Fuel Cell Powered Underground Mine Loader Vehicle

DE-FC36-01GO11095

23 May 2005

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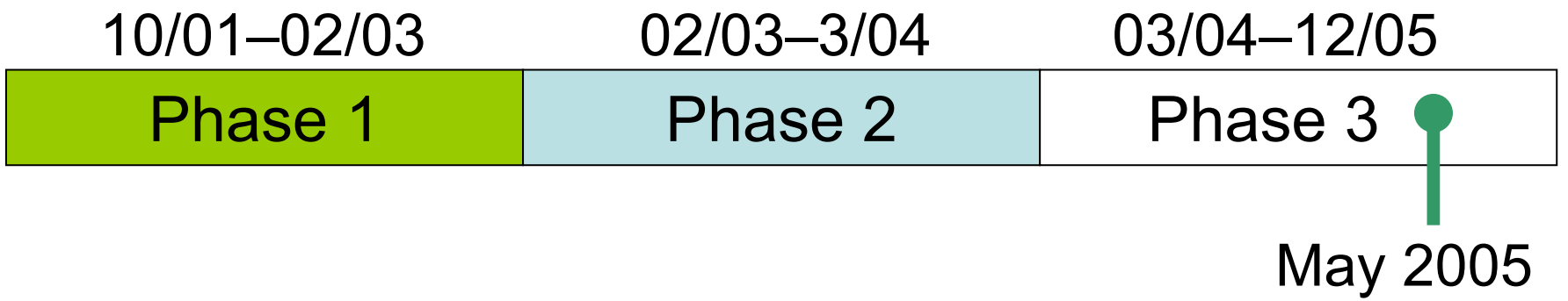
Project ID # TVP12 Paoletti

PROJECT TIMELINE



- Phase 1--Cost Benefit Analysis and Preliminary Design
- Phase 2--Detailed Engineering Design
- Phase 3--Fabrication, Integration, and Demonstration

Key Milestone: Power-up Fuelcell LHD, June 2005

BUDGET

- Total project funding
  - –DoE funding $ 2,112,776
  - –Vehicle Project funding $ 2,412,527
- Funding received FY04 $ 1,428,817
- Funding for FY05 $ 651,275

BARRIERS

- The Hydrogen, Fuel Cells, and Infrastructure Technologies Multi-year Program Plan technical barriers this project addresses include:
  - Vehicles
  - Storage

PARTICIPANTS

- AeroVironment Inc., Monrovia, CA
  - Fuel Cell Balance of Plant, Battery Pack, DC/DC Converters, Power Module Mechanical Design, and Monitoring and Control
- Caterpillar Inc., Peoria, IL
  - Drive Train, Hydraulics, Vehicle Selection, Modification, and Integration
- HERA, Longueuil, QC
  - Metal-Hydride Storage
- Nuvera Fuel Cells, Milan, IT & Cambridge, MA
  - Fuelcell Manufacturer

PARTICIPANTS, continued

- Modine Manufacturing Company, Racine, WI
  - –Heating and Cooling
- Hatch, Sudbury, ON
  - –Risk Assessment and Regulatory Review
- CANMET-MMSL, Val d'Or, QC
  - –Demonstration Oversight, Cost-Benefit Reports
- Washington Safety Mgt Solutions, Aiken, SC
  - –Hydrogen Risk Assessment
- DRS Technologies, Hudson, MA
  - –Traction Motor

PARTICIPANTS, continued

- Southwest Research Institute,San Antonio,TX
  - –Duty Cycle and Energy Modeling
- University of Nevada, Reno, NV
  - –Ventilation Evaluation
- Placer Dome Ltd., Vancouver, BC
  - –End-user Oversight and Mine Demonstration
- Newmont Mining Corporation, Carlin, NV
  - –End-user Oversight and Mine Demonstration
- MSHA, Triadelphia, WV
  - –Regulatory Oversight

PARTICIPANTS, continued

- Agnico-Eagle Mines Ltd., LaRonde Mine, QC
  - –Mine Demonstration
- Fuelcell Propulsion Institute, Denver, CO
  - –Project Advocacy and Dissemination
- Vehicle Projects LLC, Denver, CO
  - –Project Management

PROJECT OBJECTIVES

To assist the DoE in the expansion of fuelcell systems technology through development and evaluation of a fuelcell mine loader vehicle for an application with high commercial potential.

