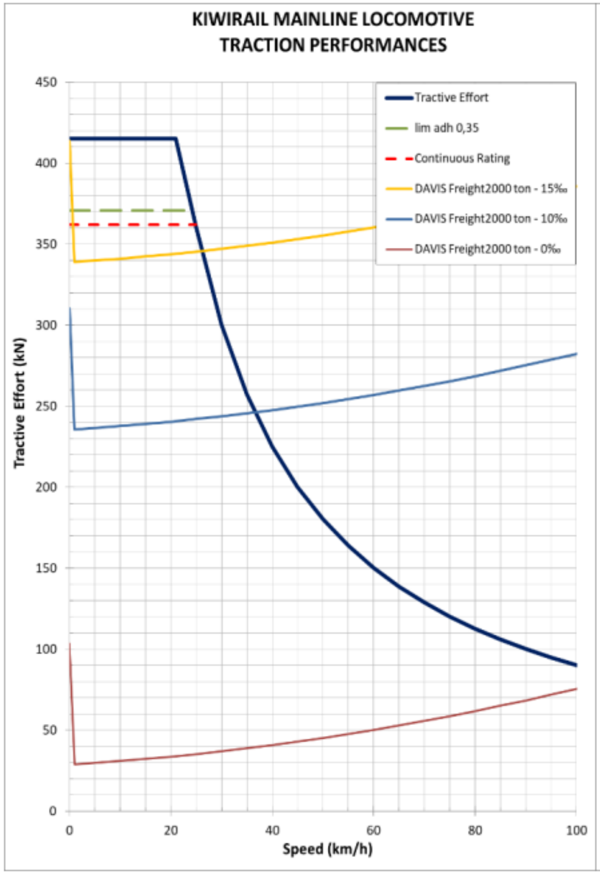
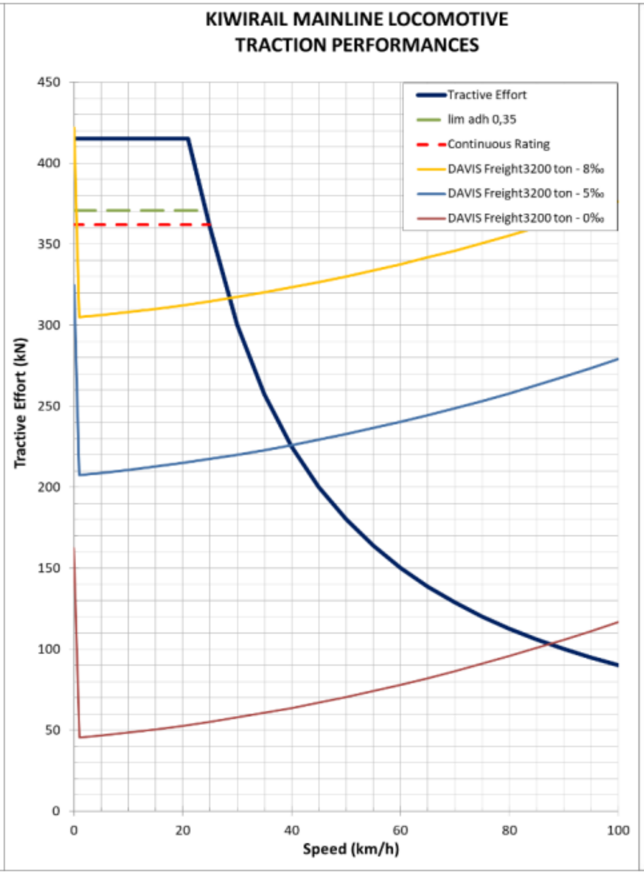
KIWI RAIL: EVOLUTION FOR NEW ZEALAND / AUSTRALIEN

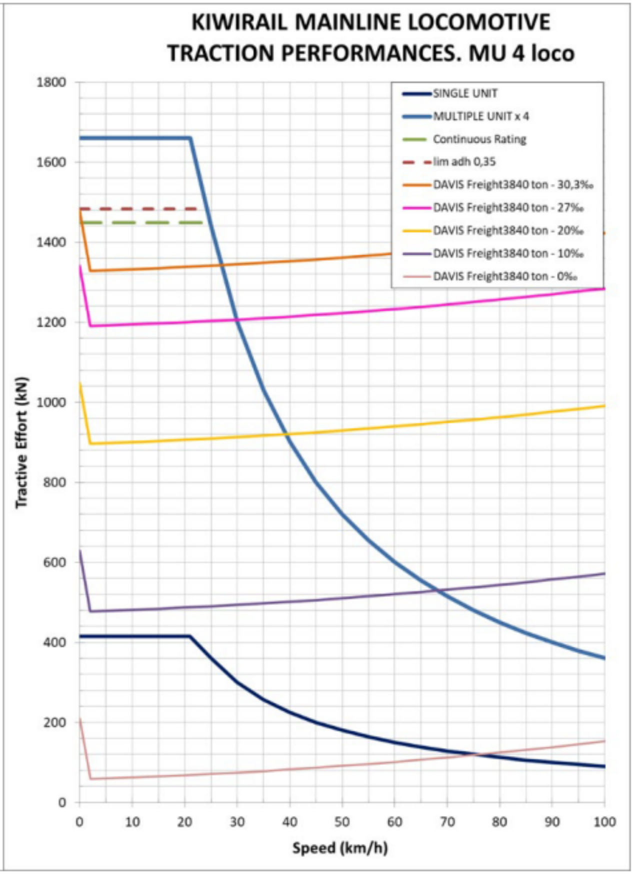
Dr. Ansgar Brockmeyer, Darmstadt 09/2024

