Assessing the Effectiveness of Current and Future Light-Duty Vehicle Powertrain Technologies

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Office of Transportation and Air Quality
Office of Air and Radiation
U.S. Environmental Protection Agency

Midterm Evaluation

- Technical review of longer-term standards (2022-2025)
- In coordination with NHTSA and California Air Resources Board
- Data driven, transparent
- Extensive, ongoing stakeholder dialogue to gather data/information directly from manufacturers

Factors being consider for the Midterm Evaluation

- ✓ Powertrain improvements
- ✓ Light-weighting and impacts on vehicle safety
- ✓ Market penetration of fuel efficient technologies
- ✓ Consumer acceptance
- ✓ Payback periods for consumers
- ✓ Fuel prices
- ✓ Fleet mix
- ✓ Infrastructure
- ✓ Employment impacts
- ✓ Many others …

Timing for Midterm Evaluation (MTE)

Schedule	Milestone in the Midterm Evaluation Process
June 2016	EPA, NHTSA and CARB jointly issue a **Draft Technical Assessment Report (TAR)** for public comment
Between the Draft TAR and Final Determination	EPA issues for public comment a Proposed Determination on the appropriateness of the MYs 2022-2025 standards NHTSA (potentially jointly with EPA) issues a Notice of Proposed Rulemaking
No later than April 2018	EPA issues a **Final Determination** on the appropriateness of the 2022-2025 standards

The Draft Technical Assessment Report (TAR) is the first step in the process, to seek public comment that will inform decisions regarding standards for MYs 2022-2025 – it is a technical report, not a decision document.

EPA's Advanced Technology Testing

EPA's National Vehicle and Fuel Emissions Laboratory – Part of EPA's Office of Transportation and Air Quality in Ann Arbor, MI

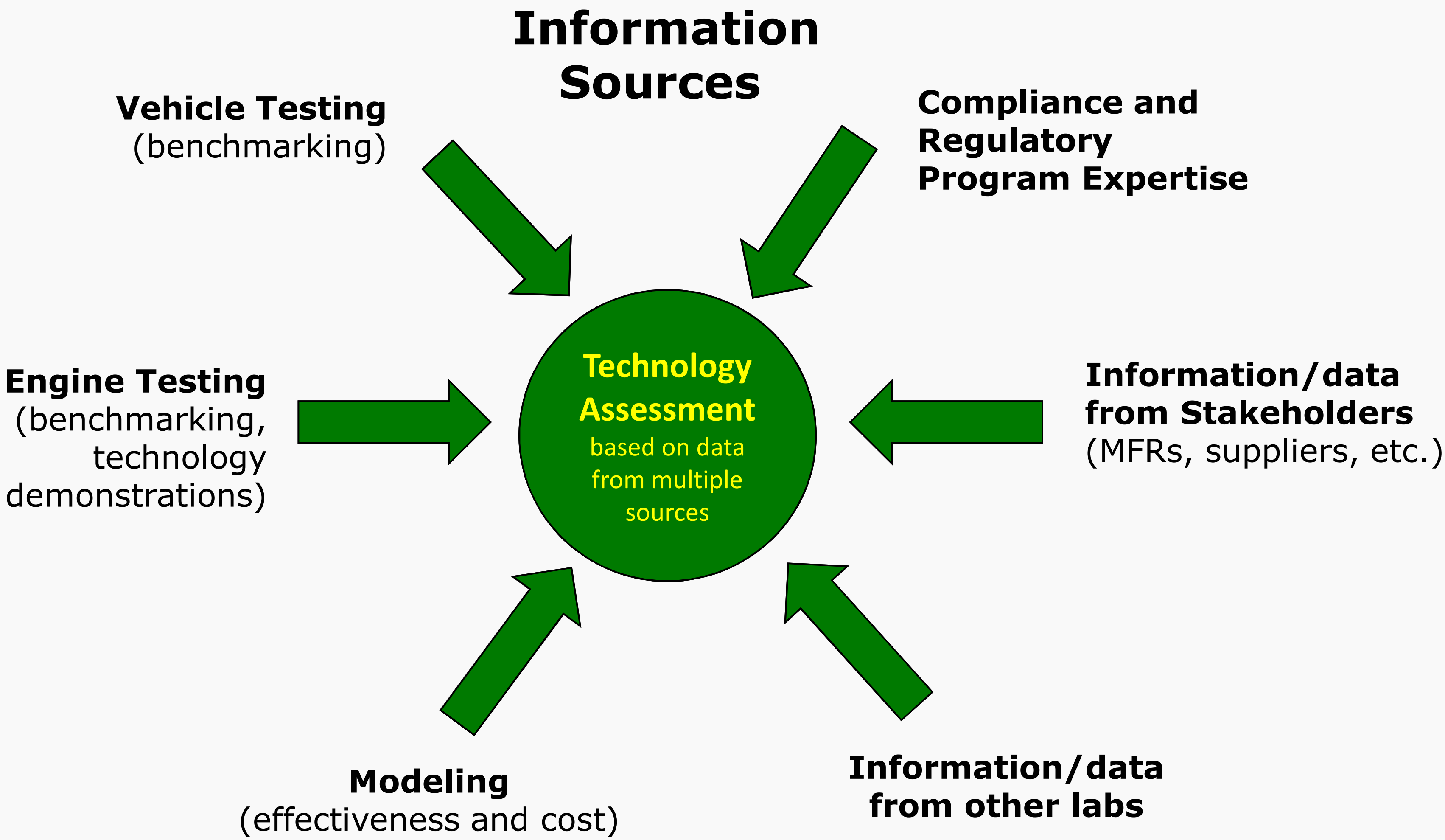
NVFEL is a state of the art test facility that provides a wide array of dynamometer and analytical testing and engineering services for EPA's motor vehicle, heavy-duty engine, and nonroad engine programs which:

- Certify that vehicles and engines meet federal emissions and fuel economy standards
- Test in-use vehicles and engines to assure continued compliance and process required enforcement actions
- Analyze fuels, fuel additives, and exhaust compounds
- Develop future emission and fuel economy regulations
- Develop laboratory test procedures
- **Research future advanced engine and drivetrain technologies** (involving 20+ engineers – modeling, advanced technology testing and demonstrations)

National Center for Advanced Technology (NCAT)

NVFEL is proud to be an ISO certified and ISO accredited lab -- ISO 14001:2004 and ISO 17025:2005.

Unique Access to Important Sources of Information for Technology



What Technologies Are We Evaluating?

We are benchmarking vehicles that incorporate these technologies:

Engines
- ✓ Downsized turbocharged
- ✓ High CR naturally aspirated
- ✓ High BMEP

Transmissions
- ✓ AT – 7 and higher speed
- ✓ DCT – 7 and higher speed
- ✓ CVT – High ratio spread
- ✓ Early upshift strategies
- ✓ Shift optimization strategies

Architecture
- ✓ Conventional
- ✓ Mild hybrid (includes start/stop)
- ✓ Power-split hybrid
- ✓ P2 hybrid
- ✓ Plug in hybrid vehicles
- ✓ Extended range electric vehicle
- ✓ Electric vehicle

e-Motors/Batteries
- ✓ Various lithium-ion types
- ✓ Permanent magnet motors
- ✓ Induction motors

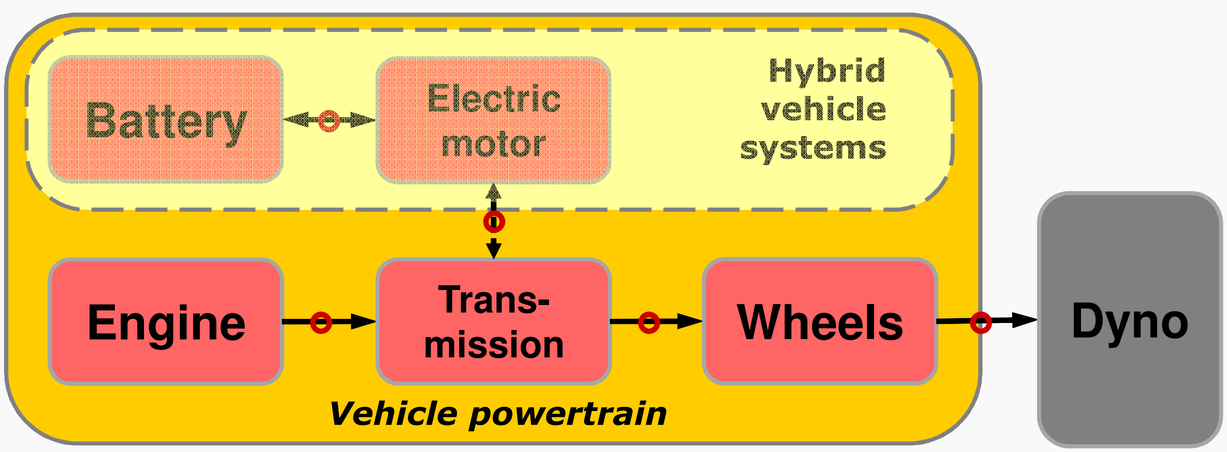
Vehicle Benchmarking

Simultaneously Characterize All Vehicle Components

- ✓ **Engine**
- ✓ **Transmission**
- ✓ **Accessories**
- ✓ **E-motors**
- ✓ **Battery packs**
- ✓ **Supervisory controls**