- Develop and demonstrate an underground fuelcell powered mine loader.
- Develop associated metal-hydride storage and refueling system.
- Demonstrate loader in an underground mine in Nevada.

APPROACH

- Perform cost/benefit analysis of fuelcell mine vehicles, including cost of pro-ducing hydrogen, method of hydrogen transfer, mine recurring costs, and ventilation savings
- Determine power (duty cycle) and drive system requirements, and onboard energy storage for a Caterpillar-Elphin-stone R1300, 165 hp (123 kW), 3.5 cu. yd. mine loader
- Perform detailed engineering design of power plant, metal-hydride storage, drive system, and control system

APPROACH, continued

- Fabricate power plant and metal-hydride storage and bench test
- Integrate power plant, metal-hydride storage, and system components into base vehicle
- Complete risk assessment and certify for underground demonstration
- Test entire vehicle and demonstrate in an underground mine in Nevada

TECHNICAL ACCOMPLISHMENTS, PROGRESS, and RESULTS

- Power plant bread board testing successful
- Power electronics tested successfully
- Battery pack packaged into module
- Power plant testing to be completed by 30 May 2005
- Metal hydride storage capacity 13.2 kilograms of hydrogen

POWER MODULE

Power Plant Accomplishments

- 112 NiMH batteries (12 kWh) liquid cooled
- Data AcQuisition (DAQ) monitors all 402 cells
- Stacks full-load 90 kW (gross)

