Electrification of a 40-ton electric mining vehicle

from vision to demonstration

Institut du véhicule innovant
Innovative Vehicle Institute

National Research Council Canada
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Institut du véhicule innovant

Innovative Vehicle Institute

Driver of innovation

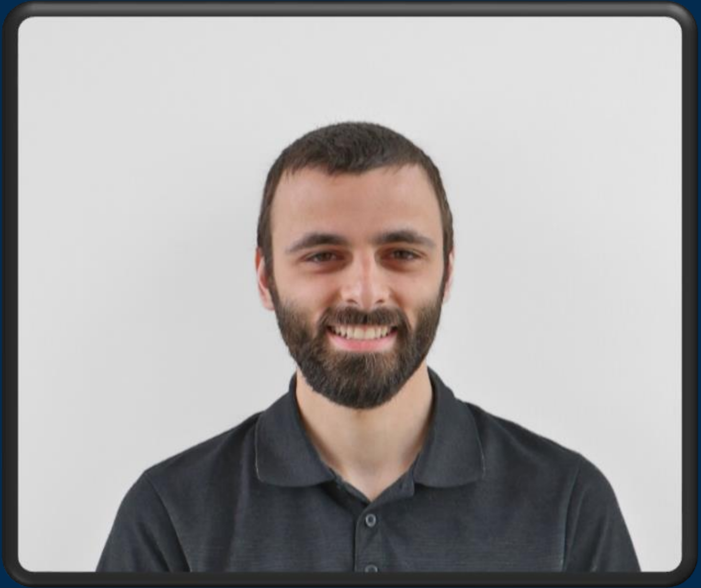
The Innovative Vehicle Institute (IVI) is a Quebec-based center for innovation and applied research, affiliated with Cégep de Saint-Jérôme, and operates as a non-profit organization.

Our team assists companies and organizations in the **design and integration of innovative technologies** applied to vehicles and supports them in the **implementation** of their technology in real-life conditions.

ELECTRIC VEHICLES

AUTONOMOUS VEHICLES

CONNECTED VEHICLES



Patrick Robitaille, P.Eng.

Electrical engineer - 8 years' experience in electric vehicle innovation

NRC·CNRC

National Research Council

We are the government of Canada’s research and development organization with over 100 years of experience.

National network of researchers and facilities performing research and technical services with partners

2,151
SCIENTISTS, ENGINEERS, TECHNICIANS, AND OTHER SPECIALISTS

179
BUILDINGS MANAGED

$1.1B
ANNUAL EXPENDITURE

1,577
R&D COLLABORATIONS AND HELPED 8,000 SMEs

Guillaume Imbleau Chagnon, P.Eng.
Program Leader, Clean and Energy Efficient Transportation

Project context

Mission:

- Development and integration of an electric propulsion system with a rapid charging infrastructure adapted to heavy vehicles in open-pit mining;
- Test the prototype in real world conditions to evaluate its suitability for open-pit mining operations.

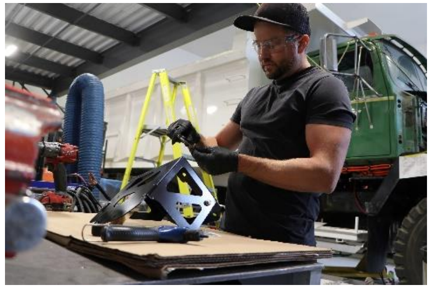
40-ton Western Star 6900XD

Project timeline

- **March 2020** — Project kickoff

- **September 2021** — Truck design completion

- **January 2023** — Prototype fully assembled



- **April 2023** — Completion of truck functional testing

- **August 2023** — Completion of vehicle performance testing in controlled conditions

- **March 2024** — Completion of vehicle testing in real conditions at the quarry

Project stakeholders

ADRIA POWER SYSTEMS ®

Charger system

DANA TM4

Electric motor

Vehicle operator

Fournier

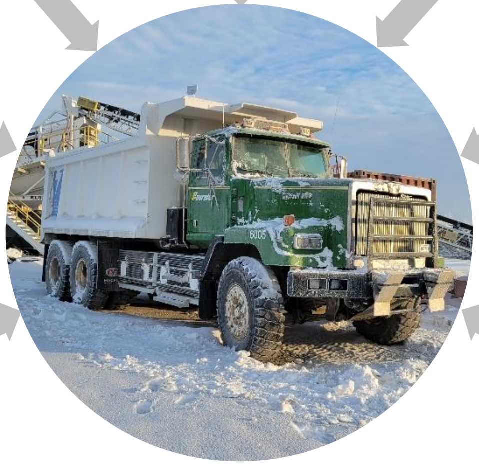
National Research Council Canada
Conseil national de recherches Canada

