ENGINEERING TOMORROW

Technical Comparison of Next-Generation Hydraulic and Electric Powertrain Architectures

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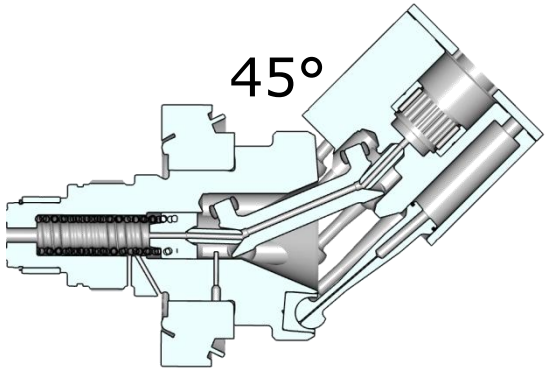
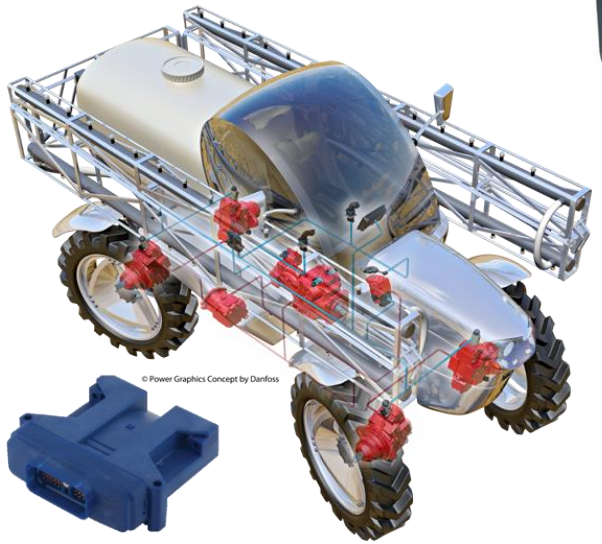
Outline

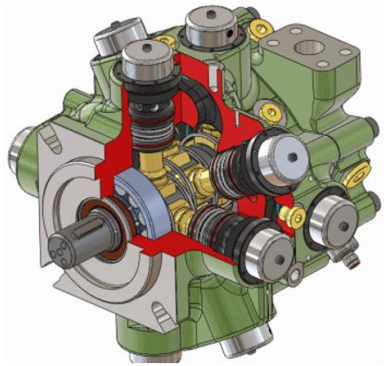
- Driving factors in powertrain diversification
- Characteristics of modern system architectures
- Outlook on future powertrain development

Progress in fluid power…

- Electrohydraulic controls
- Bent-axis, 45° kit technology
- Higher pressure and speed capabilities
- Electrohydraulic steering
- Digital hydraulics
- System solutions

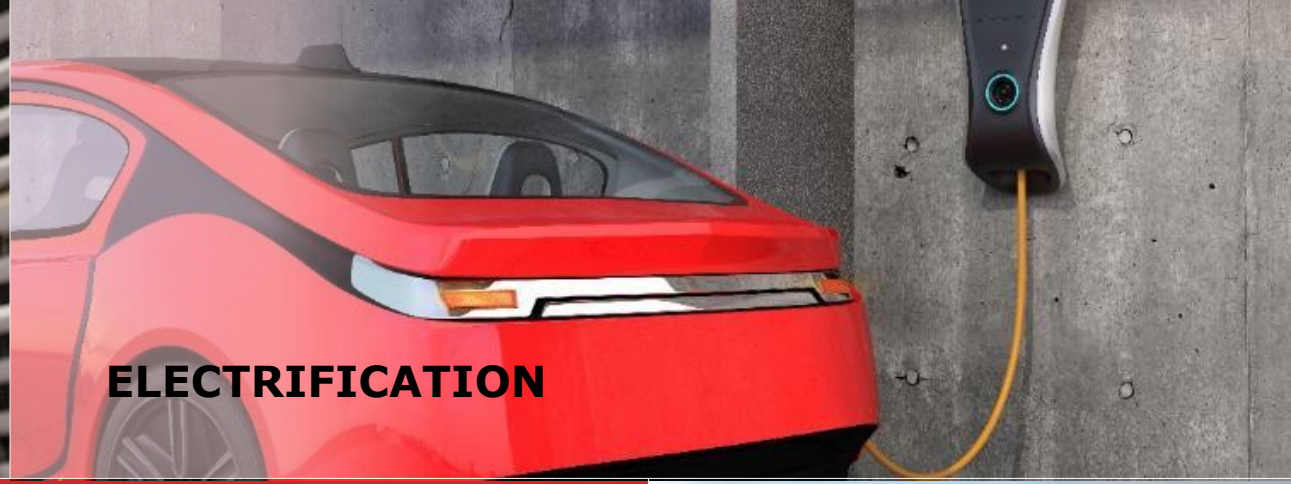






…enabling advances in:

- Performance
- Productivity
- Controllability
- Efficiency
- Emissions
- Safety
- Reliability
- Noise



GLOBAL MEGA-TRENDS

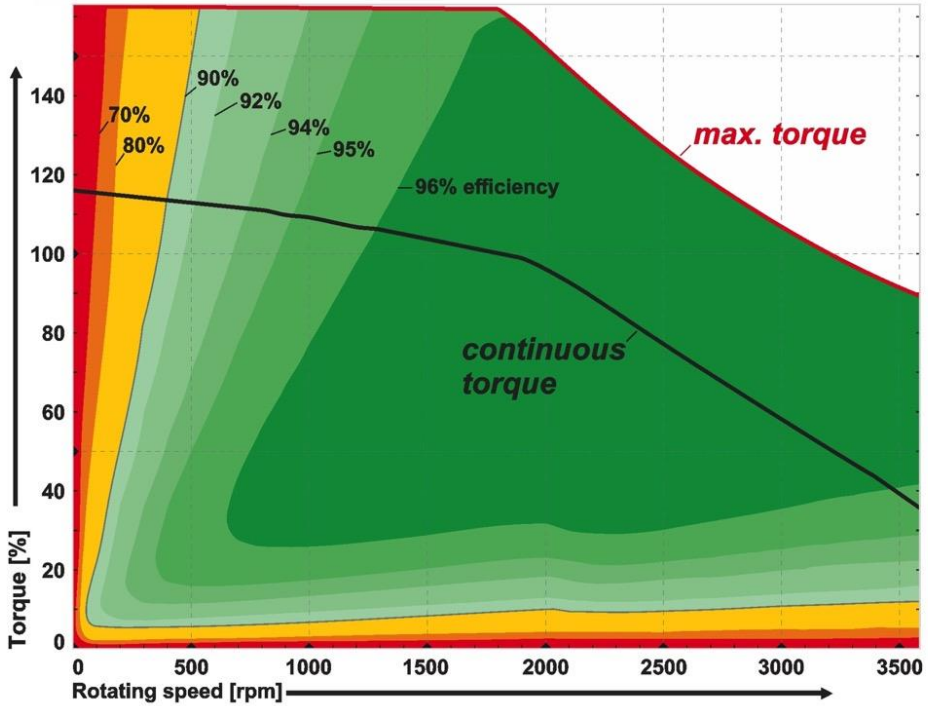
transforming our world

Key electrification drivers

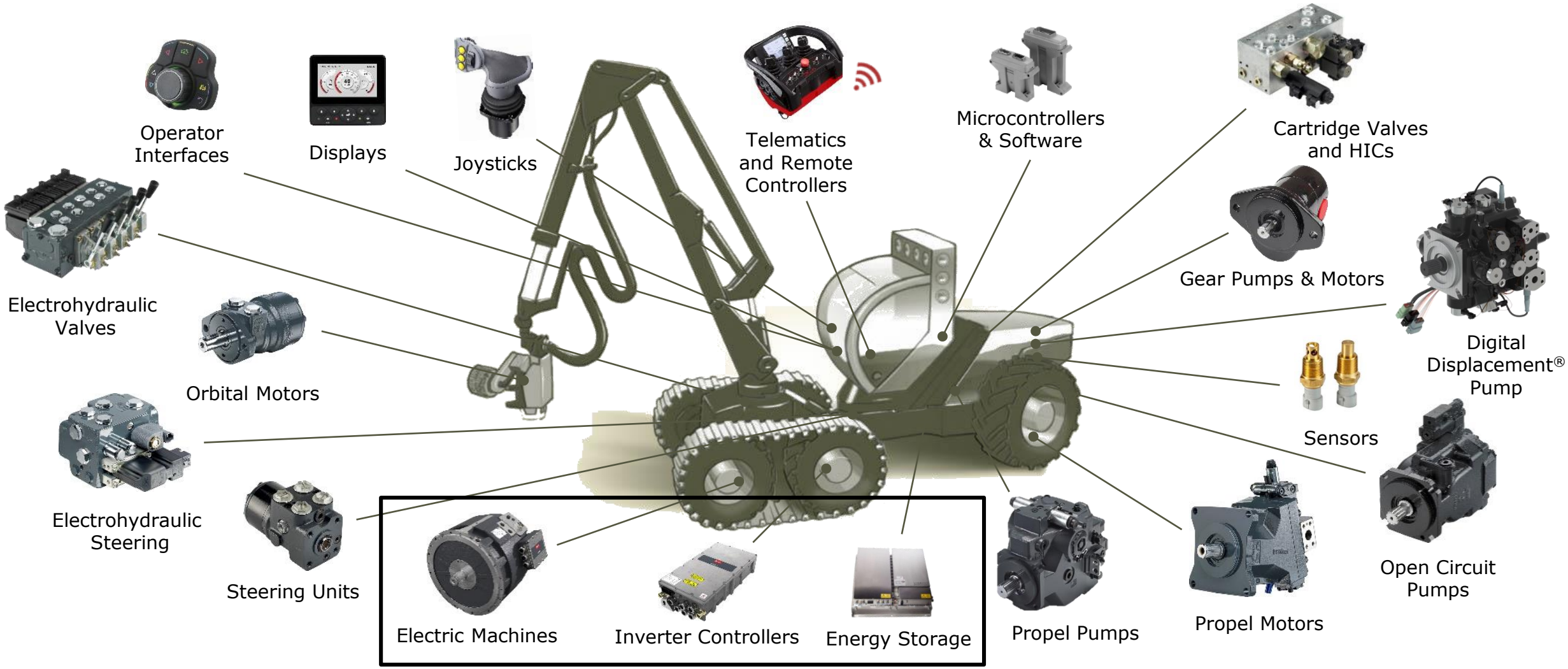
- Increased performance and productivity
- Reduced operational costs
- Zero-emission zones
- Global emission reduction
- “Doing more with less”

