Heavy Duty Truck Engine

Achieving High Efficiency at 2010 Emissions

Christopher R. Nelson
Cummins Inc.

DEER Conference
August 23rd, 2006

Program Goals and Timing

Phase I

Demonstrate

- 45% **BTE**
- 2002 **Emissions**
  - **2.5 gm BSNOx**
  - **0.1 gm BSPM**

Complete

Phase IIA

Demonstrate

- 45% **BTE**
- 2007 **Emissions**
  - **1.2 gm BSNOx**
  - **0.01 gm BSPM**

Complete

Phase IIB

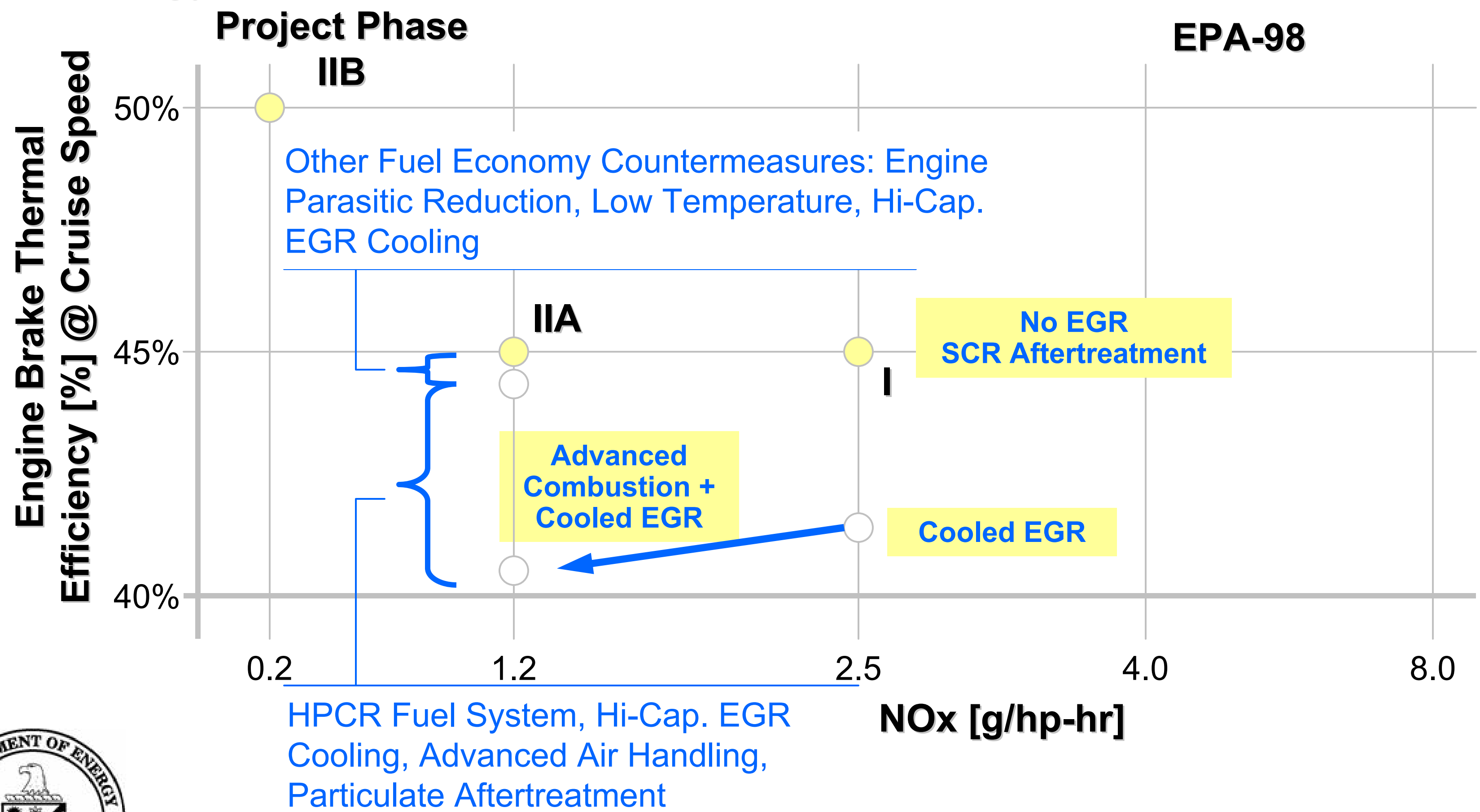
Demonstrate

- **50% BTE**
- **2010 Emissions**
  - **0.2 gm BSNOx**
  - **0.01 gm BSPM**

Complete

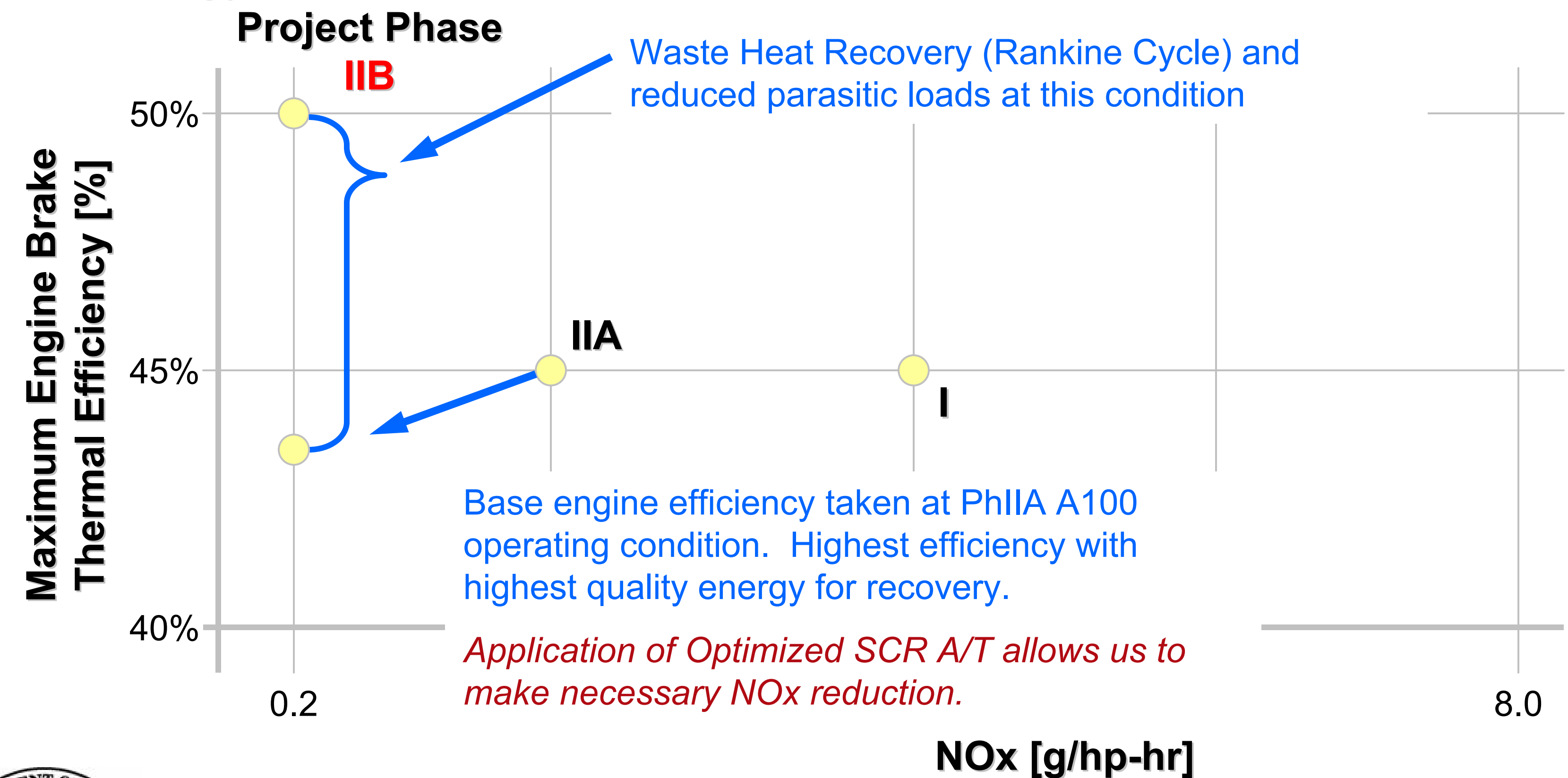
Previous Deliverables

Technology Roadmaps and Options



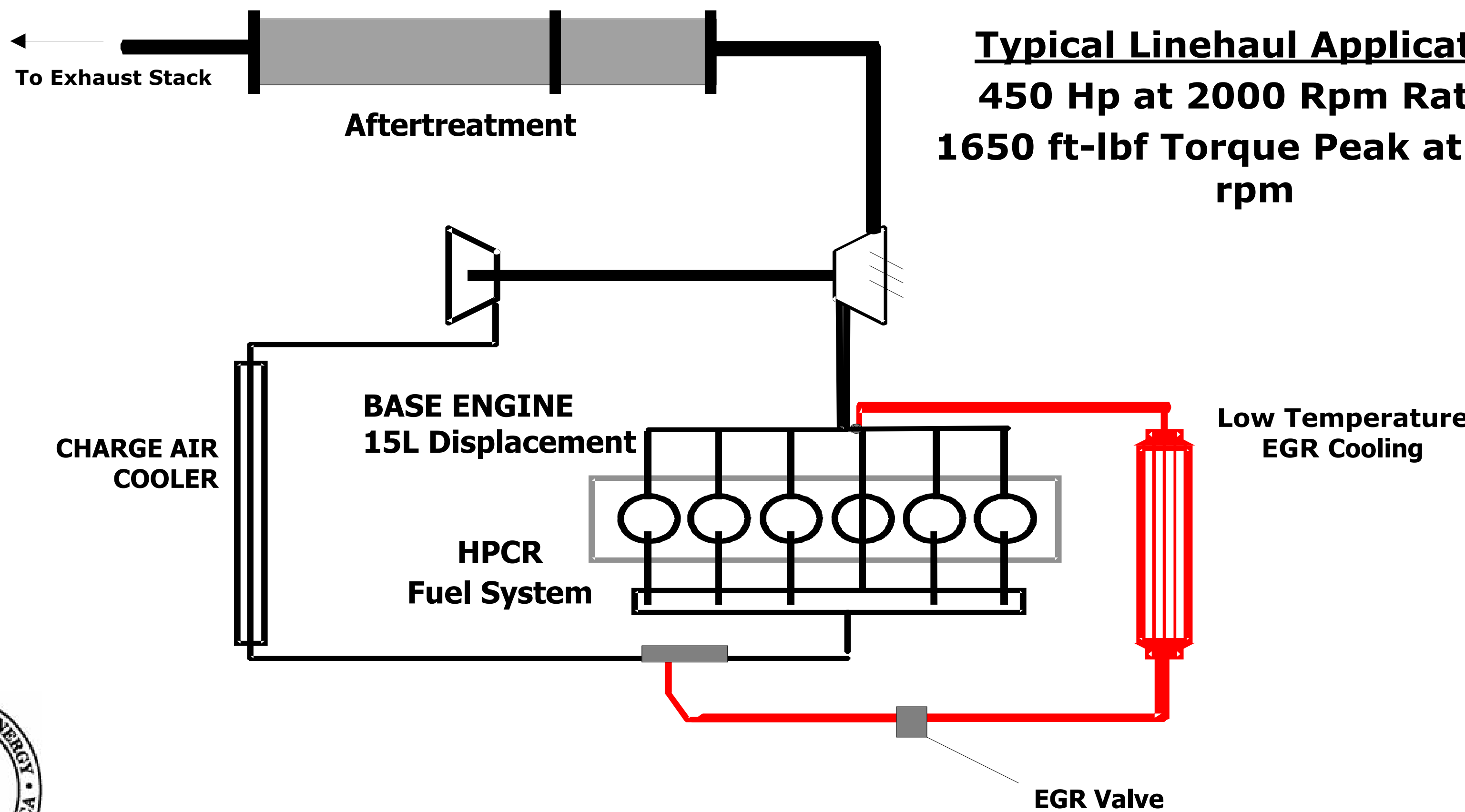
Phase IIB Approach

Technology Roadmaps and Options



Phase IIB ISX Base Engine

Ultra-Low NOx ISX: Phase IIB Demo - Base Engine Architecture



Typical Linehaul Application

450 Hp at 2000 Rpm Rating

1650 ft-lbf Torque Peak at 1200 rpm

Aftertreatment

NOx Reduction Technique

- Urea-SCR
  - A Urea-SCR Aftertreatment System operating at 85% Efficiency was assumed present in the high-efficiency test and demonstration