Technical Approach:

- ✓ Instrument entire vehicle and gather on-board CAN data
- ✓ Testing on chassis dynamometer allows **simultaneous testing** of various systems
- ✓ Simplified dynamic testing
- ✓ Real-world **influences of other systems** automatically accounted for



Approach to Advanced Engine Testing

Engine benchmarking/demonstration:

- ✓ **GDI engines** – a key enabling technology - are rapidly penetrating the market
  1. Turbocharged & downsized engines
  2. High compression ratio naturally aspirated engines
- ✓ **Considering challenges:** turbo lag, engine stability, NVH

Technical Approach:

- ✓ Test engine **tethered to chassis** to take advantage of chassis controller
- ✓ Develop **operational maps** and reverse engineer engine control strategy
- ✓ Explore **limits of engine control** (eg: flexibility from multiple injections)
- ✓ Explore **new technology** independently and with supplier partnerships (eg: cooled EGR to reduce throttling losses and eliminate enrichment)

Cell 9 – tethered Ford Focus

Tools to Model Future Fleet

Lots of DATA!

Component Data
- ✓engine
- ✓transmission
- ✓electrical components
- ✓chassis, etc.

Vertical Data

“**O**ptimization **M**odel for reducing **E**missions of **G**reenhouse gases from **A**utomobiles”

OMEGA is used to evaluate a future fleet‘s potential compliance path with LD GHG standards

- ✓ Feasibility analysis of how a fleet might utilize these technologies to comply with LD standards, not a market prediction
  - Manufacturer’s engineering, marketing, or other considerations may lead them to a different path
  - Model assumes that technology availability and cost is equivalent across manufacturers
- ✓ Detailed fleet baseline on relevant technologies for ~1300 current models in the light duty fleet (modeled as ~250 vehicle platforms)
- ✓ Future vehicle sales are based on Economic projections from DOE/EIA, and Industry forecasts from JD Powers and CSM (Now IHS)

ALPHA Model

Assesses Combinations of Light Duty Technologies

- ✓ Quantifies effectiveness of a technology or groups of technologies
- ✓ Helps assess feasibility of light-duty standards

ALPHA – **A**dvanced **L**ight-Duty **P**owertrain and **H**ybrid **A**nalysis Model

OMEGA Model

Assesses Potential Compliance Path with New LD GHG Rules

- ✓ Determines cost efficient path(s) of adding technology to vehicles in order to achieve regulatory compliance
- ✓ Quantifies economic and environmental impacts of technology changes/improvements in vehicle fleets
- ✓ Requires many scenarios of future vehicle technologies and their effectiveness (among many other model inputs) on reducing GHG emissions

Planned Vehicle Benchmarking

- Currently, there are ~20 vehicle test projects underway.
- The vehicles on the list were chosen based on our need to evaluate key technologies like:
  - advanced naturally aspirated, down-sized boosted and diesel engines
  - advanced automatic, dual-clutch and continuously variable transmissions
  - as well as hybrid technologies
- The vehicle list shown is constantly evolving and subject to change. It is provided here to give a sense of the scope of technology currently being evaluated in our testing program.
- We reassess the vehicle list every 3-6 months. We plan to continue testing even more vehicles and engines over the next 2 years building on the foundation of test data from these vehicles.

	vehicle/engine
1, 1b	**2013 Malibu Base** (6AT, NA)
2a	**2013 Escape** (1.6l ecoboost, 6AT)
3	**2013 Mercedes E350** (ETEC 7AT)
1c	**2013 Malibu Base** (6AT, NA)
2b	**2012 Focus** (1.6l ecoboost, MT)
4	**2014 Dodge Charger** (3.6 L, 5AT)
5	**2014 Dodge Charger** (3.6 L, 8AT)
6	**2013 Altima SV** (2.5 S Jatco CVT8)
7	**2013 Jetta Hybrid** (1.4L T, P2, 7DCT)
8	**2013 Chev Malibu Eco** (2.4L, 6AT, BAS)
9a	**US Mazda 6** (SkyActiv 2.5l, 6MT)
9b	**US Mazda 3 (**SkyActiv 2.0l, Auto)
9c	**Euro Mazda 3** (SkyActiv 2.0l, 14:1)
10	**2014 RAM 1500 HFE**
11	**2014 Ram 1500 EcoDiesel** (3.0L Dies, 8AT)
12	**2015 Volvo S60 T5** (2.0L Turbo with 8AT)
13	**2014 Chevrolet Silverado** (4.3L V6 LV3)
14	**2015 Ford F-150** (2.7L V6 Nano)
15	**2013 Hyundai Sonata** (2.0L Turbo, 6AT)
16a, 16b	**2015 Subaru Forester** (2.0L Turbo)

