Truck Essential Power Systems Efficiency Improvements for Medium Duty Trucks

HVSO Review Meeting

April 20, 2006

U.S. Department of Energy
Energy Efficiency and Renewable Energy

EMERSON™ SR drives CAT® DANA E.M.P

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Caterpillar More Electric Research

U.S. Department of Energy
Energy Efficiency and Renewable Energy

More Electric Truck (MET) Heavy-Duty

Advanced Electric Systems (AES) Heavy-Duty

Truck Essential Power Systems (TEPS) Medium-Duty

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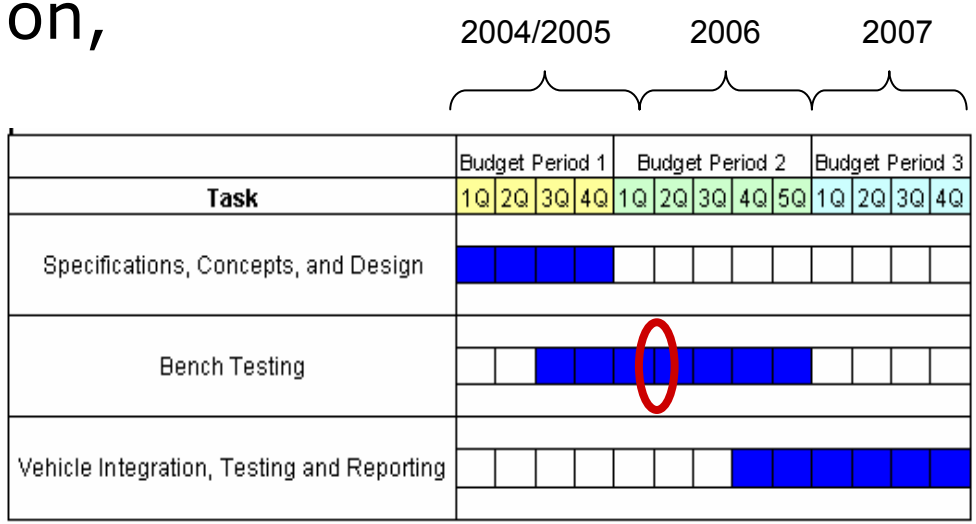
EMERSON MOTORS

DANA

2002	2003	2004	2005	2006	2007

Program Overview

- Three year program
- Three Tasks
  - Task 101 - Specifications, Concepts, and Designs
  - Task 102 – Bench Testing
  - Task 103 – Integration, Testing, Reporting



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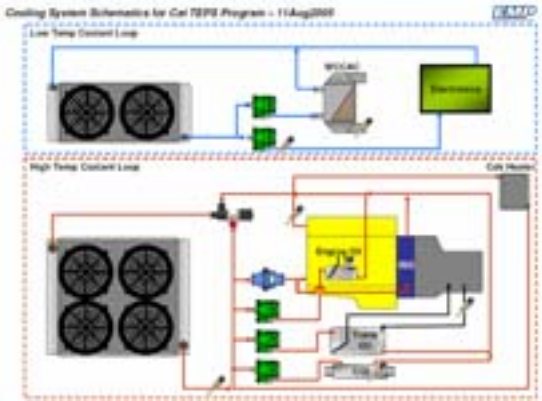
Team Composition

- Partners
  - Caterpillar Inc. – Lead Company
  - Dana Corporation – Electro-hydraulic power steering
  - Emerson Electric (SRD) – Integrated starter/generator
  - Engineered Machined Products (EMP) – Cooling package



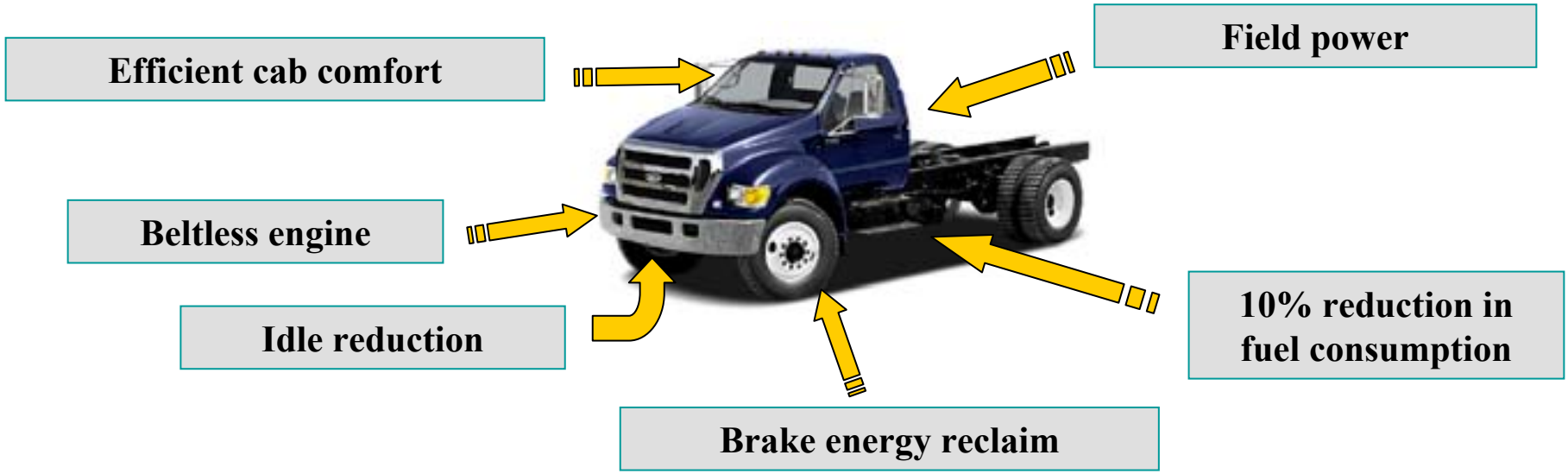
Mission

- Improve vehicle fuel economy
  - Reduce parasitic loads
  - Improve operational efficiency
  - Idle reduction
- Reduce emissions
- Offer chassis enhancements
  - Field power
  - Alternative power sources

Demonstrate on a medium duty platform

Vision

Truck electrification delivers reduced fuel consumption and idle reduction opportunities. Advanced technologies facilitate fuel economy gains as well as chassis enhancements. Electrification expands the boundaries for capability, comfort, and power source diversity in a more fuel efficient package.