Characteristics of high-performance electric drives for off-highway applications

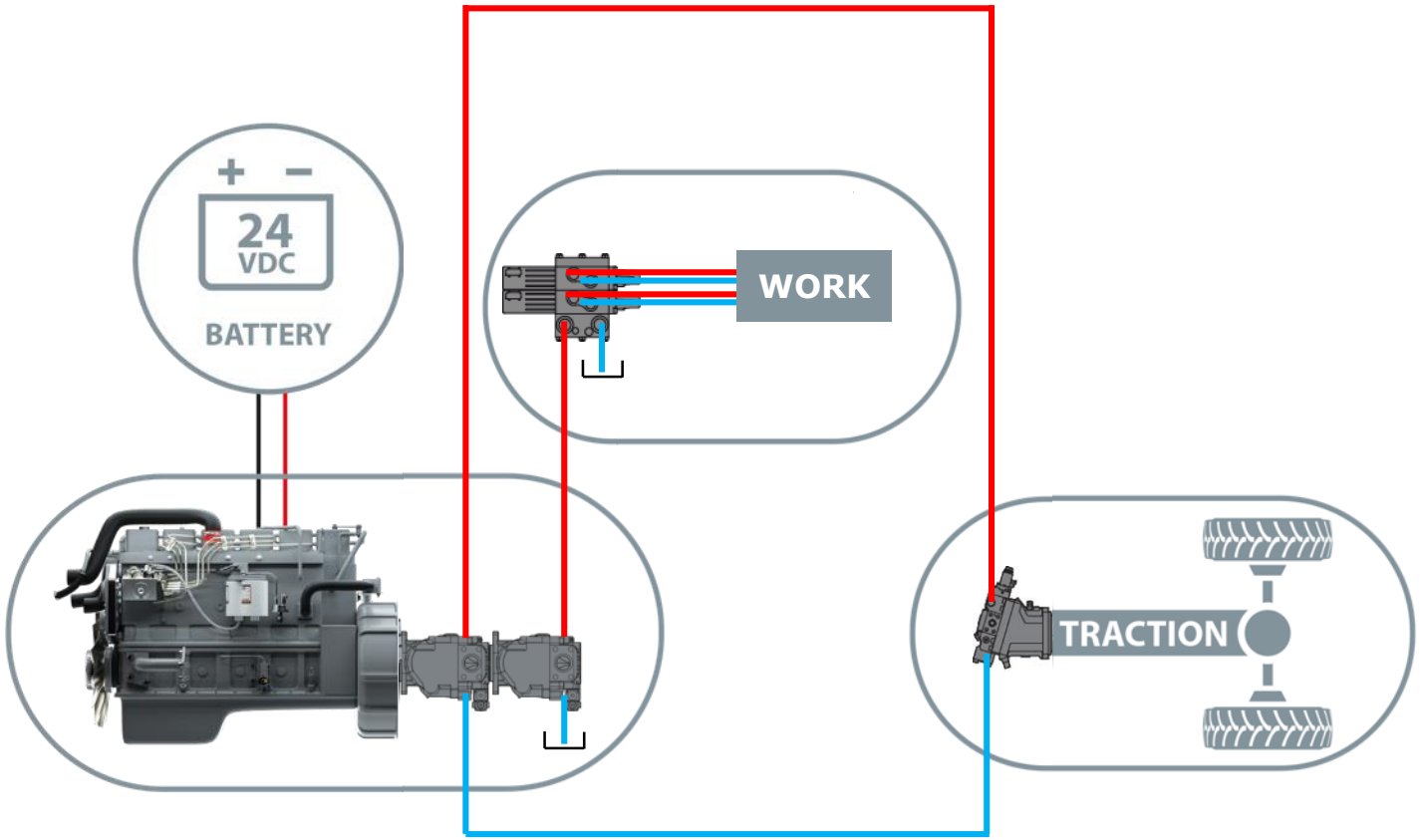
- Wide high-efficiency area
- Liquid cooled
- High peak torque
- Enclosure class IP65; IP67 option
- Internal and external rotor configurations
- Scalable design
- Wide range of power ratings
- Tolerance to shock and vibration



Increasingly diverse product portfolios



Conventional system architecture



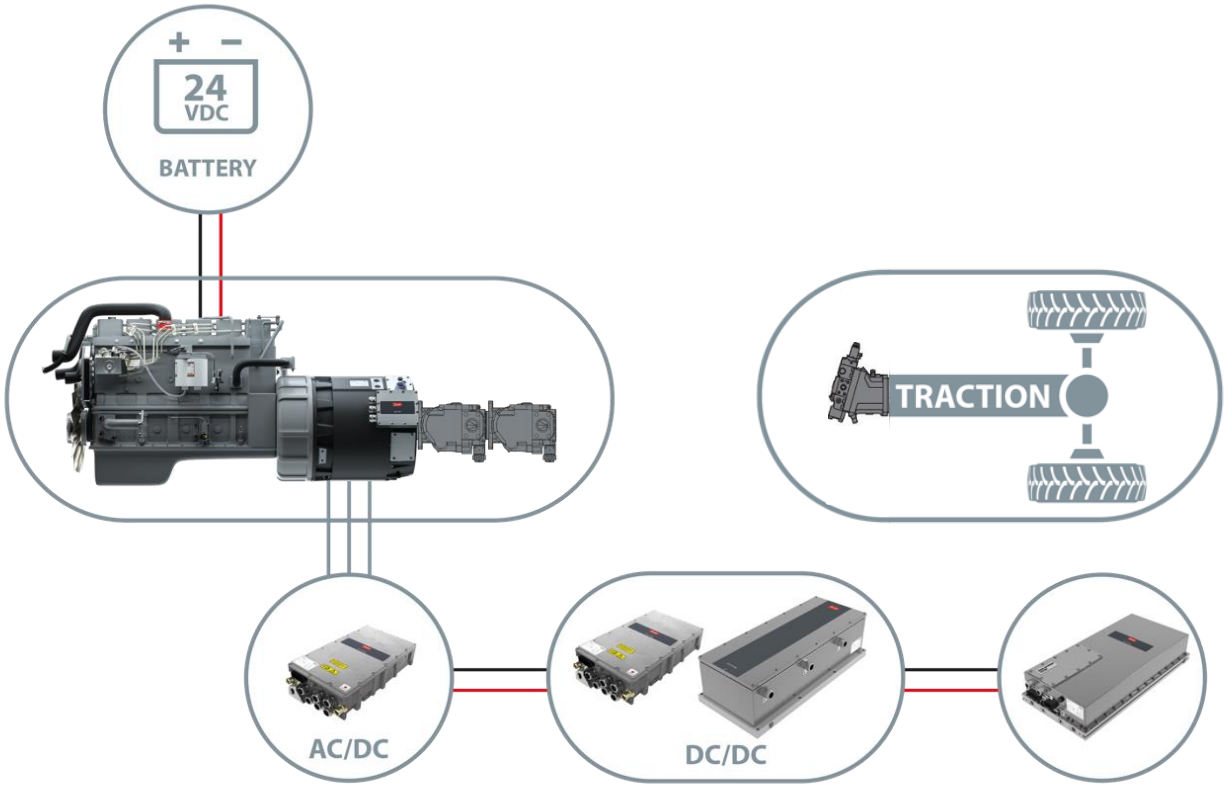
- Closed-circuit pump often used for propel
- Open-circuit pump with valve group often used for work functions

Architectures enabled with electric machines

Motor-generator used as:

- Overall prime mover
- Auxiliary prime mover
- Parallel hybrid M-G
- Series hybrid M-G
- Traction motor

Parallel hybrid



- Peak shaving – ICE downsizing or operate with extra power (for increased productivity)
- Possibility for electric-only driving if engine clutch separates ICE and M-G (P2)
- Possibility to retrofit
- Typical fuel savings up to 10-15%
- Minor emissions reduction overall
- Noise reduction

