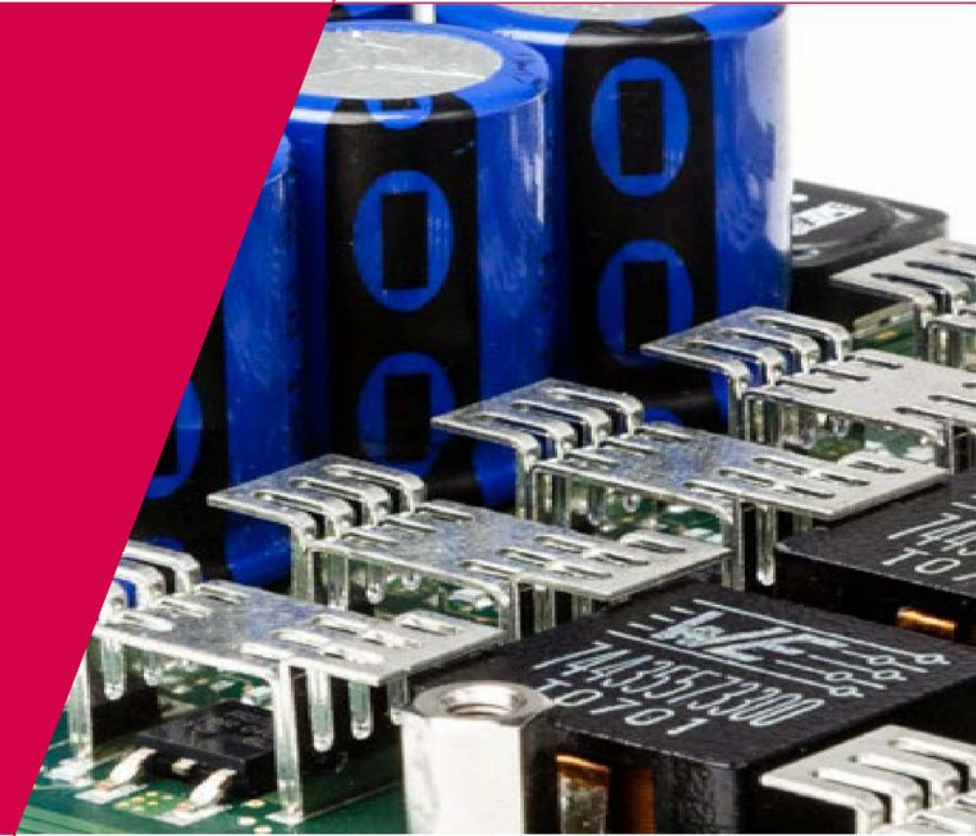


4AT060 Powertrains (ED) 5AT010 Electrical Components

Introduction

Dr. Steven Wilkins



TU / **e**

Technische Universiteit
Eindhoven
University of Technology

Where innovation starts

Lecture Content

- **Introduction and Context**
- **Market and Technology Trends**
- **General introduction to Electrified Powertrains**
- **Powertrains: What's it all about?**

Further Reading:

Chapter 1 ('Introduction'), **Electric Vehicle Technology Explained**, Second Edition, James Larminie, John Lowry

Chapter 8 ('Electric Vehicle Modelling'), **Electric Vehicle Technology Explained**, Second Edition, James Larminie, John Lowry

Chapter 2 ('Fundamentals of Vehicle Propulsion and Brake'), **Modern Electric, Hybrid and Fuel Cell Vehicles, Fundamentals, Theory, Design**, Second Edition, Mehrdad Ehsani, Yimin Gao, Ali Emadi

We face many challenges... (updated)

This is a decisive decade for our world

– Biden, UN General Assembly, 21st September 2021

MACKEY
mackaycartoons.net



Europe has the ambition to be net-zero (no GHG emissions) by 2050

- The average lifetime of a car is 12 years
- The average lifetime of a truck is 14 years
- The average lifetime of a ship can be 30 years

This means we need to be selling 100% zero emission this much earlier...

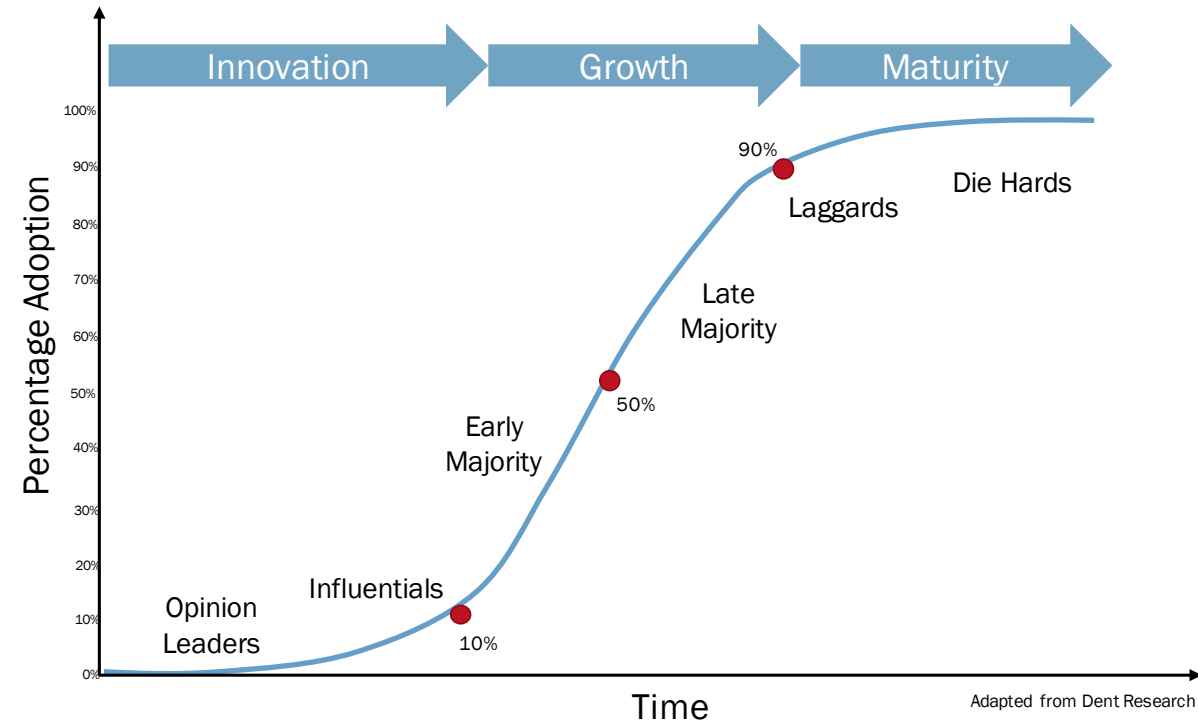
What options do we have on the table?

