Tula Technology's Dynamic Skip Fire

September 28, 2016

Agenda

DSF
DYNAMIC
SKIP FIRE

- What is *Dynamic Skip Fire* (DSF™)?
- Development Results
- Tula – Delphi 4 Cylinder DSF™ Project
  - Initial test results and projections

Dynamic Skip Fire (DSF) Attributes

1. Decision to “Fire” or “Skip” is made before each cylinder event
   - Allows the most immediate response to driver torque request
2. Enabled by individual cylinder deactivation
3. The resulting “firing density” varies between 0% and 100%, as opposed to switching between half and full engine

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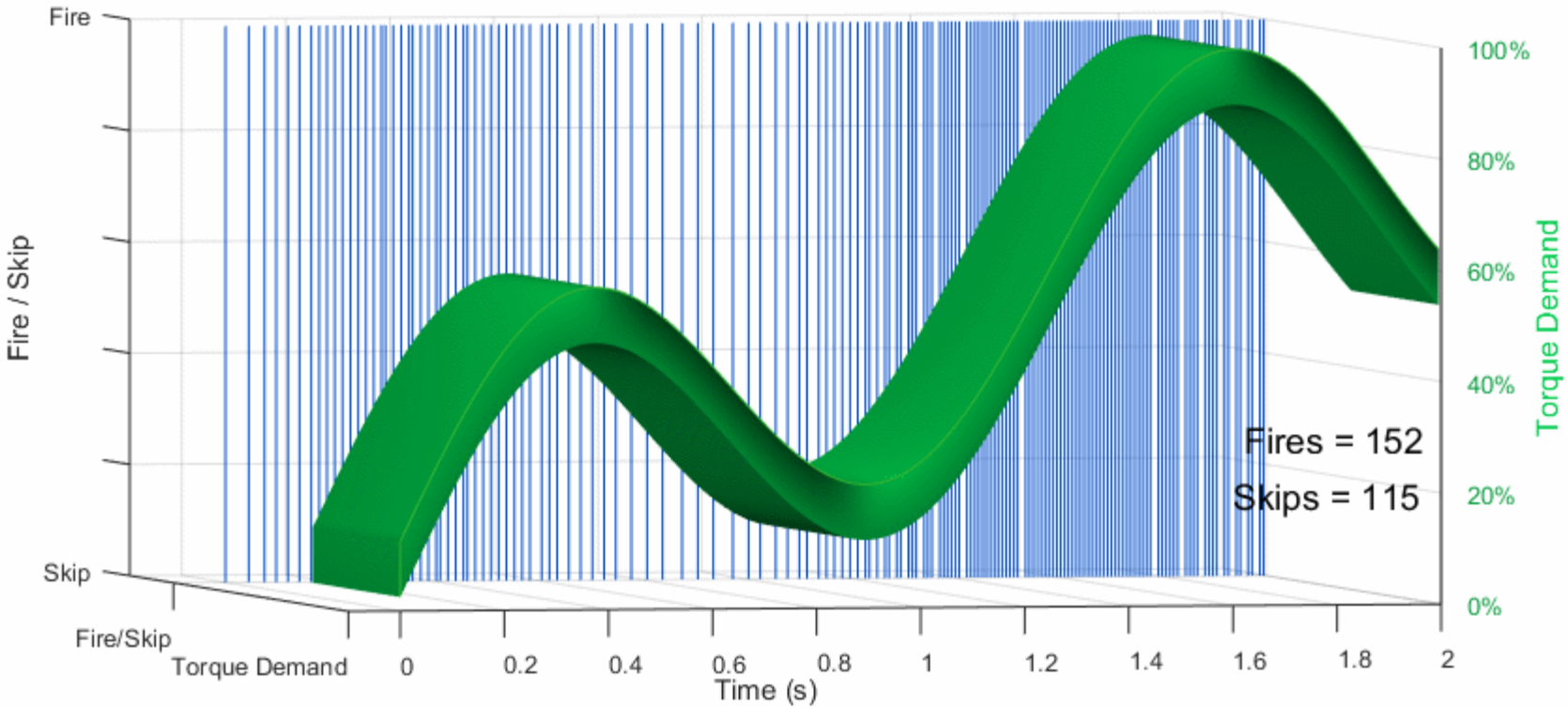

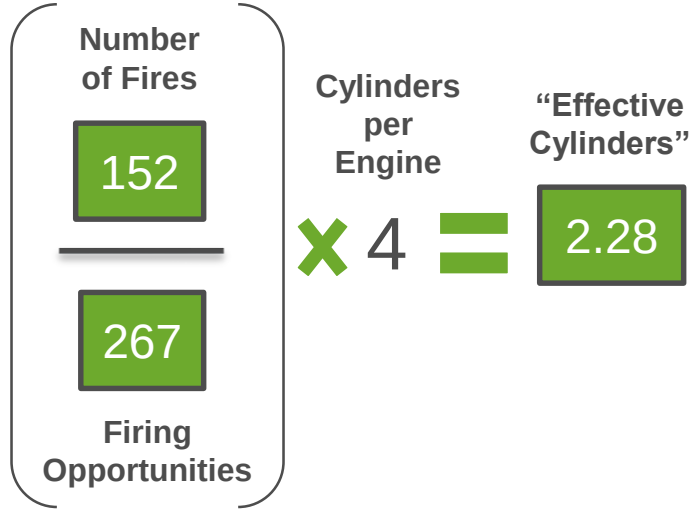

57% “Firing Density”

Dynamic Skip Fire – Fuel Efficiency Benefit

How does DSF improve fuel efficiency?

