Exhaust Energy Recovery

2008 DEER Conference

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Research & Technology

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Cummins®

Agenda

Program Objectives

- WHR Concept and Efficiency Goal Plan
- Program Schedule

First Generation Hardware and Evaluation

- Engine-integrated hardware set
- Performance Testing Results

2nd Generation Hardware Evolution

Summary

Goals and Objectives

Project Goals are:

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

10% increase in fuel efficiency would:

- Save a linehaul, Class 8 truck over 1800 gallons of fuel per year (120k miles/year at 6mpg)
- Reduce exhaust emissions due to less fuel use

Reduced need for increased heat rejection:

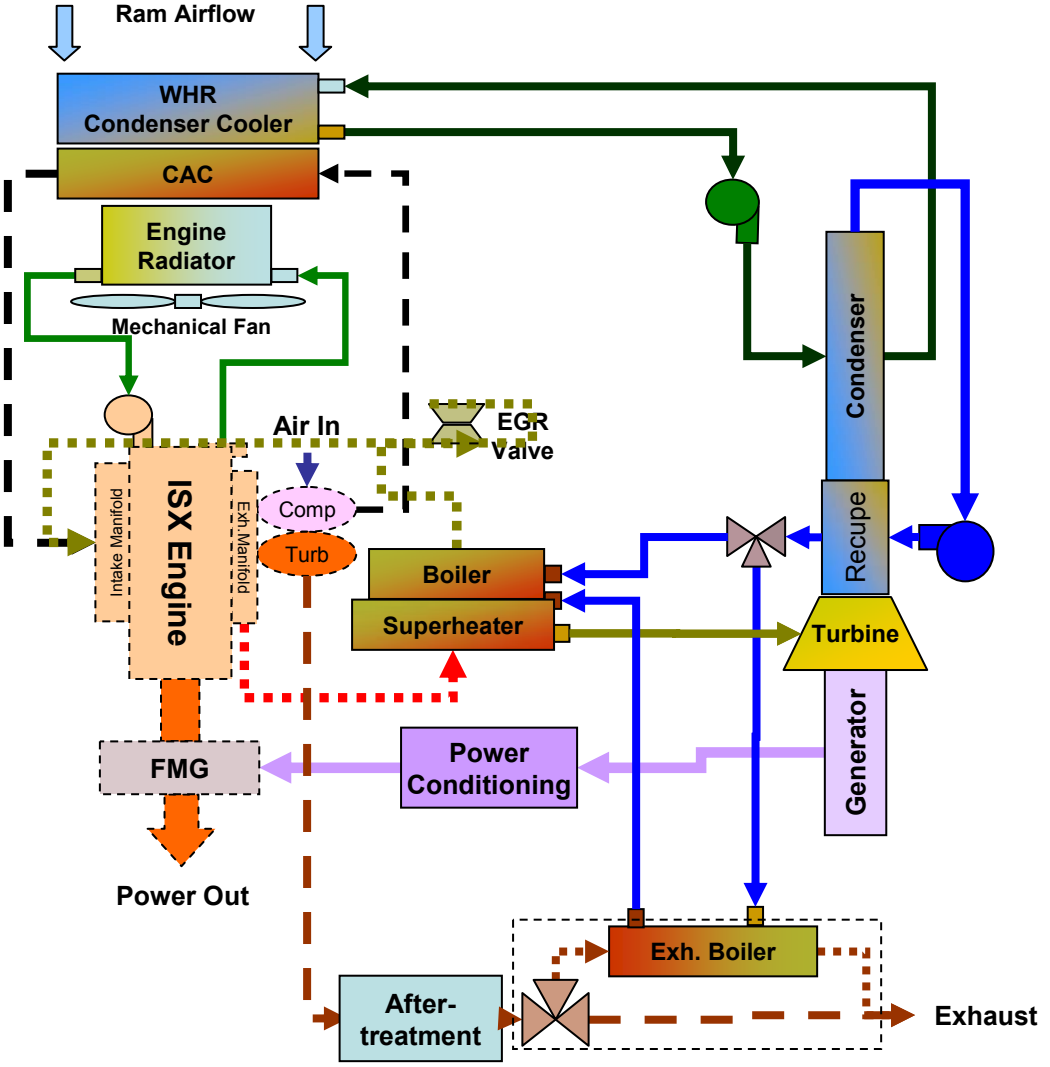
- Help maintain the aerodynamic advantages of today's trucks