Market Analysis

- QFD w/ OEM Truck Company
  - VOC
  - VOB
  - MD Vocations
  - Powertrain Configuration

Utility Truck Row Names	VOC: Payload	VOC: Storage space	VOC: Retain Functionality	VOC: Maintenance (where	VOC: Cost of acquisition	Fuel Economy	Driver / Operator Saftey	Sum of Normalized Ratings	Relative Score
VOC: Payload	1.00	0.50	0.50	3.00	3.00	1.00	0.50	0.98	14.0%
VOC: Storage space	2.00	1.00	0.50	2.00	2.00	1.00	0.50	1.00	14.2%
VOC: Retain Functionality	2.00	2.00	1.00	3.00	2.00	3.00	0.50	1.44	20.6%
VOC: Maintenance (where take it)	0.33	0.50	0.33	1.00	0.50	2.00	0.50	0.57	8.1%
VOC: Cost of acquisition	0.33	0.50	0.50	2.00	1.00	2.00	0.50	0.72	10.2%
			0.33	0.50	0.50	1.00	0.25	0.53	7.6%
			2.00	2.00	2.00	4.00	1.00	1.77	25.2%

Delivery Truck Row Names	Operator Friendliness (dr	Non- Manual Transmissio	All Environments	VOC: Can I sell when I'm	Residual value	VOC: Grid Sales	VOC: Adequate Energy ti	Sum of Normalized Ratings	Relative Score
Operator Friendliness (drive like m	1.00	1.00	1.00	1.00	0.50	9.00	9.00	1.21	17.3%
Non- Manual Transmission	1.00	1.00	1.00	2.00	2.00	9.00	9.00	1.48	21.1%
All Environments	1.00	1.00	1.00	1.00	9.00	9.00	9.00	1.83	26.1%
VOC: Can I sell when I'm done	1.00	0.50	1.00	1.00	1.00	9.00	9.00	1.13	16.1%
Residual value	2.00	0.50	0.11	1.00	1.00	9.00	9.00	1.08	15.5%
VOC: Grid Sales	0.11	0.11	0.11	0.11	0.11	1.00	1.00	0.14	2.0%
VOC: Adequate Energy time	0.11	0.11	0.11	0.11	0.11	1.00	1.00	0.14	2.0%

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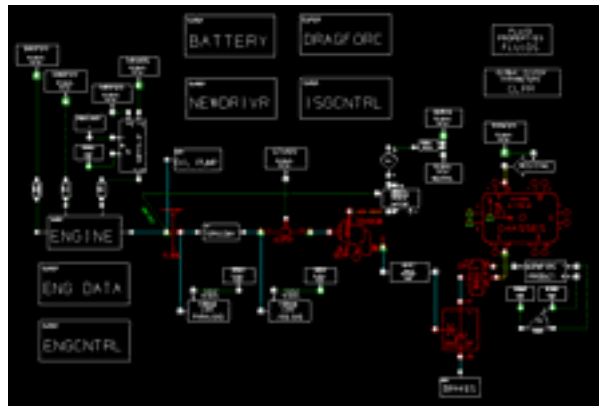
‘Best’ Application

- Caterpillar C7 Engine
- MD Chassis
  - Two wheel drive
  - Utility truck body
  - Non-manual transmission

Concepts & Design

Energy Storage System

- Investigate the effects of and select the optimum:
  - Battery size
  - Battery chemistry
- Determine best combination for:
  - Fuel consumption
  - Idle reduction
  - Battery life



Energy Storage Technologies

- Lead Acid battery pack
  - 4 KWH, 6 KWH, 8KWH, 16 KWH
- Ni-MH battery pack
  - 2.4 KWH, 4.8 KWH
- Li Ion Battery pack
  - 2 KWH

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Observations

- Battery size does not have a significant effect on fuel efficiency, but does impact idle reduction capability.
- Increasing battery size reduces the number of required battery cycles, thus prolonging battery life.

Battery Technology	Size (Wh)	Weight (kg)	Est. Life (yrs.)
VRLA	16000	400	5
NiMH	1500	46	4
Li-Ion	2000	33	4

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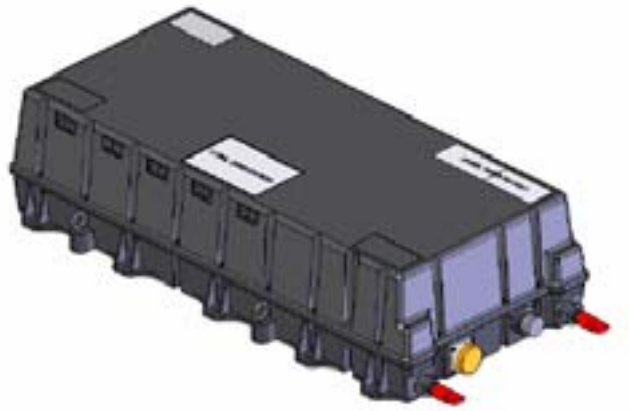
Energy Storage Selection