PM Reduction Technique

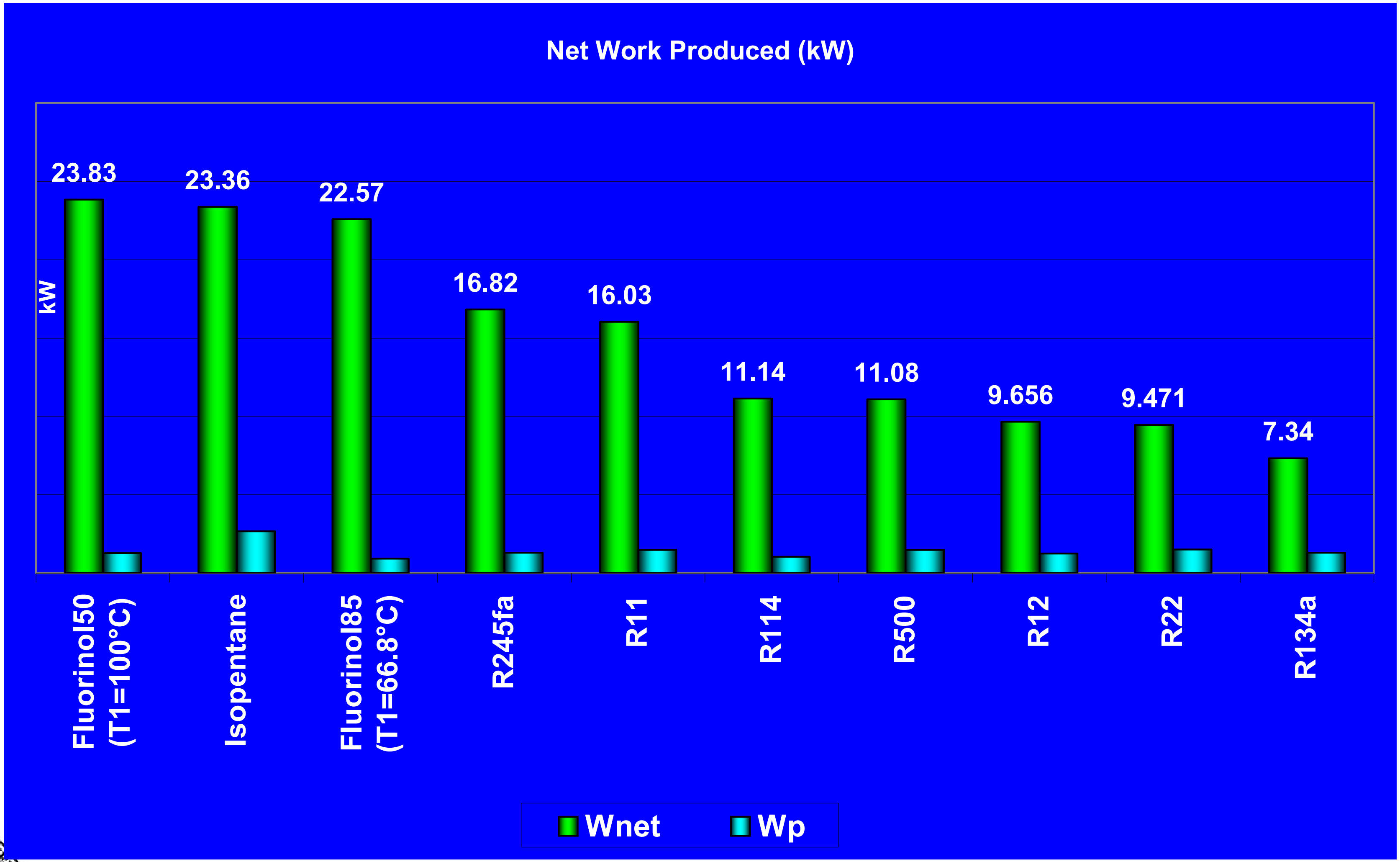
- Very similar to technology applied to Phase IIA.
- Robust RPF (DOC and PF)
  - An RPF operating at 90% Efficiency was assumed present in the high efficiency test and demonstration.

HDTE – WHR
Pugh Concept Selection Matrix

CONCEPT / CRITERIA	RANKINE CYCLE	RANKINE CYCLE (REHEAT)	THERMO ELECTRIC SYSTEMS	ELECTRIC TURBO COMPOUND SYSTEMS	RANKINE CYCLE +THERMO ELECTRIC SYSTEM
	1	2	3	4	5
1. Power Generated	S	S	-	-	+
2. System Complexity.	S	-	+	-	-
3. Resistance to temperature.	S	S	-	S	S
4. Fuel economy increase obtained.	S	-	-	-	+
5. Compatibility with actual engines.	S	S	S	S	S
6. Number of components.	S	S	+	S	-
7. Effect over the emissions.	S	S	S	S	S
8. Weight of the system	S	S	+	+	-
9. Size of the system.	S	S	+	+	-
10. Durability of the system	S	S	S	S	S
11. Price	S	+	-	-	-
12. Ease of maintenance.	S	S	+	+	S
13. Ease of installation.	S	S	+	+	-
14. Power consumption	S	S	+	+	S
TOTAL +	0	1	7	5	2
TOTAL -	0	2	4	4	6
TOTAL S	14	11	3	5	6
Best possible choice…	14	10	6	6	2

*No direct effect over emissions. Decrease emissions due to fuel economy increase.

