# OFF-ROAD VEHICLE ELECTRIFICATION ENERGY SAVINGS POTENTIAL

Project ID # VAN043

V. Freyermuth, R. Vijayagopal, A. Rousseau

## OBJECTIVES

- Develop Autonomie modeling capabilities for off-road applications
- Estimate the energy saving potential of electrification for wheel loaders and excavators

## RELEVANCE

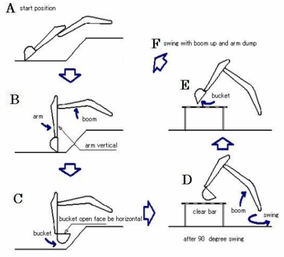
- Off-road vehicles account for 8% of transportation fuel
- As passenger car electrification is happening, the share of off-road vehicles fuel consumption will increase over time
- A 2019 DOE led workshop led to the following recommendations:
  - Develop off-road version of Autonomie
  - A set of pre-competitive simulation tools is desirable to perform assessment of upcoming electrification technologies
  - Identify duty cycles for relevant applications

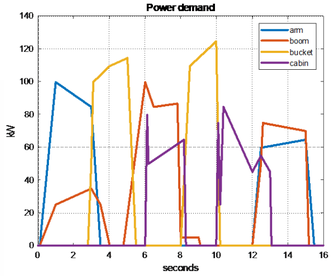
## PROJECT OVERVIEW

| Timeline | Barriers Addressed |
|---|---|
| • Project start date : Jun FY20<br>• Project end date : April FY21<br>• Percent complete: 100% | • Lack of available data<br>• Lack of standards<br>• Complexity of vehicle operations<br>• Very broad weight/capacity range<br>• Diversity of application types |
| **Budget** | **Partners** |
| • FY21 Funding : $150K | Collaborators<br>• University of Helsinki<br>• CCEFP (Center for Compact and Efficient Fluid Power) |

## EXCAVATOR DUTY CYCLE

- A representative duty cycle was identified for the excavator through literature review
- The cycle can be decomposed into 4 independent motions:
- Arm motion, bucket motion, boom motion, cabin motion

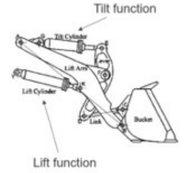



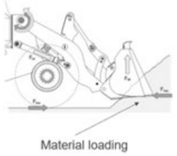



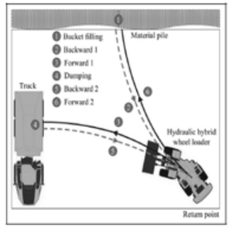

*Ref: Fen Wang, Mohd Azrin Mohd Zulkefli, Zongxuan Sun, Kim Nelson, "Energy management strategy for a power-split hydraulic hybrid wheel loader", Journal of Automobile Engineering 2016, Vol. 230, p1105-1120.*

## WHEEL LOADER DUTY CYCLE

- The V-cycle describes the repetitive back and forth vehicle motion carried out as the vehicle loads material in the bucket and dumps it in a truck
- The loading of the bucket, akin to a vehicle running into an obstacle, remains a modeling challenge involving hydraulic power, vehicle motion and tire slip.