Modeling, simulation & testing

Site operator

NMG NOUVEAU MONDE GRAPHITE

Uniroc FAIRE ROUTE COMMUNE



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Design, integration & testing

Government funding

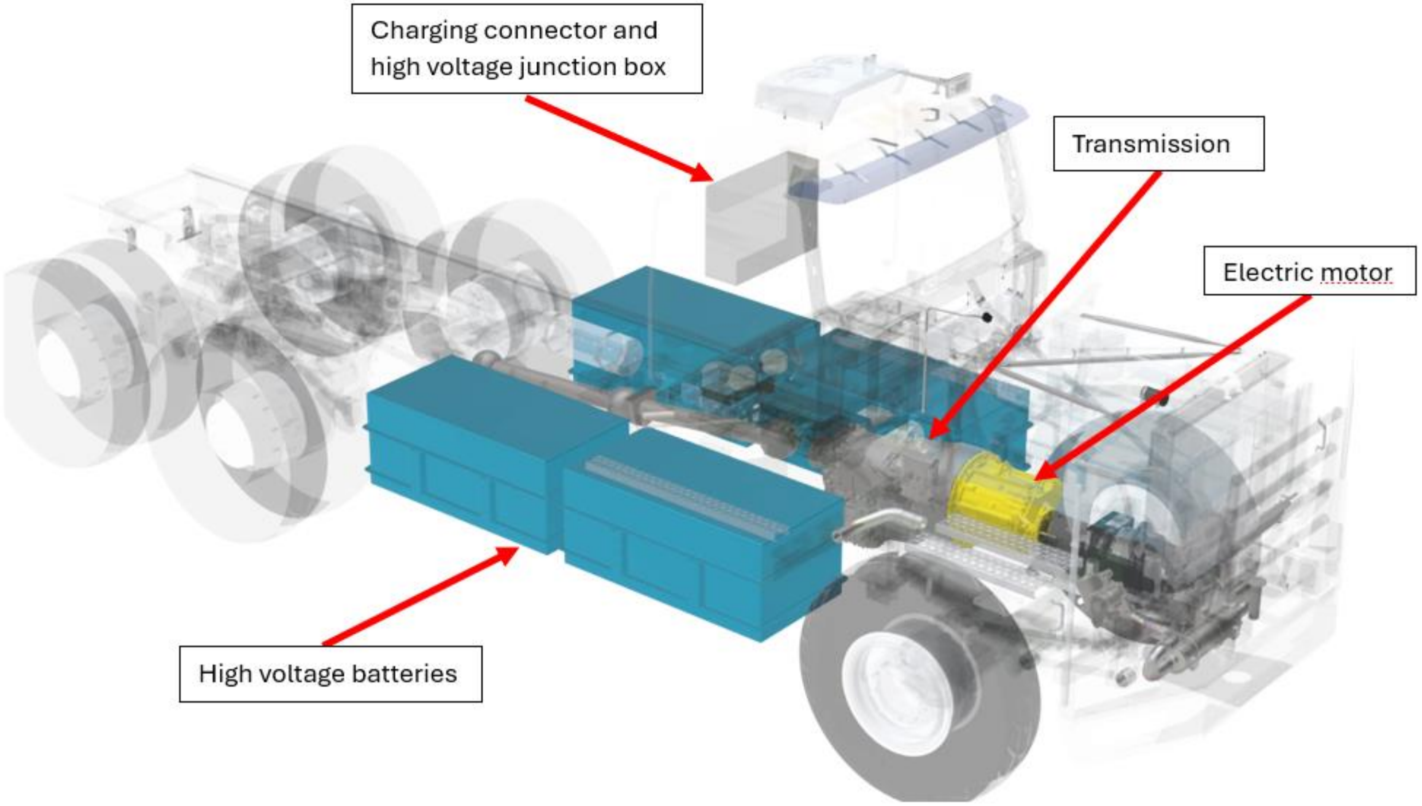
Natural Resources Canada
Ressources naturelles Canada