1. Reduction of pumping losses

2. Higher thermodynamic efficiency
   - Optimum combustion conditions even at low loads
   - Low load IMEP COV improved

3. DCCO – shuts off all cylinders during deceleration
   - Eliminates catalyst re-fueling penalty compared to fuel-only shutoff strategy
   - Reduces pumping compared to conventional strategies, enabling longer events

4. Fast torque control
   - Reduces or eliminates spark retard during trans shifts, etc

Tula V8 Test Vehicle

- Designed a unique cylinder deactivation system to allow control of all valves and cylinders
- Created a complete control system to operate in all-cylinder or DSF mode
- Invented a controls-based NVH management system

DSF Results – U.S. EPA Drive Cycles*
Tula 6.2L Yukon Denali

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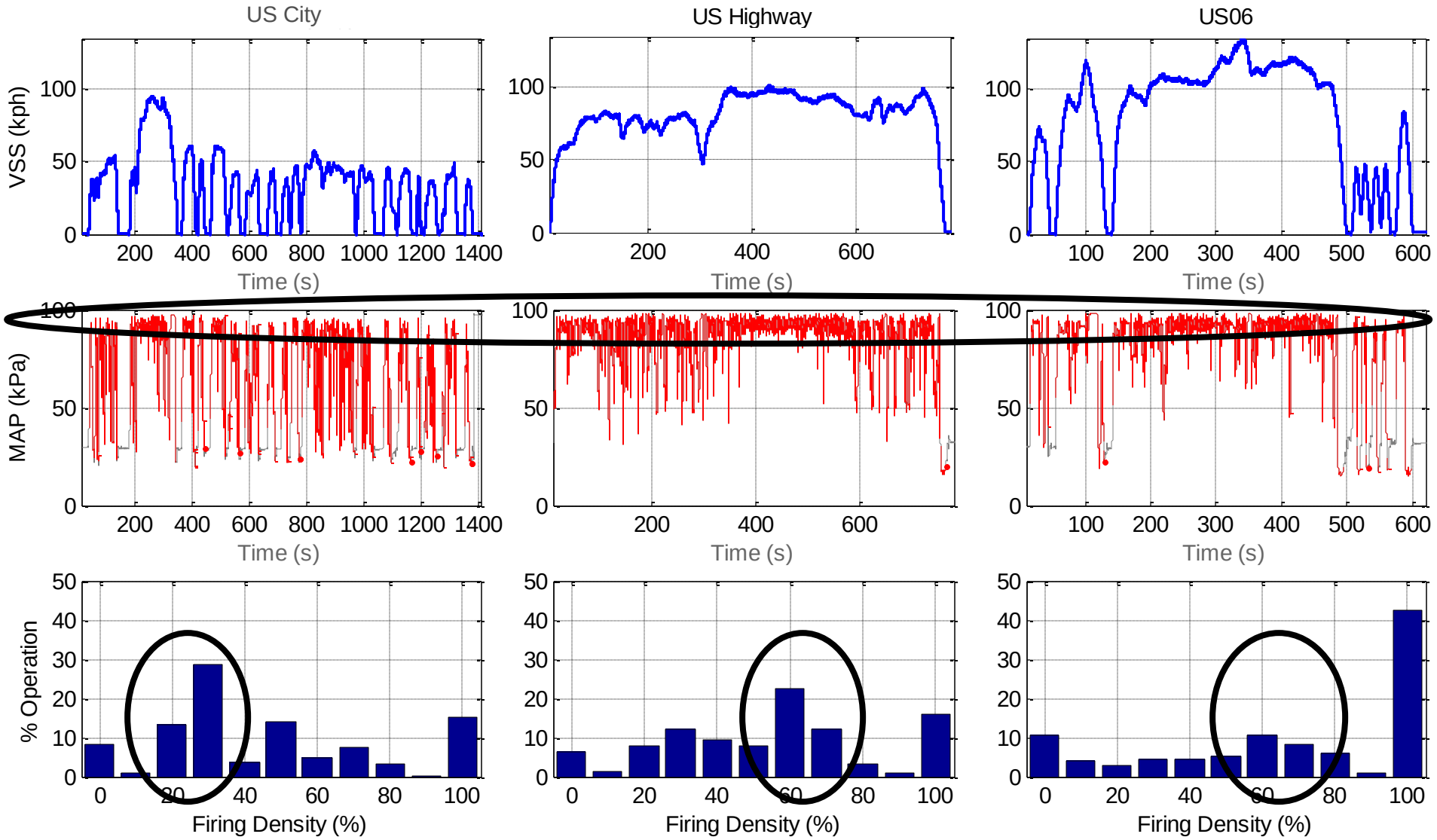
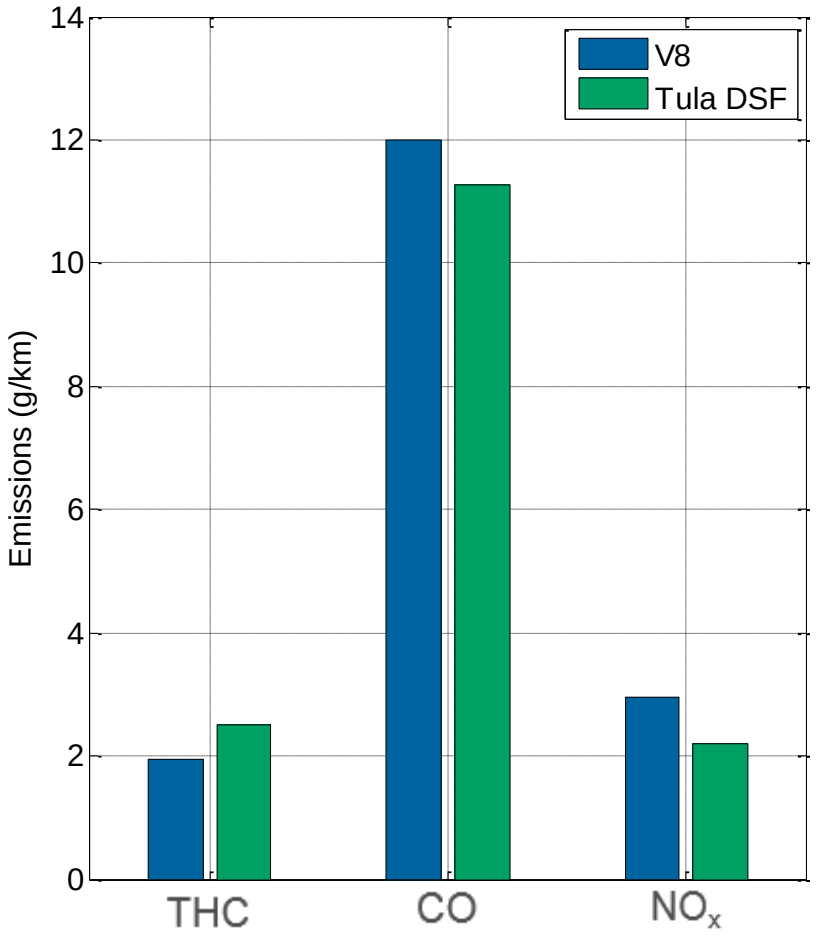
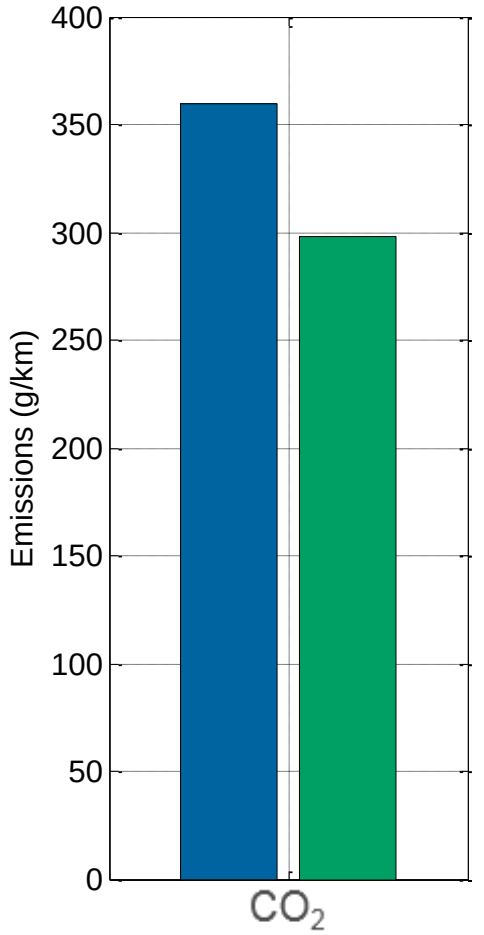
17% FE Improvement	*9.0% FE Improvement*	*6.1% FE Improvement*



