# Electrification of a Mini Excavator

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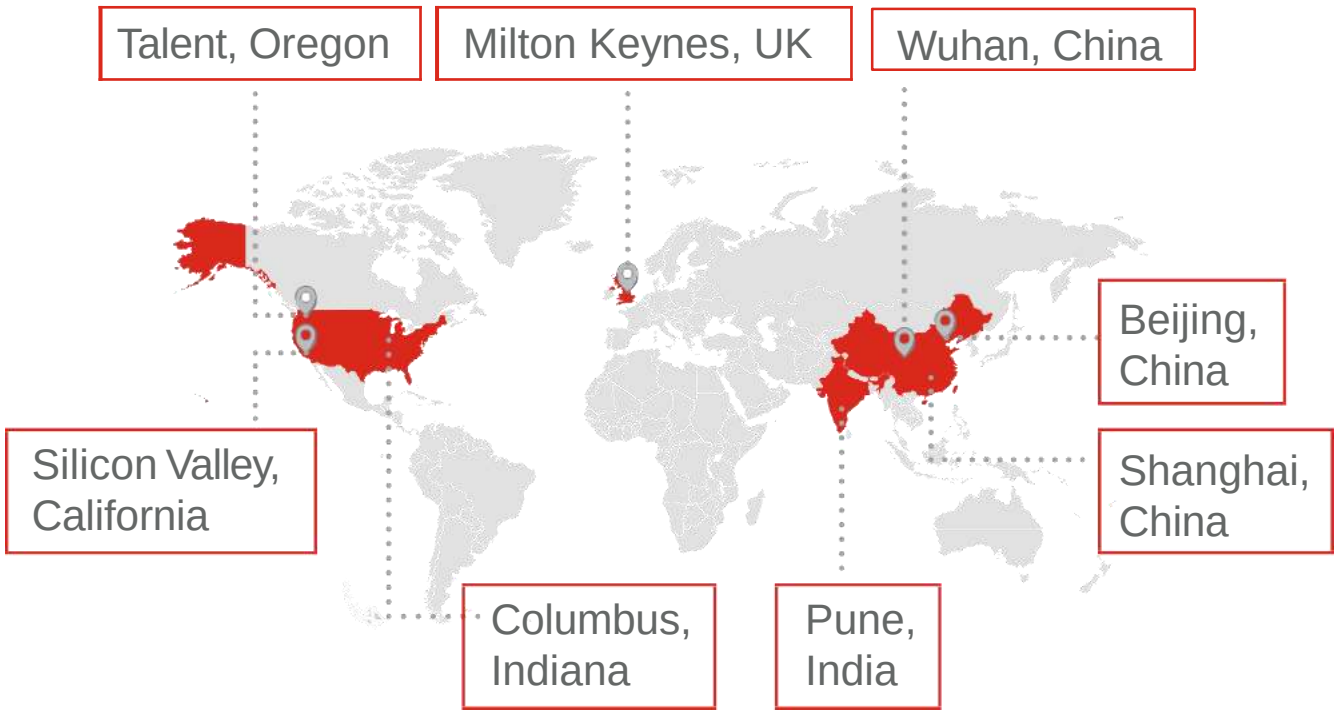
# Cummins Electrified Power Business Unit

Expanding our strategic footprint and bringing innovators together

## Locations in 4 countries




**3 new acquisitions bring new capabilities**

Brammo JMBS EDI

# Electrified Power Milestones

**2017**

**February 2017**

The Electrification Business Development Initiative officially launched.

**June 14, 2017**

Announced we would introduce a fully-electric transit powertrain in 2019, followed by a range-extended electric system for buses in 2020.

**August 29, 2017**

Unveiled our first fully electrified heavy-duty demonstration truck, Aeos, showing that Cummins is serious about electrification.

**October 10, 2017**

Announced electrified power partnership with GILLIG, which includes offering our fully-electric powertrain in the GILLIG zero-emissions transit buses.

**October 16, 2017**

Acquired Brammo, a primarily low-voltage battery designer, located in North America.

# 2018

**January 31, 2018**

Acquired Johnson Matthey Battery Systems, a primarily high-voltage battery designer, located in the United Kingdom.

**February 7, 2018**

Announced that the electrification business will become Cummins' fifth reporting segment, called the Electrified Power segment (EPBU).

**July 2, 2018**

Acquired Silicon Valley-based Efficient Drivetrains, Inc. (EDI), a fully electric and hybrid powertrain provider.

