Impact of Advanced Technologies on Engine Targets

2014 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

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Sponsored by David Anderson

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U.S. Department of Energy
Energy Efficiency and Renewable Energy
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Project Overview

Timeline	Barriers
• Start – September 2013 • End – September 2014 • 40% Complete.	• Consistent methods for modeling engine technology development. • Availability of cost models for engine technology improvement. • Rigorous method for system evaluation of engine technology improvements.

Budget	Partners
• FY14: $200K	• IAV Automotive Engineering, INC. • Fuels, Engine and After treatment Research, Argonne National Laboratory. • Advanced Powertrain Research Facility, Argonne National Laboratory. • U.S.Drive Advanced Combustion and Emissions Control Tech Team.

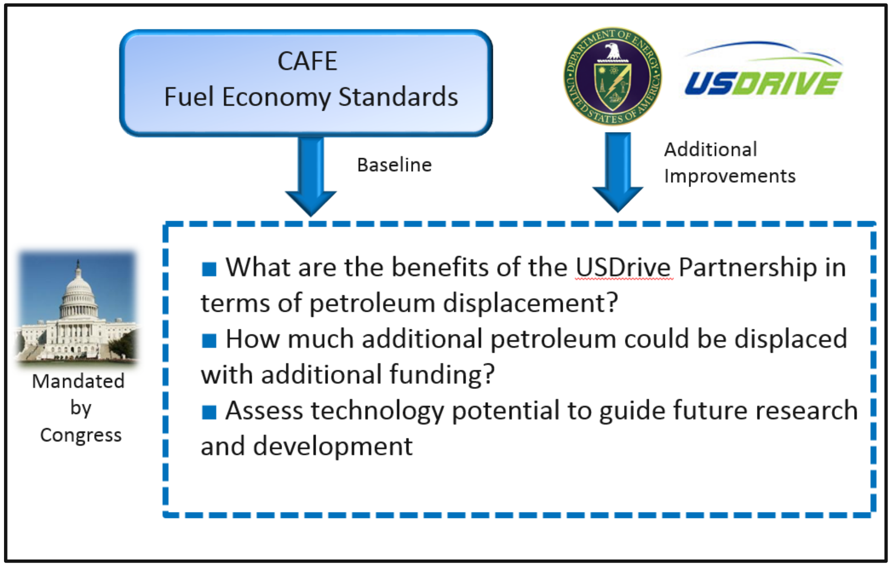
Project Objectives

Evaluate the impact of advanced technologies (i.e. engine, transmission, electrification…) on U.S.Drive engine targets & vehicle fuel consumption.

- How will advanced technologies affect engine operating conditions?
- What is the fuel displacement potential of advanced technologies for different combinations? What is the additional cost?
- How do the advanced engine technology performance data compare with the ones developed for the U.S.Drive analysis, with the ones currently being developed by the U.S.Drive engine technical team?

Relevance

Engine Technologies Critical to Displace Fuel



Engine technology is critical to VTO benefit predictions

Will the current USDrive engine operating points used for target setting be still valid?

How do future technologies compare with these targets?

		2010 Baselines				**2020 Stretch Goals[3]**		
Technology Pathway	Fuel	Peak Efficiency[1]	Efficiency[1] at 2-bar BMEP and 2000 rpm	Efficiency[1] at 2000 rpm and 20% of the peak load	2000 rpm Peak Load[2]	Peak Efficiency	Efficiency at 2-bar BMEP and 2000 rpm	Efficiency at 2000 rpm and 20% of the peak load
Hybrid Application	Gasoline	38	25	24	9.3	46	30	29
Naturally Aspirated	Gasoline	36	24	24	10.9	43	29	29
Downsized Boosted	Gasoline[4]	36	22	29	19	43	26	35
	Diesel	42	26	34	22	50	31	41

Relevance

Vehicle System Integration is Critical to Develop Engine Technology Targets

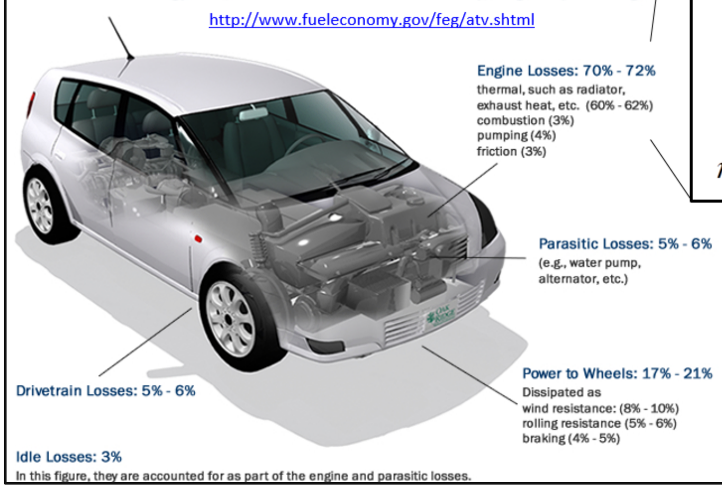
The engine is one key component in overall vehicle system performance

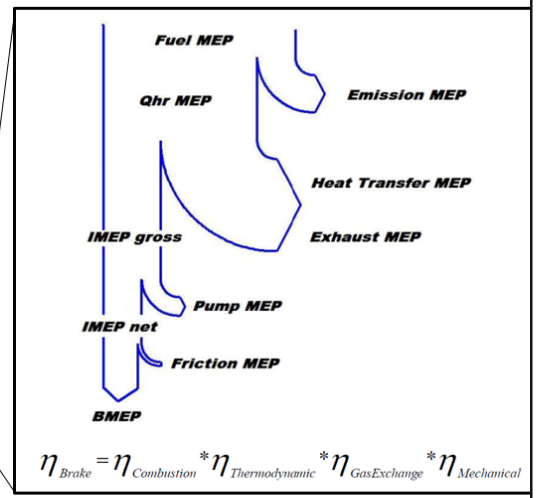
USDRIVE

- Engines expected to be in 99% of the car park in 2035 (EIA reference case)
- Potential efficiency improvement still high, ~50% (2010 DOE Colloquium Report)
- System integration critical to translating engine efficiency to higher mpg