STADLER

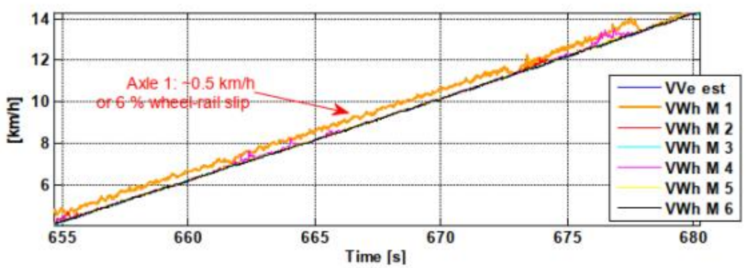
THE PLATFORM
LOW AXLE LOAD_HEAVY HAUL

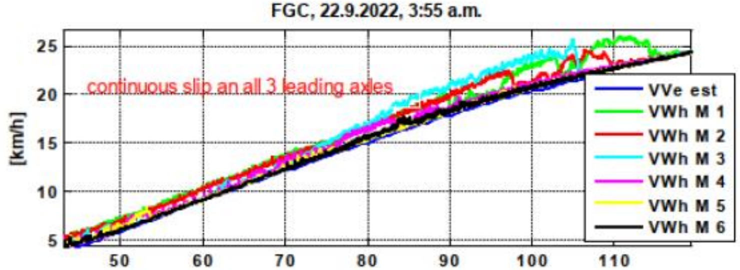


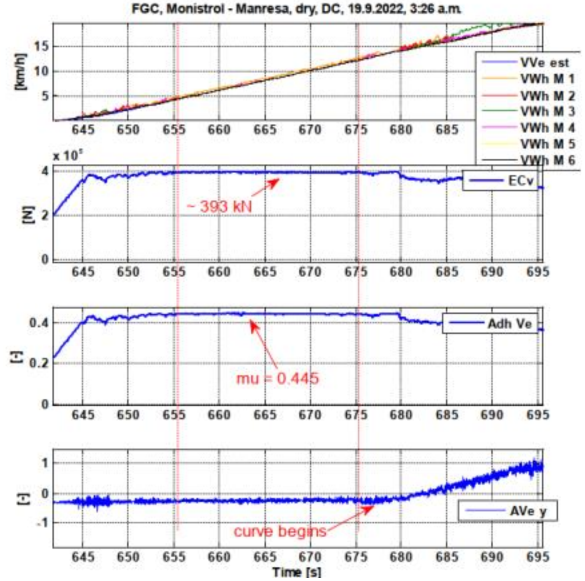




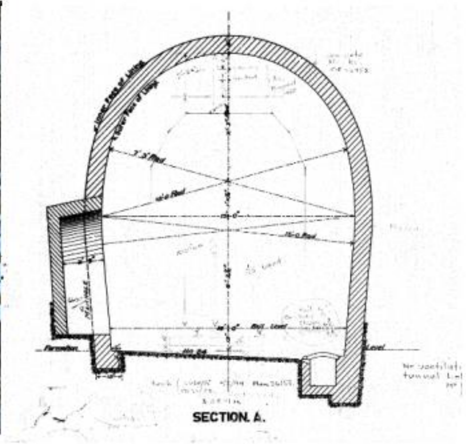
THE PLATFORM
NEW DEVELOPMENTS: TRACTION CONTROL



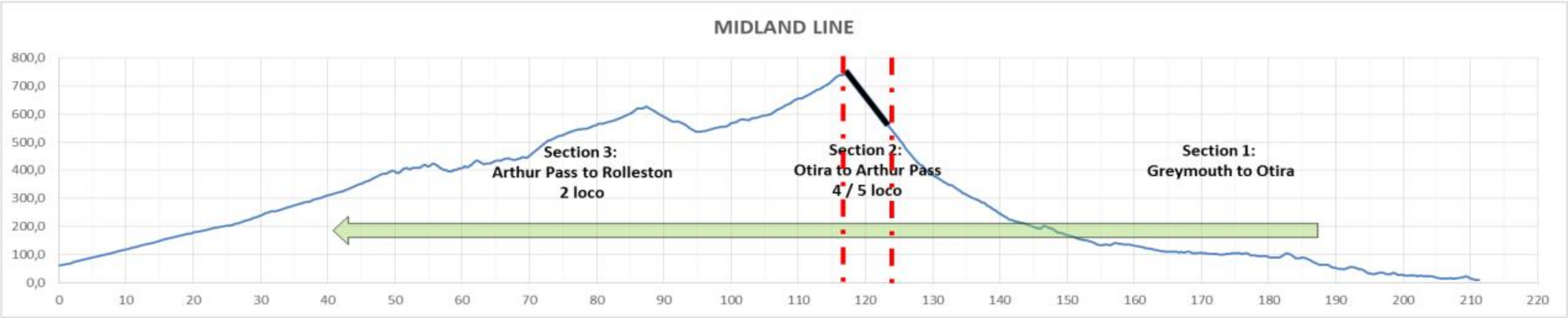




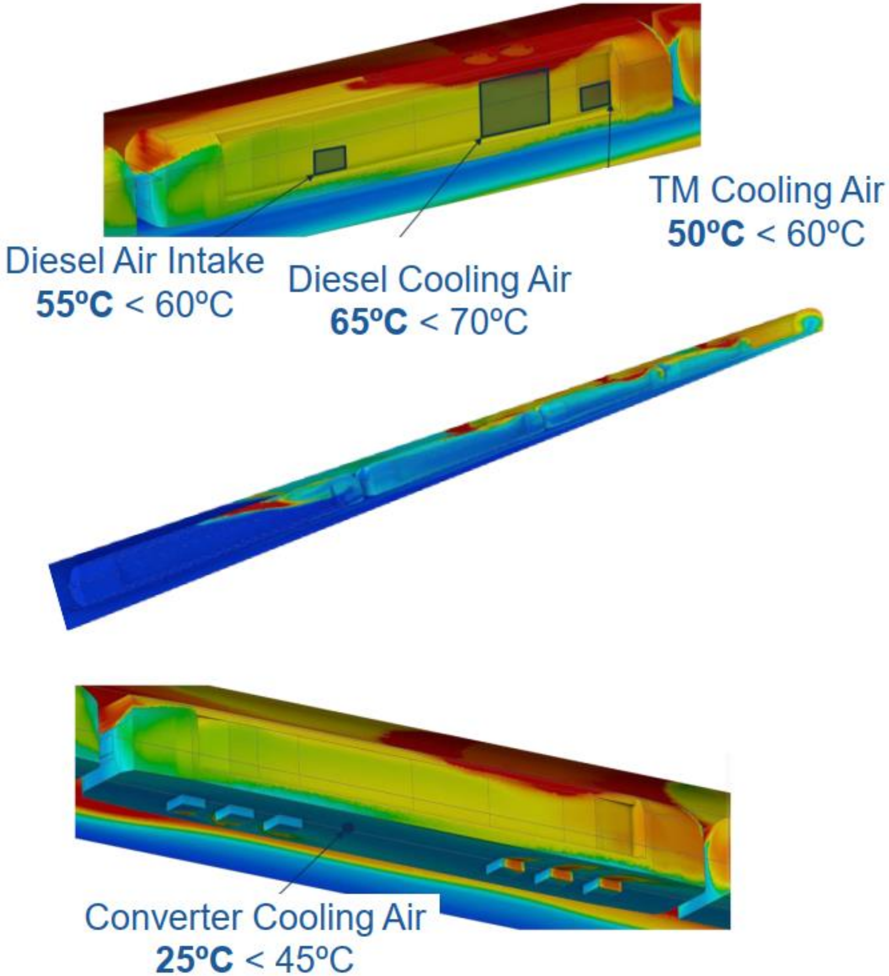
THE PLATFORM
OTIRA TUNNEL



8.5 km long on a 30,3 ‰ gradient
5.18 m high
4.57 m wide



THE PLATFORM
OTIRA TUNNEL



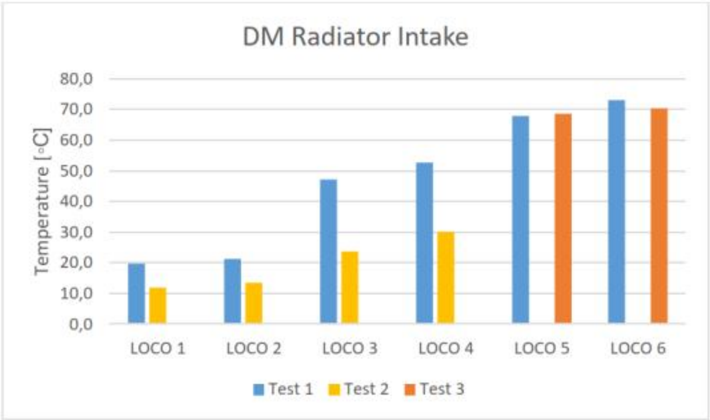


Figure 3-18: Estimated temperature for the DM Radiator Intake

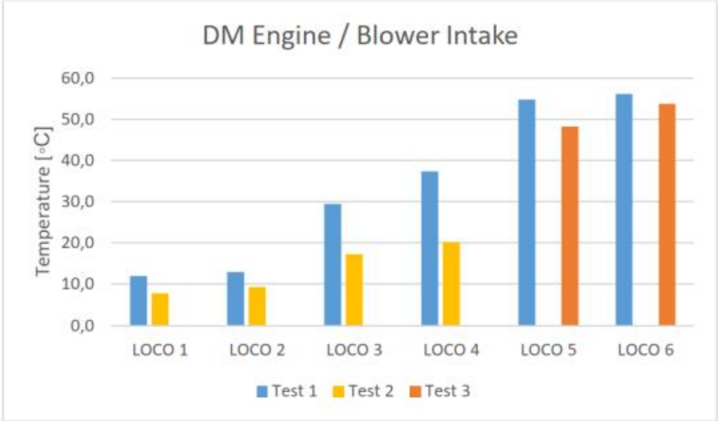
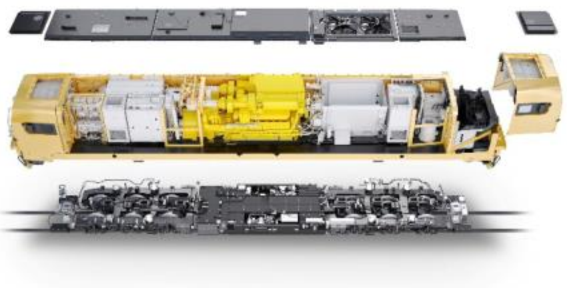


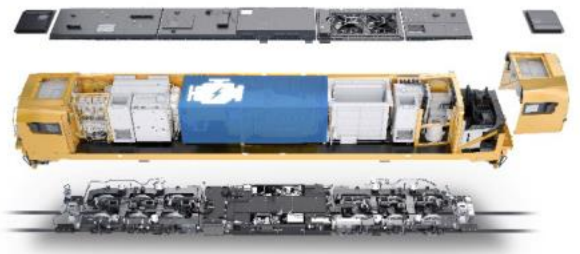
Figure 3-19: Estimated temperature for the DM Engine/Blower Intake

THE PLATFORM
"GREEN" OPTIONS

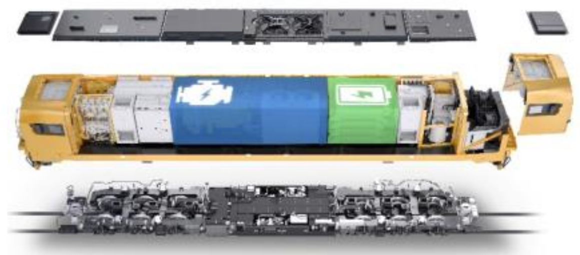
Stage V Diesel



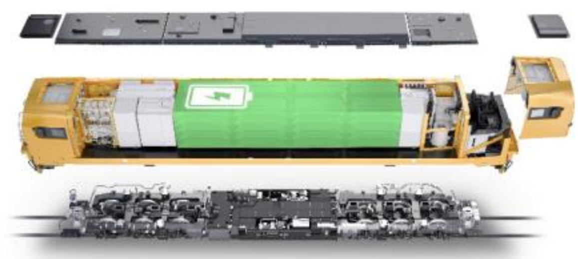
3,000 KW
18 tons/axle



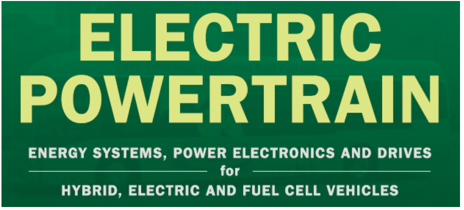
Stage V Diesel
1,800 KW
16 tons/axle



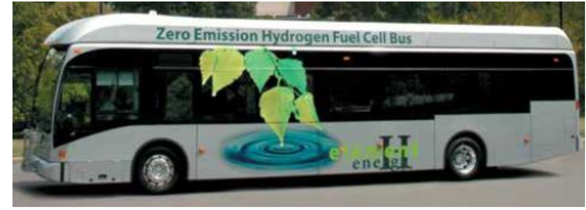
Hybrid
Stage V Diesel
1,000 KW Diesel
600 KWh Battery



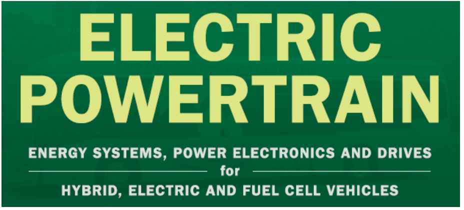
Battery only
2,000 KWh Battery



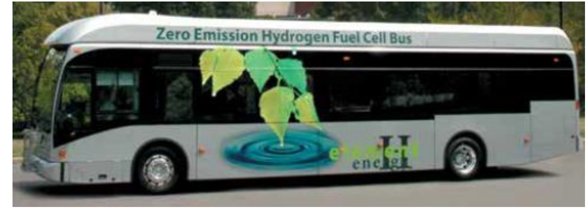
Battle of the HD EVs
With
John Hayes

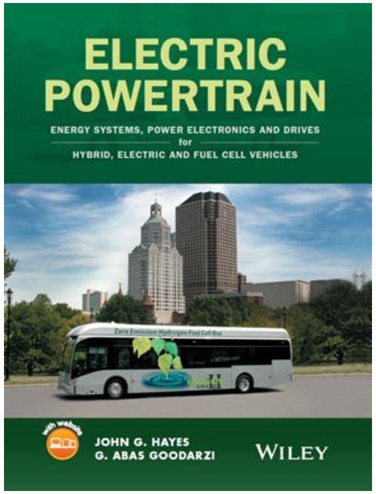


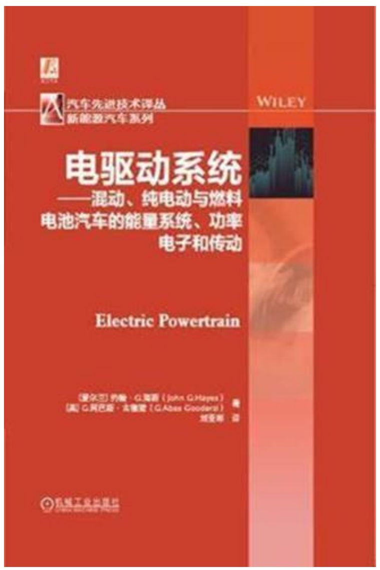
Images courtesy of Tesla, Mercedes, Timoney & Stadler



Background





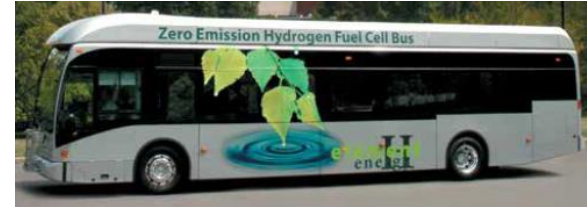


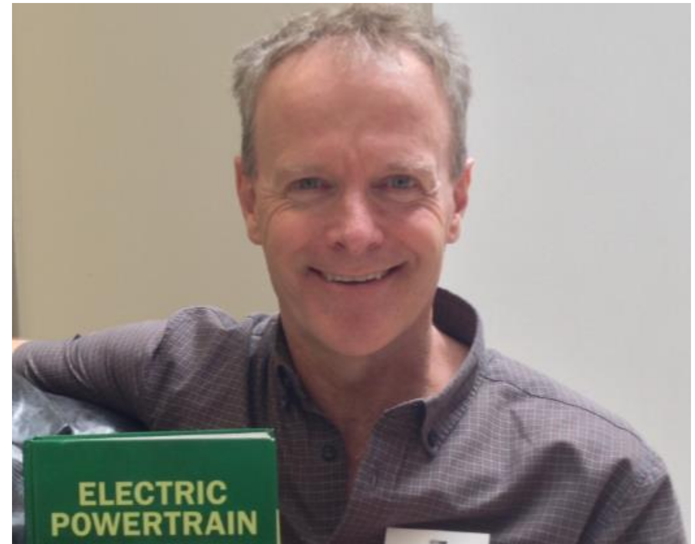
- Dedicated **university textbook** and **industry reference** on electric vehicles.
- **Chinese** language edition by China Machine Press in 2021.
- Presents a **structured university teaching stream** from **introductory undergraduate to postgraduate**.
- Introduces and **holistically integrates** the key **EV powertrain** technologies.
- Features lots of **examples, problems** and **assignments**.
- **2nd Edition** under development.

ELECTRIC POWERTRAIN

ENERGY SYSTEMS, POWER ELECTRONICS AND DRIVES for HYBRID, ELECTRIC AND FUEL CELL VEHICLES

Biographies





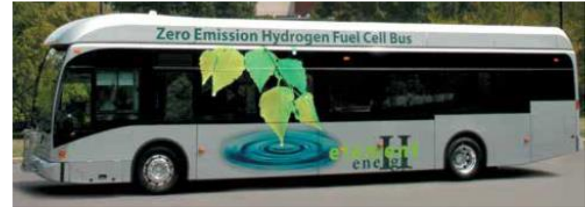
John G. Hayes, PhD, MSEE, MBA

- Senior Lecturer at **University College Cork**.
- **Energy systems, power** and **machines.**
- Worked for **ten years at General Motors** developing power systems for the **GM EV1**, the first modern production EV.

G. Abas Goodarzi, PhD, P.E.

- **Chief Executive Officer of Magmotor**
- **Former CEO and President of US Hybrid Corp.**
- **Technical Director for the GM EV1**.
- Designed various **EV, HEV, and FCEV** powertrain systems for **light, medium, and heavy-duty**, **on-road, off-road, and special-purpose vehicles**.