- Full electrification?
- Hybrid fuel cell vehicles?
- Combustion*? Hybrids?

*only with carbon neutral fuels...

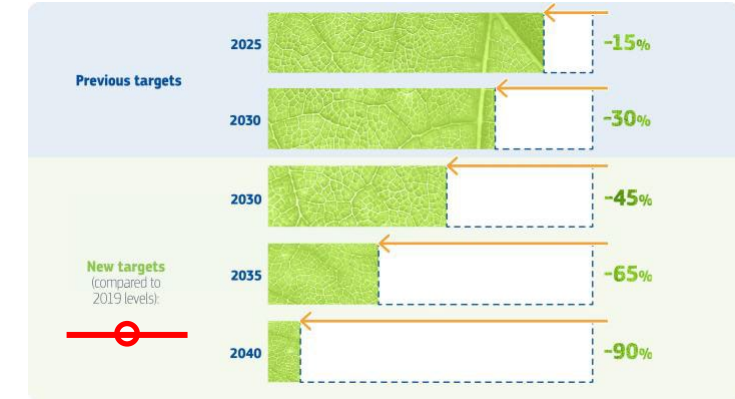
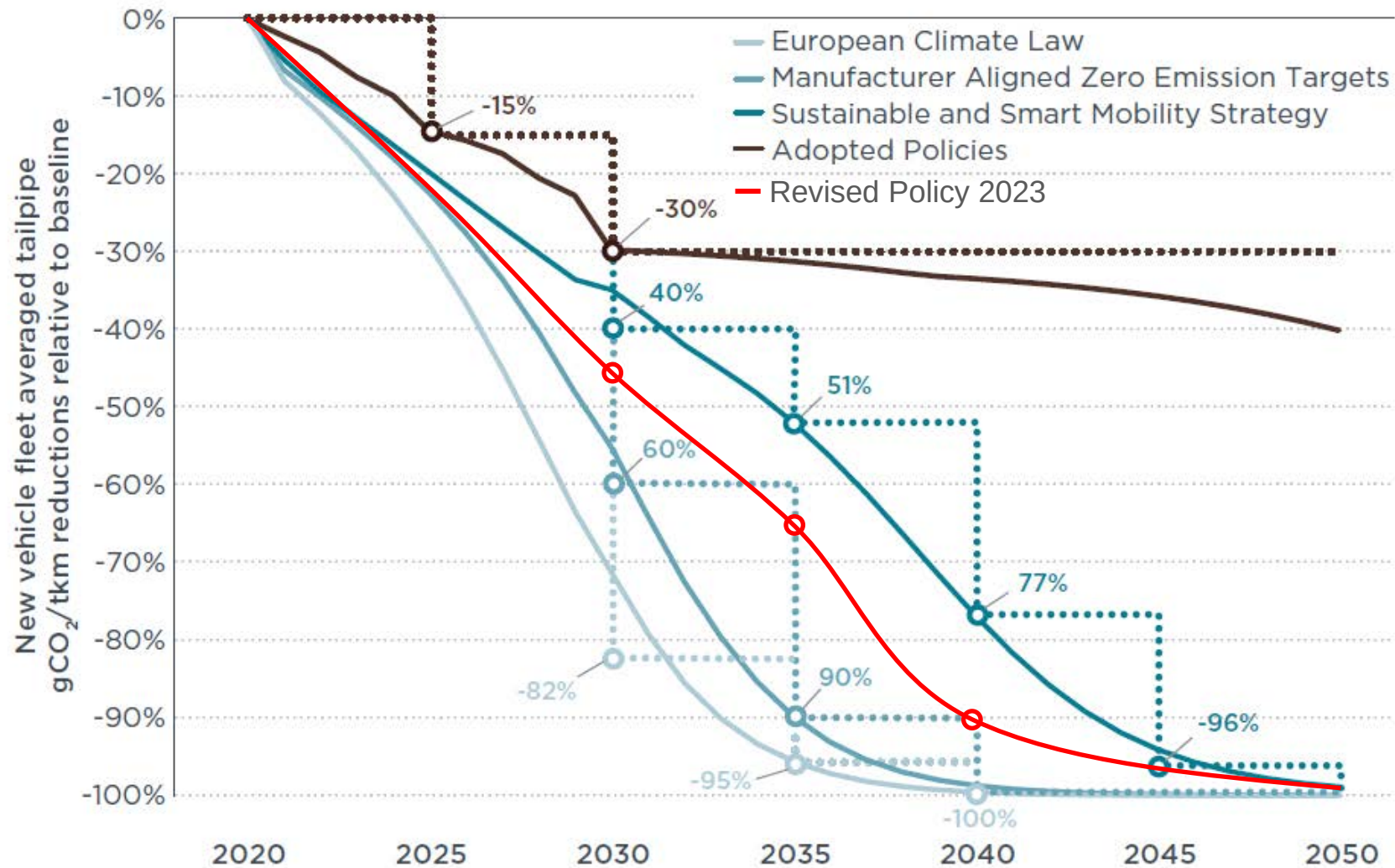
Challenges:

- Technology maturity
- Cost
- Efficiency
- Critical Raw Materials
- Infrastructure (fuelling/recharging)



Truck New Vehicle Targets

4

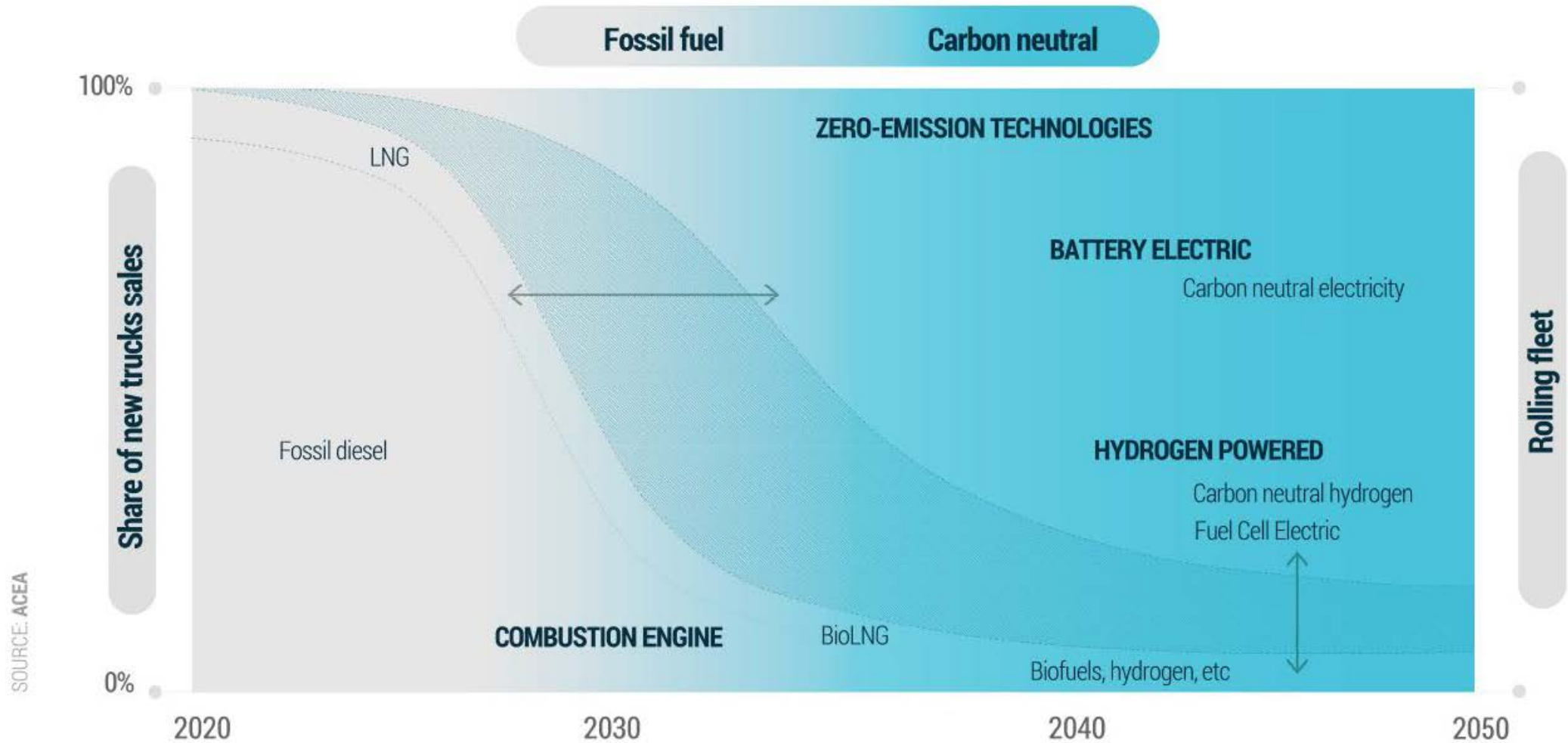


As of 2023 the truck targets are revised

- Targets set at fleet level for new vehicles
- Credit system also available to help meet targets (with a limit 2-3%)
- Financial penalties in case of non-compliance with the CO₂ targets. The level of the penalties is set to 4,250 euro per gCO₂/tkm in 2025 and 6,800 euro per gCO₂/tkm in 2030.
- Monitored and reported using VECTO simulation tool