Energy Requirements for Combined City/Highway Driving

http://www.fueleconomy.gov/feg/atv.shtml



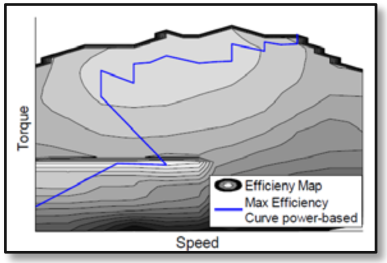


- Relating engine efficiency to vehicle-level fuel economy is a challenge
- New engine goals being set for multiple powertrain types

U.S.Drive, Advanced Combustion and Emissions Control (ACEC) Tech team presentation, October 25th, 2011, U.S. Drive All Tech Team Meeting.

Usual Approach

Engine Performance Data for Different Technologies Usually Comes From Different Engine Families, Making Comparison Difficult



HCCI: GT power model
for a 2 L engine.
Vehicle: Conventional and
Hybrid.

Comparison across different engine families, engine data sources, vehicle assumptions is impossible

LTC gasoline : GM 1.9 L diesel
Vehicle: GM Cadillac powertrain
(diesel).

SIDI gasoline: Opel 2.2 L Ecotec engine
Test data.
Vehicle: Conventional midsize, different
Powertrain assumptions from HCCI

Hydrogen Engine: Ford 2.3 L Duratec
Supercharged.
Vehicle: Conventional Ford Focus.

New Approach

Use High Fidelity Engine Models for Consistent Technology Assessment

- **Incremental** engine technology evolution from the same base technology allows rigorous assessment.

SI Gasoline technology evolution

2 L PFI, VVT engine
GT power
Based on test data

GT power model
Modified to add VVL

Same model
Modified to have
Direct Injection

Addition of turbo-
Charger to the DI
Engine

Drivetrain evolution

Same vehicle platform across engine evolution, transmissions optimized for each engine, evolution in transmissions, powertrain electrification

Vehicle system impact of advances in engine technology, coupled with consistent and optimized drivetrain assumptions.

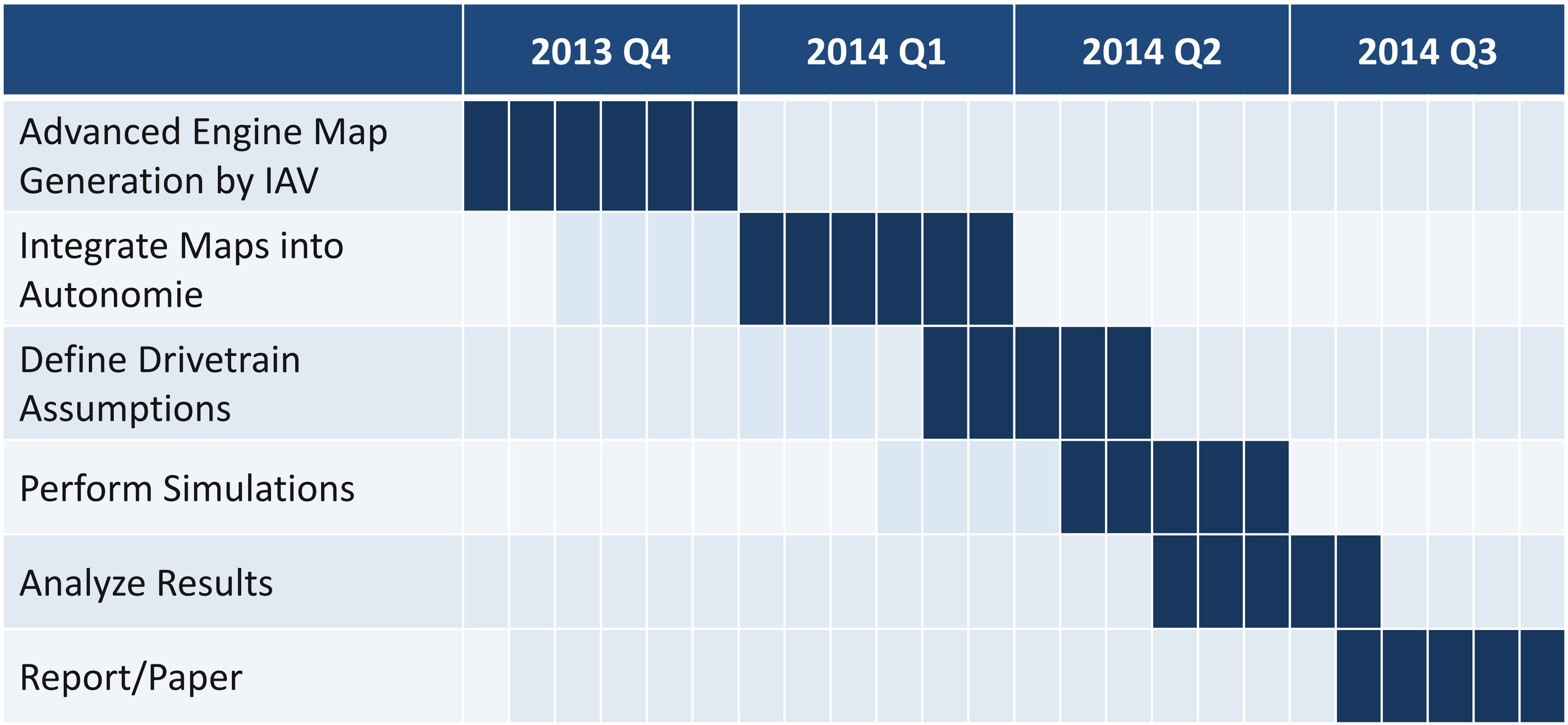
Approach

Evaluate Each Engine Technology in Incremental Steps of Drivetrain Advancements

Drivetrain	Evaluation
All engines with 6 speed auto	Performance, fuel economy and cost impact with same powertrain
All engines with 6 speed auto 8 speed auto & DCT.	Fuel economy, cost impact of engine technology in combination with transmission technology
All engines with 6 speed auto and final drive reduction, with BISG.	Fuel economy, cost impact of engine technology in combination with down-speeding and start stop
All engines with parallel pre-transmission hybrid	Fuel economy, cost impact of engine technology in combination with hybridization

Engine evaluation will be performed with and without engine resizing to match performance.

