

Exhaust Energy Recovery

2008 Semi-Mega Merit Review



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Research & Technology

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Agenda



Program Objectives

- Efficiency Goal Plan and System Concept

2007 Milestones and Accomplishments

- Schedule Alignment with HECC
- Hardware Update and Review

2008 Plans and Milestones

Review and Summary



Goals and Objectives



Project Goals are:

- **10% Fuel Efficiency Improvement**
- **Reduce or eliminate the need for increased heat rejection capacity for future heavy duty engines in Class 8 Tractors**

A 10% increase in fuel efficiency would:

- **Save a linehaul, Class 8 truck over 1800 gallons of fuel per year**
- **Reduce exhaust emissions due to less fuel use**

Reducing the need for increased heat rejection:

- **Helps maintain the aerodynamic advantages of today's trucks**





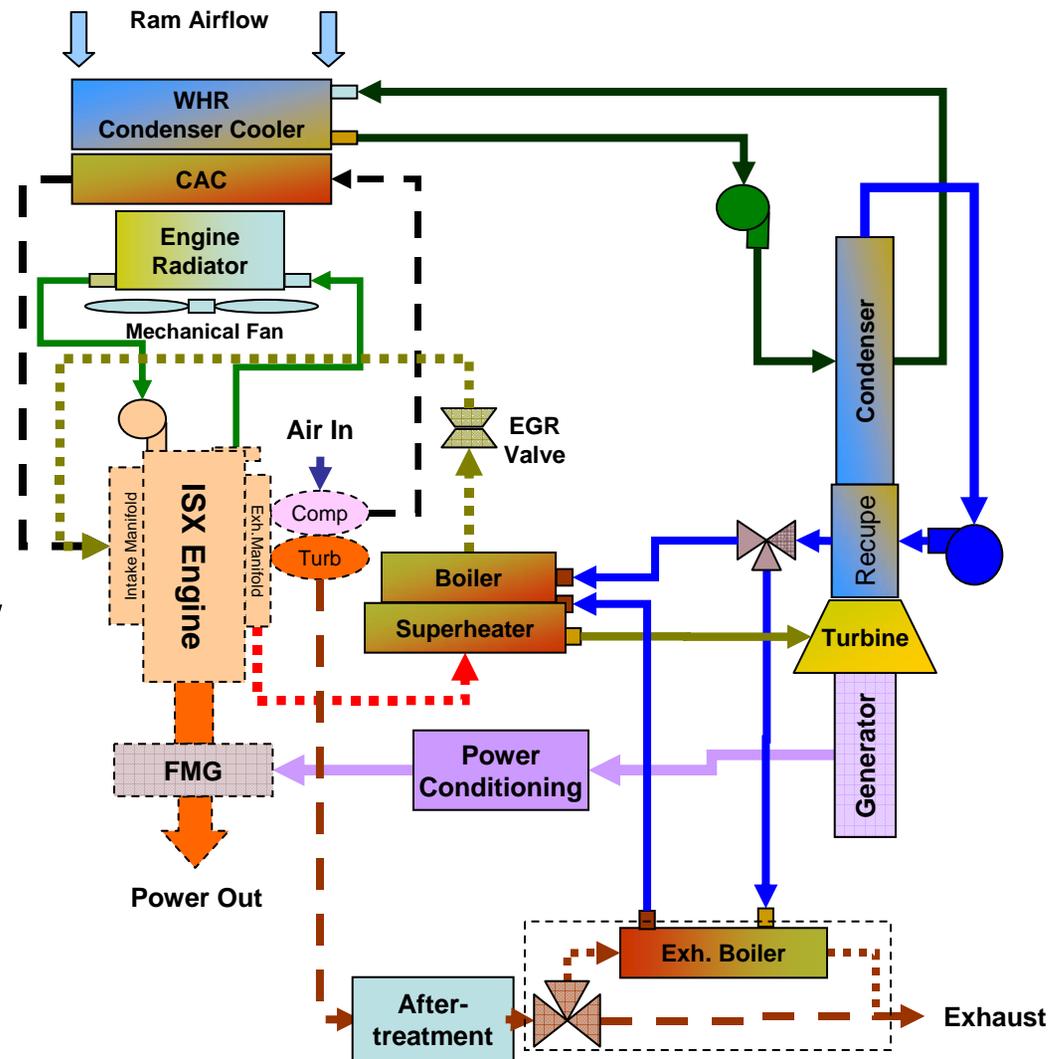
Waste Heat Recovery Concept



Organic Rankine Cycle

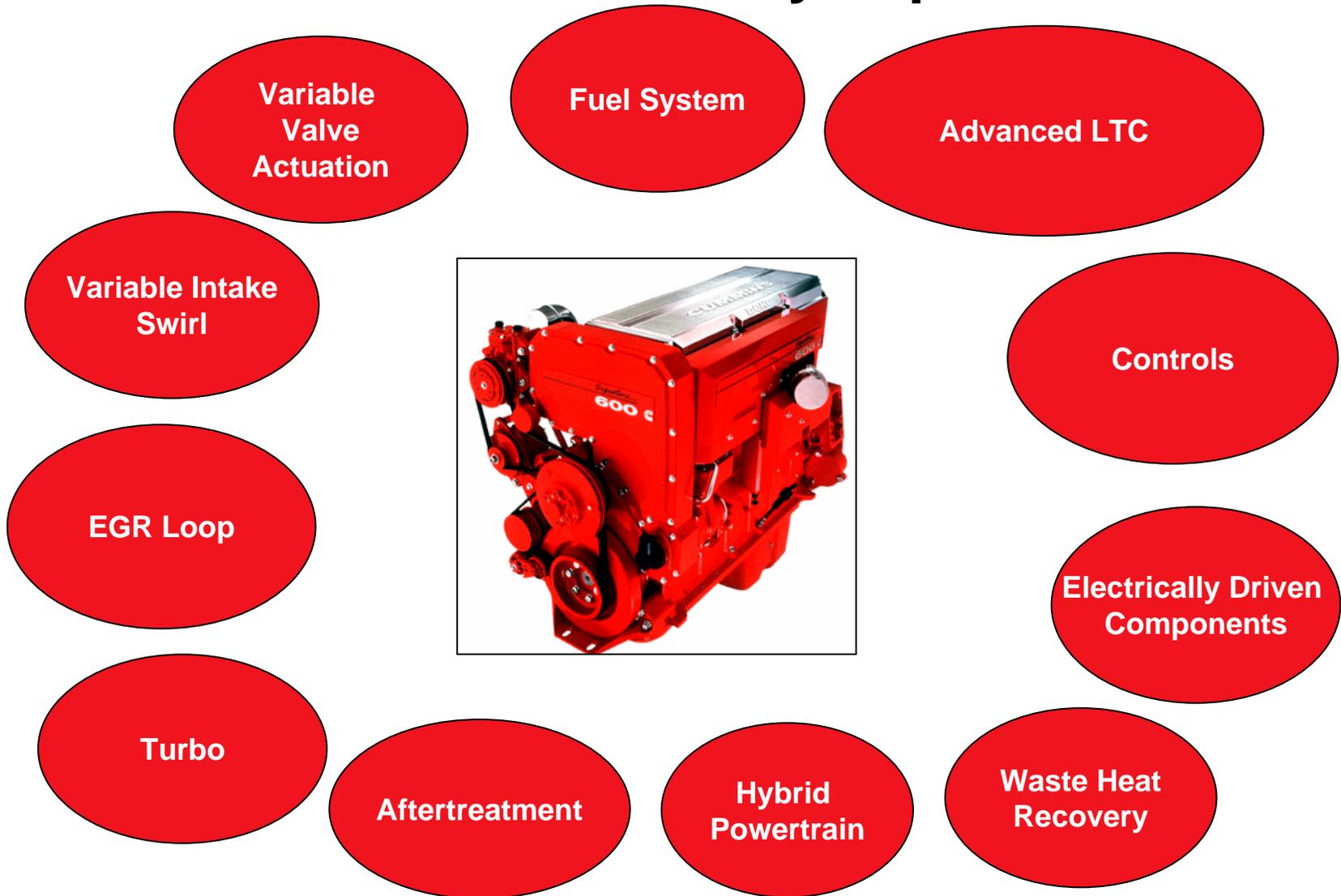
Converts otherwise wasted thermal energy from the EGR and main exhaust gas streams