Engine Benchmarking Planning

- **Component level:** there are 3 completed engine benchmarking projects which used an engine dyno with 4 more underway
- **Vehicle level:** there is 1 completed engine benchmarking which used a chassis dyno with 3 more underway
- **List of engines** is constantly evolving and subject to change. It is provided here to give a sense of the scope of engine technology currently being evaluated in our testing program. We reassess the content of the engine list every 3-6 months.
- The table also includes **other engines of interest** (non-highlighted) that we might want to test in the future, depending on resources

		N/A Gasoline	Turbo Gasoline	Diesel	Alt & hybrid
Cars	I3/I4	Chevy Malibu 2.5L	Ford Escape 1.6L EcoBoost	VW Jetta 2.0L EA288	Honda 1.8L Natural Gas
		Mazda 6 SkyActiv 2.5L	Boosted demo engine	Chevy Cruze 2.0L	Honda Accord hyb 2.0L Earth Dreams
		2015 Toyota Aygo 1.0L Atkinson (non US)	Volvo 2.0L Drive-E	BMW 2.0L B47 (non US)	
			BMW 2.0L B48 (non US)	Volvo 2.0L Drive-E (non US)	
			Lexus NX 2.0L 8AR-FTS t/c Atkinson	Mazda 2.2L SkyActiv D (non US)	
			VW Jetta hybrid 1.4L EA211		
	V6	Dodge Charger/Chrysler 300 3.6L Pentastar*	Mercedes c400 3.0L DELA30 (M276)	Mercedes E350 3.0L	
		2015 Acura 3.5L Earthdreams			
	V8		Jaguar XK 5.0L AJ133		
Trucks	I4/I5			Ford Transit 3.2L Power Stroke	
				Chevy Colorado 2.8L Duramax	
	V6	Dodge Ram HFE 3.6L Pentastar*	Ford F150 2.7L EcoBoost	Dodge Ram 3.0L EcoDiesel VM Motori	Toyota Highlander 3.5L 2GR-FXE
		Chevy Silverado 4.3L EcoTec3		BMW X5 35d 3.0L (I6)	
		Toyota Tacoma 3.5L D-4S Atkinson			
	V8	Chevy Silverado 5.3L EcoTec3		2015 Nissan Titan 5.0L Cummins TurboDiesel	

testing completed	blue -tested using engine dyno
testing active	red -tested using chassis dyno

*Note: same engine

Case Study:
Initial Learning Iteration

- We have begun to test model year 2013/15 vehicles to help us improve and validate the ALPHA model that will be used to predict 2025 vehicle GHG emissions.
- This case study was designed to look at the operation of naturally aspirated (NA) engines in a mid-size car – *3 different engines coupled with 2 different automatic transmissions*

Case Study Vehicle Configurations:

1. conventional 2013 chassis with **2010** NA engine and **4-speed** trans
2. conventional 2013 chassis with **2010** NA engine with **6-speed** trans
3. conventional 2013 chassis with **2013** NA engine with **6-speed** trans
4. conventional 2013 chassis with **2013** industry leading NA engine with **6-speed trans**

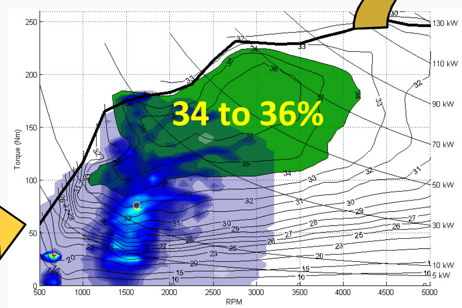
Iterative Analysis of Benchmarking & Modeling Results

- The purpose of the ALPHA model is to help us explore how technologies interact to estimate their combined efficiency potential.
- The following modeling case study is looking at the "early" implementation of new technologies.

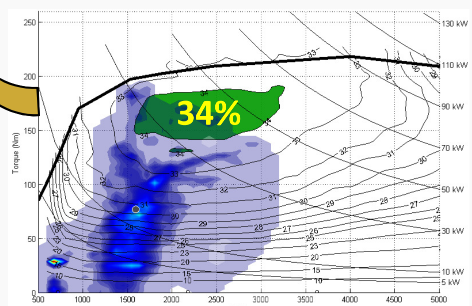
  Given more time manufacturers almost always improve the effectiveness with minor cost-effective hardware and software adjustments to extract the full benefits of a new technology.
- Initial modeling analyses often raises additional questions which can be addressed with further research, benchmark testing and modeling runs.
- Please note that the following case study is for illustrative purposes only. It is useful to guide a discussion about EPA's approach to exploring the effectiveness of engine and transmission combinations to meet Light-duty GHG standards.