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



Recipe for 10% Efficiency Improvement

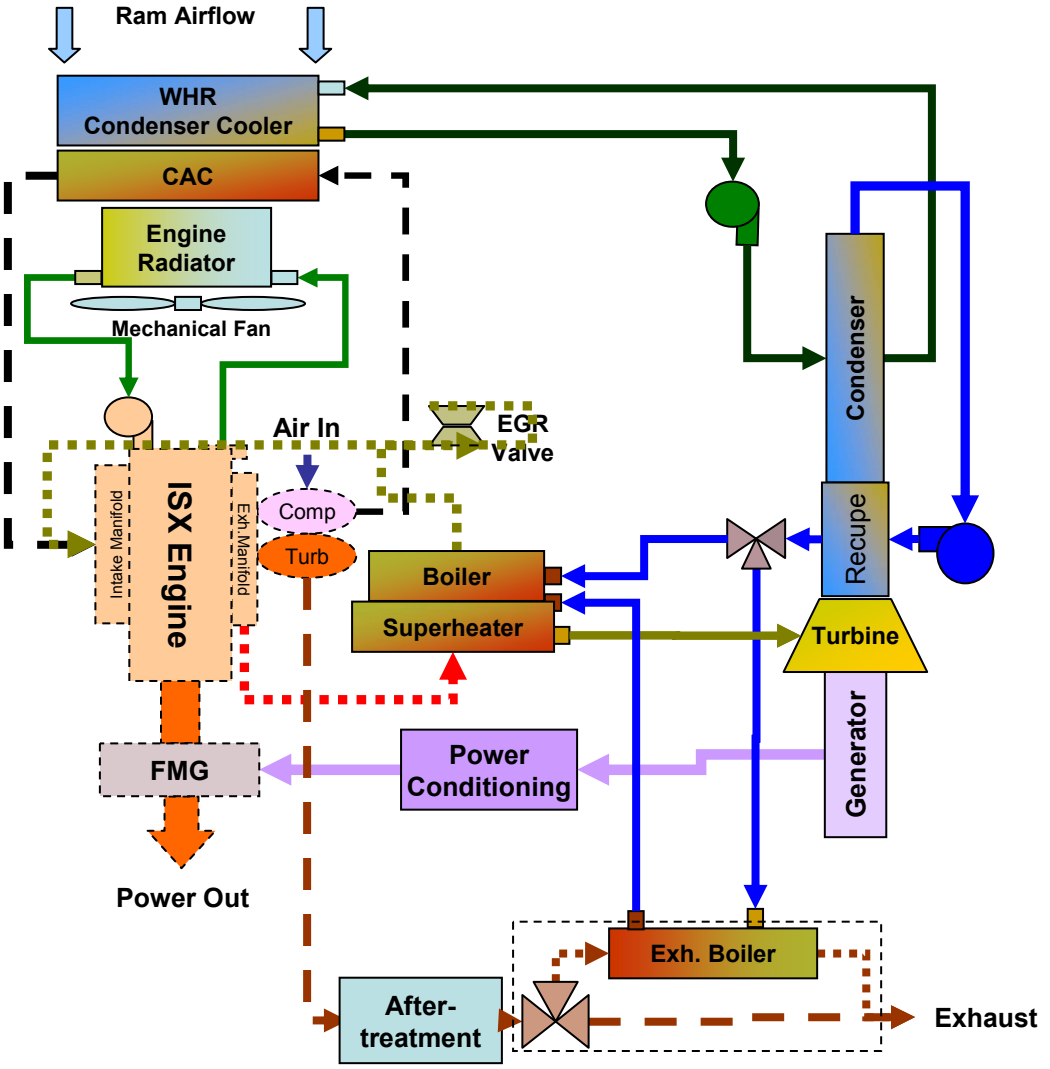
6% from EGR energy

+ 2% from Exhaust

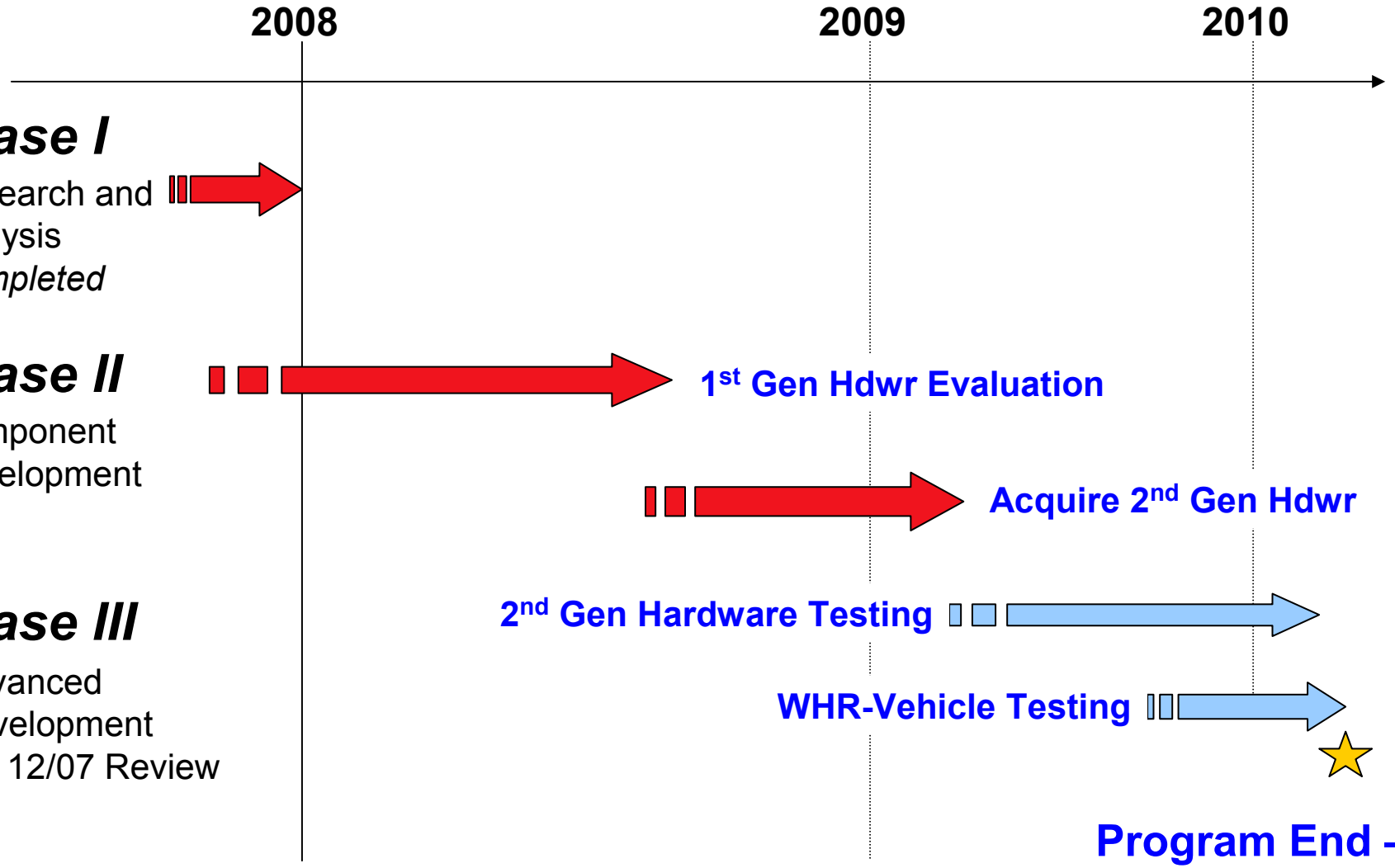
+ 2% from Electric Acc.

10% Improvement Goal

Our test results to date indicate that our model predictions are feasible and realistic



