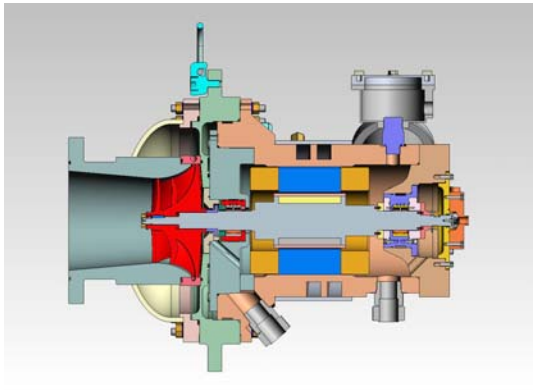
Exhaust Energy Recovery

Christopher R. Nelson
Cummins Inc.

DEER Conference
August 24th, 2006

Energy Recovery Agenda



- Program and Goals
- Recovery System
- Technology Challenges
- Customer Benefits
- Summary and Questions

Program Goals

- **Improve fuel efficiency by 10% by recovering waste heat energy**
  - **Composite Improvement**
  - **MY2010 Base Engine Assumed**
- **Reduce the need for additional heat rejection capacity**
- **Provide charge cooling capacity to support engine combustion**

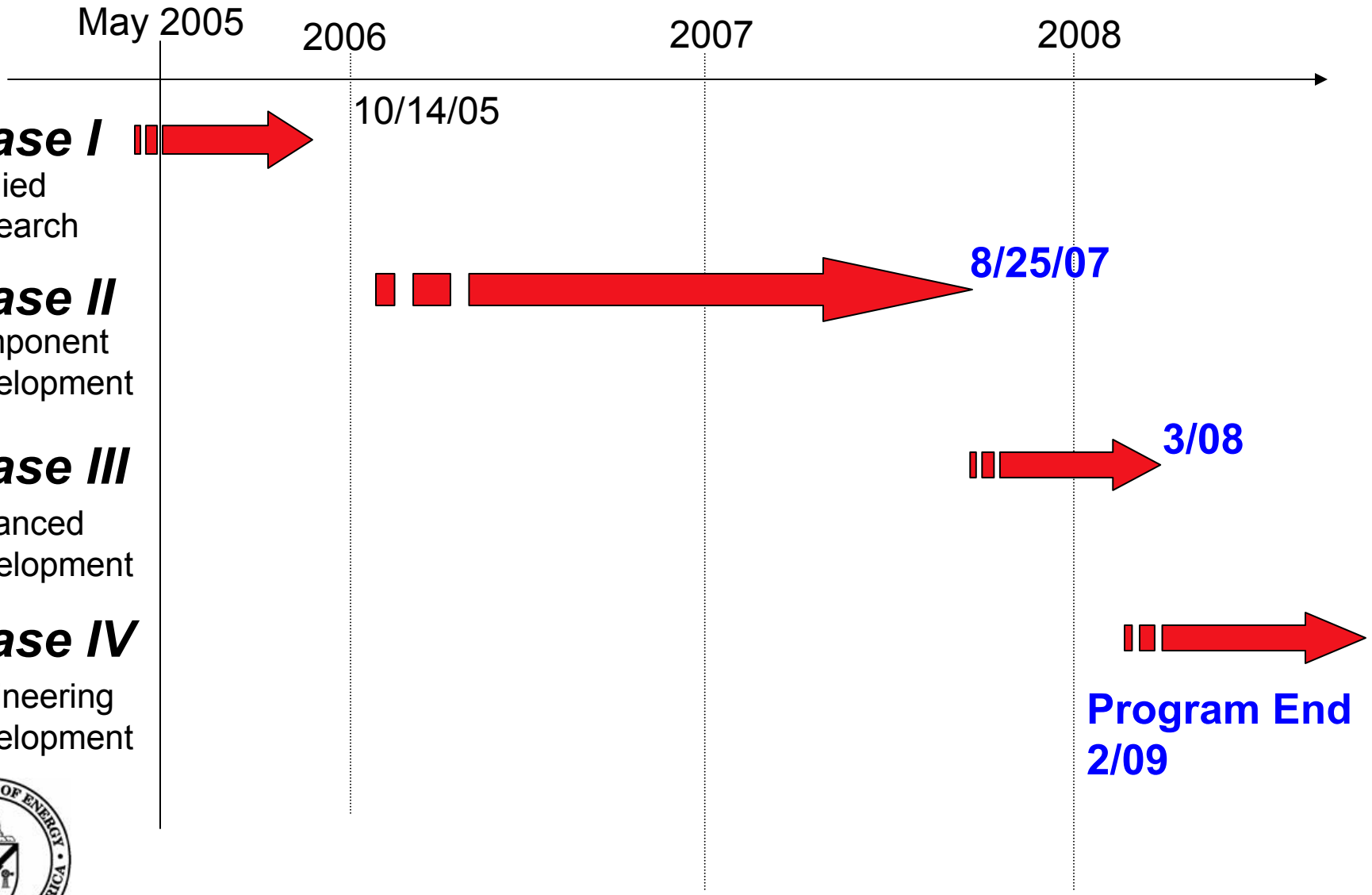