**September 19, 2018**

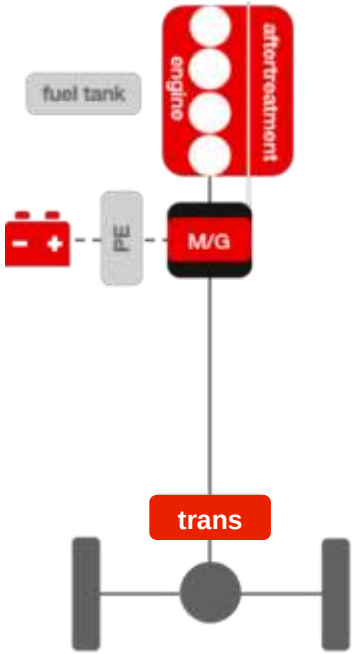
Debuted the Cummins PowerDrive Suite at IAA, the largest global On-Highway show, as well as fully-electric DAF truck

**October 29, 2018**

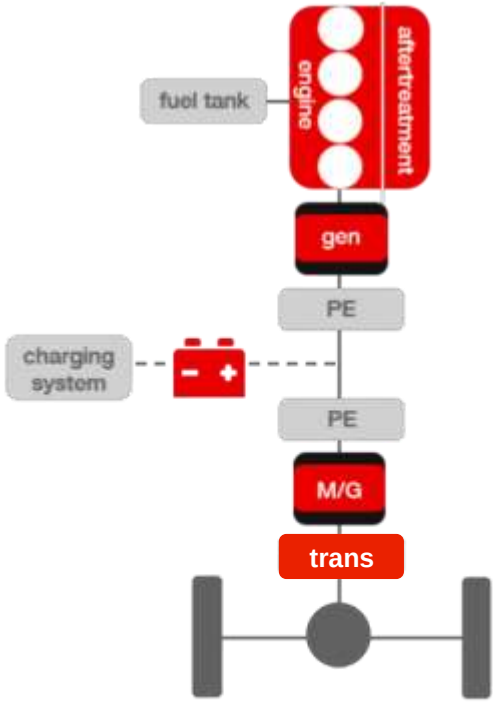
Released a fully electric mini excavator prototype in partnership with Hyundai Construction Equipment

