SuperTruck – Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer

Engine Systems

DOE Contract: DE-EE0003303

Project Officer: Ralph Nine

Project Manager: Roland Gravel

Navistar Principal Investigator: Russ Zukouski

DOE MERIT REVIEW

12 June, 2015

Project ID: ACE059

Program Overview

Timeline

Project Start:	October 2010
Project End:	Sept 2016
% Complete:	62%

Partners

Navistar	Principal Investigator, Vehicle Systems Integrator Controls Systems, Engine & Vehicle Testing
Bosch	Fuel Systems
Wabash	Trailer Technologies
Argonne ANL	Dual Fuel Engine testing, simulation & evaluation
Lawrence LLNL	Aerodynamic CFD

Barriers

Achieving 50% freight efficiency while balancing Voice of Customer Needs

Alignment with business needs

Reducing tractor weight while adding new systems

Budget

Total Funding:	$76,178,386
DOE:	$35,754,460
Prime:	$40,423,926
Funding FY2014	$6,025,644
Funding for FY2015	$8,965,646

Objectives and Relevance

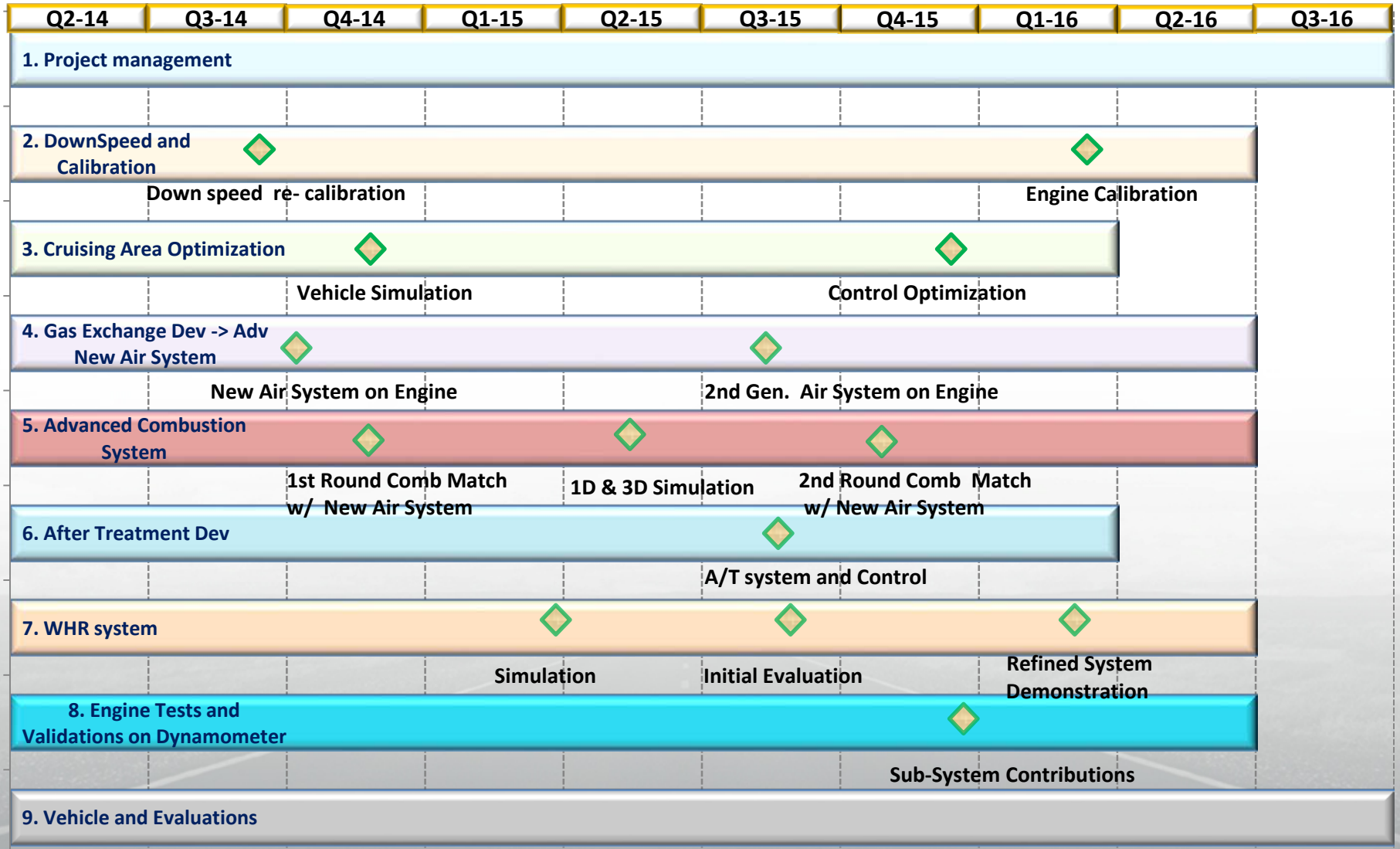
Goals and Objectives

1. Demonstrate 50% improvement in freight efficiency
   - 20% through Engine technologies
   - 30% through Vehicle technologies
2. Demonstrate 50% BTE on Engine Dynamometer
3. Demonstrate technical pathway towards 55% BTE

Relevance

- ✓ Provide a realistic technology demonstrator to reduce petroleum consumption in the truck market:
  - → Engine technologies closely worked with business requirements
  - → Focus on packaging and customer interface (key in the case of Waste Heat Recovery)
- ✓ Work with Partners to develop robust products for commercial integration:
  - → High efficiency common rail Fuel Injection System (FIS) (BOSCH) for advanced combustion
  - → Advanced base engine technologies for friction reduction
  - → Worked with Argonne National Labs to provide technical path for alternative fuels and clean combustion systems
- ✓ Work with Collaborators…

