Very High Fuel Economy, Heavy Duty Truck, Narrow Range Speed Engine, Optimized Via Unique Energy Recovery Turbines and Facilitated by High Efficiency Continuously Variable Drivetrain

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"This presentation does not contain any proprietary or confidential information"

OUTLINE

- Goals and Objectives
- Barrier
- Approaches
- Performance Measures and Accomplishments
- Technology Transfer
- Collaborations
- Plans for Next Fiscal Year
- Summary
- Publications

GOAL & OBJECTIVES

- To apply waste heat recovery to improve the efficiency of a heavy duty diesel engine operating over an on-highway cycle. An overall efficiency increase of 10% is expected to be achieved while meeting 2007 emissions standards

- To operate a heavy duty diesel engine at a narrow range speed to eliminate the inefficiencies associated with varying speed engines. Engine always operates at its peak efficiency

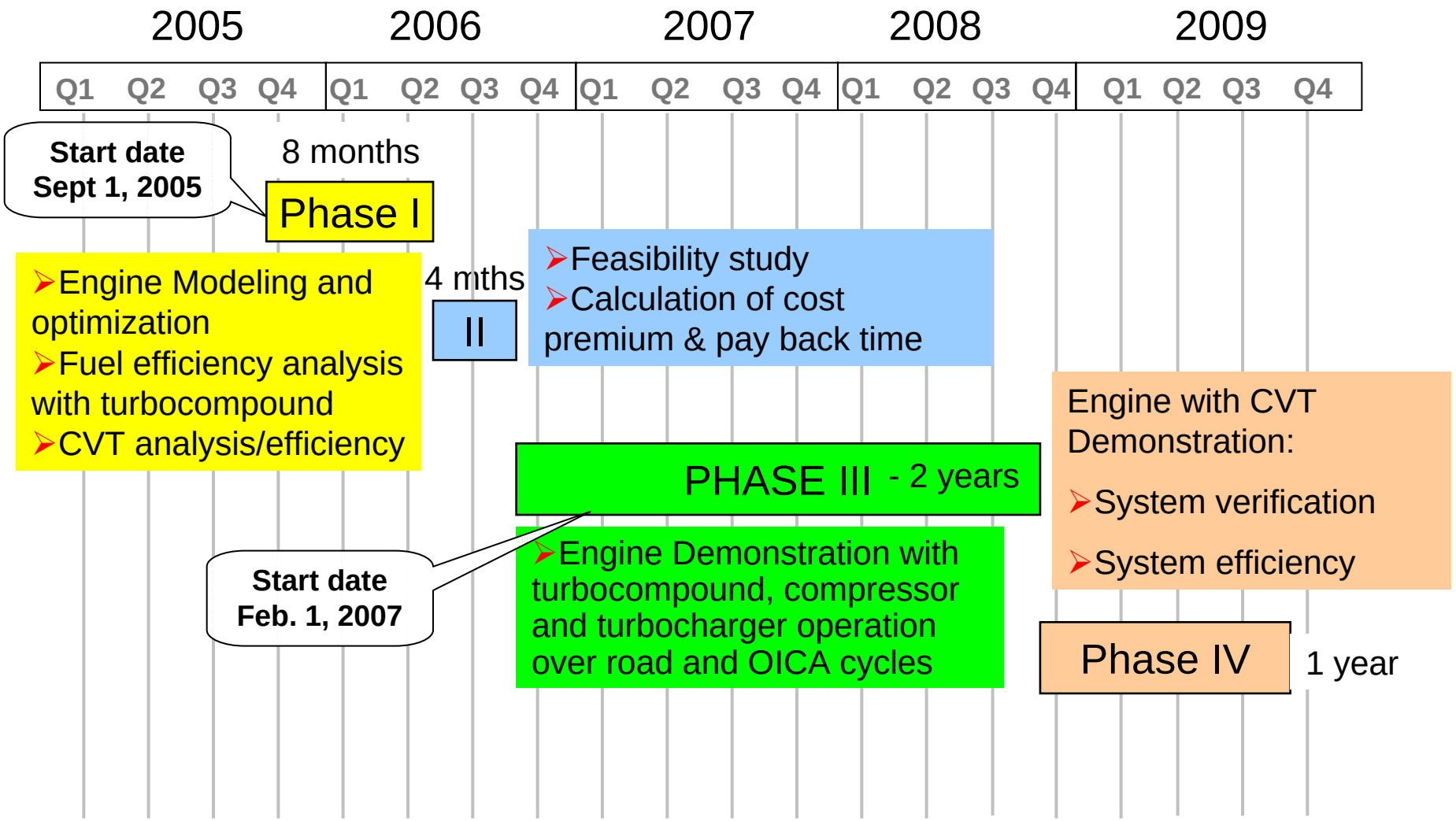
- The enabling technology for the single engine speed operation will be achieved by coupling the engine to a Continuously Variable Transmission (CVT)