Current Program Timeline

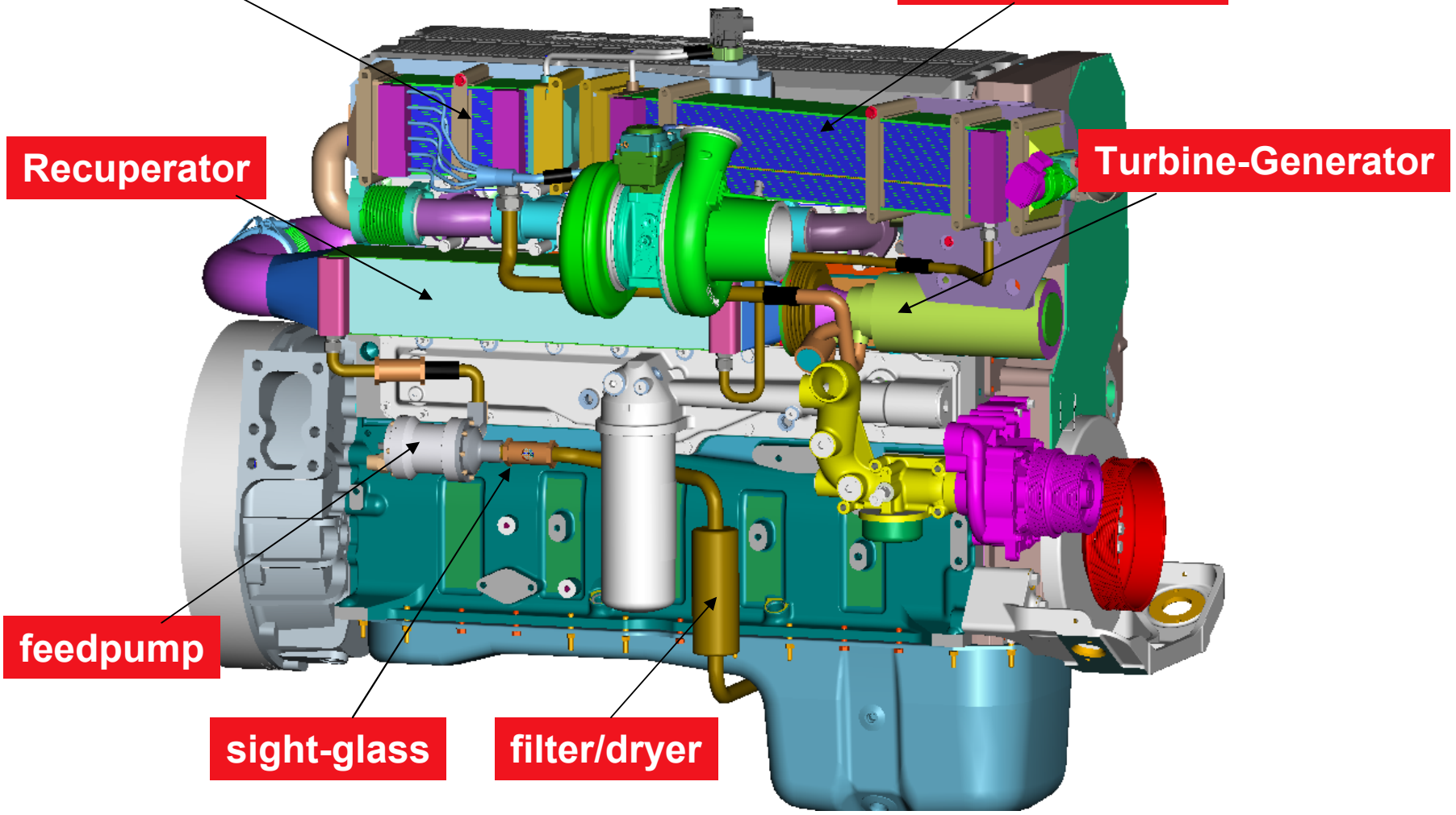


Milestones for 2007/2008

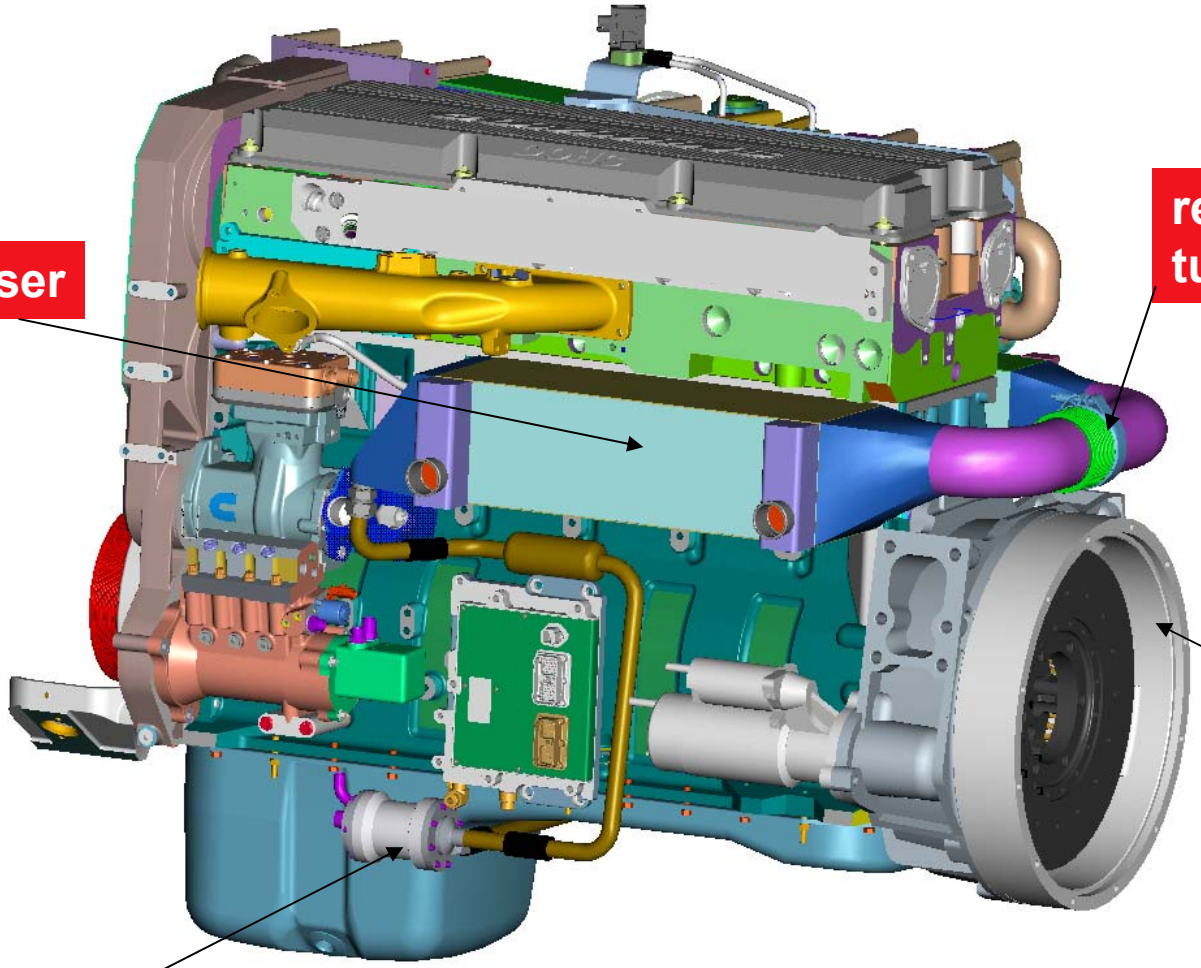
Steady Progress -

Design 1st Gen Hardware	June ’07	★
Acquire 1st Gen Hardware	Dec. ’07	★
1st Gen Engine Build	Feb. ‘07	★
First WHR Engine Start –	April ‘08	★
WHR Steady State Power Generation –	June ‘08	★
Exhaust Recovery and Transients –	August ’08	
Second-Generation Hardware Design -	Q3/Q4 ‘08	