Working Fluid Research



Fluorinol-50

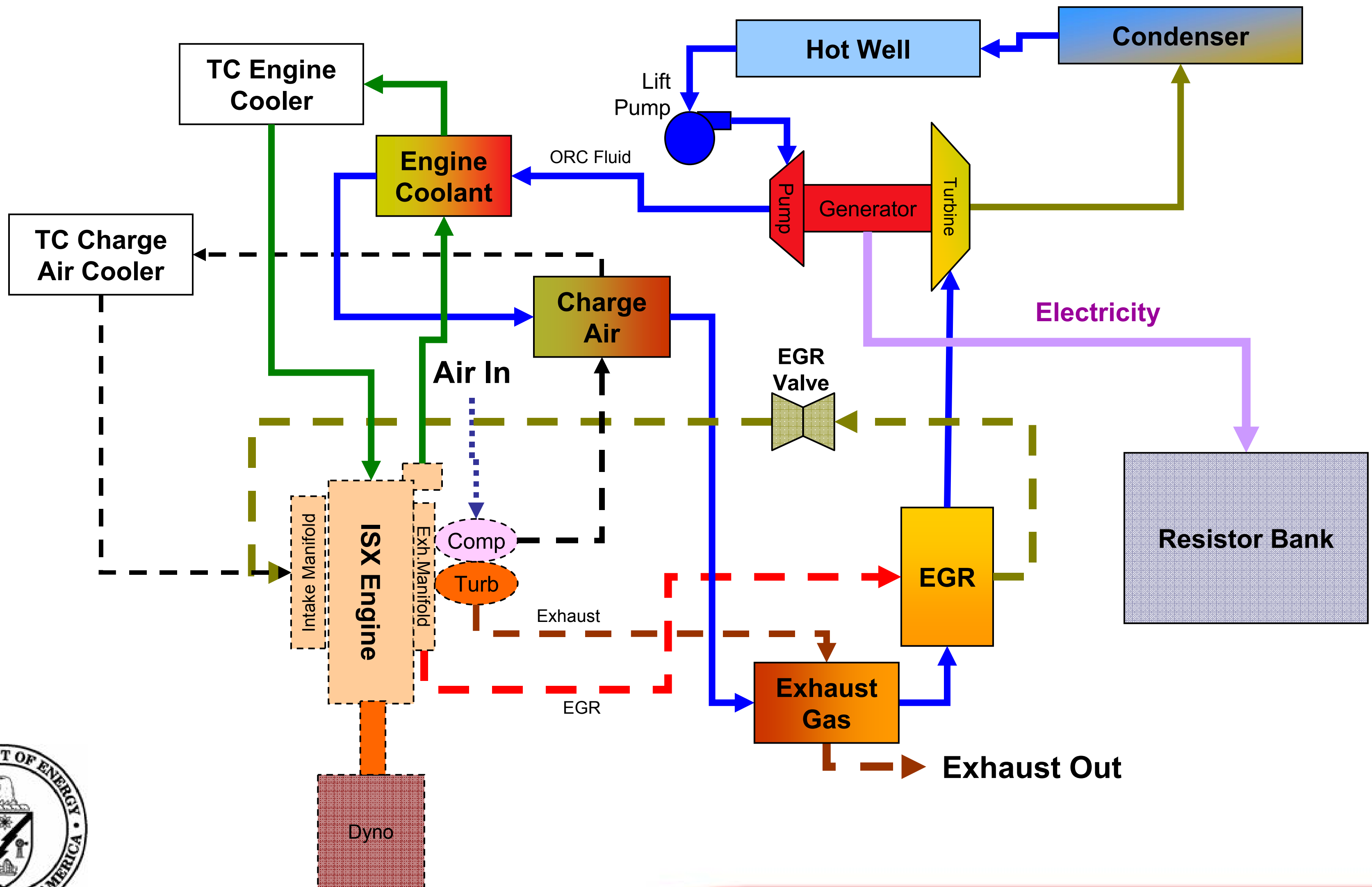
Fluorinol or 2,2,2 Trifluoroethanol and water

- CAS No. 75-89-8
- Molecular Weight 100.04
- Chemical Formula – F_3CCH_2OH
- Flammable Liquid/Vapor
- More toxic than Ethlyene Glycol
- Used in previous ORC DoE demonstration