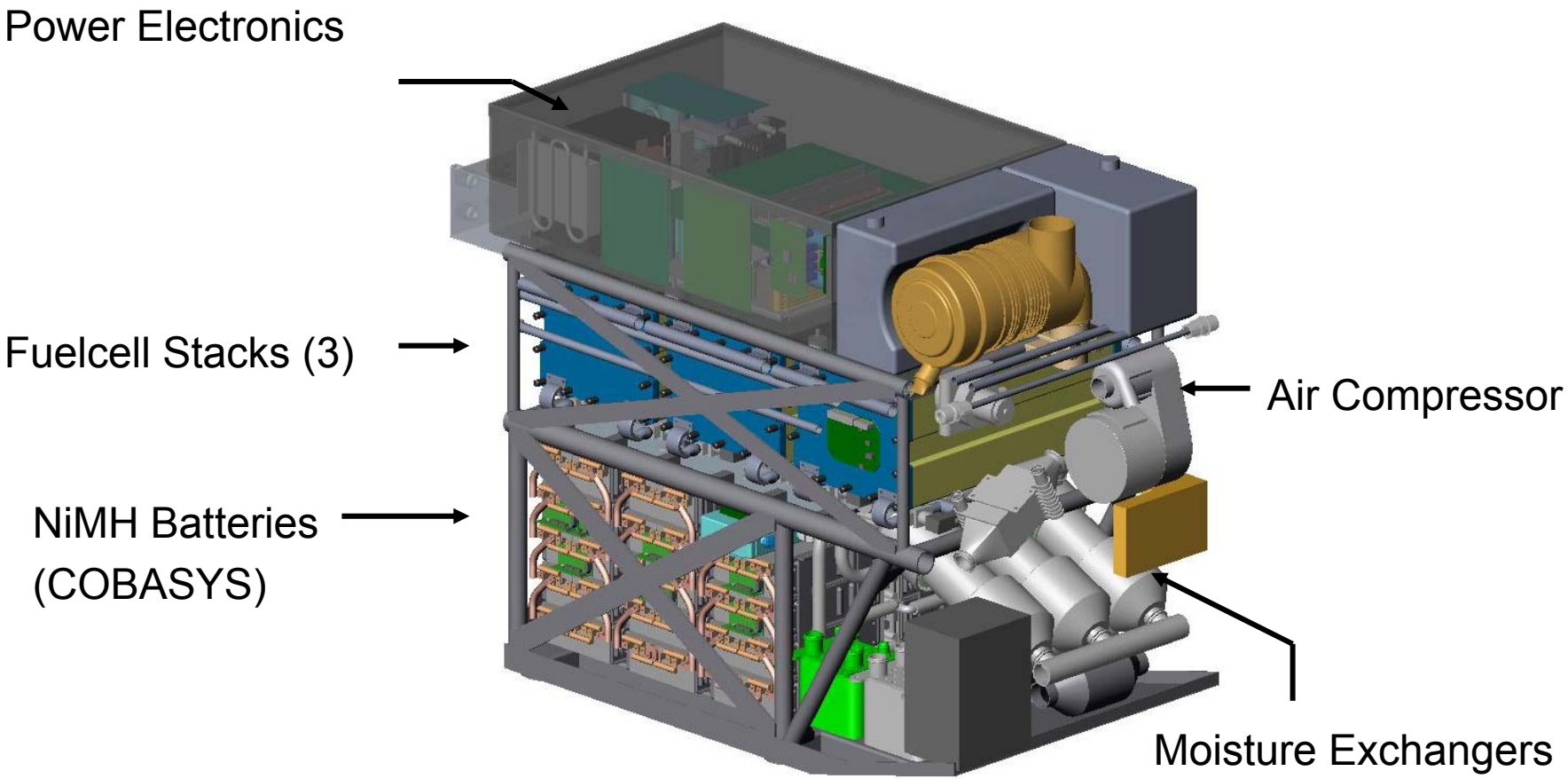
POWER MODULE, continued

Power Plant Accomplishments, continued

- Power plant full-load 160 kW (gross)
- Hydrogen pressure 2.0 bara
- Air pressure 1.8 bara