Tesla Truck Video

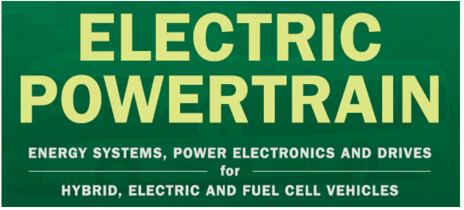


Elon Musk of Tesla Inc. introduced the new Tesla truck in November 2017, as documented in the following Youtube video.

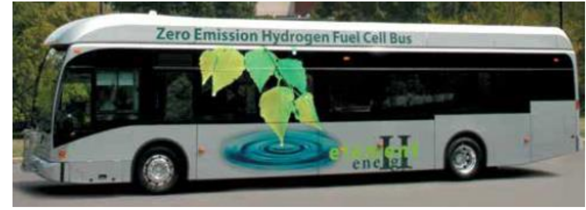
https://chargedevs.com/newswire/tesla-semi-hits-the-highway-with-a-bang/

In the following slides we will estimate the battery size based on information presented in the video.

First watch the video.



Tesla Truck – Key learnings

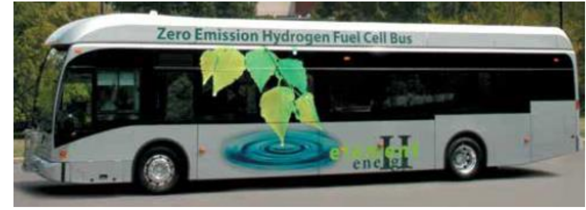


- Maximum gross weight for tractor-trailer **80,000 lbs**.
- **Range** is **500 miles** at an average speed of **60 mph**.
- The **drag co-efficient** C_D is **0.36**.
- **0 to 60 mph** in 5 seconds empty
- **0 to 60 mph** in 20 seconds full.
- **65 mph fully loaded** up a **5% grade**.
- **Recharge to 400 miles** of range in **30 minutes**.
- There are **4 motors** – one on each of the rear wheels.
- **Battery life of 1,000,000 miles**.

ELECTRIC POWERTRAIN

ENERGY SYSTEMS, POWER ELECTRONICS AND DRIVES for HYBRID, ELECTRIC AND FUEL CELL VEHICLES

The Problem



Determine the battery size in kWh and kg if the specific energy SE is 0.17 kWh/kg.

Assumptions:

Frontal area A = 9 m^2,

Rolling resistance C_R = 0.006,

Auxiliary load P_{aux} = 2 kW.

G. Paterlini et al., *Rolling Resistance Validation Final Report*, Minnesota Dept. of Trans. 2015.

Solution

$$\text{Battery Power} = P_b = \frac{P_D + P_R}{\eta_{pt}} + P_{aux} = \frac{0.5\rho\, C_D\, A v^3 + C_R m g v}{\eta_{pt}} + P_{aux}$$

$$= \frac{37.5 + 57.3}{0.85} + 2000 = 74.7\,\text{kW}$$

$$\text{Fuel Consumption} = \frac{P_b}{v} = \frac{74.7\,\text{kW}}{1.609 \times 60\,\text{km/h}} = 1.15\,\frac{\text{kWh}}{\text{km}}$$

$$\text{Battery Size} = E_b = FC \times Range = 1.15\,\frac{\text{kWh}}{\text{km}} \times 800\,\text{km}$$

$$= 920\,\text{kWh}$$

$$\text{Battery Mass} = m_b = \frac{E_b}{SE} = \frac{920\,\text{kWh}}{0.17\,\text{kWh/kg}}$$

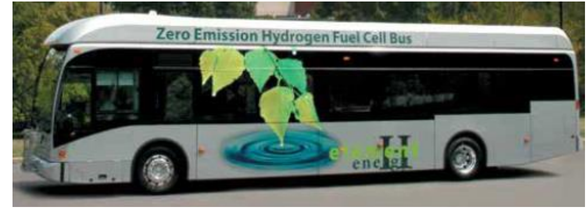
$$= 5{,}400\,\text{kg}$$

Reference Websites

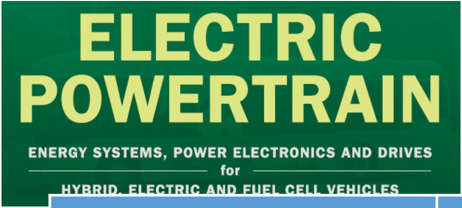
- https://chargedevs.com/newswire/tesla-semi-hits-the-highway-with-a-bang/
- https://hub.mercedes-benz-trucks.com/int/en/trucks/eactros-600.html
- https://www.timoneygroup.com/heavy-duty-electric-vehicle-solutions
- https://stadlerrail.com/en/

ELECTRIC POWERTRAIN
ENERGY SYSTEMS, POWER ELECTRONICS AND DRIVES for HYBRID, ELECTRIC AND FUEL CELL VEHICLES

HD EVs
Vehicle & Battery



	Tesla Semi	Mercedes eActros 600 Semi	Timoney Off-road	Stadler Locomotive
Mass	36,290 kg (80,000 lb)	40,000 kg (88,000 Ib)	9,000 kg per axle	2,000,000 kg
Range (Fuel Consumption)	800 km (500 miles) @ 96.5 kph (60 mph)	500 km (1.2 kWh/km)		5,000 L
Battery (useable/gross)	*960 kWh* (≈ *6,000 kg*)	600/621 kWh (3 x 207 kWh packs)		2,000 kWh
Chemistry	?	LFP		LTO (NMC)
Voltage	850 V (250 to 300 cells in series?)			1.5-2 kV (3-level) IGBT
Battery Warranty	1,609,000 km (1,000,000 miles)	6 years/720,000 km/1,800 charging cycles		10 years
Service Life		10 years/1,200,000 km/3,000 charging cycles		30 years, 300,000 km/year



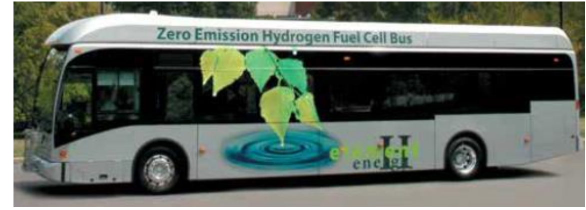
HD EVs
Power & Vehicle

	Tesla Semi	Mercedes eActros 600 Semi	Timoney Off-road	Stadler Locomotive
Charging	400 miles in 30 min. ≈ 1,000 kW	20 % to 80 % in 30 min. ≈ 720 kW		
Continuous Power		400 kW		3 MW
Peak Power		600 kW	200 kW per axle	
Speeds		Four		100 km/h
Challenges	104.6 kph (65 mph) up a 5 % grade		60 % grade, 30 % side slope	6 % grade
Drag Coefficient	0.36			
Rolling Resistance	*0.6 %*			*0.1 +%*

ELECTRIC POWERTRAIN

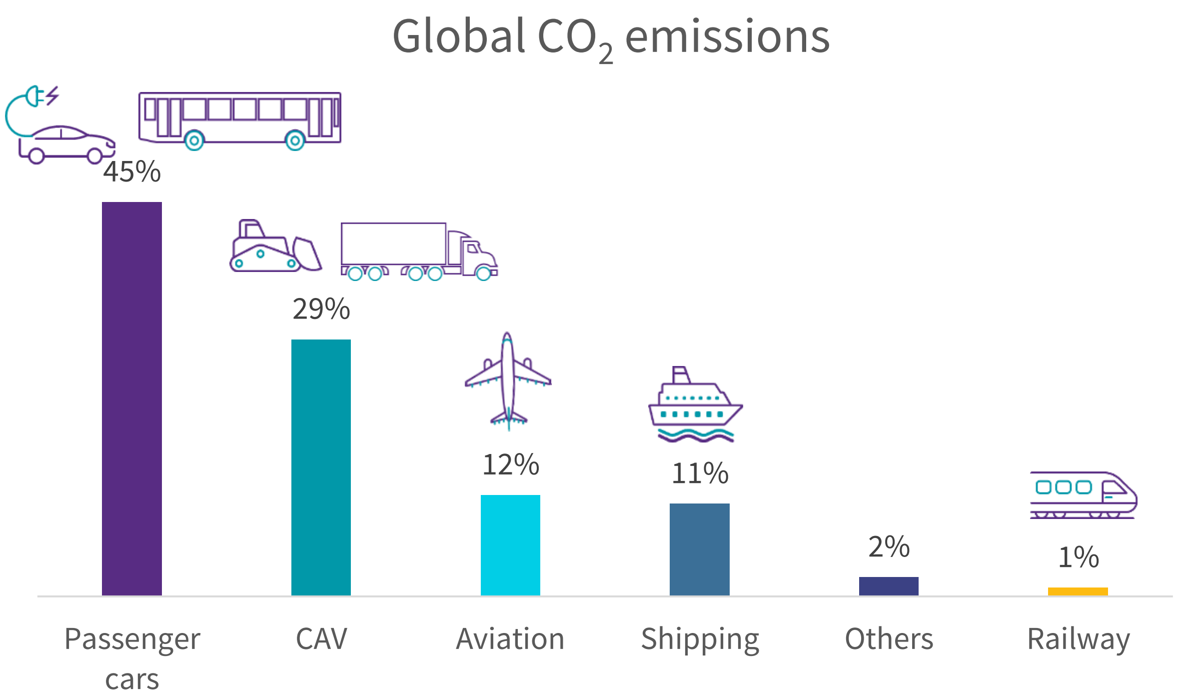
ENERGY SYSTEMS, POWER ELECTRONICS AND DRIVES for HYBRID, ELECTRIC AND FUEL CELL VEHICLES

Questions

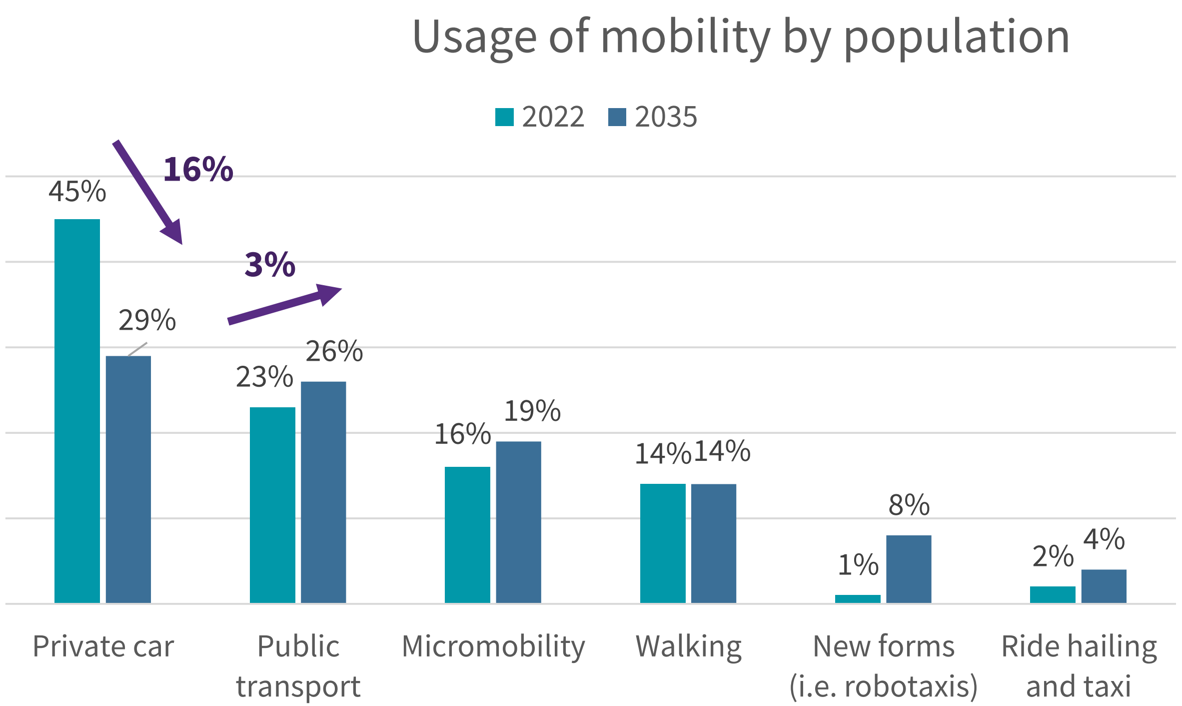


- Battery packs… LTO vs. NMC vs. LFP?
- Machines- EESG+Induction, IPM?
- Semiconductors: IGBT vs. SiC MOSFET
- Modelling: torque vectoring, speed vectoring