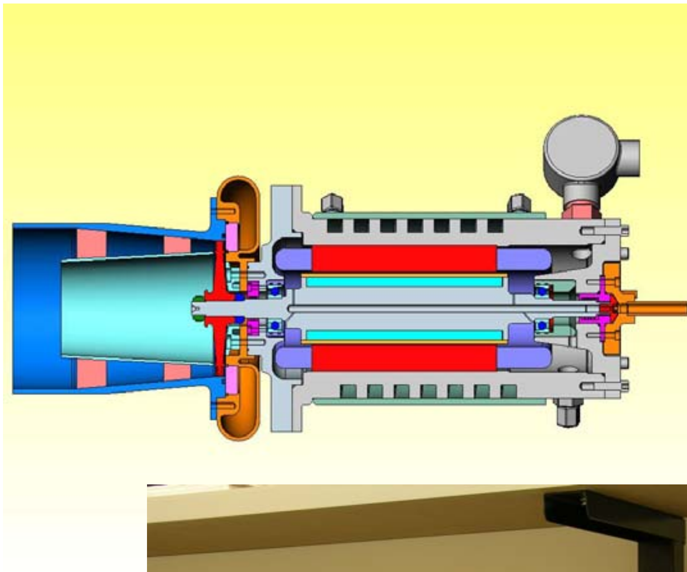
Excellent heat transfer properties with a high thermal stability - >550F

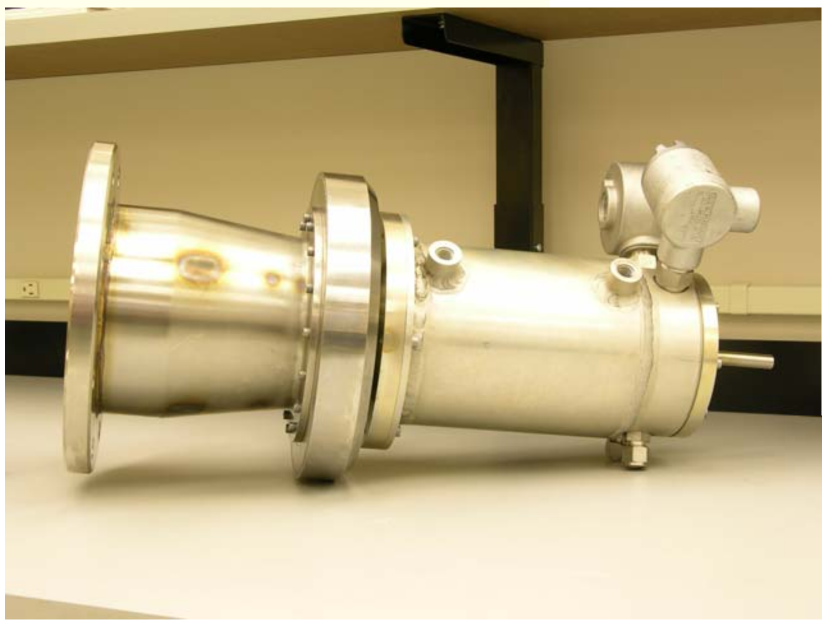
Fluorinol-50 (50-50 molal mix of Fluorinol and Water) provided the best performance -

High BTE
Lab Demonstration Schematic



Turbine Generator





Designed and built by Barber Nichols, Inc.