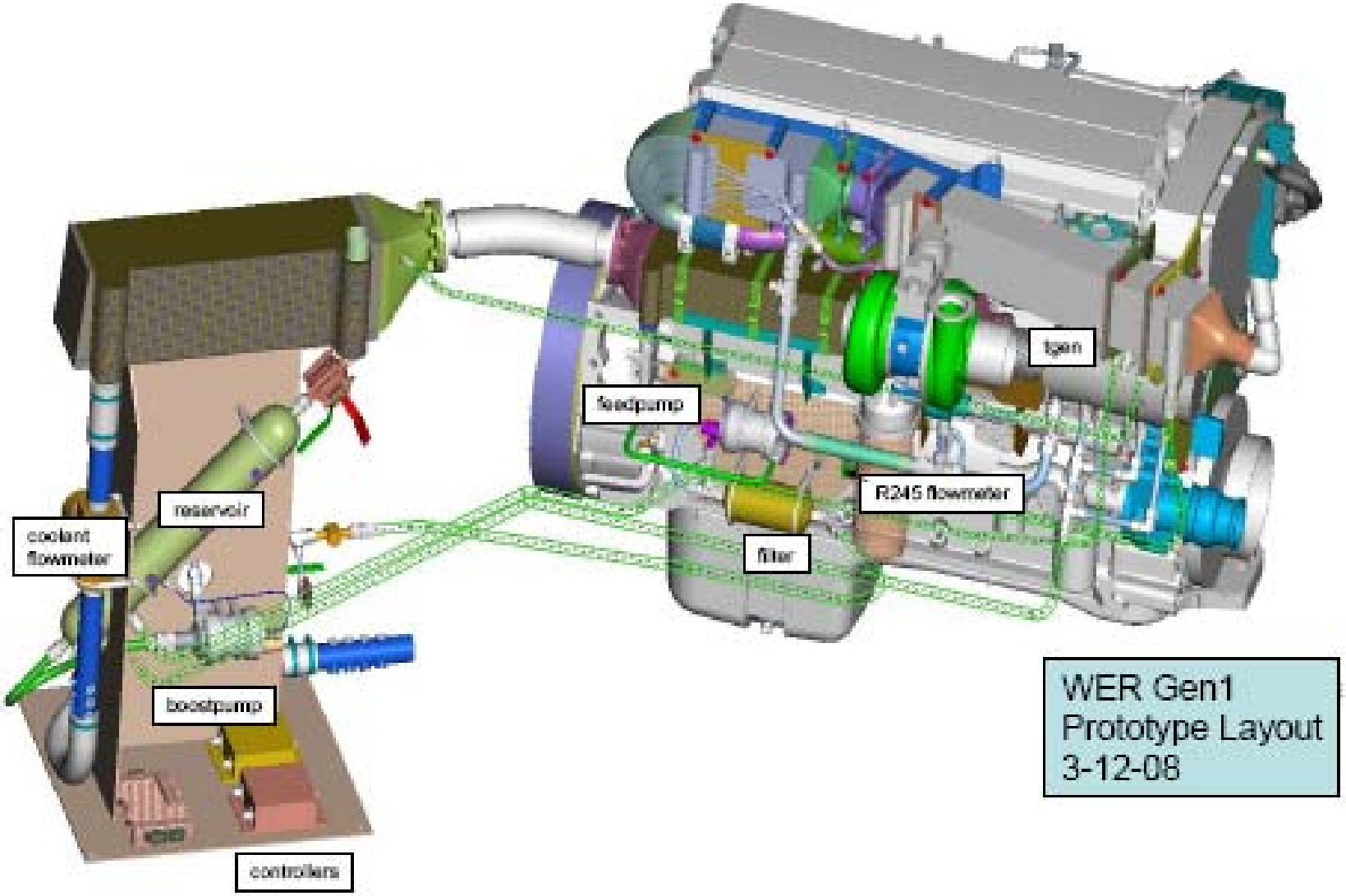
WHR
First Generation Hardware Design



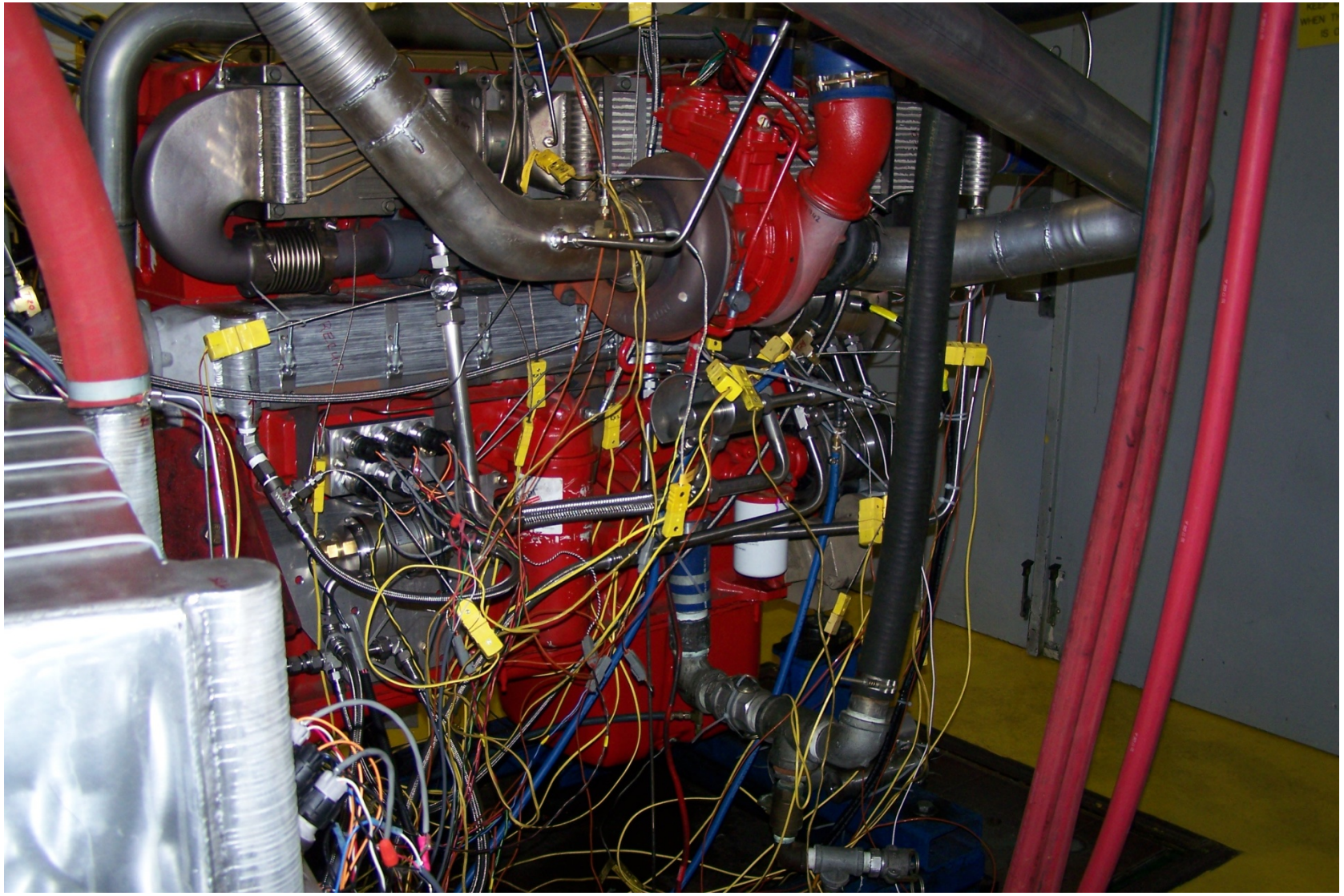
WHR
First Generation Hardware Design



First Generation
Test Cell Installation

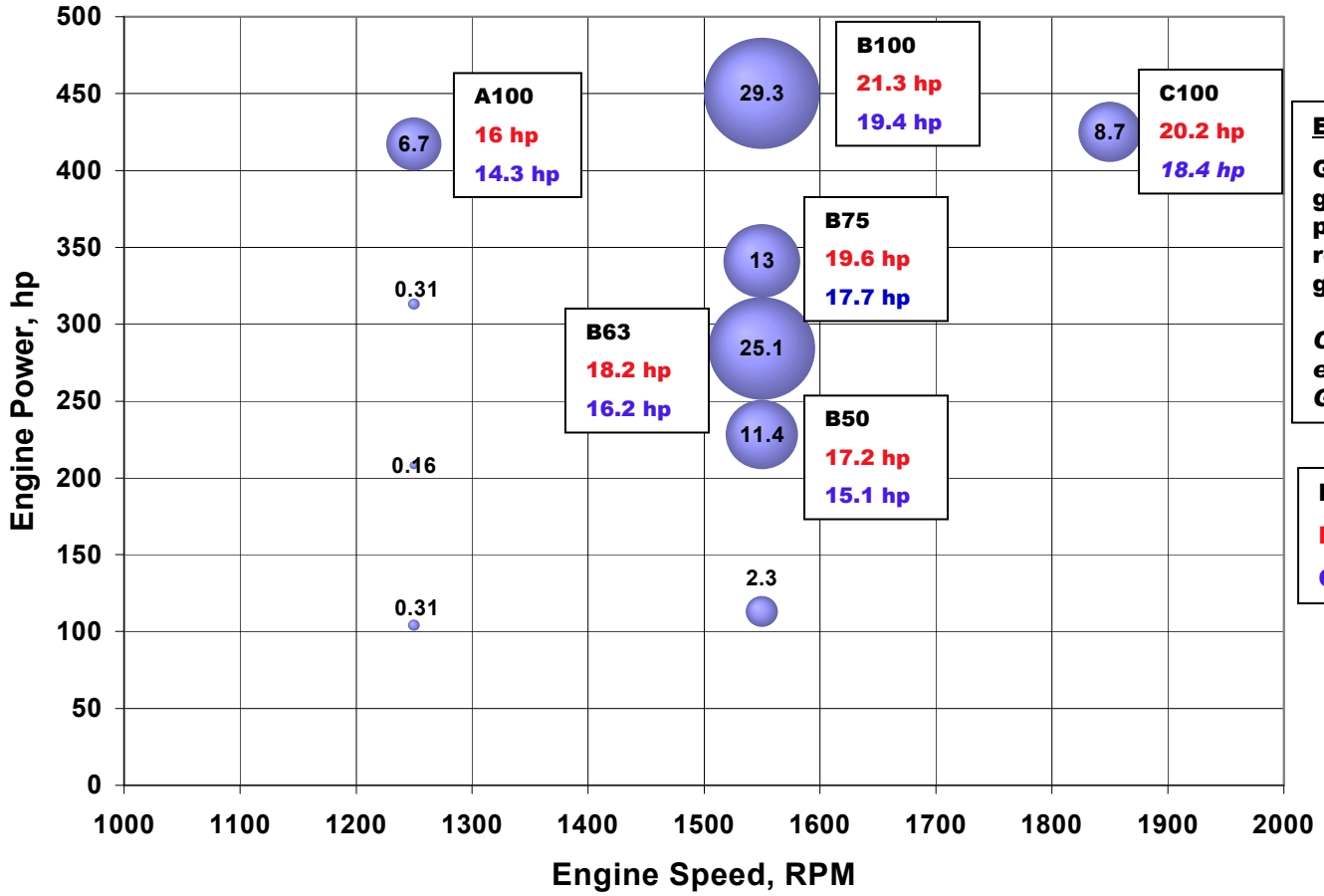


ISX with WHR System in Test Cell



Duty Cycle Fuel Efficiency Improvement

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



EGR Only Heat Recovery

Gen1 Test results reflect greater than expected parasitics which may be reduced in future hardware generations

