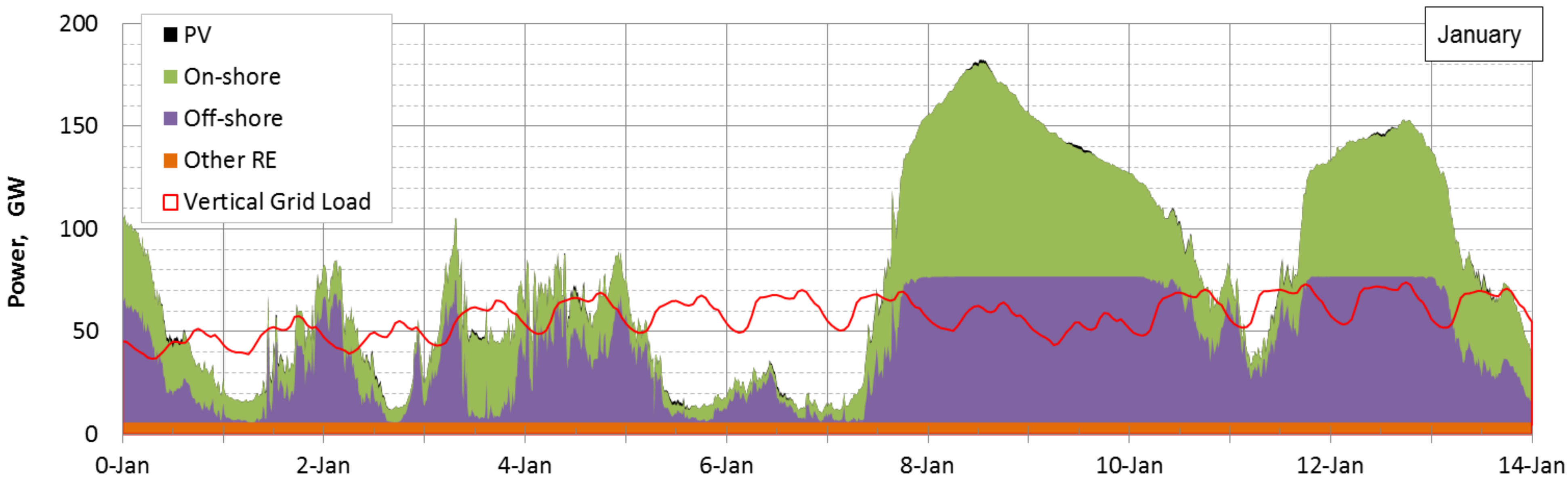
Increasing dependency on fluctuating supply of wind, solar and water power



Data from: European Commission. 2050 low-carbon economy. Climate Action

When depending on wind and solar power, there is need for buffering excess energy for periods of calm darkness

Power sector has to build up excess capacity to allow storage



Source: Stolten: Future Energy Mix and Mobility, ERTRAC Conference 2017-03-08

Any storage of electric power requires conversion into potential energy (pressure, altitude) or chemicals (batteries, e-fuels)

Long term storage: compromise between durability, density, efficiency and environmental impact


Foto: Deutsche Energie-Agentur


Foto: BYQ

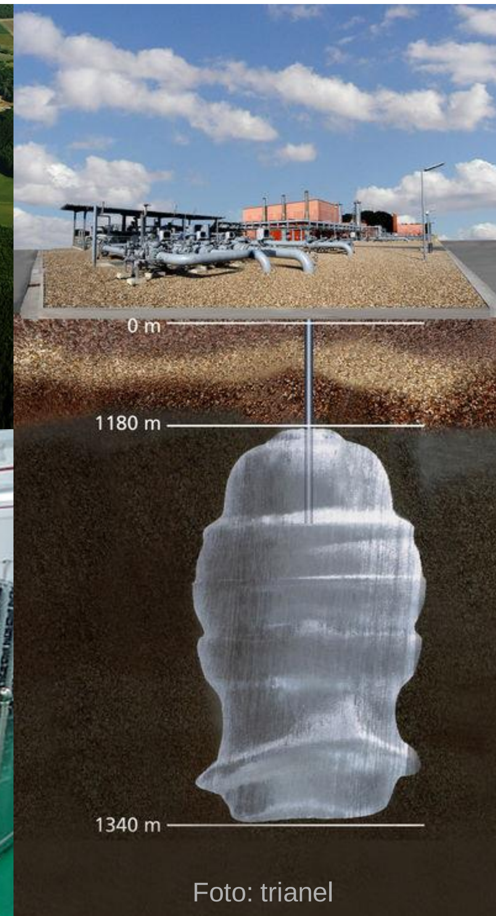


Foto: trianel

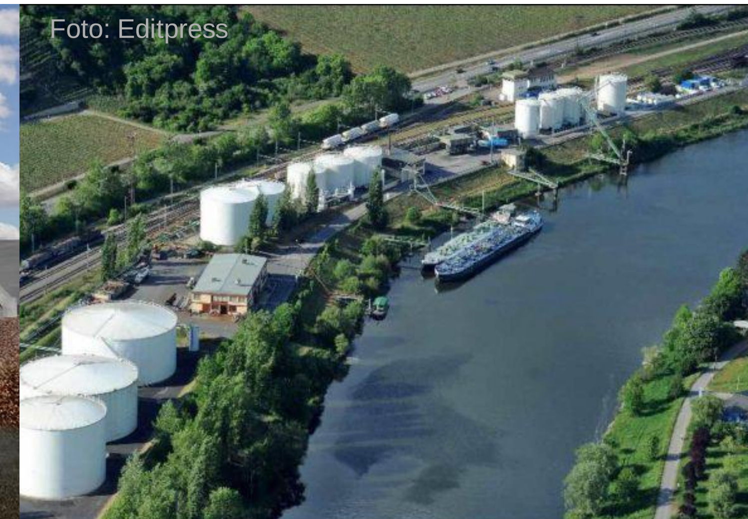


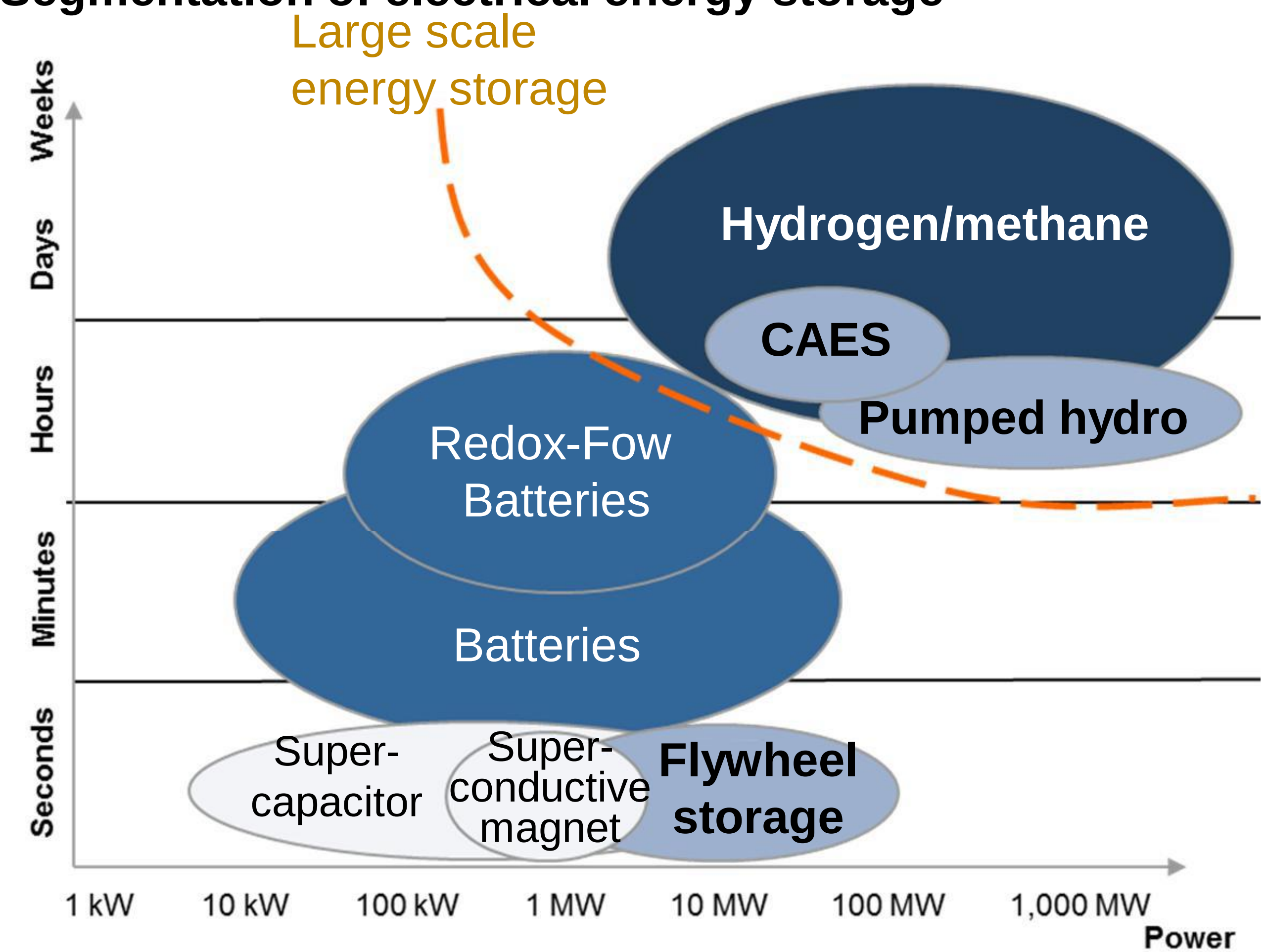
Foto: Editpress


Foto Ikar.us (talk) - Karlsruhe:Raffinerie, CC BY 2.0 de, https://commons.wikimedia.org/w/index.php?curid=191898