Peering into FE Improvements

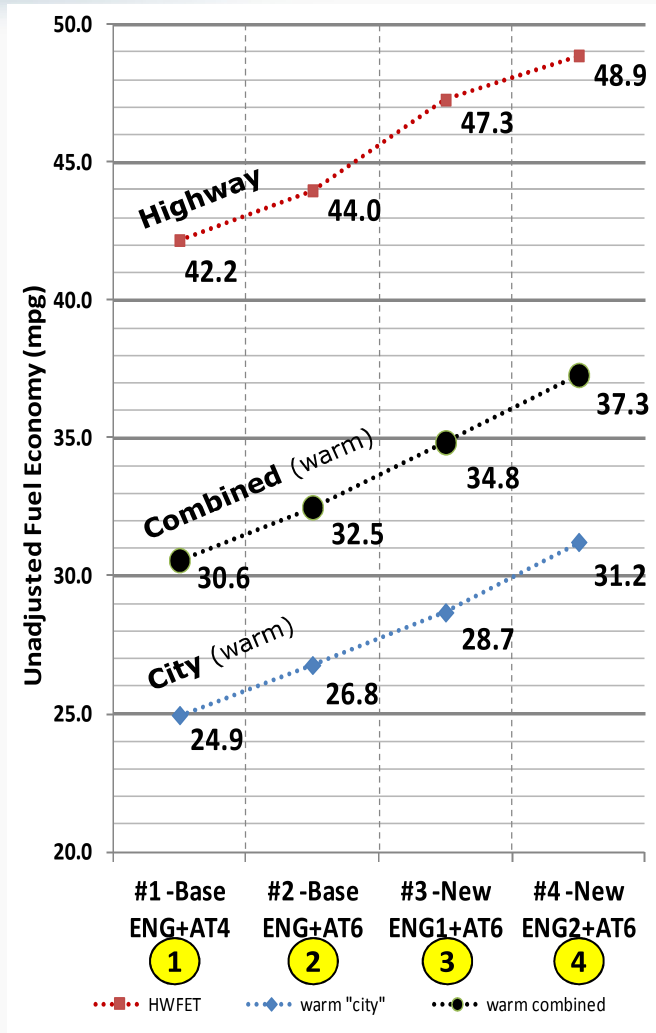
ALPHA modeling – UDDS Cycle

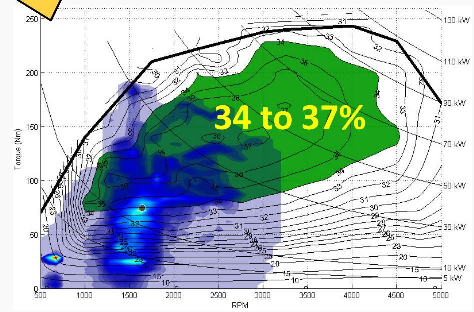


3 **Upgrade to 2013 GDI Engine**
2013 conventional chassis with
2013 naturally aspirated engine &
2013 6-speed transmission



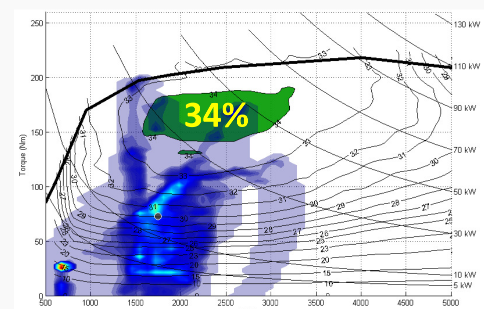
2 **Upgrade to 6-speed Trans**
2013 conventional chassis with
2010 naturally aspirated engine &
2013 6-speed transmission





Upgrade to Industry Leading GDI Eng.