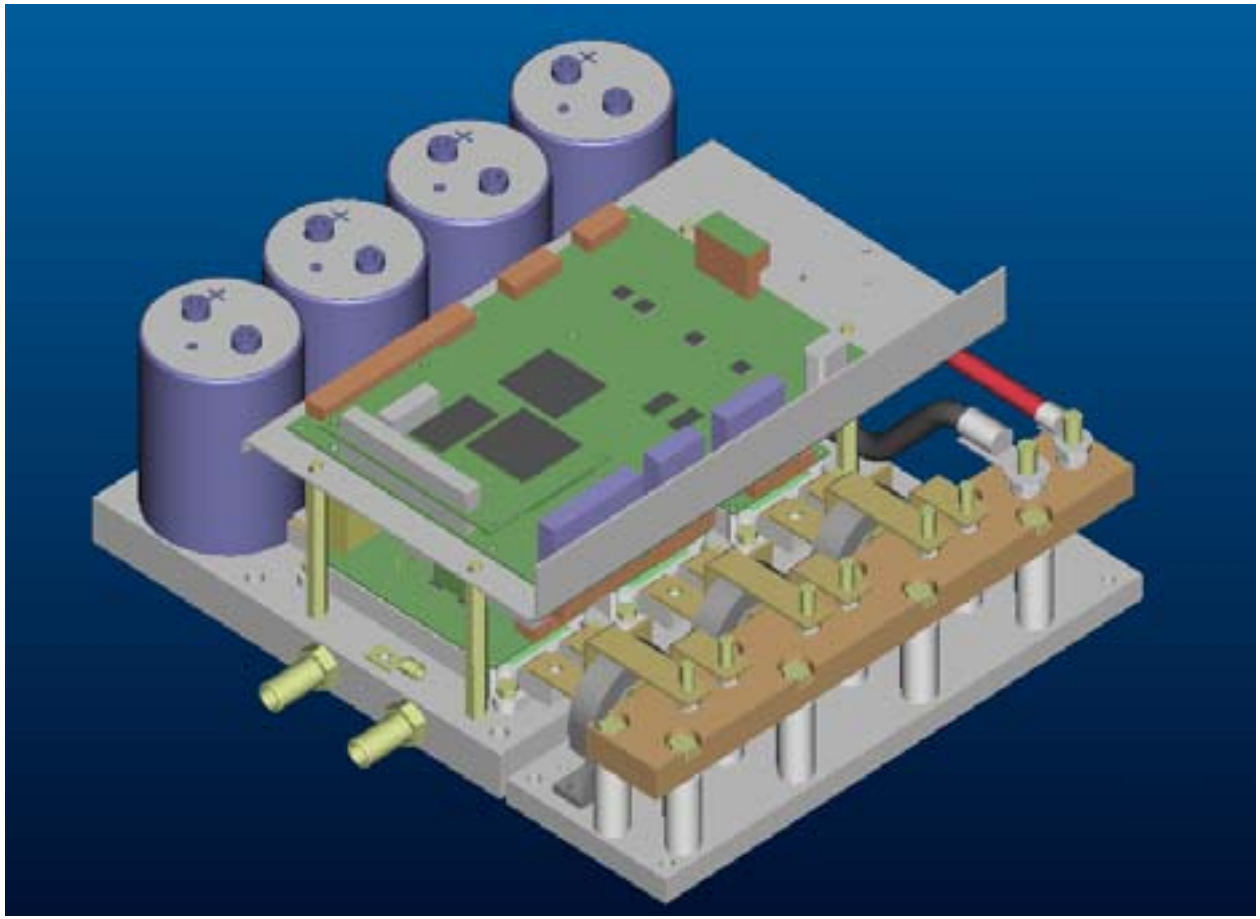
- Nominal Voltage 288V
- Energy 2.4kWh
- Power 60kW
- Dimensions 430x850x 210mm
- Weight 75kg



Integrated Starter/Generator (ISG)

- Provided by Switched Reluctance Drives Ltd. (SRD)
- Switched reluctance machine
- 20kW power
- Liquid cooled, max. inlet 100°C
- Nominal voltage range: 209-372 V
- Supplied as a rotor and a liquid cooled stator, suitable for fitting within an engine mounted housing

ISG Electronics Design



Control electronics in place

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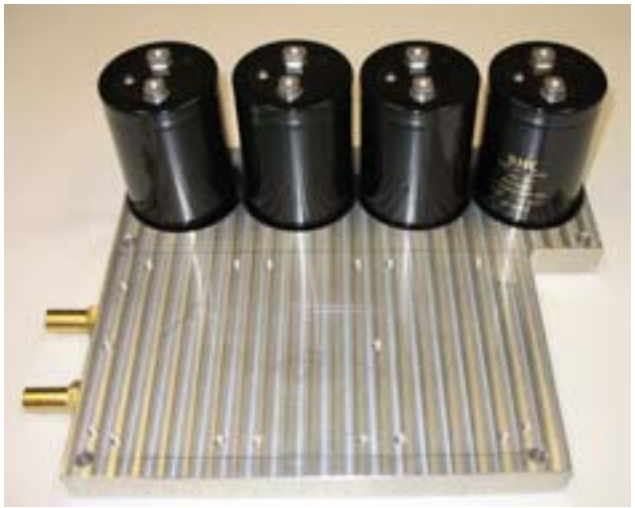
ISG Electronics Hardware