Source: see note in picture

Options to address large scale "grid storage" are limited

Segmentation of electrical energy storage



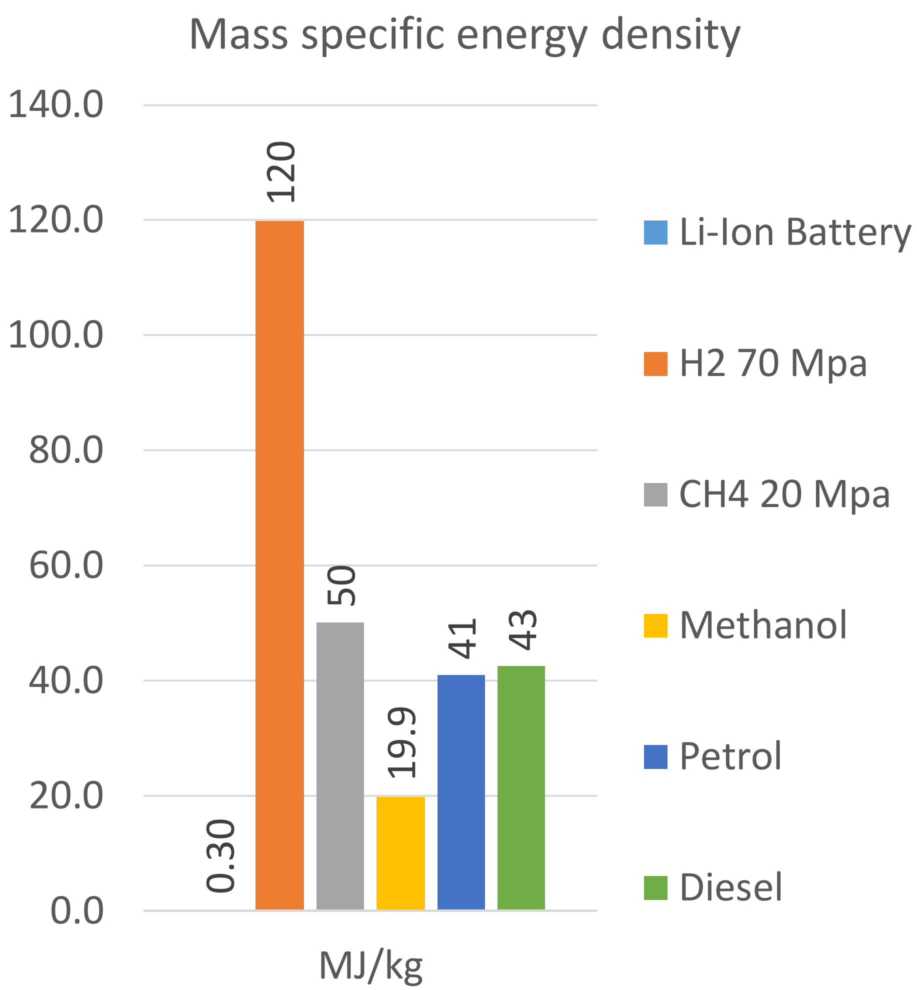
Source: Gaëlle Hotellier: "PEM-Electrolysis – a technological bridge for a more flexible energy system", http://www.wissenschaft-frankreich.de/de/wp-content/uploads/2014/07/3_Hotellier_Siemens_online.pdf

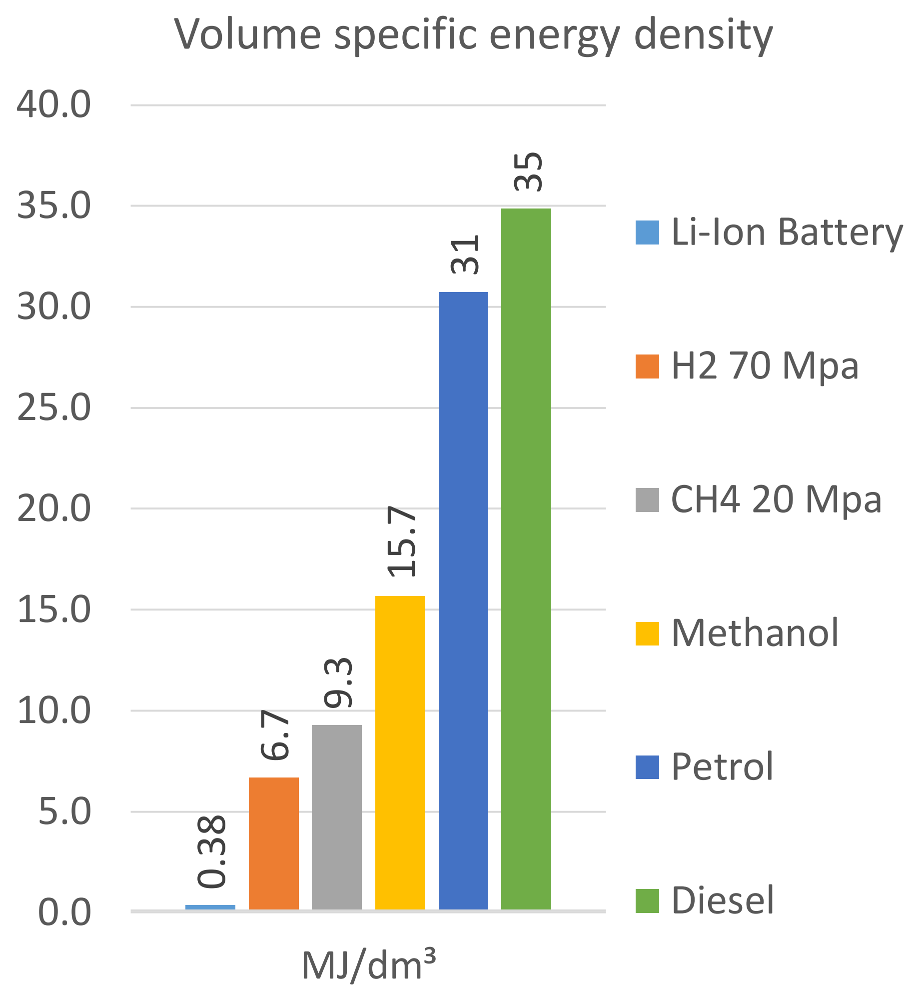
No universal solution for electric storage

- Large scale storage can only be addressed by
  - pumped hydro,
  - compressed air energy storage (CAES) and
  - chemical storage media like hydrogen and methane
- The potential to extend pumped hydro capacities is very limited
- CAES has limitations in operational flexibility and capacity

Energy storage density of any common fuel superior to batteries. Batteries have to accommodate all reactants and all products. m=const.

BUT BATTERIES CAN STORE ENERGY RECUPERATED DURING DECELERATION.





BEV: Per definition, it is propelled by electric motors, and its only source of power is the battery charged from the grid

Facts and prospect

Energy use (m=1400 kg)

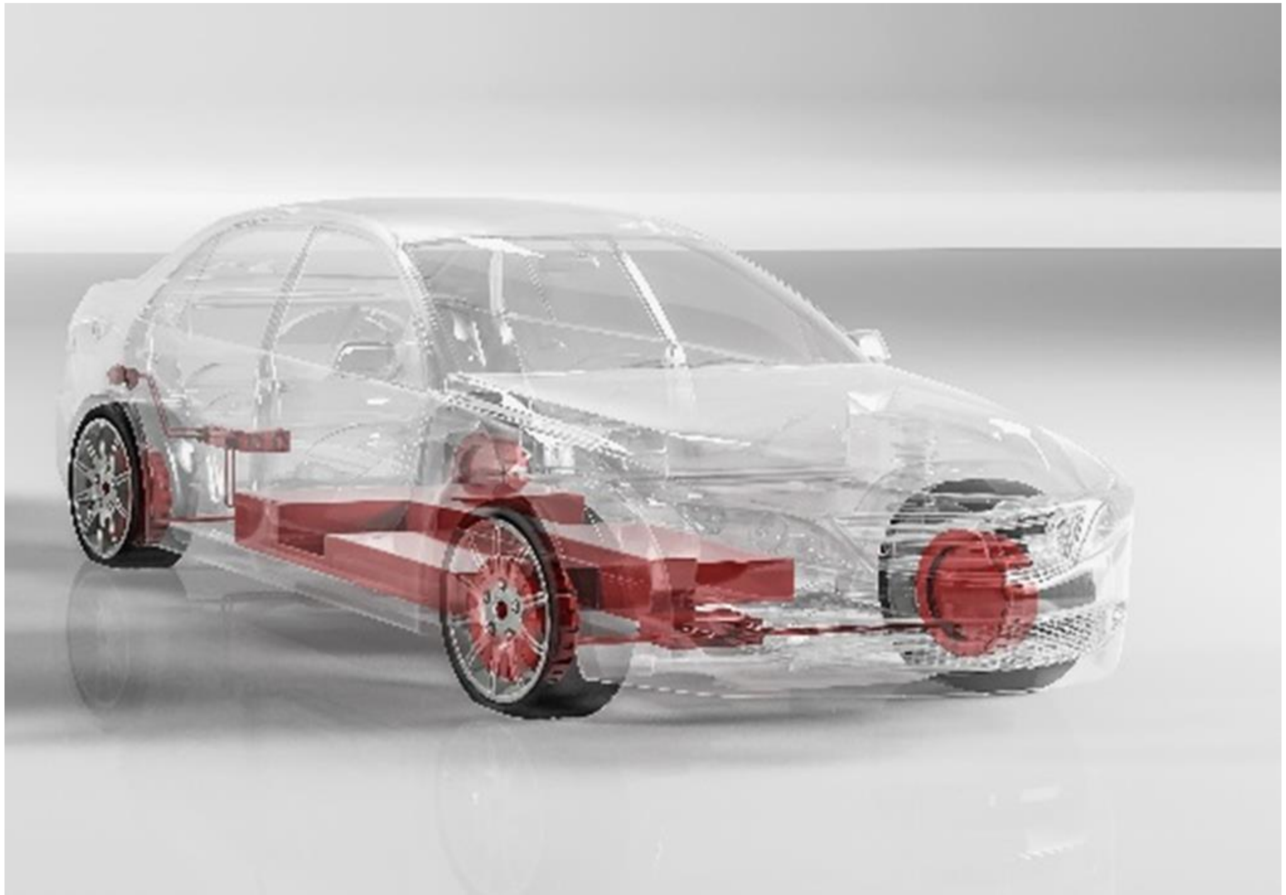
- 2016: 162-171 Wh/km (NEDC)
- 2030: 115-120 Wh/km (NEDC)

Battery pack energy density

- 2016: 160 Wh/kg
- 2030: 330-500 Wh/kg

Environmental impact:

- Zero CO_2/km T2W
- 2016: 45-47 g CO_2/km W2W (EU mix 2014: 275.9 g/kWh)
- 2030: 23-24 g CO_2/km W2W (EU mxi 2030 ~ 180 g/kWh)
- Li-Ion battery production causes ca. 140 kg CO_2 per 1 kWh capacity [IFEU2016]
- Non-zero particulate emissions from brake & tires



Battery production and material sourcing assigns a big GHG backpack for lifecycle

Source: European Roadmap:Electrification of Road Transport,3rd Edition Version 8.0, ERTRAC EPoSS SmartGrids, 2017. [IFEU2016]: see pg. 14

BEV: Per definition, it is propelled by electric motors, and its only source of power is the battery charged from the grid

Facts and prospect

Energy use (m=1400 kg)
- 2016: 162-171 Wh/km (NEDC)
- 2030: 115-120 Wh/km (NEDC)