*** Idle excluded – stop-start assumed**

Weighted Engine Out Emissions - Hot 18
Tula Yukon DSF 6.2L V8



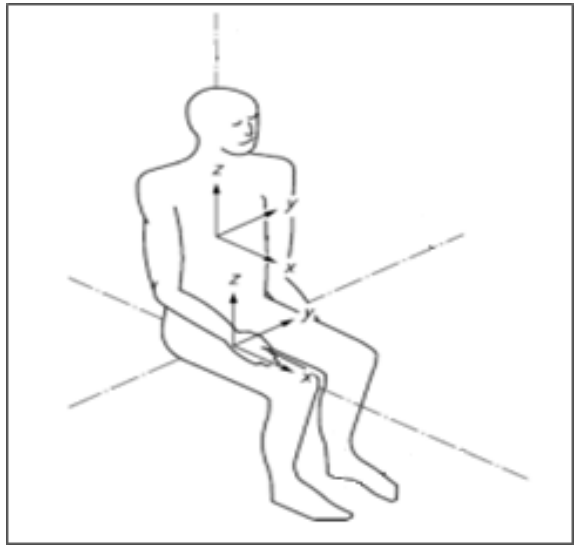


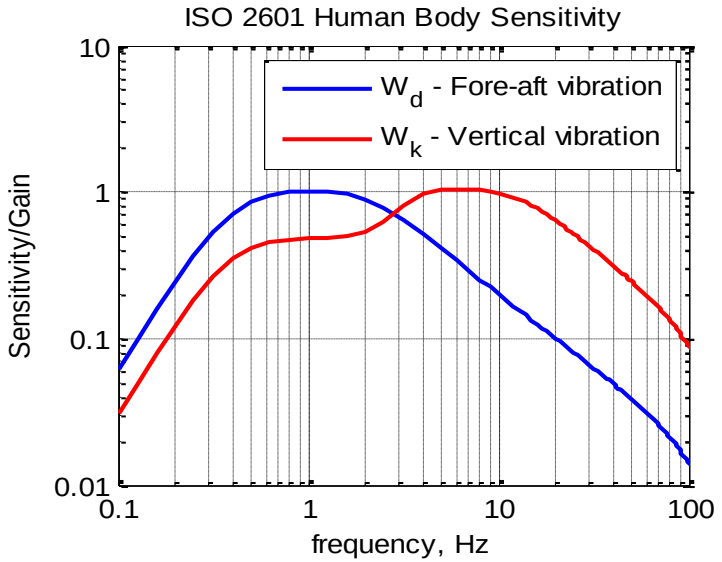
DSF produces carryover emissions relative to base engine operation…