Recovery System

Proposed Solution -

- **Integrate a Rankine Cycle system with the ISX engine to recover waste heat energy from the engine's CAC and EGR**

This solution continues the energy recovery effort initiated under the HDTE program

Program Timeline



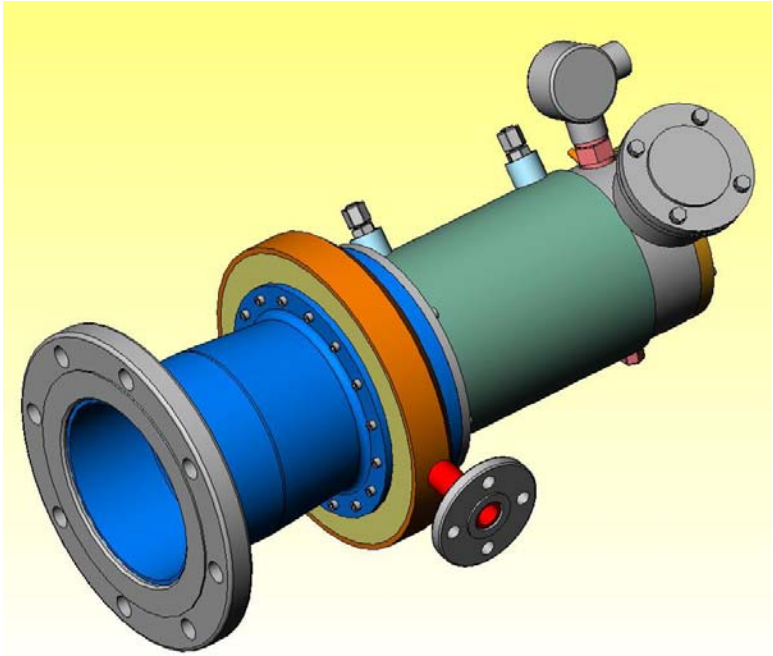
Recovery System Example

HDTE Phase IIB

- **2010 emissions-capable engine**
- **Operated at Peak Torque Condition -**

  Highest quality heat to recover with best base engine efficiency

- **Rankine cycle extracted waste energy from jacket water, charge air, exhaust and EGR**