- Operating temperature between 60°-75°C
- Parasitic power losses < 18%

FUELCELL POWERPLANT

Traction Motor Layout



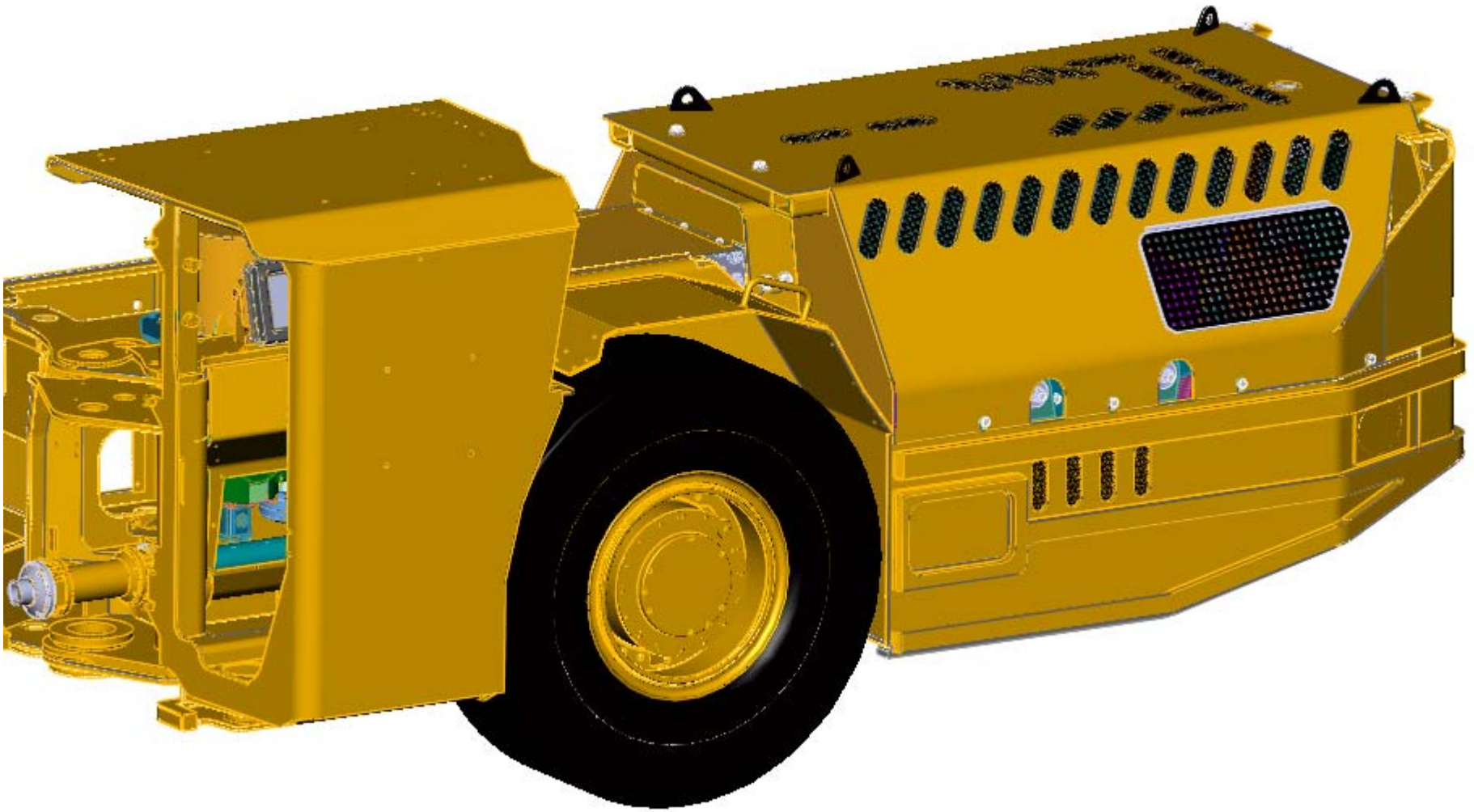
AeroVironment--Electronics and Layout
Nuvera Fuel Cells--Stacks