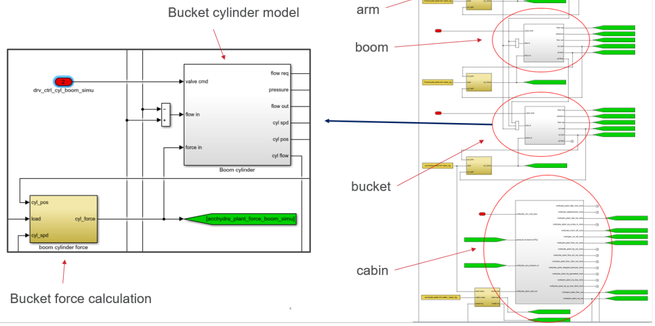




## ACCOMPLISHMENTS: DEVELOPED AND IMPLEMENTED OFF-ROAD VEHICLE MODELS IN AUTONOMIE

AUTONOMIE

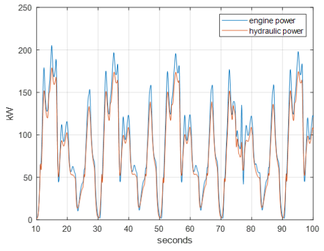
### New Hydraulic Component Models

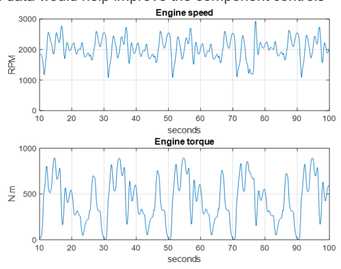
- Each vehicle work function is modeled independently
- A centralized hydraulic system provides power to each work function
- Hydraulic pump, valve, cylinder and motor models were added




### New Controllers

- Engine power closely follows the hydraulic power.
- The current engine control in Autonomie shows relatively high engine speed fluctuations, which could be higher than what is actually seen in a physical excavator
- Working with OEMs and accessing additional data would help improve the component controls



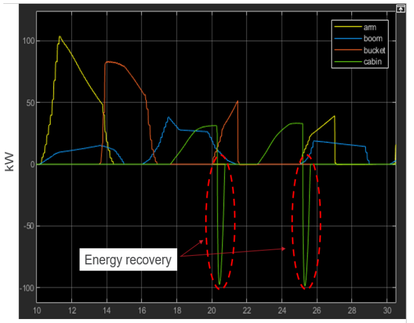

### Vehicle Models Integrated

- New powertrain configurations and models implemented
- New duty cycle process developed
- New post-processing
- Developed electrified powertrain models reusing existing components (e.g., battery)

## ACCOMPLISHMENTS: QUANTIFIED EXCAVATOR AND WHEEL LOADER ELECTRIFICATION BENEFITS

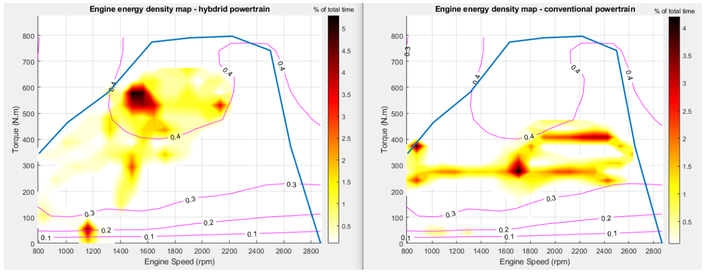
### Excavator

The excavator was hybridized by electrifying the cabin rotation. The hydraulic system used for the cabin in the conventional system was replaced by an electric machine and li-ion battery. When the cabin slows down, regenerative energy is captured through the electric machine and stored in the battery.
In the duty cycle considered, a 5% fuel saving is achieved.




### Wheel-loader

In the hybrid wheel loader, the transmission torque converter is replaced by an electric machine geared to the transmission input, a clutch to mechanically connect the engine to the gearbox, and a high voltage li-ion battery. The combination of reduction in torque converter losses, the capture of regenerative energy as well as the change in engine operations provide a 15% reduction in fuel consumption over the duty cycle.




## SUMMARY & PROPOSED FUTURE RESEARCH

- Hydraulic models were developed and integrated into Autonomie to enable off-road vehicle modeling.
- Component models include hydraulic pump, valve, actuator and cylinder.
- A conventional and a hybrid version of a wheel loader and an excavator were developed.
- For the duty cycles considered, electrification is expected to reduce fuel consumption by 5-15%.
- The project was presented at the CCEFP (Center for Compact and Efficient Fluid Power) 2020 Summit. Feedback was positive and the benefit of a public tool to quantify the benefits of electrification was highlighted.
- Given the lack of publicly available data and the lack of standards in the off-road vehicle market, engagement with the industry is required to validate the models and increase the level of fidelity.
- The off-road vehicle models will be included in future Autonomie releases.

Argonne NATIONAL LABORATORY