FACTORS DRIVING INDUSTRIAL E-MOBILITY



Source: NESTE:Towards sustainable mobility / April 2023



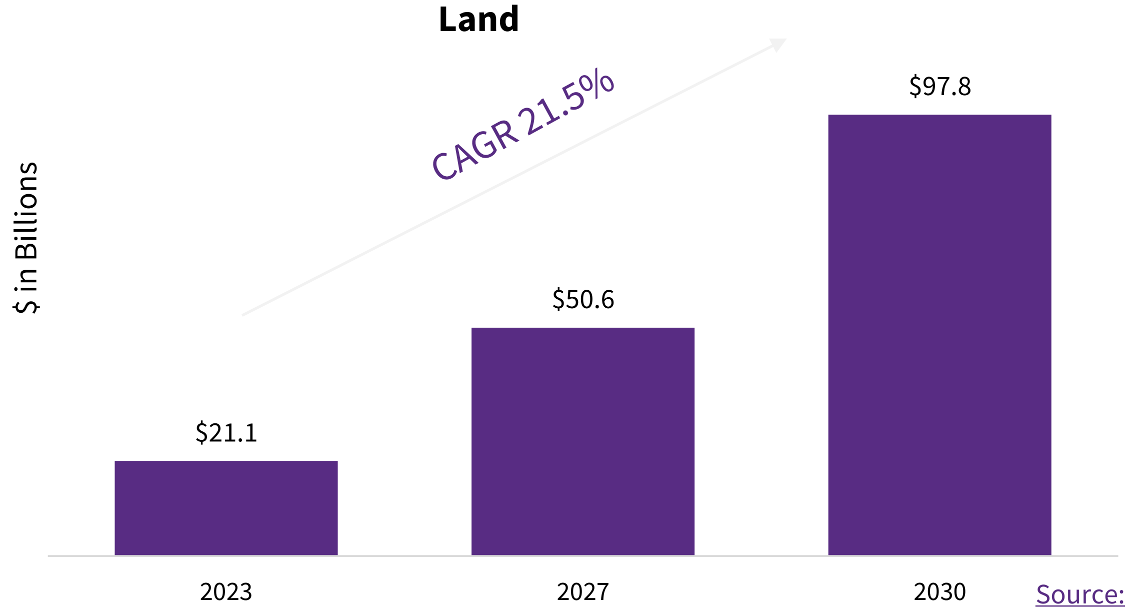
Source: McKinsey Center for future Mobility April 2023

24% of global emissions come from transportation

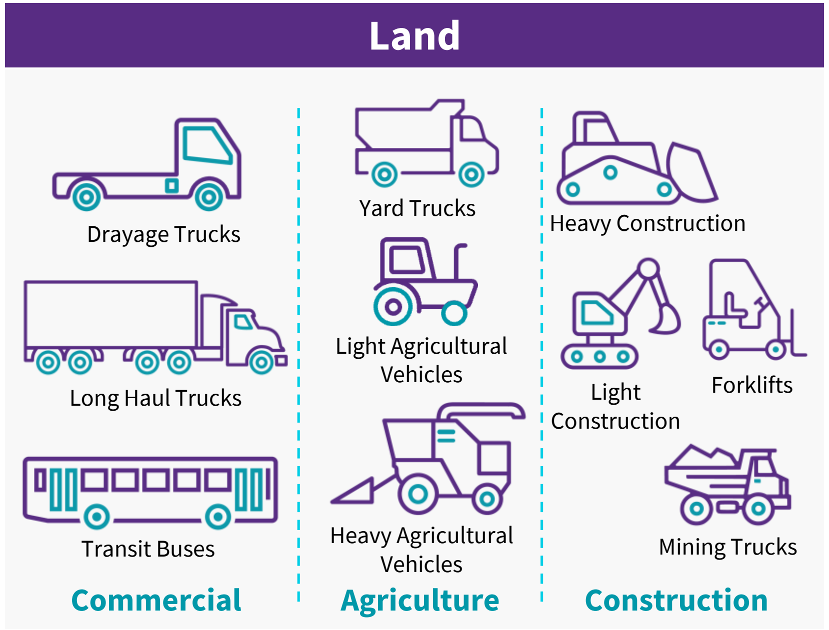
(worldwide = ~30Gt)

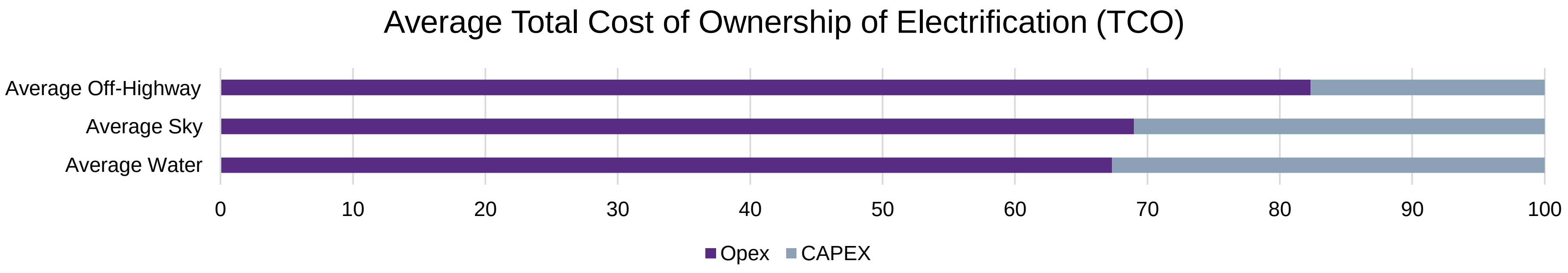
Global population will reach ~8.9B by 2035, growing by more than >10% as today

MARKET GROWTH FOR ELECTRIFICATION



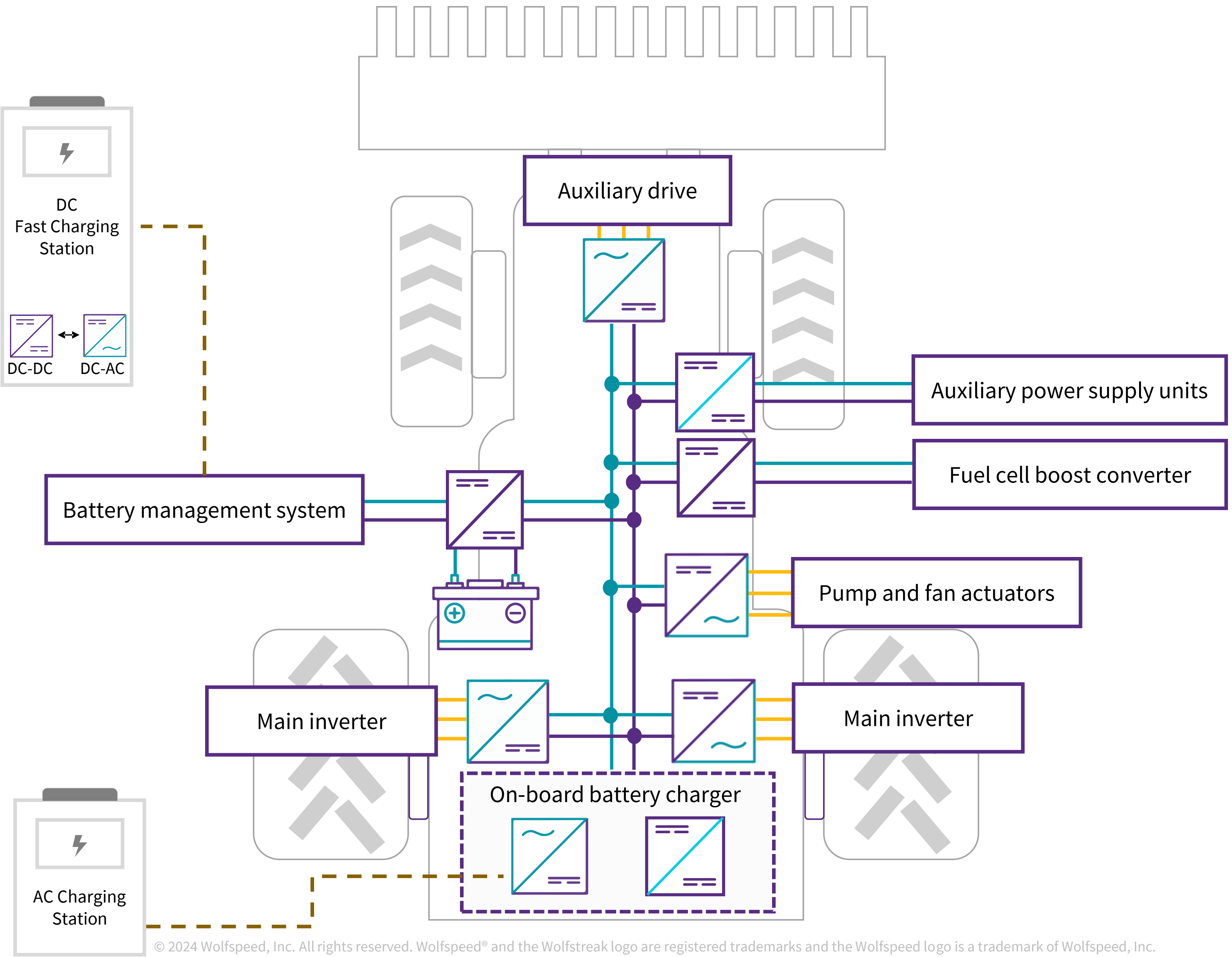
Source: Facts & Factors





*Source: The Future Powertrain Portfolio - Porsche Newsroom

LAND APPLICATIONS - ELECTRONIC SYSTEM OVERVIEW



Technical specifications
- Main Inverter: **75 – 500+ kW**
- Auxiliary Drive: **10 – 30 kW**
- Auxiliary Electronics: **200 W – 1kW**
- Switching Frequency: **30+ kHz**