Battery pack energy density
- 2016: 160 Wh/kg
- 2030: 330-500 Wh/kg

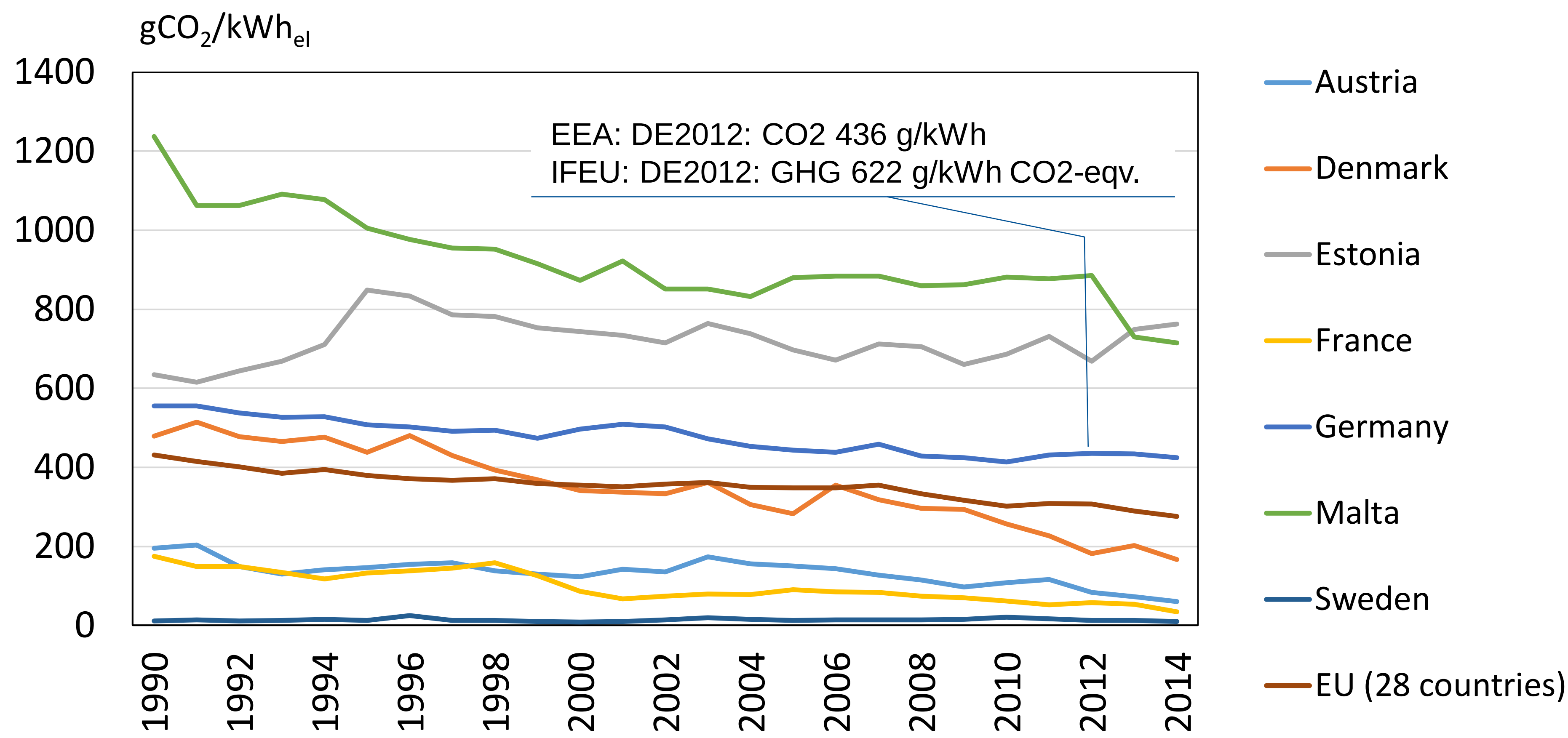
Environmental impact:
- Zero CO2/km T2W
- 2016: 45-47 g CO2/km W2W (EU mix 2014: 275.9 g/kWh)
- 2030: 23-24 g CO2/km W2W (EU mxi 2030 ~ 180 g/kWh)
- Li-Ion battery production causes ca. 140 kg CO2 per 1 kWh capacity [IFEU2016]
- Non-zero particulate emissions from brake & tires

Battery production and material sourcing assigns a big GHG backpack for lifecycle

Source: European Roadmap:Electrification of Road Transport,3rd Edition Version 8.0, ERTRAC EPoSS SmartGrids, 2017., [IFEU2016]: see pg. 14

Austria and Sweden among the leaders of sustainable decarbonisation, Germany, Estonia depend still too much on coal, Malta on oil

BEV W2W CO2 EMISSION DEPENDS ON SPECIFIC CO2 EMISSION FOR ELECTRICITY PRODUCTION



Source: European Environment Agency, http://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-3.

FCEV combine fuel cell and battery in an electric powertrain

Key facts

Emissions:

- Noxious = zero
- CO_2 = zero
  - T2W: H_2 only
  - W2W: H_2 and CH_3OH only if from RES
- Particulate emissions (tire, brakes) depend on vehicle weight, i.e. battery size

Concepts:

- FCREX: BEV with small FC as range extender and small tank
- FCHEV: FC as main power source, smaller battery for transient peak demand and recuperative braking

Fuel tank for high-pressure hydrogen or methanol depending on fuel cell type

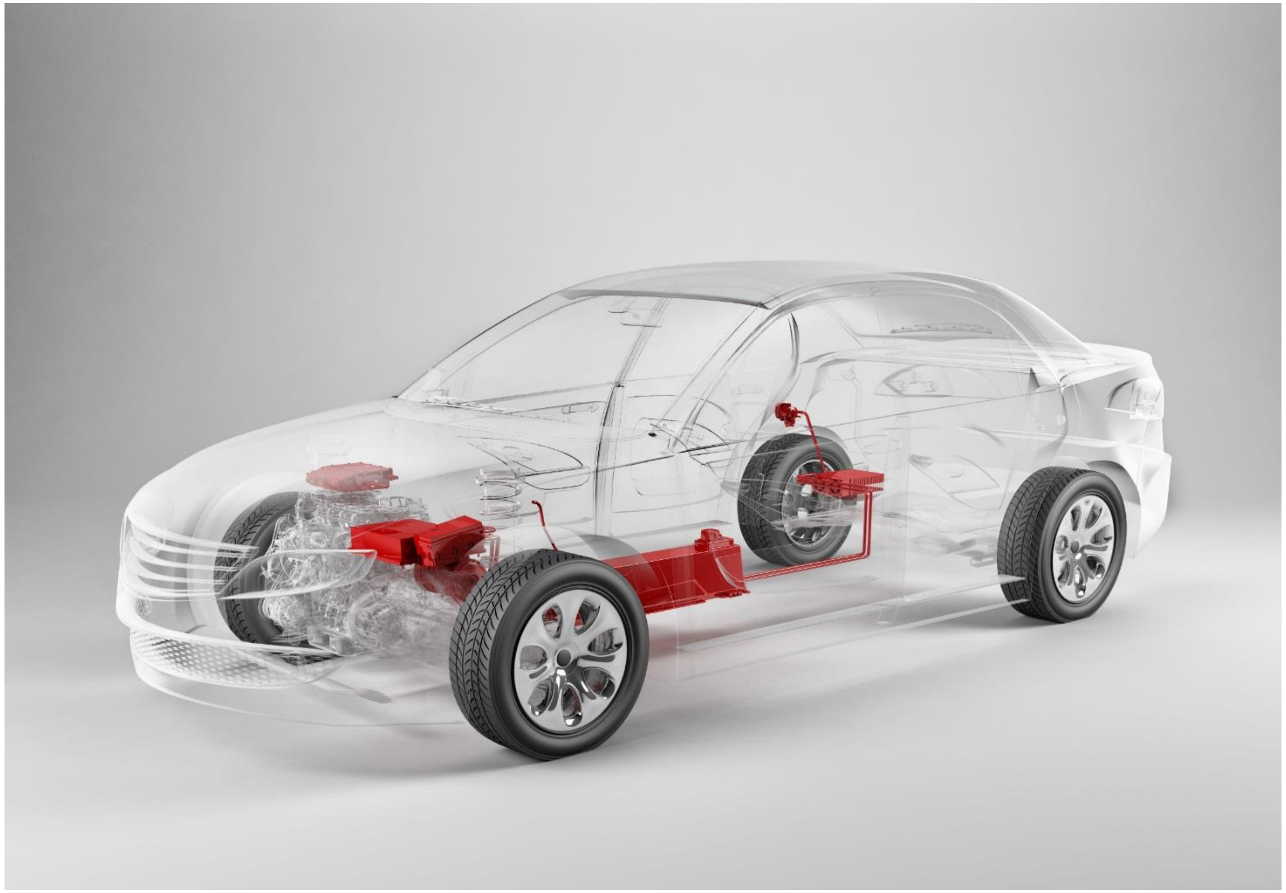
Source: FEV

(P-)HEV: mixed propulsion powered by ICE (typically) & battery with different degrees of hybridization from micro/mild to full/plug-in hybrid

Definitions

Benefits from full HEV

- Replace operation near-idle by electric driving
- Enable emission optimized transient control by electric propulsion support
- Emission-free operation allows access to urban areas
- Typically, battery as energy storage, KERS-like flywheels with motor/generator as niche application
- Electric range depends on battery capacity (CO_2 backpack)
- Heavier than conventional vehicle
- Low certified CO_2 for PHEV



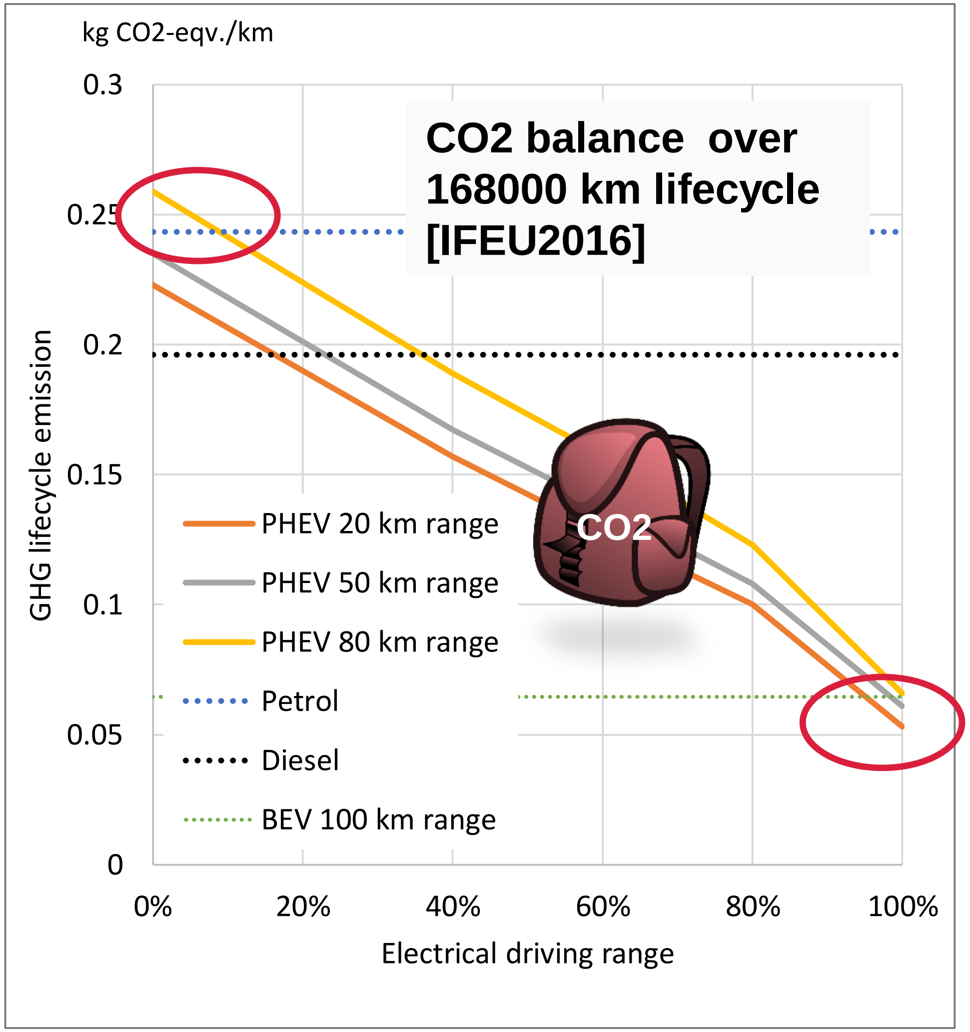
Def.: HEV unlike PHEV recharges battery from ICE only