# Power of Choice

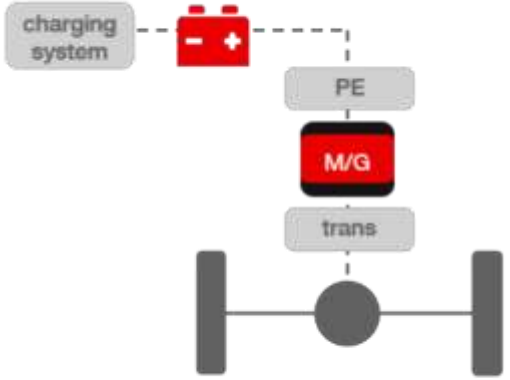
**INTERNAL COMBUSTION ENGINE**



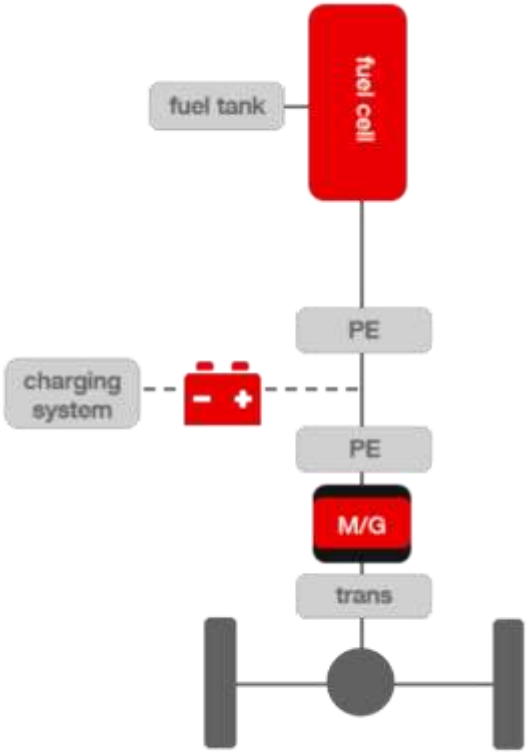

**HYBRID**




**BATTERY ELECTRIC**



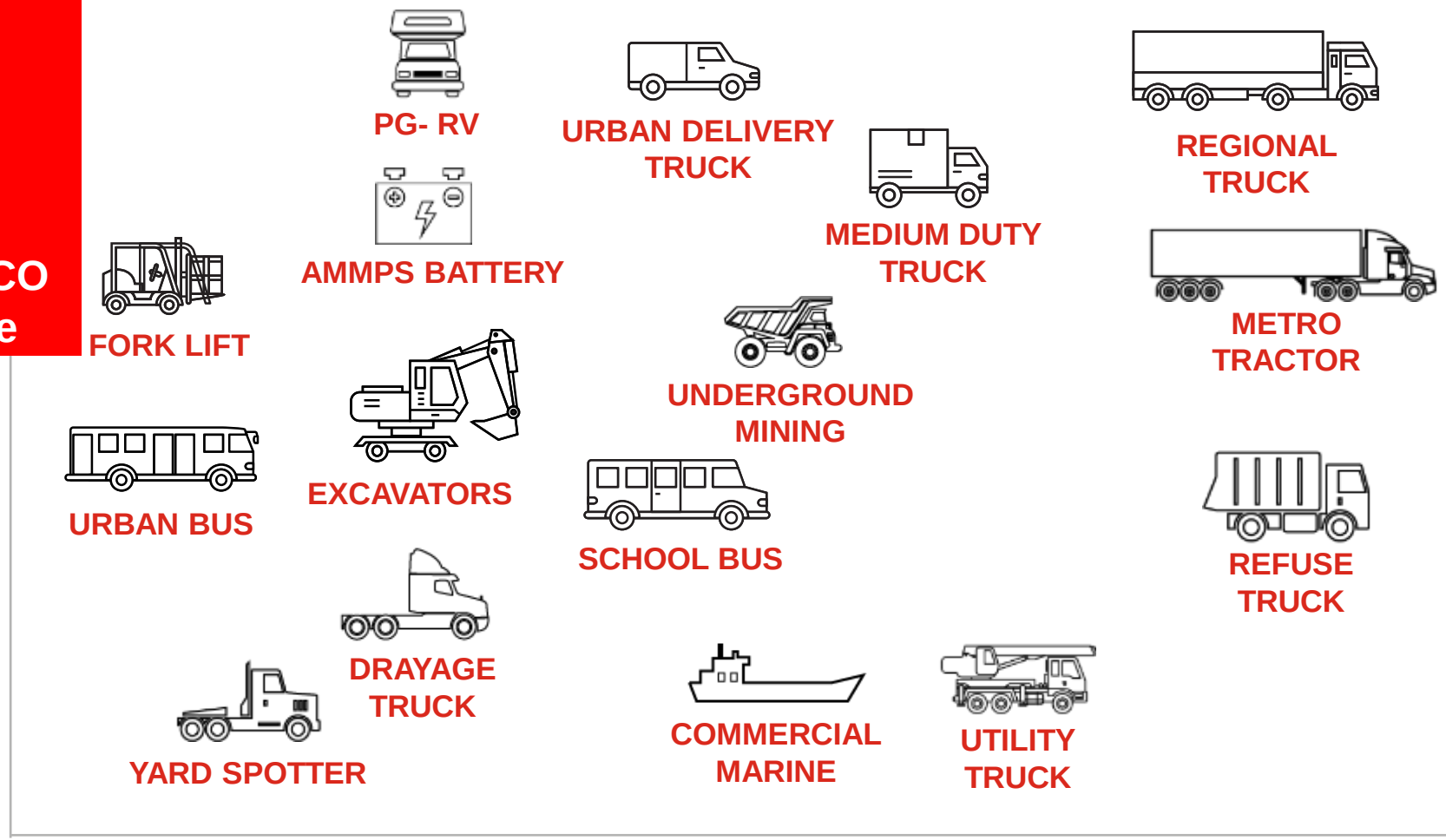

**FUEL CELL ELECTRIC**



# Cummins Electrified Power Adoption

**Adoption in most sectors being paced by**

- Legislation
- Politics
- Incentives
- Economics/ TCO
- Infrastructure




- Inter

# Mini Excavator Electrification - Pictures


Diesel Version

Cummins have converted a 3.5t Hyundai mini excavator.

This is a single motor solution, maintaining hydraulic actuation.

