Comparison of Diesel Emissions from a Conventional LHD and a Proposed Hybrid Version

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Presentation Outline

- Objectives
- History
- Proposed hybrid system
- Results of bench emissions testing

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Objectives

- **To reduce the pollutants from production diesel equipment at an acceptable cost.**
- **Development of a hybrid power pack that is compatible with equipment in the underground mine.**
- **To be proactive in the reduction of diesel emissions related to the underground mine regulations.**
- **To improve the mechanization and mining efficiency of deposits.**

History

- **Pre-feasibility study (2000)**
  - **Preliminary concept, hybrid performance simulations**
- **Discussions with partners (2001)**
  - **Mining industry very interested in concept**
  - **Laboratory assessment required to validate the concept (emissions)**
- **Contracted CANMET-MMSL-, through funding from IRRST to conduct laboratory assessment of comparative emission levels**

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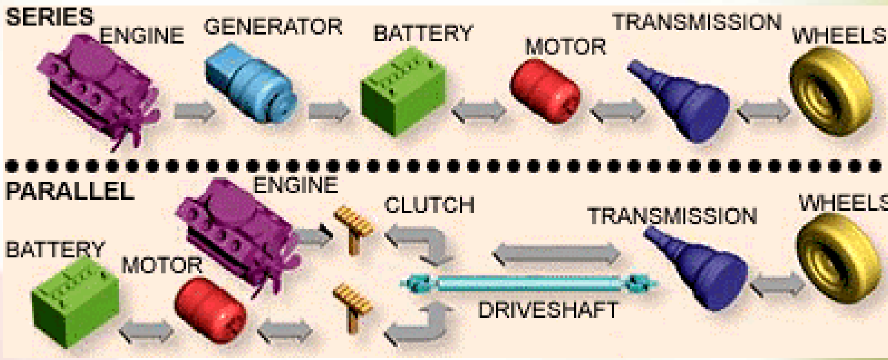
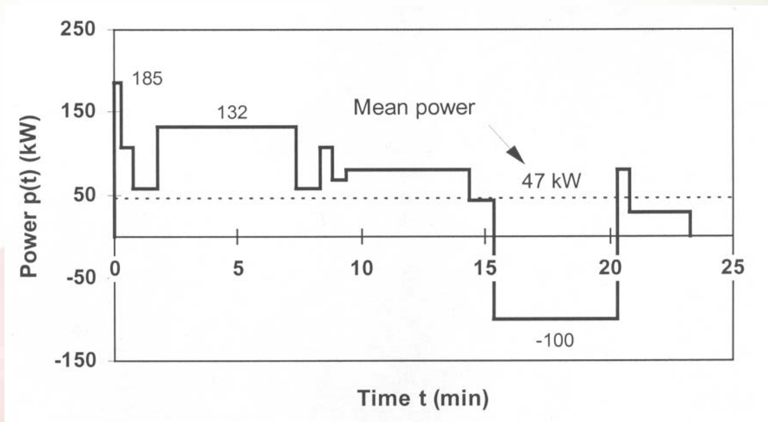
Principal Types of Hybrid Systems



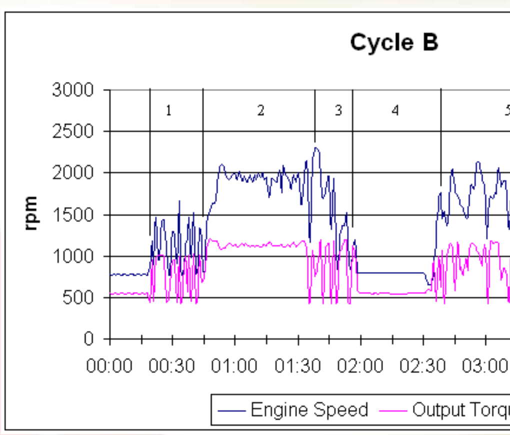
Hybrid System Advantages

- **The motor of the proposed hybrid system is twice as small (54 HP vs 31 HP).**
- **Hybrid: Operation is continuous and intermittent vs Conventional: transient operation throughout the shift.**
- **Less heat being generated.**
- **Less gases and solids being released to the environment.**
- **Hybrid application is very friendly to the implementation of a diesel particulate filter (DPF).**