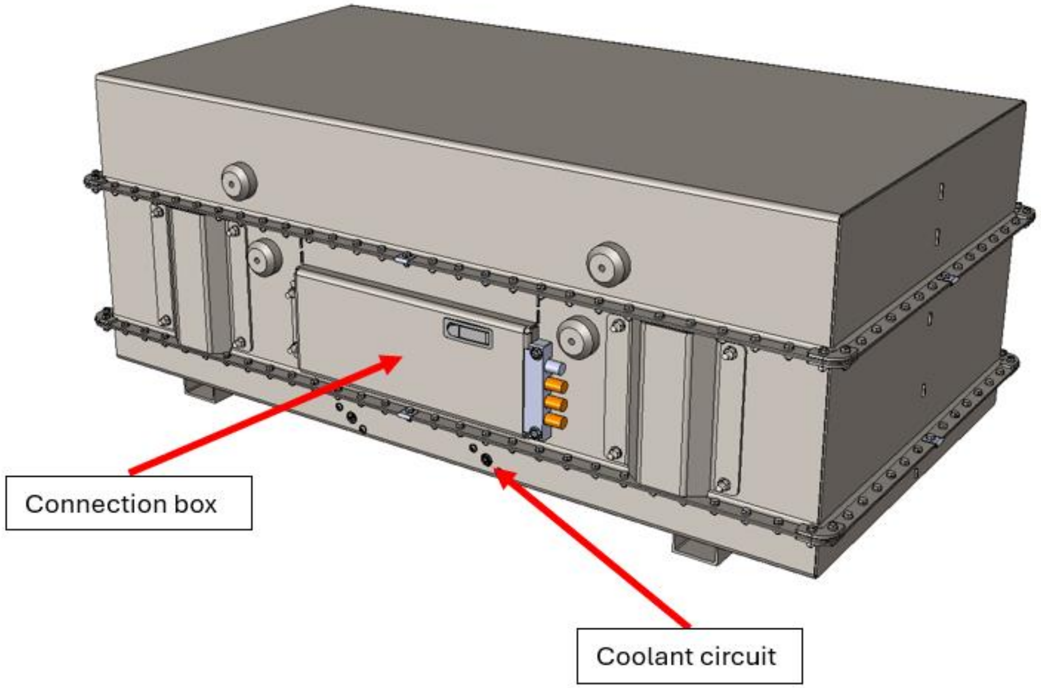
Économie Innovation et Énergie Québec

propulsion Québec

INNOV-R

Truck introduction





Preliminary drawing of the mining truck

Preliminary drawing of high voltage battery

Truck introduction

Vehicle :

- Vehicle weight : 30 920 kg
- Payload capacity : 29 801 kg
- Electric motor : 360 kW, 2050 Nm
- Original Allison 4500 RDS transmission
- Top speed : 70 km/h

Battery :

- 5x batteries at 82 kWh each
- Total capacity: 411 kWh
- Chemistry : NMC, pouch cell

Charging :

- Onboard AC Charger of 18 kW
- Compatible with CCS charger up to 475 kW

Test sequence

- Three-day test was completed at the Uniroc quarry site
- The goal was to cover two different seasons for comparison: fall and winter
- The three routes were different to reflect actual site operations

Result	Day 1 (November 17 2023)	Day 2 (December 7 2023)	Day 3 (March 1 2024)
Total round trip distance (km)	3.6	1.4	1.2
Maximum elevation (m)	58	30.4	85
Maximum incline (deg)	10.12	9.46	11.28
Outdoor temperature (°C)	10	-15	-11
Load (ton)	30	30	30

Day 1

Day 2

Day 3

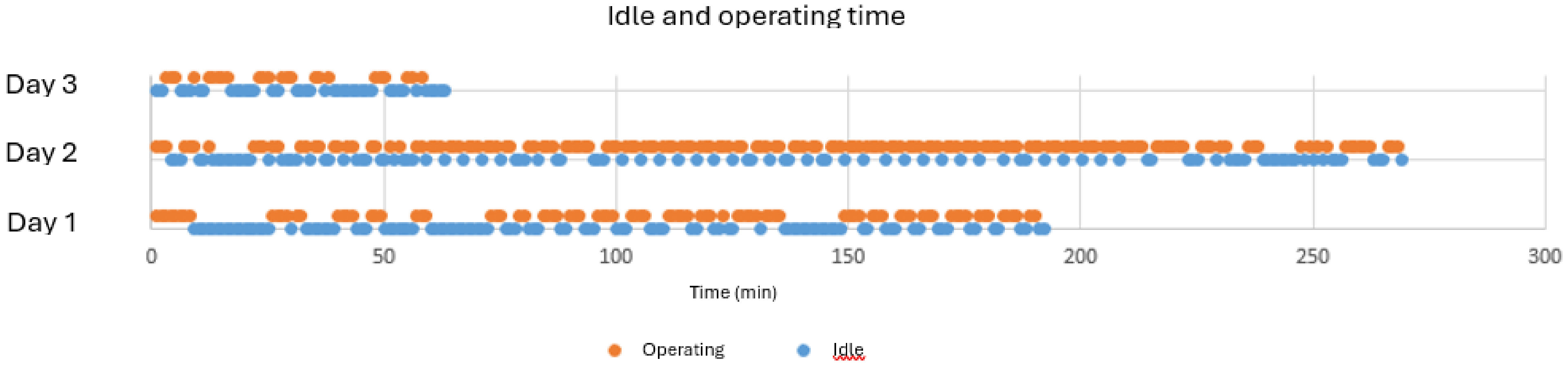
Result – Vehicle Performance

- The truck's anticipated autonomy (100% DoD) varies by season:
  - Summer : ≈ 9.75 h
  - Winter : ≈ 7.83h

- We are experiencing a notable loss of autonomy during winter months, with a decrease of around 19.7% compared to summer operations.