FUELCELL/DIESEL

Power plant comparison

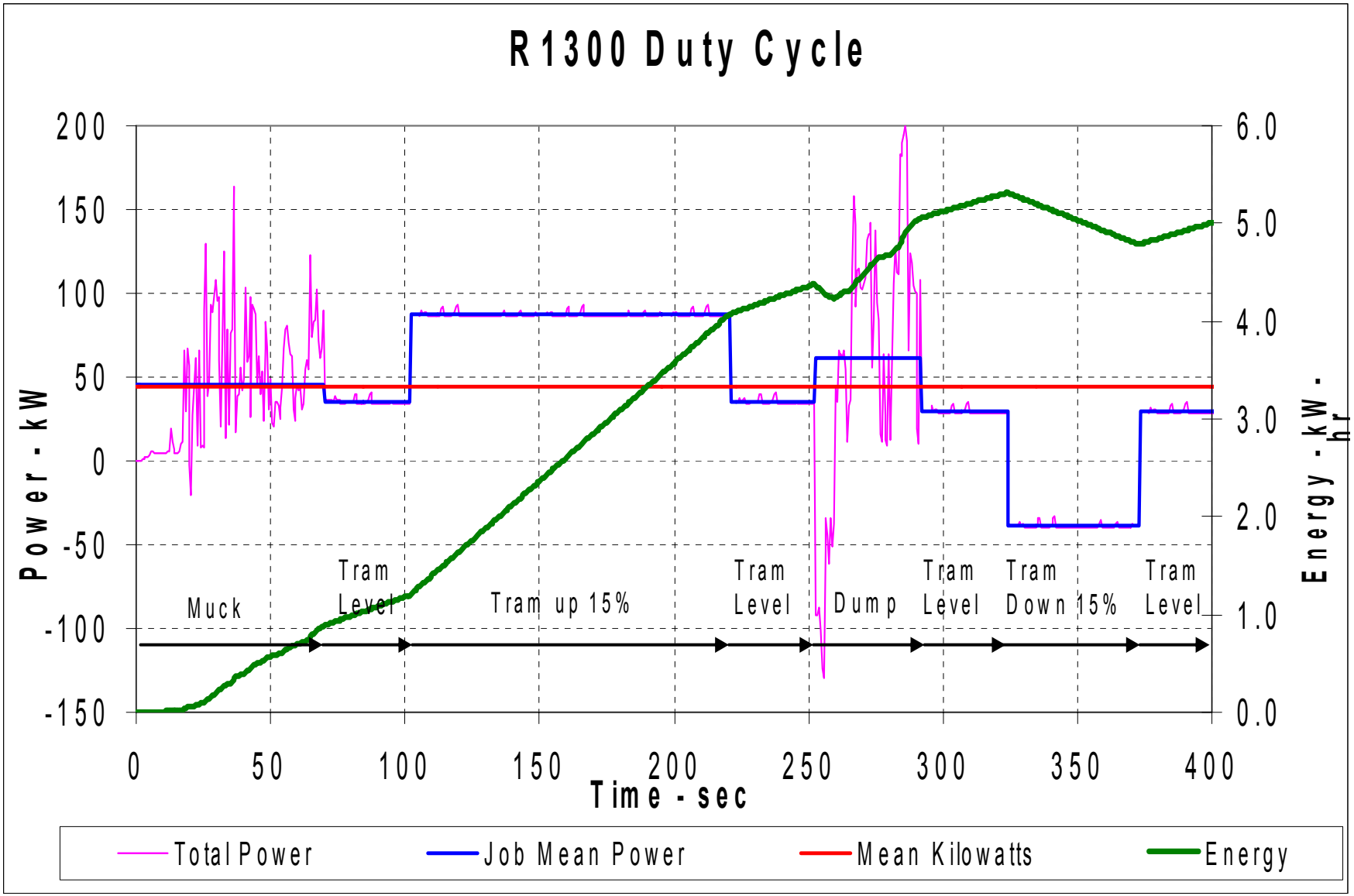
	Conventional Diesel	Hybrid Fuelcell
Power continuous net	123 kW (165 hp)	70 kW (94 hp)
Power peak net	123 kW (165 hp)	140 kW <10 mins. (188 hp)
Endurance	8 hr	6 hr
Vehicle mass empty	19750 kg (43,450 lbs)	22700 kg (49,940) lb
Fuel capacity	295 L diesel (78 US gal)	142560 L hydrogen (13.2 kg)
Regenerative braking	no	yes
Hydraulic power source	integrated with engine	separate 100 kW peak motor