Replaced a 18kW engine

35kWh Battery and electric motor

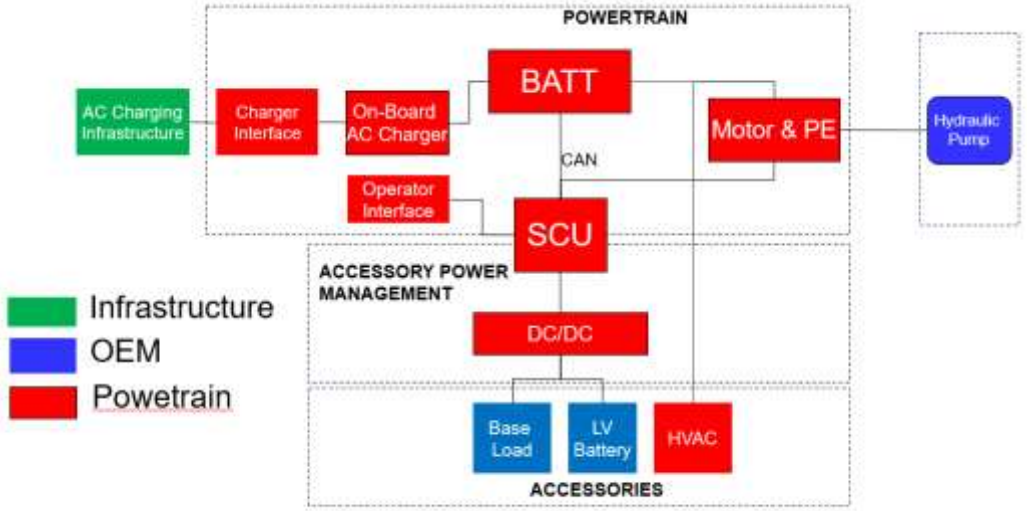
System Voltage = 350 volts

Electric Version

# Mini Excavator Electrification - System Architecture

For Off highway applications the large amount and variation in duty cycle brings additional challenges not faced by on highway product

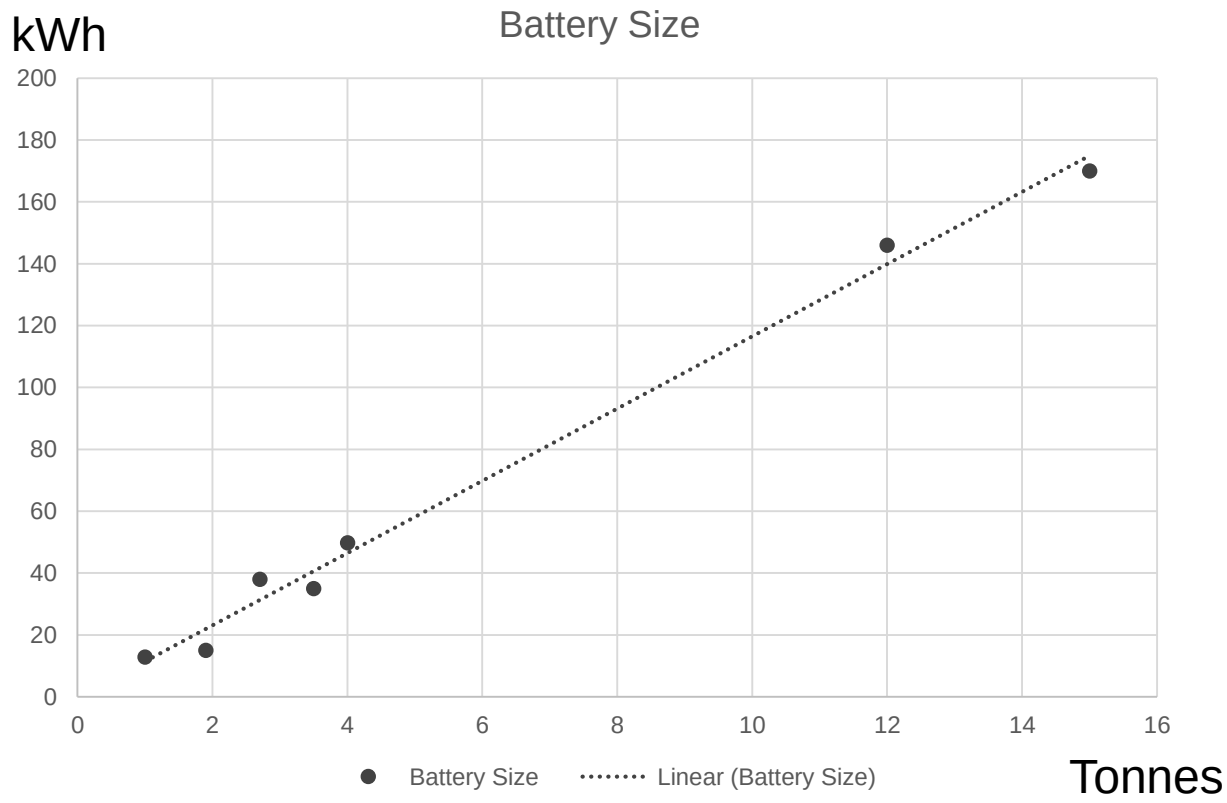
- There is a large variation in duty cycle depending on end user for mini excavators.
- Day to day variation is likely to be higher for a mini excavator than a larger excavator which may perform similar functions day after day
- Mini-Excavators see more idle/off time because they are often used by small construction firms and move from site to site
- Hypothesis is that mini excavators have lower duty cycle than larger excavators and experience longer periods of idle or off time.