Milestones


2013 Q4
2014 Q1
2014 Q2
2014 Q3
Advanced Engine Map Generation by IAV
Integrate Maps into Autonomie
Define Drivetrain Assumptions
Perform Simulations
Analyze Results
Report/Paper

Technical Accomplishment

Engine Data for 17 Incremental Technologies Developed by IAV* Using GTPower

DOHC

1. VVT (baseline*)
2. VVL
3. GDI
4. Cylinder deact

SOHC

(no friction change)
5a. VVT (fixed overlap)

(Red friction –Stage1)
5b. VVT
6a. VVL
7a. GDI
8a. Cyl deact

(Red friction –Stage2)
5c. VVT
6b. VVL
7b. GDI
8b. Cyl deact

DOHC Turbo**

12. Downsize Level1 → 1.6l, 4cyl,18bar bmep
13. Downsize Level2 → 1.2l, 4cyl, 24bar bmep
14. Downsize Level2 → 1.2l, 4cyl, 24bar bmep, cooled EGR
15. Downsize Level3 → 1.0l, 4cyl, 27bar bmep, cooled EGR
16. Downsize Level3 → 1.0l, 3cyl, 27bar bmep, cooled EGR

*baseline - Gasoline, 2.0l, 4 cyl, NA, PFI, DOHC, dual cam VVT (Each additional engine 2,3,4 adds a technology on top of the previously added technologies)
**DOHC Turbo - Gasoline, Turbocharged, DI, dual cam VVT, VVL

Diesel

17. Diesel engine → 2.2l, 4cyl

*baseline Naturally aspirated engine, baseline turbo and diesel engine maps generated from actual test bench data.