Works best for high-EGR flow engine recipes for low-NOx combustion



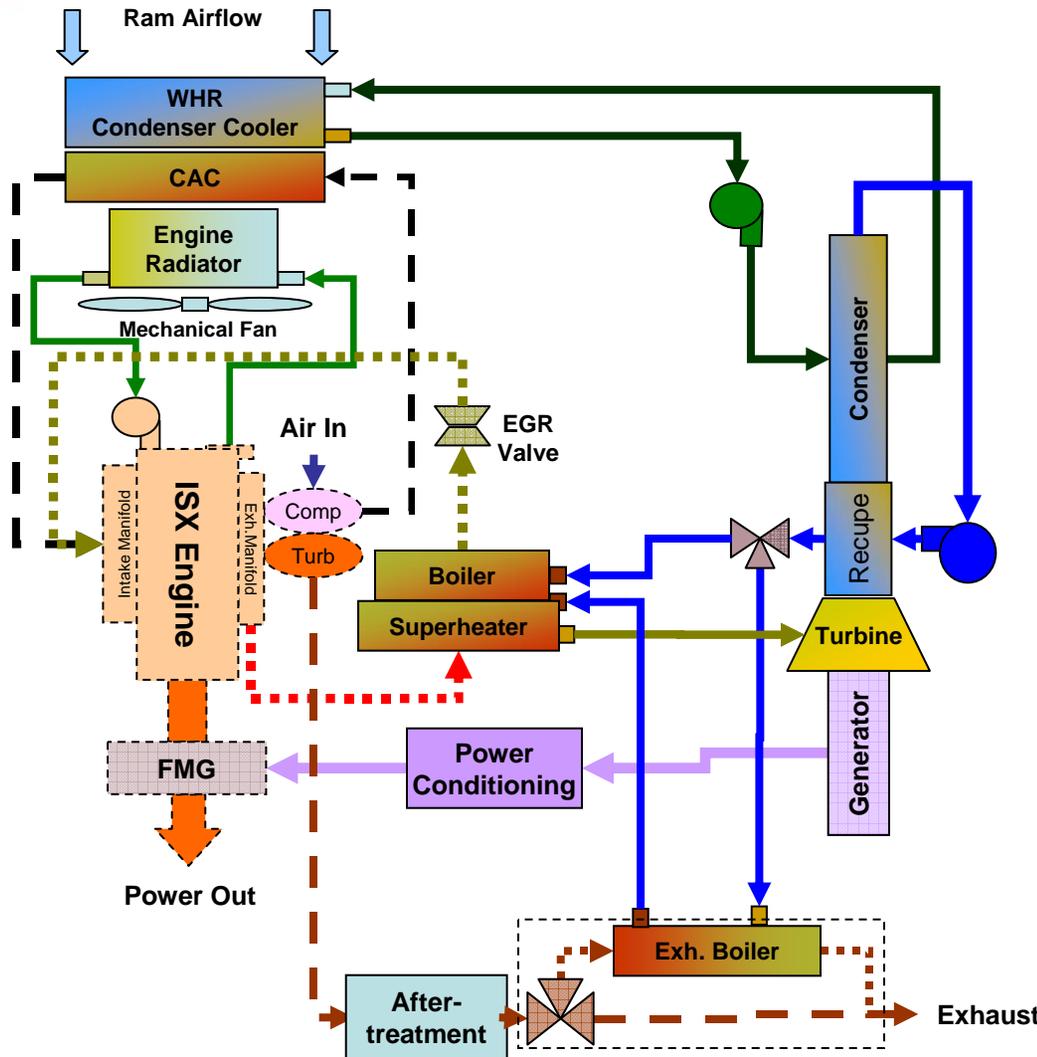


ISX Technology Roadmap for Efficiency Improvement





Recipe for 10% Efficiency Improvement



6% from EGR energy
+ 2% from Exhaust
+ 2% from Electric Acc.

10% Improvement

Model-based results across Heavy Duty drive cycle

The benefit of electric accessories is included by the presence of high-voltage electricity on-engine.



Waste Heat Recovery Program Status



Phase 1 was 'completed' in 2005

- Initial System Modeling and Performance Predictions
- Working Fluid Research and Selection

Program Phase 2 Ongoing

- System Architecture Defined
- Subsystem and Component Design
- Performance Modeling
- Vehicle Packaging Studies
- Initial Hardware Fabrication and Delivery
- Program Alignment with HECC



Program Milestone Review



Phase II Milestones for 2007/8

as reported in June of 2007

- Cyber Truck Mileage Analysis – June '07
- Refined Vehicle Layout – Sept '07
Vehicle Cooling Module Study - results and component models
- Test Cell Start Up – October '07
Engine base performance and test cell shake-down

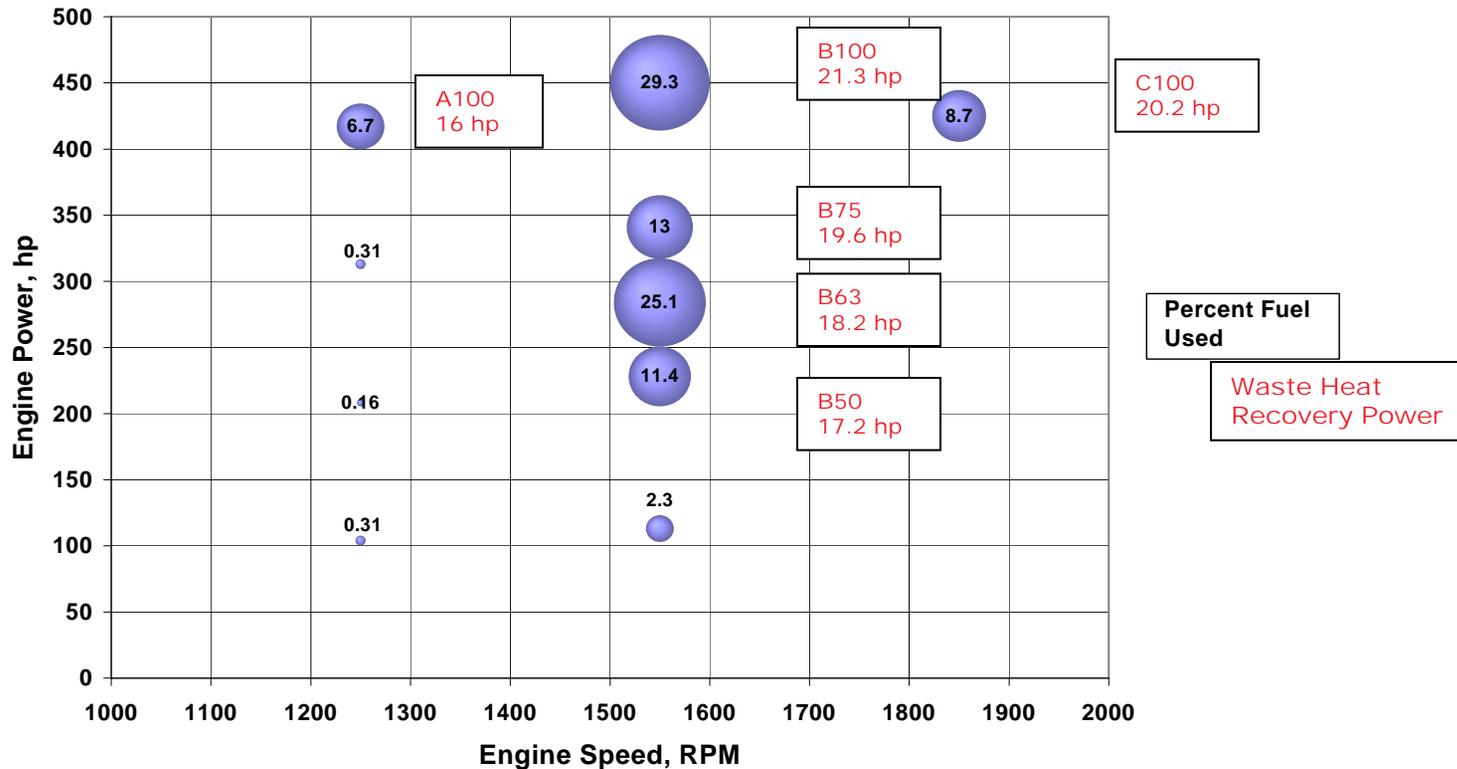
- WHR TC Components Received – January'08
- WHR Engine Startup – February '08
- WHR Vehicle Installation Start – April '08
- WHR Transient Performance Demonstrated – May '08
- WHR Vehicle Startup – May'08