- Idle periods play a vital role in the overall performance of the truck.

Performance	Day 1 (November 17)	Day 2 (December 7)	Day 3 (March 1)
Estimated runtime with full battery usage (Hour)	9.75	7.03	8.62
Power consumption (kWh/km)	4.51	7.09	9.99
Ton moved per hour (T/h)	84.44	173.91	83.14
Idle period (%)	54.2	40.2	63.4

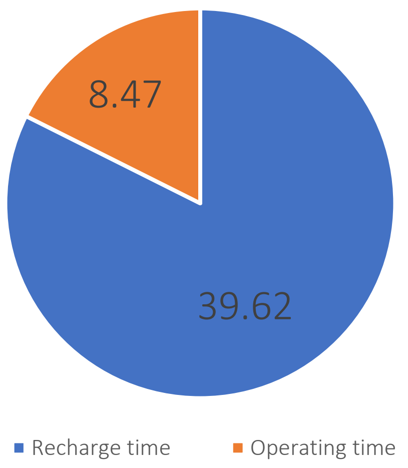


Result – Charging time

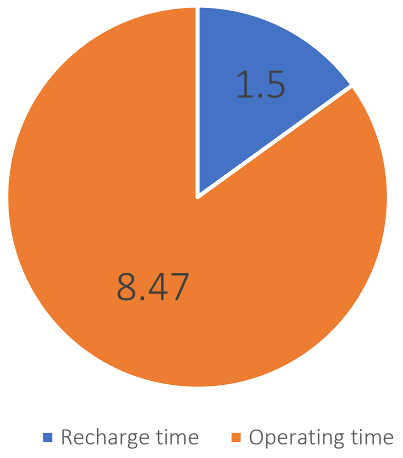
- The charger used at the quarry site was a Level 2 charger with a capacity of 19.2 kW
- The power of the charging station has a significant impact on vehicle downtime.
- With the current charging infrastructure used during the test, the vehicle was unable to operate daily.
- A 1-megawatt charger is excessive for the truck's usage in a quarry.
- >50 kW recommended for one 8 hours shift with 15 hours overnight recharge

Charging station	Level 2 charger (19.2 KW) (At winter temperature)	Level 3 charger 24 KW (At summer temperature)	Adria charger 1 MW **(Estimated)**
Charging time (h) (0-100 %SoC)	39.62	23.1	1-1,5