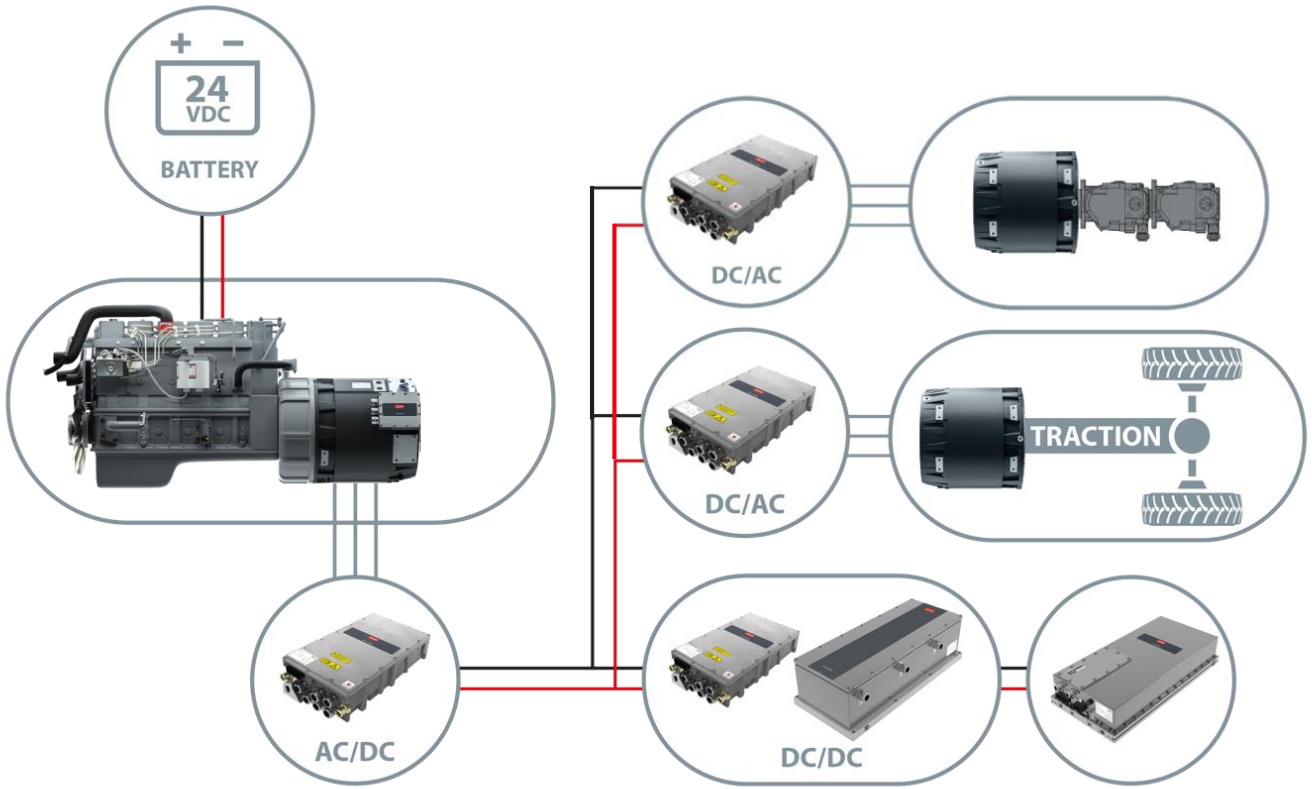
Case study

Parallel hybrid forest harvester

MAIN BENEFITS

- Power increase +72%
- Productivity increase up to 30%
- 15-25% reduction in fuel consumption per m^3 processed
- World’s most powerful forest harvester - 380 kW
- Maximum torque – 2000 Nm

Series hybrid

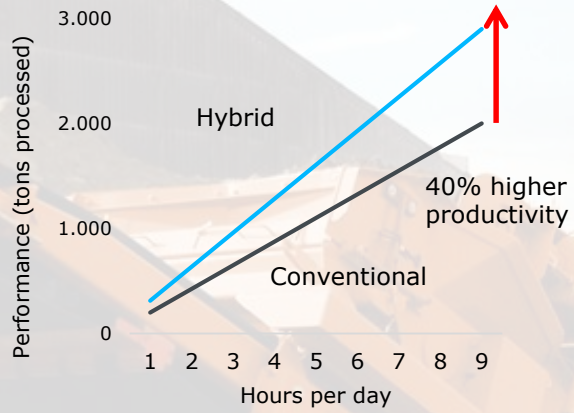


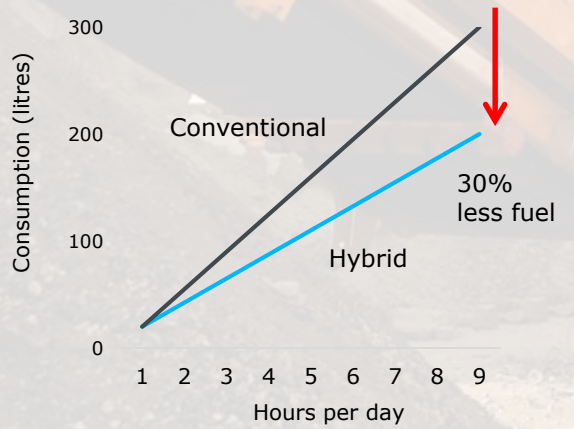
- Peak shaving – major downsizing of ICE, or operate with extra power (for increased productivity)
- Possibility for electric-only operation if configuration allows
- Typical fuel savings of 20-35%
- Emissions reduction
- Noise reduction
- Traction motor(s) must handle full requirements of application

Case study
Series hybrid stone crusher

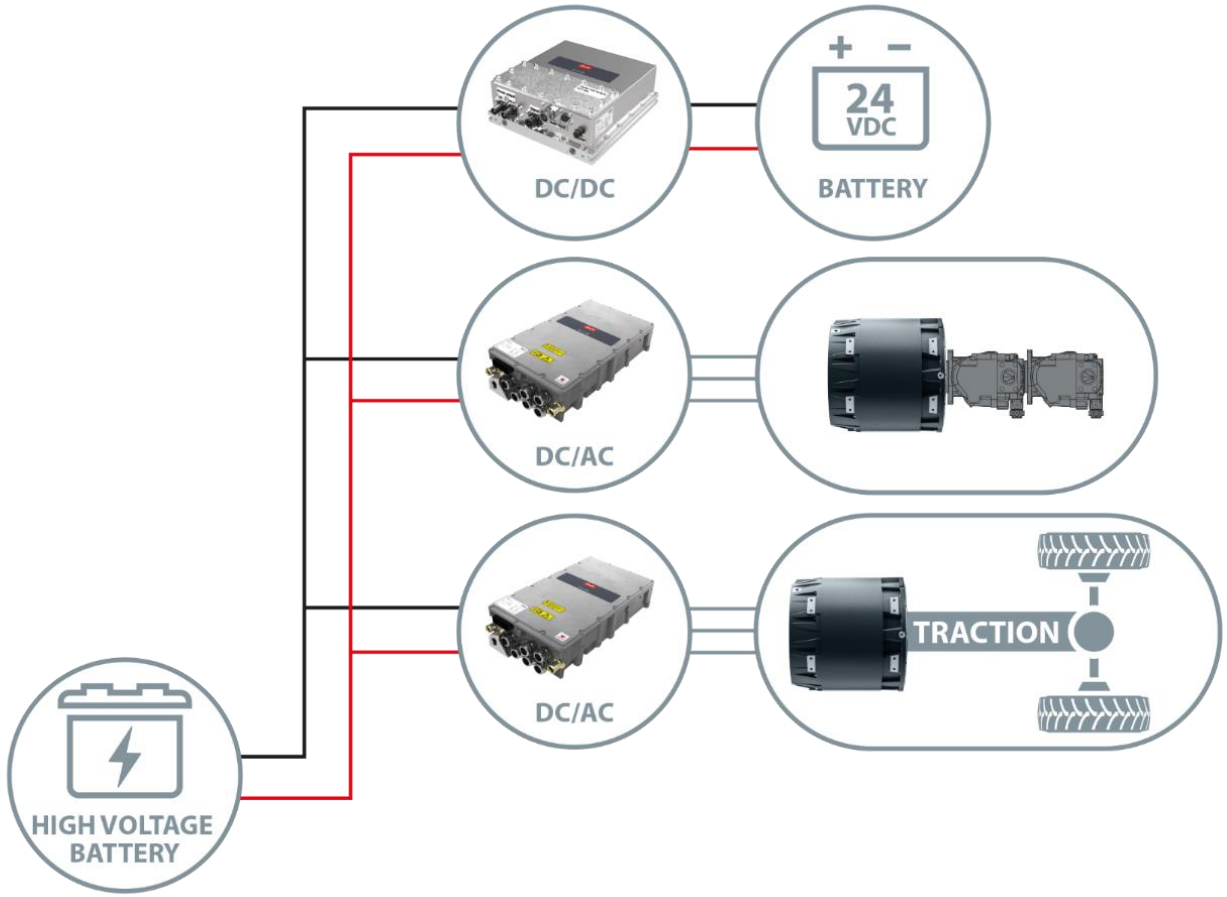
MAIN BENEFITS

- Saves up to 16,000 L diesel annually
- 40% higher productivity
- 9 month payback period
- First-of-its-kind hybrid on the market
- Optional capability to run off of a grid connection





Full electric 1



- Zero emission vehicle
- Significant noise reduction
- Major efficiency improvement