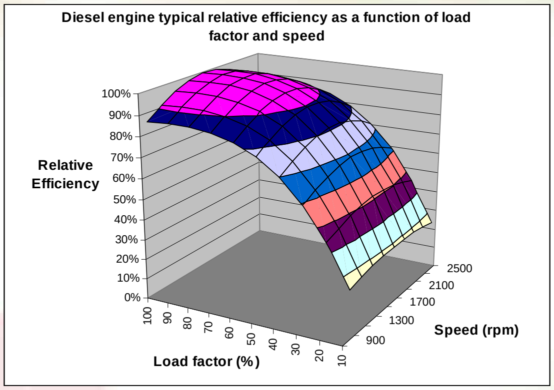
Energy Needs – Hybrid versus Conventional



Transient Operation



Diesel Motor



- Diesel engine efficiency is less at reduced loads
- Diesel emissions are reduced on a HP basis when the diesel engine is run at its most efficient load and speed.

Running a small engine at peak efficiencies will reduce emissions

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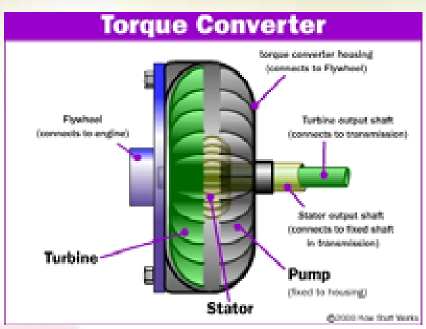
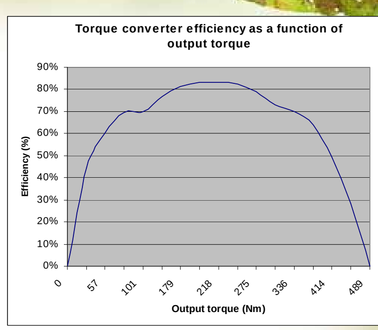
Torque Converter





The torque converter is another source of inefficiency. The hybrid system provides a direct coupling between the electric motor and the transmission.

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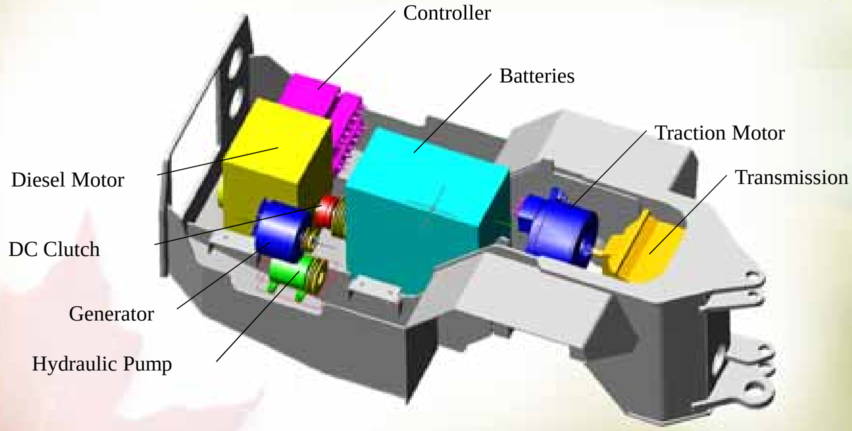
Important Components-
Hybrid Power Pack



Evaluation of the Original
Hybrid Concept

- **Evaluation of the duty cycles and work loads from a conventional scooptram (1.5 yd^3).**
- **Reproduction of transient duty cycles with the AC dynamometer.**
- **Evaluation of emissions (54HP Conventional vs 31HP Hybrid).**
- **Application and evaluation of the DPF to reduce emissions.**

LHD Duty Cycle Development

- Acquire engine speed and load data from Load, Haul, Dump duty cycle from a conventional scooptram operating underground
- To study the effects of the transient nature of the LHD duty cycle on emissions
- Utilization of duty cycles collected from the Deep Light-Duty Vehicles project conducted at Kidd Creek Mine, Timmins