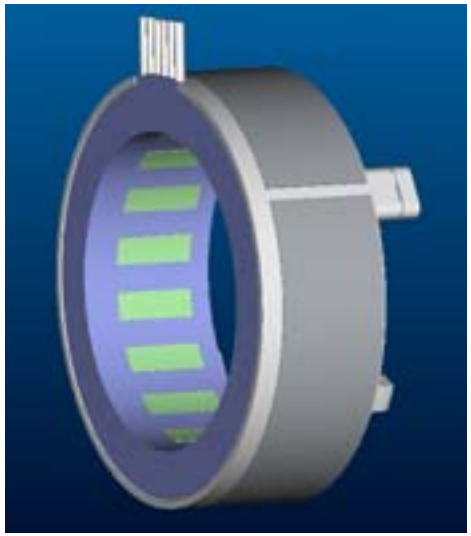


Heatsink and Capacitors

DSP-based Control PCB

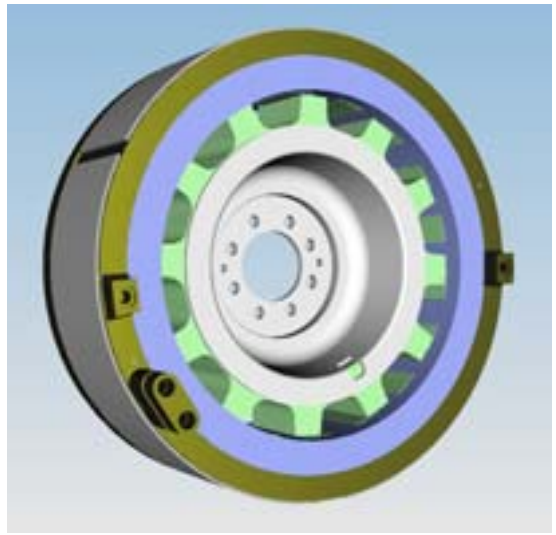
Current Transducer and Terminal Bar

ISG Mechanical Design



Stator

Rotor

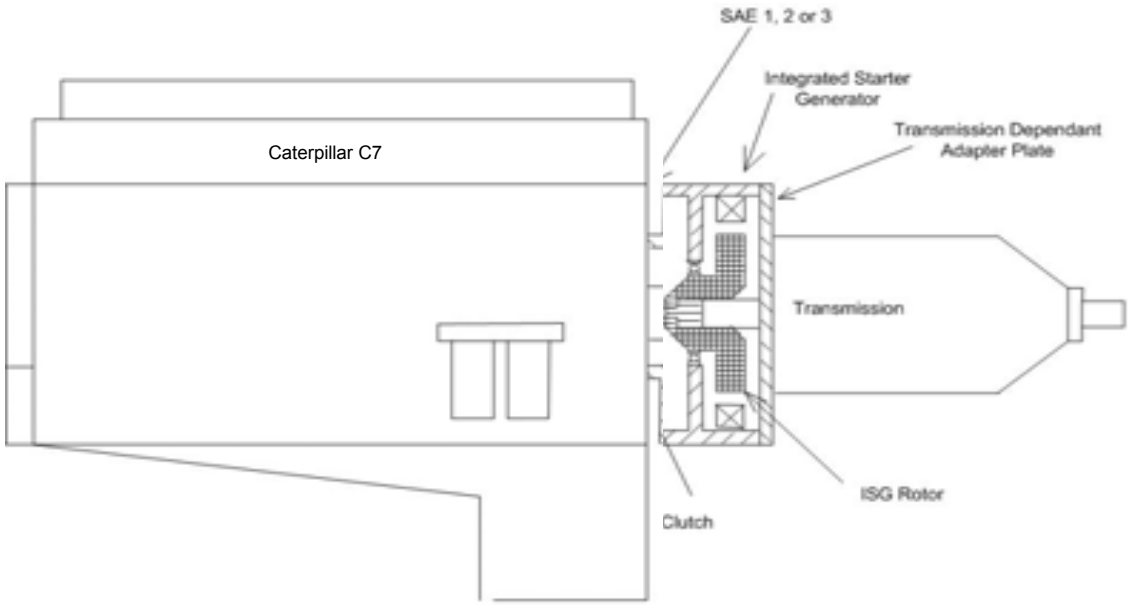


ISG Assembly

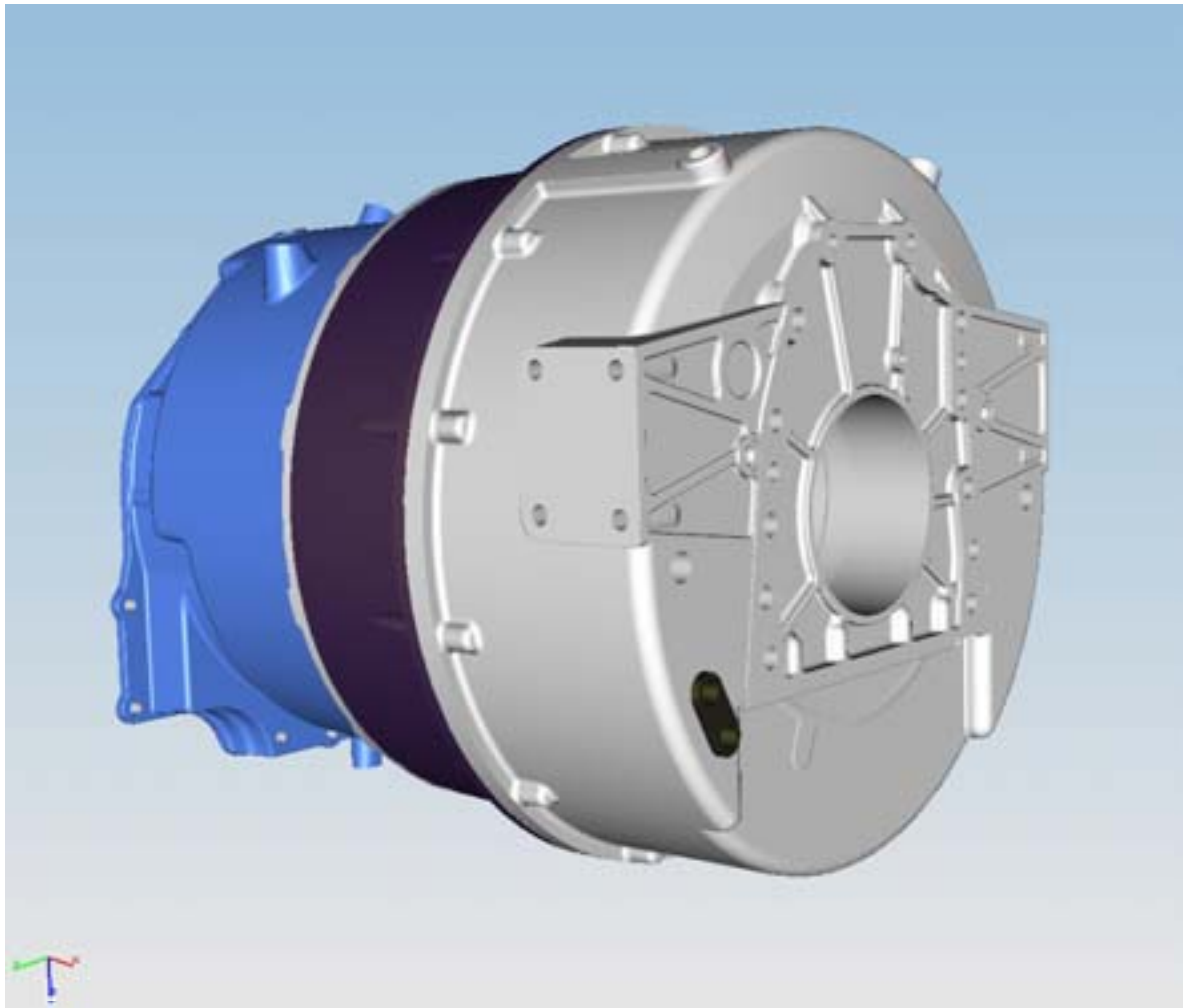
TEPS Powertrain

- QFD -> Non-manual
- Pugh Analysis

	Score
Crankshaft Mounted ISG (Automated Man.)	0
Floating ISG (Automated Man.)	3
Crankshaft Mounted ISG (Automatic)	25
Floating ISG (Automatic)	7
Crankshaft Mounted ISG (Manual)	0
Floating ISG (Manual)	0



Powertrain Design



Electro-Hydraulic Power Steering (EHPS)