PHEV – plug-in HEV, i.e. HEV with a charging connector: T2W and W2W CO2 balance depend on electric range and usage of Regenerative energy

Architectures

Different concepts:

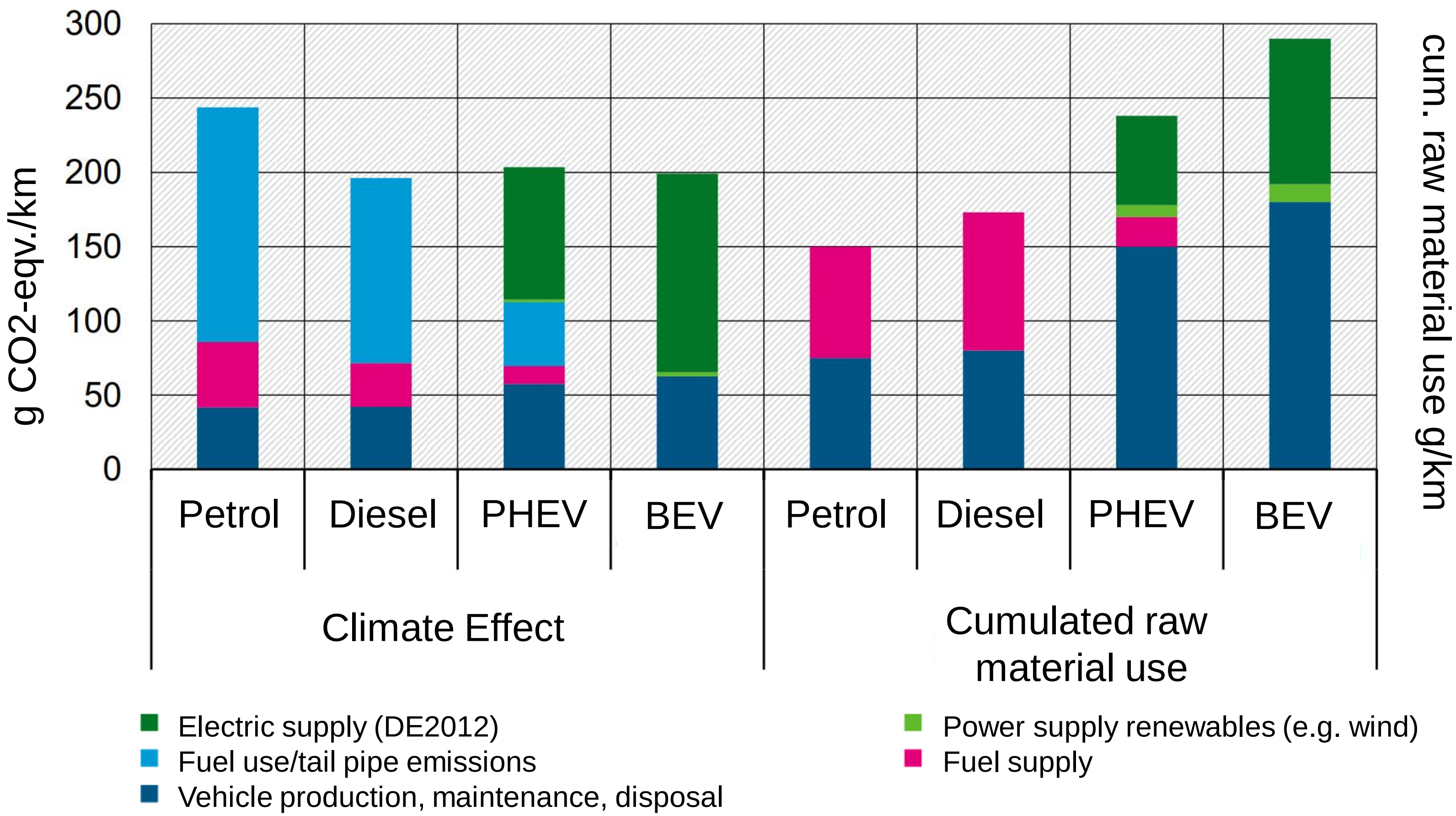
- BEV with REX (e.g. BMW i3)
- HEV with electric range but full performance only with ICE
- Legislation considers electric power from grid as zero CO2
- W2W zero CO2 for electric driving requires charging from 100% RES
- Charging from 100% RES, lifecycle balance better for PHEV with short e-range
  - CO2 “backpack” from battery and ICE
  - Gasoline PHEV better than conventional Diesel, if operated in BEV mode for 17 – 37% depending on range
  - Better than BEV with 100 km range only in case of mostly electric use and short electric range.



Source: [IFEU2016] IFEU , UBA: Weiterentwicklung und vertiefte Analyse der Umweltbilanz von Elektrofahrzeugen. , 4. April 2016

Consumption of other resources and material is seen critical also in other studies → significant need of ramping up BEV component recycling

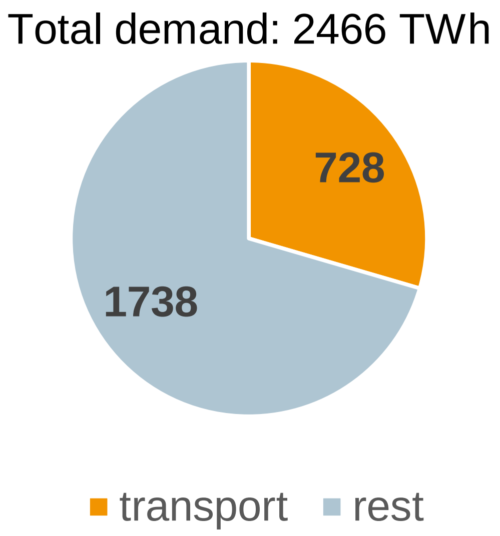
Climatic effects and raw material usage (base year 2014, Energy mix DE2012)

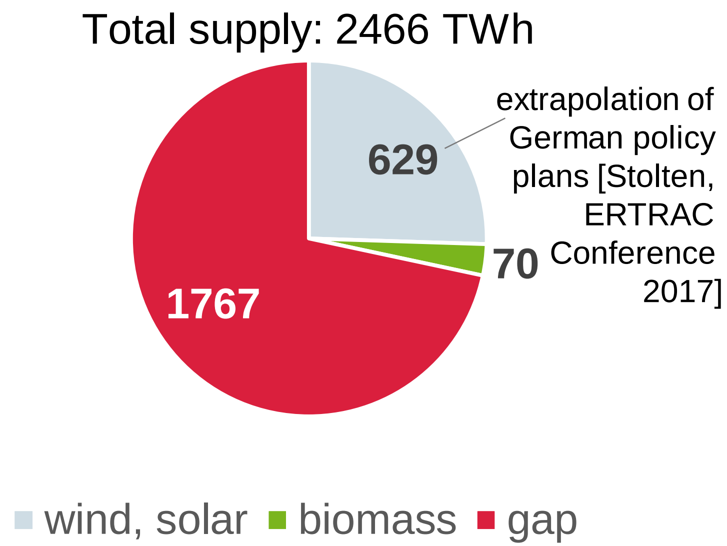


Source: Lange, Mönch: *Elektromobilität fördern und Motorisierten Verkehr steuern – Eine Einführung.* UBA-Forum mobil & nachhaltig, 2017

Projecting a constant end-energy demand in 2050, its supply from RES will force Germany to import renewable energy carriers

Higher transport efficiency will likely be compensated by increase of transport as a whole





Need for imported renewable energy

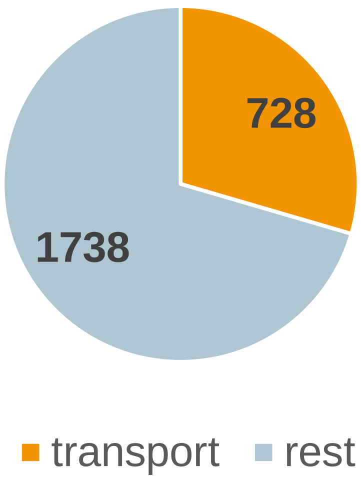
- Germany has limited potential for wind, solar and water power
- Need to buffer domestic renewable energy peaks
- Need to import energy from renewable sources
- Excess solar power available from Spain (likely) or N-Africa

Source: own considerations based on UBA Endenergieverbrauch des Verkehrs 2017, UBA Endenergieverbrauch nach Energieträgern 2017, Stolten 2017

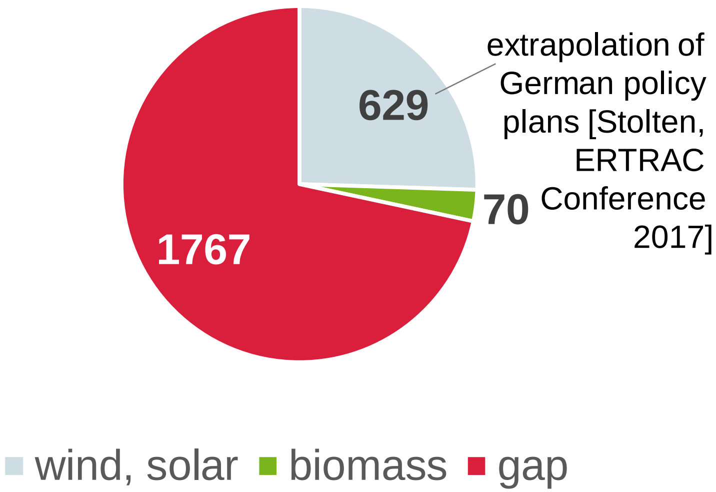
Projecting a constant end-energy demand in 2050, its supply from RES will force Germany to import renewable energy carriers