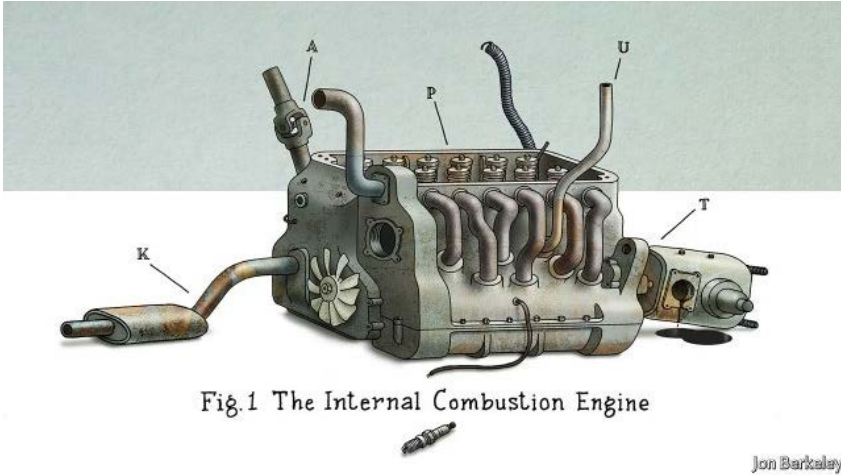
Example View (ACEA*)

5



SOURCE: ACEA

Death of the Internal Combustion Engine? (not yet...)



“General Motors believes in an **all-electric future**,” Reuss (chief of global product development) said. “Although that future won’t happen overnight, GM is committed to driving increased usage and acceptance of electric vehicles.”

BMW has already said it will electrify its entire range, as has Volvo. Volkswagen introduced 20 new all-electric cars by 2020, with a manufacturing plan capable of building “2 to 3 million all-electric cars a year by 2025”.

Volvo Trucks targets 50% sales of e-trucks by 2030

Netherlands (and other countries) have declared intentions to ban emissions-producing trucks by 2040, with passenger cars earlier at 2035. ACEA has already planned to phase out fossil fuel vehicles by 2040

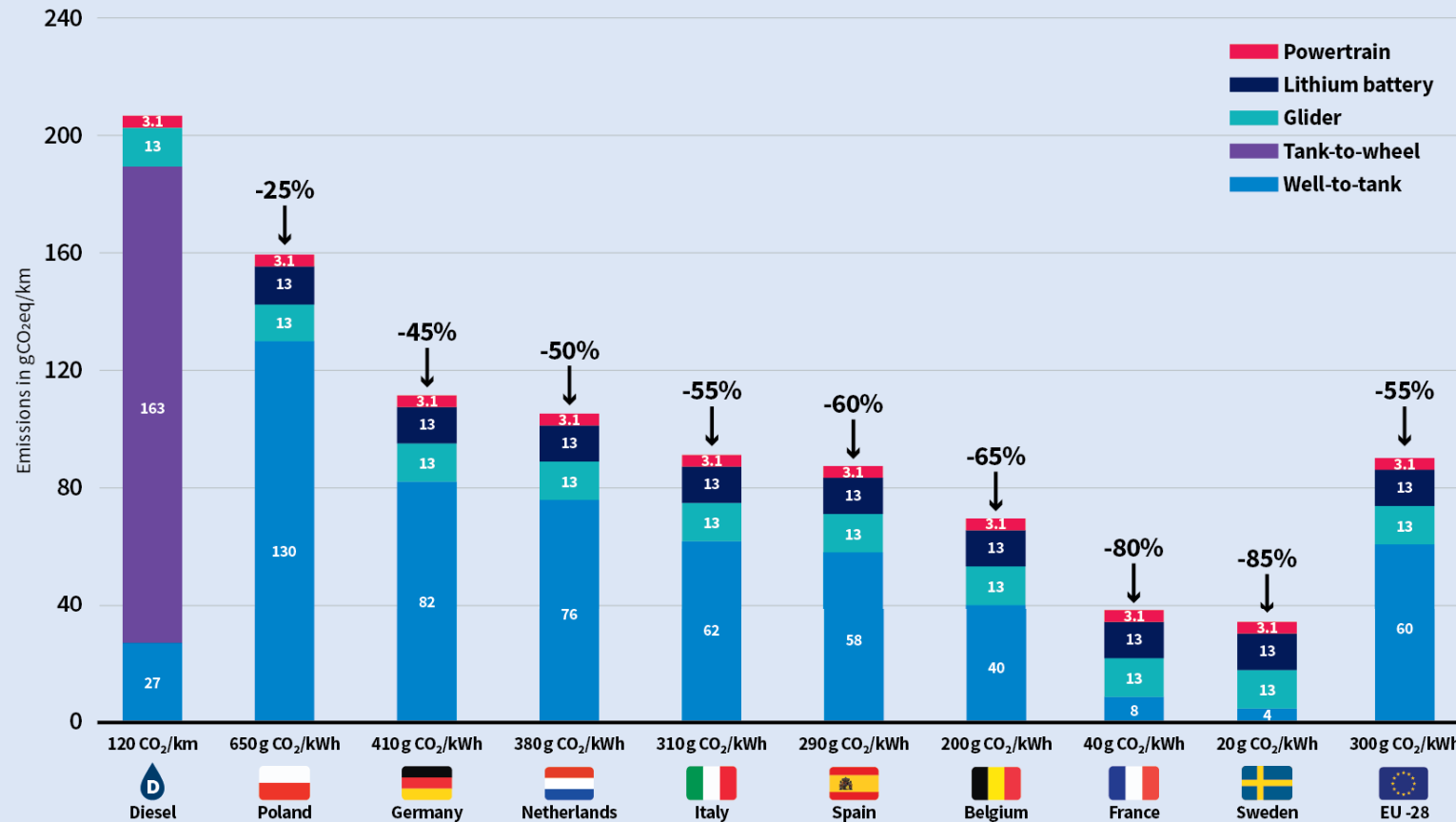
Battery costs are plummeting, and Bloomberg New Energy Finance predict that electric vehicles (EVs) will be cheaper than petrol cars by 2022. A Nissan Leaf can already receive a 80% charge in 30 minutes, and that will only improve.

