CHRYSLER

High Efficiency IC Engines

With an Emphasis on SI Engines

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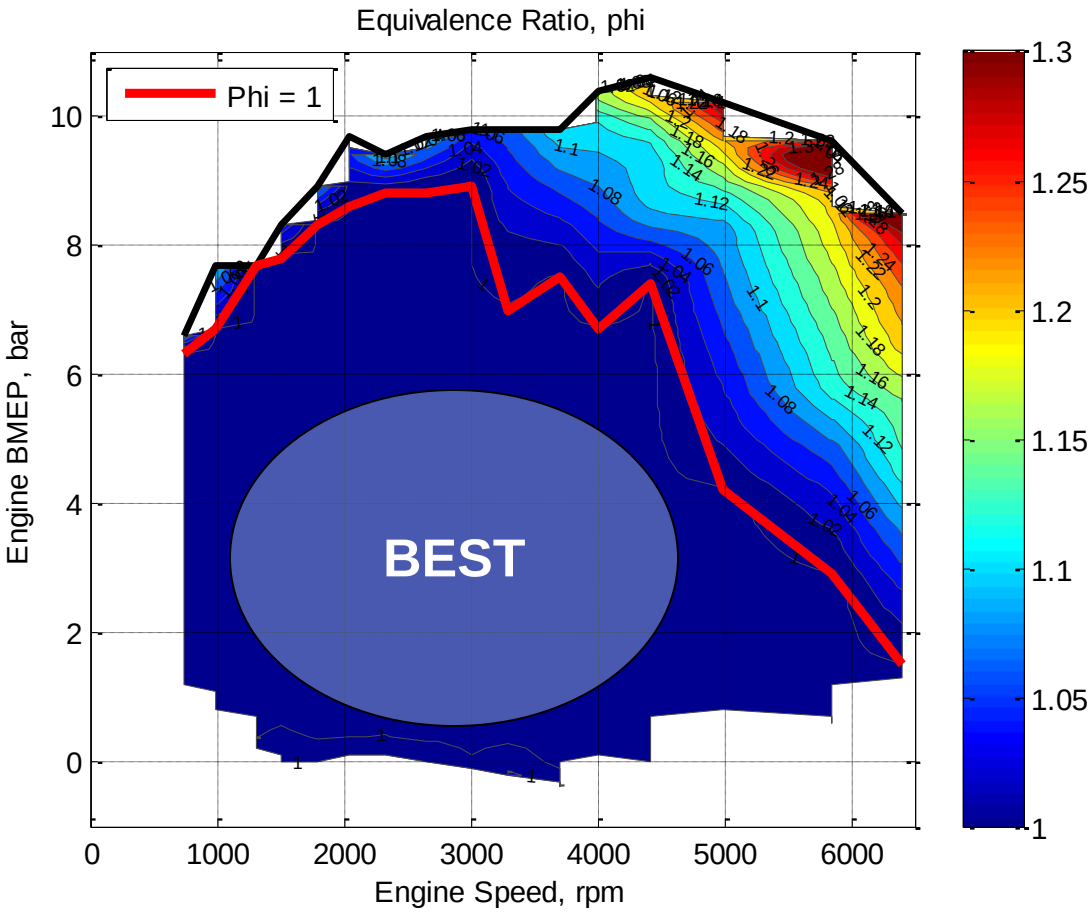
Agenda

- Real-world sources of inefficiencies (losses)
  - a.k.a. “opportunities”
  - SI Engine empirical examples
- The engine – as part of a larger system
  - Operational issues / opportunities
  - Development of an efficiency metric
- Technology Examples
  - Using the efficiency metric developed above
- Summary / Close