Usage cycle with a 19.2 kW charger



Usage cycle with a 1 MW charger

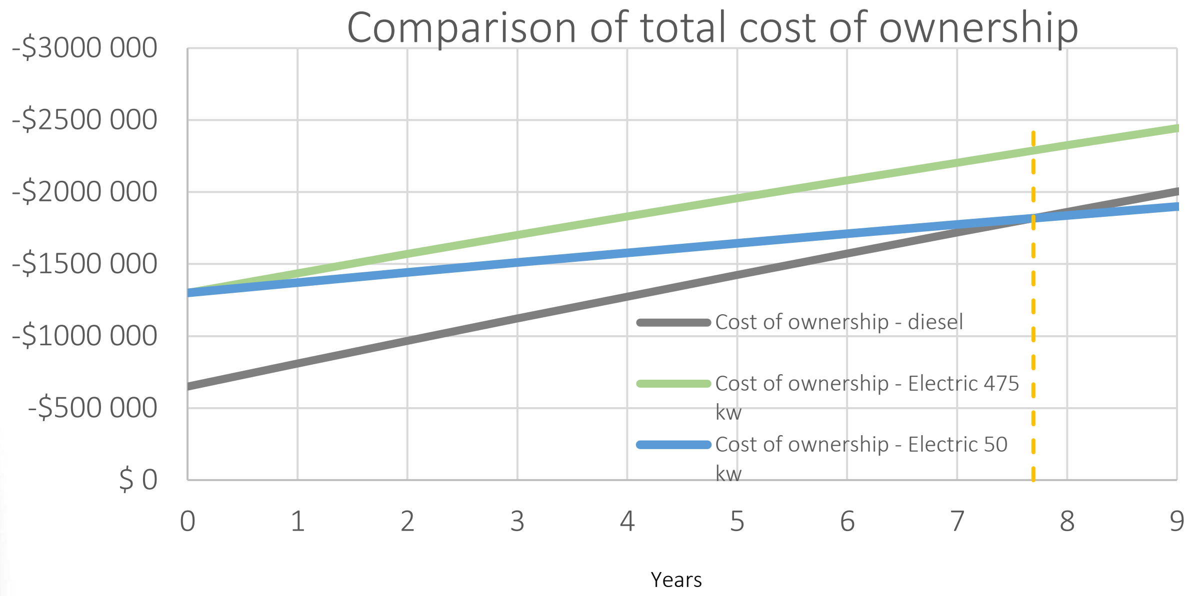


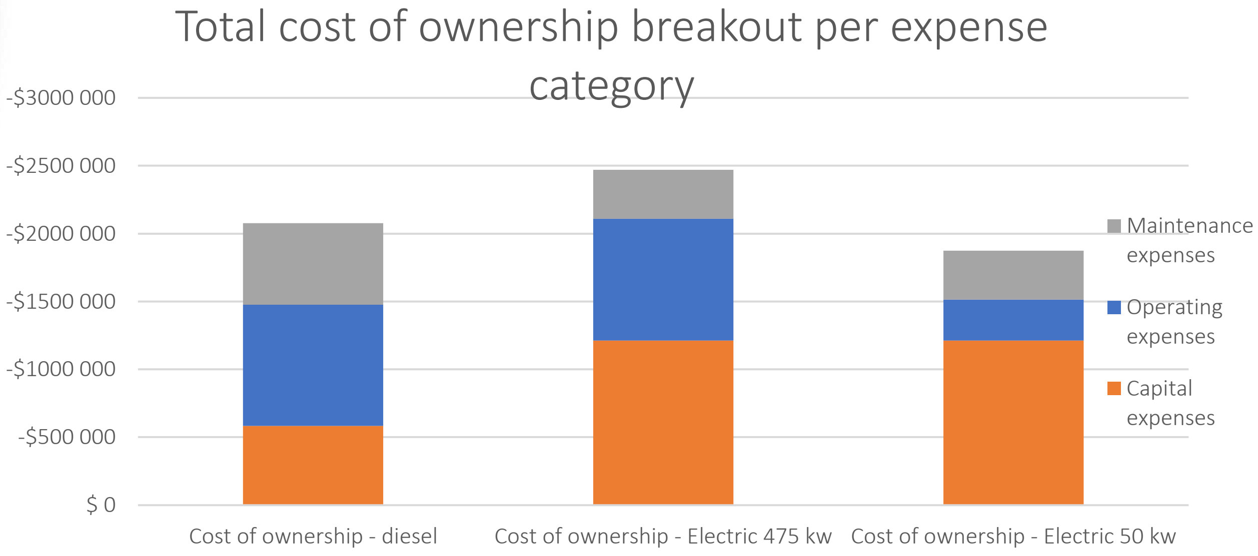
Result – Economic analysis

10-Year Cost Estimation

After a decade of operation, our estimate indicates:

- Diesel:
  - ≈ $2,076,854
- Electric truck with a 475 kw charger
  - ≈ 2 471 329 $ which is +18.99 % higher than the diesel truck
- Electric truck with a 50 kw charger
  - ≈ 1 874 422 $ which is -9.75 % lower than the diesel truck
  - The cost equivalence point is reached after approximately 7.7 years of operation.