C100 Gen1 Test Result is extrapolated from other Gen1 data

Engine Operating Point

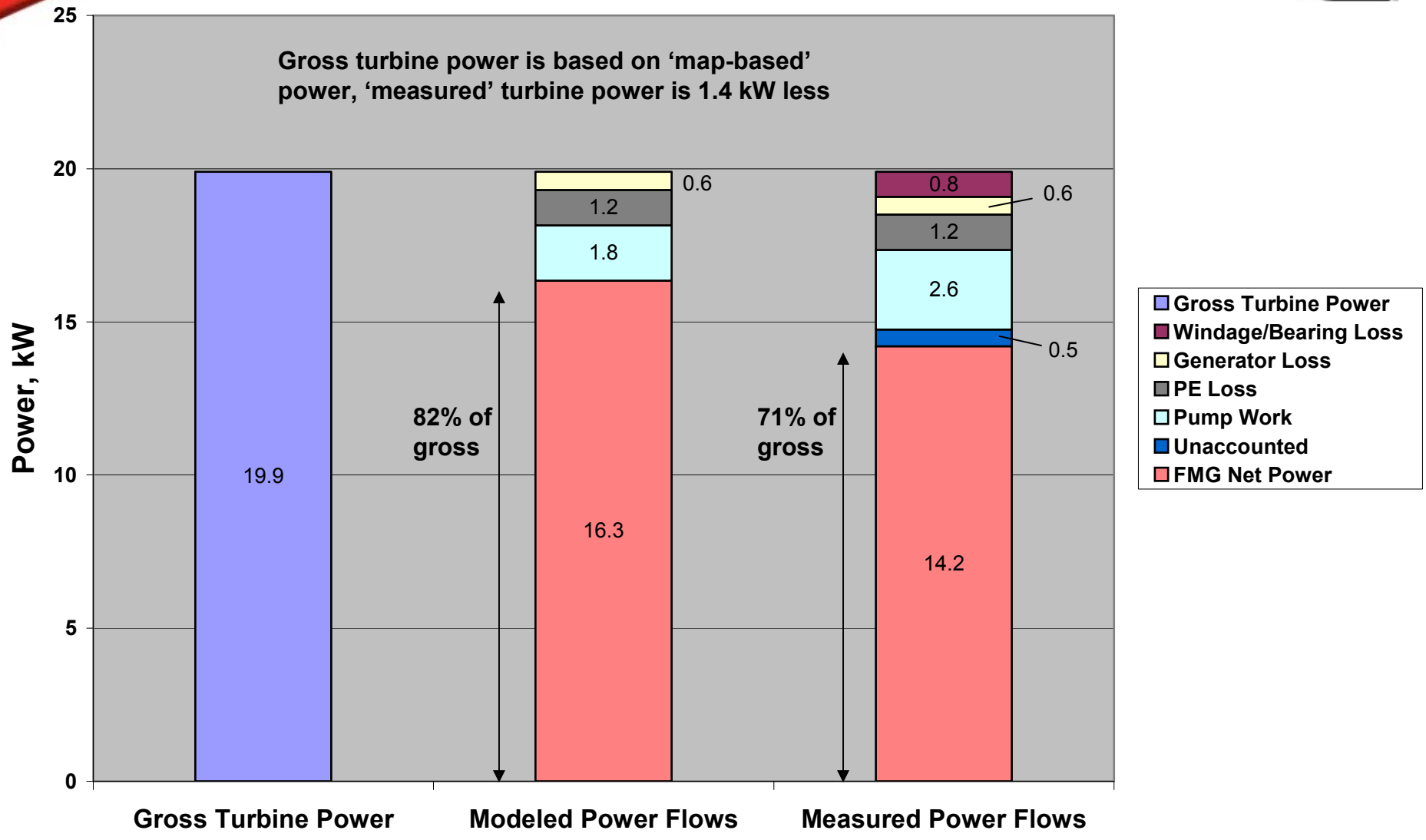
Predicted WHR Power

Observed Gen1 Power

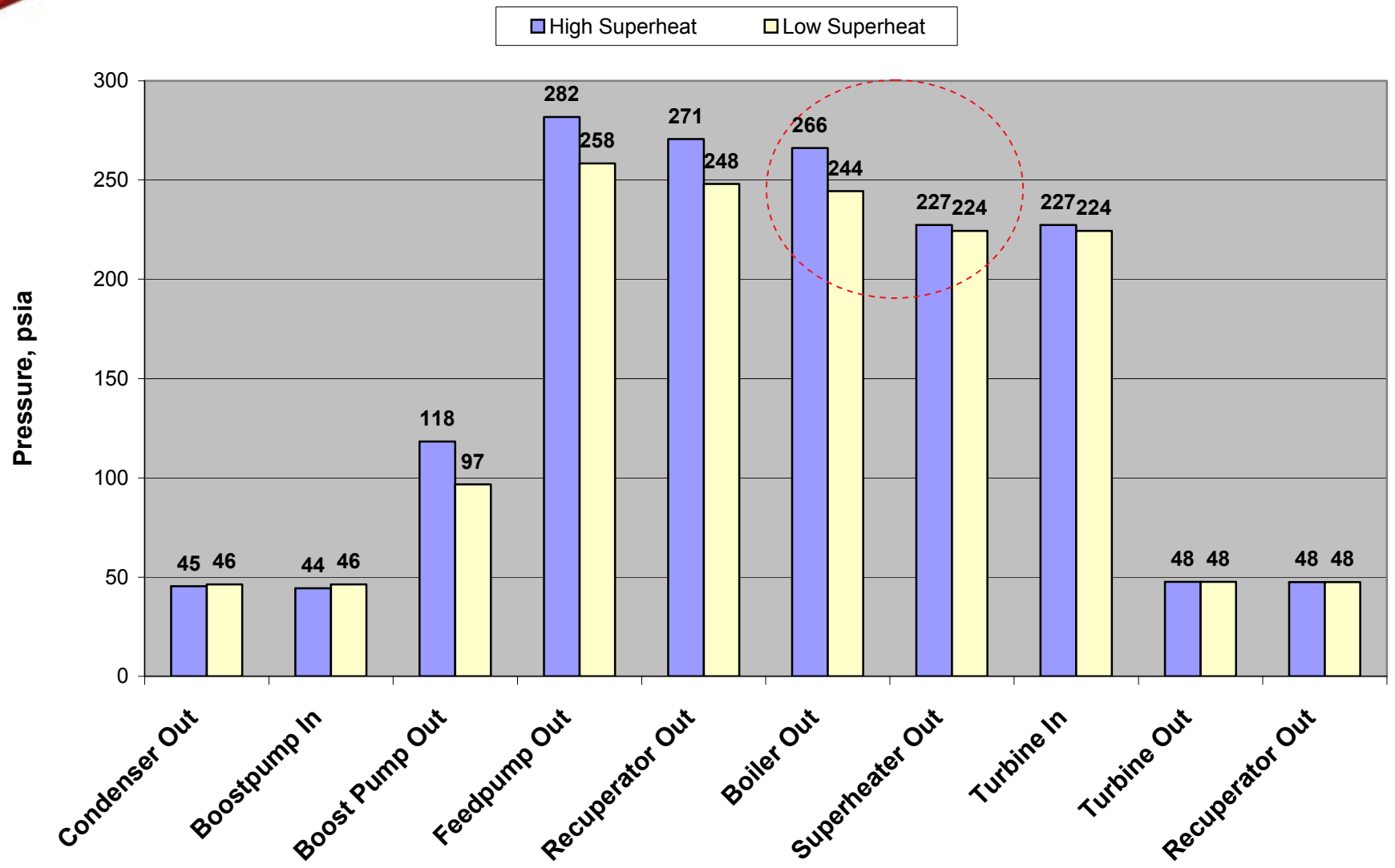
EGR-Only WHR Net benefit for Prostar on HDCC cycle = 6% Predicted