- To recover a portion of the energy lost in the exhaust a turbocompound system will also be incorporated optimized for the single speed operation

BARRIERS

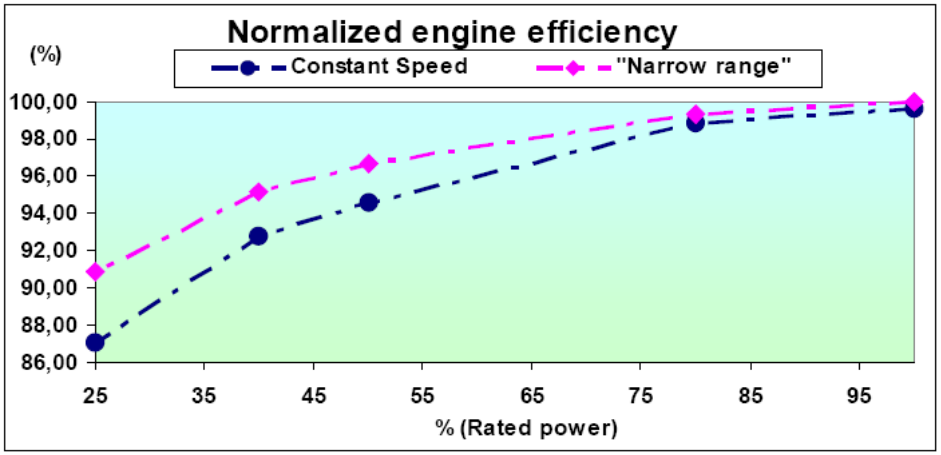
- Design new turbocharger unit with high performance efficiency for narrow range speed engine operation
  - High performance compressor
  - High performance turbine
- Design turbocompound unit based on Volvo D12 engine
  - Optimize for narrow range speed operation
- Repositioning of EGR valve

APPROACH


2005
2006
2007
2008
2009
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
Start date Sept 1, 2005
8 months
Phase I
Engine Modeling and optimization
Fuel efficiency analysis with turbocompound
CVT analysis/efficiency
4 mths
II
Feasibility study
Calculation of cost premium & pay back time
PHASE III - 2 years
Start date Feb. 1, 2007
Engine Demonstration with turbocompound, compressor and turbocharger operation over road and OICA cycles
Engine with CVT Demonstration:
System verification
System efficiency
Phase IV
1 year

PHASE I ACCOMPLISHMENTS

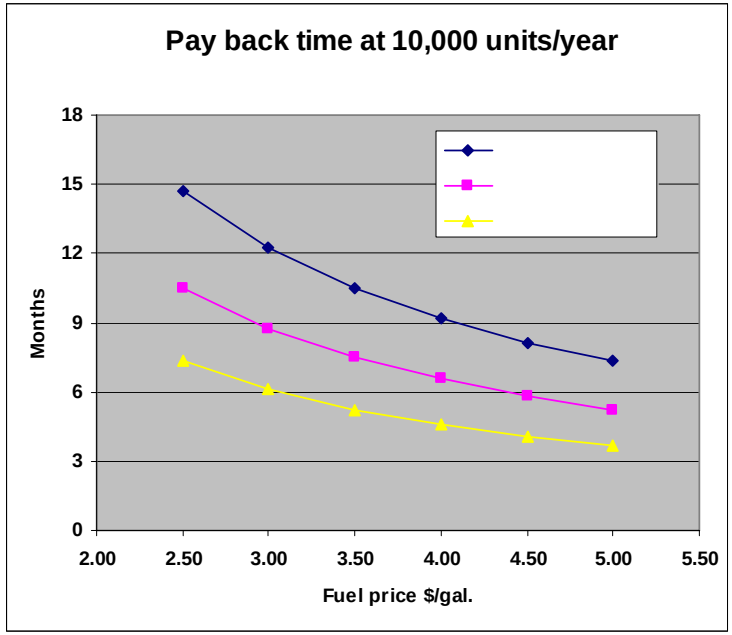
- Narrow Range Speed picked over the Constant Speed engine