…while improving CO_2 by 17%

Tula's NVH control approach

- Low frequencies and high peak amplitudes cause unacceptable vibration
- Frequency of excitation depends on engine speed and sequence of fires/skips
- Tula proactively manages the engine firing sequence
- Subjective and objective evaluations are used to deliver production benchmark NVH



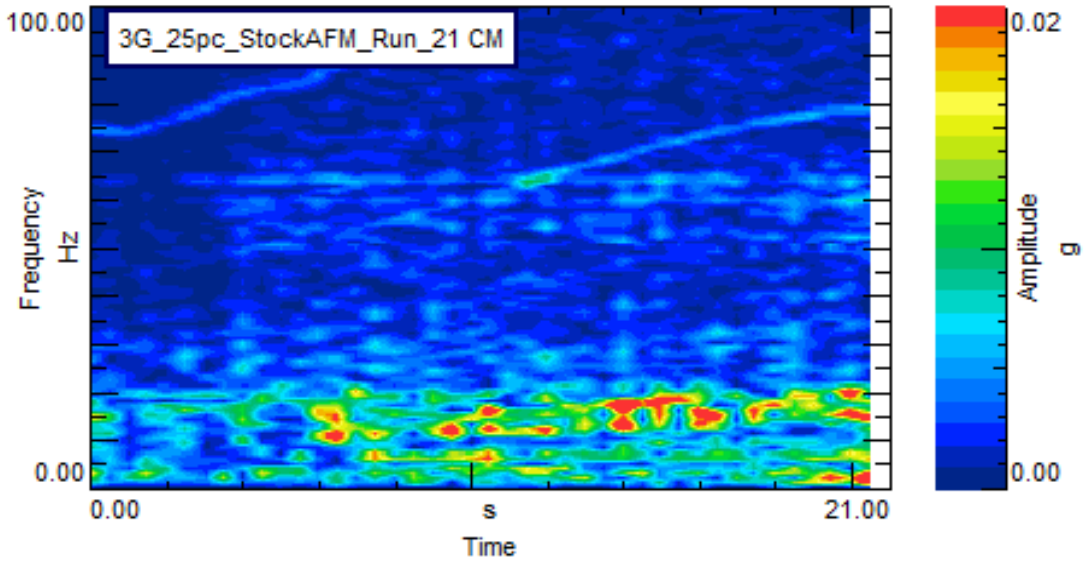


Example: Driver's Seat Vibration

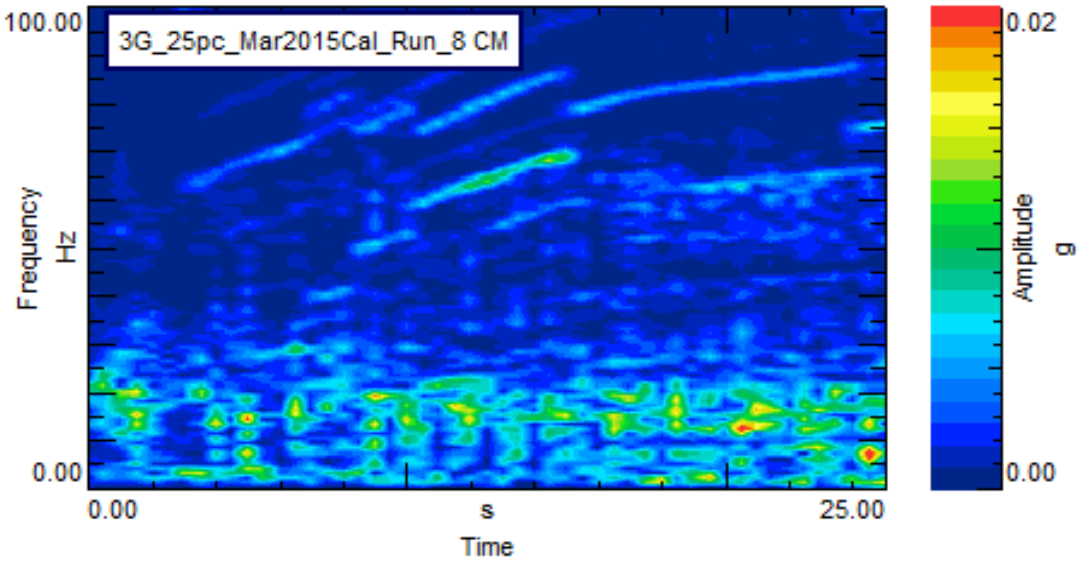
V8 engine, 3rd gear, 25% pedal acceleration, in z direction