Timing / Milestones



Engine Partnerships and completed tasks

Apr-12 | Oct-12 | Apr-14 | Apr-15 | Apr-16

Phase I | PAUSE | Phase II | Phase III-IV

Navistar

- ✓ *Combustion and Emission*
- ✓ *Turbo compounding*
- ✓ *Base Engine*
- ✓ *VVA*

- ✓ *Optimal cruising area*
- ✓ *Adv Combustion*
- ✓ *Adv Air System*
- ✓ *Reduction of Parasitic*
- ✓ *1D/3D simulations*
- ✓ *VVA*

50% BTE Demo

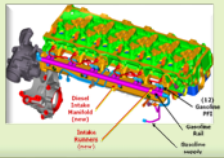
BOSCH *Hi-injection press deployment*

- ✓ *CFD-Testing benchmarks*
- ✓ *High CR testing*

- ✓ *Adv comb with FIS strategies*
- ✓ *WHR system dev*

55% BTE Path

ANL



- ✓ *Engine Design*
- ✓ *Controls deployment*
- ✓ *Fuel Reactivity testing*

- ✓ *VVA with updated comb*
- ✓ *Adv Technologies*
- ✓ *Fuels*

55% BTE Path

Engine Collaborators and completed tasks

Oct-12 Apr-14 Jan-15 Apr-16

PAUSE

Phase II

Phase III-IV

Mahle ✓ Adv. Power Cyl. Concepts ✓ Heat Exchangers	✓ Pwr cyl optimization ✓ WHR system and components re-defined by simulation	55% BTE Demo
Borg Warner ✓ Turbos / Air Systems	✓ Optimized turbocharger system	50% BTE Demo
Jacobs Vehicle Systems ✓ Variable Valve Actuation	✓ Pumping work reduction for specific operating modes	55% BTE Path
Philos Technology ✓ Surface Treatment	✓ Improvements to critical wear components	55% BTE Path
Federal Mogul ✓ Accessory prove out ✓ Kit procurement	✓ Friction Engine Testing	55% BTE Path
C.E.S.	✓ High Efficiency Aftertreament	50% BTE Demo
Benteler	✓ Advanced Thermal Mgmt.	55% BTE Path

Barriers and technology roadmap

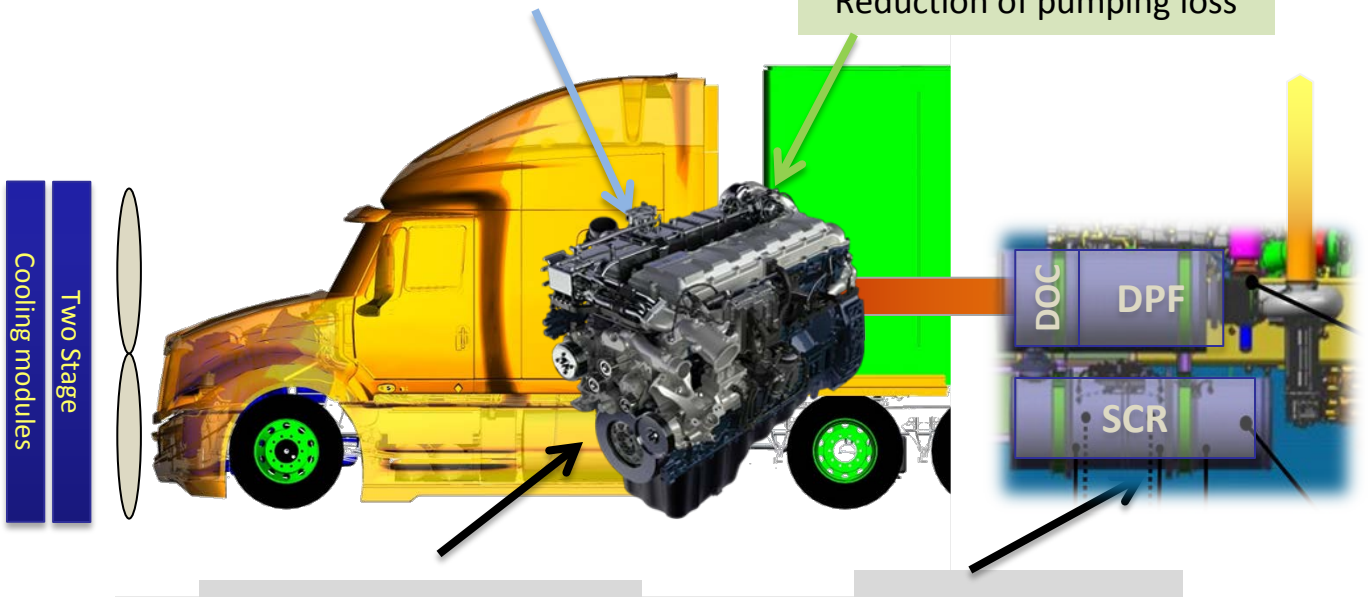
Key: ✓ high confidence to contain
✸ working on improving solution