Radial Inflow Turbine coupled to a Unison high-speed 4-pole generator

Capable of 60+kW

Generator cooled with process water

Integrated Feedpump

Hermetically sealed system

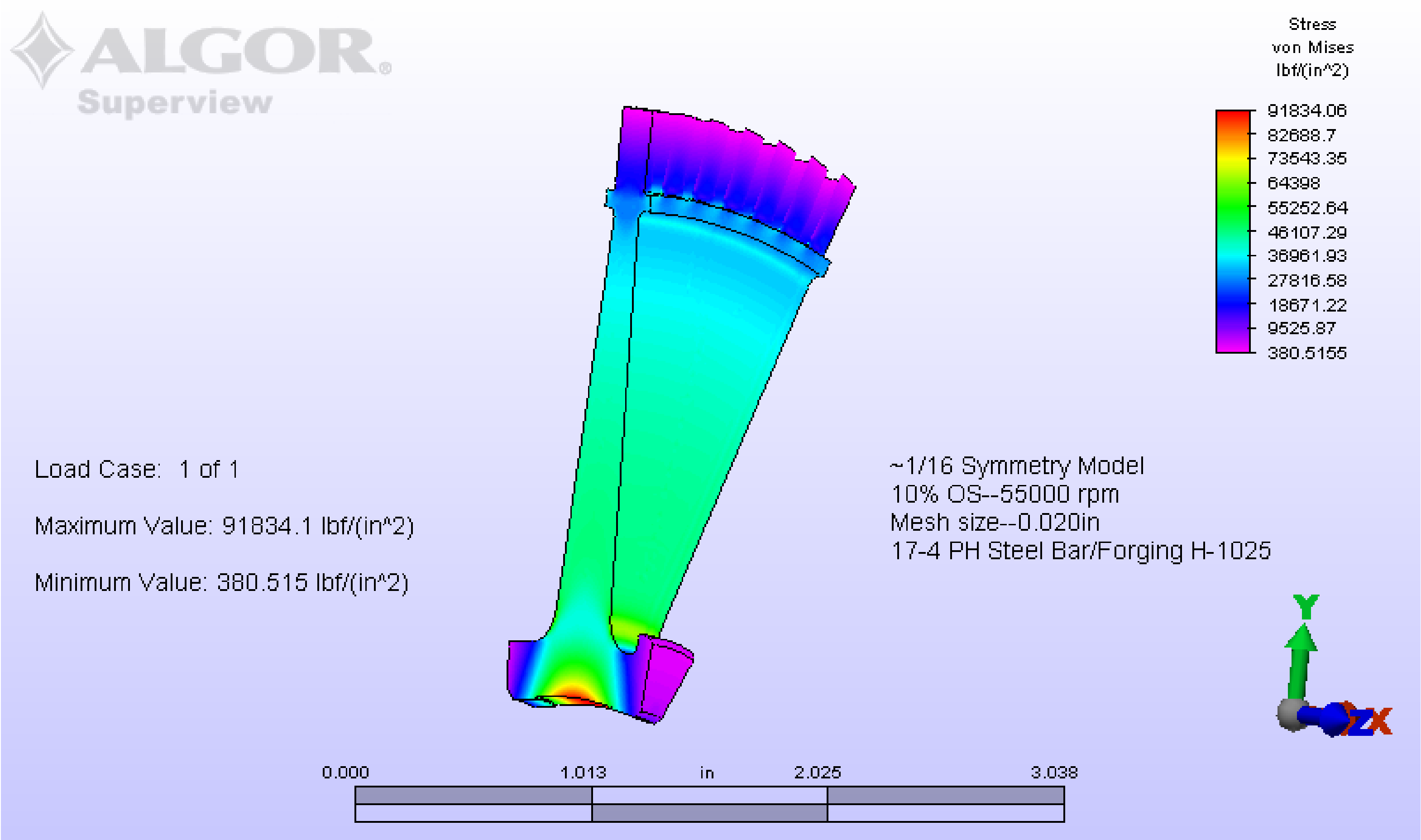
Approximately 10” diameter by 16” length (without diffuser)

Turbine and Rotor

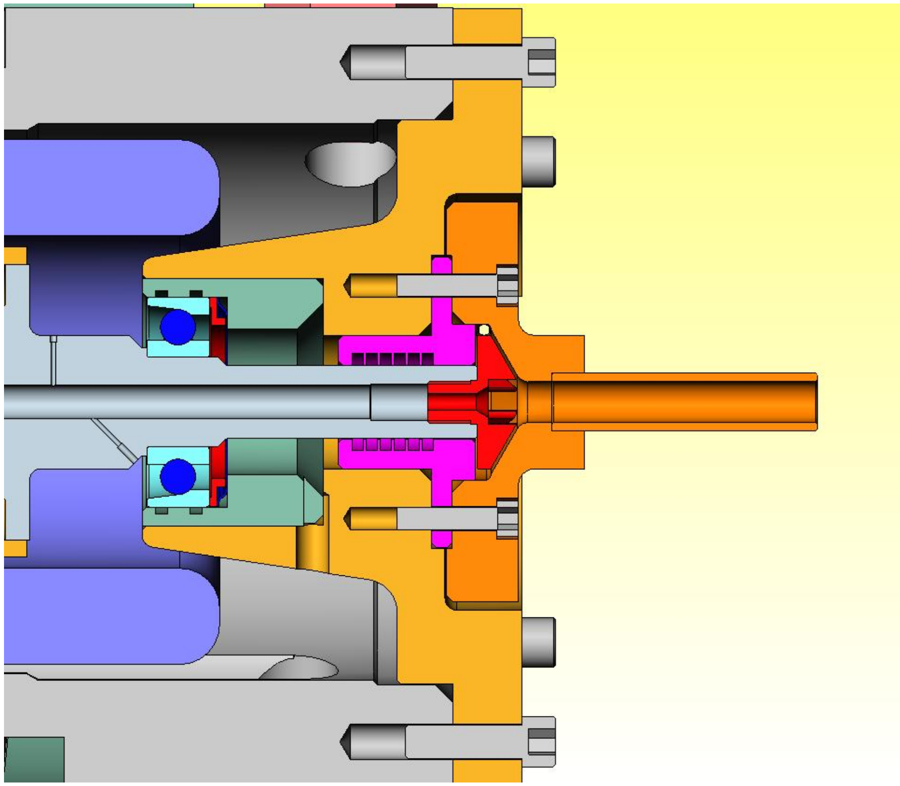
Permanent Magnet rotor
Hybrid-Ceramic, self-lubricated bearings cooled with F-50.