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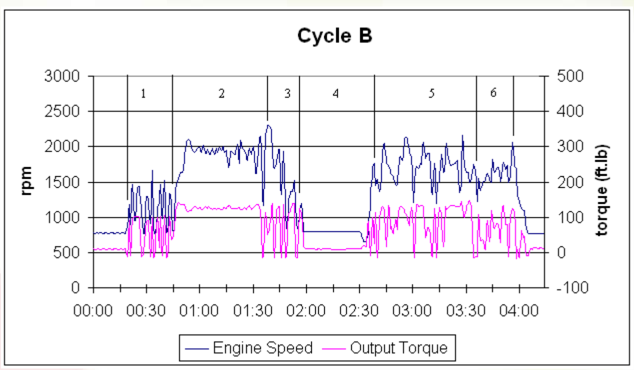
LHD Duty Cycle B



1	Loading
2	Haul loaded
3	Dumping
4	Idle
5	Return Empty
6	Reposition scooptram

Average Power : 16.3 HP

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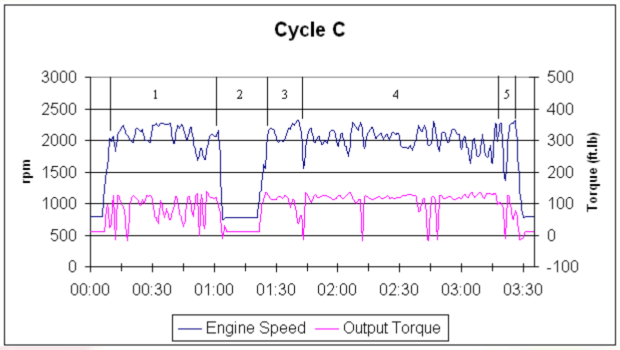
LHD Duty Cycle C



1	Return empty
2	Idle
3	Loading
4	Haul loaded
5	Dumping

Average Power: 27.7 HP

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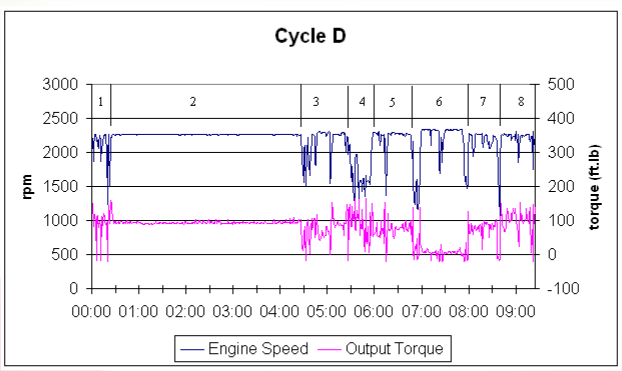
LHD Duty Cycle D



1	Tram to ramp
2	Haul up ramp loaded
3	Tram to dump point
4	Dumping
5	Tram back to ramp
6	Down ramp
7	Tram to draw point
8	Loading

Average Power : 29.4 HP

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Exhaust Air Quality Index (EQI)

- **The EQI expression is used to determine the ventilation rate for diesel engine certification.**
- **EQI is the ventilation quantity required to dilute diesel pollutants to safe ambient concentrations.**
- **EQI:**

$$EQI = \frac{CO}{50} + \frac{NO}{25} + \frac{RCD}{2} + 1.5 \times \left\{ \frac{SO_2}{3} + \frac{RCD}{2} \right\} + 1.2 \times \left\{ \frac{NO_2}{3} + \frac{RCD}{2} \right\}$$

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Test Parameters

- **The emissions produced by the conventional transient cycles were measured, averaged and the EQI expression was used to determine the EQI based ventilation for each cycle**
- **The emissions produced by the hybrid engine cycle was measured with and without the DPF and the EQI based ventilation rate was calculated for each set-point**
- **Additional hybrid engine cycles were measured and EQI based ventilation rates calculated for each set-point to address other operating points**

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F4L912W and Cattrap Set-up in CANMET-MMSL Diesel Test Cell