- Net efficiency gain over the baseline engine US07 MD13
  - Turbo-compound
    - OICA 10.3%
    - Road 8.3%
  - Coupled to a 95% efficiency CVT the gain 5%

PHASE II ACCOMPLISHMENTS

- The turbocharger and turbocompound can be designed for high efficiency
- Different EGR systems are relatively similar in performance
- The cost premium is paid back in approx. 12 months at a fuel consumption improvement of 5% and a fuel price of $3.00/gallon



SUMMARY OF PHASE III

- Risk analysis and design of components
- Manufacturing
  - Turbocharger
  - Turbocompound
  - Modification parts
- Turbo testing
- Baseline engine testing

- Build prototype engine
- Engine/Turbo testing
- Control system development
  - Emission verification
  - Fuel efficiency verification

TURBO DESIGN AND TESTING

- Turbo design:
  - Compressor : Titanium impeller designed for high pressure ratio
  - Turbine : High performance radial turbo turbine
  - Compound Turbine: The compound turbine is of the axial type

- Gas stand test:
  - Rotor dynamic test
  - Mechanical functionality
  - Compressor performance and bearing system efficiency

- Turbocharger tested on engine

- Turbo compound unit to be tested on engine to control the mechanical function and rotor dynamics

NON-TURBO MODIFICATIONS

- Modified Exhaust Manifold
- Modified Camshaft
- Timing Gear Plate
- Flywheel Housing
- Idler and Bull Gears

TECHNOLOGY TRANSFER

- Operating the diesel engine at a narrow range speed is not a radical new concept but an attempt to further optimize engine components by removing the inefficiencies associated with speed changes
- Decoupling engine speed from road speed by means of a CVT allows optimizing engine speed for best fuel consumption.
- Prototypes are designed such that there is least packaging problem on the chassis, although truck demonstration is not part of this program.

ACTIVITIES FOR NEXT FISCAL YEAR

- Assemble engine with new designed components:
  - Turbocharger
  - Turbocompound
  - Exhaust manifold / modified EGR system
  - Interface to flywheel housing / rear transmission
  - Camshaft

- Develop control strategy
  - Evaluate fuel economy over the OICA and road cycle
  - Comply US07 engine out emission

- Study on CVT hardware and engine/CVT integration strategy

SUMMARY

- Narrow range speed engine with turbocompound coupled to a CVT with 95% efficiency provides 5% in fuel efficiency improvement
- Cost premium for the engine waste heat recovery component is estimated to be paid back within 15 months in fuel saving
- Turbocharger and turbocompound units are built and tested
- Baseline engine is tested
- Engine to be assembled with turbocompound and other modifications
- Engine control strategy to be developed

COLLABORATIONS

- Volvo Powertain Malmo
  - Specialized in the design of turbocharger and turbo-compound machinery and engine simulation
- Volvo Technical (VTEC)
  - Specialized in vehicle simulation developing new technology
- EATON
  - Specialized in transmission and CVT provider

PUBLICATIONS

Bahman Habibzadeh, “Very High Fuel Economy, Heavy Duty, Constant Speed, Truck Engine Optimized Via Unique Energy Recovery Turbines and Facilitated by High Efficiency Continuously Variable Drivetrain”, DOE/NETL Contract - DE-FC-05NT42421, Quarterly Reports.

THANK YOU!

QUESTIONS?