Higher transport efficiency will likely be compensated by increase of transport as a whole

Total demand: 2466 TWh



Total supply: 2466 TWh



Need for imported renewable energy

- Germany has limited potential for wind, solar and water power
- Need to buffer domestic renewable energy peaks
- Need to import energy from renewable sources
- Excess solar power available from Spain (likely) or N-Africa

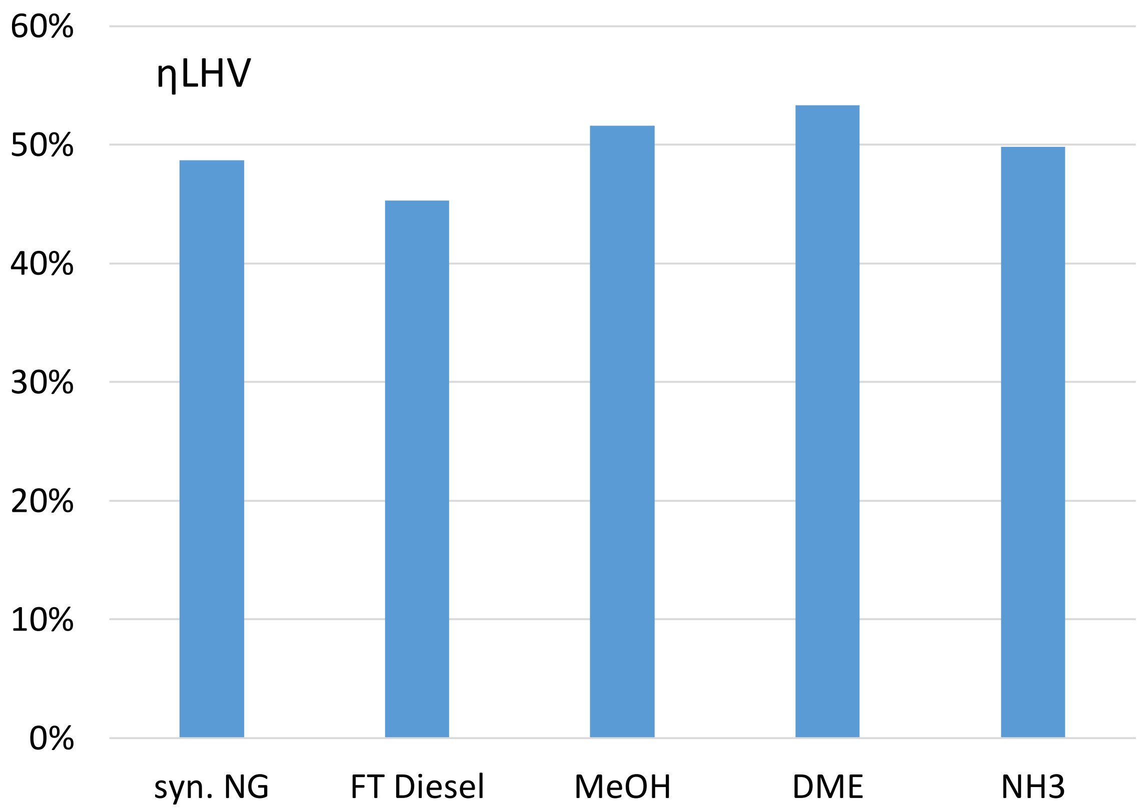
Tackling energy transportation from overseas by liquid synthetic fuels based on H2 from regenerative electrolysis

- Power lines across Mediterranean sea: excessive material usage, ohmic losses ☹
- Hydrogen from electrolysis: low density, if gaseous (vessels, pipelines), 30% of LHV expense for liquefaction 😐
- Liquid fuels from regen. H2 and CO2 as viable path for shipping and buffering, e.g. MeOH 16% add, losses to H2, long term storage possible and transport with low effort and cost possible

Source: own considerations based on UBA Endenergieverbrauch des Verkehrs 2017, UBA Endenergieverbrauch nach Energieträgern 2017, Stolten 2017

When storing excess renewable energy in “e-fuels”, many ways lead from electricity over hydrogen to secondary synthetic fuels

Overall conversion efficiencies for different P2F routes based on flowsheet simulations



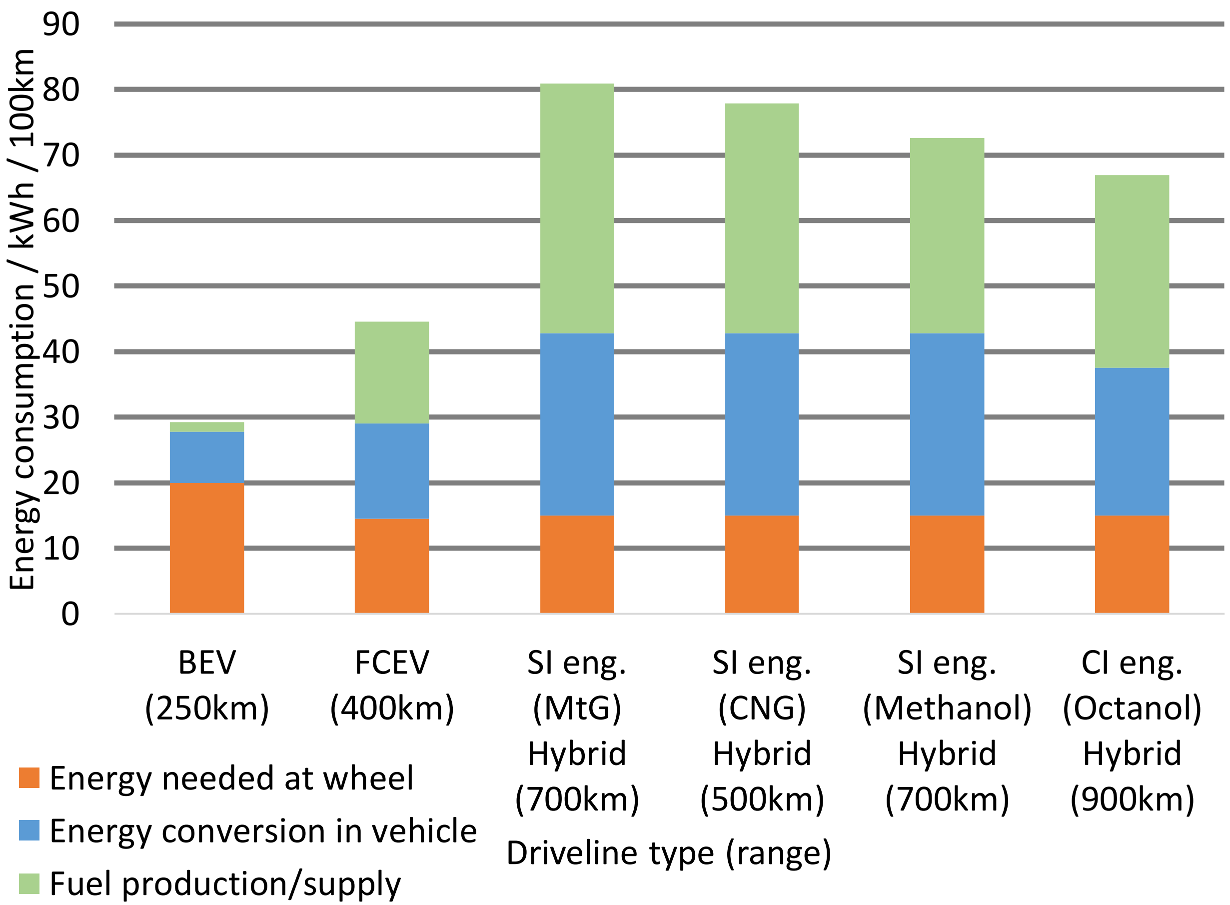
Fuel characteristics

- Fischer-Tropsch Diesel has lower power-to-fuel efficiency than the others, but better compatibility with infrastructure
- Syn. NG compatible with NG networks, positive market vision for use in SI ICEV (VW/Audi, Fiat, Ford)
- Methanol high P2F efficiency, use in ICE or FC
- NH3: LHV similar to MeOH, possible use in ICE or FC
- It takes about twice the renewable energy for generating one unit of PtF heating value

Source: Tremel: *Green hydrogen and downstream synthesis products – electricity-based fuels for the transportation sector.*, 4th Int. Engine Congress., ATZlive, VDI, 2017

Reducing environmental impact when after 2050 all energy for mobility comes from RES

Estimated primary energy consumption of different driveline types (base vehicle weight 1400 kg)



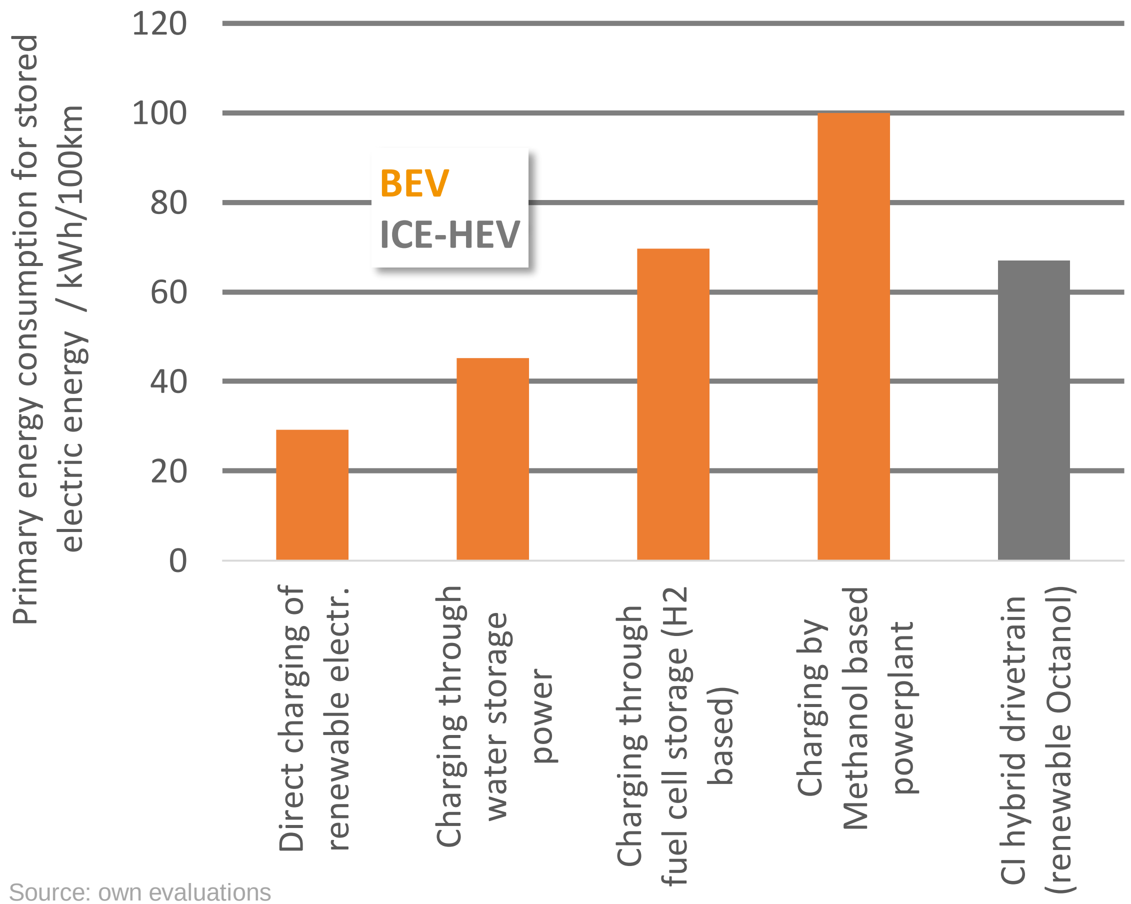
Source: own evaluations

W2W balance

- BEV with 250 km range shows lowest primary energy consumption
- FCEV and ICE-hybrids with similar package space for fuel system
  - FCEV/BEV: 153%
  - MtG SI-HEV to BEV: 277%
  - …
  - Octanol CI-HEV to BEV 229%