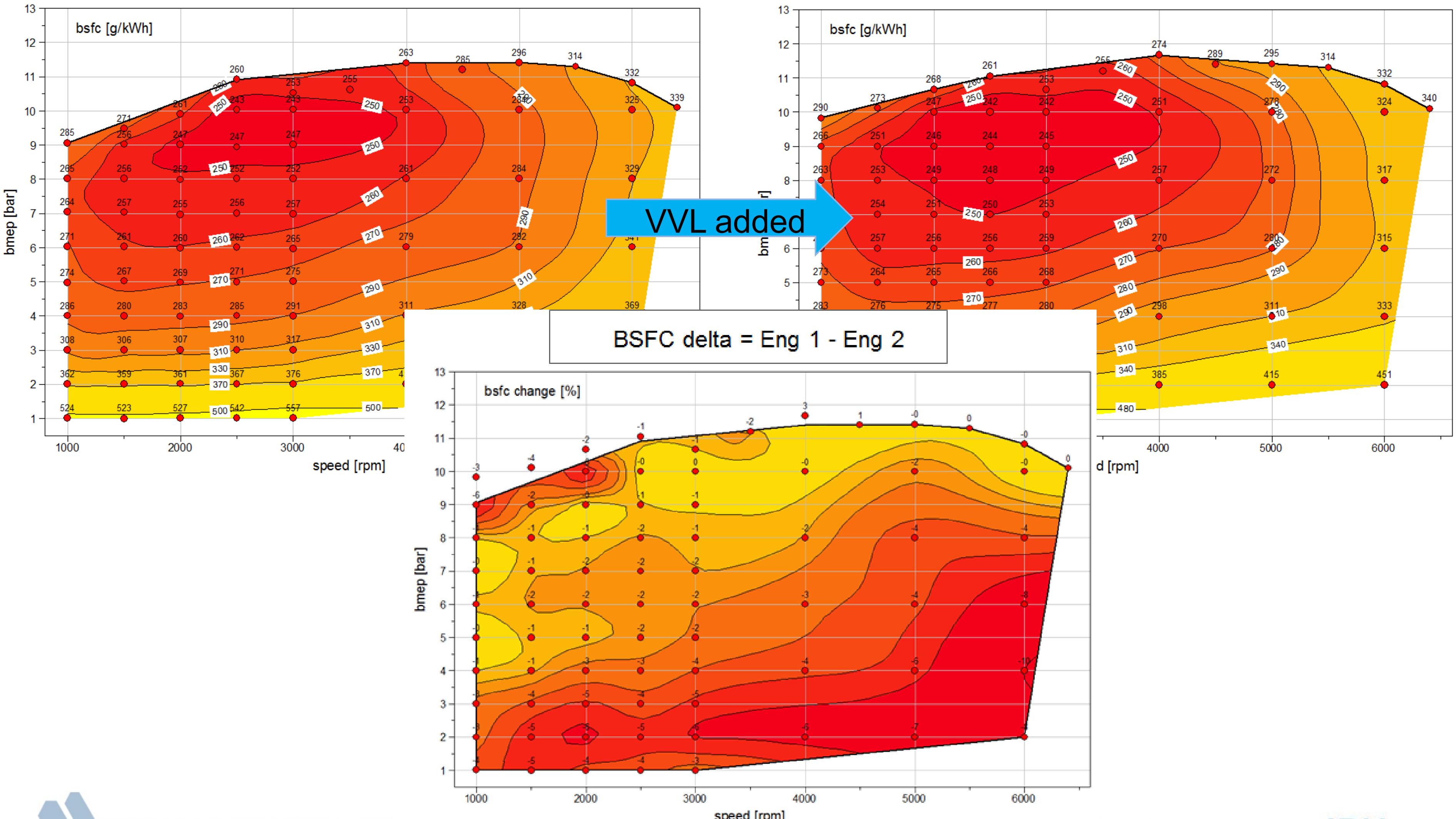
automotive engineering iav

Technical Accomplishment

Engine Performance Map Example

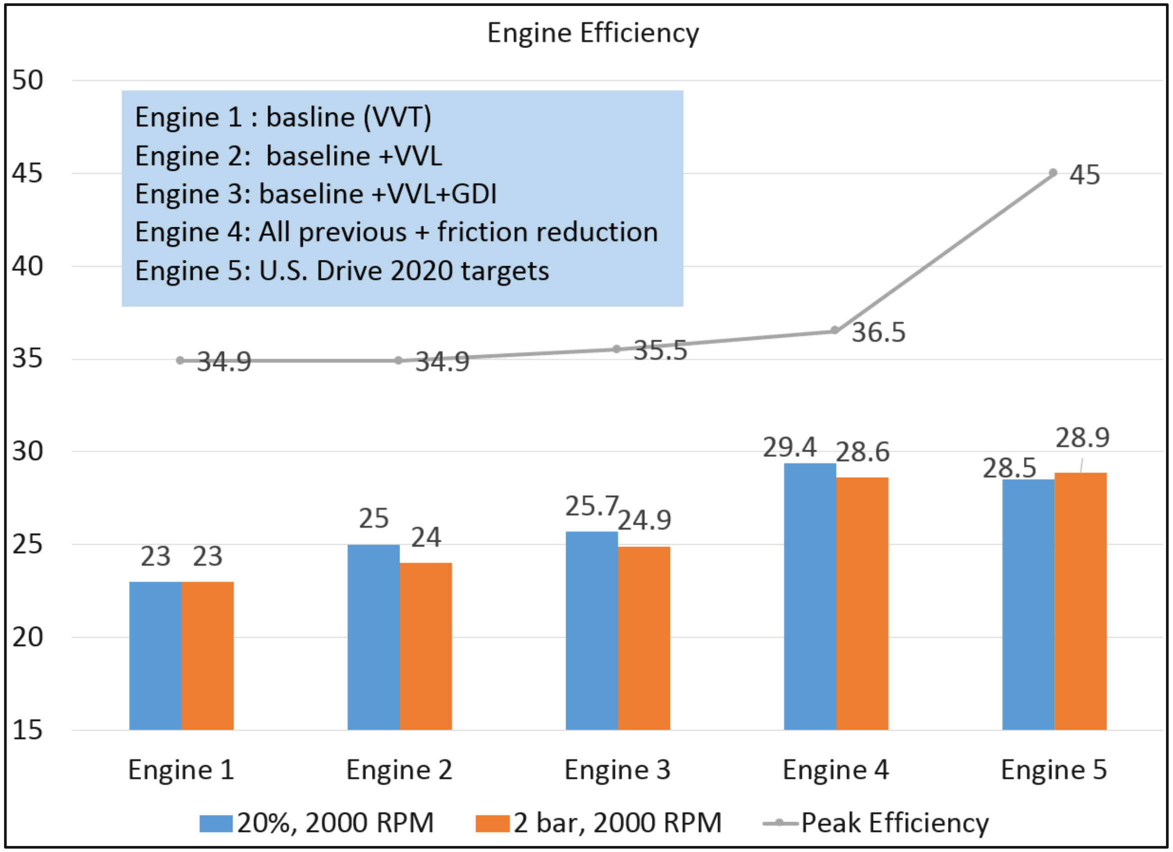
BSFC Engine 1

BSFC Engine 2

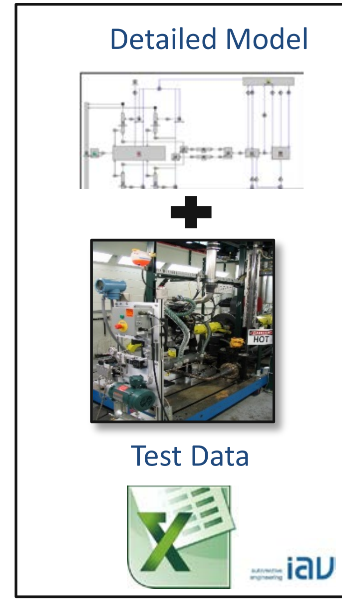


Technical Accomplishment

IAV Engine map part load efficiencies comparable to U.S.Drive targets.



Comparison of peak and part-load efficiency for Naturally aspirated engines



AUTONOMIE

- Engine technology progression shows significant improvement in part load efficiency.
- IAV assumptions and method on engine technology was presented to the ACEC tech team.

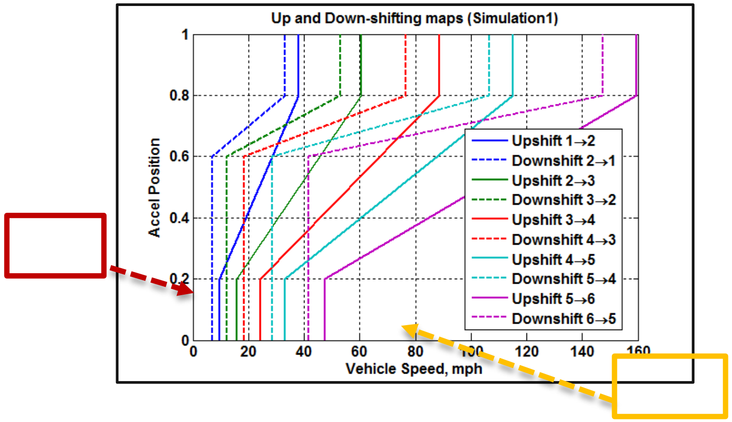
Technical Accomplishment
Vehicle and Transmission Ratio Selected

- Vehicle Class: Compact (year 2020).
- Criteria for transmission ratio selection:
  - Engine speed above 1300 RPM in top gear to prevent 'engine lugging'.
  - Vehicle maximum speed and engine max speed considerations.
  - 8 speed DCT should have higher first gear to match performance of an 8 speed automatic.
  - IVM – 60 mph acceleration in ~8.5 seconds for the 6 speed automatic (year 2020).