2007 Milestones WHR Cyber Truck Model



International Prostar on HDCC Cycle in VMS (13-Mode)

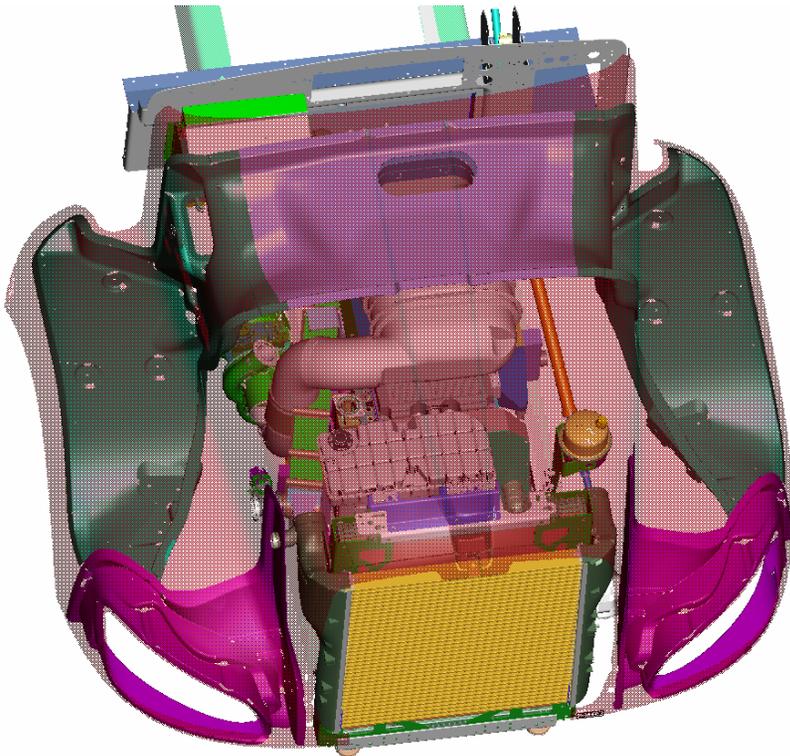


EGR-Only WHR - Net benefit for Prostar on HDCC cycle - **6%**

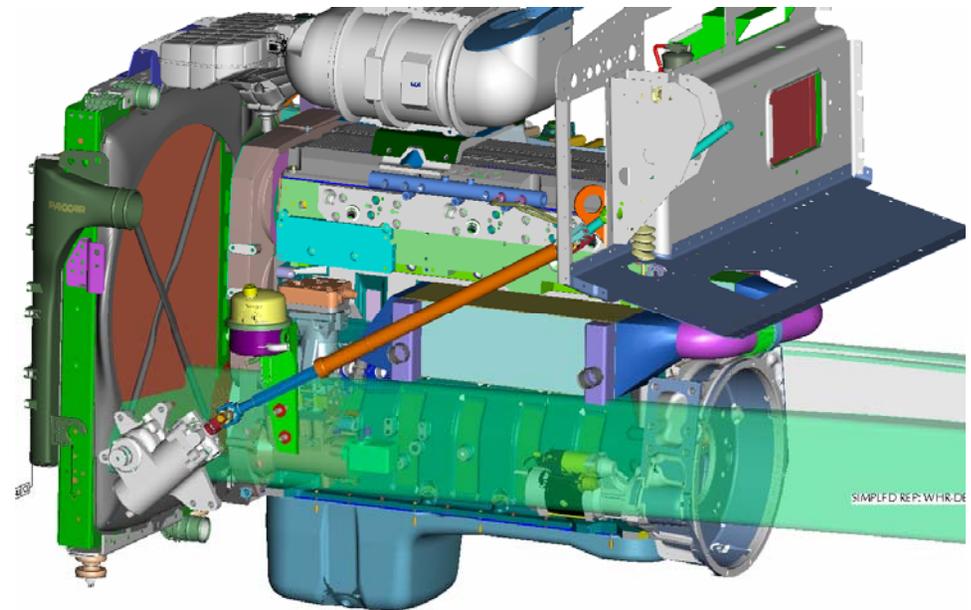
EGR+Exhaust WHR - Net benefit for Prostar on HDCC cycle - **8%**