When electricity for charging BEV's comes from buffers, the related conversion efficiency has a strong impact

Estimation of primary energy consumption of different types of (electric) energy storage



Source: own evaluations

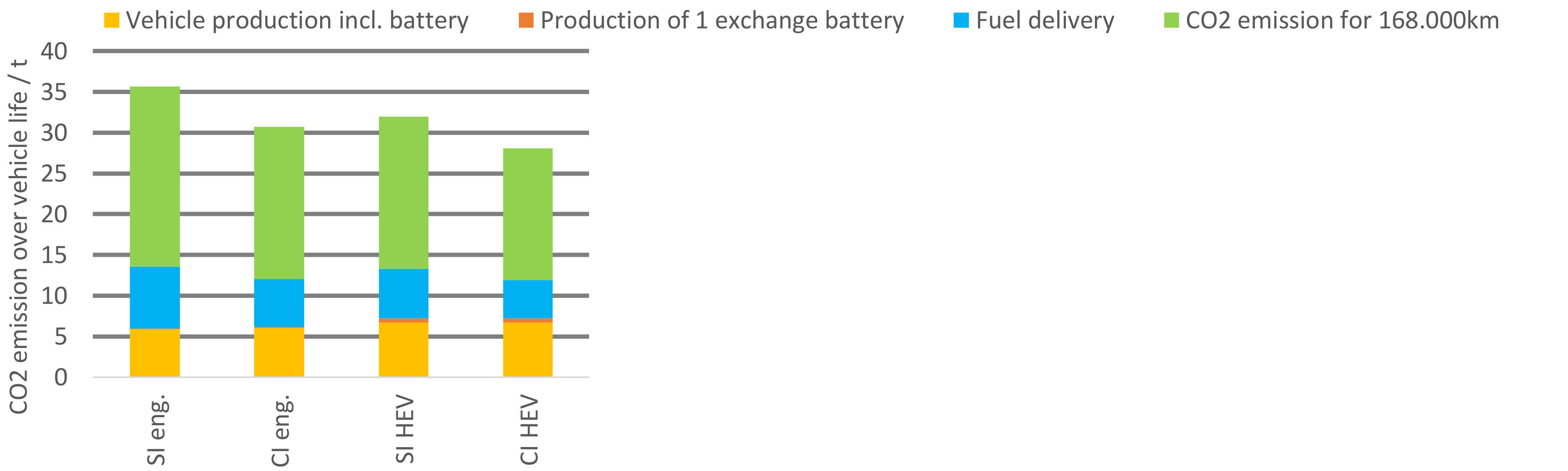
Assessment

- Pumped –storage hydropower plants have best efficiency after charging BEVs directly from RES
- Large battery power plants on similar or better level, but critical because of raw material usage
- Re-electrification using FC and H2 uses more than double the primary energy demand, but grid and cavern storage is possible
- Methanol uses even more
- Using regenerative Octanol in CI HEV ranges on same level as BEV running on re-electrified H2, but is more efficient than re-electrifying long term chemicals such as methanol

There is a possible role for ICE powered HEV in 2050 and beyond to consume buffered RES for transport

In DE2012 scenario, BEV W2W CO2 is on ICEV level. Decarbonisation of power brings BEV to excellent level, like decarbonized fuels for ICE-HEV

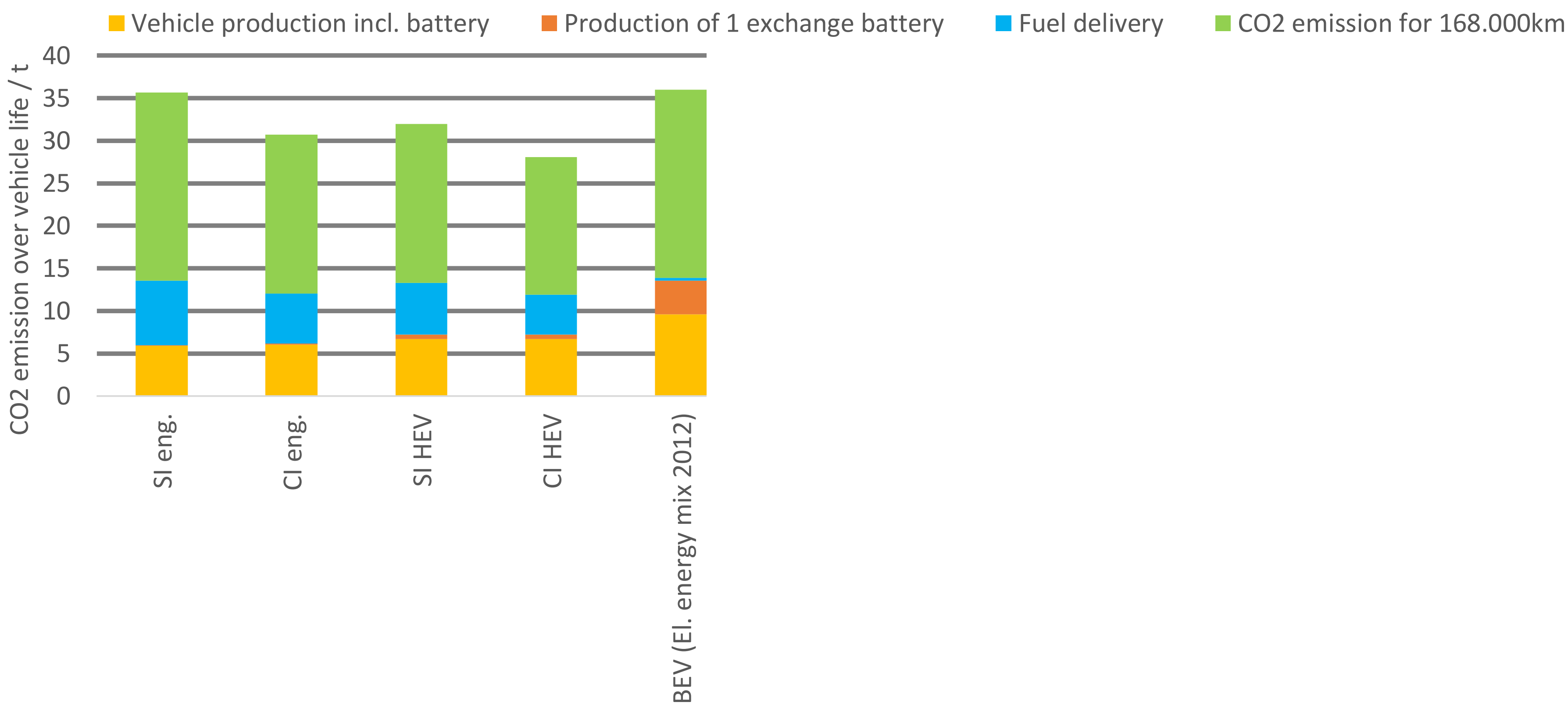
Estimation of lifetime CO2 emission of different driveline and fuel supply variants



Source: own evaluations

In DE2012 scenario, BEV W2W CO2 is on ICEV level. Decarbonisation of power brings BEV to excellent level, like decarbonized fuels for ICE-HEV

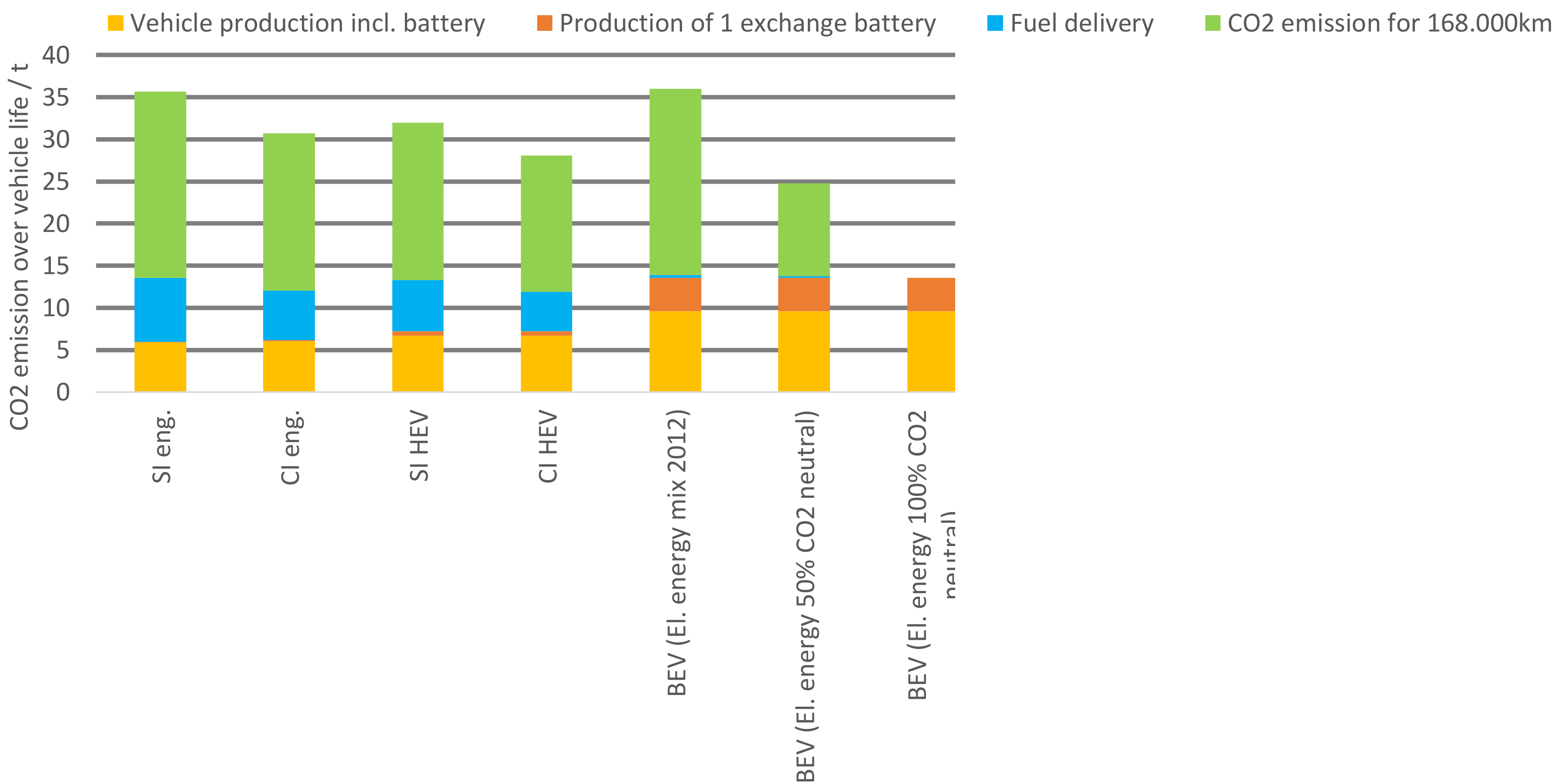
Estimation of lifetime CO2 emission of different driveline and fuel supply variants