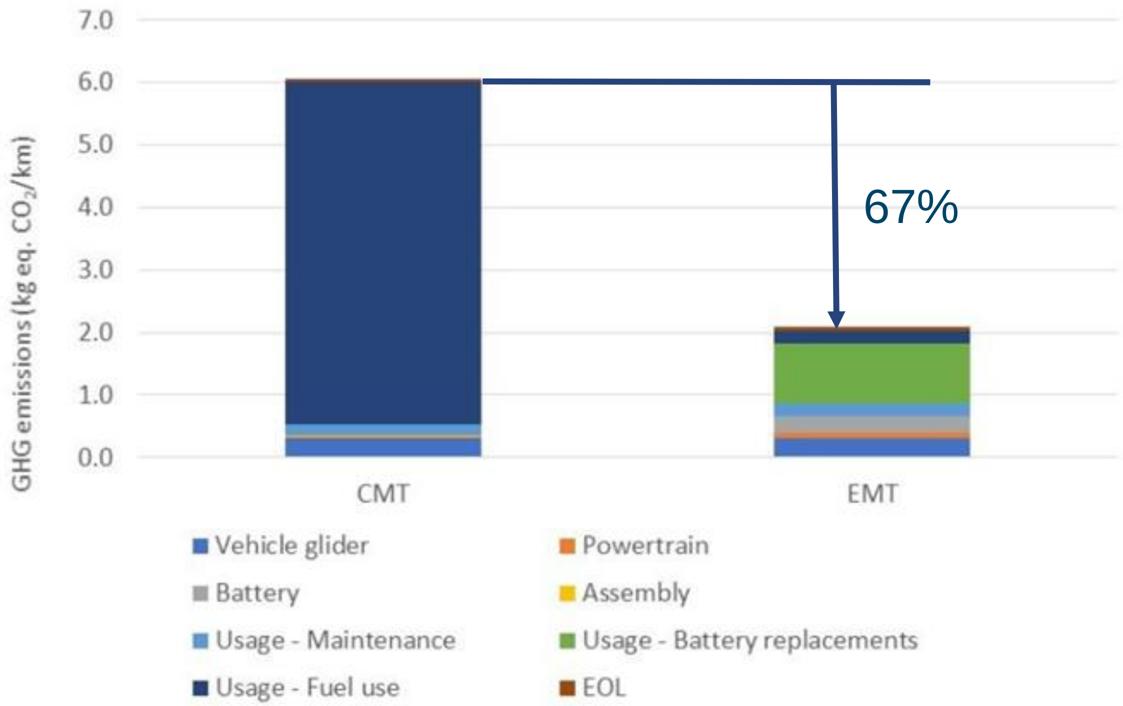
Results – GHG emissions

67% reduction of overall lifecyle GHGs for operations **in provinces with clean electricity grid**

High influence of electricity grid emissions

Electric mining truck has higher manufacturing emissions

GHG reduction
~105 up to 215 tons per year

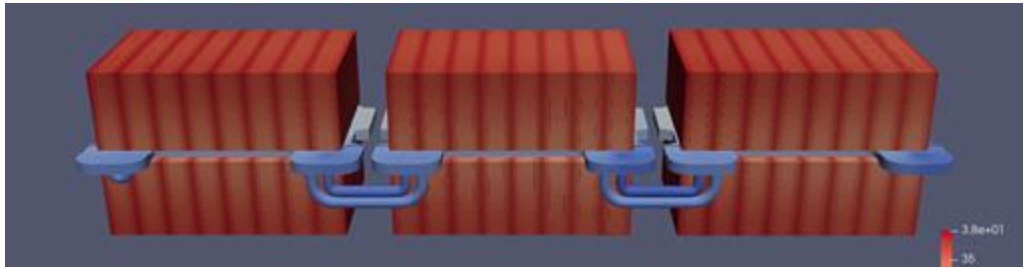


Lifecycle GHG emissions of Conventional (CMT) and Electrical (EMT) mining truck when operated in Quebec

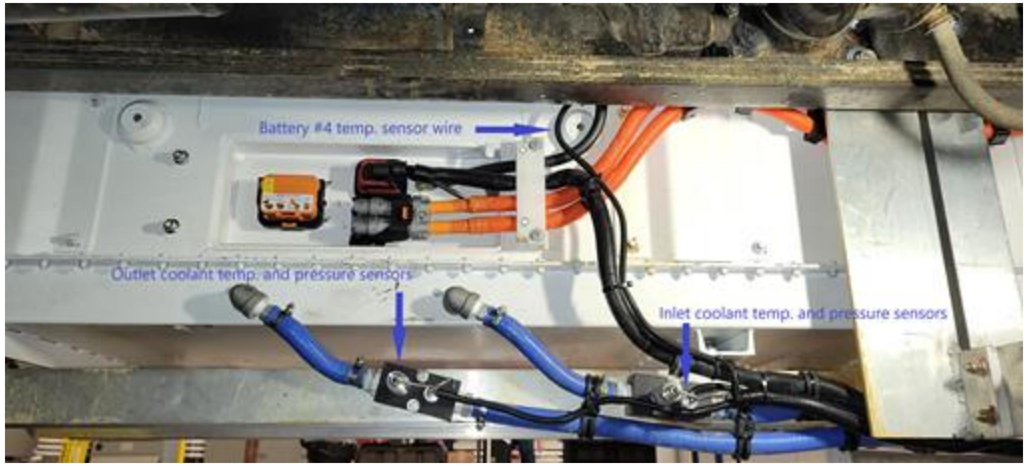
Numerical tools for prototype design

Thermal models

- Experiment validated cell electrochemical-thermal model
- Integration of drive cycles demands
- Module thermal distribution with cooling strategy
- Vehicle instrumentation for thermal evaluation