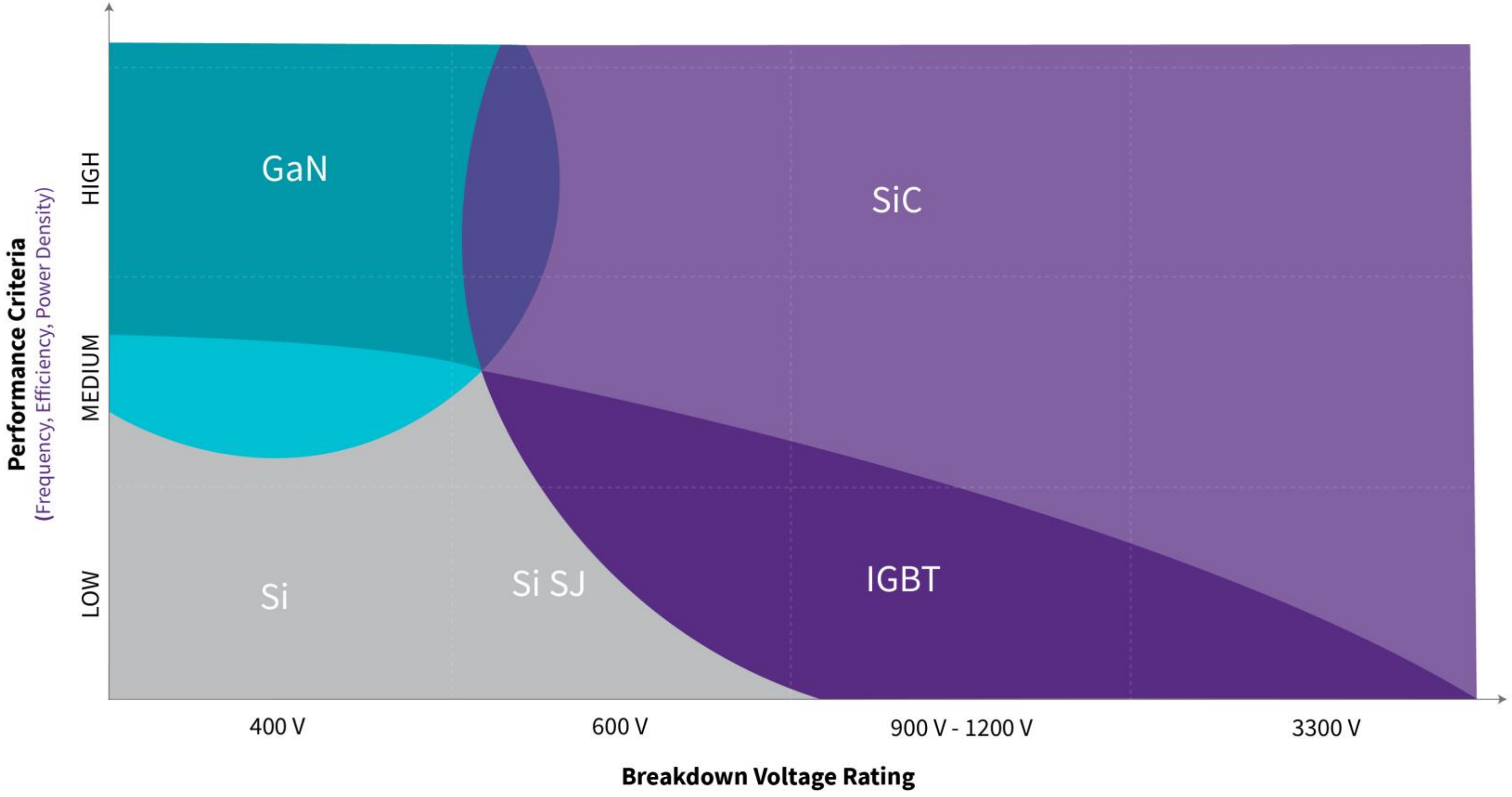
Topology technical highlights
- Low component count
- Wide soft-switching range available
- High conversion efficiency (>95%)
- Galvanic isolation
- Bi-directional power flow

Key Features

- Combination of trolley and battery power reduces CO_2 emissions/fossil fuel consumption, ventilation requirements
- Estimated energy recovery as high as 65% in off-road mining dump trucks depending on load, grade, speed
- Low maintenance, long lifetime, reduced operating costs
- High efficiency, high power, bidirectional inverter

POWER TECHNOLOGY COMPARISON

Typical performance criteria verses breakdown voltage rating



Si, GaN, and SiC compete at the 650 V range

Silicon carbide is the best-in-class technology for power applications from 650 V – 3300 V+
- Baseline performance brings lower conduction losses and improved thermal efficiency
- Enables system size reduction
- Reduces system cost

Silicon does the job – "adequately" – up to 650 V
- MOSFETs: 5 V to ~900 V
- IGBTs: 650 V to mid voltage
- Not suitable for high-speed switching

GaN is touted for 40 V to 600 V
- High switching frequency, high power density
- Lower current & power:
  - 40 V to 200 V at low current
  - 600 V in low to medium current (5A to 50A max)

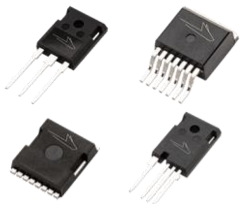
WOLFSPEED SILICON CARBIDE POWER PRODUCTS

Scalable Solutions from 600 V to 3300+ V

Discrete Advantages:
- Maximize design flexibility
- Minimize total BOM cost

200 W — 50 kW — 100 kW — 200 kW — 300 kW — 400kW — 500 kW+

Discrete Solutions



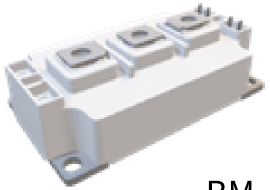
Wolfspeed WolfPACK™ Modules

WolfPACK FM
62mm X 33.8mm

WolfPACK GM
62mm X 48mm

DM
51.6mm x 40.8mm

High Power Module Solutions…



BM
106mm X 62mm

XM
80mm x 53mm

HM
106mm x 62m

LM
140mm X 100mm

Module Advantages:
- Maximize power density
- Simplify layout and assembly
- Minimize assembly costs & component counts

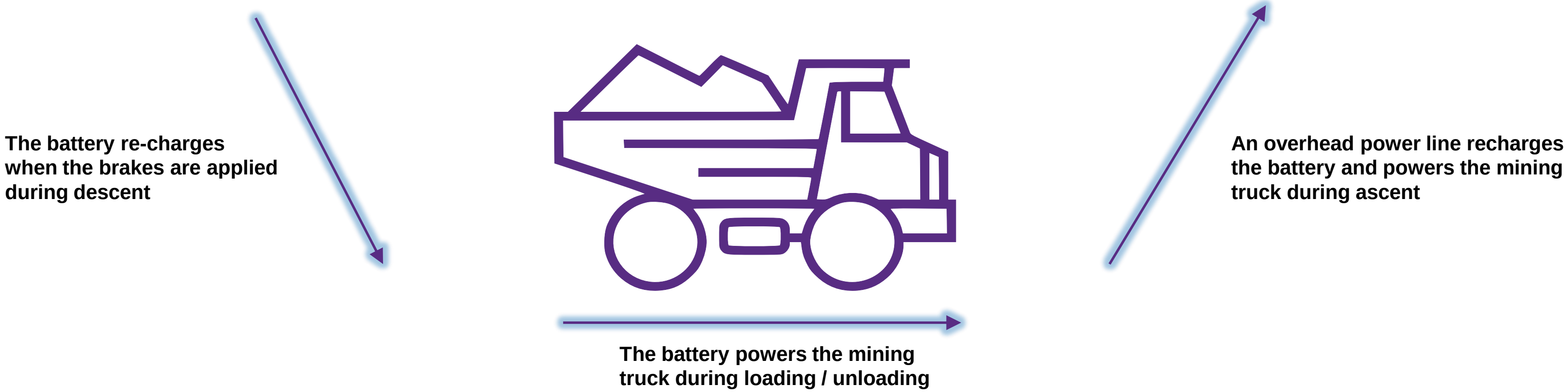
CASE STUDY: REGENERATIVE BRAKING OF PURE ELECTRIC MINING TRUCKS

Premise and Objective

- Mining industry is exceptionally energy intensive: earth moving, hauling, sorting
- Diesel mining dump trucks can consume up to 34 liters/km in operation
- Decarbonization of supply chain for clean energy technologies via regenerative braking of dump truck for material hauling
- Kinetic energy recovered by inverter motor drive charges battery for use when trolley power is unavailable

Key Features

- Combination of trolley and battery power reduces CO_2 emissions/fossil fuel consumption, ventilation requirements
- Estimated energy recovery as high as 65% in off-road mining dump trucks depending on load, grade, speed
- Low maintenance, long lifetime, reduced operating costs
- High efficiency, high power, bidirectional inverter

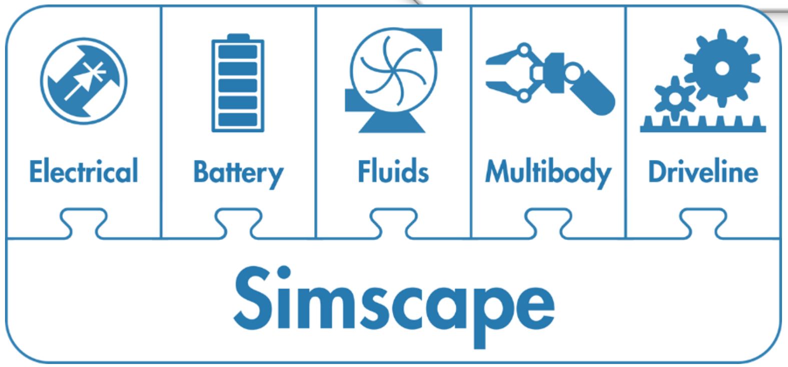


Modeling and Simulation of Electric Powertrains for Heavy-Duty Applications

ECCE Europe
ENERGY CONVERSION CONGRESS & EXPO
2024
2-6 September, Darmstadt

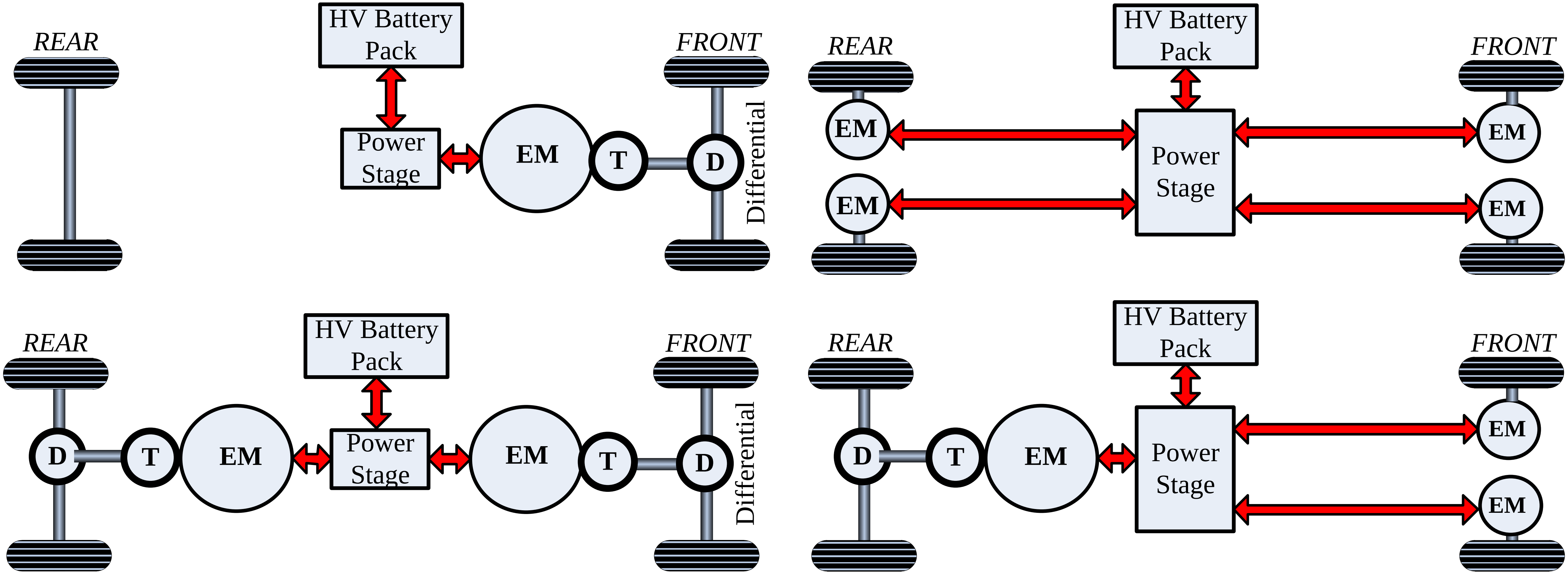
Sabin Carpiuc, PhD
Principal Physical Modeling Engineer
MathWorks

Introduction



Electric Powertrains for Heavy-Duty Applications

- **Heavy duty electric powertrains are complex systems**
- **A variety of architectures can be used**



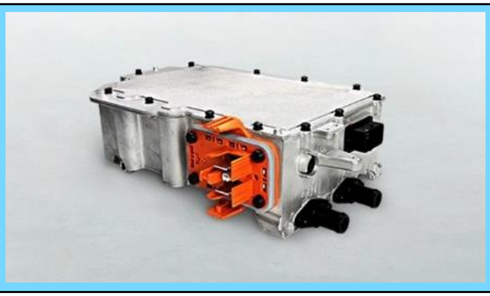
Electric Powertrains for Heavy-Duty Applications

- **Challenges**
  - Reducing development time
  - Dealing with various temperature levels
  - Reducing cost
  - Reducing losses
  - Minimizing failure rate
  - Increasing power density
  - Optimizing power per unit weight

- **HOW can we tackle these challenges?**
  - **Through modeling and simulation**