System	Barriers (challenges)	Technology Roadmap
Engine & Vehicle	• **Cost effective** • **Robust** (controls, durable) • **Reduced weight**	Rely on analysis to select technology ✓
Engine	• **High combustion efficiency** • **High efficiency A/T System** • **Air system with minimum losses**	Improve FIS and combustion match ✓ Advanced combustion regimes ✓ Improve gas exchange efficiency ✓ Advanced after treatment ✸
Engine	• **Modest bottoming cycle efficiency** • **Parasitic reduction** • **WHR system**	Advanced designs ✓ Close collaboration with suppliers for new technologies ✸ Optimum integration to engine ✸
Engine	• **Non optimum fuel formulation** • **Optimal dual fuel reactivity**	Introduce reactivity control ✓ Understanding of chemical kinetics ✸

Approach – Technology Selection

2 Air System
VG turbo with improved Efficiency
Variable Valve Actuation

3 Friction-Accessories
VOP, VWP
Power Cylinder Components
Reduction of pumping loss



5 WHR
Driven Turbo
ORC system

1 Combustion
New combustion chamber
Bowl- optimization
Increased PCP
Thermal management

4 Aftertreatment
DOC/DPF + SCR
Close coupled
Hi efficiency
Low DP

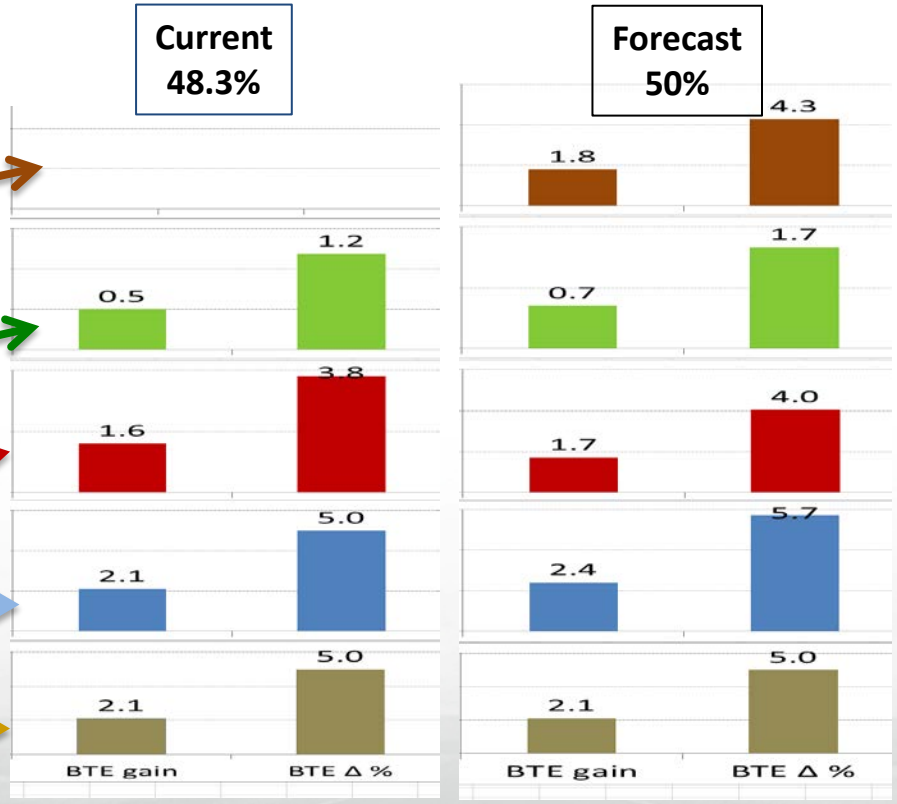
Optimize Integration Criteria

- Efficiency gain (BTE)
- Weight (Ton-mile/gallon)

Approach - Optimum Roadmap Towards 50% BTE

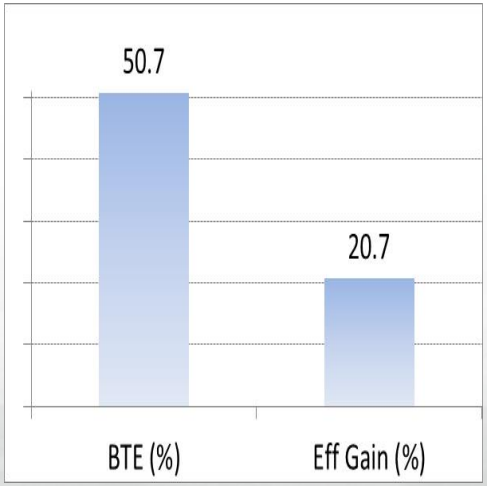
NAVISTAR®
Integrated Product Development
Advanced Technologies

Target :
20% Efficiency gain
50% BTE



Forecast:

- 20.7% Eff Gain
- 50.7% BTE



Selection completed

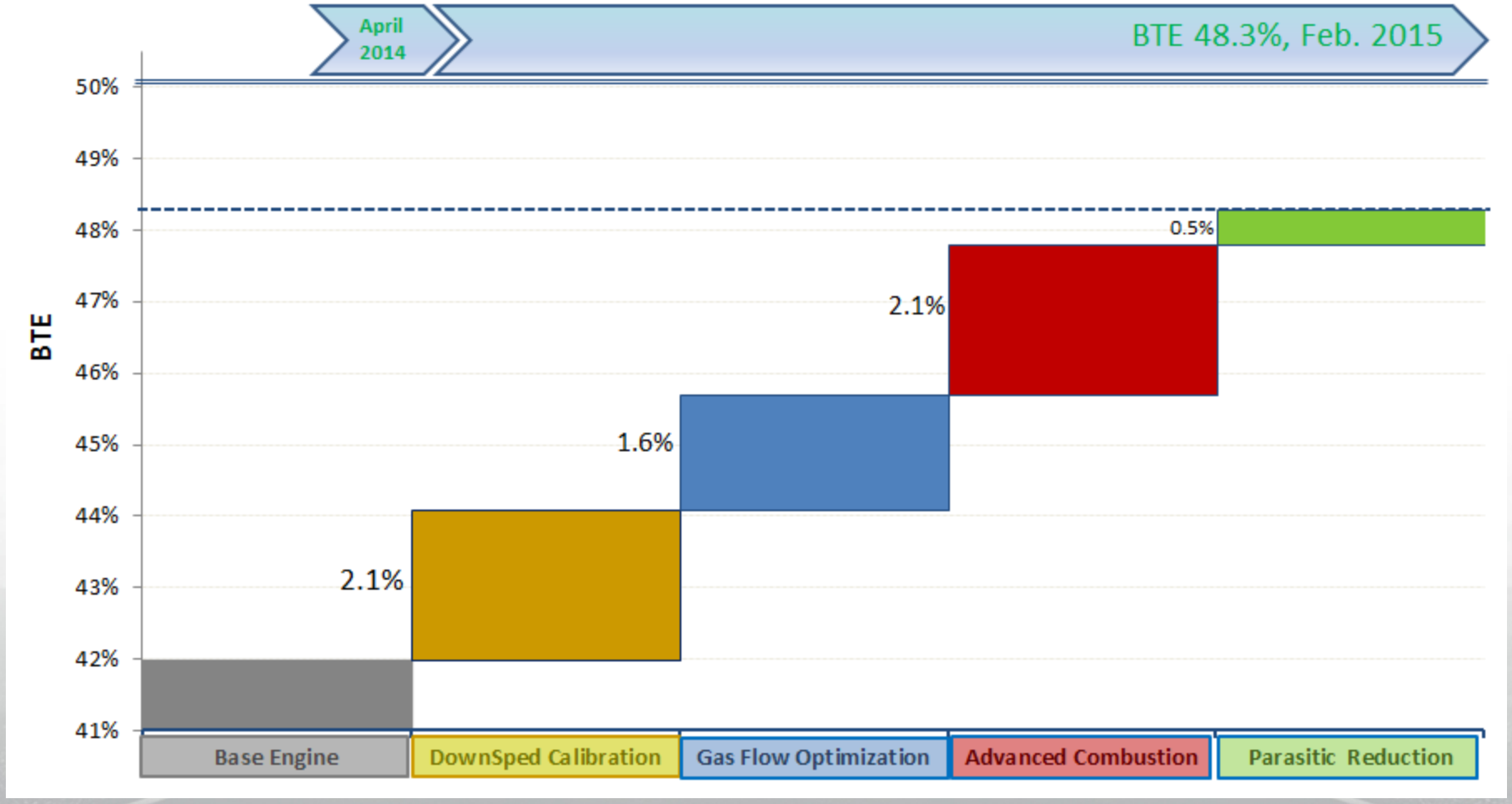
✓ Testing and present projections indicate the program goals will be attained.

Addressed Concerns

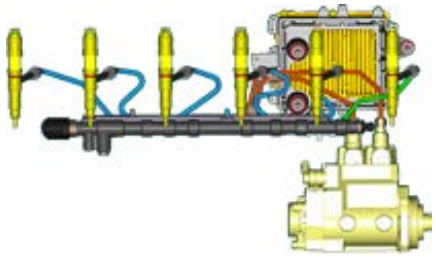
✓ Program will deploy only driven turbo.
✓ ORC system could be further pursued for 55% BTE.

Accomplishments - Engine Dyno efficiency @ 48.3% BTE

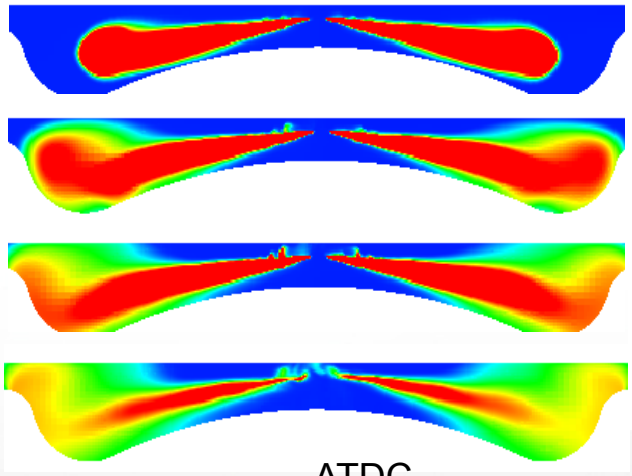
NAVISTAR®
Integrated Product Development
Advanced Technologies