2007 Milestones ProStar In-Vehicle Packaging

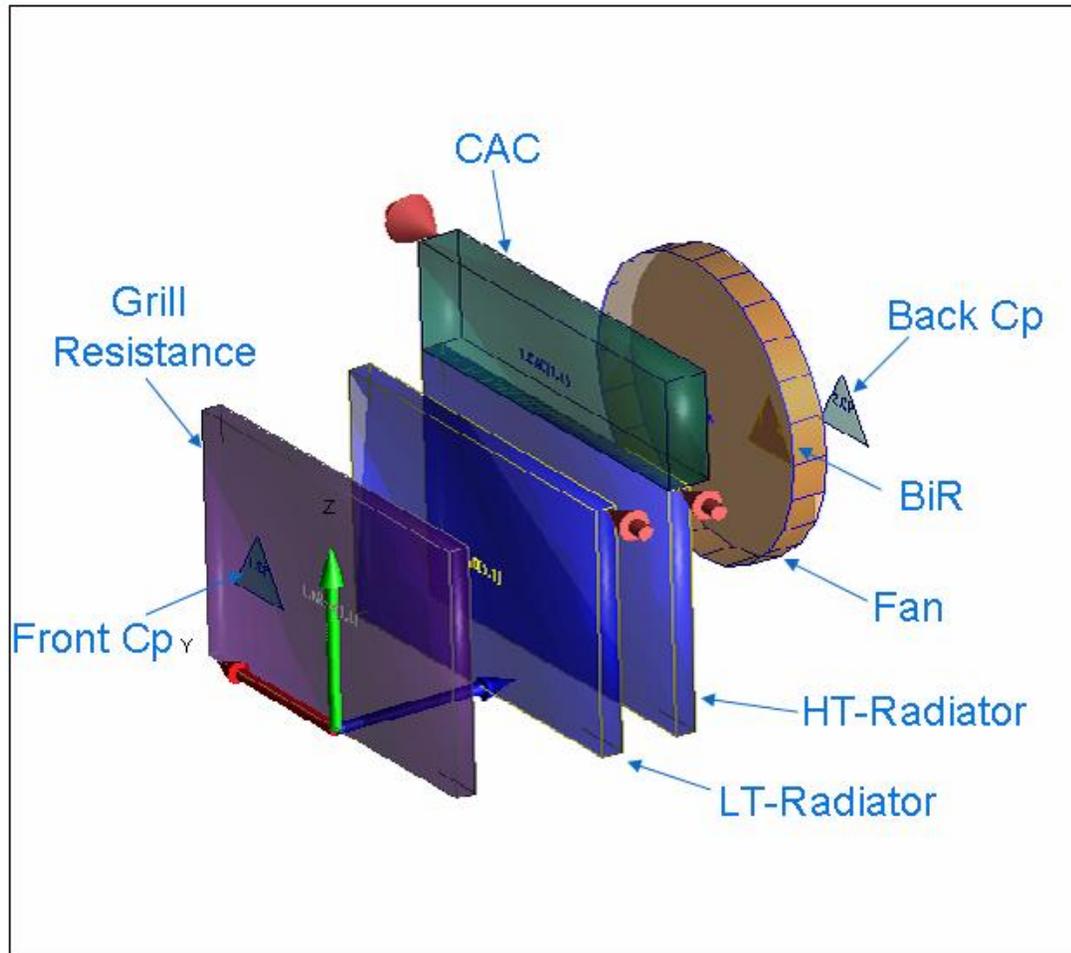


An ISX-WHR engine model was successfully packaged with its cooling system in a MY2007 Prostar





2007 Milestones Prostar Vehicle Cooling Analysis



Modine Mfg. showed that a Cooling package for a 2010-based ISX with WHR would perform and could be packaged in the MY2007 ProStar

CAC – Charge Air

HTR – Engine Radiator

LTR – WHR Radiator



2007 Milestones Test Cell Start Up



■ Test Cell Start Up –

October '07

Test Cell Testing to baseline the 2010 prototype ISX engine was postponed

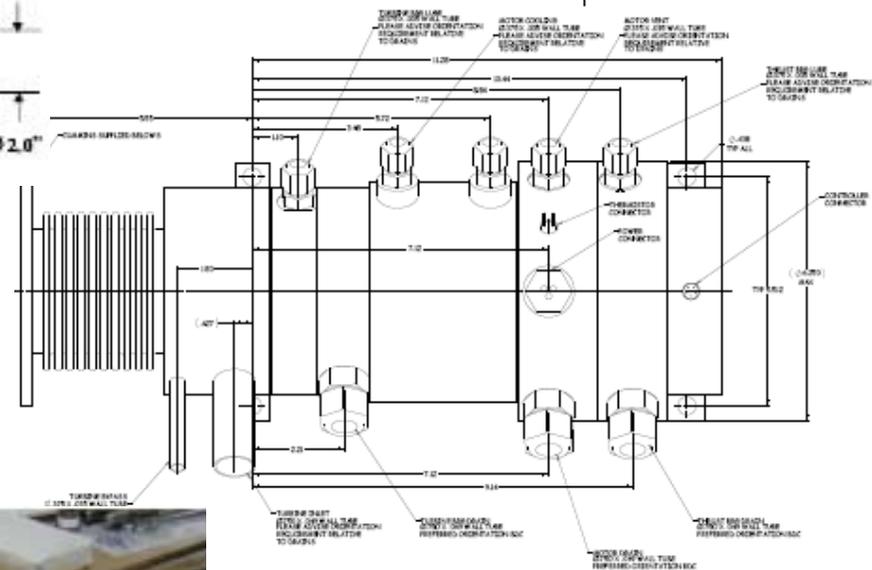
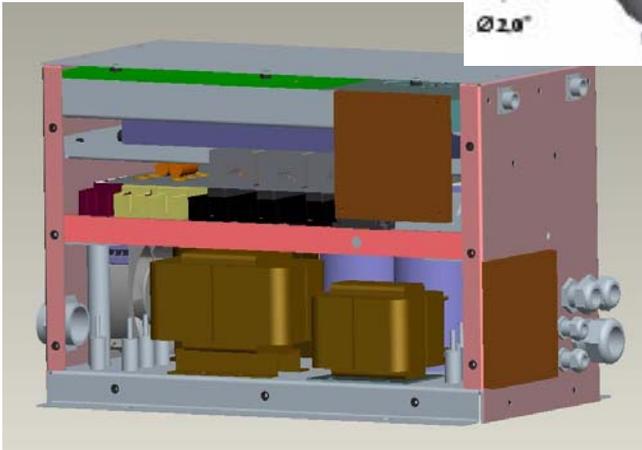
2007 current production ISX engine was chosen for initial WHR System – engine baselining was therefore eliminated from this portion of the plan

2007 ISX base engine allows focus on WHR system development without base engine development distractions.

Sufficient EGR/Exhaust heat energy is available from this engine to verify system performance models



2007 Milestones WHR Component Receipt



Hardware is being delivered now for start of testing in March



2007 Milestones Vehicle Testing Plans



- WHR Vehicle Installation Start – ~~April '08~~
- WHR Transient Performance Demonstrated – ~~May '08~~
- WHR Vehicle Startup – ~~May '08~~

During Q4'07, the WHR program schedule was aligned with the HECC program. WHR came along too late for 2010 product development. A 2013-intent focus for WHR will increase its potential development on/into future products.

Vehicle testing is now planned in mid-2009 and will be coupled with engine recipes capable of 2013 emissions