VEHICLE LAYOUT–CATERPILLAR



DUTY CYCLE

Loader Power Requirements



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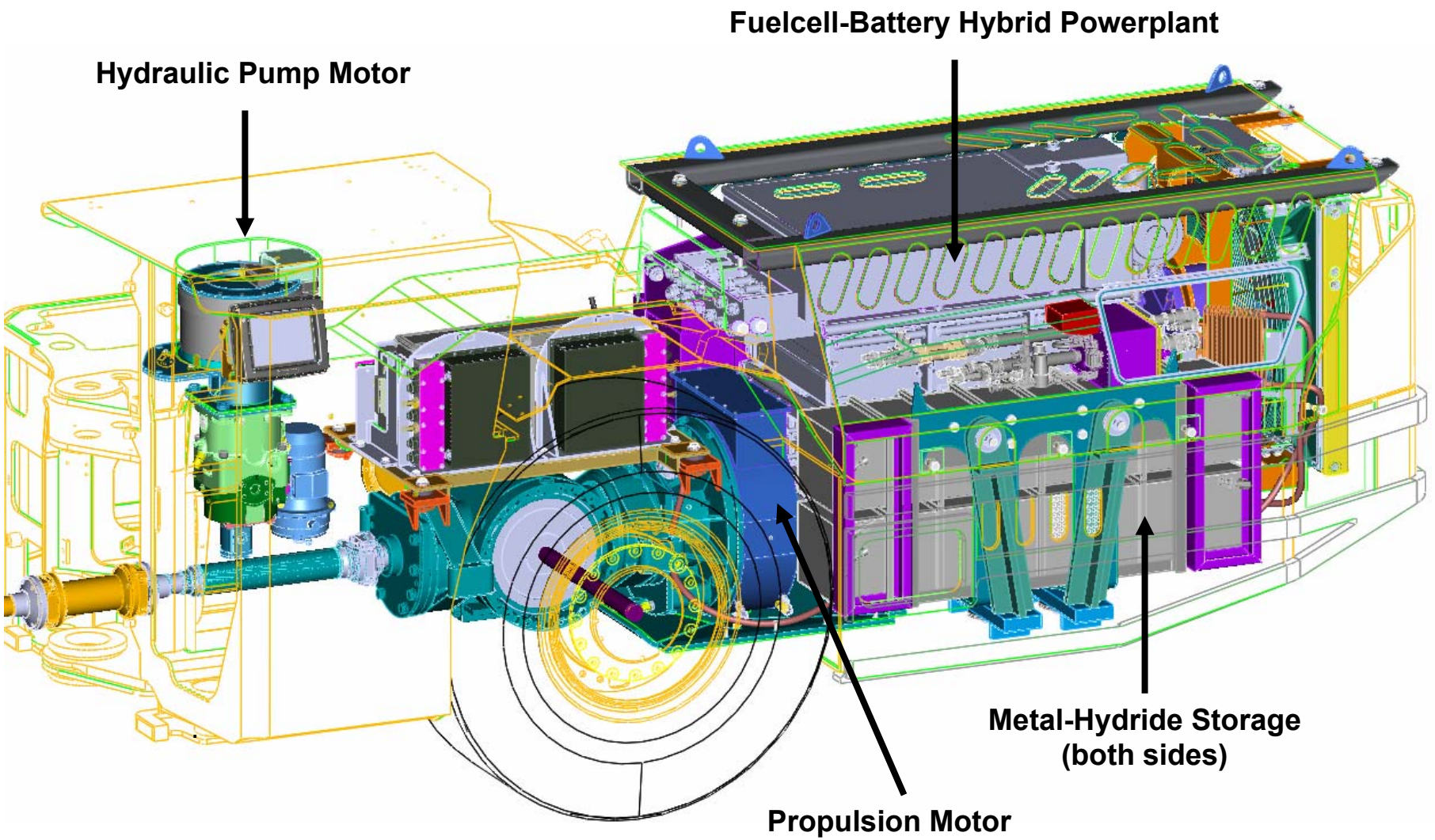
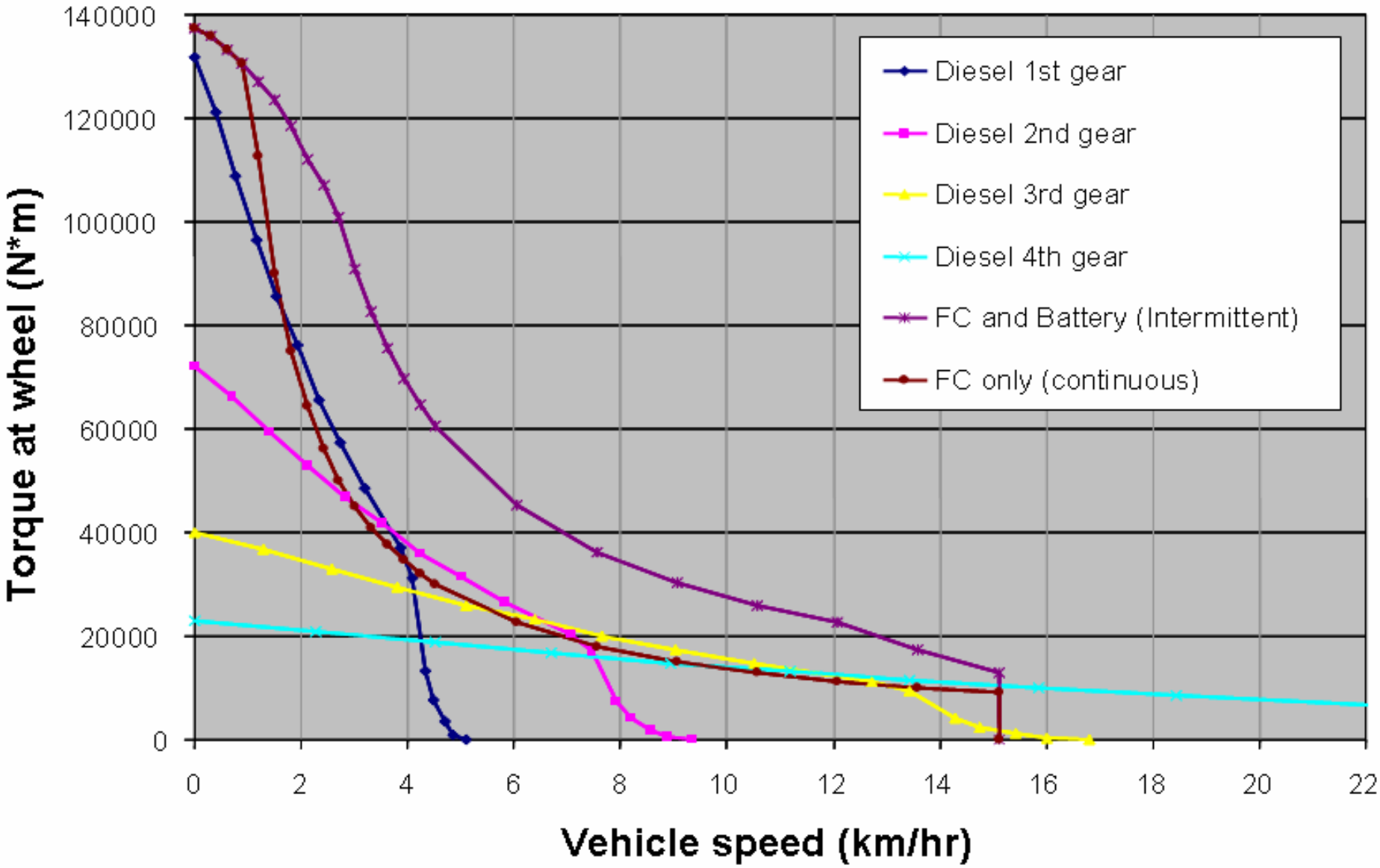