- Provided by Dana
- Electro-hydraulic booster
- Operation on demand
- Builds on previous efforts

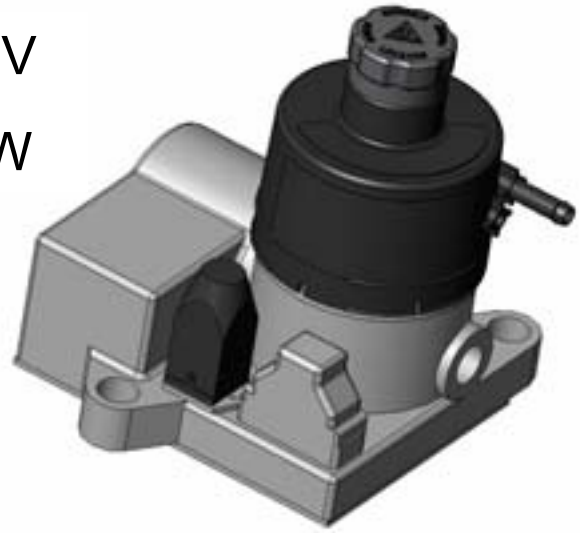
Power Road Map

42V

1.6KW

300V

3KW



12V

550W

12V

700W

Prototype Unit

- Performance @ 300V 50°C
  - Output
    - 19 l/m @150Bar
  - Overall efficiency
    - 74%
- Weight ~ 3.5kg

Cooling Package

- Provided by EMP
- Increased heat rejection
- Electric devices
  - On-demand
  - Variable speed

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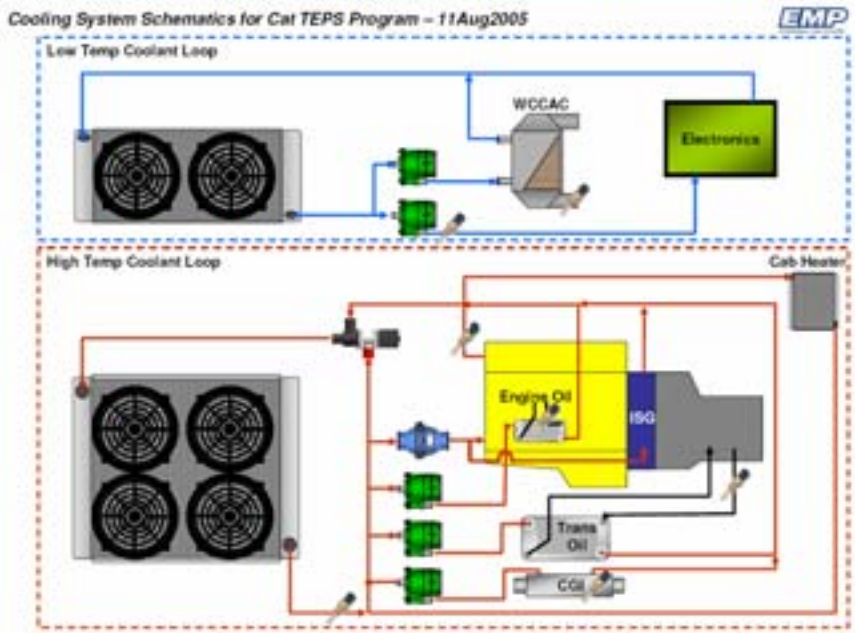
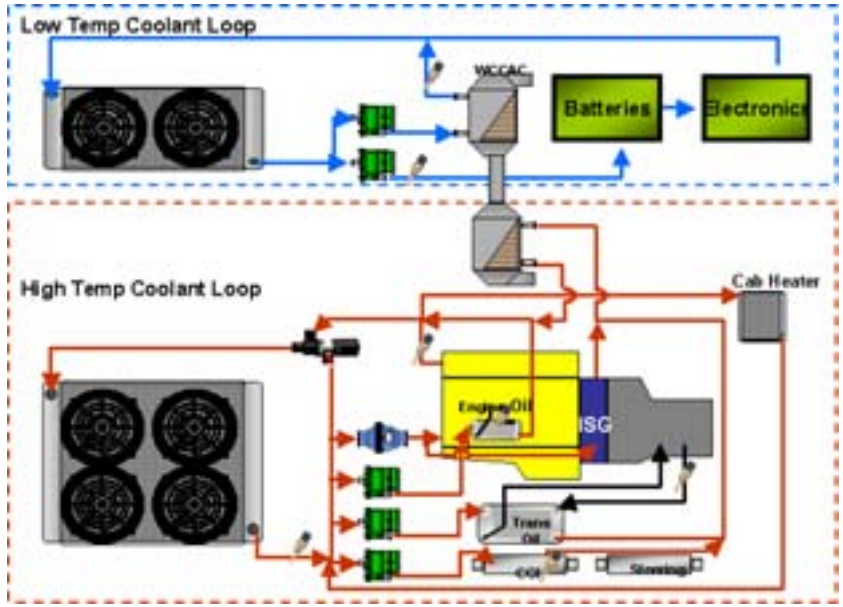
Thermal Loads