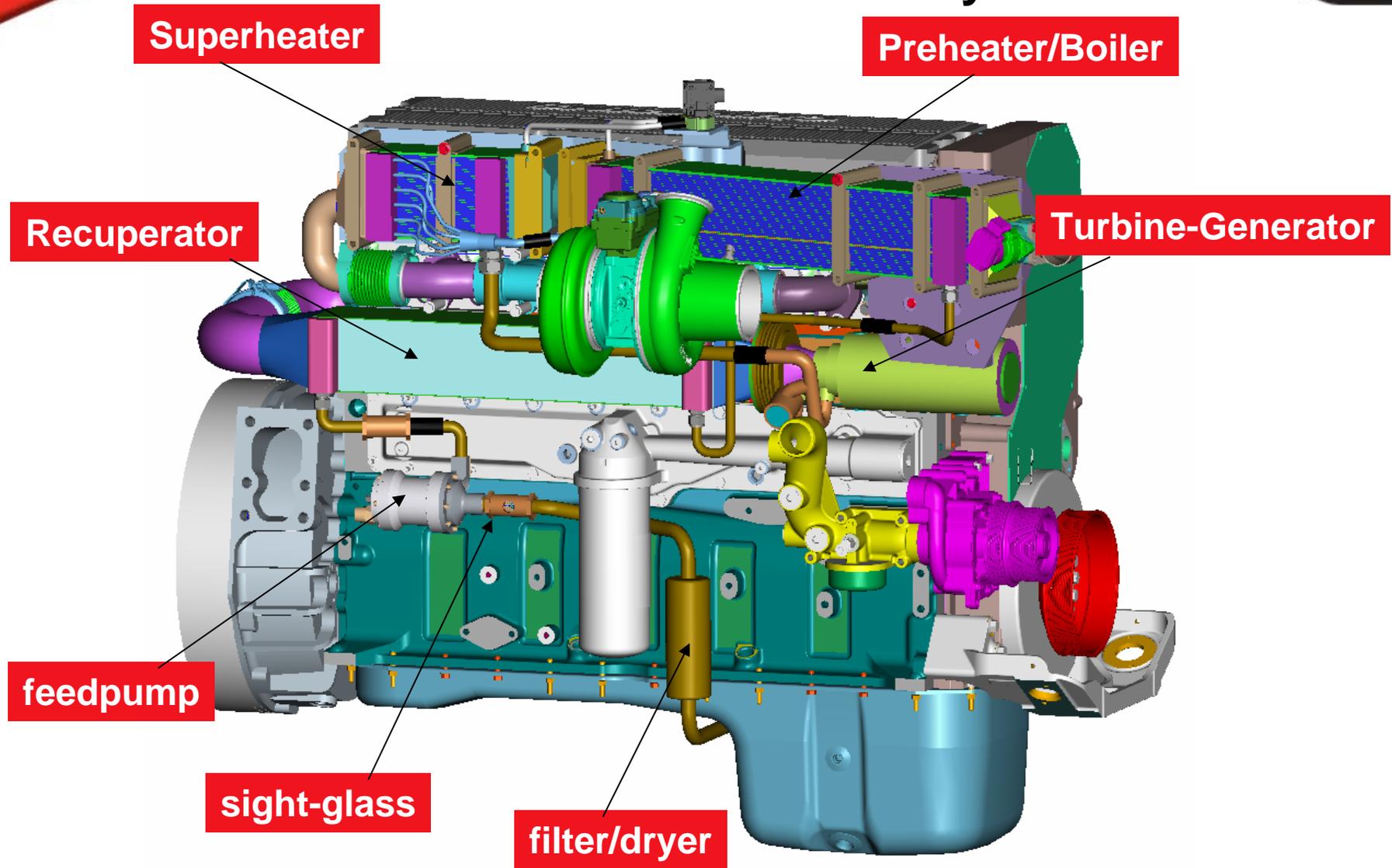
2007 Accomplishment Summary



- **System Analysis and Recipe for 10% Goal** Completed
- **Cybertruck Drive Cycle Performance Analysis** Completed
- **First-Generation Hardware Design** Completed
- **In-Vehicle Design Layout** Completed
- **In-chassis Cooling Module Analysis** Completed
- **Fabrication of First-Generation Hardware** Underway
- **Hardware Deliveries for Initial Testing** Underway

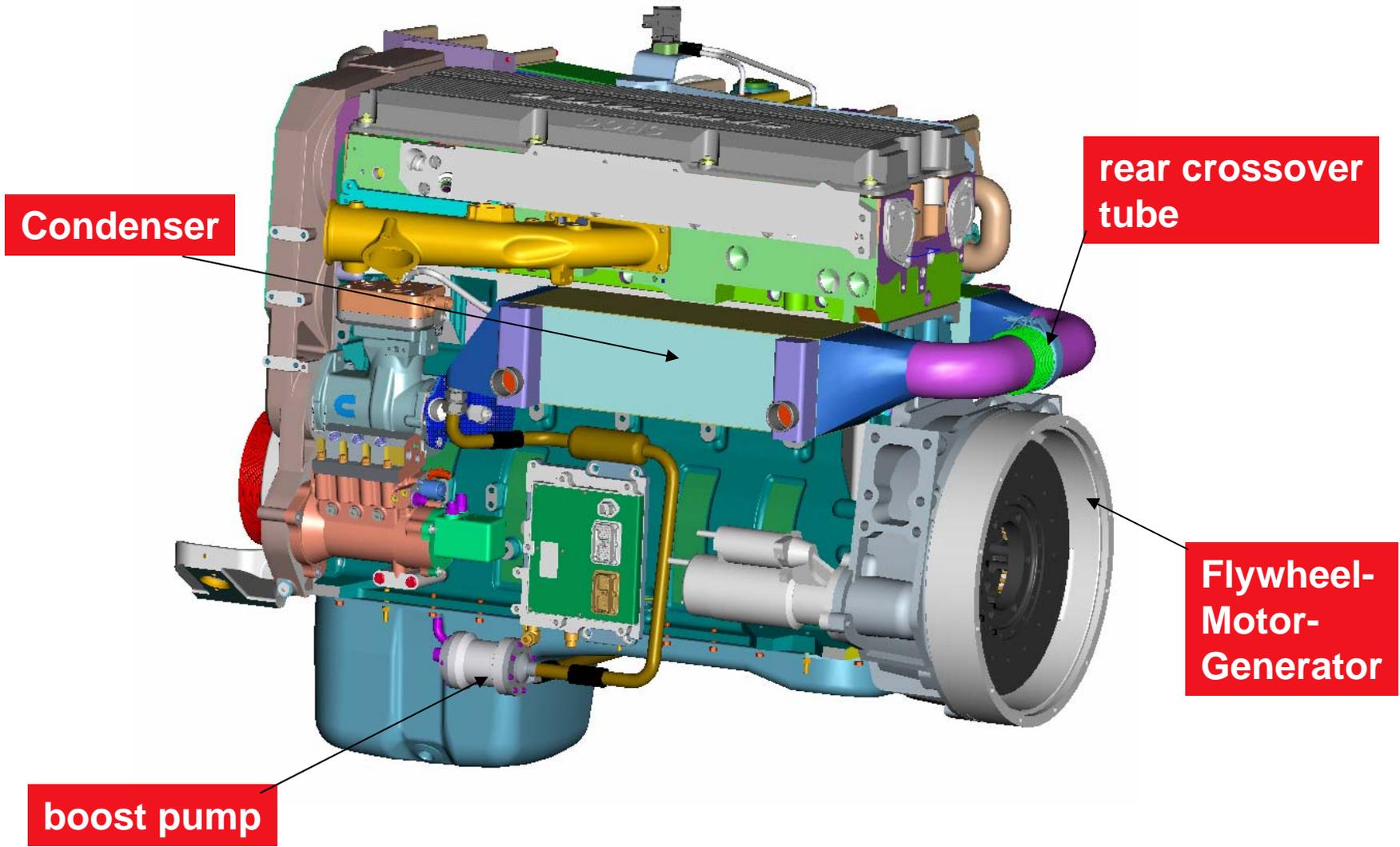


WHR Hardware Update First-Generation System





WHR Hardware Update First-Generation System





Boost/Feed Pumps



Boost Pump Controller



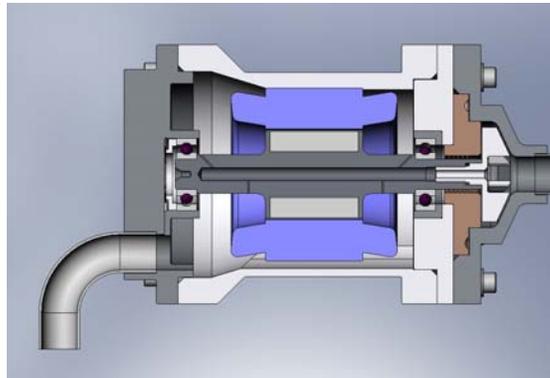
Boost Pump

Boost Pump –

- 60 psid
- 3-9krpm
- 7.5 lbs
- Hermetically Sealed
- Variable Speed
- CAN Bus Control Interface