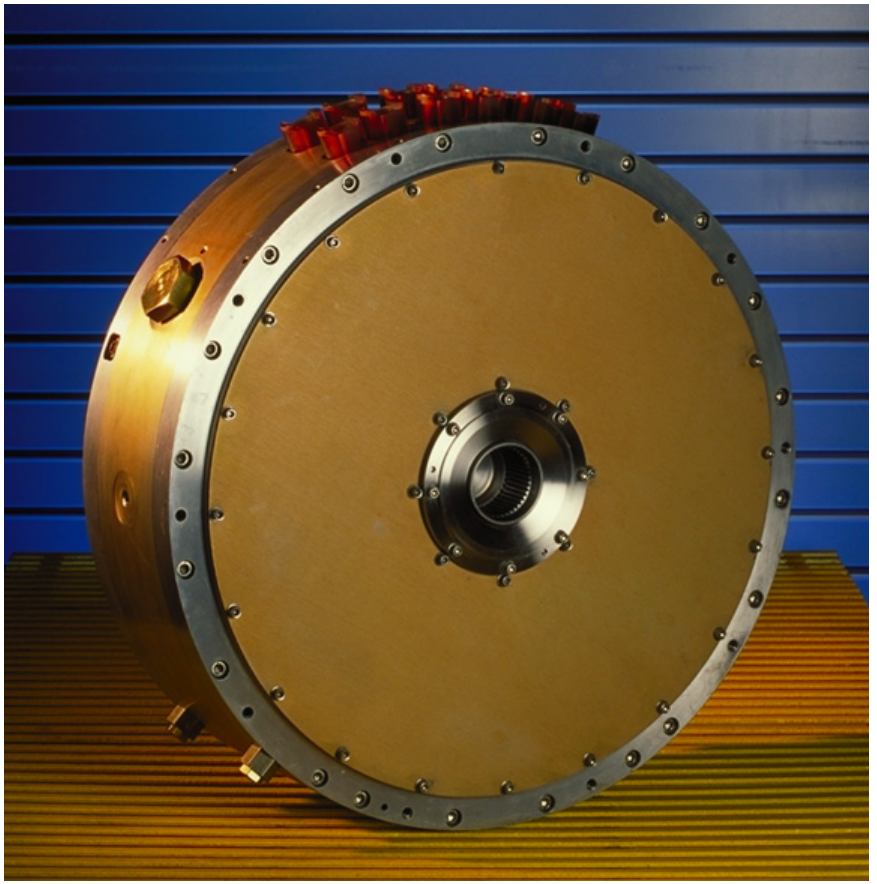
TORQUE-SPEED COMPARISON

Torque-speed comparison



TRACTION MOTOR

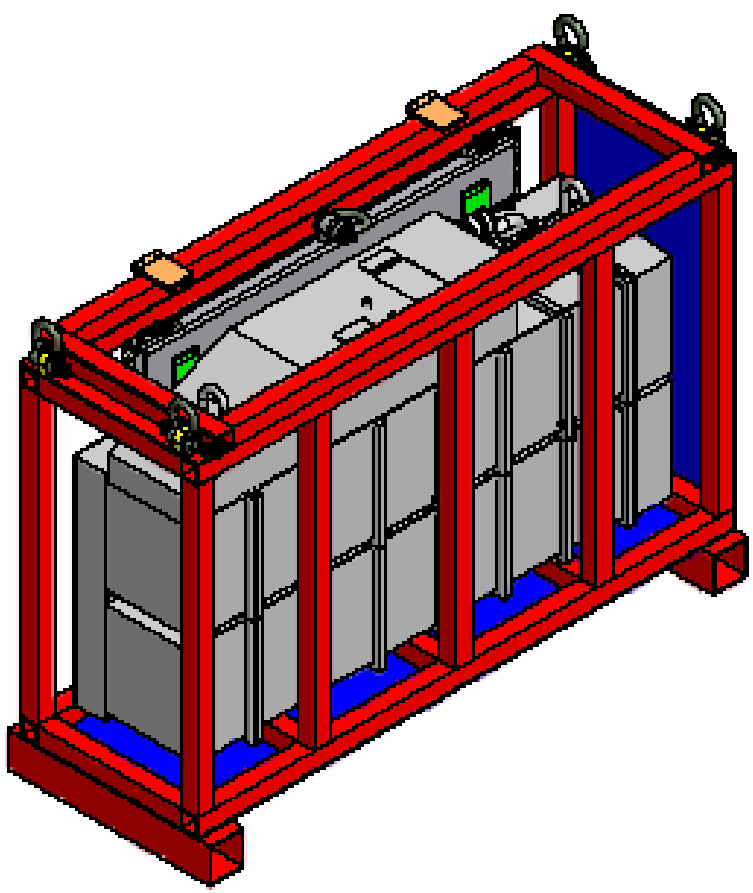
- Brushless Permanent Magnet
- Rated Power–336 kW (450 hp)
- Efficiency @ Rated Power–95%
- Maximum Current–425 A rms
- Rated Voltage–800 V peak
- Diameter–648 mm (25.5 inches)
- Length–224 mm (8.8 inches)
- Weight–195 kg (395 lbs)
- Cooling–Liquid (water/glycol)