Technical Accomplishment

Shift Parameters Optimized for Each Engine Technologies

- Shift parameters in Autonomie are adjusted for each engine

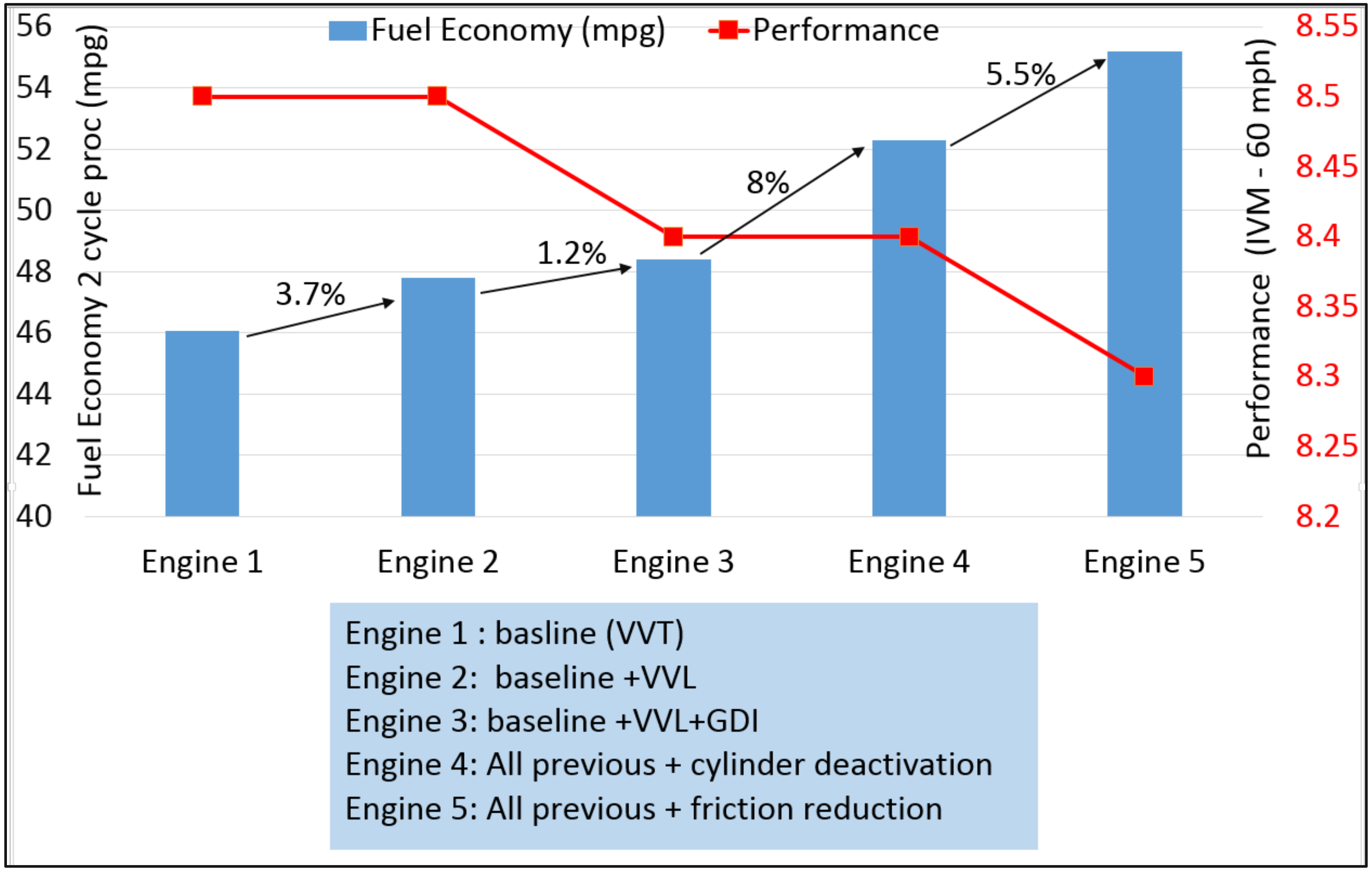


Upshift speed and pedal position for upshift are tuned to maximize fuel economy

- Shift parameters adjustment is subject to the following criteria, based on analysis of APRF test data for conventional powertrains.
  - Vehicle should be in top gear around 45 mph.
  - Number of shifts with parameter adjustment should not be greater than test data by more than 10%.
  - No engine operation in low speed, high torque region.
- All simulations assume hot start conditions with 3 way catalyst fully warmed up. Therefore emission implications of parameter tuning are considered negligible.