Feed Pump Controller



Feed Pump Cross Section

Feed Pump –

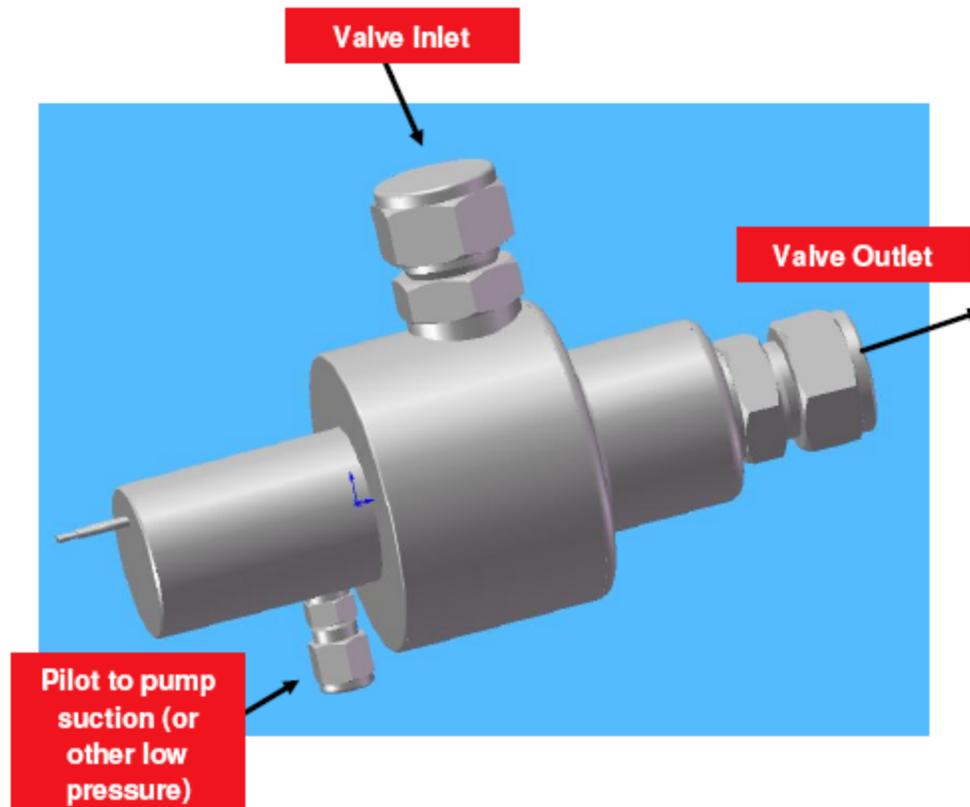
- 300 psid
- 0.7-1.7 lbm/sec flow
- 25krpm
- 8 lbs
- Ball Bearing
- Hermetically Sealed
- CAN Bus Control Interface

Delivery of pumps/controllers occurred this month





Bypass Control Valve



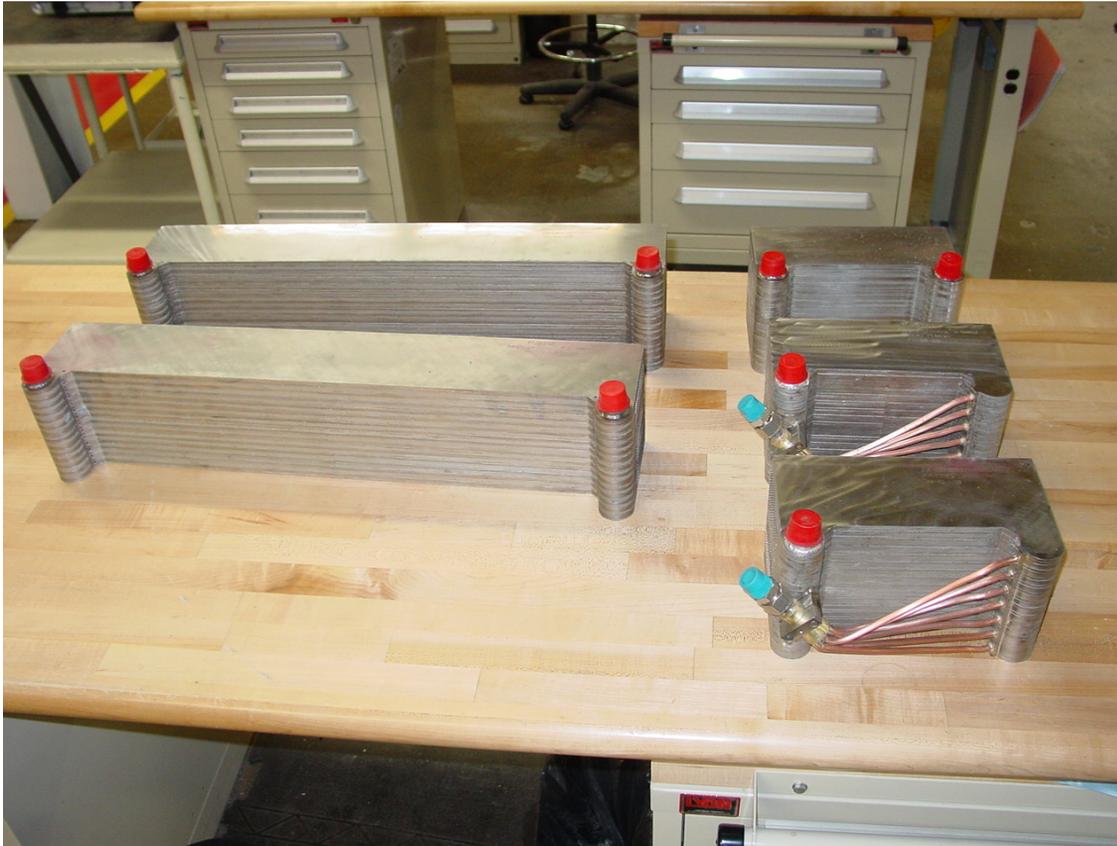
Cross-Turbine Bypass Valve

- G.W.Lisk PN M3-3240
- Inline, NC
- Direct Lift, 2 Position
- Poppet Type
- Solenoid Operation
- Flow Control by varying duty cycle – 10 Hz PWM Max

Delivery is planned to occur in March



Heat Exchangers



Superheater and Boiler –

- 304SS Construction
- 500 psi test pressure
- ‘Vented’ edge welds to allow R245 to vent to atmosphere in case of leak