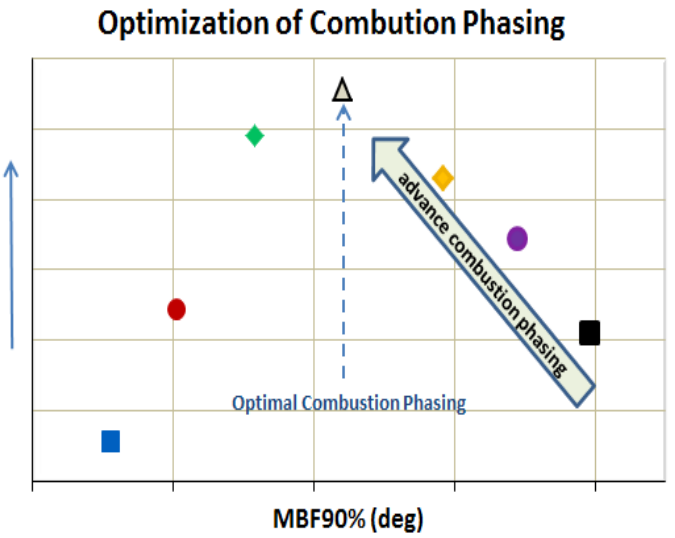


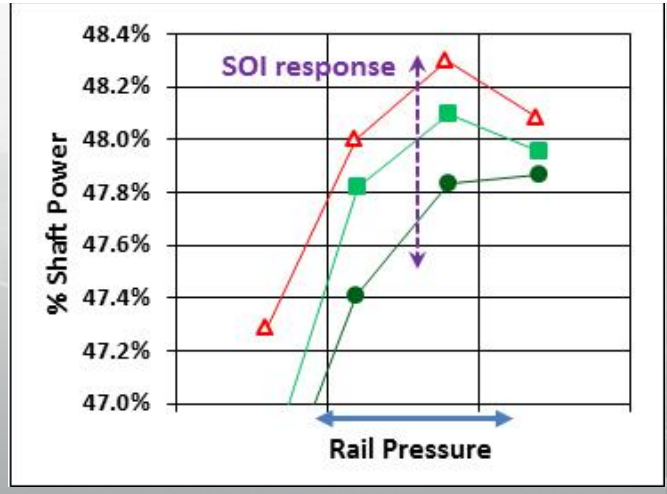
Accomplishments - Advanced Combustion



Fuel system improvement
w/ Fuel injection strategies

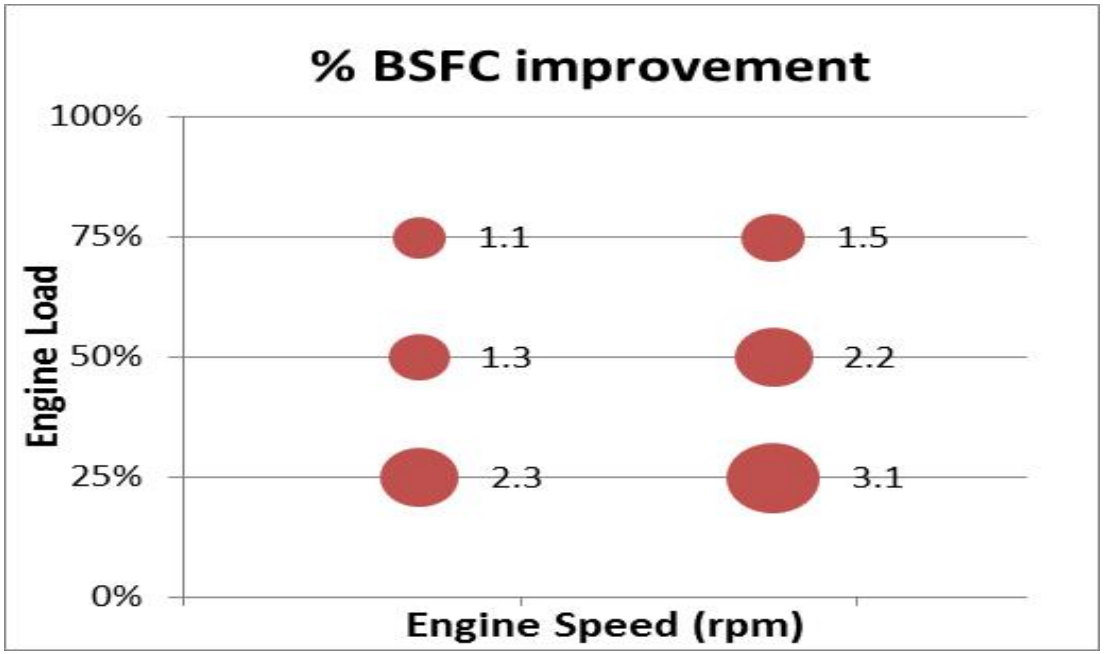




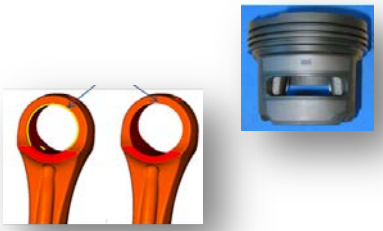


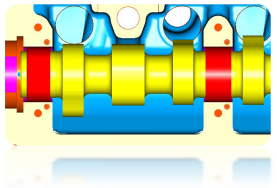
Combustion optimization: Compression ratio (CR), combustion chamber and matching fuel injection strategies, combustion phasing, down-sizing effects