Addressing Challenges Through Modeling and Simulation

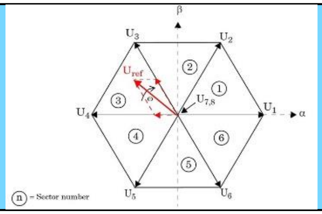
PHYSICAL
SYSTEM



Abstraction

MATHEMATICAL MODEL

Goal: the simplest possible model that incorporates the major features of the real system



$$\frac{d\omega_r}{dt} = \frac{1}{H}(T_{em} - b\omega_r - J_0 - T_{load}) \quad (1)$$

If
$T_{load} = 0$
$T_{em} = 0$

Then

$$\omega_r = \left(\omega_{r0} + \frac{J_0}{b}\right)e^{-\frac{b}{H}t} - \frac{J_0}{b} \quad (2)$$

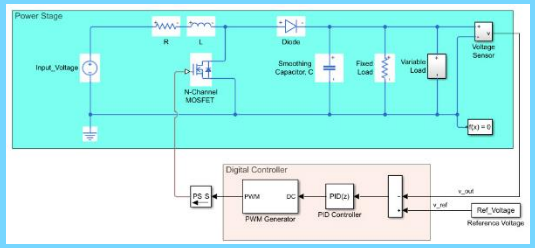
computer language,

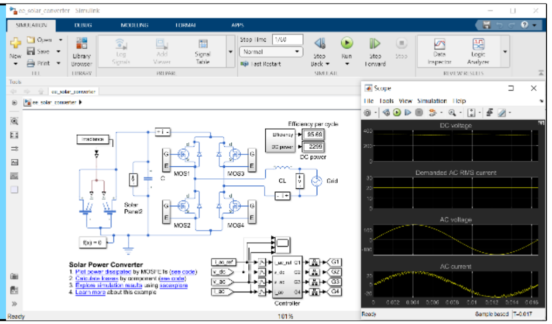
Discretization

SIMULATION MODEL

Desktop simulation

Real-time simulation

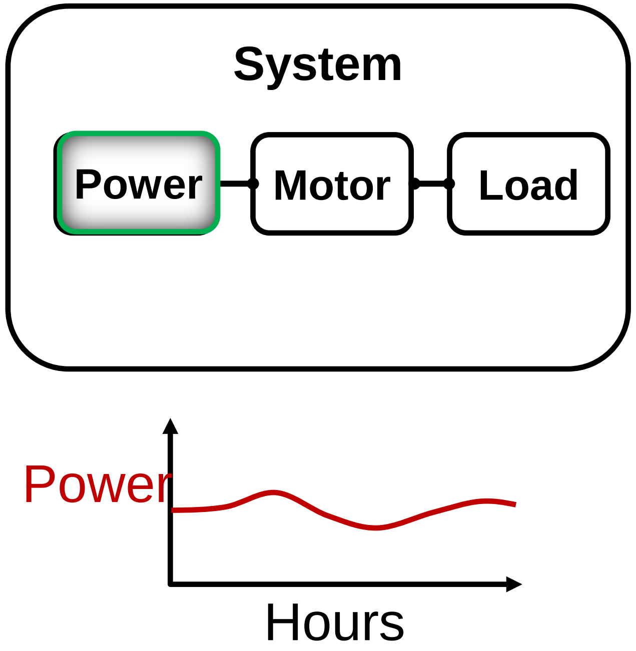


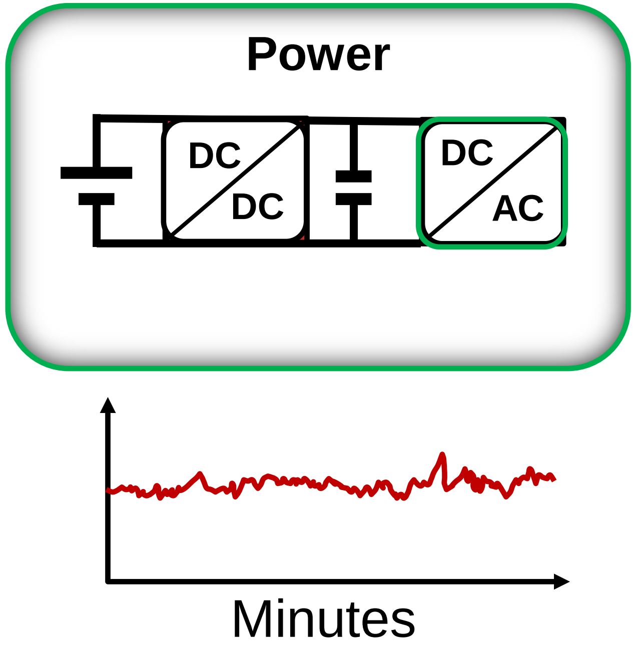


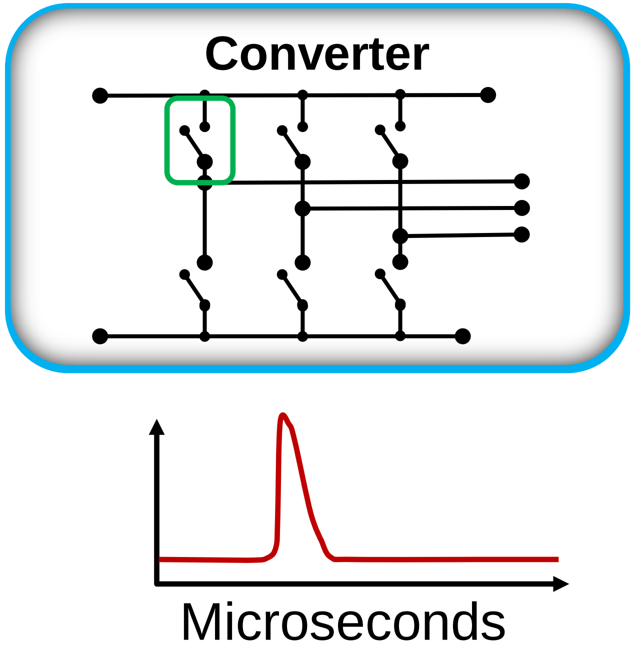
Addressing Challenges Through Modeling and Simulation

- The **Simscape™ Electrical™** library provides a range of fidelity levels for users to design with

System-level	Component Validation	Component Design
Determine power requirements Evaluate system-level response Measure efficiency	Stay within design envelope Effect of switching dynamics	Losses during switching events Analyze & predict fault behavior

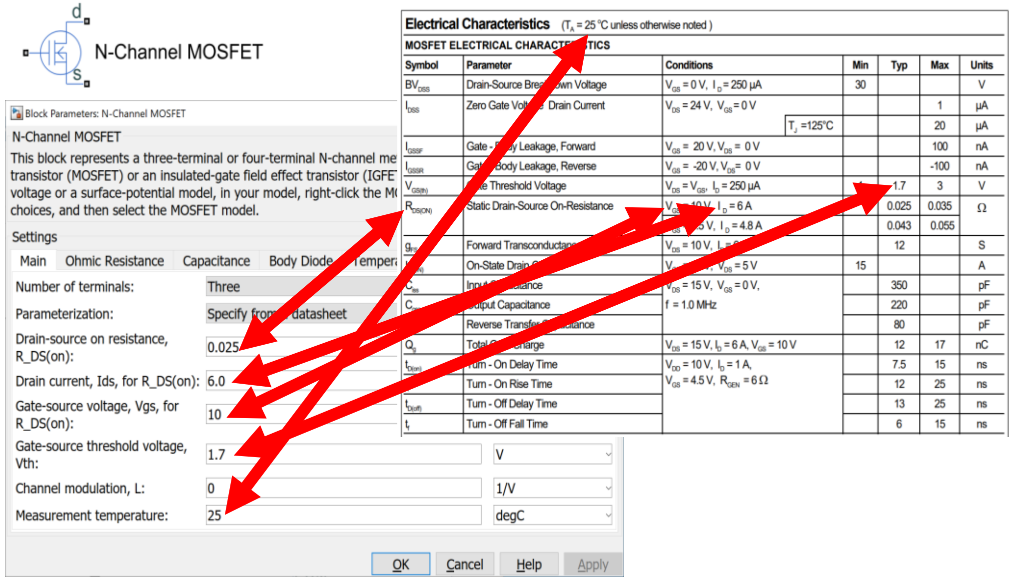


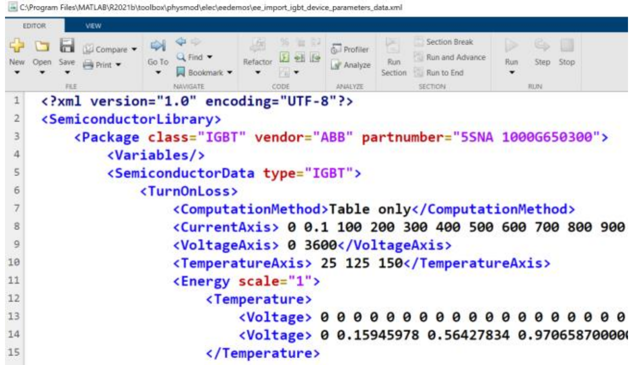




Parameterization workflows for Semiconductor Devices

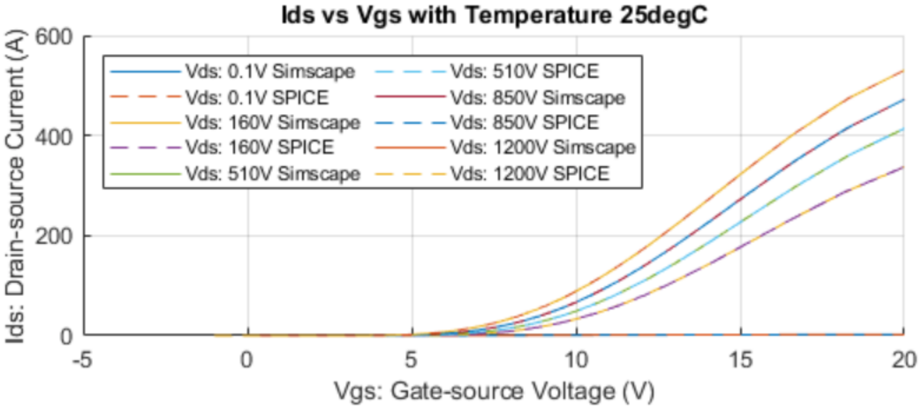
- Parameterize from a datasheet
- Parameterize from a datasheet (**using physics model**)
- Parameterize from a datasheet (**using tabulation**)
- **Import** parameters from **XML** file
- Import from **SPICE**