Recuperator and Condenser

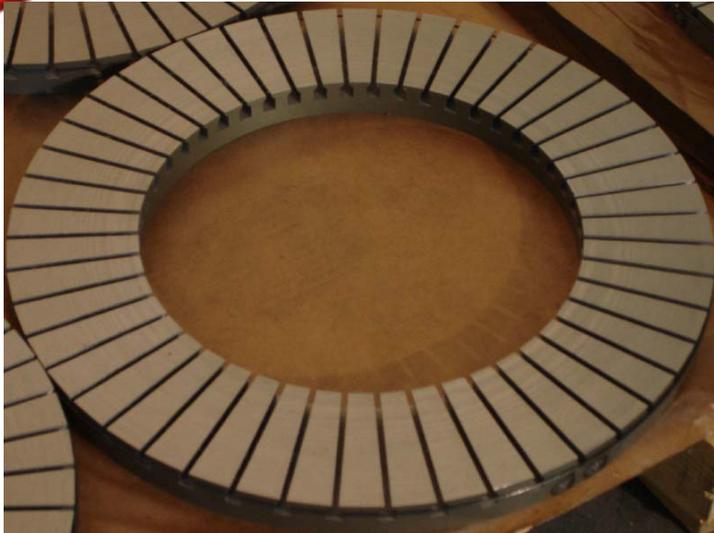
- Aluminum Construction

Delivery of all first-generation heat exchangers has occurred this month

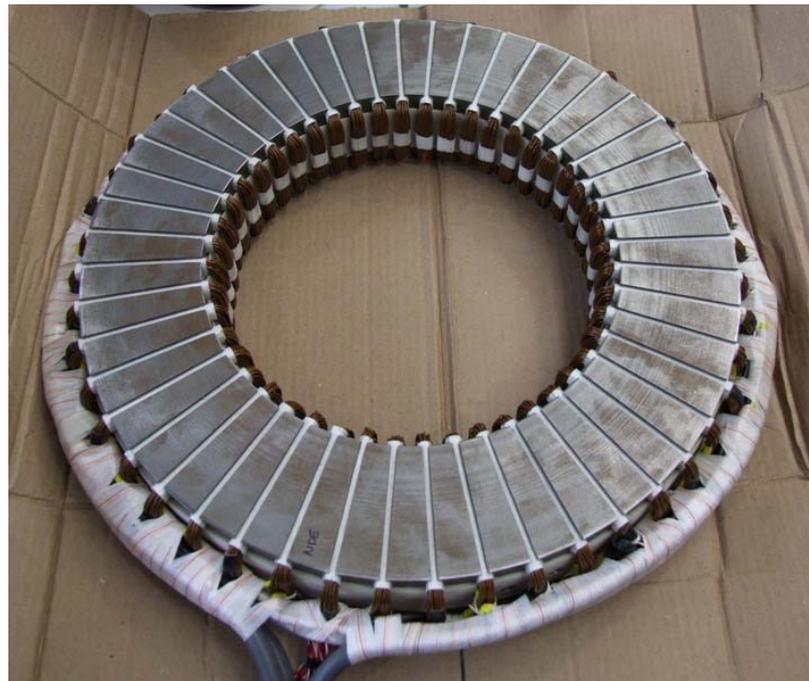
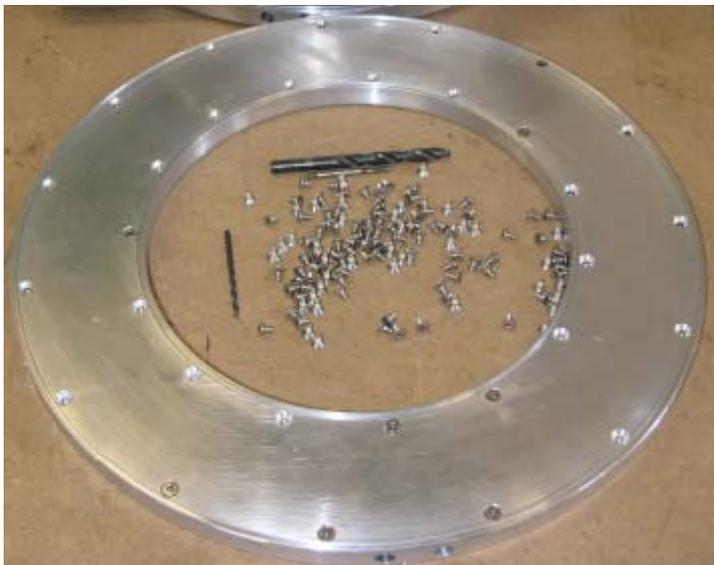




Flywheel Motor/Generator



Stators – assembled around water jacket core and installed into Flywheel Housing





Flywheel Motor/Generator



Assembled FMG on test at CGT



Half of Rotor Assembly showing magnet mounting details

Delivery of the first FMG and controller occurred in January



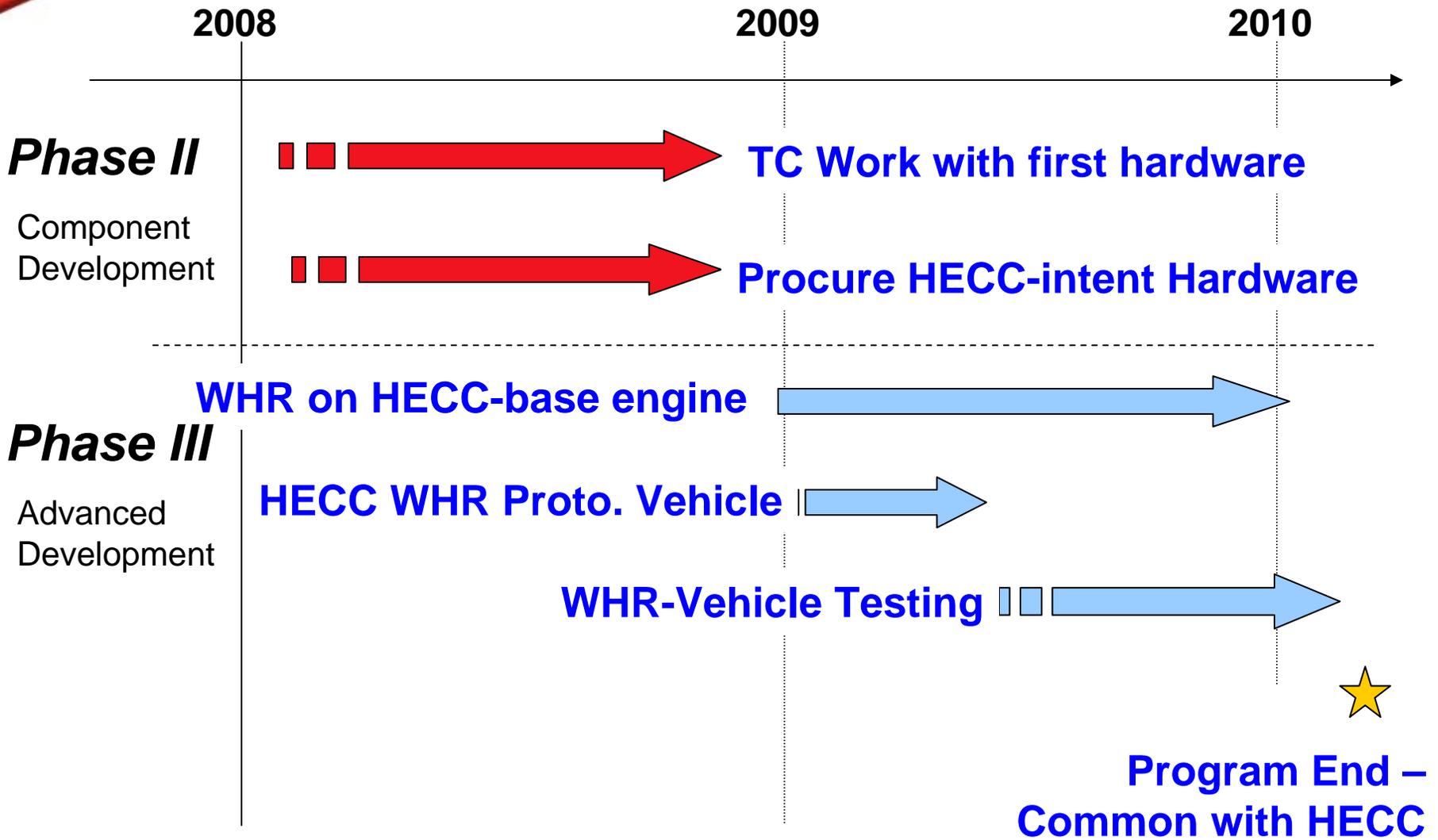
Plans for 2008



- **First hardware has been received**
- **First engine build occurring now**
- **Test Cell Startup April 1st**
- **System Design Revisions are being performed to refine the system and to be tailored to HECC-intent engine recipes**
- **Fabrication of revised 2nd Generation hardware set will occur this year**
- **New WHR Engine builds at end of 2008 (Phase 3)**