Accomplishments - Reduction of Parasitic Losse

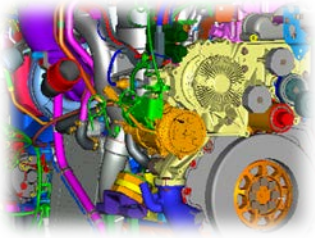


Power Cylinder

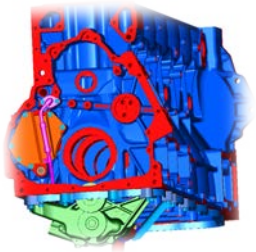




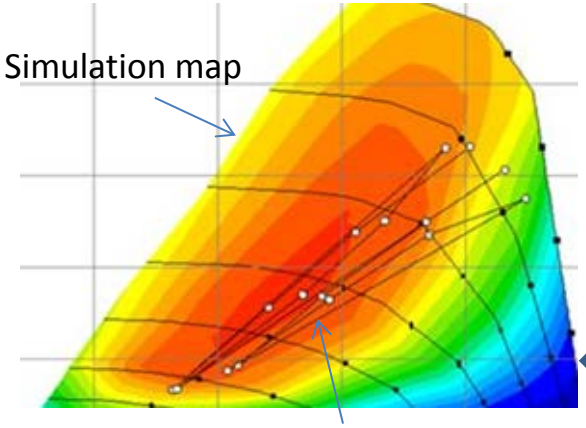
Cooling system



Lube + Cooling



Accomplishments - Air System / VVA

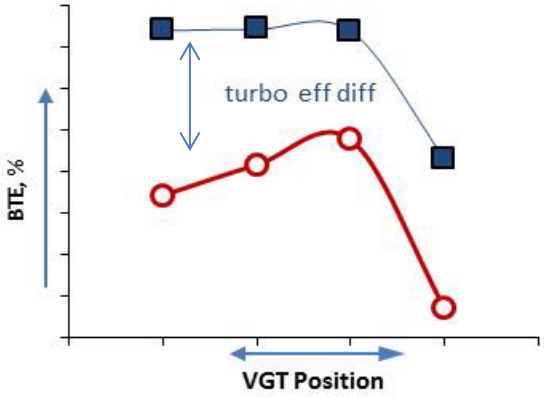


VVA system with upgraded combustion system

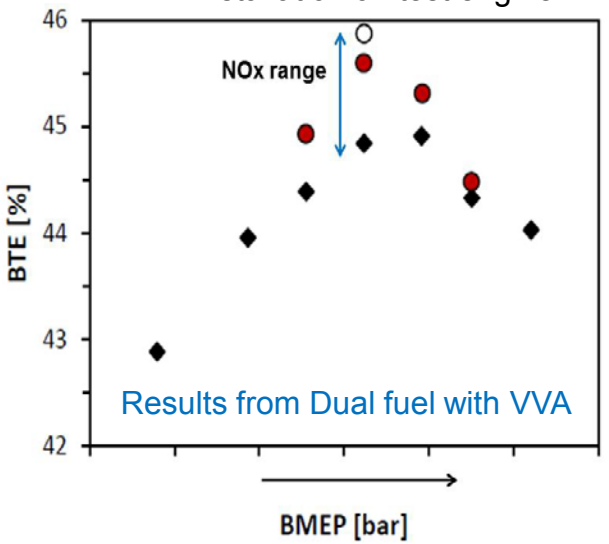
VVA installation on test engine

Initial tests show hardware alignment to system simulation

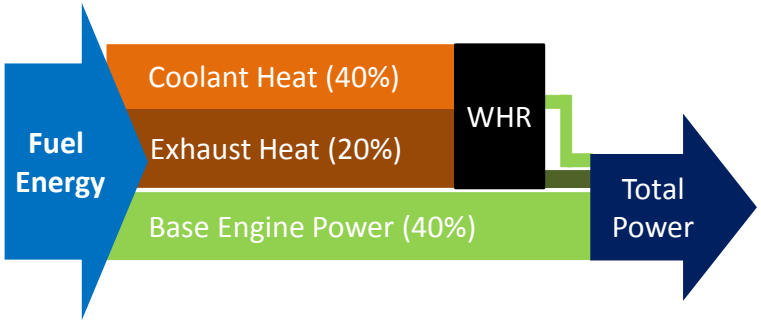
Demonstrates turbo system efficiency as an enabler for BTE gain

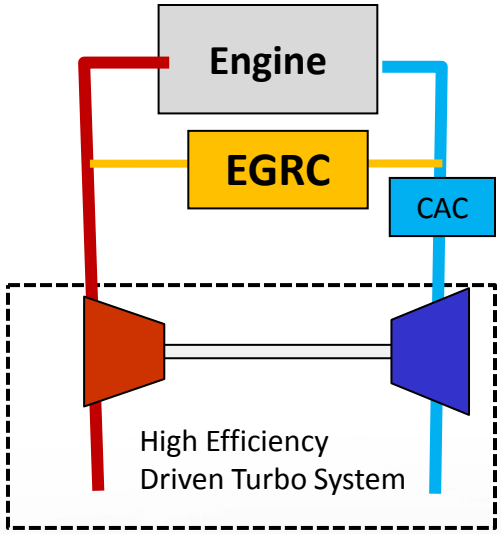


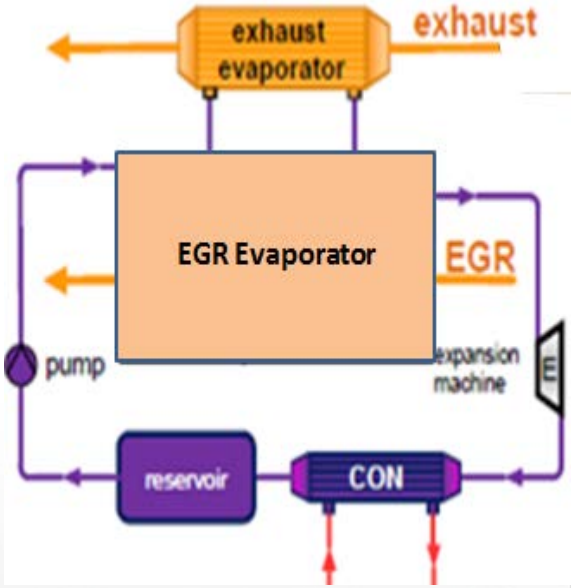
Successful implementation of turbo system technology to test engine