# Mini Excavator Electrification – Battery Size

## Excavator Size vs. Battery Capacity

- Adjusted battery size for 8 hours of operation
- **Linear relationship may not be valid especially for smaller excavators. Impacted by features such as heating or A/C and also would expect larger excavators to have higher duty cycle**
- **The competitive data would indicate for an excavator between 3-4T the battery size would be ~ 40 KWH**

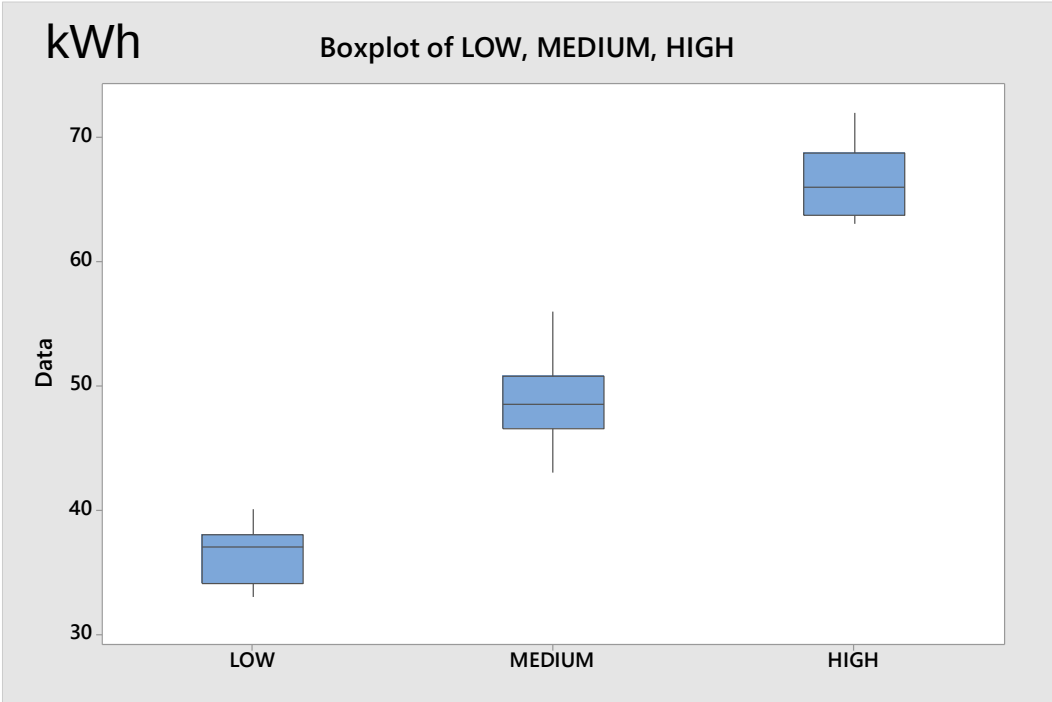



**Competitive Analysis**

# Mini Excavator Electrification – Battery Size

- For accurate battery sizing the best method is to obtain data with torque and speed based.
- Data logging timeframe should be sufficient to capture any day to day duty cycle variation.
- Any seasonal changes in operation should also be considered in data logging.
- Hydraulic Pressure and Flow should be added to understand the benefits of regeneration of hydraulic energy
- What about Simulation?
  - It's feasible to develop an accurate model of an excavator system
  - As more information becomes available this will be the preferred method