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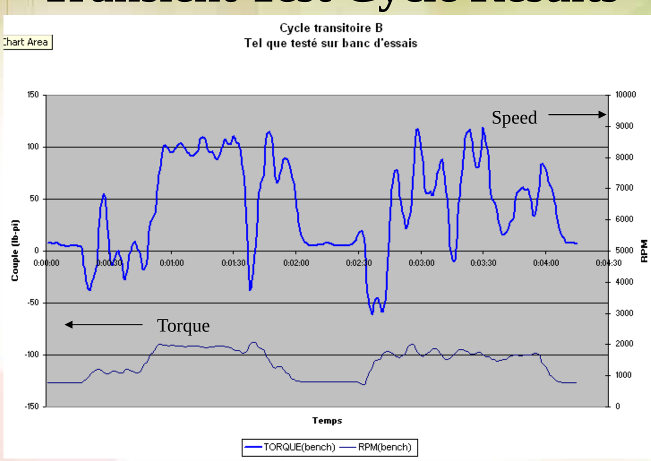
Transient Test Cycle Results



For this cycle the hybrid system diesel engine would be operating 43% of the time

Reduction in ventilation: 73%

Average Power : 14.1 H.P.

EQI based ventilation rate for above cycle :	**1900 CFM**
EQI based ventilation rate for small engine (DPF) :	**1700 CFM (1200 CFM)**

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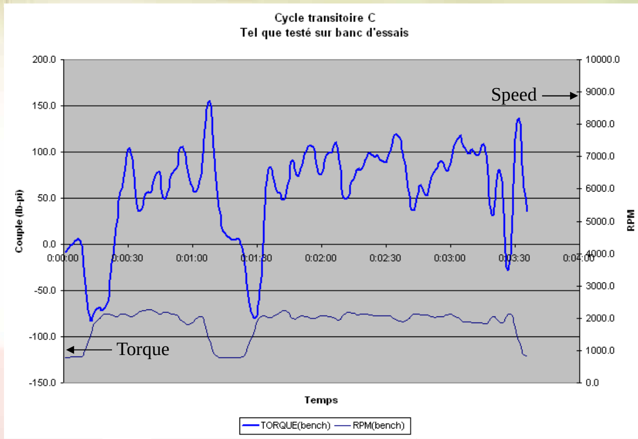
Transient Test Cycle Results



For this cycle the hybrid system diesel engine would be operating 80%of the time

Reduction in ventilation: 67%

Average Power : 19.8 H.P.

EQI based ventilation rate for above cycle : 2900 CFM

EQI based ventilation rate for small engine (DPF) : 1700 CFM (1200 CFM)

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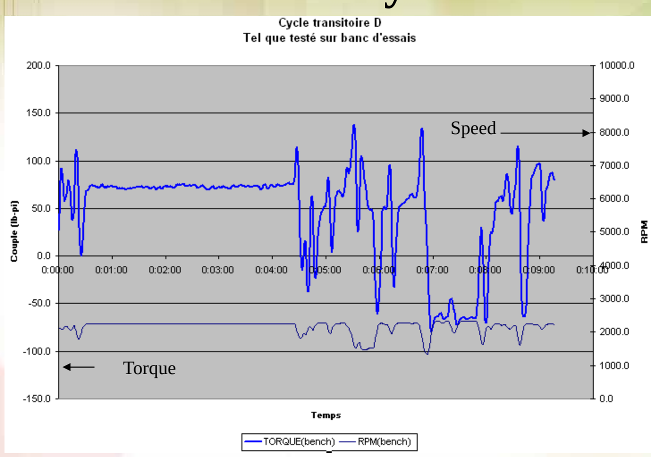
Transient Test Cycle Results



For this cycle the hybrid system diesel engine would be operating 63%of the time

Reduction in ventilation: 75%

Average Power: 30.2 H.P.