Accomplishments -
Evaluation of WHR Strategy

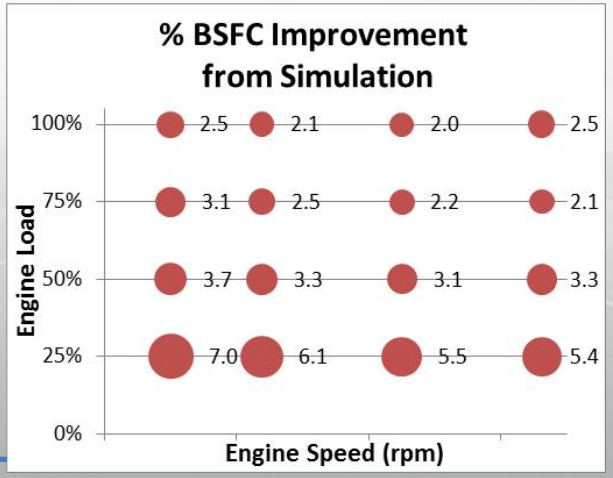






ORC System

✓Simulation work for high efficiency driven turbo system completed
-Engine validation will follow



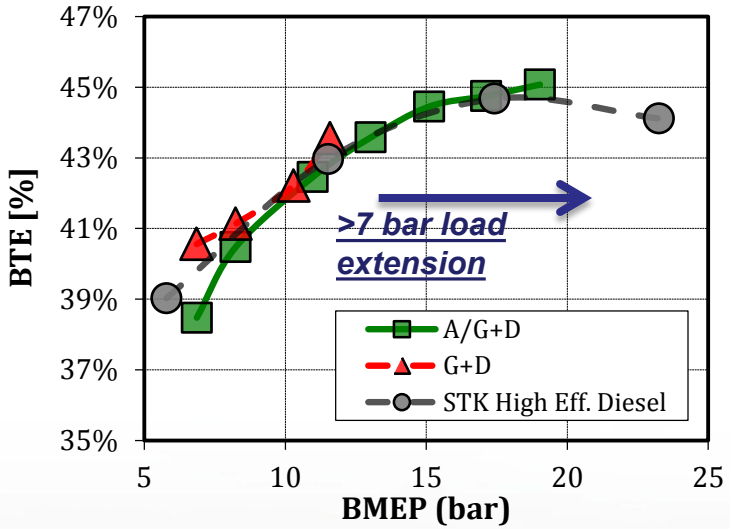
✓Simulation work in progress on ORC system

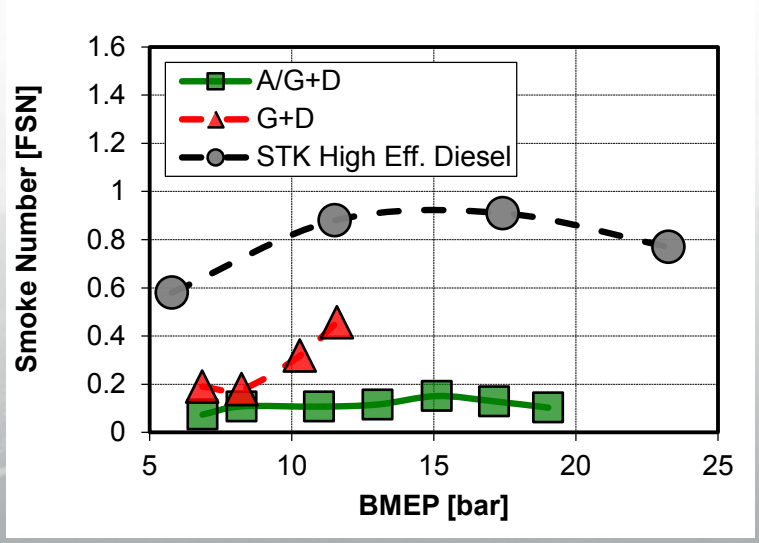
Accomplishments - 55% BTE Target with Dual Fuel Engine

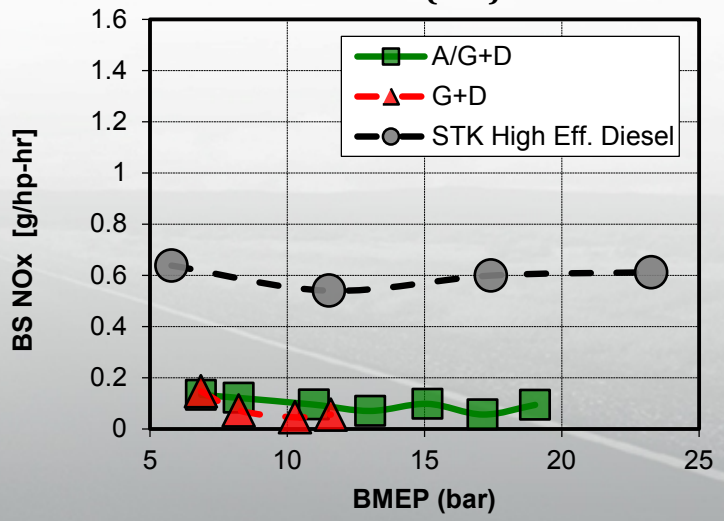
Engine Setup at Argonne:

- ✓ Alcohol/gasoline extended LTC load to **19 bar** BMEP
- ✓ Fuel-bound oxygen led to soot reduction
- ✓ improved fuel efficiency: best BTE: **45.1%**