Technical Accomplishments

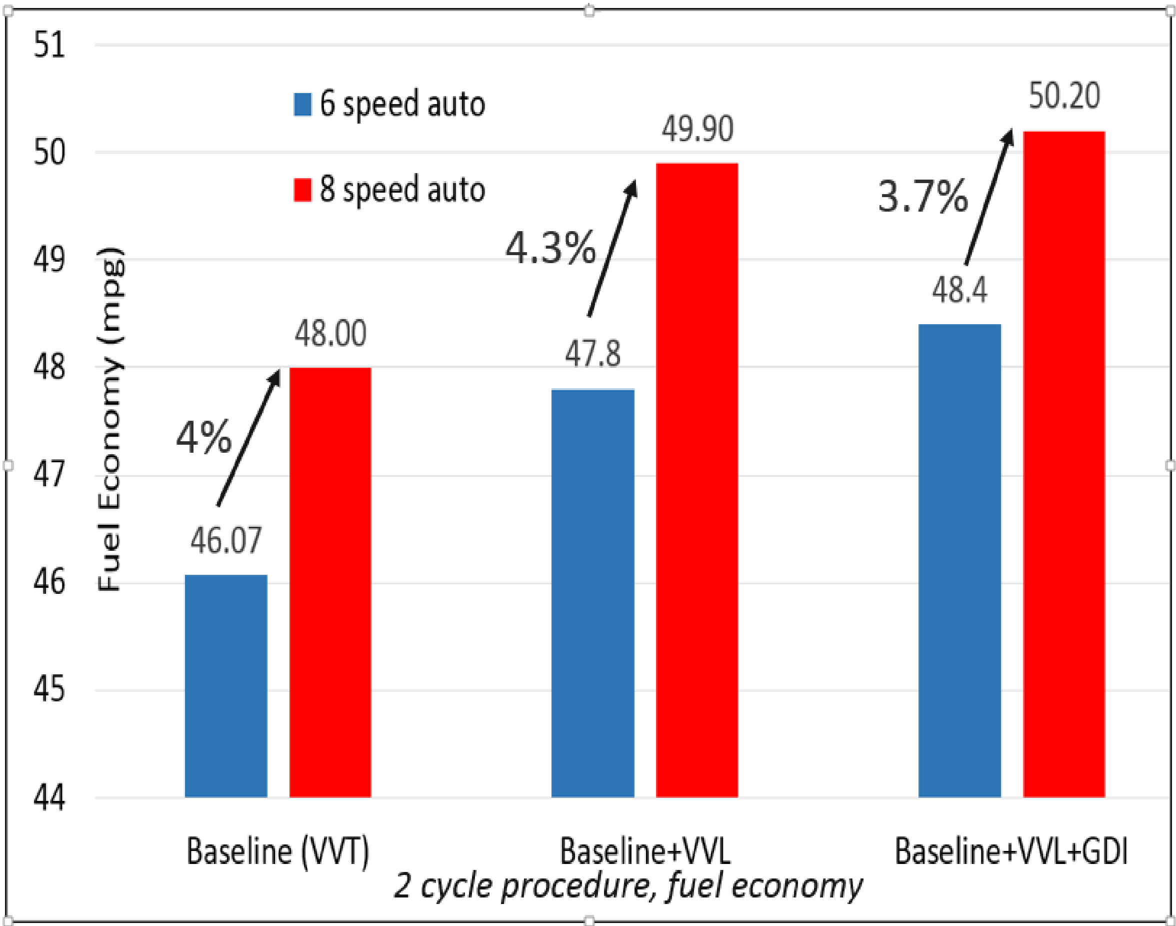
Engine Technology Benefits Quantified On Standard Driving Cycles



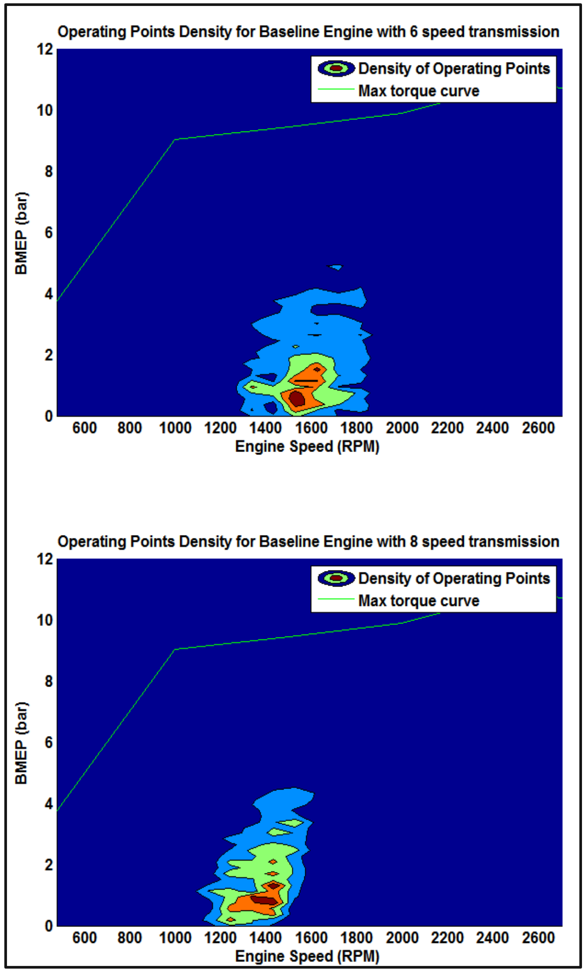
- Cylinder deactivation and friction reduction offer significant improvement in fuel economy.
- GDI and friction reduction cause an improvement in performance.

Technical Accomplishments

Impact of Advanced Transmissions (6 speed to 8 speed) vary with engine technology.