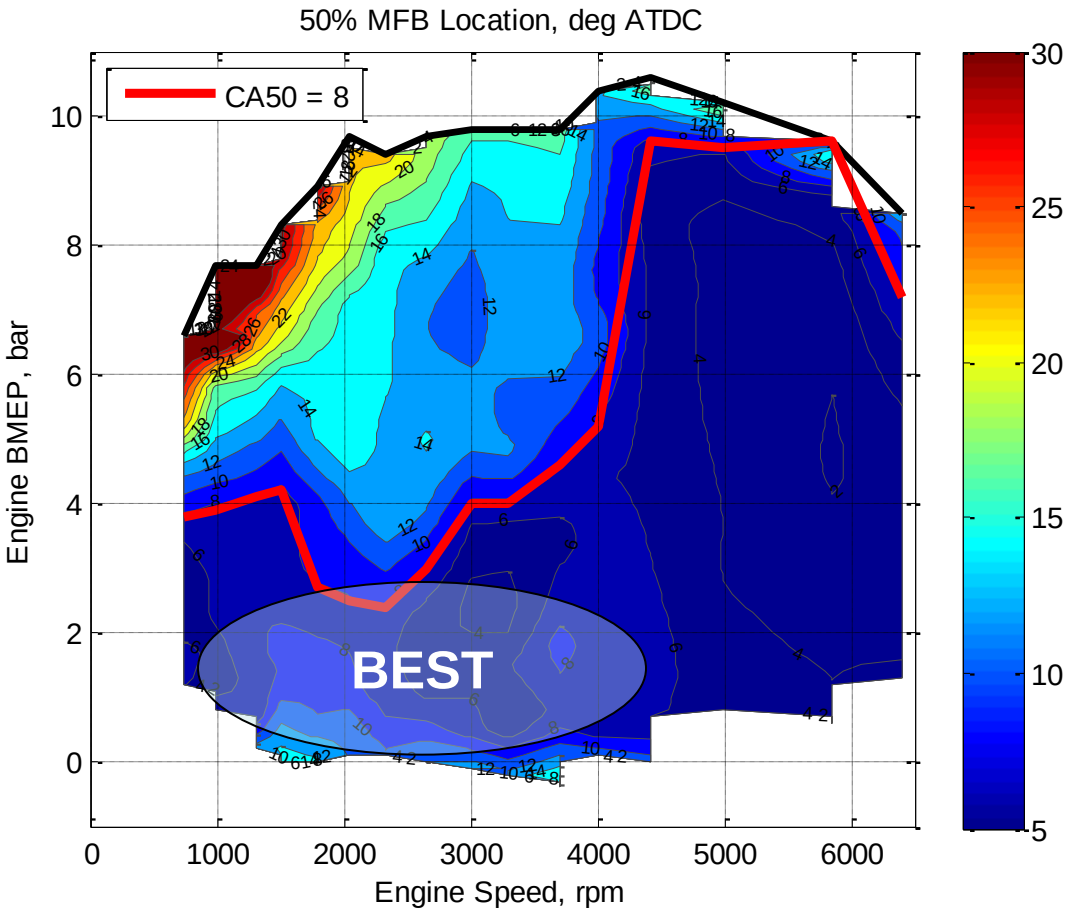
Loss Ex. 1: Fuel Enrichment (Phi > 1)

- Phi > 1 leads to a decrease in combustion efficiency, and an increase in fuel consumption
- It is used for:
  - Full load power enhancement
  - Component temperature protection due to material durability limits



Loss Ex. 2: Non-ideal (late) Combustion Phasing

- Ideal combustion phasing occurs at a 50% MFB location of ~8°ATDC
  - Anything later comes at the expense of thermal efficiency
- Combustion phasing is retarded due to knock
  - Which is heavily dependant on compression ratio and fuel octane