Axial impulse turbine
50krpm design speed
77% Efficiency Predicted
93 blades, 15 nozzles
17-4 PH Steel Bar/Forging

Turbine Rotor dynamics and Stress Analysis



Integral Feedpump



- •Small Impeller Feed pump
- •Hollow Shaft for Bearing Supply
- •6 bladed pump
- •Aluminum
- •470 psia at 50 krpm

Heat Exchangers

Procured from FlatPlate, Inc.

Stacked Plate type.

Copper brazing on jacket water, condenser and charge air coolers.

Nickel brazing on Exhaust and EGR coolers.

Controls and Data Acq.

Turbine speed was controlled by PWM control of generator amperage to the resistive load bank.

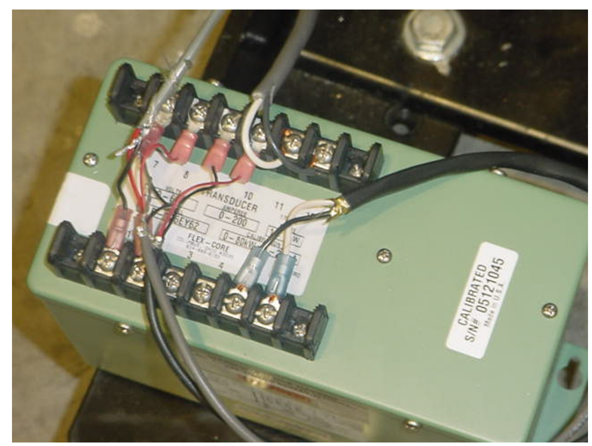
Turbine speed was determined from measured AC voltage.

WHR System operating temperatures and pressures were monitored with the Labview data acquisition system.

Electric power was measured with a Flex-Core Watt Meter calibrated to our target generator frequency and voltage (1600 Hz and 500VAC).

Electric power was also measured by monitoring cooling water flow and temperature rise across our resistive load bank.

Good agreement between the two power measurements was observed.



HDTE Phase IIB Results on 5/11/06

<u>A100 Engine Condition –</u>

Engine Load – 378 Hp

Engine Speed – 1200 rpm

<u>Engine</u> bsfc – <u>0.322</u> or 43.2% BTE

Engine Out bsNOx – 1.39 gm/Hp-hr

- **SCR Aftertreatment achieves 0.2 gm BSNOx**

42.5 kWe / 57 Hp Recovered Power

Combined Cycle bsfc – 0.279 or <u>*50.0%BTE*</u>

Peak WHR Cycle Efficiency was <u>21.0%</u>

HDTE and ISX Engine Architecture

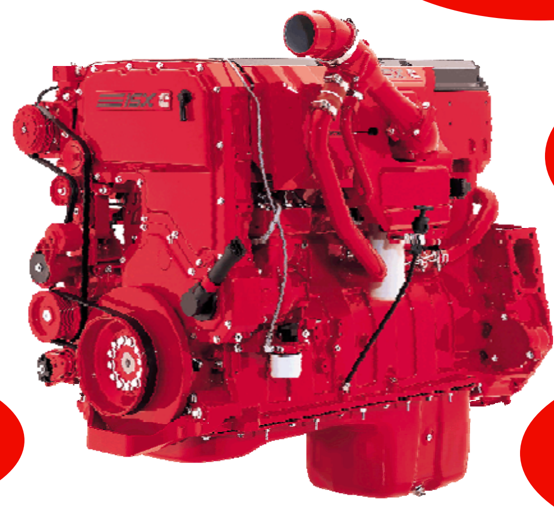
Electronic Controls

Exhaust Aftertreatment

Combustion Optimization

Optimized/Electric Parasitics

Fuel System Development



Air Handling

Cooling System Optimization

Base Engine Updates

Thanks to our Sponsor!

Cummins Inc. thanks –

The United States Department of Energy

for their support throughout this program