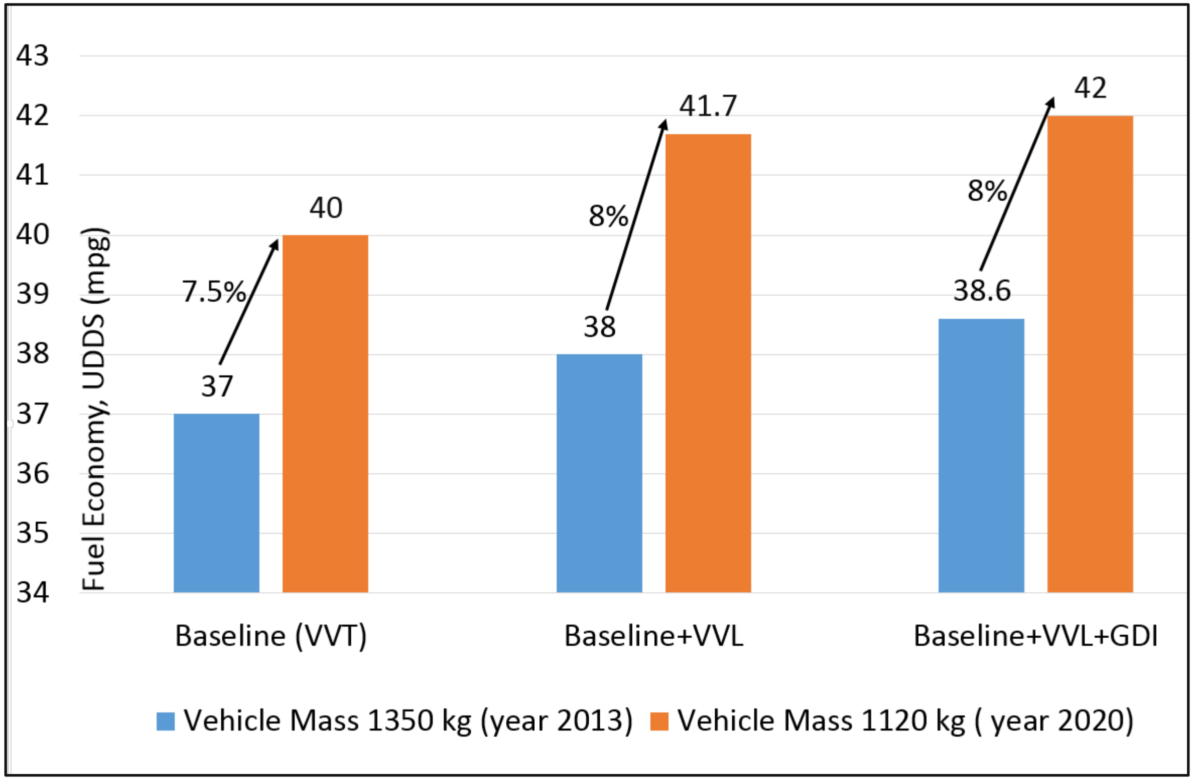
Down speeding of the engine operation with the 8 speed transmission results in a higher fuel economy.

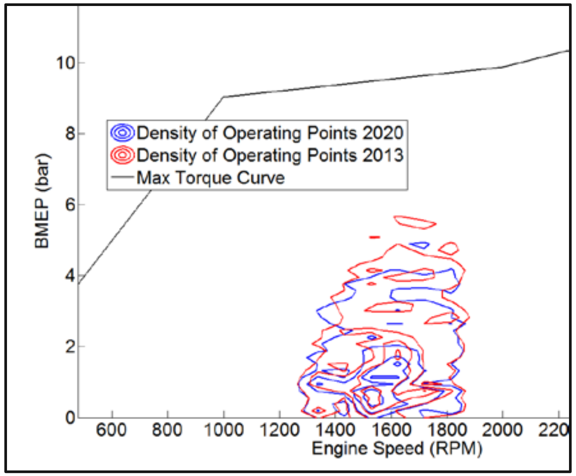


Comparison of engine operating points for 6 speed and 8 speed transmission - UDDS

Technical Accomplishments

Impact of Light Weighting on Fuel Economy and Engine operation is similar across engine technologies.

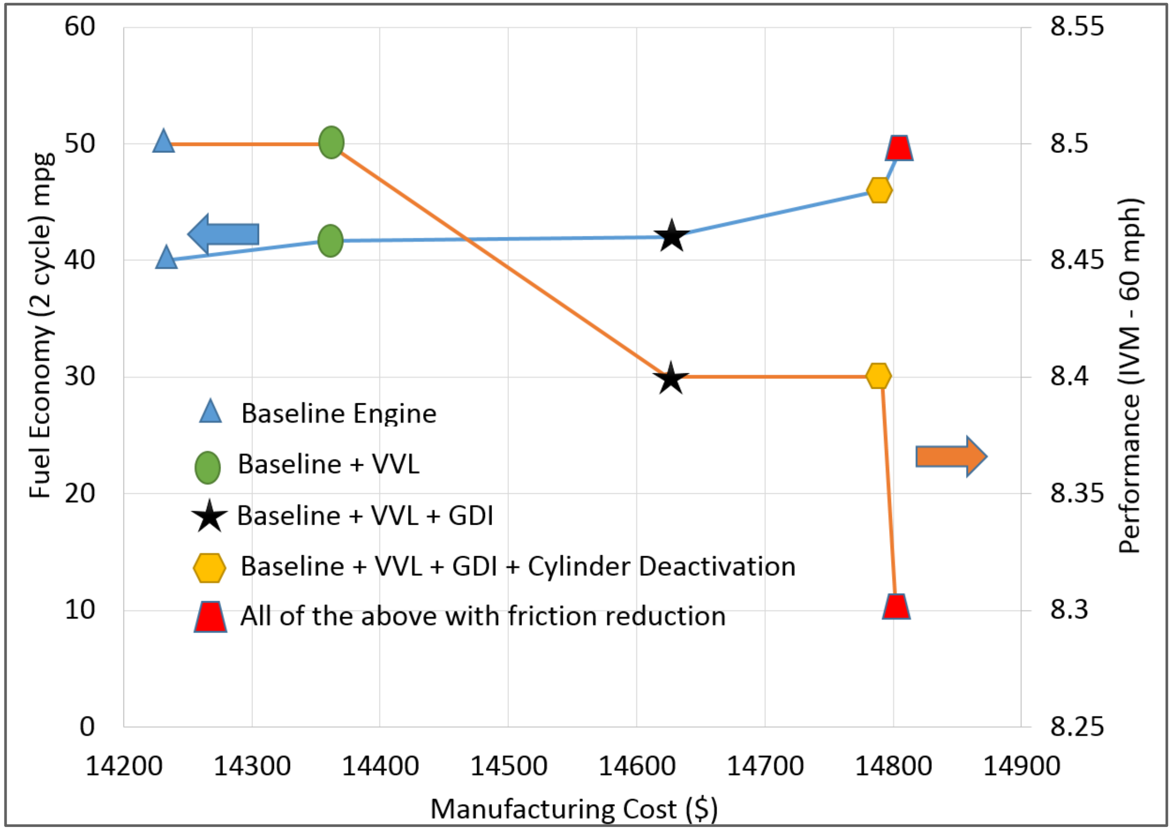




- Vehicle mass reduction from 2013 to 2020 is due to reduction in glider mass , based on DOE targets for lightweigting for year 2020.
- Similar impact of vehicle mass reduction observed for different engines.