EQI based ventilation rate for above cycle : 3000 CFM

EQI based ventilation rate for small engine (DPF) : 1700 CFM (1200 CFM)

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Application of the CATTRAP ™

- The application of CATTRAP™ requires regeneration temperatures ranging between 380°C and 420°C for at least 25% of the duty cycle.
- The exhaust temperatures did not exceed 315°C for transient test cycles B, C, D for the conventional design - 54HP engine.
- This filter trap is not suitable for transient test cycles B, C, D.
- The operation of the hybrid engine (F2L2011)produces exhaust temperatures that allow for the application of the DPF.

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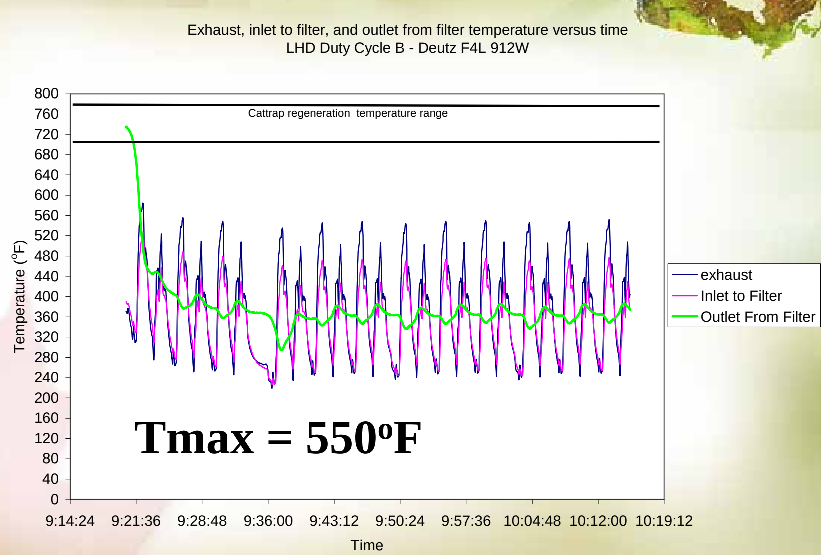
Temperature Profile Cycle B