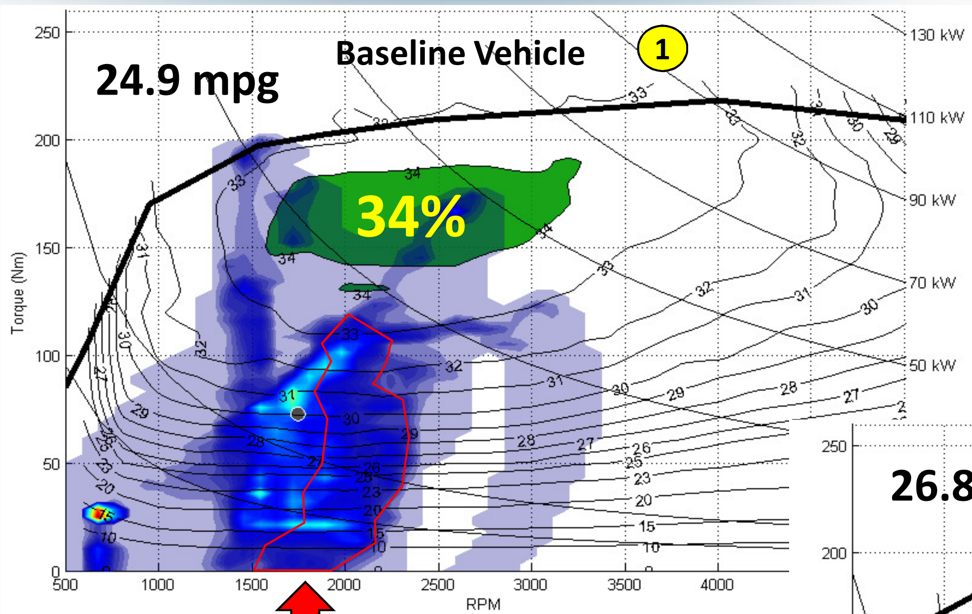
4 **2013** conventional chassis with
2013 industry leading engine &
2013 6-speed transmission



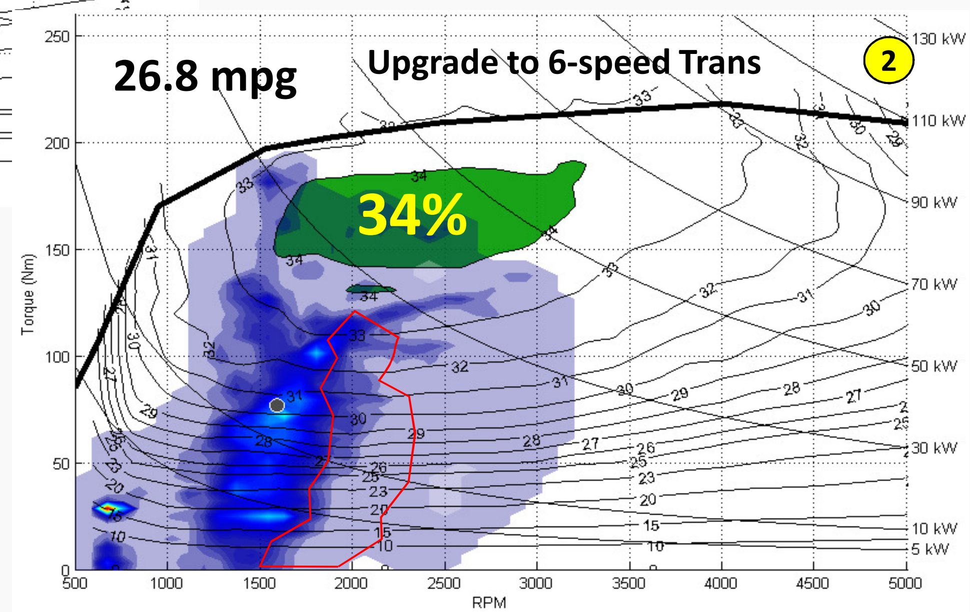
1 **Baseline Vehicle**
2013 conventional chassis with
2010 naturally aspirated engine &
2008 4-speed transmission

Shaded clouds shown on engine maps represent where the fuel would be burned on a UDDS drive cycle.
Please note that this case study is for illustrative purposes only.

More Fuel Burned within the Efficiency "Sweet Spot"



ALPHA modeling – <u>UDDS</u> Cycle



Transmissions with more gears allow engine "down-speeding," which eliminates inefficient higher speed, lower load operating points to obtain better UDDS fuel economy. Also, the torque converter locks up quicker in a 6 spd, reducing torque converter losses.