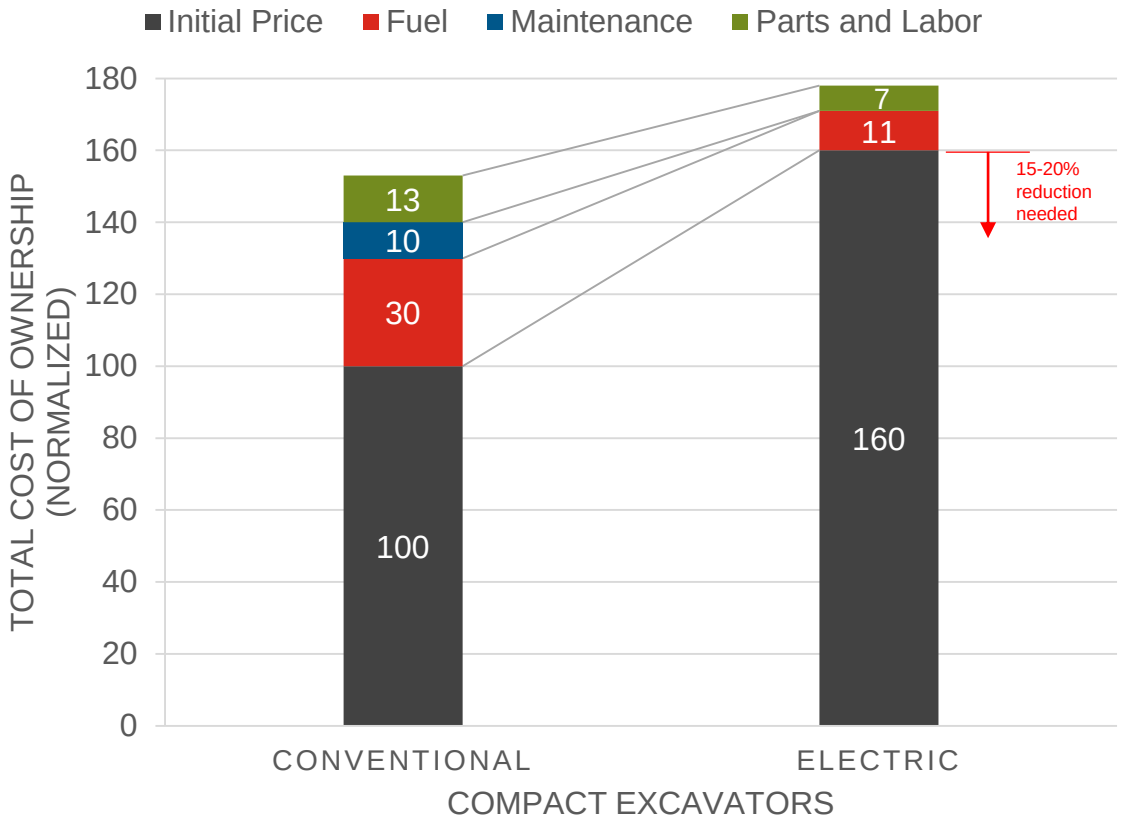
**Representation Only – One Machine Size** : Low, Medium, and High Duty Cycle



# Mini Excavator Electrification – TCO

- Electric compact excavators expected to cost 40-60% higher than conventional today
- Expected to become TCO neutral at 35% premium
- Regulation, Infrastructure, Politics and Commercials all influence adoption.