5.0% Observed as modeled with observed data

Electrical Power Flows – B100 Operation

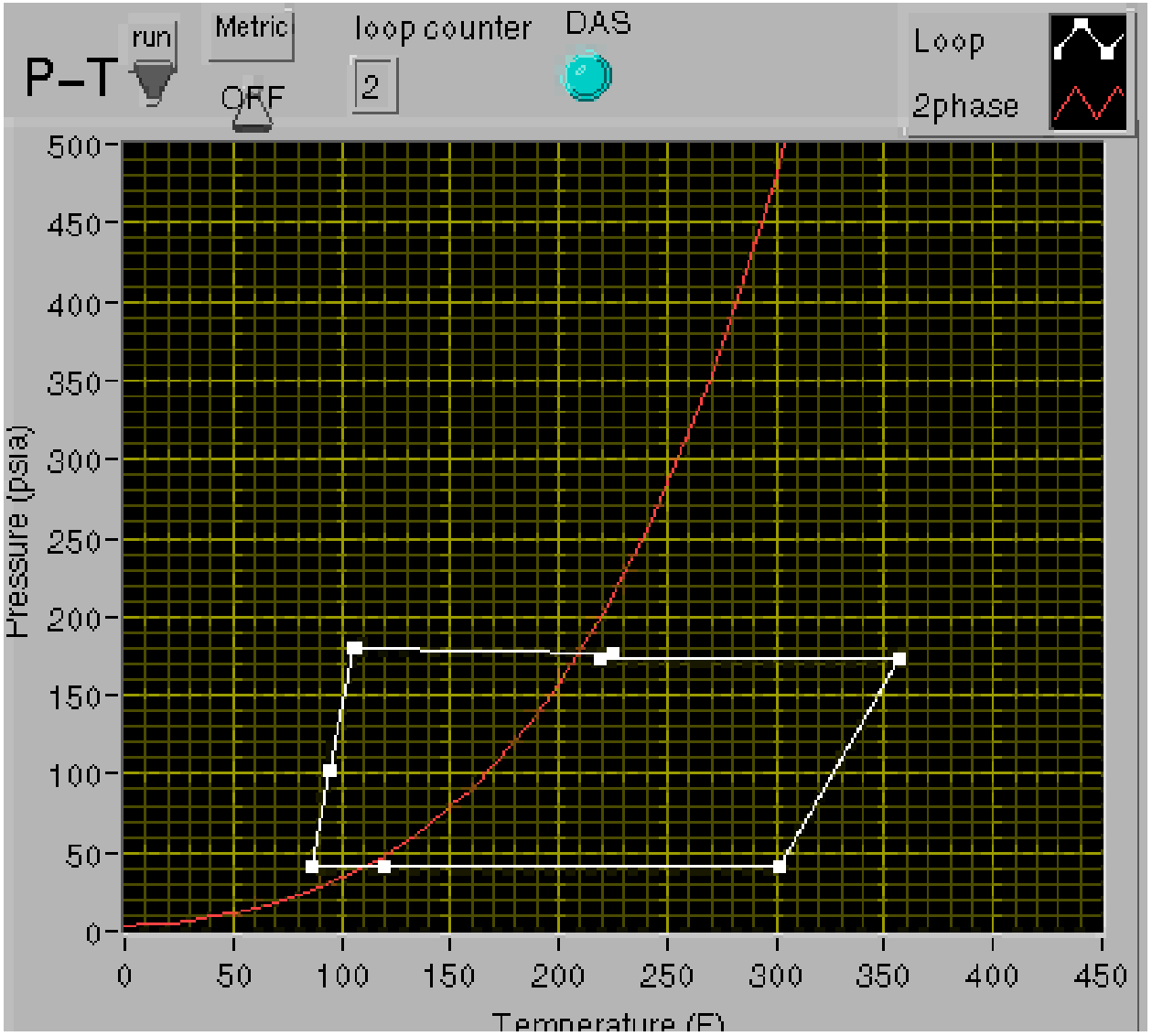


Refrigerant Side Pressures

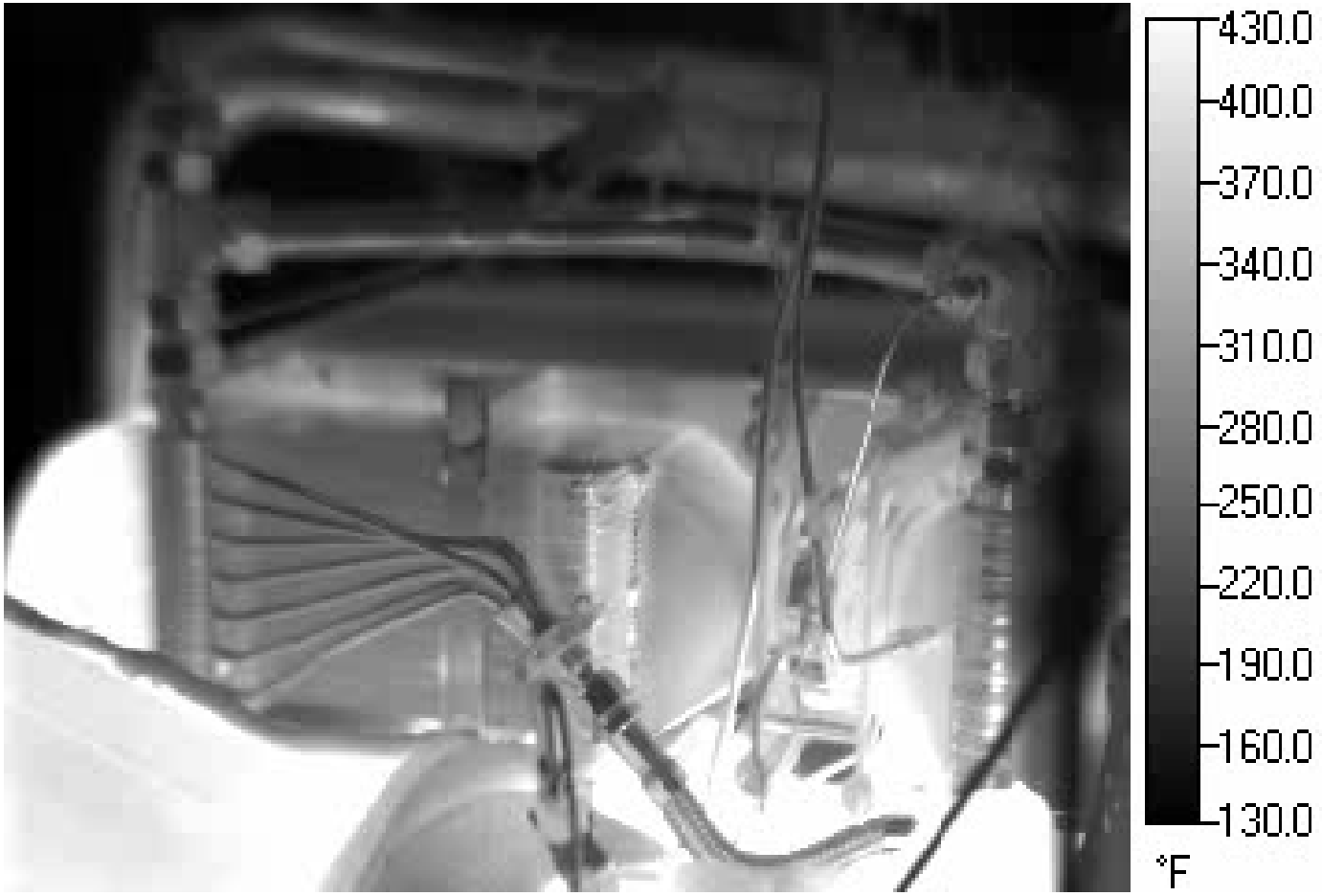


Need to reduce high-side system pressure drop, costs additional pump work

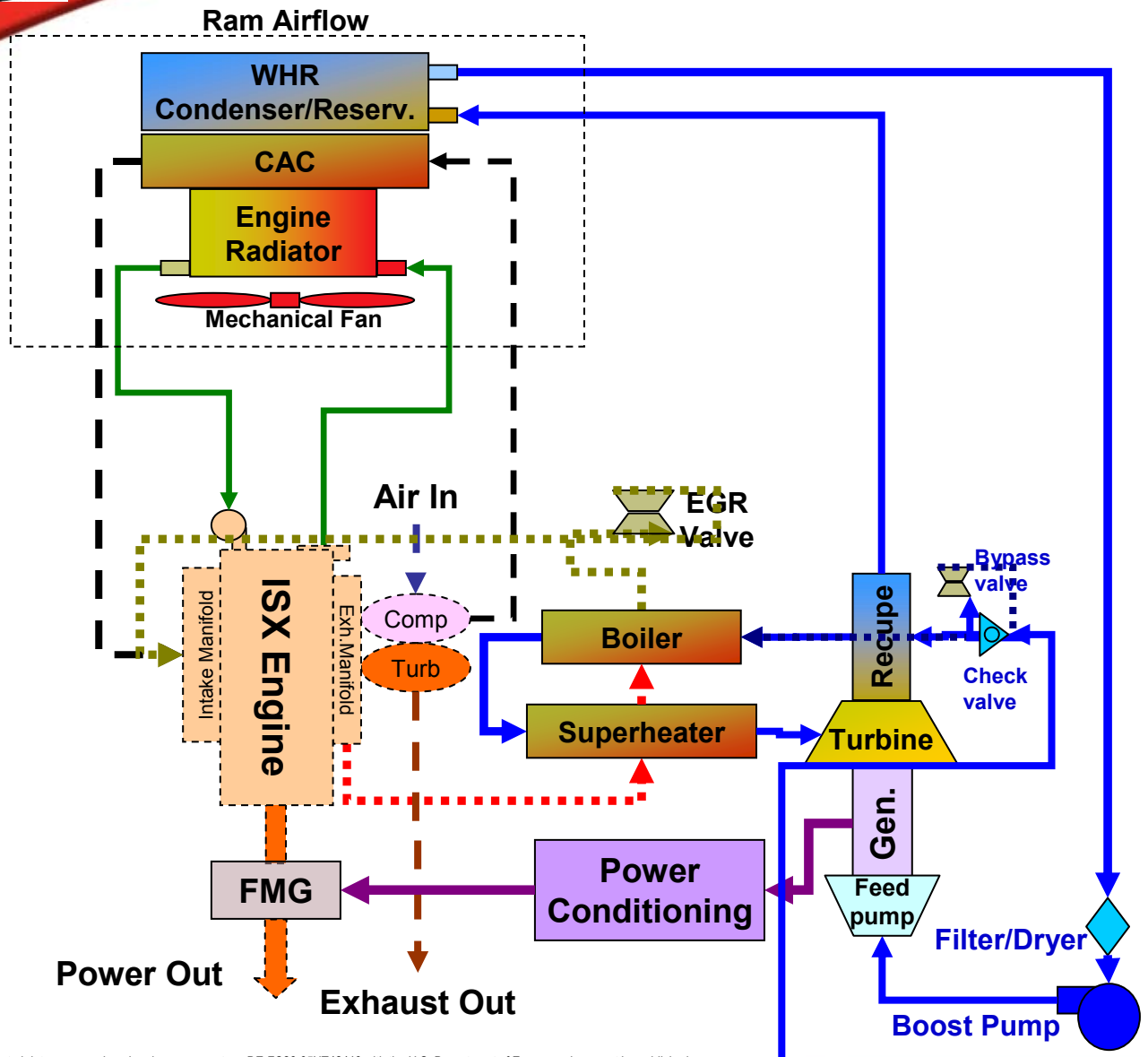
System Cycle Demo



System Thermal Image Movie



2nd Generation System Evolution



Air-cooling the condenser will eliminate cost and system complexity

Performance should be slightly improved without the water pump parasitic, making up for windage losses in the turbine

Modine Mfg. has performed modeling of an in-vehicle, air-cooled condenser

Review and Summary

Significant Progress -

- First Generation evaluation is well underway
- Initial results are promising - we are building our knowledge base
- Now moving to exhaust heat capture in addition to EGR heat
- Development of transient controls for driveability. Initial results look good.

Go Forward Plans

- 2nd Generation system design and analysis is underway
- Continue System refinement and evolution

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!