Shaded clouds shown on engine maps represent where the fuel would be burned on a **UDDS drive cycle**.
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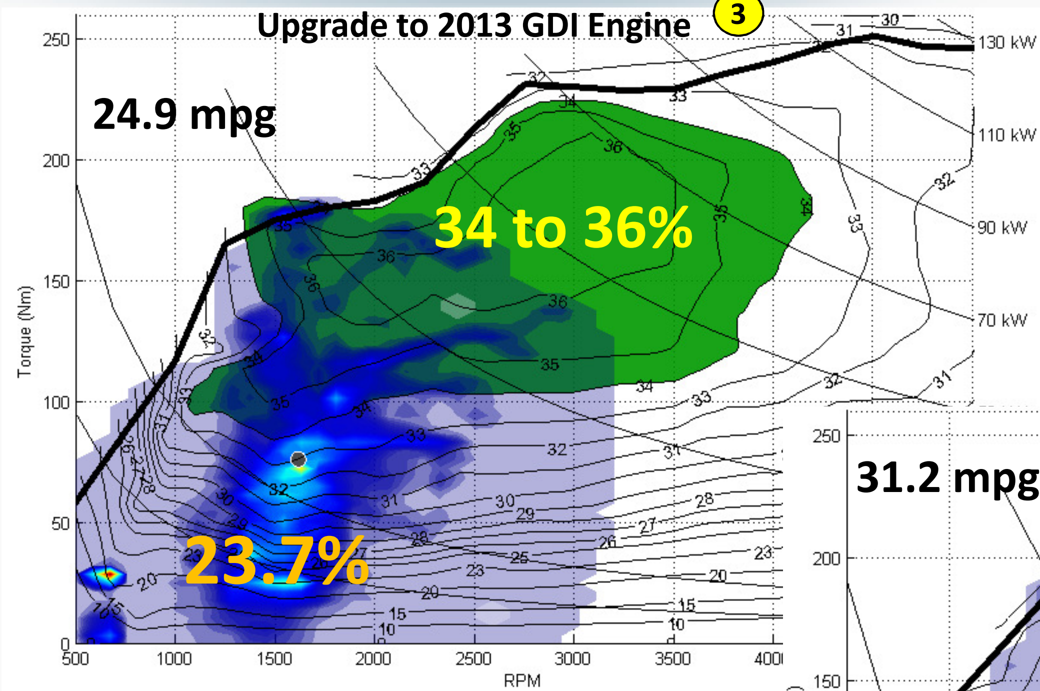
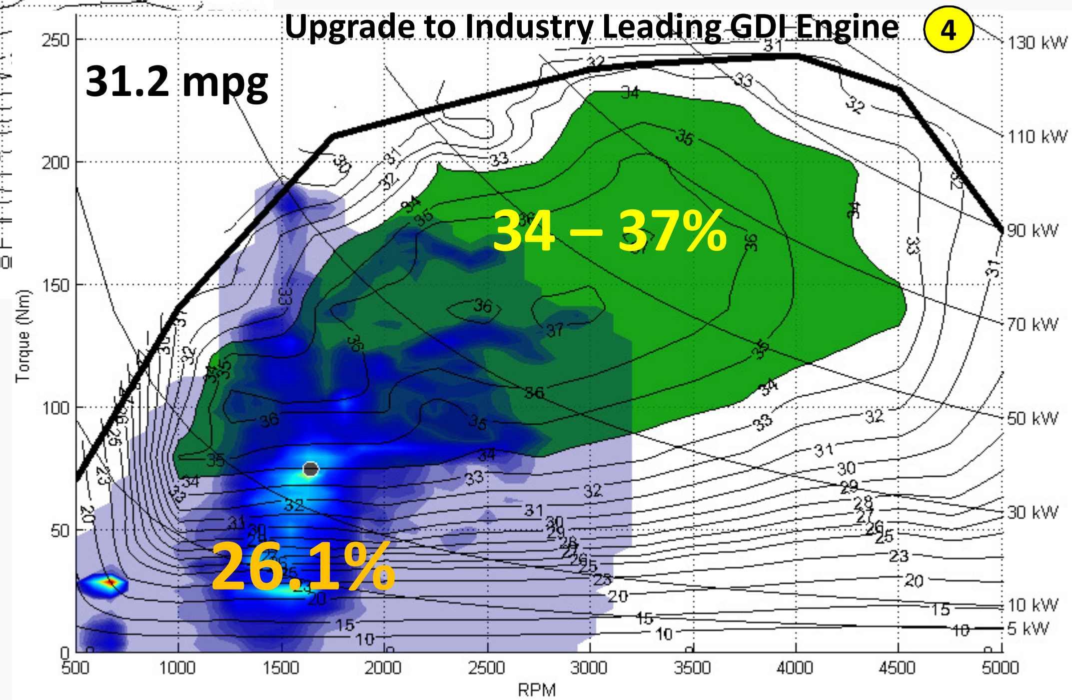
More Fuel Burned within the Efficiency "Sweet Spot"