Conventional Excavator

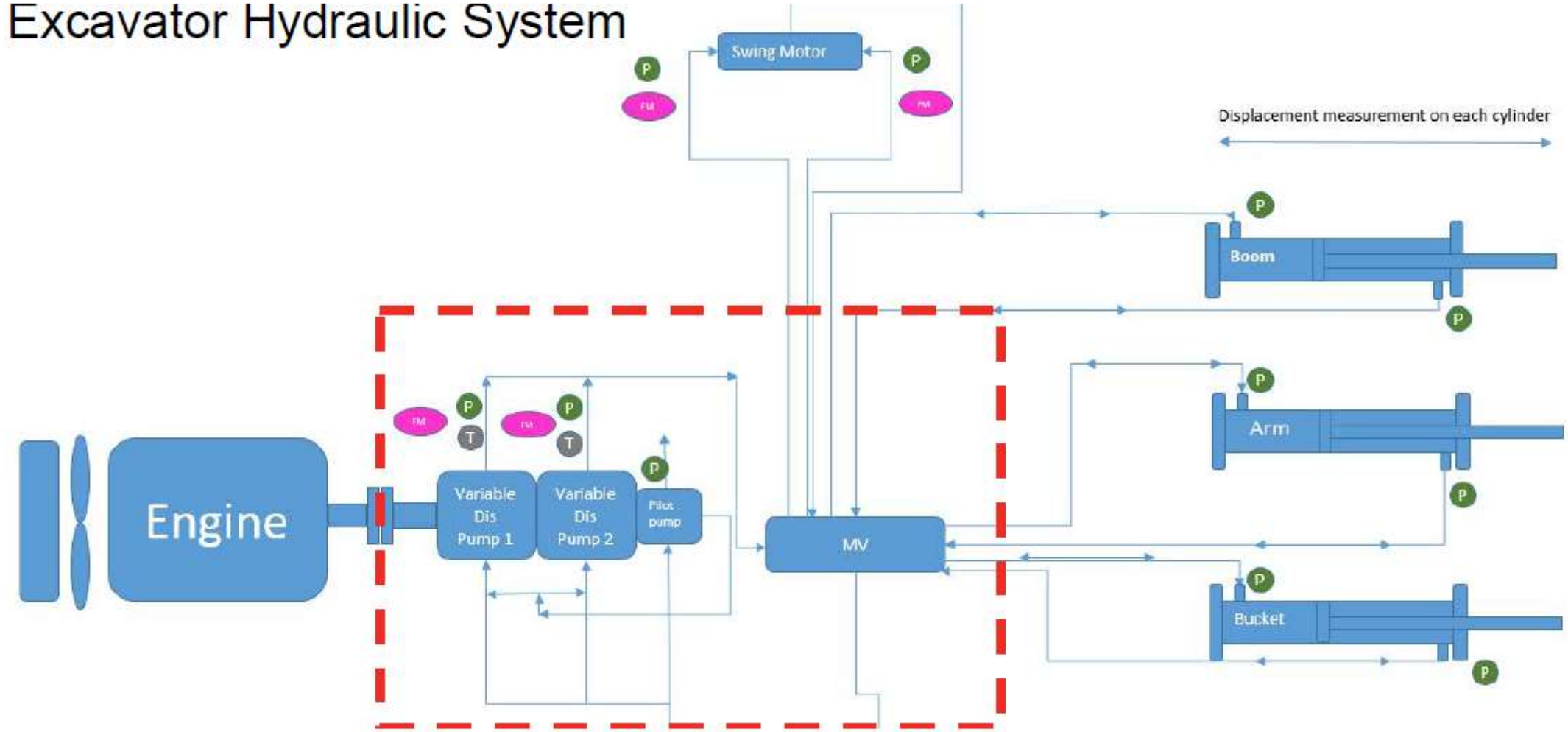



Electric Excavator

Assuming - $4/gal price of diesel, $0.1/kWh cost of electricity in US
5 year life of equipment, 750 hours per year usage

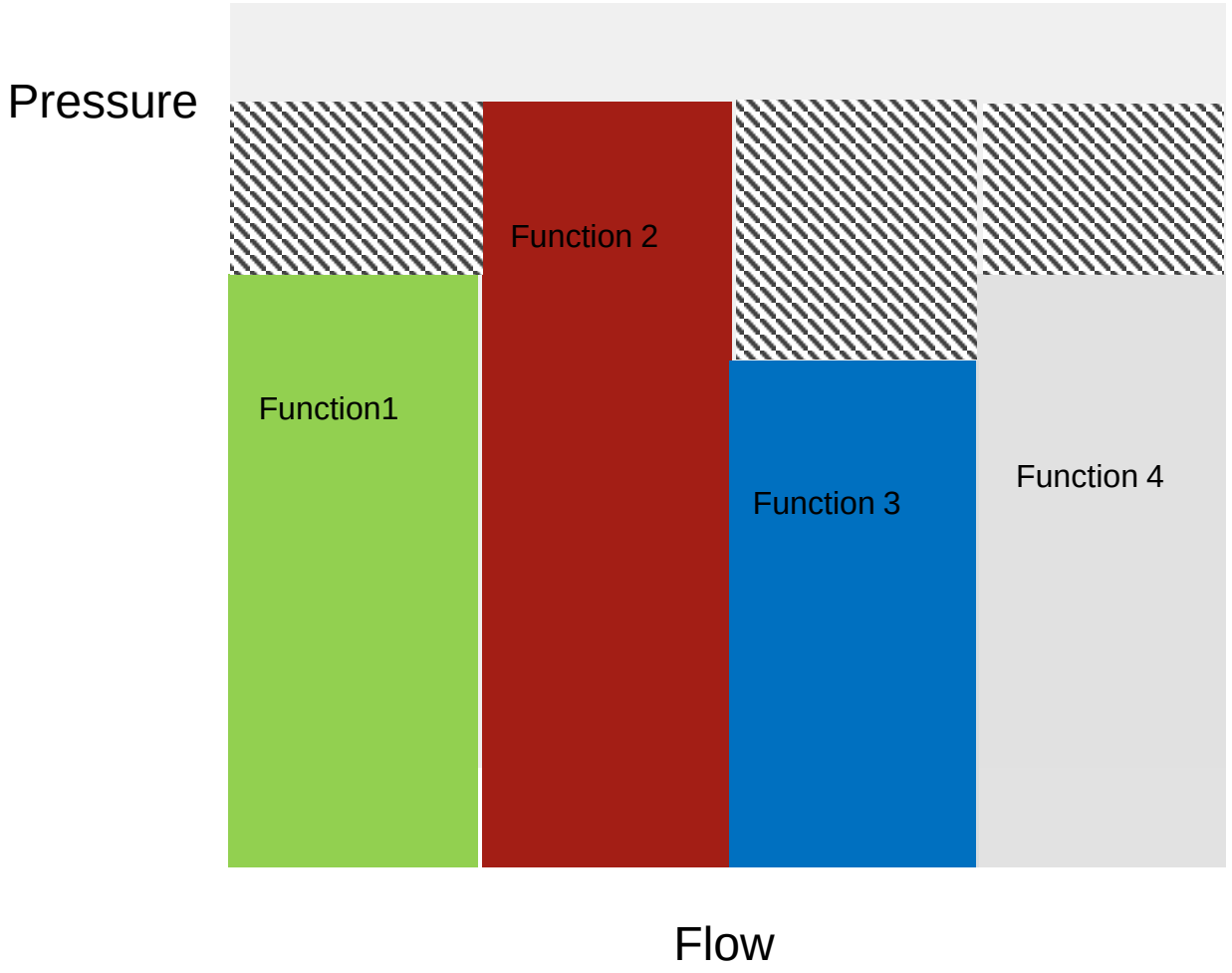
# Excavator Electrification – Hydraulic System