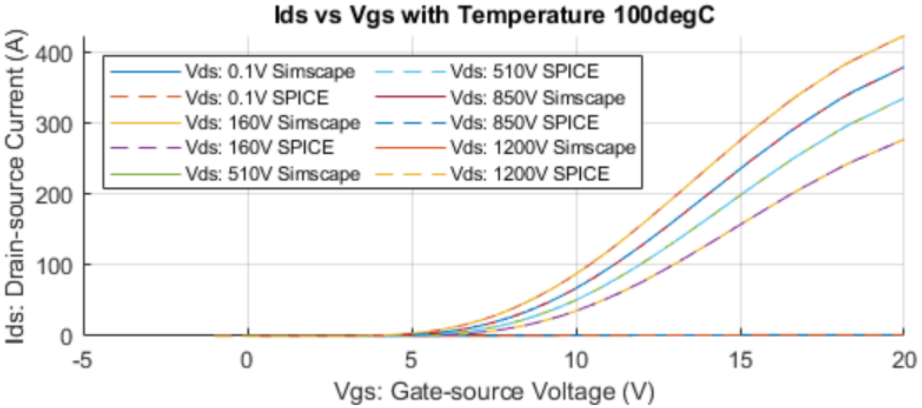


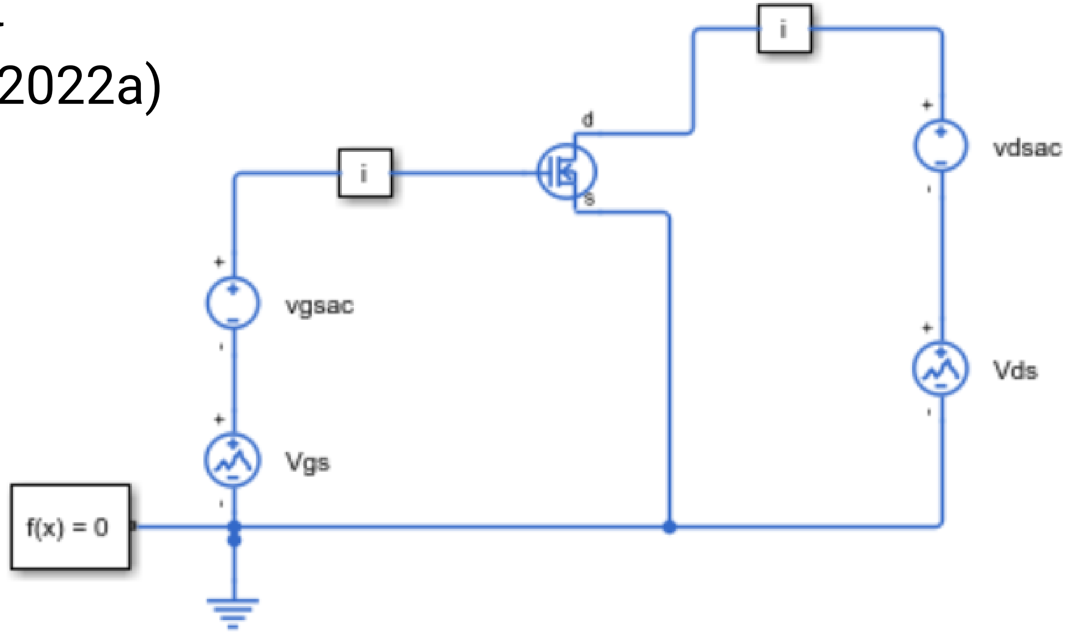


Parameterization workflows for Semiconductor Devices

- Uses LTSPICE to generate the TLU data
  - ee.spice.semiconductorSubcircuit2lookup (R2022a)
  - ee.spice.diodeSubcircuit2lookup (R2023a)







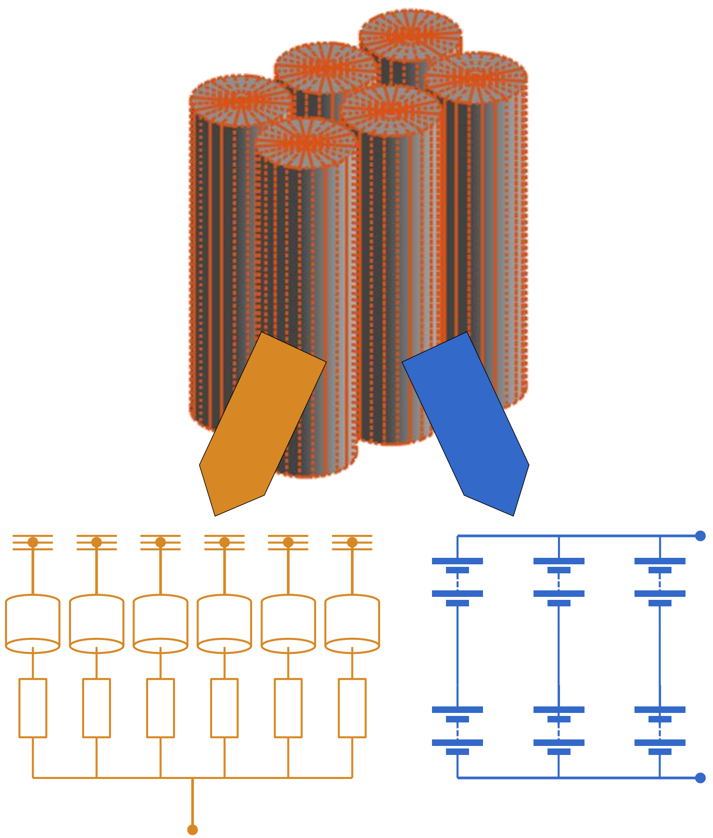
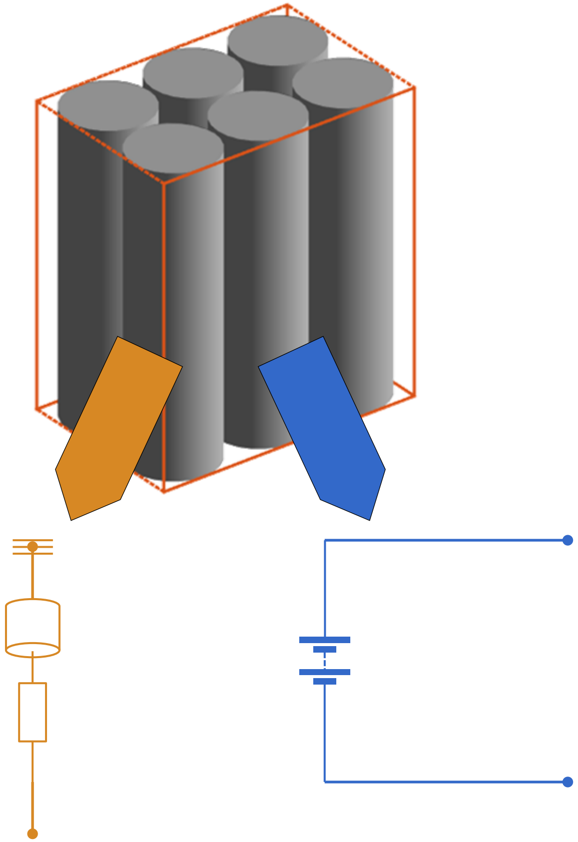
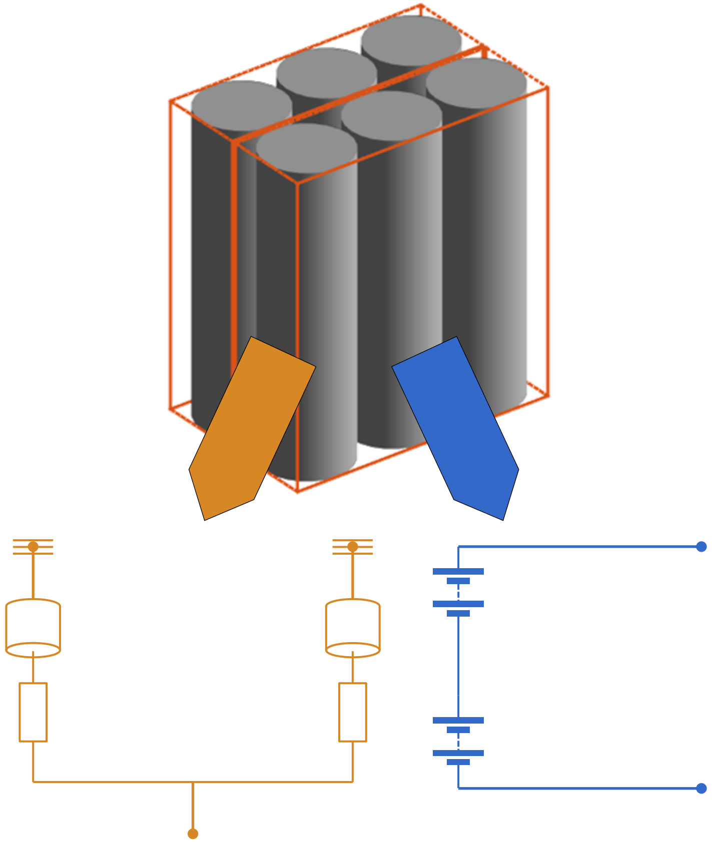
SiC MOSFET Parameterization Using Simulation Results from SPICE

1. SPICE subcircuit (see SPICE netlist)
2. Set lookup table parameters (see code)
3. Compare results with SPICE (see code)
4. Explore simulation results using Simscape Results Explorer
5. Learn more about this example

https://www.mathworks.com/help/sps/ug/sic-mosfet-tabulated.html

Battery pack model fidelity

Find tradeoff between calculation speed and precision

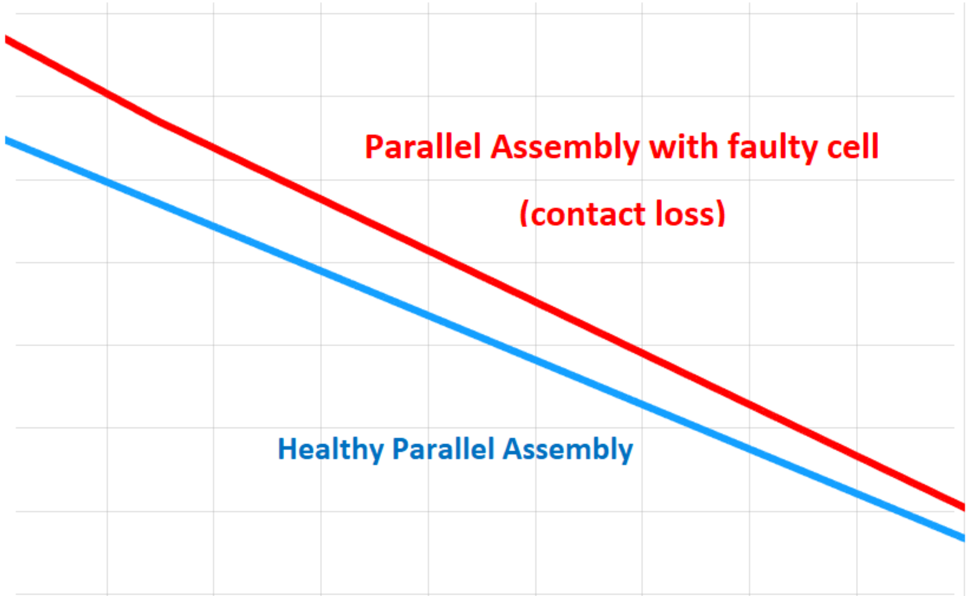
Detailed module	Lumped module	Grouped module
		

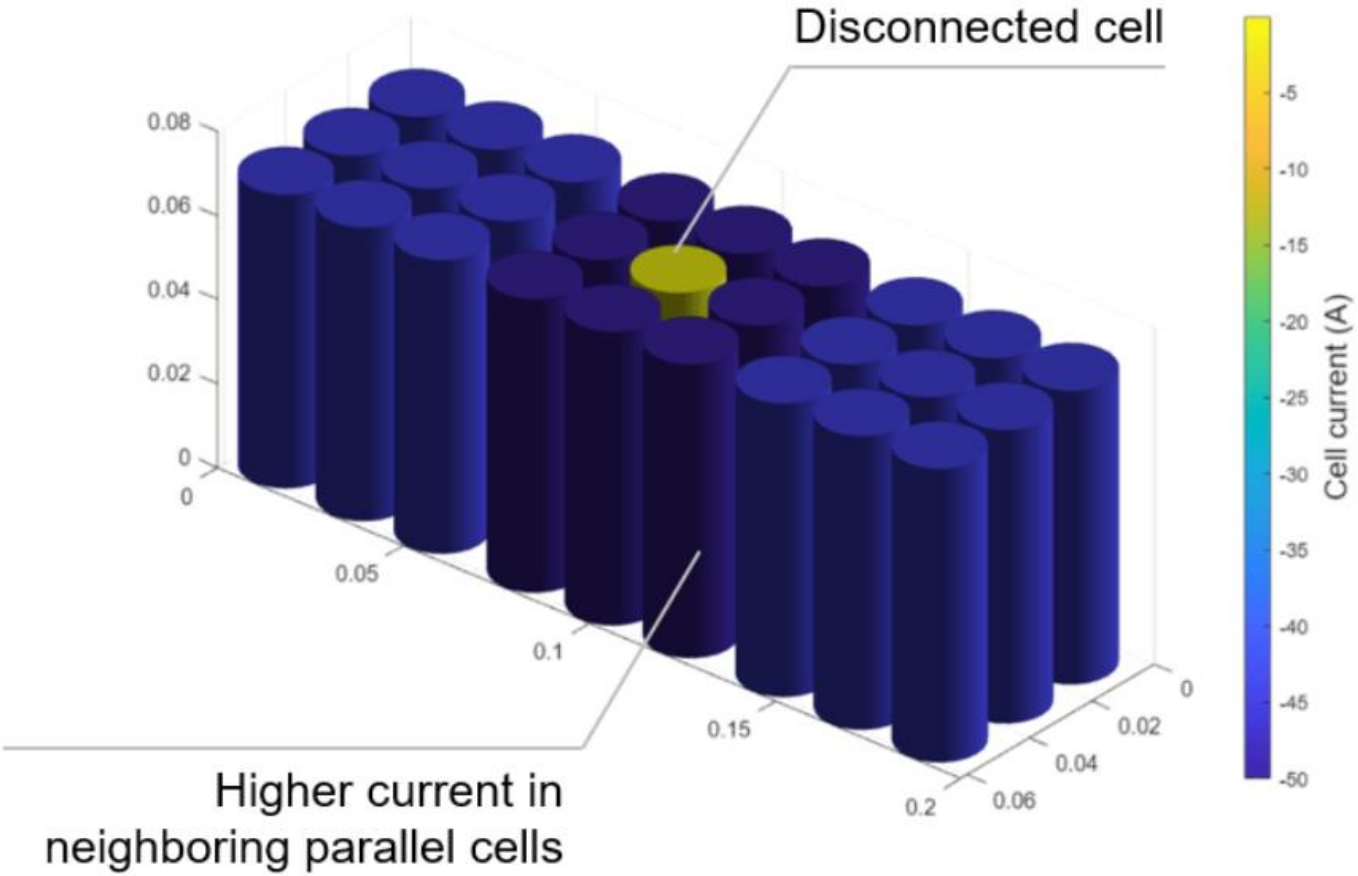
» [More to Model Resolution]