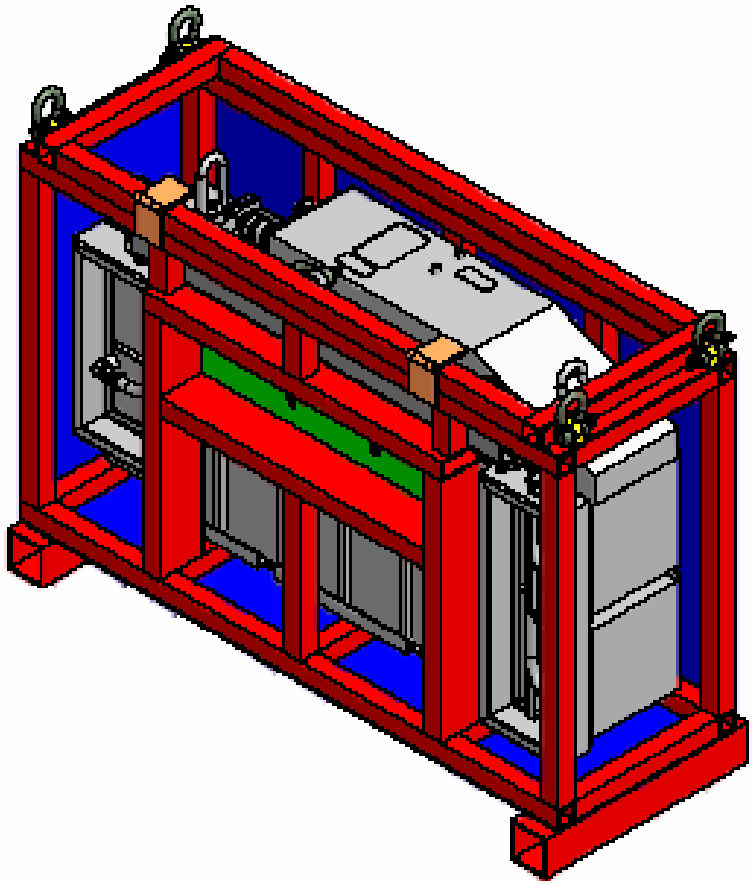


DRS Technologies

METAL HYDRIDE TRANSPORT

Refueling and Transport Container





RESPONSES TO PREVIOUS YEAR'S REVIEWER COMMENTS

- Bench testing could address issues relative to the cost of mine vehicles
  - Bench testing incorporating powerplant pre-installation and three months testing prior to commencing mine demonstrations
- Other considered applications
  - Fuel cell powered industrial applications
  - Industrial vehicle applications--in- and outside mining industry
  - Construction vehicles
  - Heavy equipment applications

FUTURE WORK

- Remainder of FY05
  - –Fueling of metal-hydride storage tanks.
  - –Power plant acceptance testing.
  - –Integrate associated fuelcell-power components into R1300 base vehicle.
  - –Completed fuelcell loader testing at Caterpillar.
- FY06
  - –Evaluate performance and durability at an underground mine in Nevada and Ontario.

HYDROGEN SAFETY

The most significant hydrogen hazard associated with this project is release of hydrogen caused by a compromise of the metal hydride bed.

HYDROGEN SAFETY

- Our approaches to deal with this hazard are:
  - Release of hydrogen will be diluted due to established minimum airflow within the mines.
  - Designed in capability to shut down the loader systems upon release of hydrogen.