“E-mobility is coming now. The technology is mature and most efficient. In our estimation, 80[%] or even 90% of logistics trucks will be electrically driven,” MAN CEO told Austrian newspaper Der Standard.

Dieselpgate did not help....

Are Electric Vehicles Really Better for CO2?

Electric vehicles' climate impact in different energy mixes



Requires Life Cycle Assessment (LCA)

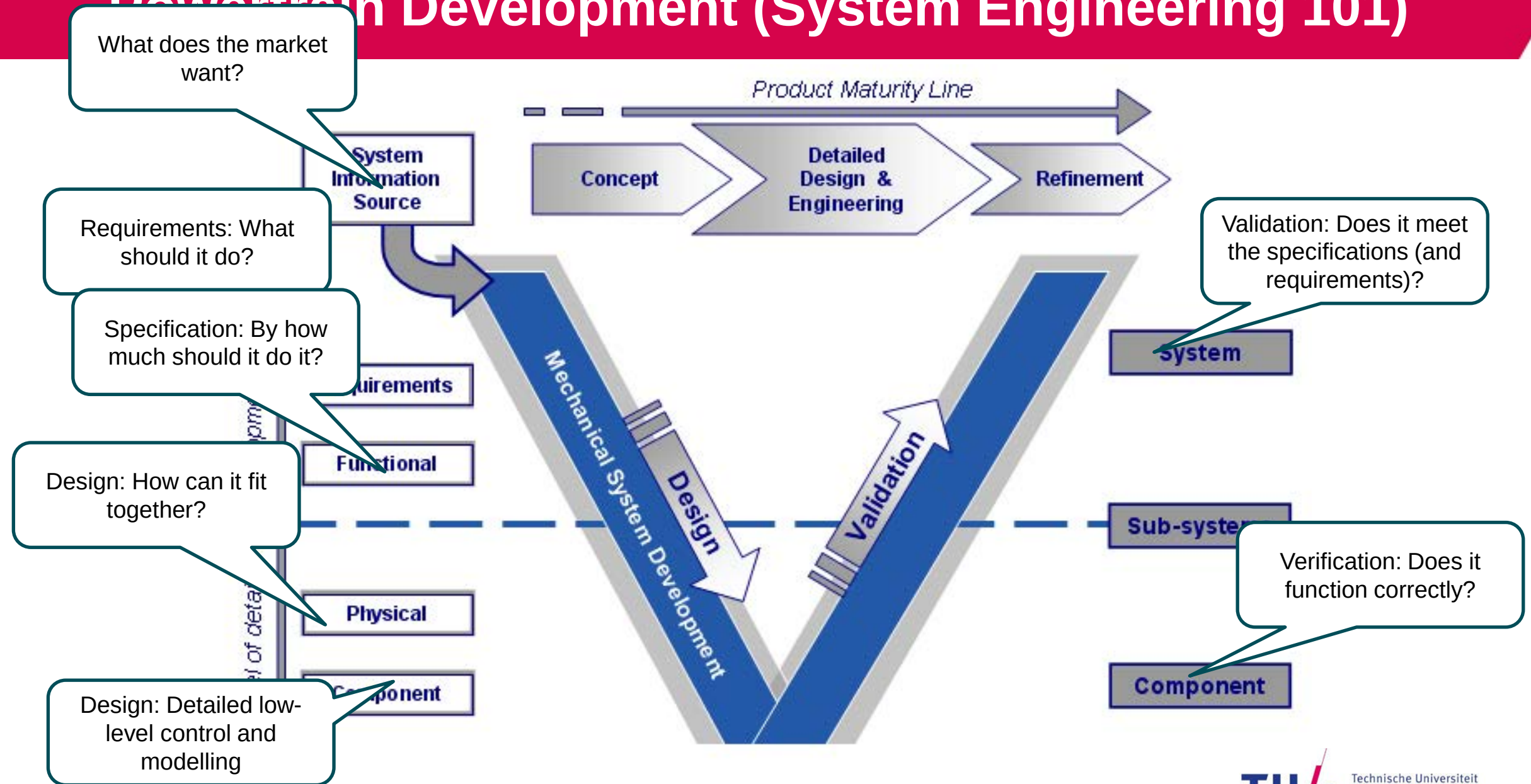
Complex analysis; depends on battery production, lifetime, efficiency, and energy production (country dependent)

About Powertrains

Powertrains – A Definition of the Discipline

- A powertrain is a system inside a vehicle, vessel, or another type of machinery. The system is mainly designed to propel the vehicle forward, but can support other functions.
- In a car, bus or truck, a powertrain consists of the engine or motor and its internal components, such as the energy storage system, transmission and driveshaft.
- Powertrain studies require a systems engineering approach – a methodical, multi-disciplinary approach for the design, realization, technical management, operations, and retirement of a system.
- Modern powertrain development follows a **Model Based System Engineering (MBSE)** approach. To do this, you need to be familiar with models and how to connect them.
- However, for optimization and control, it is important to understand each component in more detail! We deal with this in the following lectures...