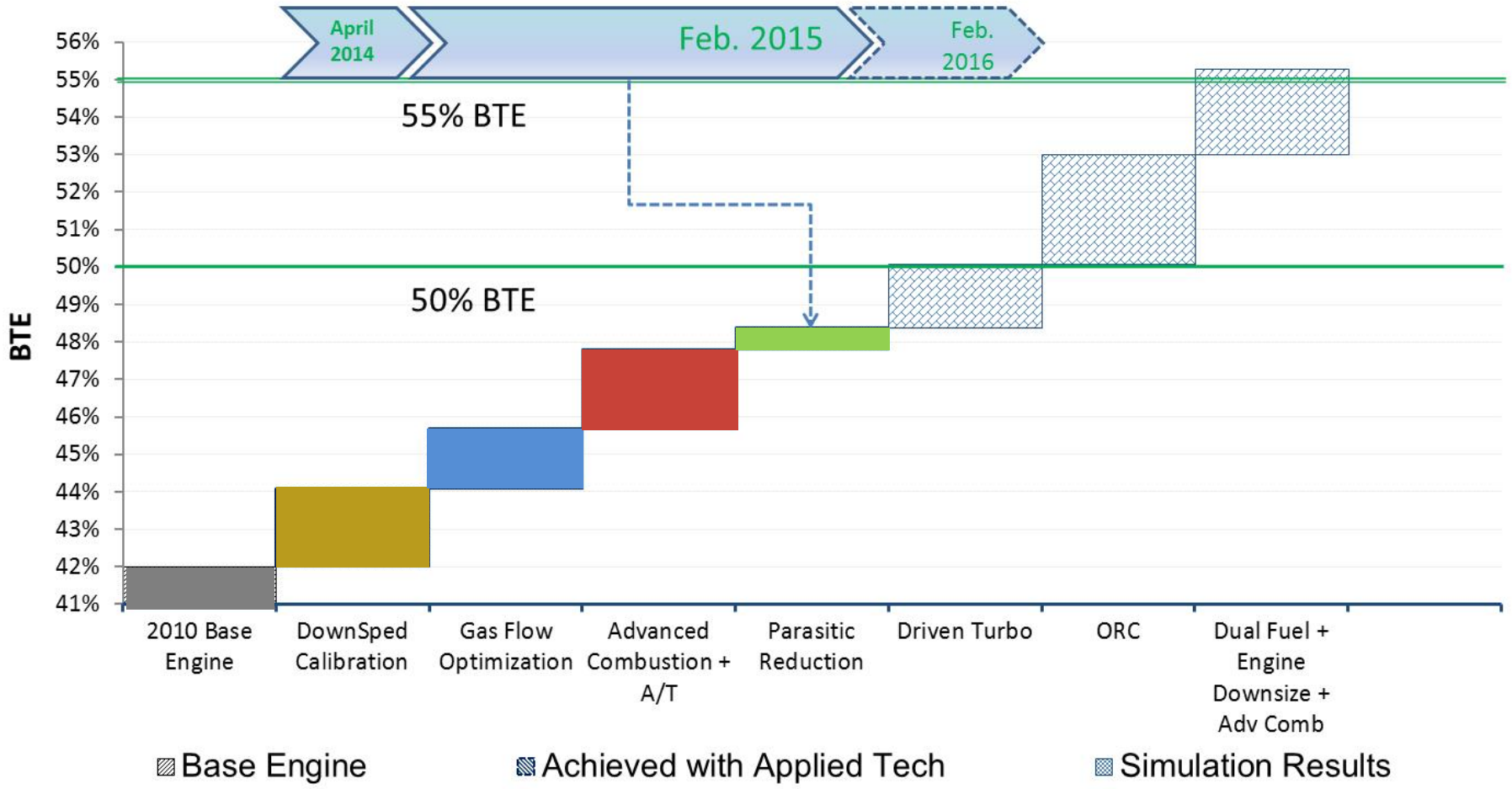
Significant improvement on BTE with fuel reactivity at better controlled engine out emissions







Future Work - Moving Forward



Future Work

Ongoing	**FY15**	• Advanced combustion with FIS technologies/strategies • Driven turbo + ORC + Thermal management • Further improvement of gas exchange efficiency • Reduction of parasitic losses • Control Strategy • System Integration • VVA system with higher compression ratio • Downsize engine with low friction materials • Simulation to fully understand the factors on BTE gain
Planned	**FY16**	▪ Optimization of WHR ▪ Advanced combustion with new FIS optimization ▪ New high efficiency air system ▪ In cylinder thermal management ▪ Reactivity studies performed with gasoline and alcohol fuel ▪ System integration and packaging

✓ Following technologies / methods utilized to achieve 48.3% BTE

- ✓ **On engine combustion:**
  - Newly designed combustion chambers and system match
  - Investigation and understanding combustion phasing
  - Extended peak cylinder pressure capability
- ✓ **Engine Downsped**
  - Re-cal and optimization
- ✓ **Reduction of Parasitic Losses**
  - Base components, lube and cooling, were updated raising BTE
  - Power cylinder components were procured and evaluated
- ✓ **VVA engine upgraded with advanced combustion system**

Project Summary

- ✓ **WHR system**
  - Simulation to define system
  - Driven turbo with advance air system

✓ Advanced 55% BTE technical path

- ✓ **Reactivity studies performed with gasoline and alcohol fuels**
  - High engine efficiencies were compatible with very reduced engine emissions
  - Study will continue with enabling features recently added VVA system, such as high compression ratio, new combustion system

✓ **Both 1D and 3D simulations are used for technical feasibility study**