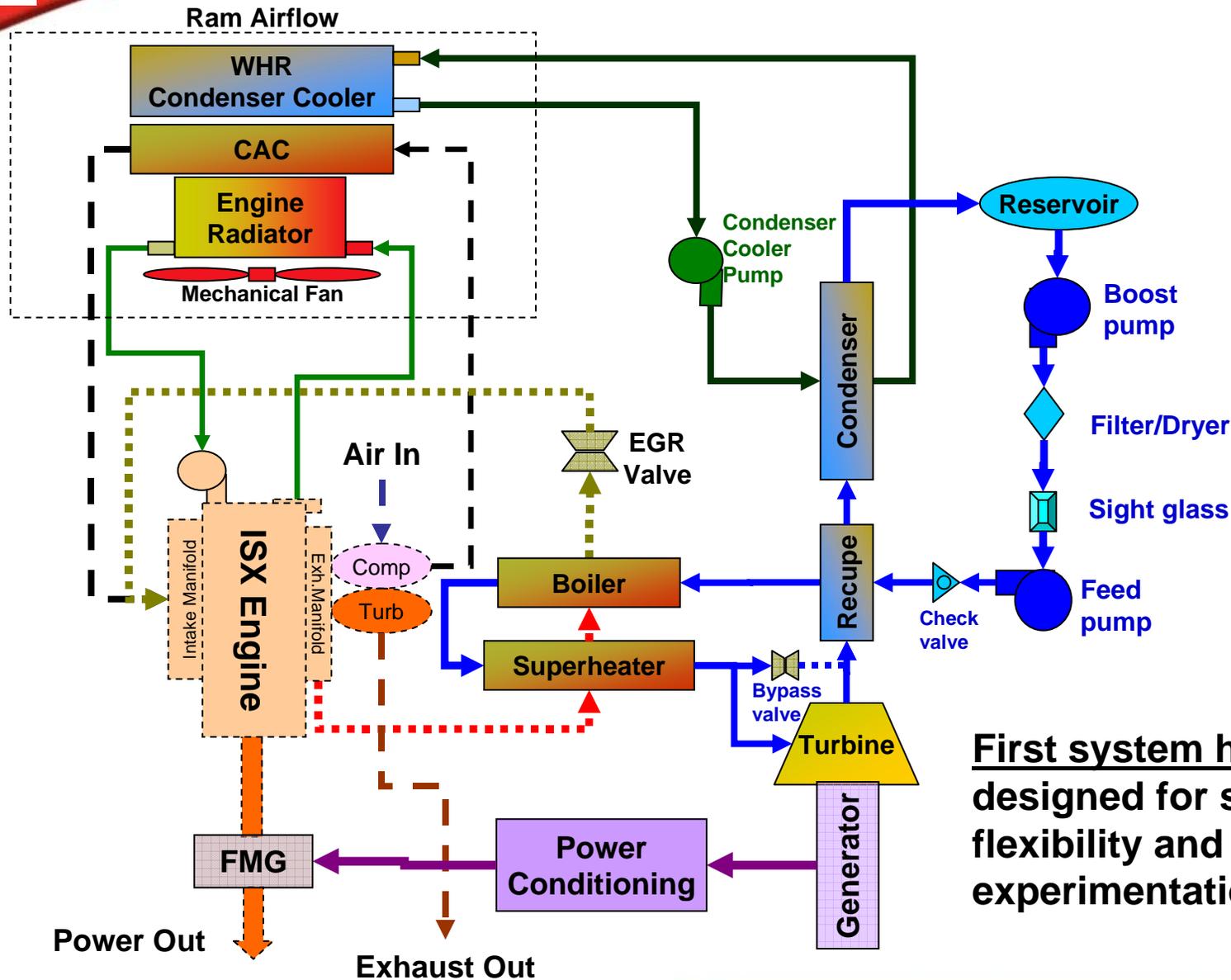


WHR Remaining Program Timeline





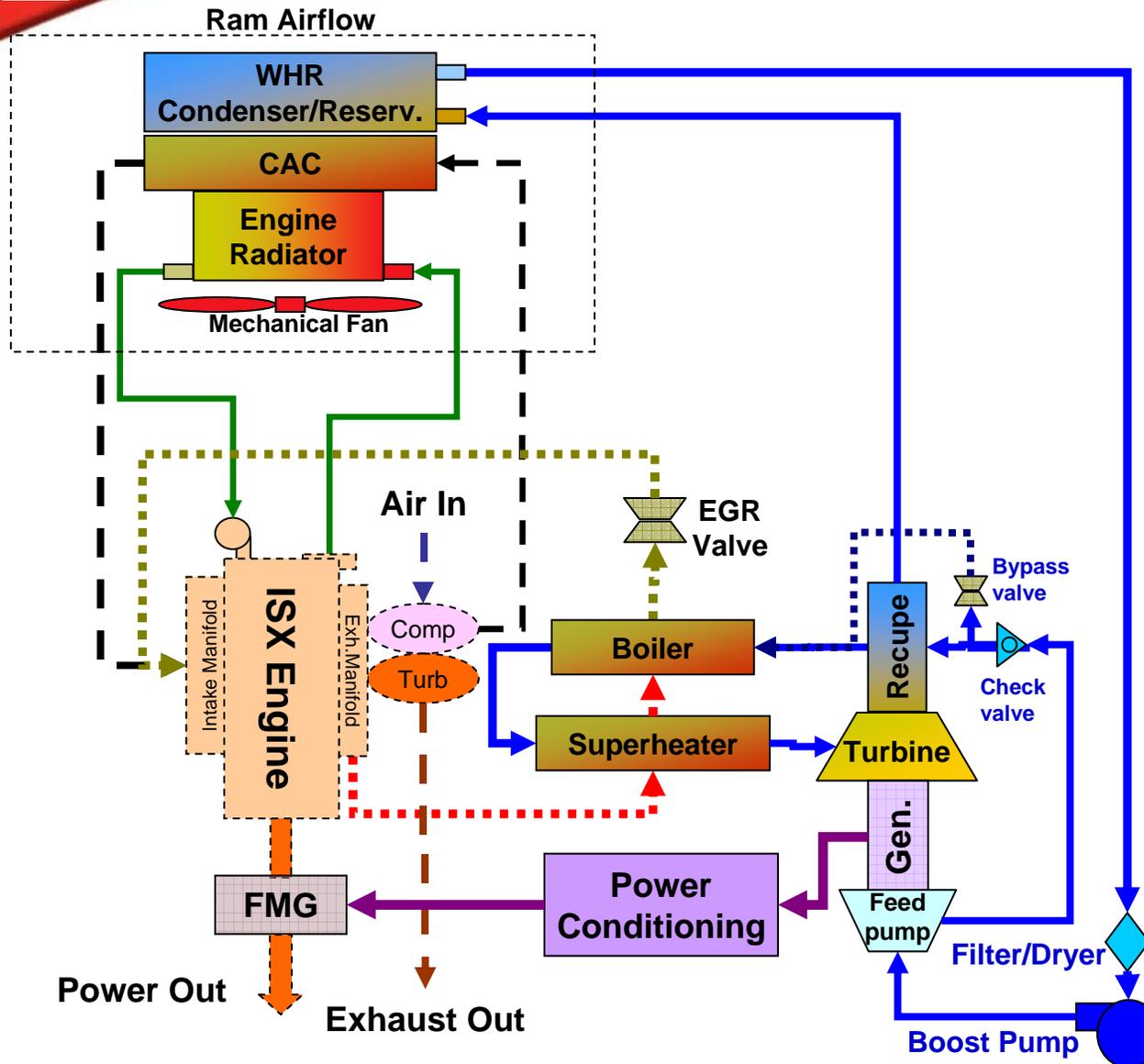
2008 WHR System Evolution



First system hardware designed for system flexibility and experimentation



2008 WHR System Evolution



Second-Generation hardware will be designed to simplify and reduce cost.

An Air-cooled condenser is an option which will be studied in 2008.



Milestones for 2008



Testing and Development with first hardware set -

First WHR Engine Start –	April '08
WHR Steady State Power Generation –	June '08
R245fa Thermal Cycle Test Results –	August '08
Exhaust Recovery System Results –	October '08

Refinement and Evolution of the WHR System –

Air-Cooled Condenser Analysis -	June '08
Second-Generation Hardware Procurement -	November '08
Next Generation Engine Build (Phase 3) -	December '08



Review and Summary



Significant Progress in FY 2007

- Drive Cycle Analysis Performed
- System Architecture Determined
- Recipe for 10% Efficiency Improvement Goal
- Component Design and Fabrication
- Hardware Deliveries Now Underway

2008 Plans

- Testing and Investigation of first-generation hardware
- System analysis for refinement and evolution
- Procurement of second-generation hardware
- Integration with HECC engine architecture



Cummins Waste Heat Recovery



Cummins Inc. Appreciates the Partnership Support of the U.S. Department of Energy in this highly innovative and unique program –

Thank You!