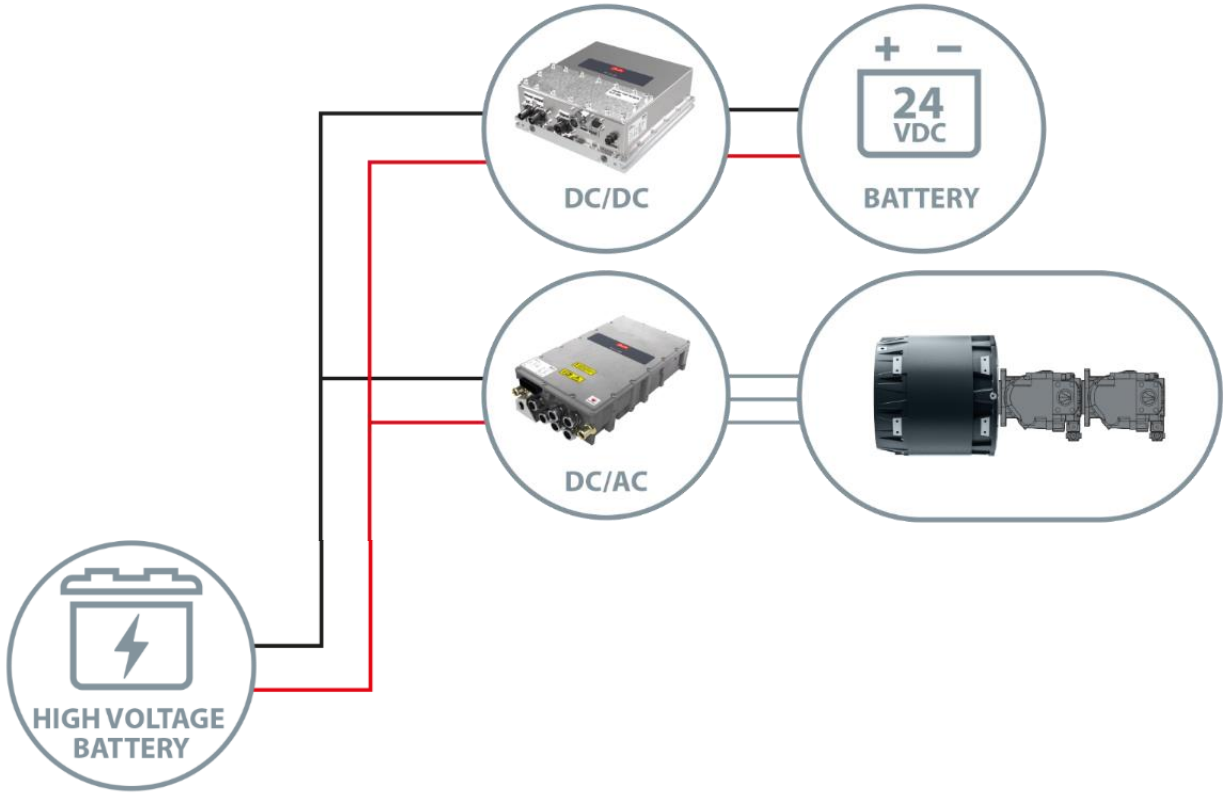
Case study

Battery-electric mine vehicle

MAIN BENEFITS

- Health protection for miners through emission-free electromobility
- Cost reduction through lower fuel and ventilation costs
- Up to 50 percent lower energy costs

Full electric 2



- Engine replaced by electric machine
- Retain existing transmission

Case study

Battery-electric excavator

MAIN BENEFITS

- Zero emissions
- Significantly quieter
- Safer and more reliable operations

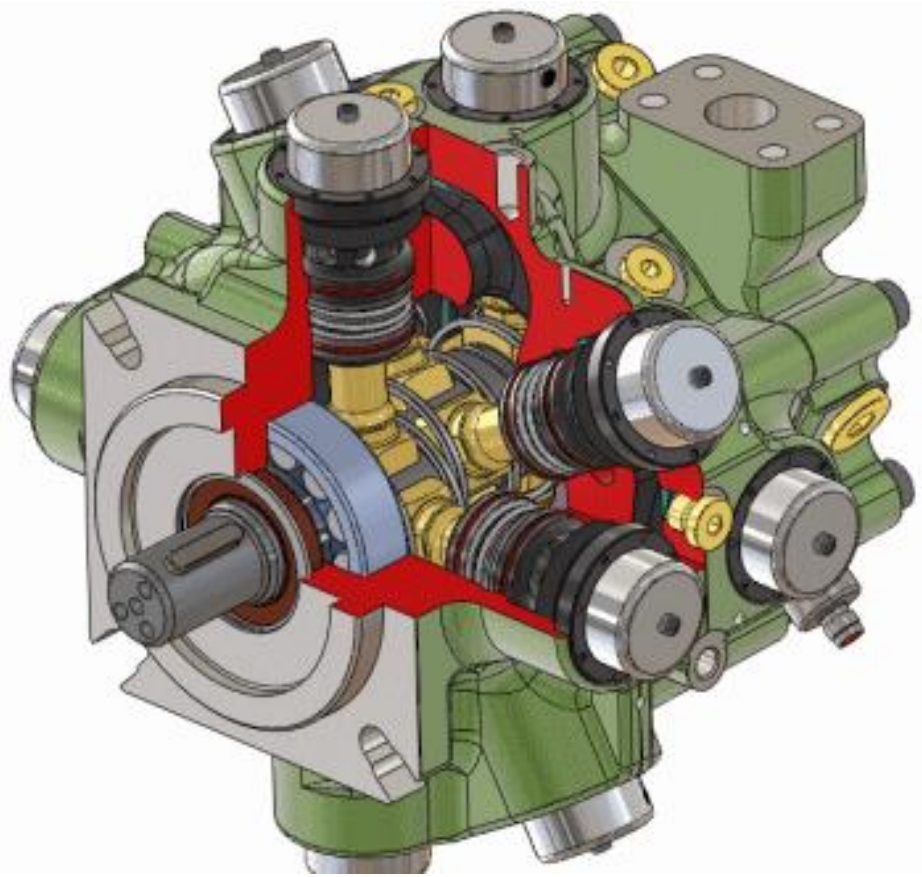
What about linear actuation, work functions?

- Hydraulic cylinders have long been the standard and are difficult to beat
  - Robustness
  - Production cost
  - Force density
  - Simplicity
- Open-circuit system efficiencies are largely impacted by throttling and idling losses. Some means to address this include:
  - Improvements in valve metering technology
  - Displacement-controlled actuators
- Electromechanical and electrohydraulic linear actuators remain in concept and research stage
- Electric pump drives increasingly available

Digital Displacement® Technology

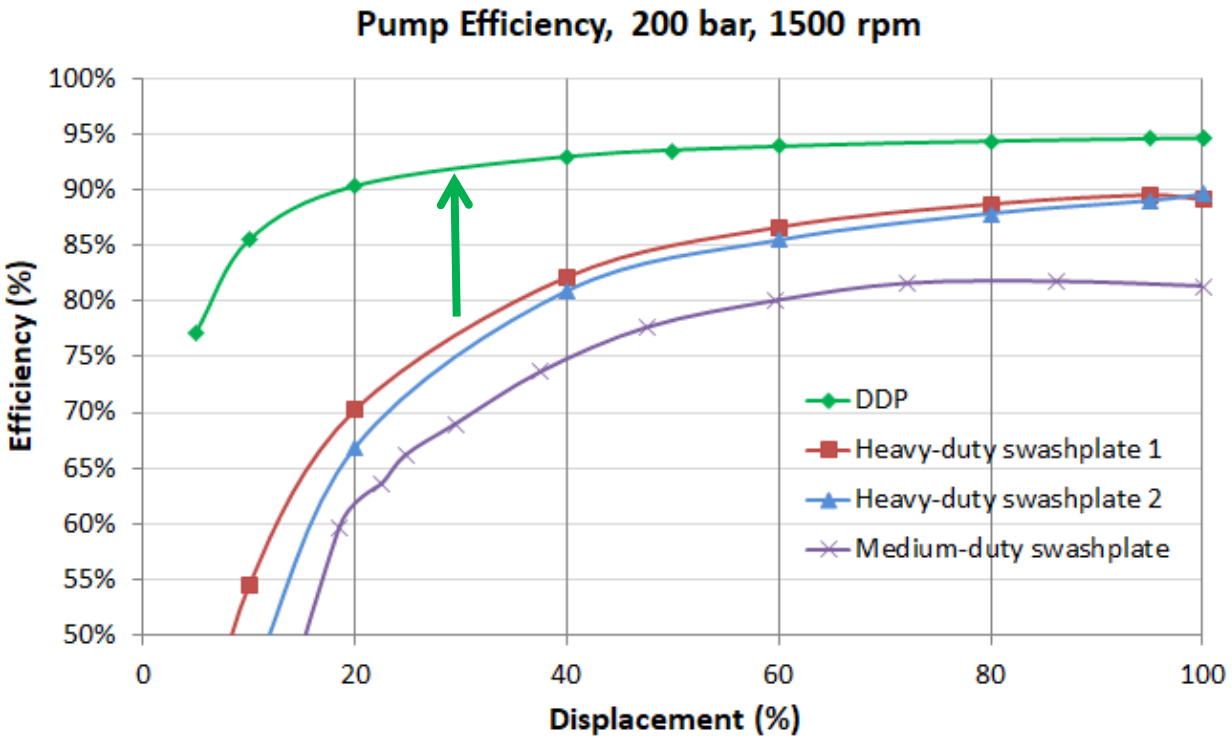
Digital Displacement Pump (DDP):

- Radial-piston design
- Digital control of each piston
- High efficiency, low idle losses
- 420 bar continuous capability
- Fast and accurate response
- Control modes and parameters electronically tunable
- Capable of multiple output ports

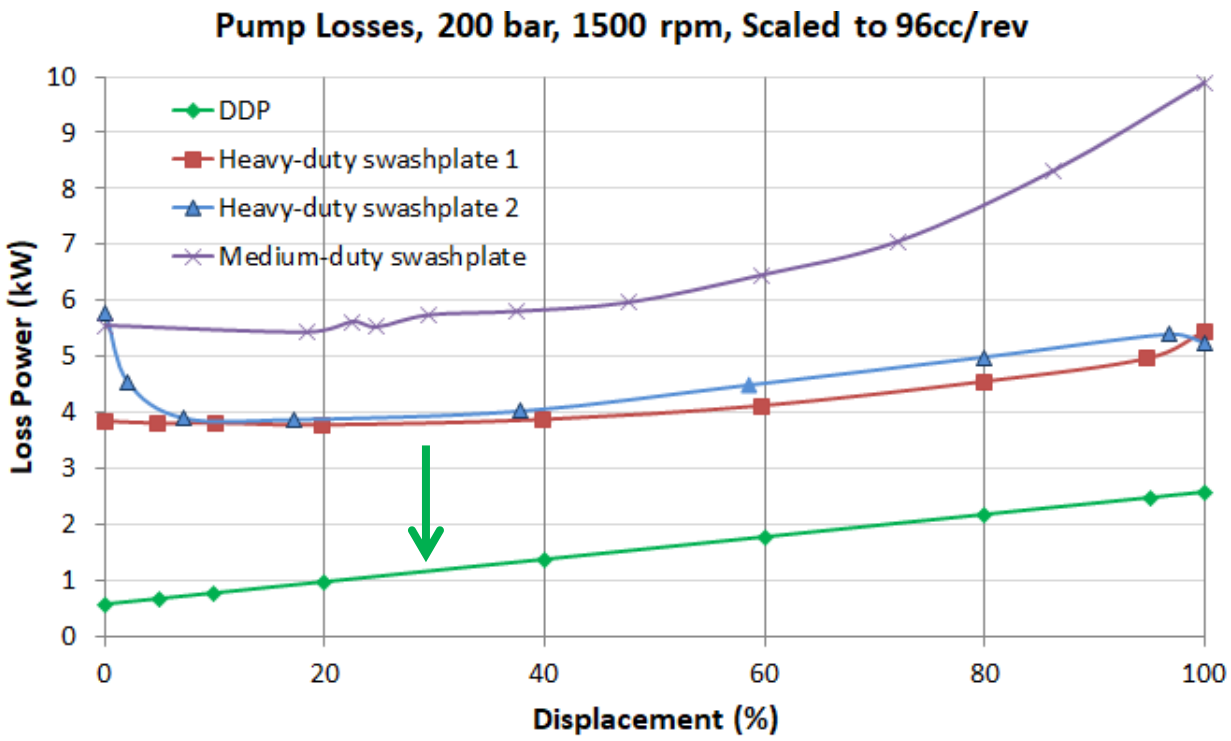


DDP efficiency & losses

Efficiency:

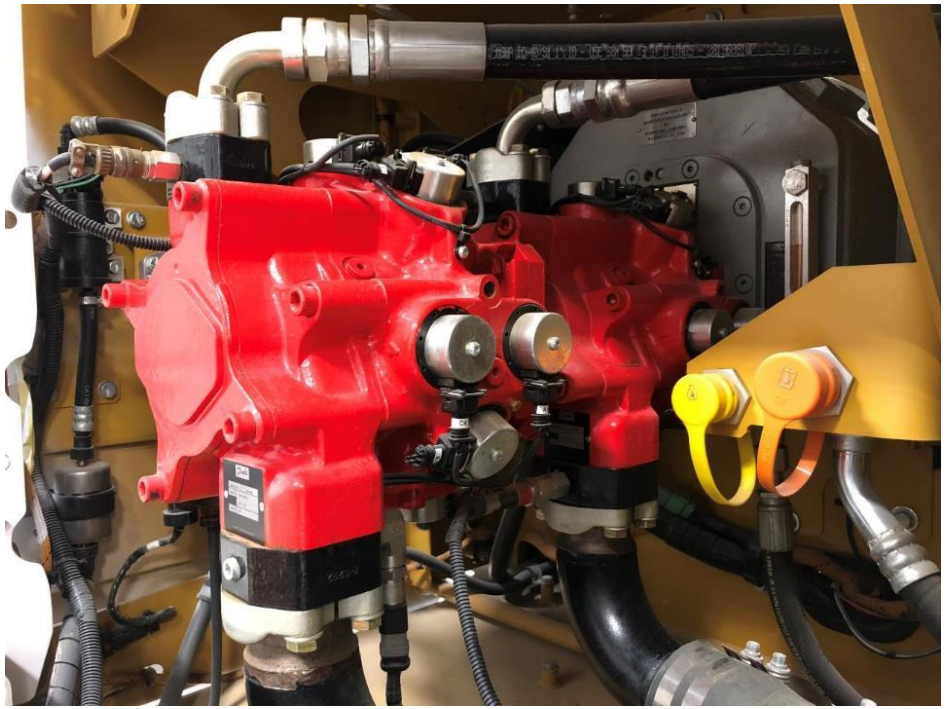


Losses:

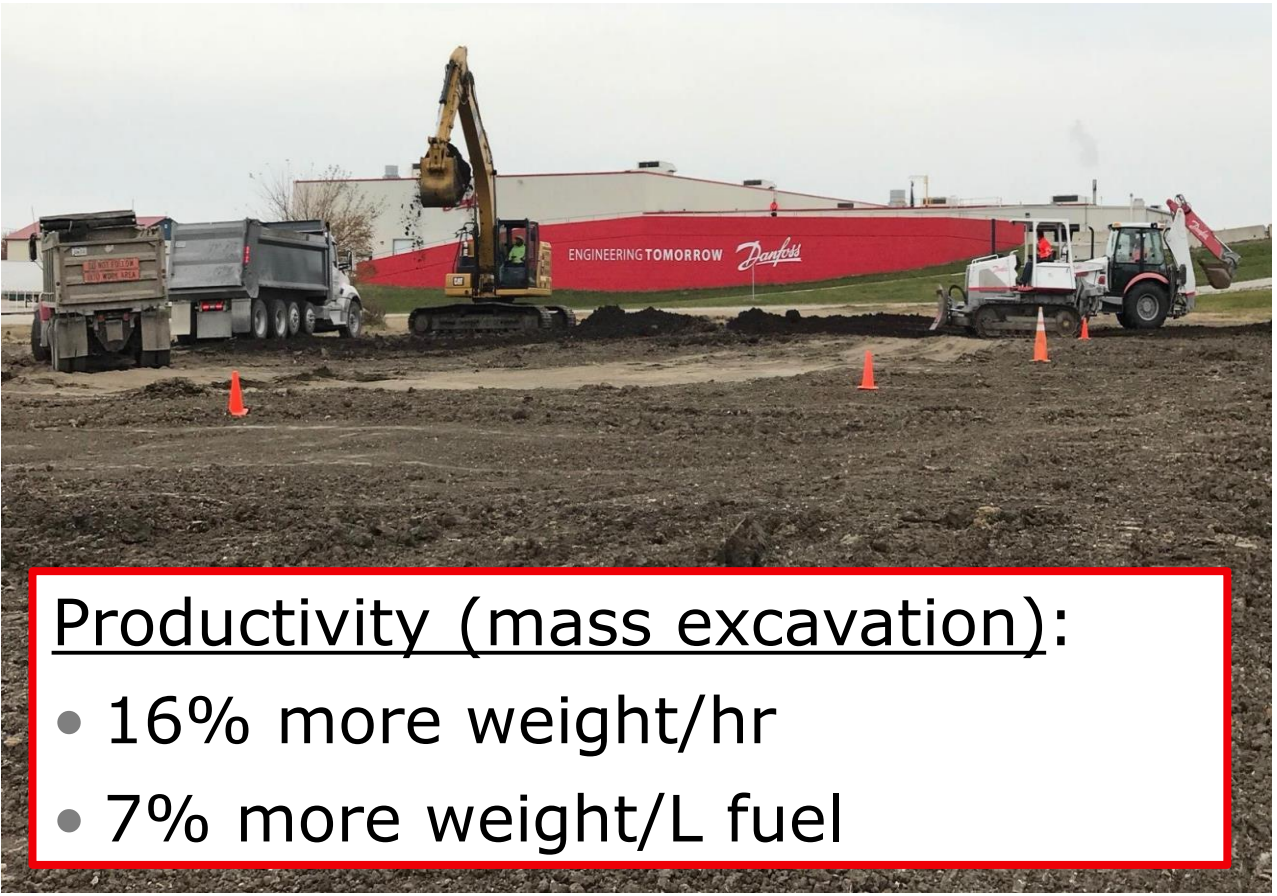


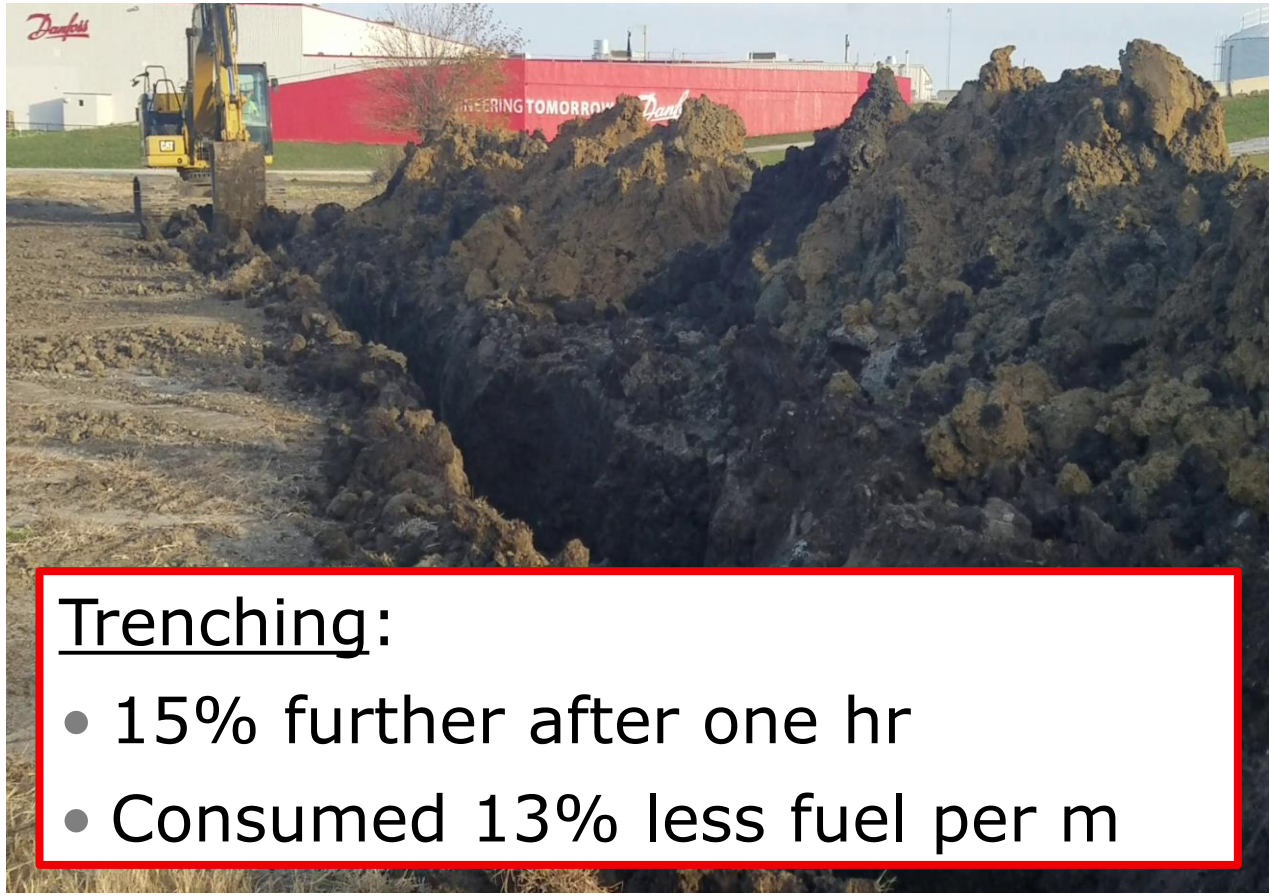
Technology project: Excavator conversion to DDP