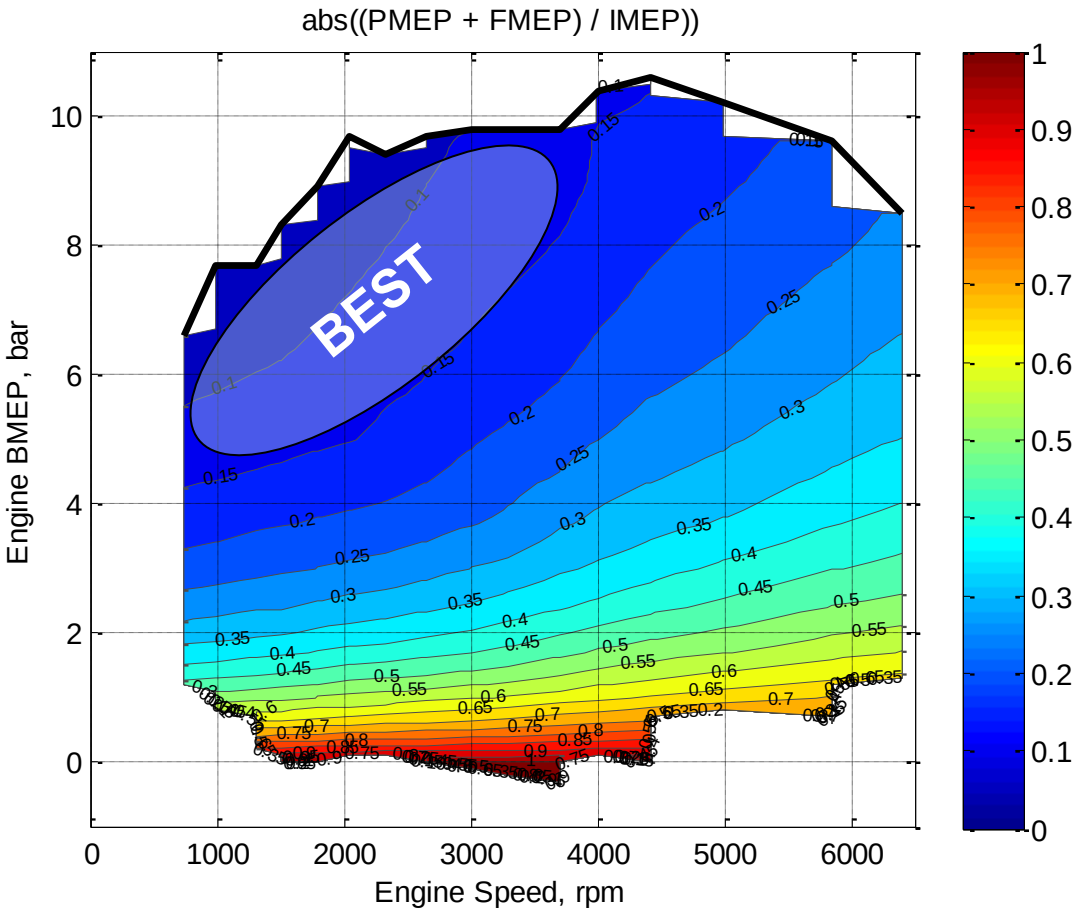


Loss Ex. 3: Pumping + Friction (η_m < 100%)

- Mechanical Efficiency
  - the cost of moving the air, and the rest of the engine translating and rotating components

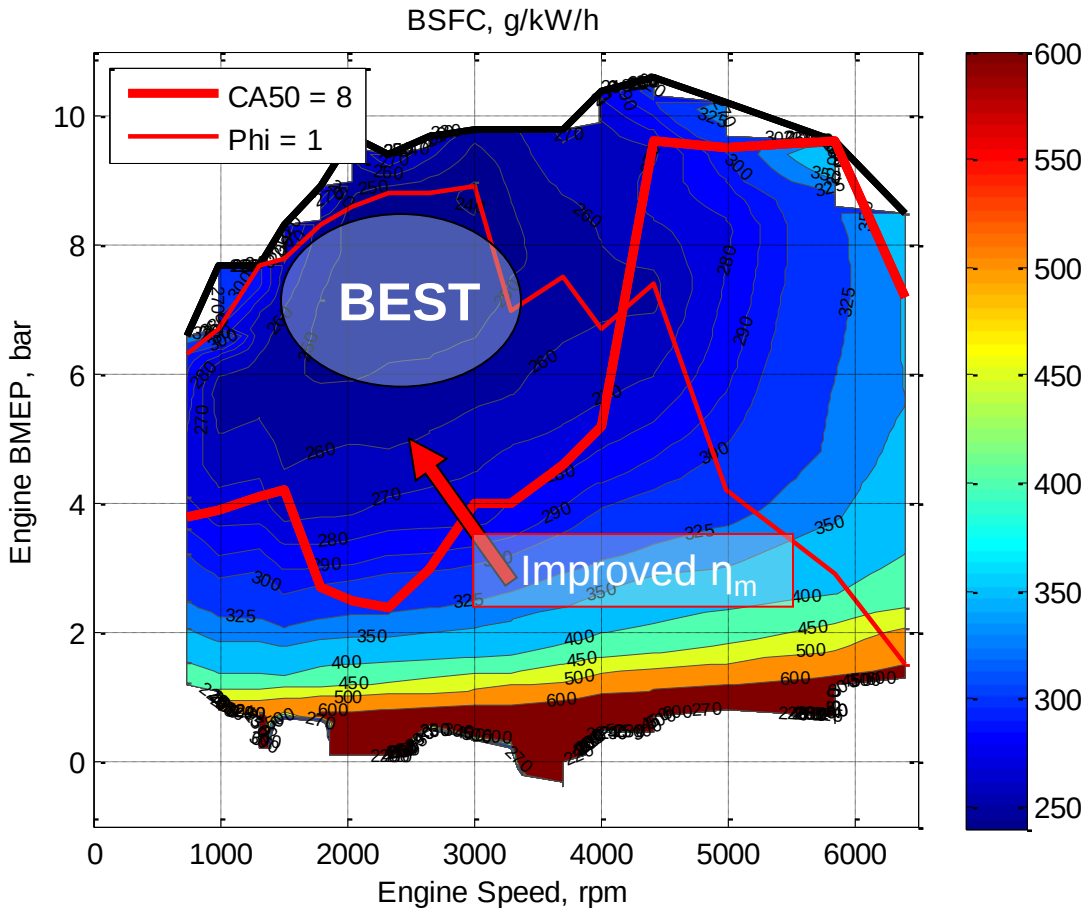
    $$\eta_m = 1 - \frac{(PMEP + FMEP)}{IMEP}$$