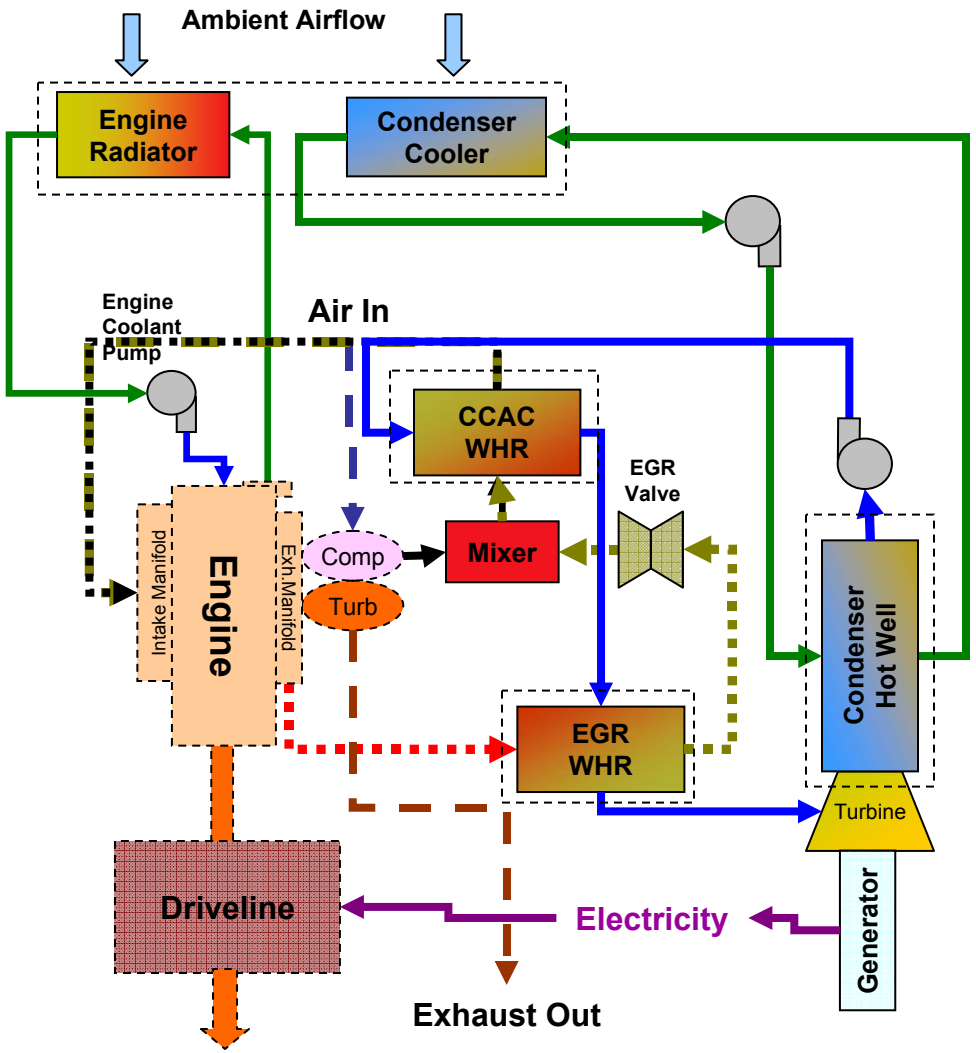


42.5 kWe / 57 Hp Recovered Power

Achieved Program goal of 50.0% BTE

Peak WHR Cycle Efficiency was 21.0%

Diesel/Rankine Cycle Schematic



Rankine Cycle capturing energy from EGR and combined EGR and CAC (CCAC)

Working fluid is proposed as R245fa
Honeywell Genetron

Working Fluid – R245fa

Main Advantages of R245fa

- •Hydrofluorocarbon
  - •Not a chlorinated fluorocarbon
- •Non Ozone Depleting
- •Low Global Warming Potential
- •Non-Flammable