- High Temperature Loop ~ 200 kW
  - Engine
  - ISG Machine
  - Transmission
- Low Temperature Loop ~ 22 kW
  - Power Electronics
  - Charge Air
  - Energy Storage

Cooling Module Proposals



- Heat loads identified
- Array of available components



- Concepts prepared
- Remaining specifications from chassis

ISG Supervisory Control

- Make efficient use of the ISG as motor or generator in different truck operation scenarios to reduce the fuel consumption.
- Operating modes:
  - Engine start/stop
  - Generate during brake events
  - Engine shut down for reduced idle at job site
  - Potential to provide additional tractive power

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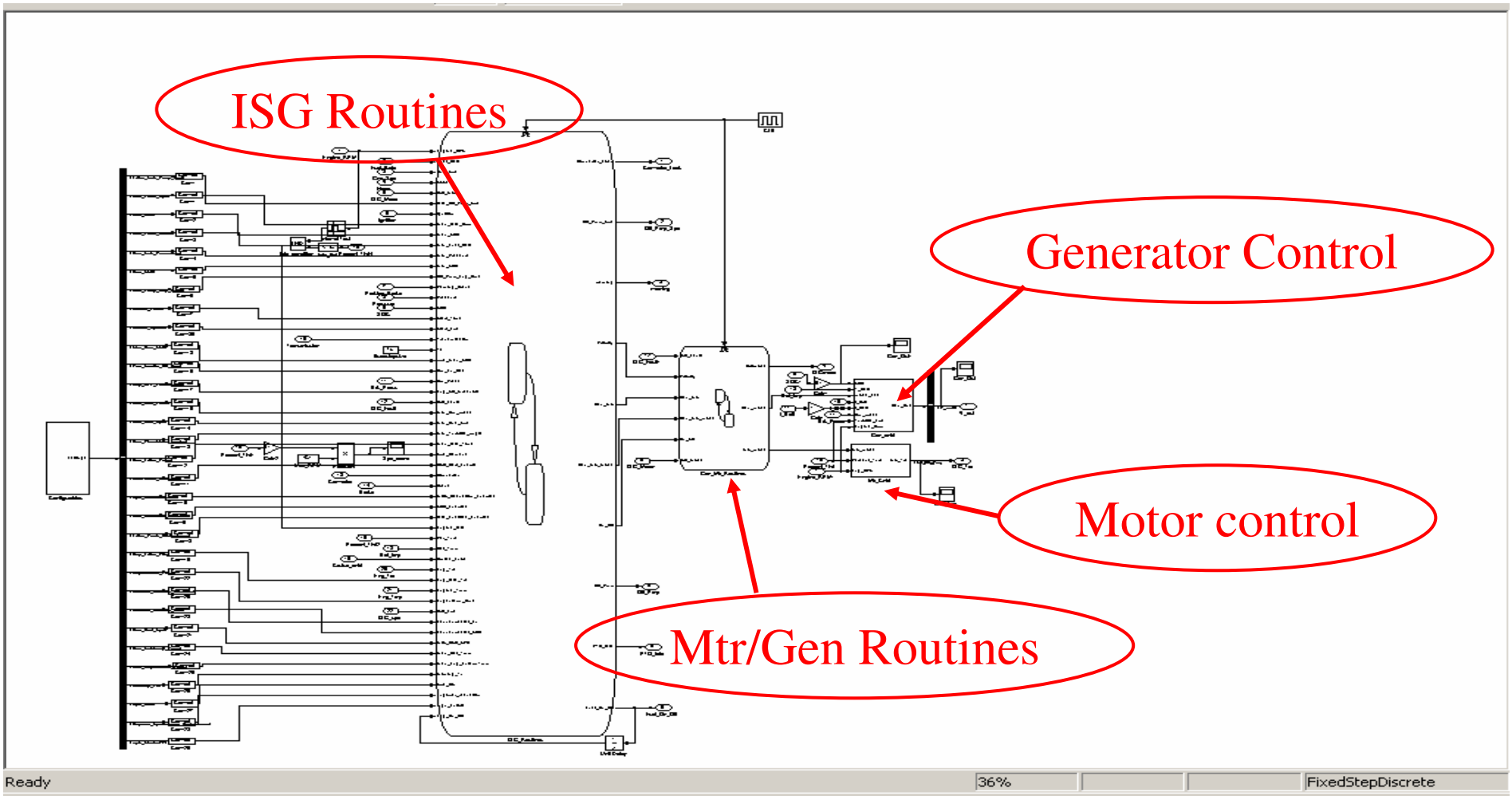
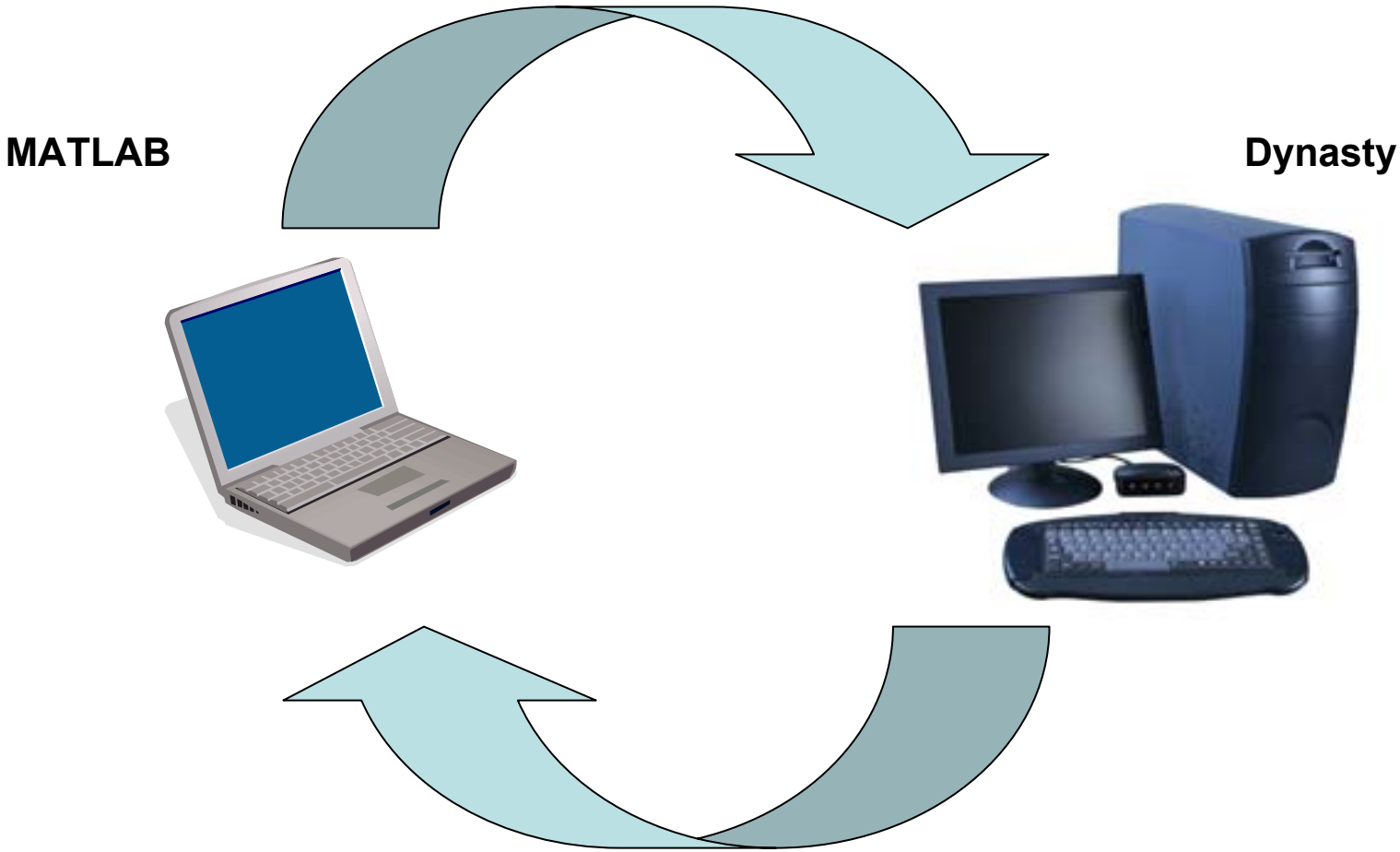
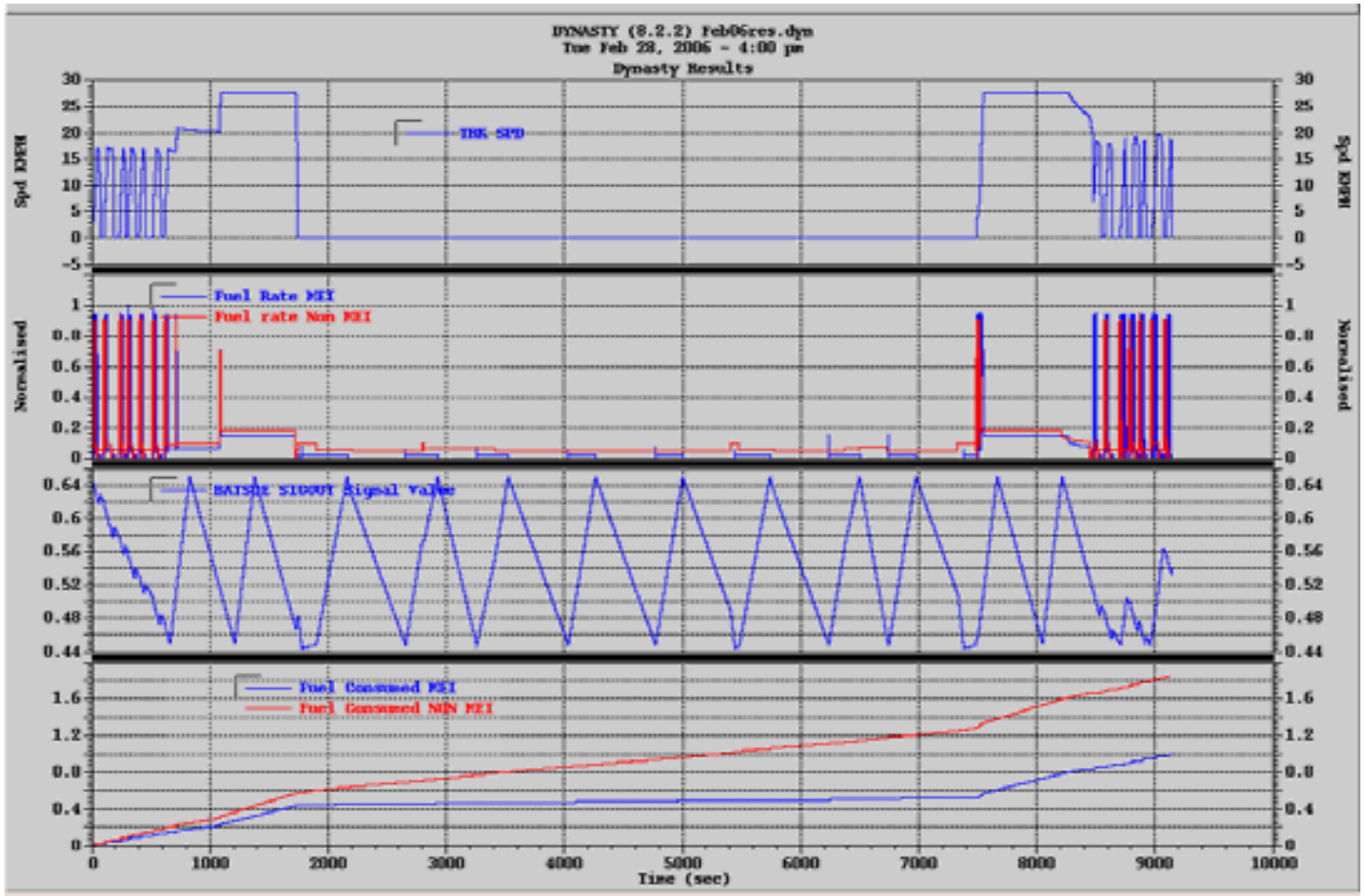
Controller model