- New, CAT 320 next-generation excavator
- Original, axial-piston, swashplate pumps exchanged for DDP in tandem
- All other engine and machine controls left in original state



Post-conversion test results (vs. original configuration)





Productivity (mass excavation):

- 16% more weight/hr
- 7% more weight/L fuel

Trenching:

- 15% further after one hr
- Consumed 13% less fuel per m

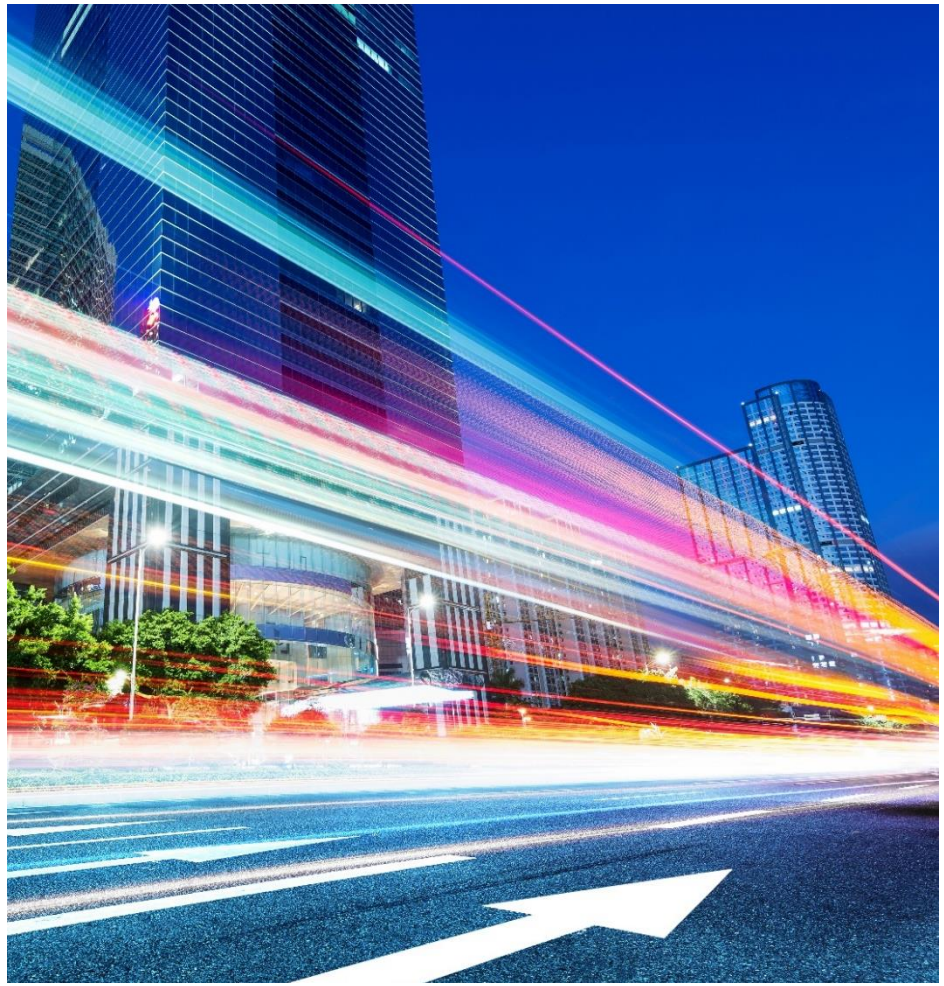
Budden, J. and Williamson, C. 2019. Danfoss Digital Displacement® Excavator: Test Results and Analysis. ASME/BATH 2019 Symposium on Fluid Power and Motion Control. Sarasota, FL, USA.

Digital Displacement® as a tool in electrification

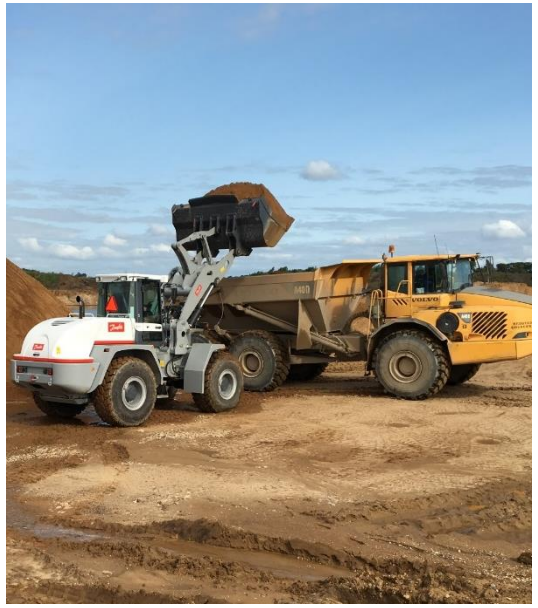
- Efficiency has increased value on BEVs
- DDP may have a lower hurdle cost than other methods for reducing power and battery capacity
- Internal analysis shows that the Pon battery-electric excavator with DD architecture SA2 (multi-output + control valves) could achieve the same working capability and run time with **20-25% less battery capacity**

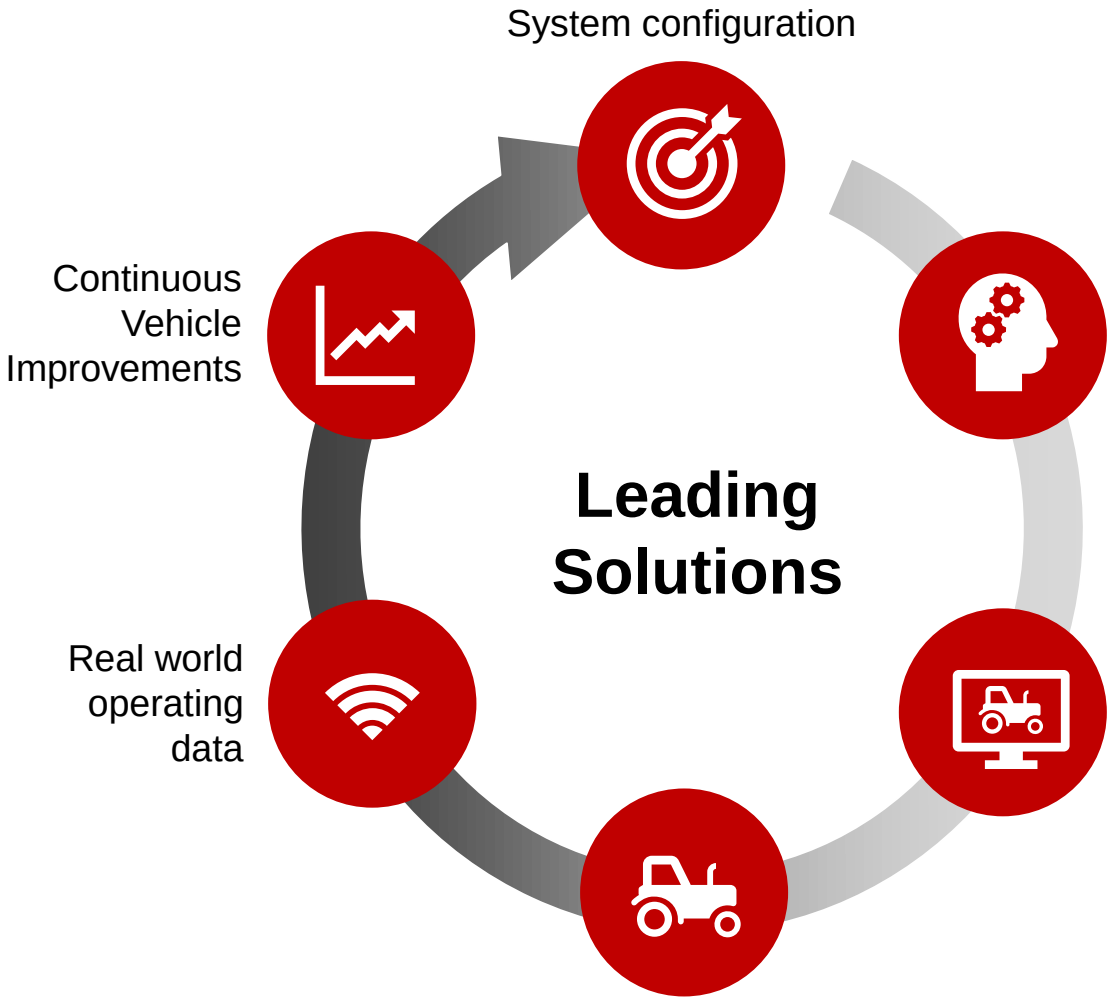
Overall challenges we see in electrification

- Energy storage
- Charging infrastructure
- Power/torque/force density vs. hydraulics
- Working out the business case and TCO compared with current price points of hydraulic products
- Field service and support
- Training the workforce