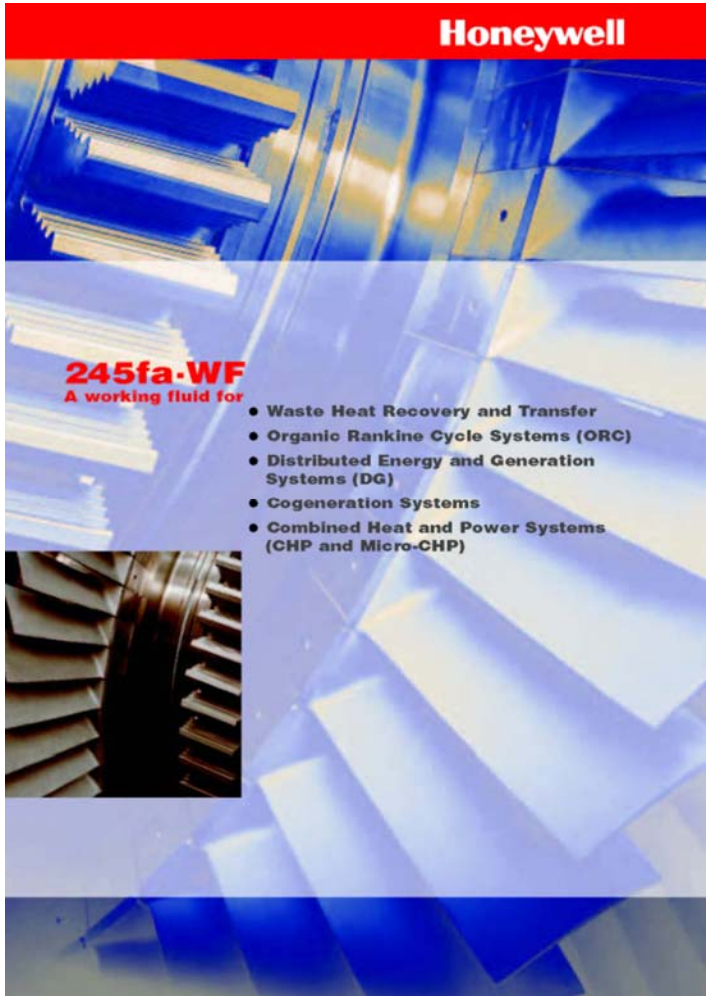
•Also –

- •Good heat transfer ability
- •Excellent Thermal Stability
- •Low viscosity

•It can work with the existing AC tool set in service shops

•It runs above atmospheric in its cycle

- •Similar in behavior to R134a