- Typical excavator has 2 variable displacement hydraulic pumps and a pilot pump for control
- The master valve distributes flow to the actuators and there are often considerable losses through throttling



# Excavator Electrification – System Efficiency

- A hydraulic excavator has efficiency losses due to throttling from the main valve
- Whatever function is at the highest load will set the pressure and therefore potentially create losses.



# Excavator Electrification – System Efficiency

- Moving the machine to electric is the time to think about how to improve system efficiency given the importance of extending operation time and using the smallest possible battery.
- There are different architecture options

| Options | Advantages | Disadvantages |
|---|---|---|
| • Separate hydraulic circuit for Boom<br>• Combined hydraulic circuit for arm and bucket<br>• MG for Swing | • Improved efficiency by converting swing to electric<br>• Improved efficiency by having separate boom circuit<br>• Recovery of boom energy | • Higher cost<br>Expect to be lead solution. Cummins active on developing a technical solution now |
| • 3 Separate circuits for boom, arm, and bucket each with pump and MG<br>• MG for Swing | • Improved efficiency by converting swing to electric<br>• Improved efficiency from having separate hydraulic circuits capable of regen<br>• Highest efficiency | • High Cost<br>• Low benefit of energy recovery from arm and bucket |
| • Move to full electric including electric actuators | • High Efficiency | • Electric actuators may not be capable of surviving high cyclic loads of excavator (more study is needed)<br>• High Cost |

# Excavator Electrification – Key Challenges

- Battery Sizing
  - It is more difficult to determine the correct battery size for an Off Highway Application.
  - In some cases due to large variation it may make sense to offer multiple battery sizes for the same application.
  - It's certainly feasible to model an off highway machine like an excavator including the hydraulics but there is no standard operating cycle. This makes it very difficult to predict the battery capacity needed

- Battery Packaging
  - Mini Excavators tend to be zero tail meaning the tail does not extend beyond the tracks. This can make battery packaging extremely challenging.

- Economics
  - Market for small machines is highly cost sensitive
  - Often sold into rental channel skewing the EV economics – rental house has to pay the incremental upfront capital cost, but person renting it realizes the operating cost benefit.
  - Not clear how much premium rental houses will be able to charge – will only find out once there is a large number out in the market

# Excavator Electrification – Summary

- Expectation that mini excavator duty cycle will vary more than larger excavator
- It’s important to work with the OEM to identify duty cycle variation and ideally identify a range of machines from which to collect data.
- Architecture changes to improve system efficiency should be considered when moving to electric excavator.
- Energy recovery should be considered.  For smaller excavators in particular more data is needed to verify recovery opportunity.


Cummins