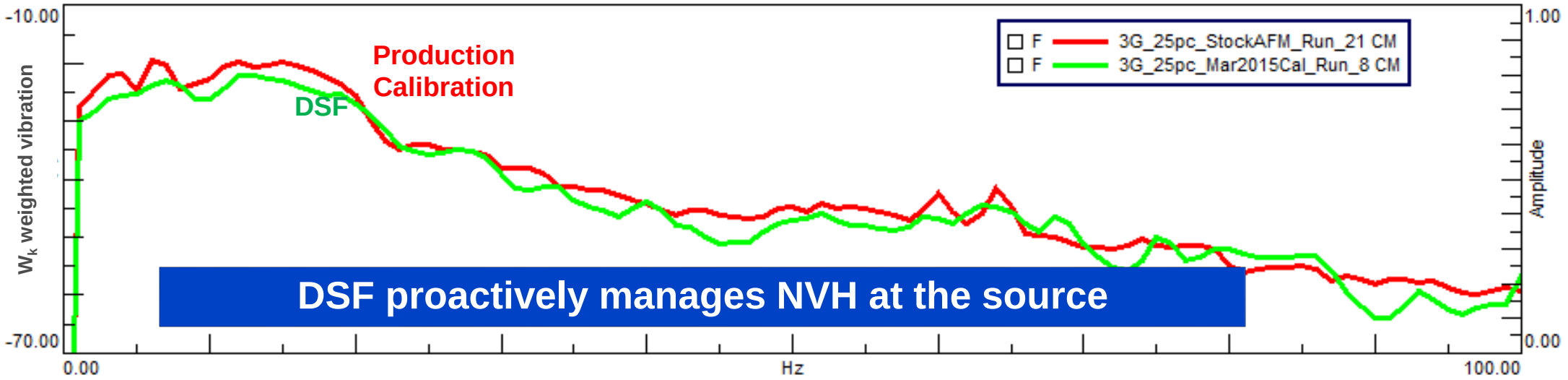
TULA

Production Calibration V8 mode



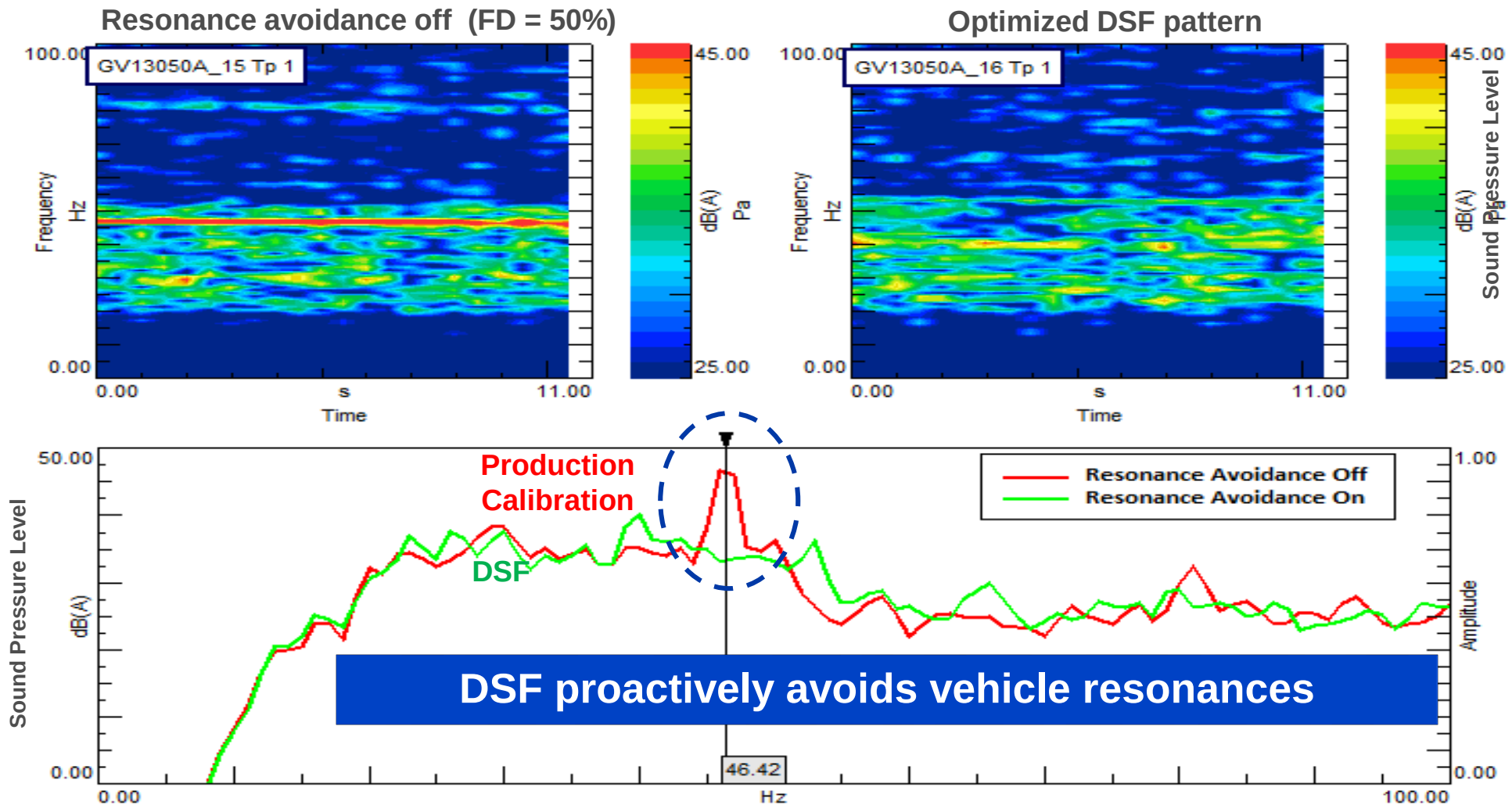
Optimized DSF with transitions





Resonance Avoidance for Cabin Boom

V8 engine, 3rd gear, 14% pedal, constant road speed, driver's left ear



Tula & Delphi 4 Cylinder DSF Program

- **Objective:** Prove fuel economy benefits of DSF on smaller, boosted engines
- A collaborative effort with Delphi
  - VW Jetta 1.8L Turbocharged GDi engine
  - Delphi EMS with integrated Tula DSF controls
  - Delphi Cylinder Deactivation Hardware