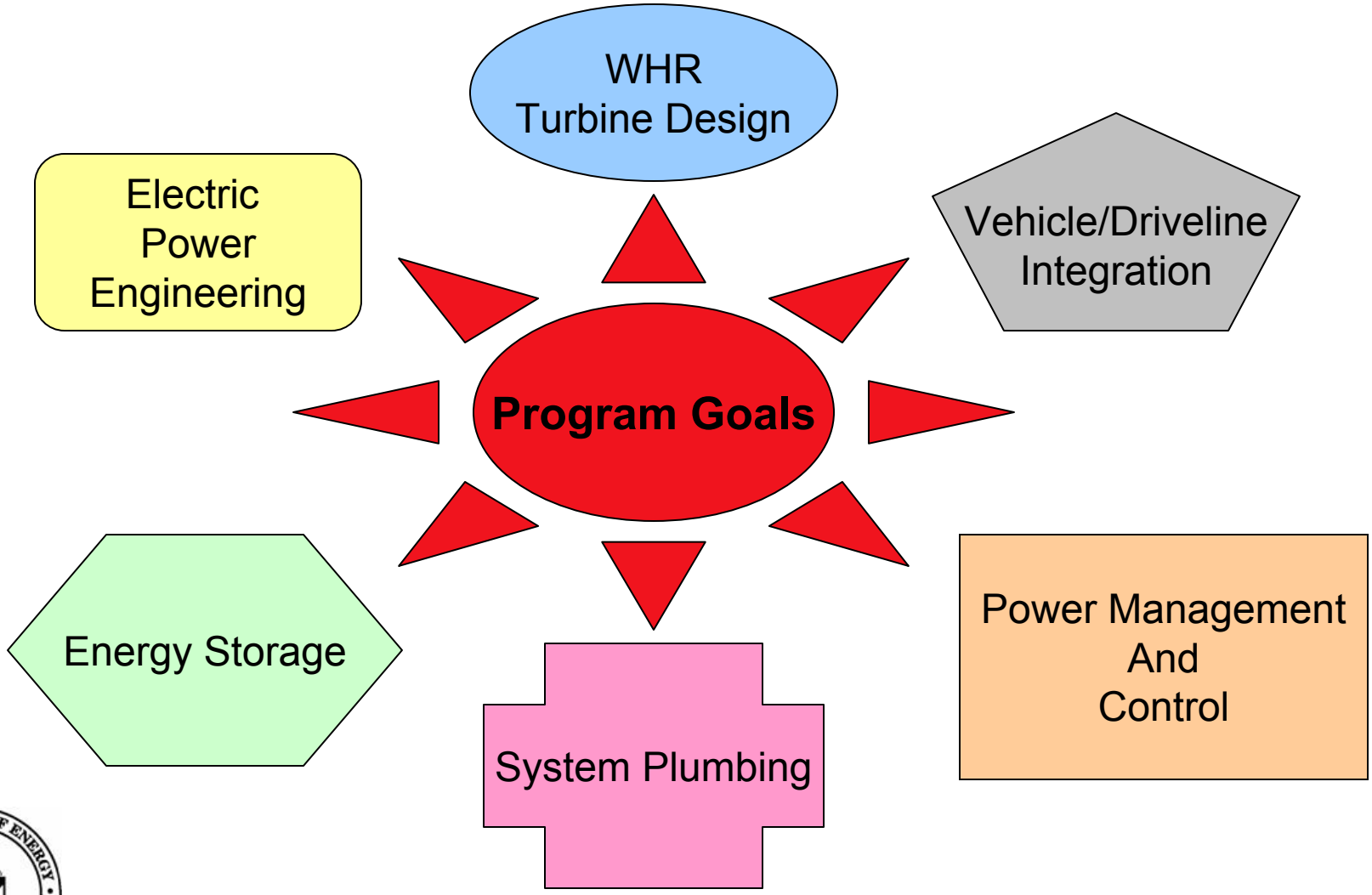


Vehicle Integration

The proposed solution must be integrated into a Class 8 Tractor and be demonstrated on-highway

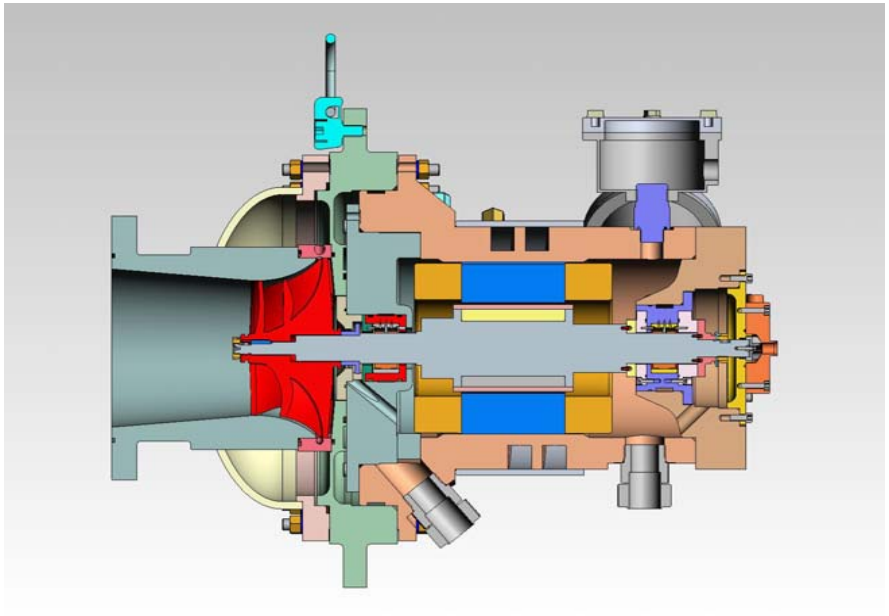
We are planning on using the International ProStar for this program