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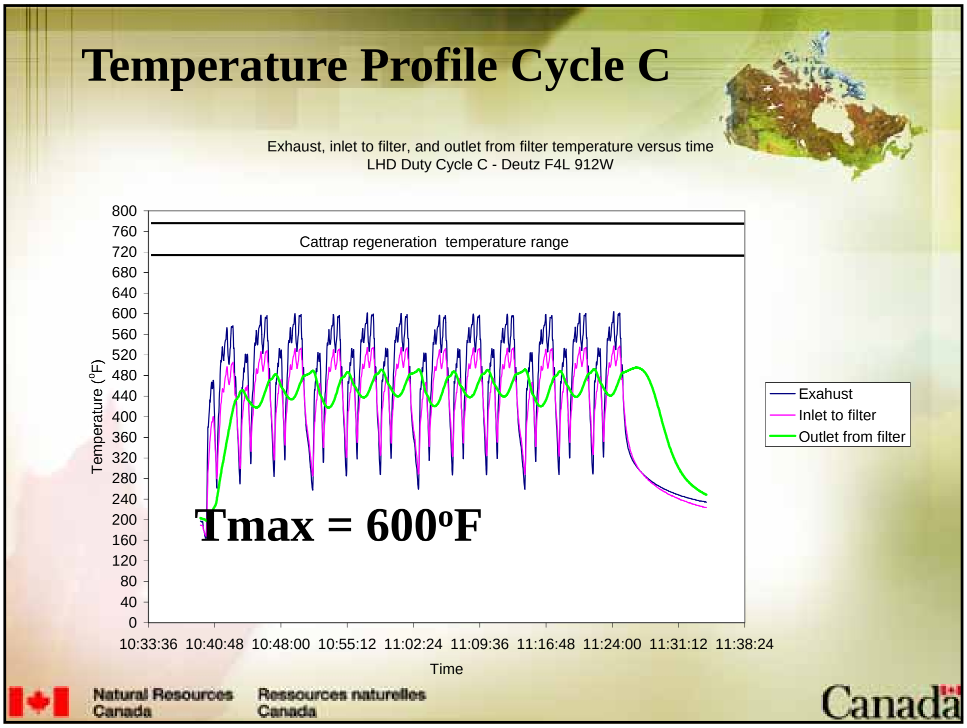
Temperature Profile Cycle C
Exhaust, inlet to filter, and outlet from filter temperature versus time
LHD Duty Cycle C - Deutz F4L 912W
Cattrap regeneration temperature range
Temperature (°F)
Time
Exhaust
Inlet to filter
Outlet from filter
Tmax = 600°F
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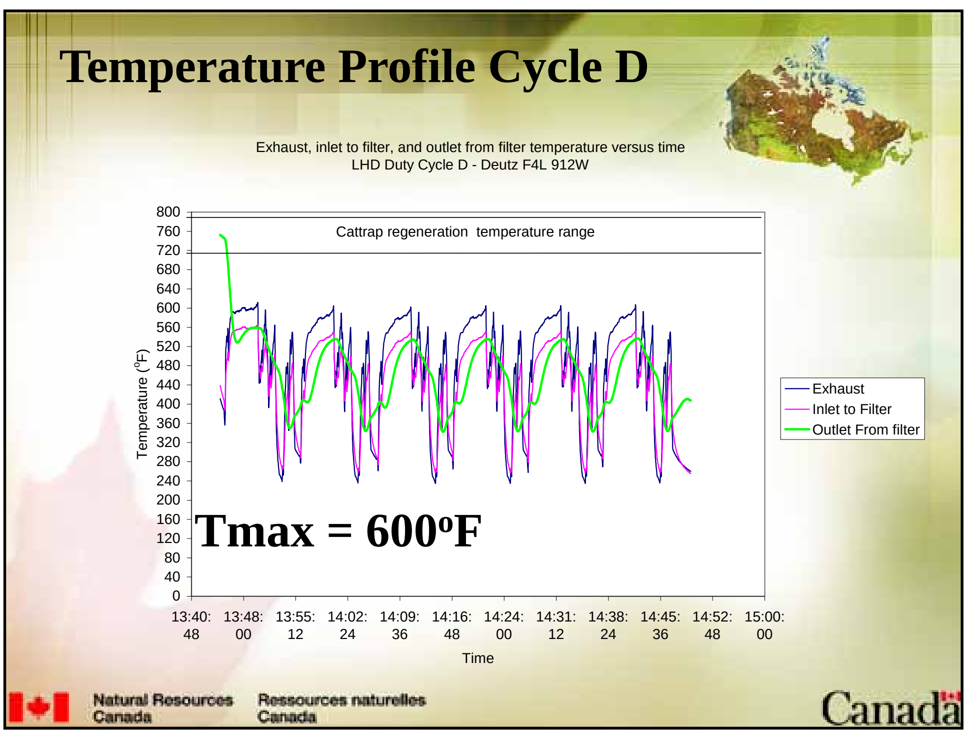
Temperature Profile Cycle D
Exhaust, inlet to filter, and outlet from filter temperature versus time
LHD Duty Cycle D - Deutz F4L 912W
Cattrap regeneration temperature range
Temperature (°F)
Time
Exhaust
Inlet to Filter
Outlet From filter
Tmax = 600°F
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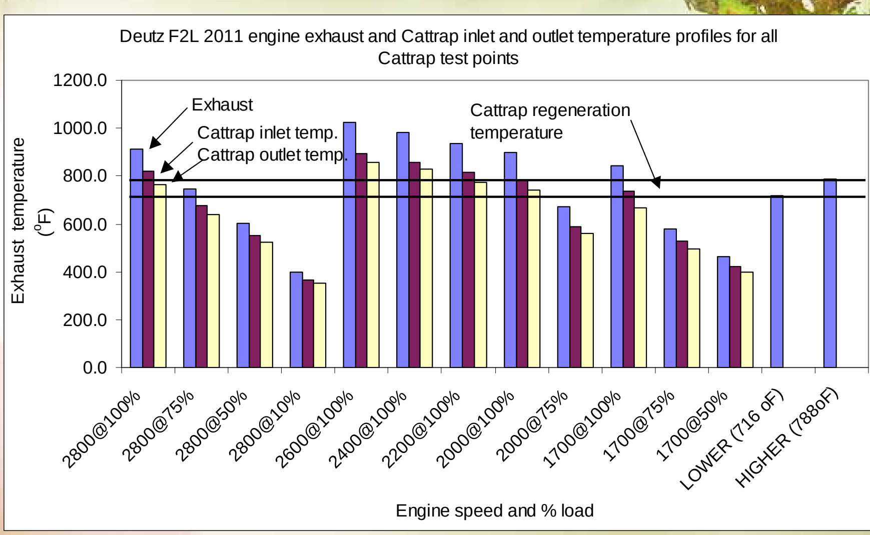
Deutz F2L2011 and Cattrap Set-up in CANMET-MMSL Diesel Test Cell