Solution development approach

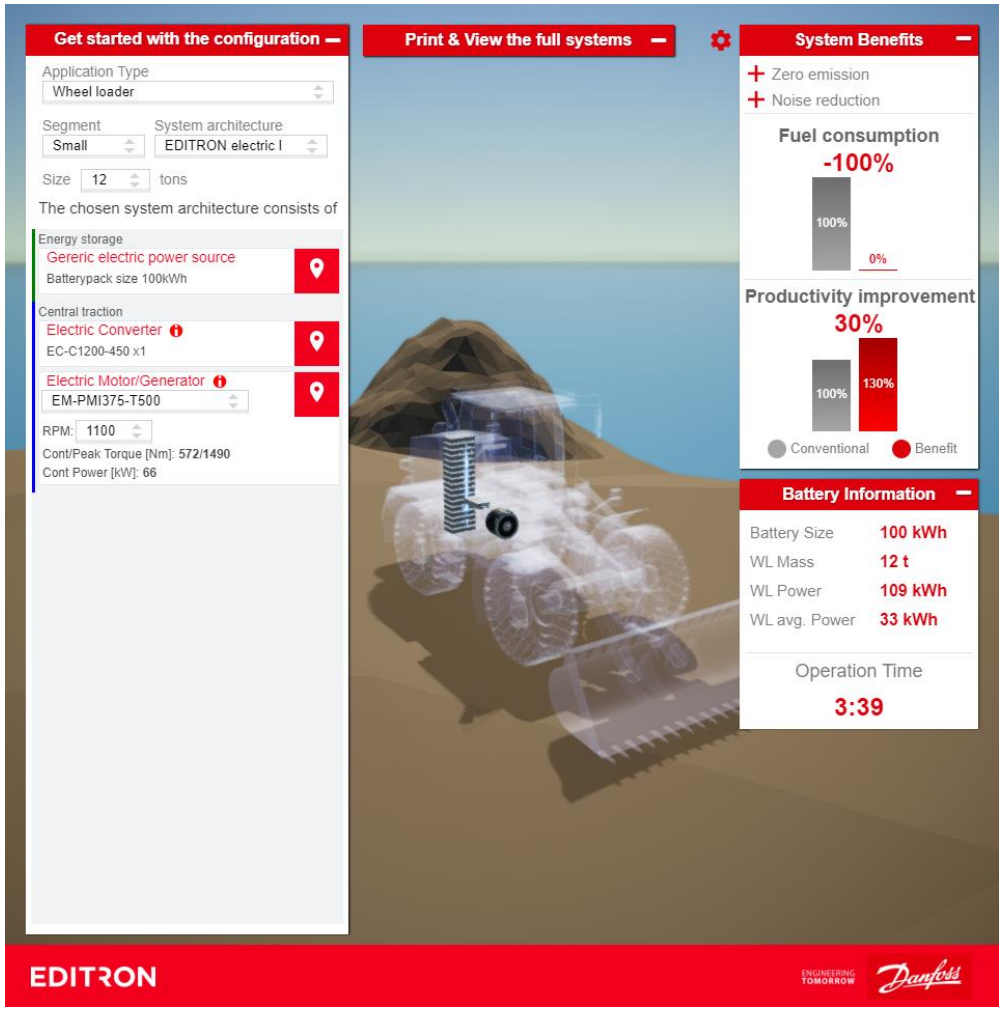


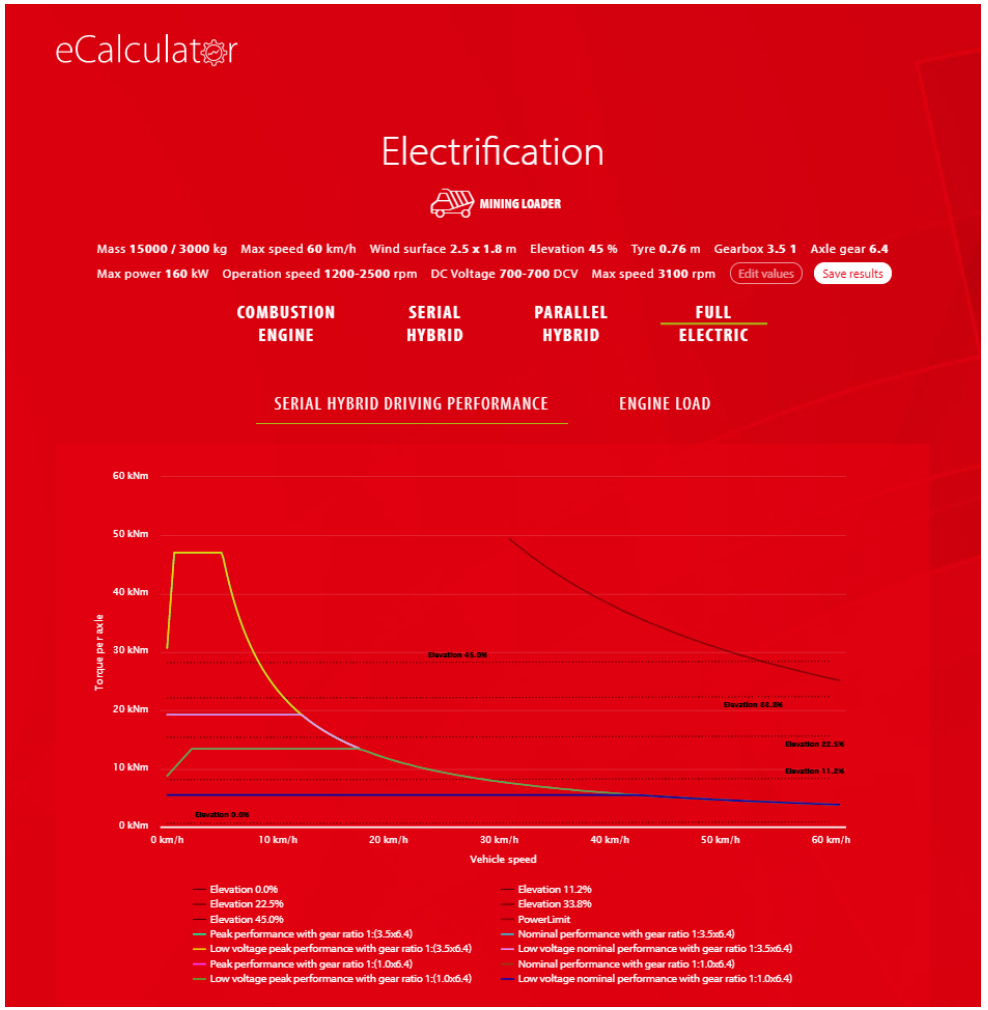


Which system architecture should I choose?

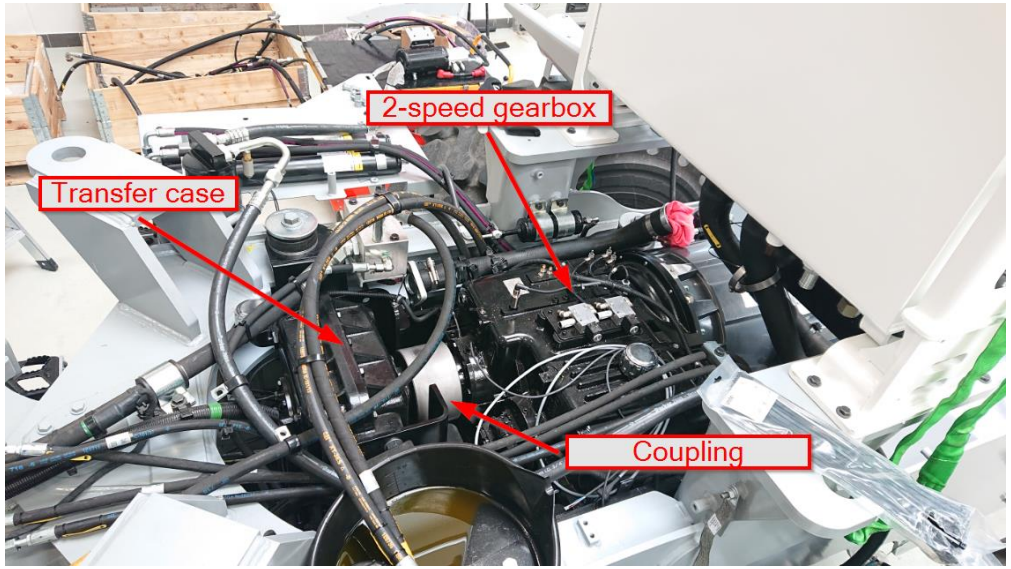
- Ability to modify machine design?
- Maximize productivity or efficiency?
- TCO vs. initial cost?
- Zero-emission operation needed?
- High- or low-utilization duty cycle?
- Ability to recover energy?
- Access to energy source?
- Shift length?