Modules and cooling plate model



Battery pack instrumentation for thermal evaluation

Numerical tools for prototype design

Vehicle energy model

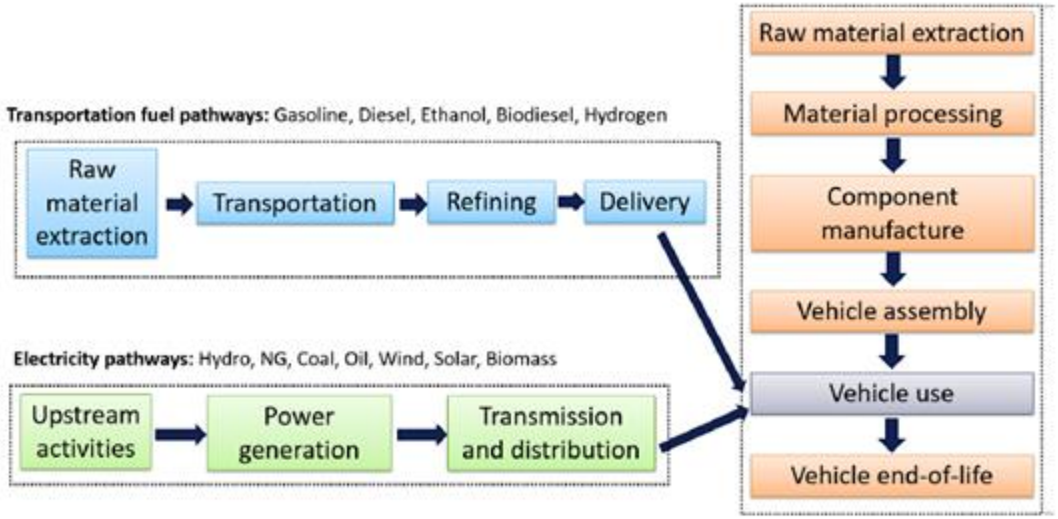
– Assess energy demands from specific mining operations

Life Cycle Analysis (LCA) model

– Estimate GHG emissions from manufacturing, operations and end of life activities

Drivetrain | Vehicle Dynamics | Driver | Regen Braking

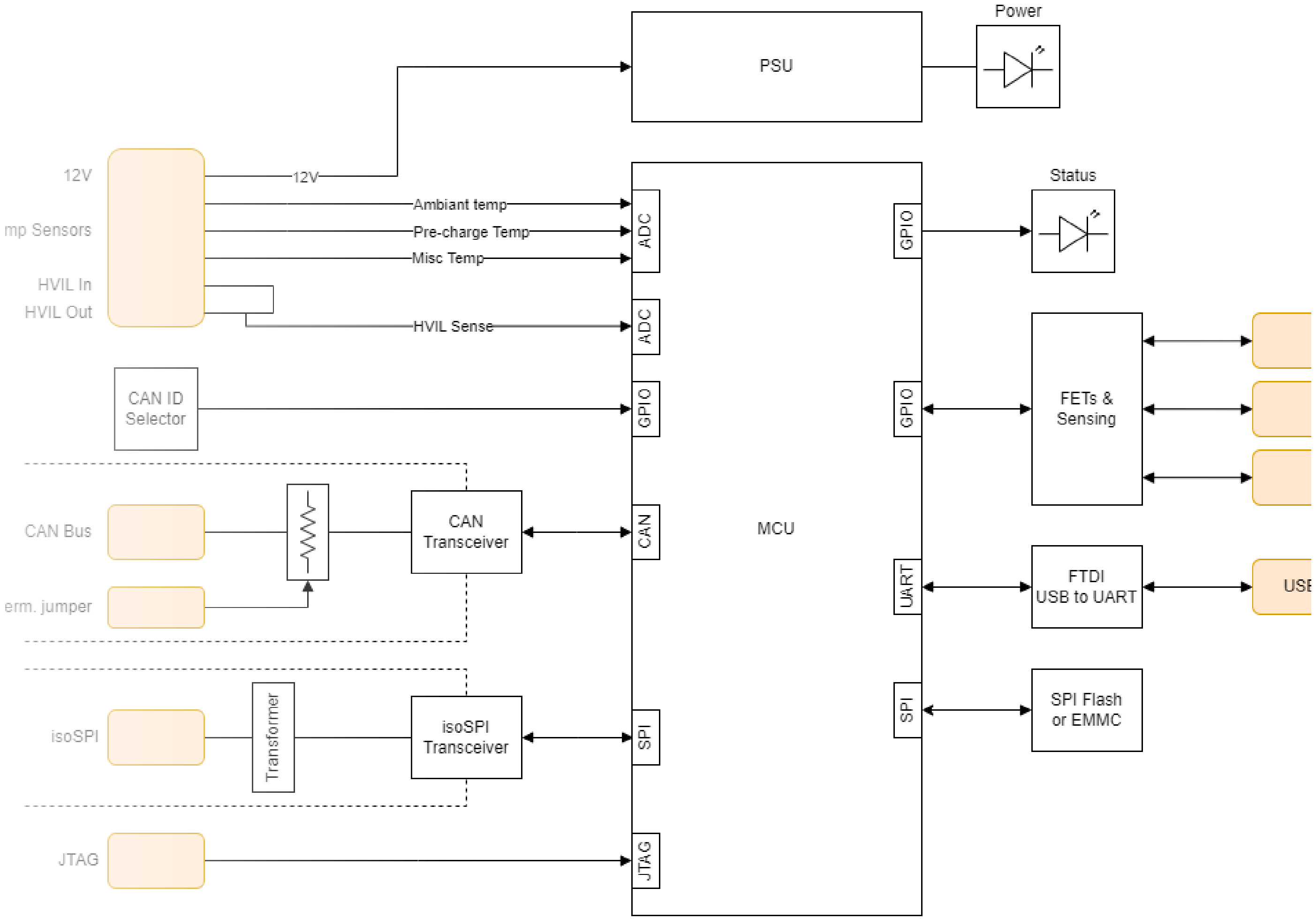
Main vehicle models for energy demand in operations