  - η_m > 80% at high loads
  - η_m < 50% at low loads, largely due to pumping

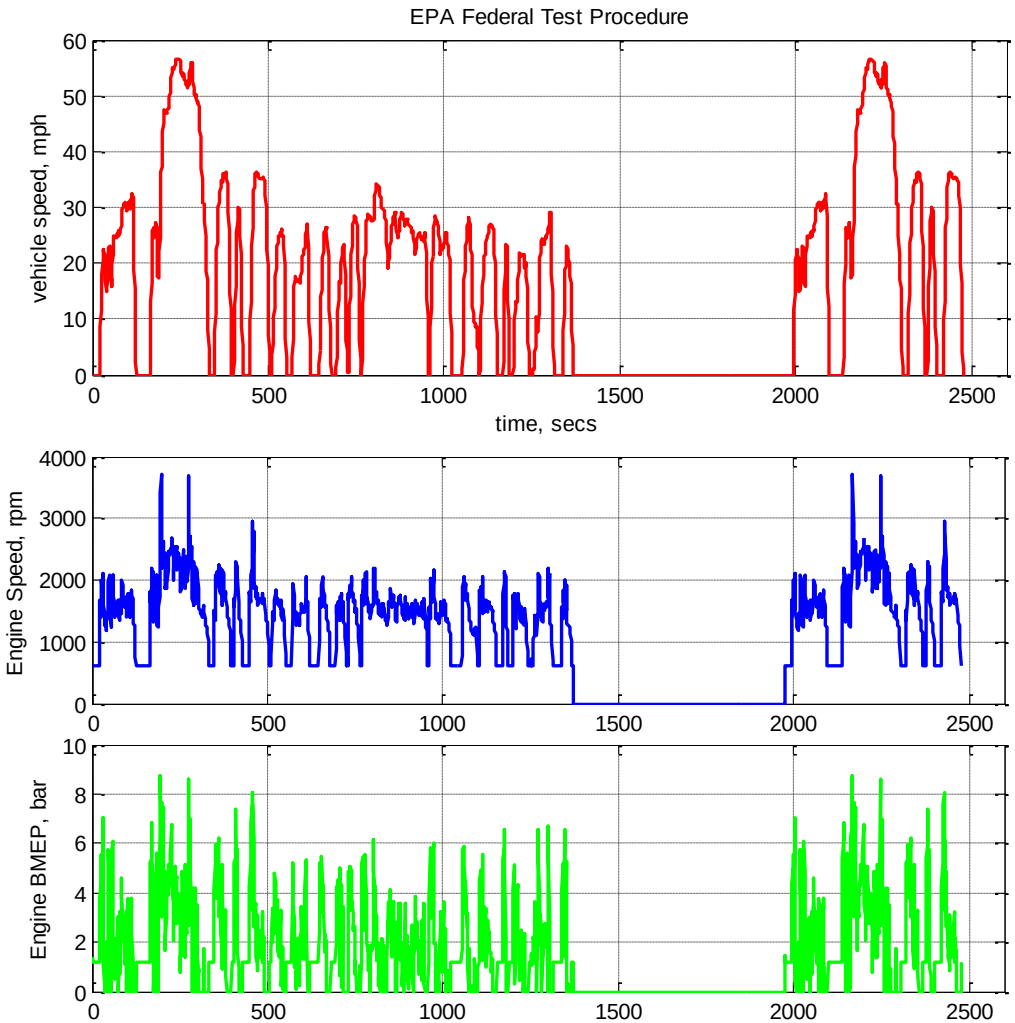


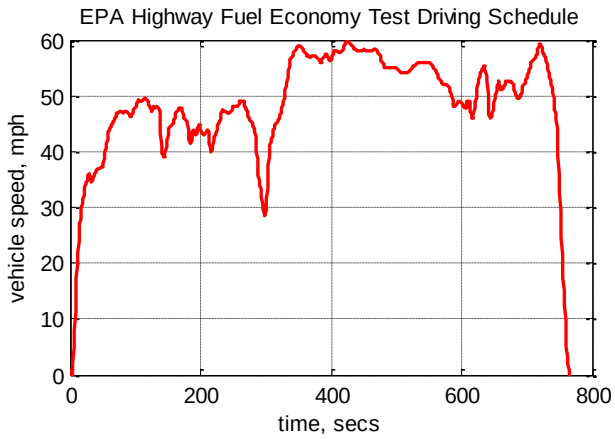
Net Result of all Losses: "The BSFC Map"