Temperature Profile - Hybrid



Costs and maintenance CATTRAP ™

- Costs and maintenance - CATTRAP Model CT6 4800$ CAN
- Life expectancy 4000-8000 hours
- Inspection and cleaning of ash could be approximately every 1000 hours

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Conclusions

- A hybrid vehicle concept allows a smaller diesel engine to be used for a comparable conventional diesel vehicle application.
- The operation of this smaller engine will be in stead-state mode and will produces less emissions compared to transient operation in conventional vehicles.
- Theoretical modeling suggests that it is possible to operate the small engine in strict electrical mode 20 to 60 percent of the time (diesel engine off).
- The hybrid application also reduces heat emissions.
- The hybrid concept allows for a comparatively simpler application of high-efficiency filtration technology.

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Next Steps

- Contact investors regarding financing of the next phase of the project
- Final design of the 1.5 yard hybrid system
- Construction of the prototype and official presentation to the mining industry (2004-05)

Acknowledgements

- IRSST
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- Jean-Marie Fecteau and Sylvain Ouellette, Mine Laboratoire – Val-d'Or
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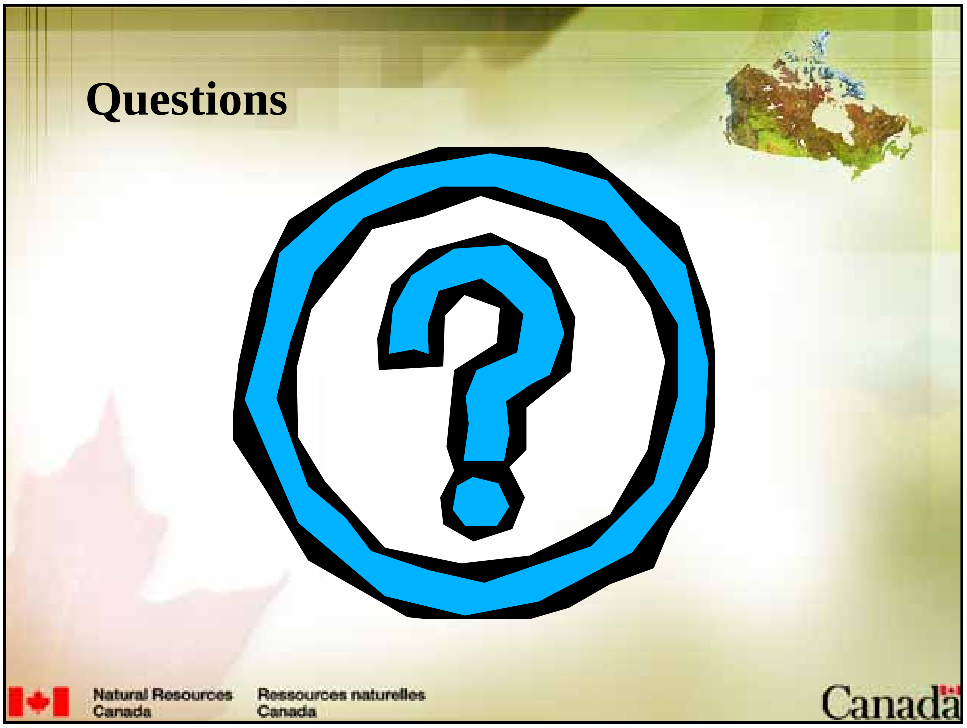
- Engine Control Systems, Ted Tadrous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