Powertrain Development (System Engineering 101)



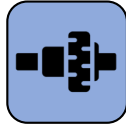
Powertrains: What is it all about?

- Many interlinked functions and variables:
 - Reduction in direct or indirect CO₂ (g/km or kWh)
 - Energy efficiency (kWh/km)
 - Pollutant emissions (PM, NO_x, HCs, g/km)
 - Noise (dB)
 - Comfort (torque interruption)
 - Safety/stability (road handling, torque vectoring, brake blending)
 - Sport (acceleration, top speed)
 - Commercial applications
 - ...
- Extremely important subsystem of the vehicle! What is optimal?
- Purpose of the rest of this lecture: Basic background for working in the field of electric powertrains

Powertrains Lego



Gearbox
AMT/Manual
2+ gear ratios



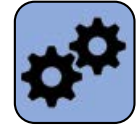
Differential



**Car
Chassis**



Epicyclic



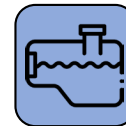
Fixed Gear



Wheel



**Truck
Chassis**



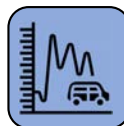
Fuel Tank



Engine



Clutch



Drive Cycle



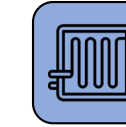
Motor



**Charger
AC->DC**



**HVAC
(Electrical)**



**Fuel Cell
(Electrical)**



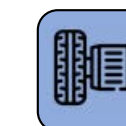
Generator



**DC-DC
Converter**



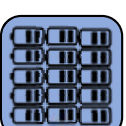
**Pump
(Electrical)**



**In-Wheel
Motor**



**Inverter
DC->AC**



**Battery
Pack**



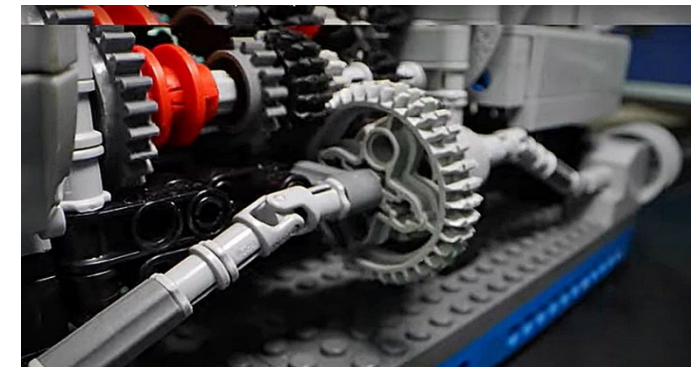
**Aux Load
(Electrical)**

You have at hand a library of potential components

Which should you choose?

How should you connect them?

What size should they be?



Powertrains Topologies

A wide number of options are possible – these can be generated by hand or automatically (with logical connections and connection rules)

	ICE	MG1	MG2	MG3	MG4	PSD1	PSD2	PSD3	PSD4	TR1	TR2	TR3	TR4	TR5	DIF2N-1
ICE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
MG1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MG2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
MG3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
MG4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
PSD1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
PSD2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
PSD3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
PSD4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
TR1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
TR2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
TR3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
TR4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
TR5	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
DIF2N-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DIF2N-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Logical Connectivity Matrix

Conditions to exclude infeasible component combinations

- CE_1^1 Component is never connected to itself
- CE_1^2 A power source is not connected to another power source
- CE_1^3 A power source is not directly connected to an axle
- CE_1^4 A power source is not directly connected to a differential
- CE_2^1 The ICE cannot be connected directly to a differential
- CE_2^2 PSD is connected to $\leq$ one differential
- CE_2^3 PSD is connected to $\leq$ one axle
- CE_2^4 PSD is connected to $\leq$ two power sources
- CE_2^5 PSD is connected to $\leq$ two transmissions
- CE_3^1 GBM is always connected to ICE or PSD
- CE_3^2 GBM is never connected to a MG
- CE_3^3 GBM is never connected to an axle
- CE_3^4 GBM is never connected to a differential
- CE_4^1 TR is never connected to both a differential and an axle
- CE_4^2 TR is never connected to other transmissions
- CE_4^3 TR is never connected to two axles
- CE_4^4 TR is never connected to two differentials
- CE_4^5 TR is never connected to both ICE and GBM
- CE_4^6 TR is never connected to both ICE and an axle
- CE_5^1 An axle is never directly connected to a power source
- CE_5^2 An axle is never connected to another axle
- CE_5^3 A differential is never directly connected to a power source
- CE_5^4 A differential is never connected to another differential