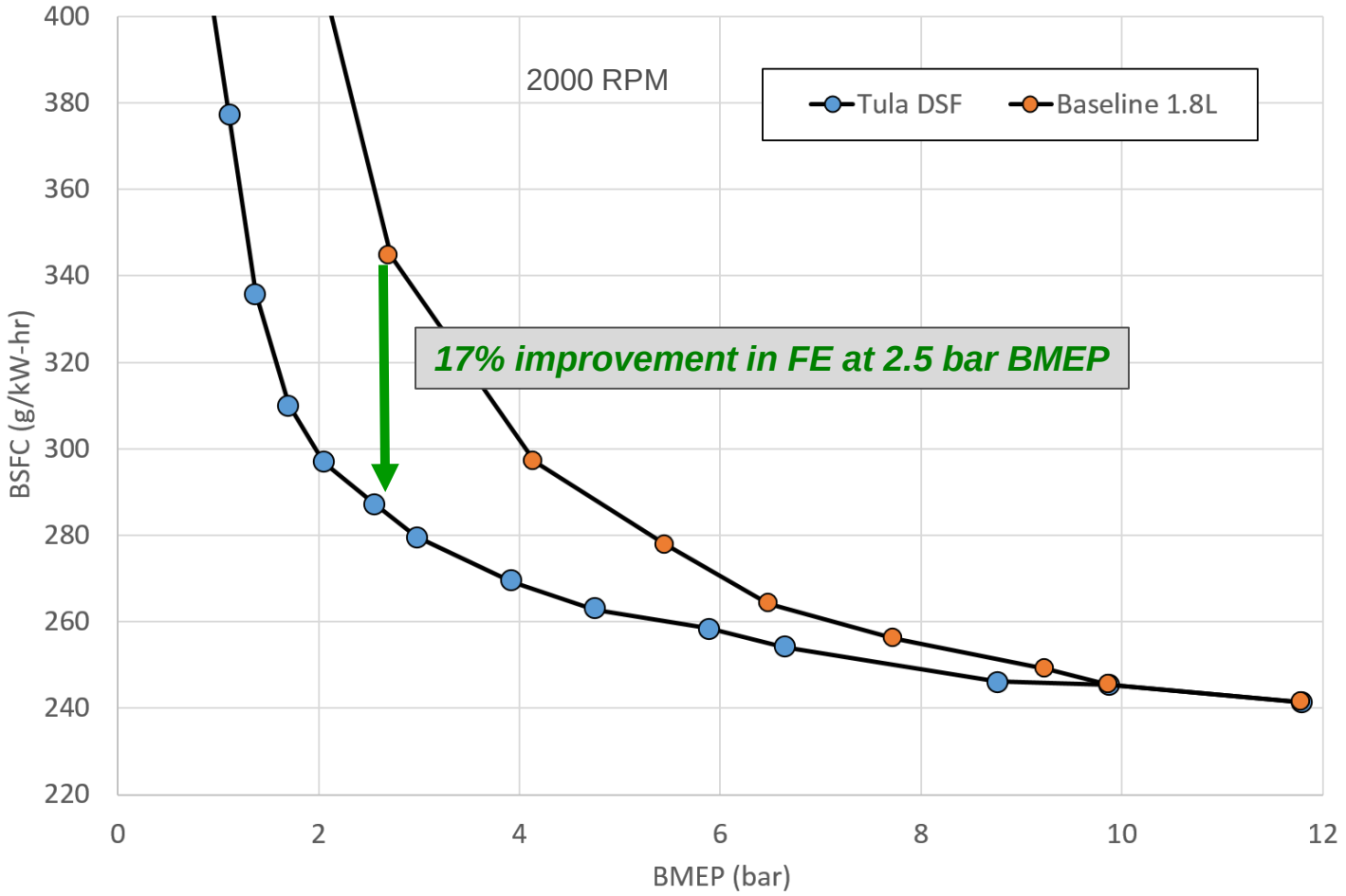
2015 Volkswagen Jetta SEL 1.8L TC

EA888 - Generation 3

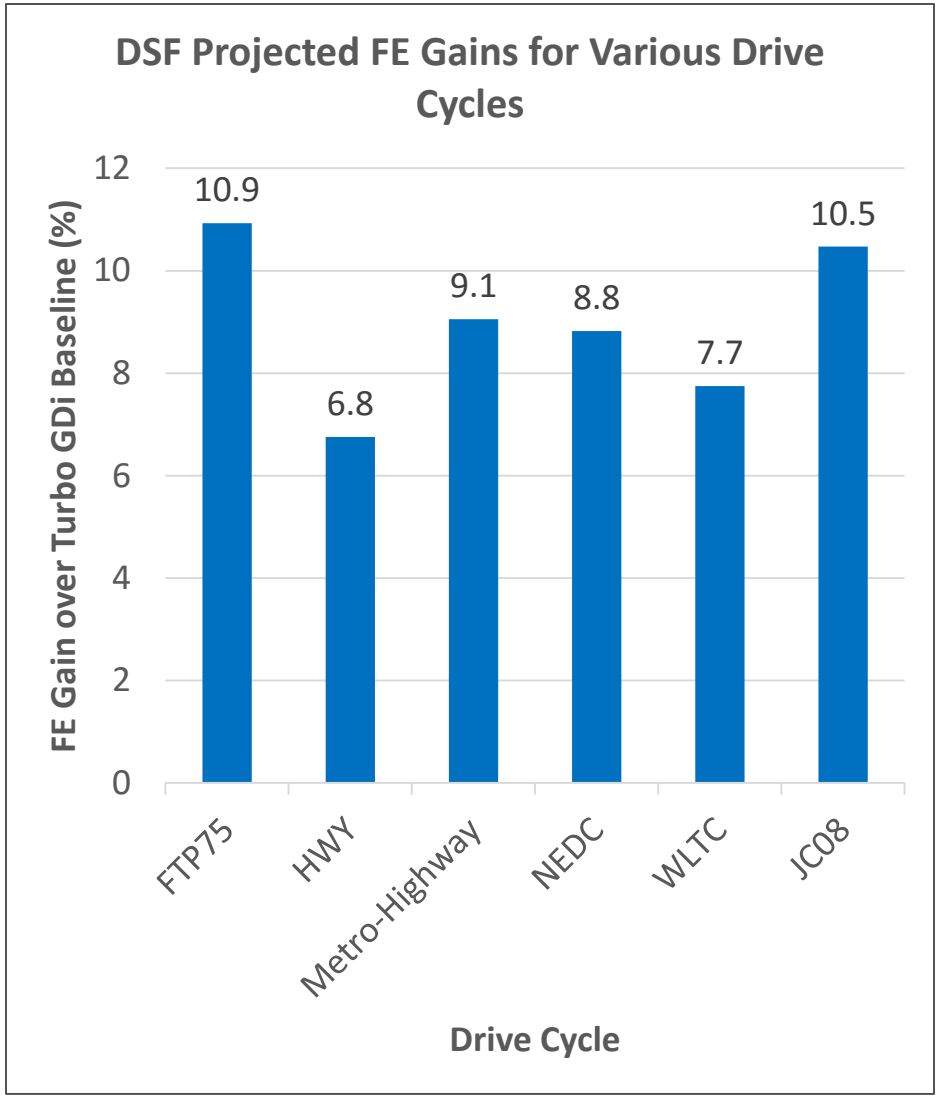
Specifications	
Engine Displacement	1.8L TSI®
Test Weight Class	3625 lb. (1644 kg)
Transmission	6 speed AT Tiptronic
Tailpipe Emissions	SULEV
Evaporative Emissions	Zero Evap
Projected DSF Fuel Economy Improvement	8 - 10%

DSF in action

4-Cylinder DSF Fuel Economy Improvement Projected with Optimized Passive NVH Mitigation HW