Source: own evaluations

In DE2012 scenario, BEV W2W CO2 is on ICEV level. Decarbonisation of power brings BEV to excellent level, like decarbonized fuels for ICE-HEV

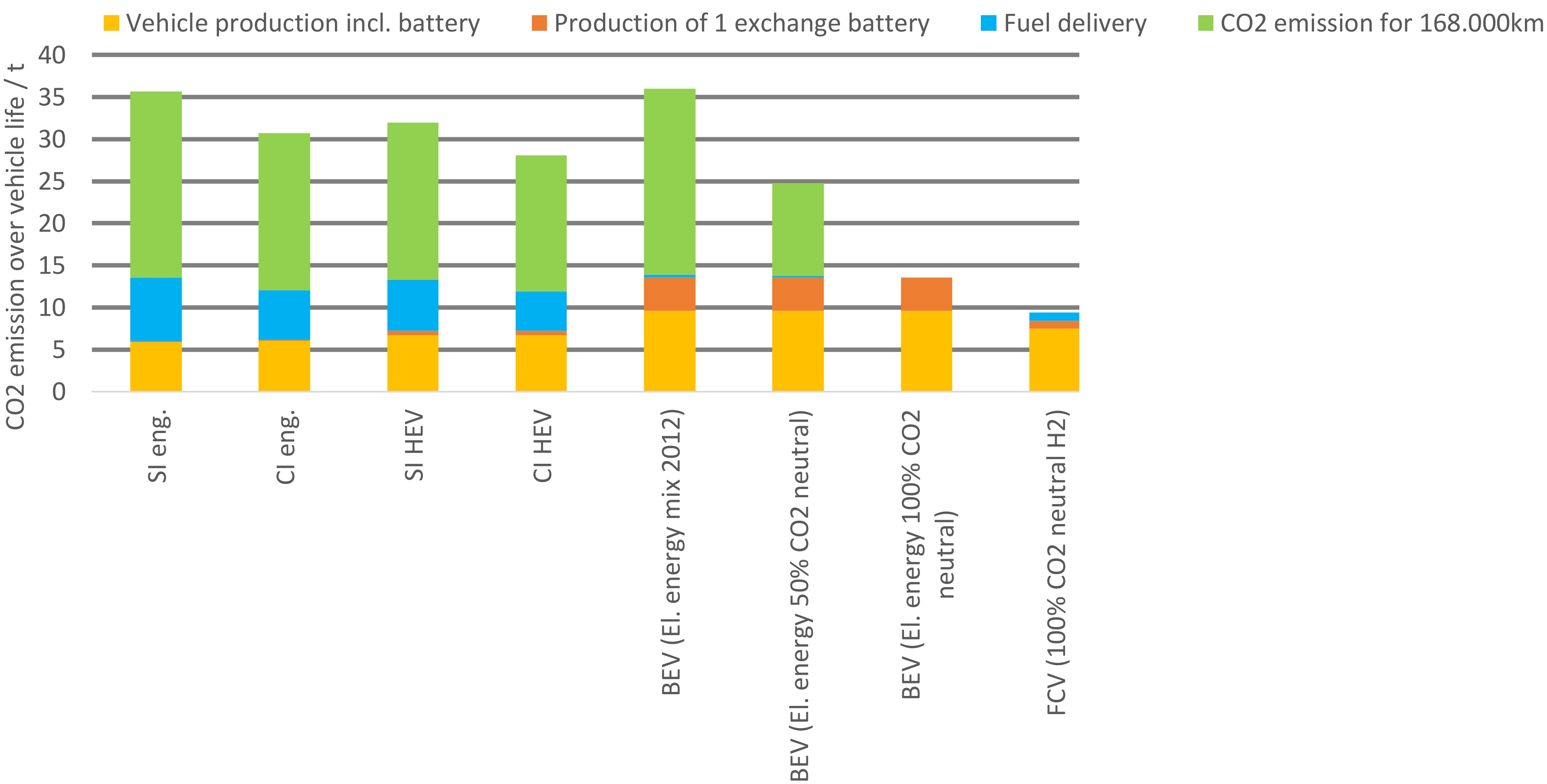
Estimation of lifetime CO2 emission of different driveline and fuel supply variants



Source: own evaluations

In DE2012 scenario, BEV W2W CO2 is on ICEV level. Decarbonisation of power brings BEV to excellent level, like decarbonized fuels for ICE-HEV

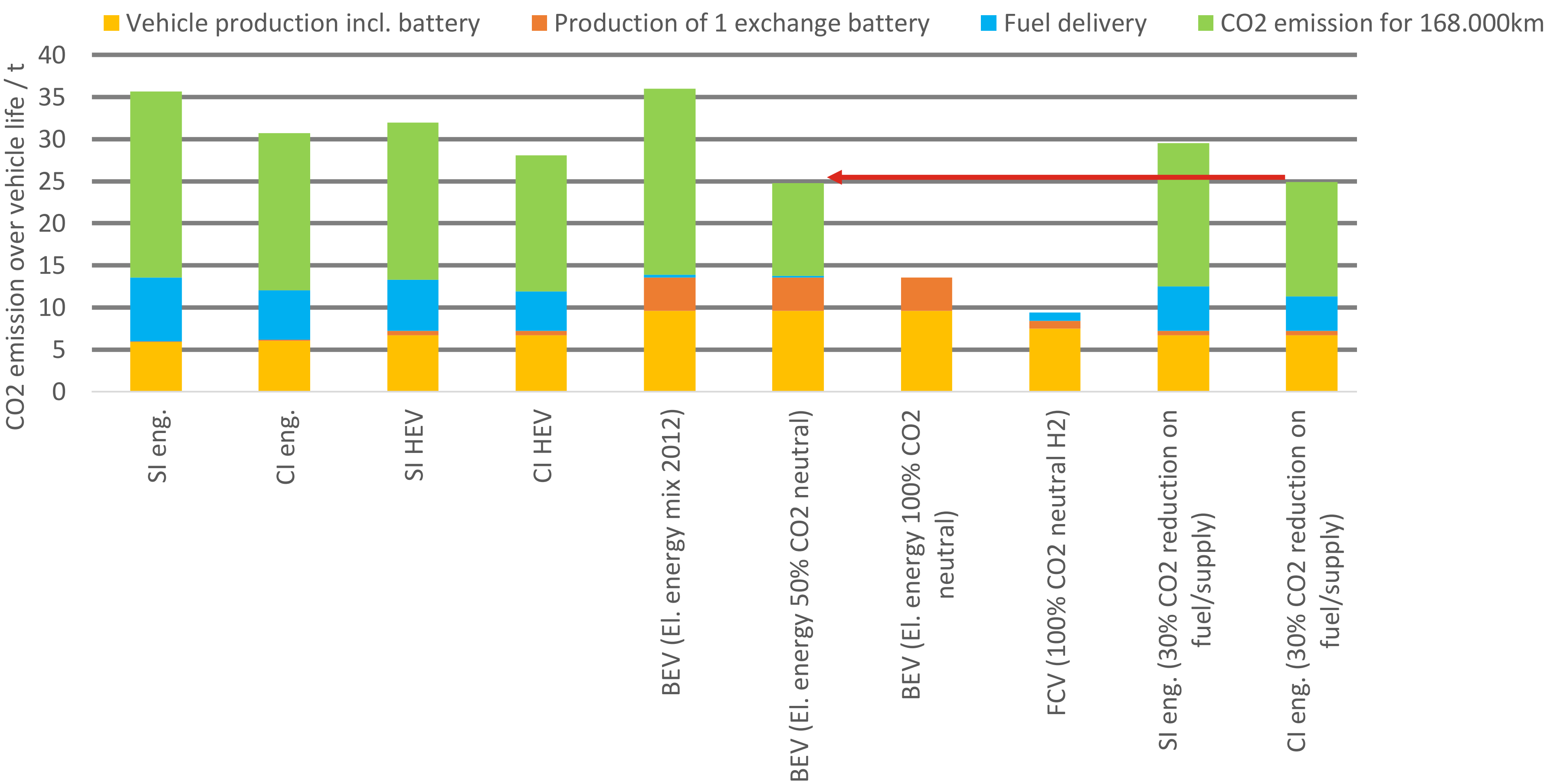
Estimation of lifetime CO2 emission of different driveline and fuel supply variants



Source: own evaluations

In DE2012 scenario, BEV W2W CO2 is on ICEV level. Decarbonisation of power brings BEV to excellent level, like decarbonized fuels for ICE-HEV