Boundary and key components for vehicle GHG assessment

New knowledge developed within the project

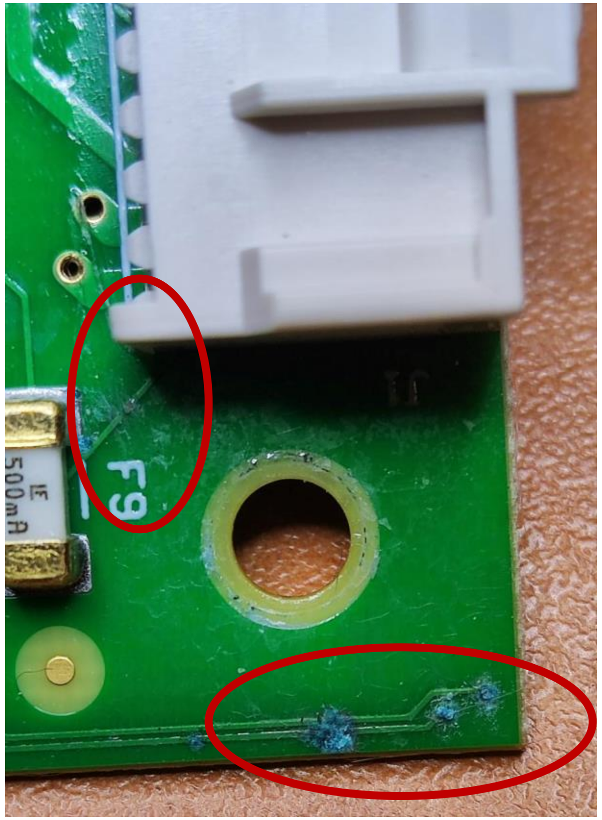
- Understanding and integration of heavy-duty batteries
- BMS architecture
- Reverse engineering
- Transmission operation with an electric motor
- Reality of mining and quarries
- Big data acquisition system



BMS architecture schematic

Lessons learned – project specific

- **Electrical utilities:** mining/quarry sites often fall short of the requirements for charging station operations.
- **Component failure:** experienced significant issues with rust on electronic boards within batteries.
- **Standard operations:** vehicle idling ~50% of operating window.



Rust on electronic boards

Lessons learned – recommendations

- **Standard operations:** utilizing idle times during operations for opportunistic charging could significantly increase autonomy and next-shift readiness
- **Optimal charging power:** clear understanding of operations to determine energy requirements -> minimize overall expenses (CAPEX, OPEX).
- **Demanding operations:** robust weatherproofing to avoid premature degradation of electronic components.

Average recoverable theoretical energy and range with opportunistic charging using idle time

Charging station power	Recovered energy (kWh)	Additional runtime (hours)
50 kW	48.7	0.99
1 MW	974	19.75

Conclusion

This project demonstrated how **heavy duty electric vehicles could meet operational and environmental objectives in open pit mining**.

Importance in **planning a charging solution using site specific operational requirements**

- Not a one size fits all and requires significant investment

Technology constantly improving: **Medium and Heavy Duty sector is the next electrification challenge**

Project partners

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Uniroc
FAIRE ROUTE COMMUNE

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