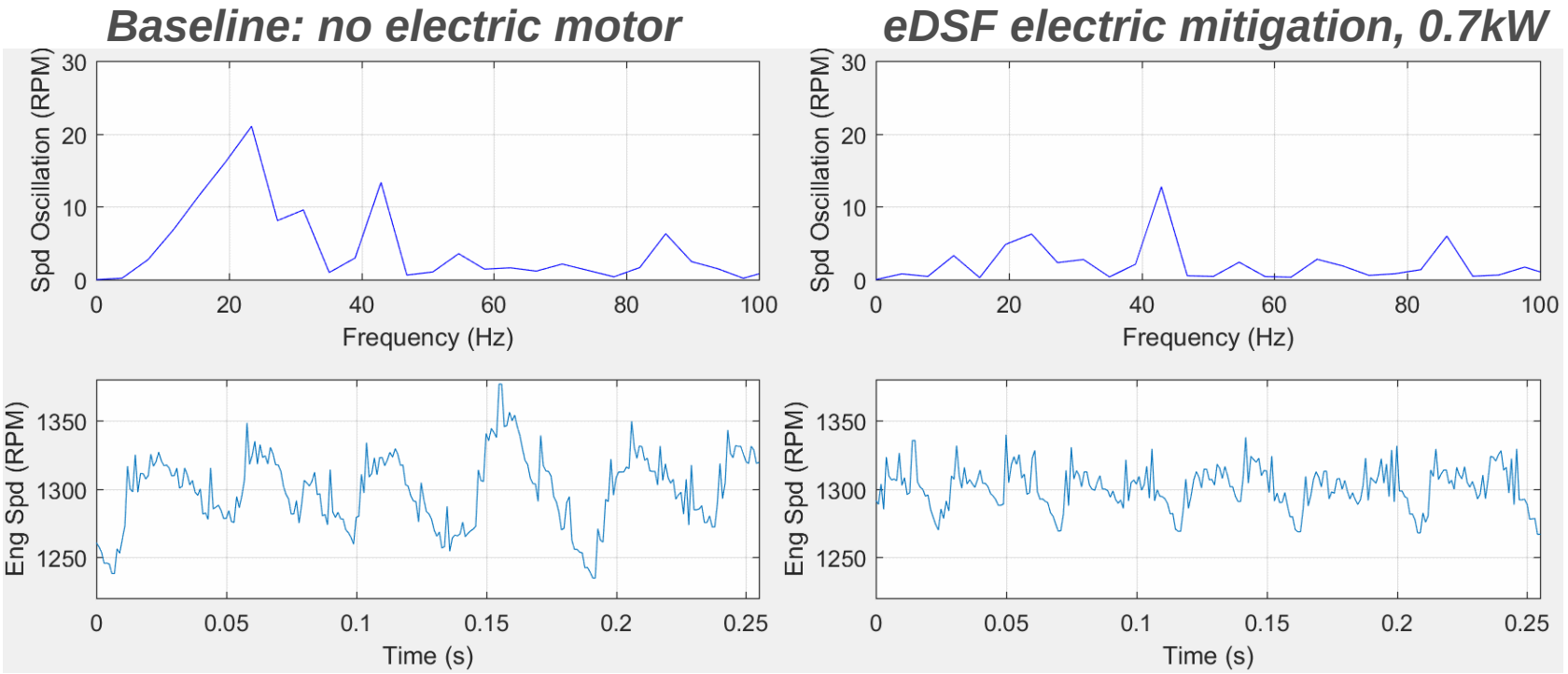


Fuel Economy improves substantially on all drive cycles, while maintaining production NVH

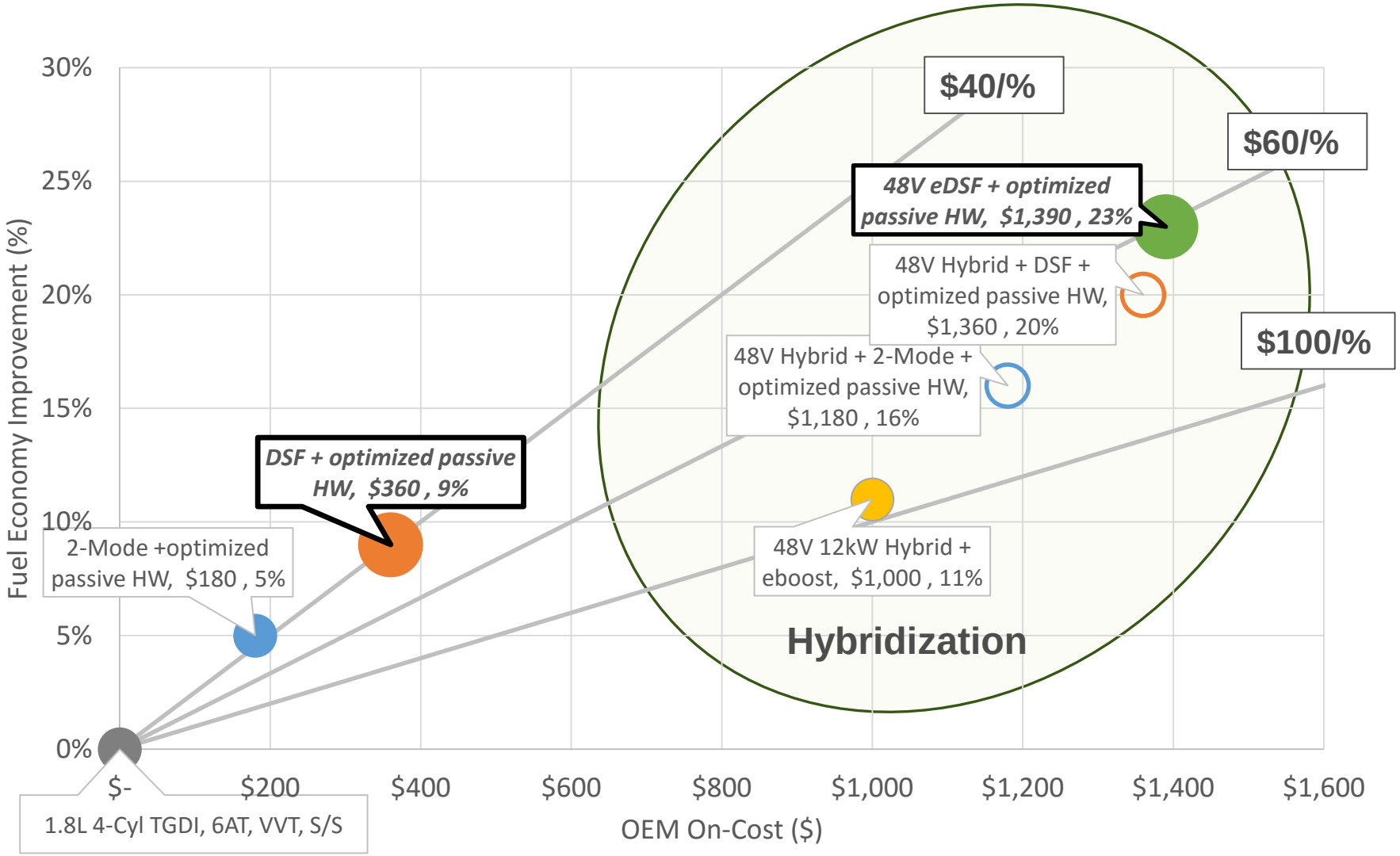


Impact of eDSF

- **e**lectric **D**ynamic **S**kip **F**ire couples DSF with vehicle electrification
- DSF flyzone is enhanced with P0/1/2 electric machine
- Synergies between electrification and DSF improve projected P0 system efficiency to 12% over baseline GTDI engine



DSF 4 Cylinder Value Propositions



Summary

- Significant fuel efficiency gains for spark ignited engines at a compelling cost
- Production level NVH, drivability and emissions
- Excellent potential for future efficiency gains
  - Electrification
  - Advanced combustion concepts
- Tula welcomes evaluation of our Technology!
  - Four-cylinder vehicle will be at the Aachen Colloquium on October 11th, 12th
  - Evaluation will also be possible in Plymouth, MI and/or San Jose, CA

A simple, unique and game changing technology

Contact

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