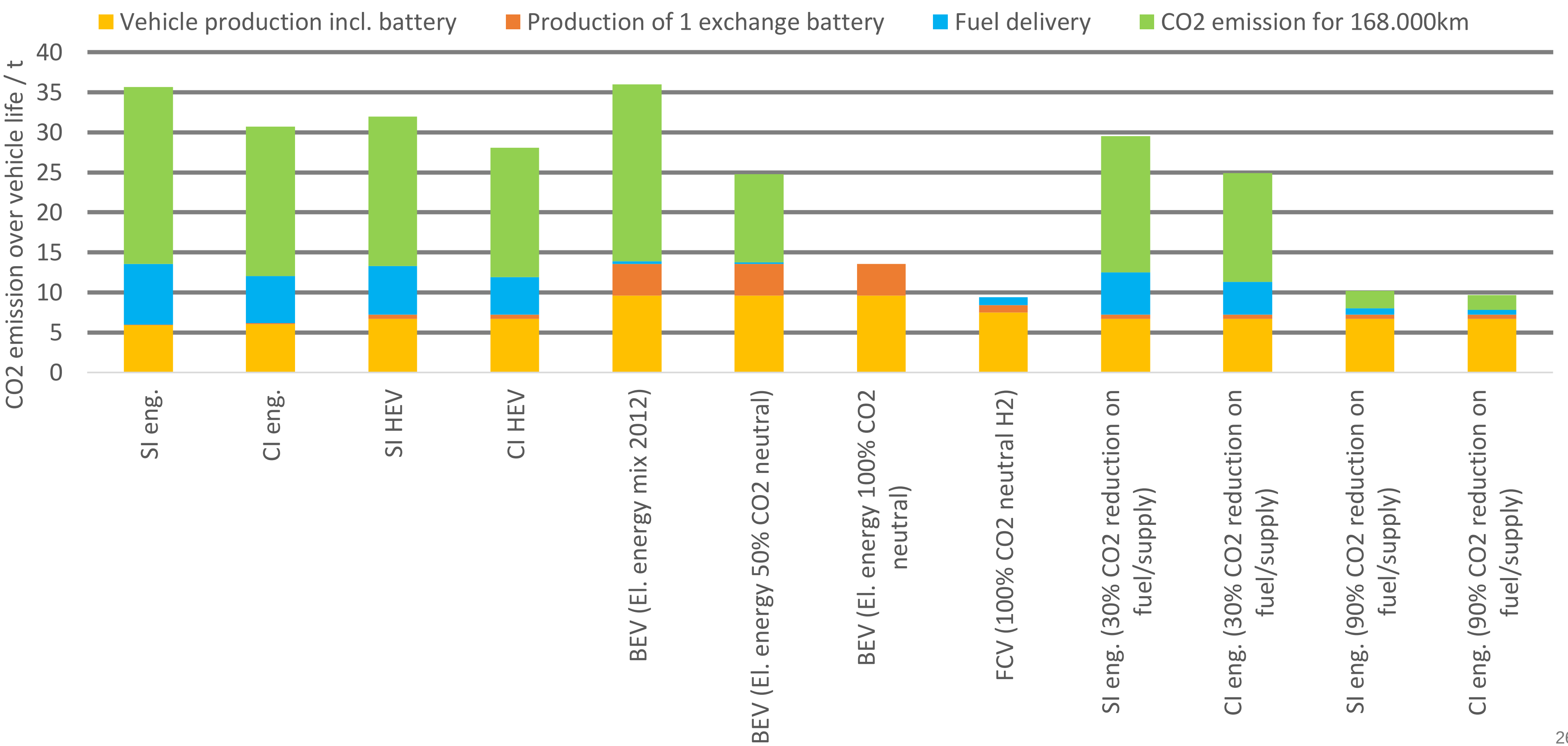
Estimation of lifetime CO2 emission of different driveline and fuel supply variants



Source: own evaluations

In DE2012 scenario, BEV W2W CO2 is on ICEV level. Decarbonisation of power brings BEV to excellent level, like decarbonized fuels for ICE-HEV

Estimation of lifetime CO2 emission of different driveline and fuel supply variants



26

Source: own evaluations

Lifecycle environmental impact of all options has to be considered

Raw material sourcing, processing, bio-/e-fuel production and storage to be tackled

Gold mine in Chudja, N-E of Kongo
© Lionel Healing/AFP/Getty Images

Acid mine drainage at RioTinto (Spain) from copper mining
Courtesy of Carol Stoker, NASA

Experts investigating oil leakage from a cavern on meadows near Gronau, Germany.

Sources (left-right, top-down):
Polke-Majewski, Faigle: "Das Kongo Dilemma"; in: Zeit Online, 12. Juni 2014, 12:37 Uhr / Aktualisiert am 12. Juni 2014, 12:55 Uhr
https://upload.wikimedia.org/wikipedia/commons/b/b0/Rio_tinto_river_CarolStoker_NASA_Ames_Research_Center.jpg
Marco Poltronieri: "Seit zwei Jahren sickert in Gronau das Öl", in: WDR Nachrichten Westfalen-Lippe, vom 12.04.2016, 20:00

Recyclable BEV are the best choice in a world of renewable energy supply. ICE or FC (P)HEV to consume excess RE buffered in PtF

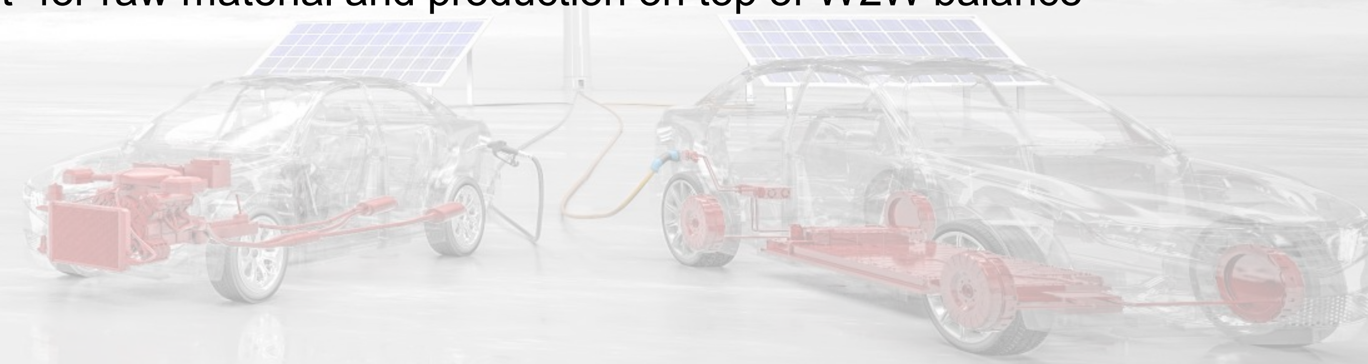
Summary and conclusions

- Combustible fuels from local RES and biomass waste may be on short supply
  - Priority usage in transport modes where they are inevitable like aviation and long-haul
- BEV more efficient if built for short range (battery mass, raw material usage)
  - Need for intensified recycling of rare earths and other material
- Importing “sun-fuels” seems inevitable for European countries like Germany to enable 100% renewable energy supply for all economy sectors
- Once sun-fuels are there, their use in ICE HEVs can be more efficient than re-electrification for BEV’s

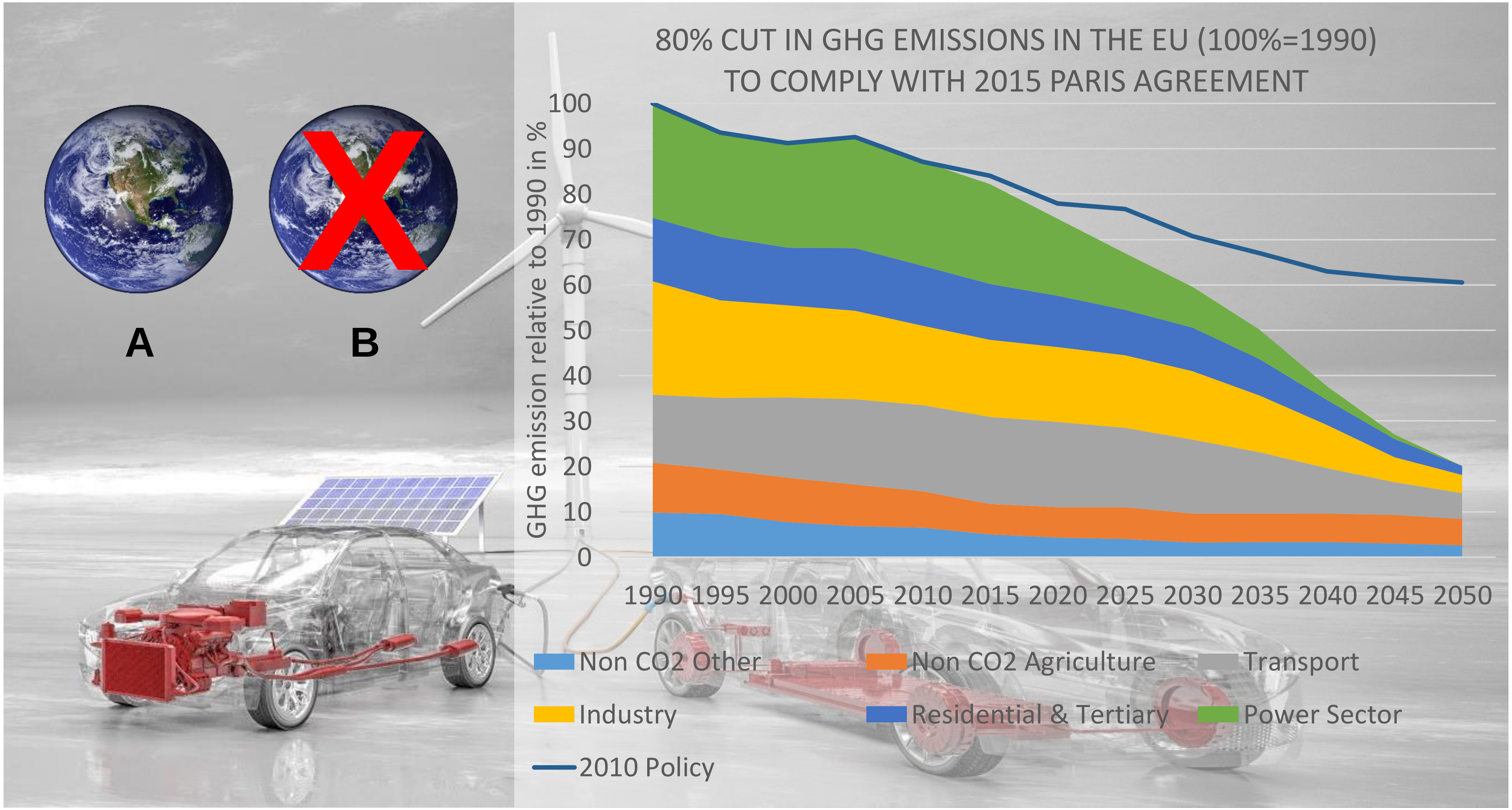
Recyclable BEV are the best choice in a world of renewable energy supply. ICE or FC (P)HEV to consume excess RE buffered in PtF

Summary and conclusions

- FCEV are ideal for using Hydrogen from domestic excess renewable energy
- On a well-to-wheel perspective, BEVs are approximately
  - 3-times more efficient than e-fuels and
  - 1.5 times more efficient than FCEV's
- Only lifecycle balance gives the full picture on environmental impact of mobility concepts
  - Hidden "cost" for raw material and production on top of W2W balance



All sectors of economy have to share regenerative energy. It is available only once. Just like our planet.



Questions?

Thank you

- Christof Schernus
- FEV Europe GmbH
- Neuenhofstr. 181, 52078 Aachen, Germany
- +49 (241) 5689-6753
- Schernus@fev.com

Thanks to Thorsten Schnorbus, FEV Europe GmbH, for his contribution