Technology Pallet

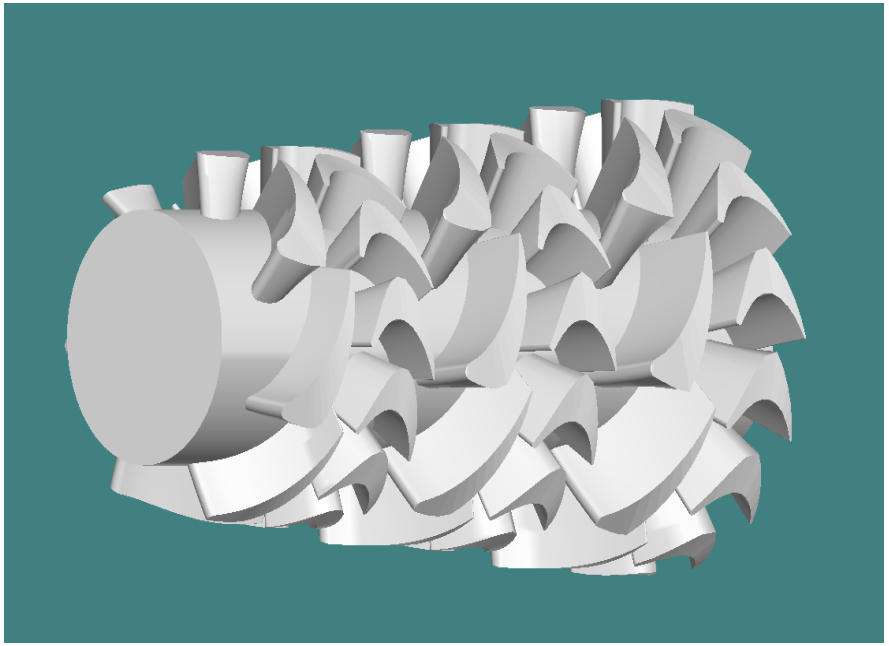


Turbine/Generator Designs

- Radial inflow turbine



- Axial flow turbine



Both turbine technologies are being evaluated

Partial Admission or Variable Nozzle concepts to broaden operating map width are being considered.

Power Engineering

- **On-Vehicle High Voltage Bus**

  Departure from typical 12 VDC

- **Incorporates technology common with HEV**

  Battery Storage, Power Conditioning, etc.

- **Offers opportunities for high voltage accessories**

  Driveline Motor/Generator
  Coolant Pump(s)
  Power Steering
  etc.
  Electric Fans
  Air Compressor
  HVAC

Engine duty cycles and Subsystem duty cycles must be studied and compared for best overall <u>in-vehicle</u> efficiency improvement

- ***A comprehensive Energy Utilization study will be performed***

Heat Exchanger Technology

- **Combined Charge Coolers (Fresh Air and EGR)**
  - Corrosion/Fouling issues
- **Single and 2-Phase Fluid Conditions**
  - Will require different designs/types at different points
- **High Pressure (500 psia) working fluid**
  - Against lower pressure air/exhaust gases
- **Space/weight/performance constraints**
- **Plumbing and connections similar to current HVAC systems but up-scaled for pressures/temperatures**

Vehicle/Driveline Integration

- **Driveline motor (/generator)**
  - May replace alternator/belt assembly
  - Size depends on power management strategy
  - May influence transmission matching and tuning
  - Active crank damping being investigated

- **Electric Cooling Fans**
  - Necessary to provide shutdown cooling for WHR system
  - Will supplement mechanical fan and minimize its operation
  - Offers opportunities to further optimize overall cooling system

Customer Benefits

Recovery of Combined Charge CAC/EGR and EGR will achieve the program 10% performance goal and –

reduce CAC and EGR heat rejection by the recovery cycle efficiency –

~*20*% at peak power conditions

This reduction offers a <u>significant</u> benefit to the Vehicle OEM

Customer Benefits

A 10% fuel savings represents ~$9000 savings across an 18 month payback to a Class 8, Linehaul end user (at $3/gal and 120,000 miles per year).

- **To make this additional system attractive it must cost significantly less than this to purchase and -**
  - **It must cost significantly less than this to manufacture.**

Feasibility must be demonstrated not only in-vehicle but also in-cost

Summary

Going Beyond the Engine –

- **New Thermodynamic Cycle**
  - **It's not just diesel anymore**
- **Non-Traditional Fluid**
  - **2 Phases and it's not coolant**
- **High Voltage Power Engineering –**
  - **Much more than 12V**
- **System Power Management –**
  - **Parasitics, Vehicle Needs, etc.**

A challenging technology development program that will affect how we approach on-vehicle power systems -

Thanks to our Sponsor!

Cummins Inc. thanks –

The United States Department of Energy

for their support of this program