Connection Ruleset

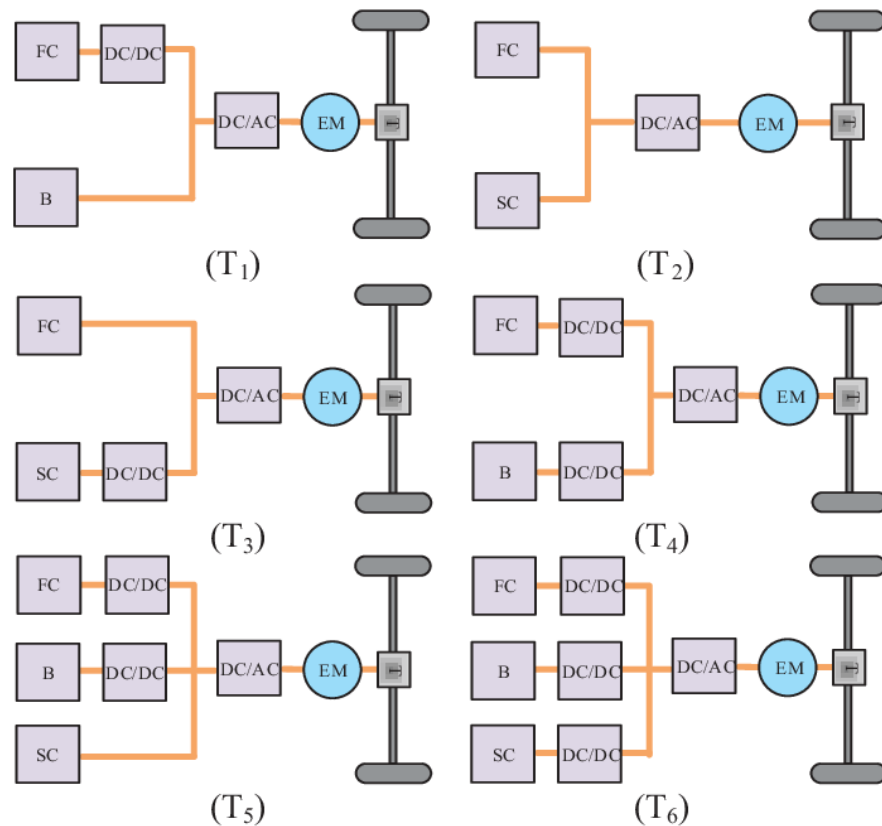
Please remember; a larger number of components is not always desirable
Common architectures/components for different vehicle variants might be desired



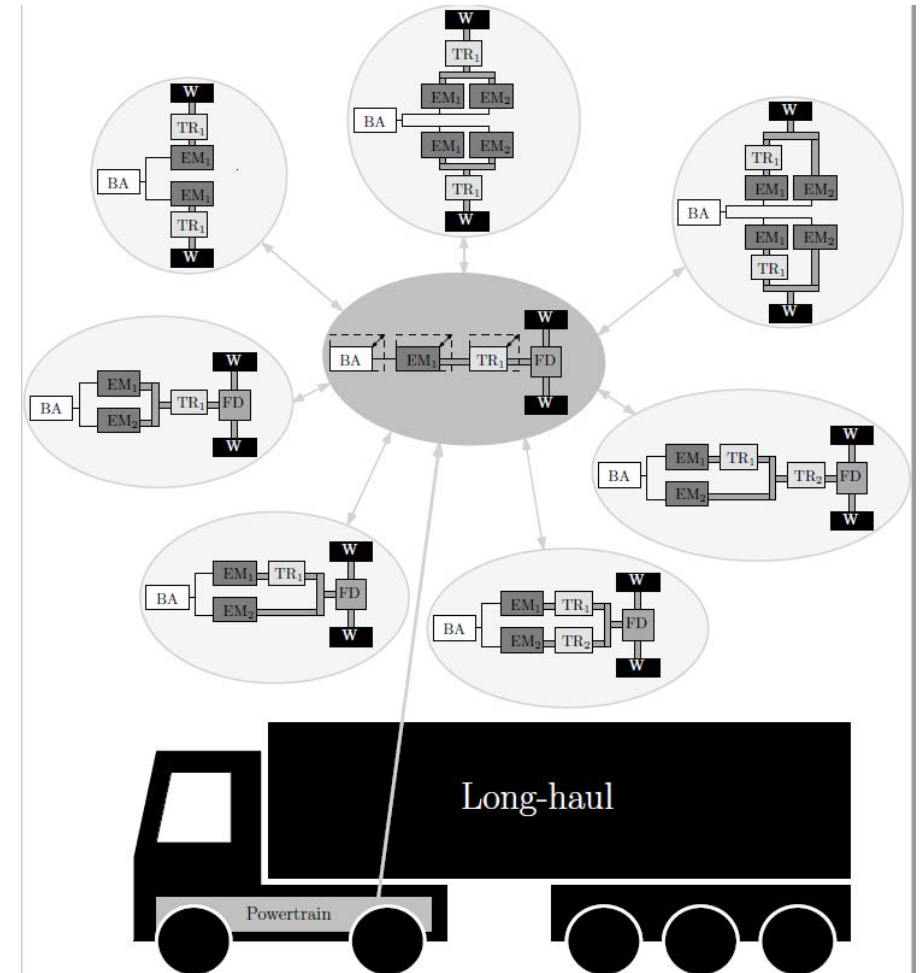
PHOTO: VOLKSWAGEN

Example car options

Powertrain Research



Fuel cell variants



Electric variants

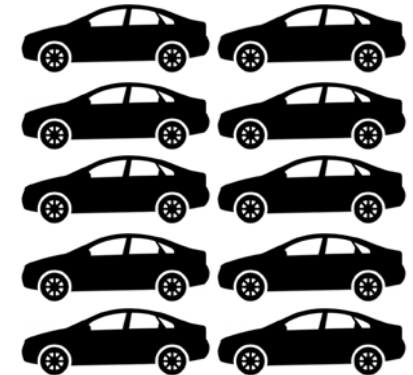
Heavy duty Energy, Charging power

THE DEMANDS OF LONG HAUL FREIGHT, 2030

1-1.5kWh/km, 300-1000km trips, 1MWh, 1-2MW charge



0.1kWh/km, <50km trips
120kWh, 350kW charge



Heavy duty debate:

- Fully electric is accepted for urban and some regional distribution applications
- For long-haul, heavily electrified vehicles will all contain batteries
- Charging will need to coincide with logistics patterns placing high power requirements on remote areas. Hydrogen attractive for fuel cell and/or ICE

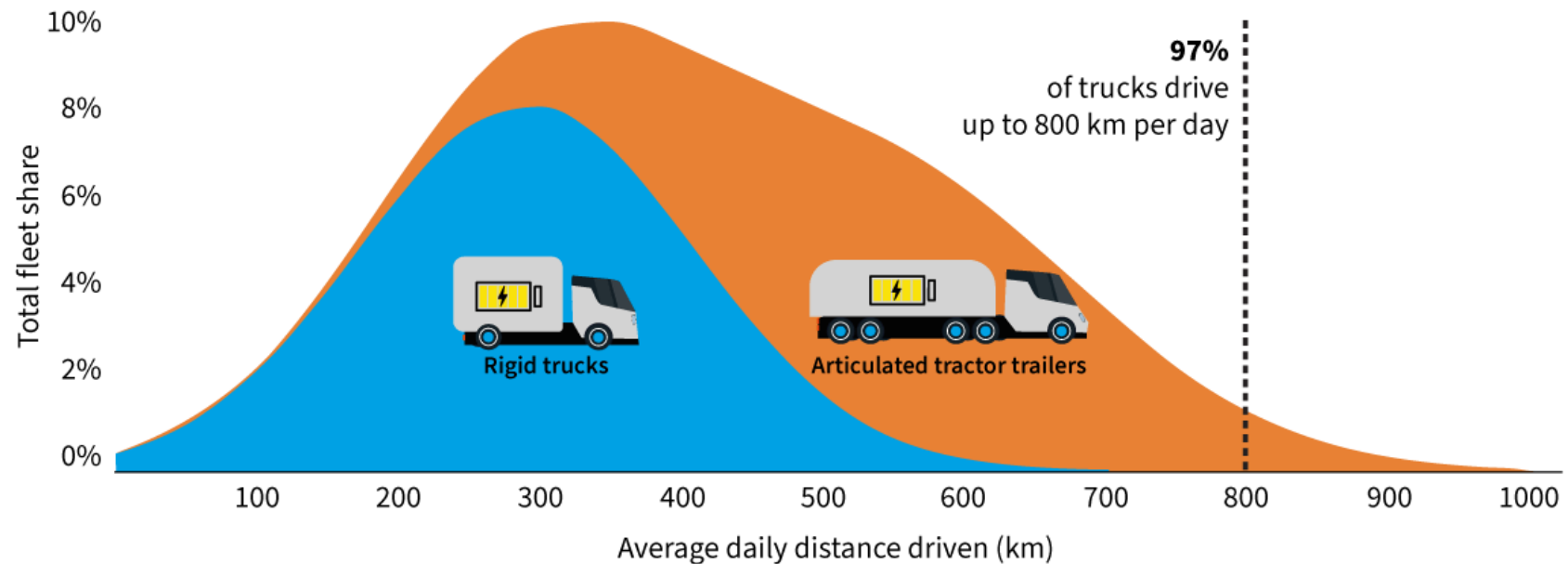
=> Freight corridors (TEN-T) present challenges for deployed infrastructure

What is required for Electric Trucks



Electric trucks can go the distance

97% of trucks in Europe drive less than 800km a day



HD E-Axle Transmission Systems

Electric Axles

- Covering both electric and hybrid vehicles
- Novel and integrated transmission systems; LD Daimler/Renault
- 4x LD motors alternative option (c.f. Tesla)
- Volvo VERA example of integrated example
- AxleTech / Thor trucks recent examples [1]



Tesla (@150-200kW each) Model 3 LD

INTEGRATED E-AXLE FOR MD & HD TRUCKS



800V
148 kW (continuous)
16.000 rpm (e-motor)
13.000 Nm @ wheel
540 kg (w/o oil)
16t GVW (urban truck)

ADDED VALUE:

- HIGH PERFORMANCE
- HIGH EFFICIENCY
- SMALL PACKAGING
- LOW WEIGHT
- MINIMUM NUMBER OF CONNECTORS
- 1 COOLING / LUBRICATION MEDIUM (OIL)
- MODULARITY & SCALABILITY

AVL KNOW-HOW:

- AVL high-speed e-motor (direct oil cooling)
- AVL power electronics incl. TCU
- AVL 2-speed transmission
- AVL system integration



[1] <http://www.greencarcongress.com/2018/10/20181017-axletech.html>

HD E-Axle Transmission Systems



Tesla (@150-200kW each) Model 3 LD

HD E-Axle Transmission Systems

Summary

- Broad overview of context
- General Powertrains themes
- Enabling technologies
- About Powertrains



Questions