Co-Simulation



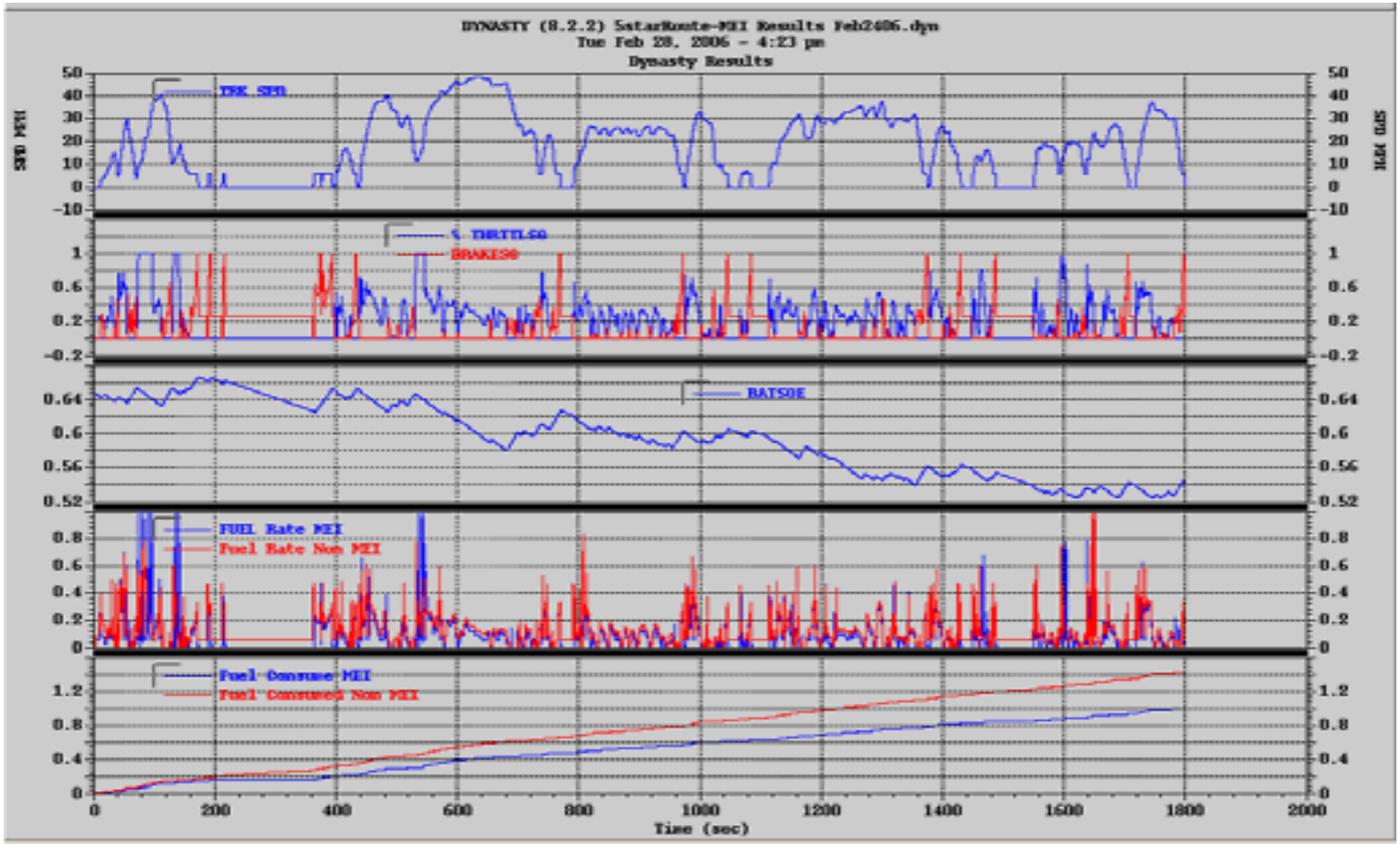
Results – Utility Cycle



Simulation Results – Utility Cycle

- Utility Truck Route
  - 13 stop lights
  - 1 job site of 95 min duration
  - Truck speeds between 0-60 kph
- Fuel Consumption Improvements:
  - Jobsite: ~ 80%
  - Road travel: ~ 20%
  - Complete route: ~ 45%

Results – 5Star Cycle



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Simulation Results – 5Star Cycle

- Delivery Route
  - Top speed = 48.5 mph
  - Average Speed = 18.6 mph
- Fuel Consumption Improvements:
  - Complete route: ~ 30%

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Potential Impact

- Assume 30% reduction in fuel consumption
  - 30 L/100km → 21 L/100km
  - 7.8 MPG → 11.2 MPG
- 17K Annual Miles → 2200 gal vs. 1500 gal
- 900K Class 6 Vehicles → ***630M gal/yr***
- ***@ $2.75/gal → $1.7B/yr***

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Program Accomplishments

- Team formed
- Application/architecture defined
- ISG electronics downsized and assembled
- Electrical architecture
- Energy storage specified
- EHPS assembled and testing
- Integration PCB’s assembled and tested
- Chassis selected
- Detailed model/simulations developed

Looking Ahead – 2006

- ISG Fabricated & Assembled – 5/2006
- EHPS Bench Testing – 6/2006
- ISG Bench Testing – 8/2006
- Control Algorithms Written – 6/2006
- Baseline Testing – 7/2006
- Vehicle Integration – 8/2006+

Thank You…