ALPHA modeling – UDDS Cycle

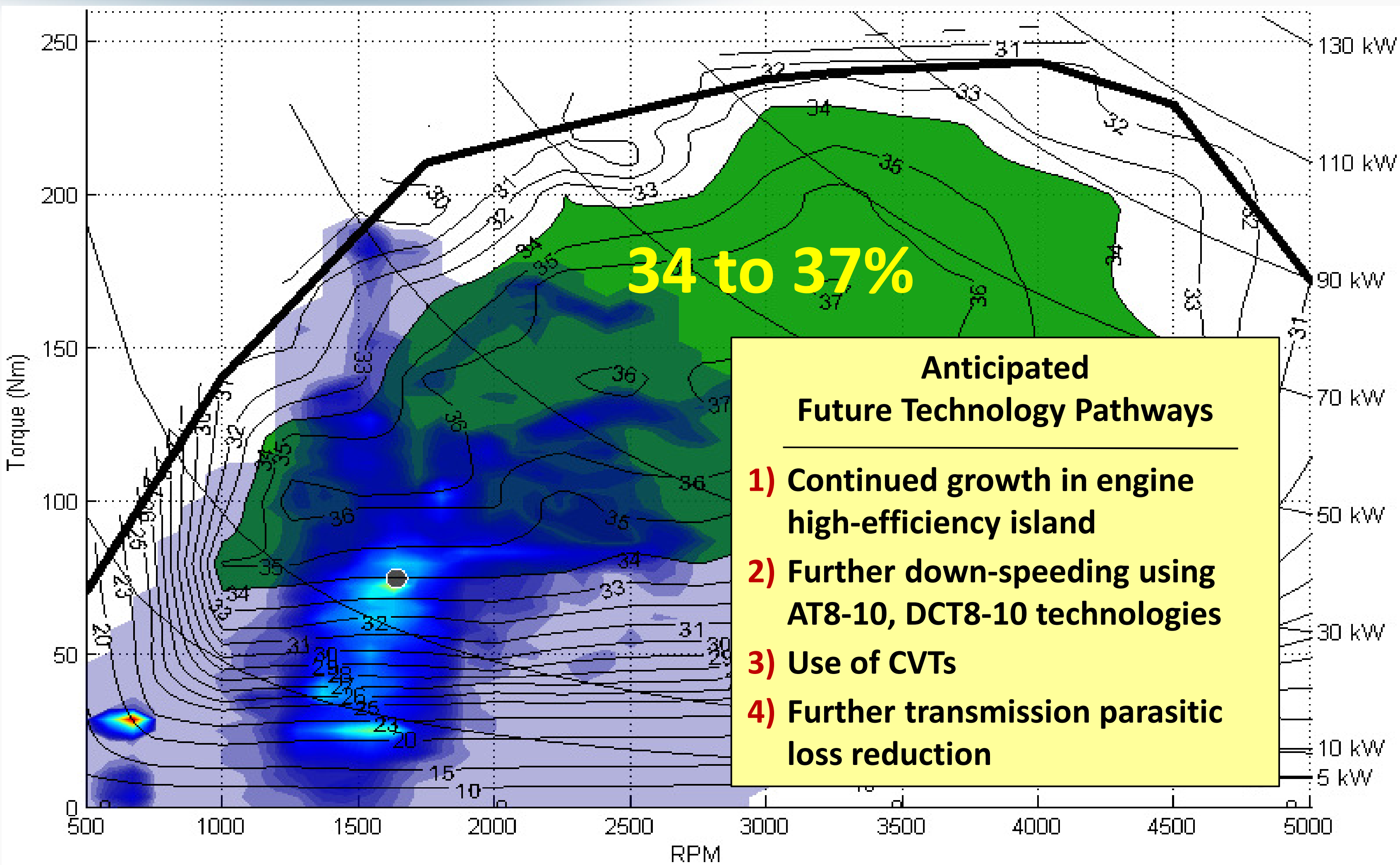
yy% -PEAK EFFICIENCY Island
xx% -energy weighted AVG EFFICIENCY over UDDS

High efficiency islands are getting larger, allowing more operation at higher engine efficiency to obtain better UDDS fuel economy.

Shaded clouds shown on engine maps represent where the fuel would be burned on a **UDDS drive cycle**.
Please note that this case study is for illustrative purposes only.

Future Powertrain Efficiency Improvements…?

ALPHA modeling – UDDS Cycle



Anticipated Future Technology Pathways

1) Continued growth in engine high-efficiency island
2) Further down-speeding using AT8-10, DCT8-10 technologies
3) Use of CVTs
4) Further transmission parasitic loss reduction

Shaded clouds shown on engine map represents where the fuel would be burned on a UDDS drive cycle.
Please note that this case study is for illustrative purposes only.

Future MTE Engine-Transmission Modeling Work

- Add other vehicle technologies like start-stop, low RR tires, mass reduction, etc. to this case study
- Continued benchmarking to refine the ALPHA model & enhance its predictions for "future" vehicles
- We intend to model several vehicle technology packages in ALPHA to assess effectiveness of key "technology combinations" (e.g. High CR GDI w/DCT, start-stop, & 10% reduction in RR/aero/mass)

Questions?