Technical Accomplishments

Friction reduction offers the least expensive method for fuel economy and performance improvement

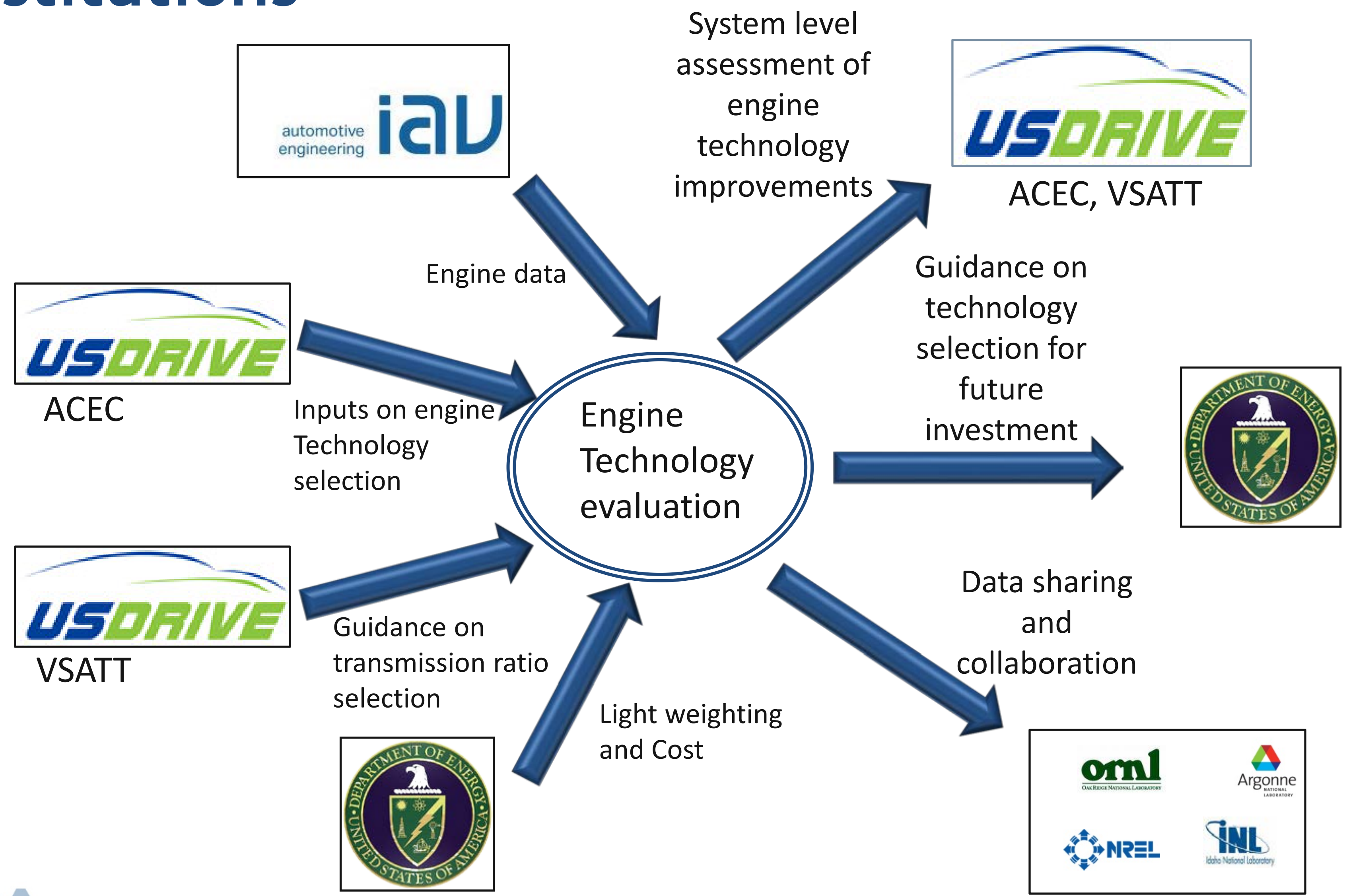


- All cost assumptions for vehicle and engine technology have been reviewed by DOE.
- Direction Injection is the most expensive engine technology to implement.

Response to Previous Year Reviewers' Comments

- New project started this year.
- There was no presentation on this topic last year.

Collaboration and Coordination with Other Institutions



Proposed Future Activities

- Use of thermal and emissions models to consider impact of cold start and emissions.
  - Use high fidelity GTPower engine models in Autonomie.
  - Use after-treatment models for tailpipe emissions assessment.
- Impact of improving engine efficiency on reduced exhaust temperature and catalyst light –off for starter-alternator vehicles.
- Engine assessment with transmission ratio design for each engine (currently only shift parameters optimized for each engine).

Summary

- Previous approach to system evaluation of engine technologies made comparison of vehicle system level impact difficult.
- New methodology relies on engine performance maps generated from high fidelity GTPower models.
- Multiple engine technologies have been modeled by IAV.
- Preliminary simulation results for the naturally aspirated engines quantified engine technology improvements.
- Drivetrain selection (i.e., gear ratio numbers, light-weighting) impacts engine operating conditions.