Digital calculation tools

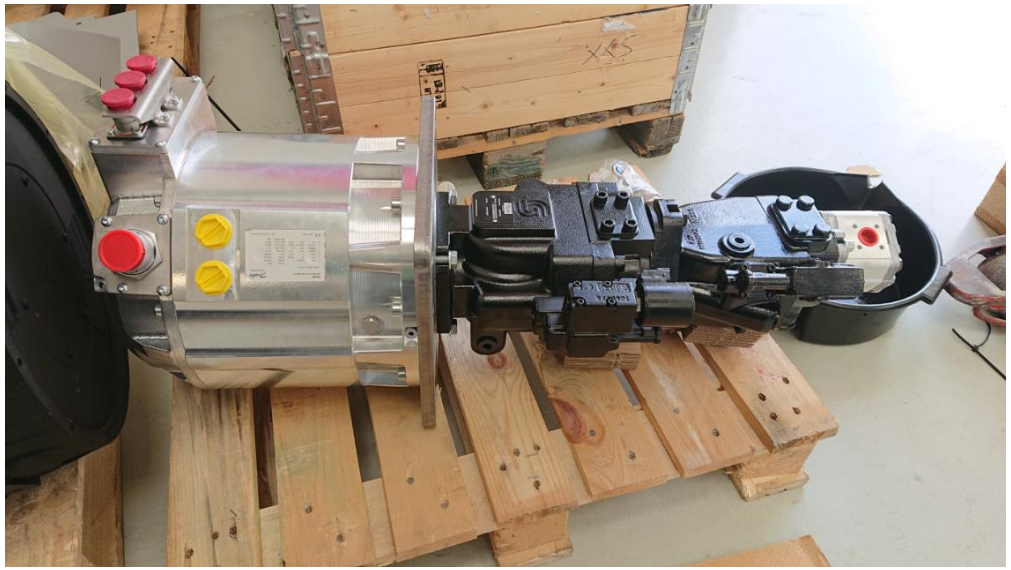




Vehicle development


2-speed gearbox
Transfer case
Coupling


PMI-375-T800



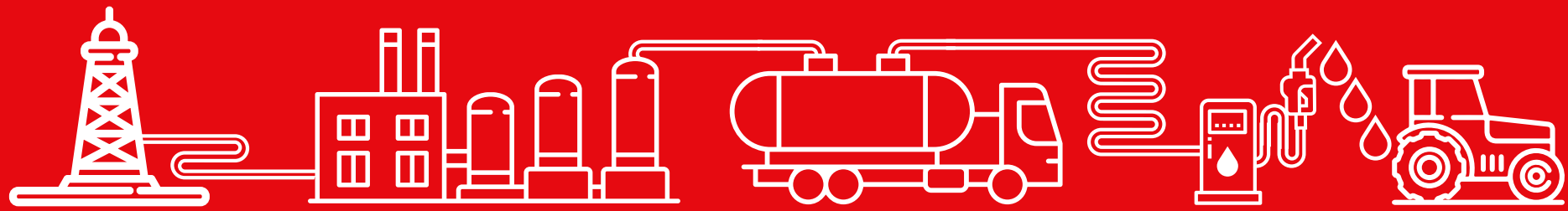
Evaluating applications with duty-cycle data

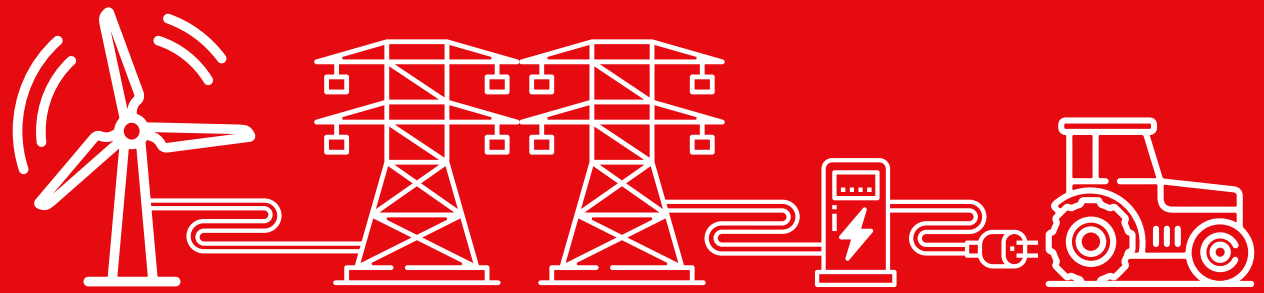
Scenario 1

Work in and around main farm site

Avg. utilization of rated engine power

Daily energy consumption of this work type never exceeded 100 kWh





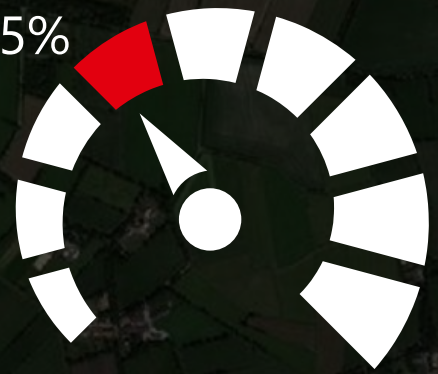
30-80%

Reduction in CO_2 emissions for most of EU

Scenario 2

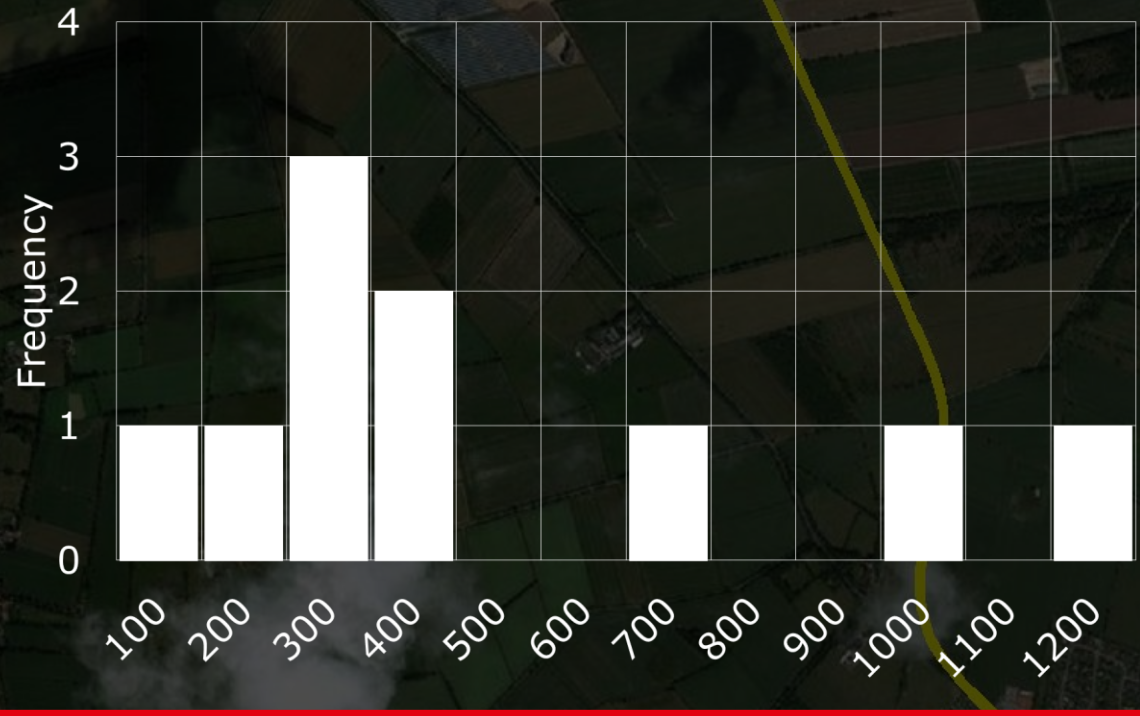
Work completed over repeated trips

35%



Avg. utilization of rated engine power

Histogram, Daily Energy Used (kWh)



BEV feasible in some cases, using high-power charging between trips and during regular break periods


10%
reduction in overall energy consumption possible with regenerative braking
STOP

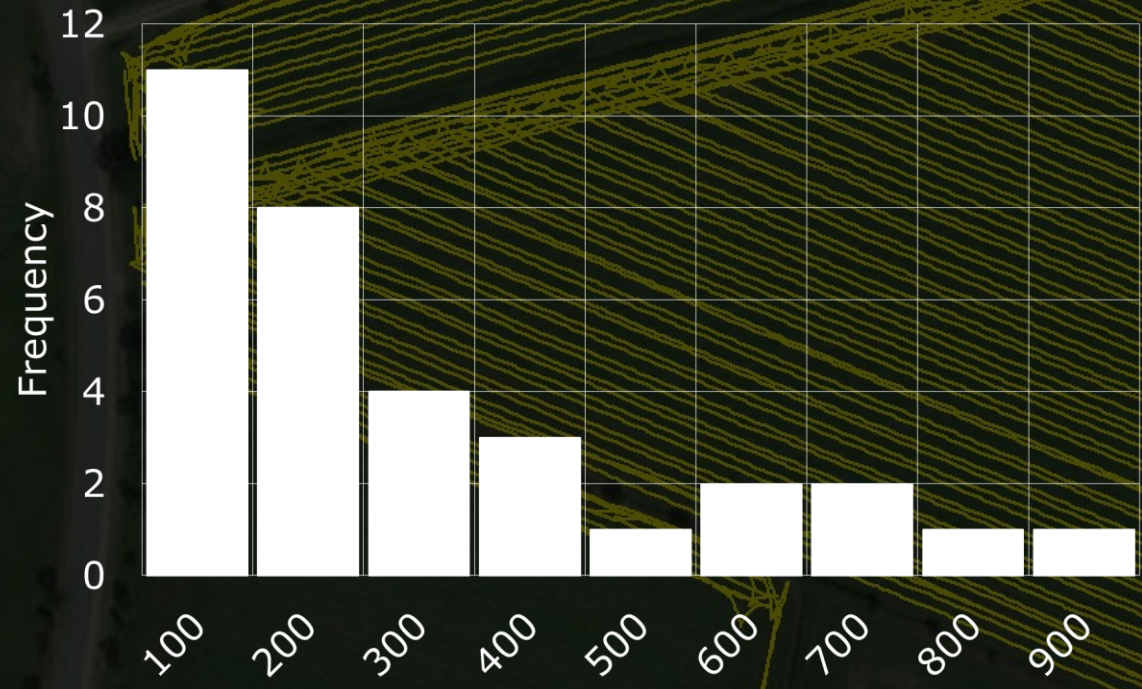
Scenario 3

Extended work at remote sites

50%

Avg. utilization of rated engine power

Histogram, Daily Energy Used (kWh)



Remote, high-power operations over extended periods better suited to ICE-based drivetrains

Our outlook

- System solution portfolio will become more diverse
- Electric and hydraulic component technology will become more integrated
- Mobile hydraulics have some unique advantages that will be difficult to replace in the short run
- Improvements to hydraulic system efficiency will continue to have merit
- Electrification will be largely driven by zero-emission requirements and productivity improvement
- Digital tools and technology demonstrators will support development activities
- **Many companies joining electric revolution; Integrated hydraulics suppliers have some advantages**

Thank you

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