Battery pack model fidelity

Inject Faults

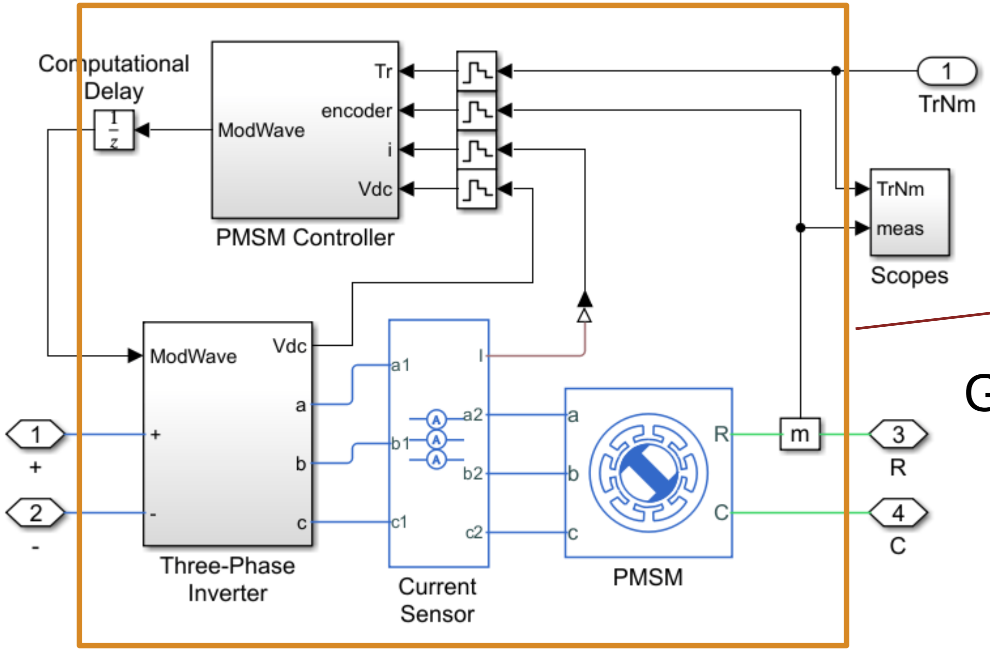
If one cell loses contact in a parallel assembly, the overall voltage is minimally affected



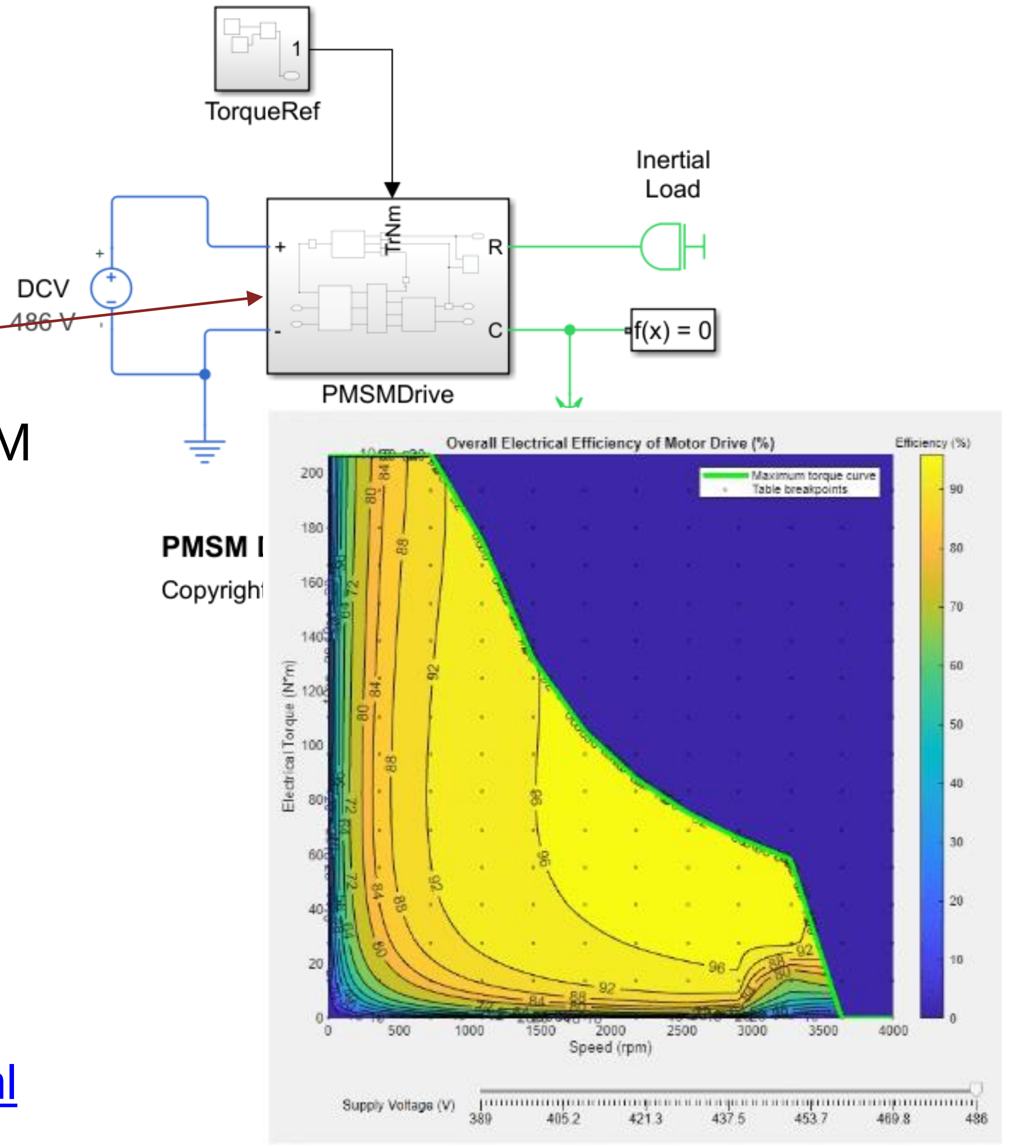


https://www.mathworks.com/help/simscape-battery/ug/detect-disconnected-cells-example.html

Generate reduced order model for motor



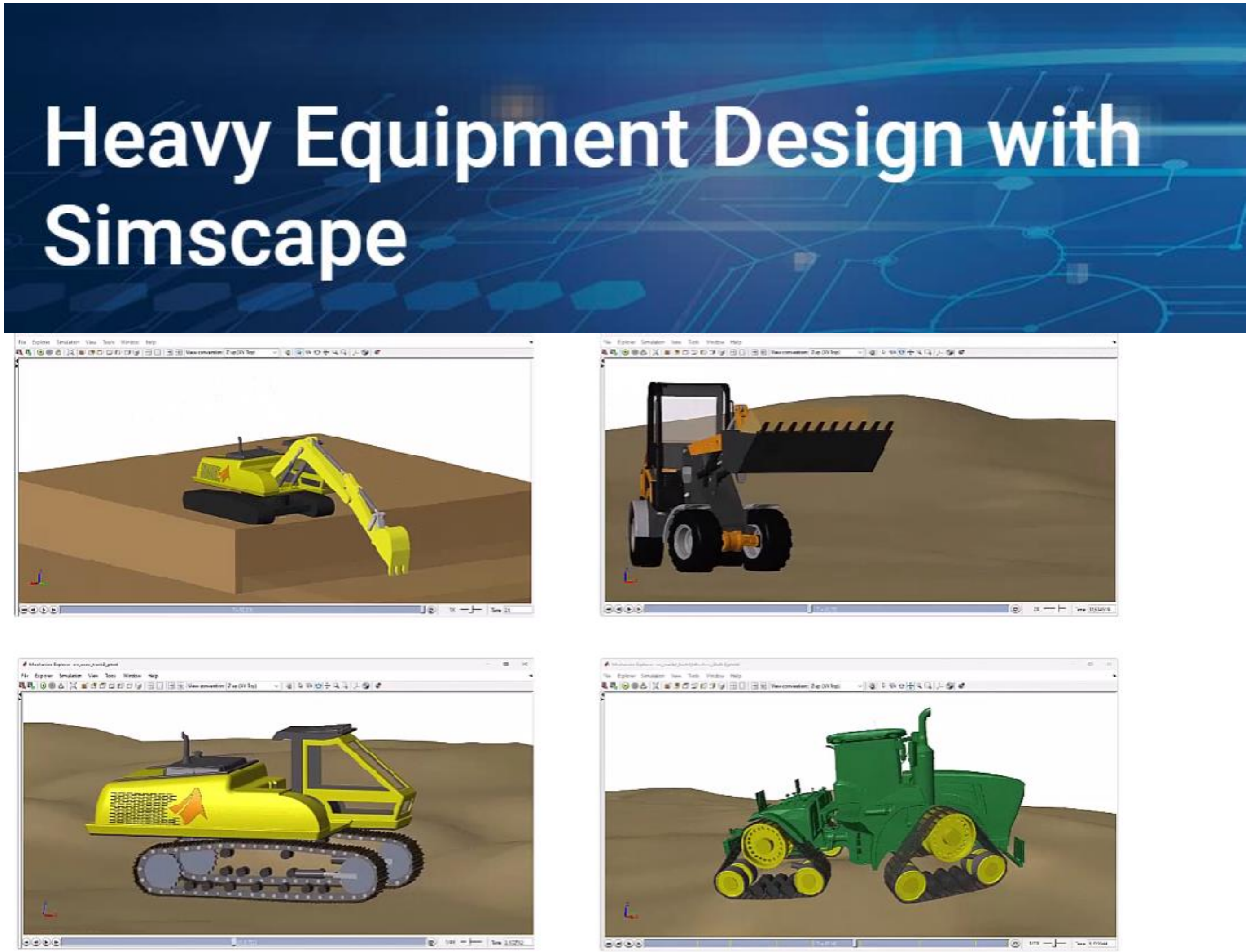
Generate ROM



https://uk.mathworks.com/help/sps/ref/generatemotordriverom.html

Multidomain Simulation

- Tailor Simscape models to your exact design
- Include hydraulics and multibody



https://www.mathworks.com/solutions/physical-modeling/heavy-equipment.html

Key Takeaways

- Simulation can play a key role in understanding and optimizing **electric powertrains**
- Selecting an appropriate **fidelity level** and effective **parameterization** is crucial when developing simulation models
- **Simscape Electrical** and **Simscape Battery** offer a framework for simulating electrical systems with a variety of different levels of fidelity
- **Simscape** enables **multidomain simulation**