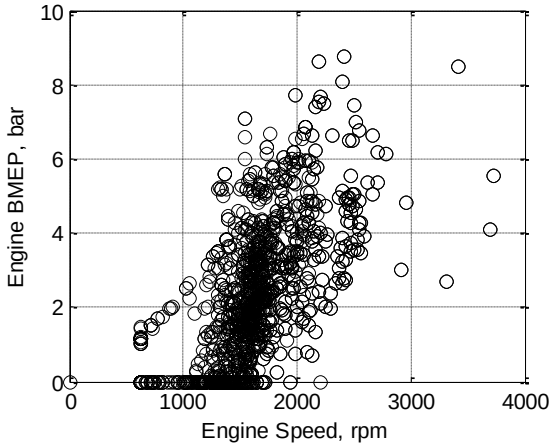
- The BSFC map appropriately weights and depicts where losses sum to a minimum
- Which loss is most important?
  - It depends on the cycle being driven, and how the engine is controlled within the system (next topic…)



Op. Issues: EPA Fuel Economy Cycles

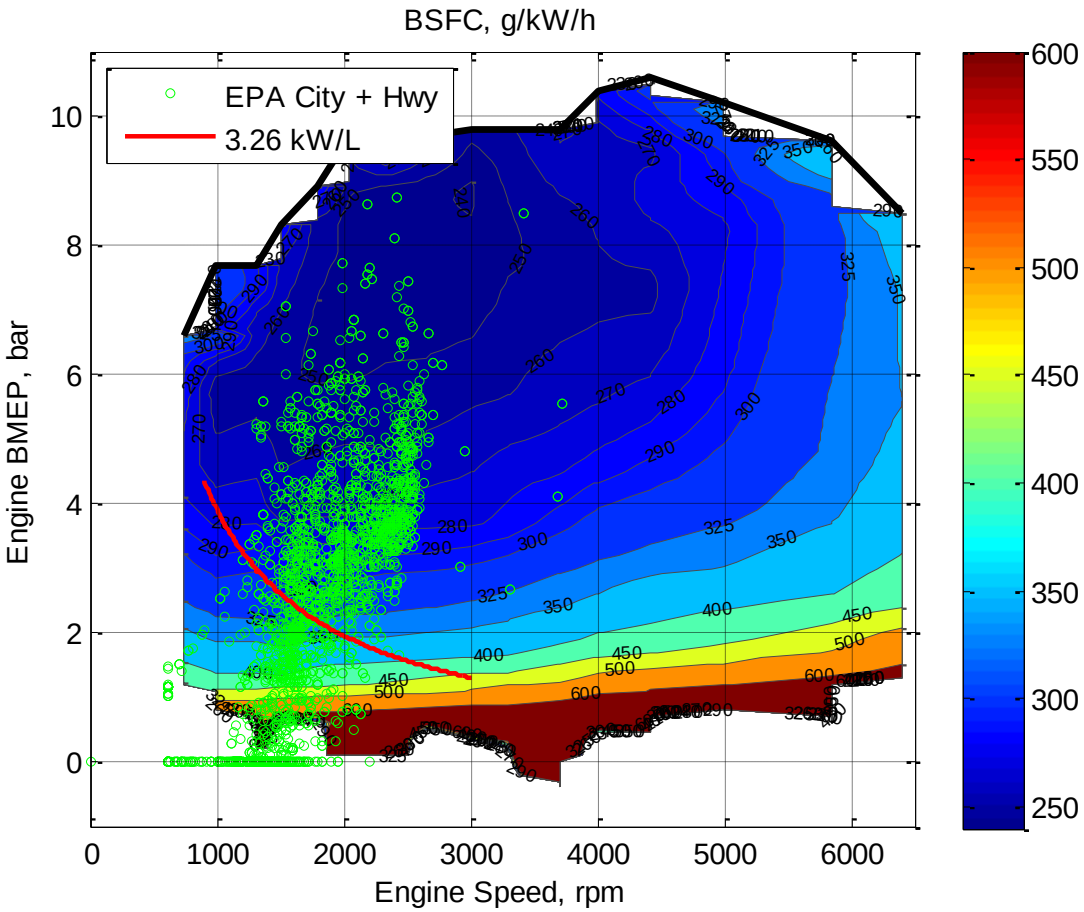






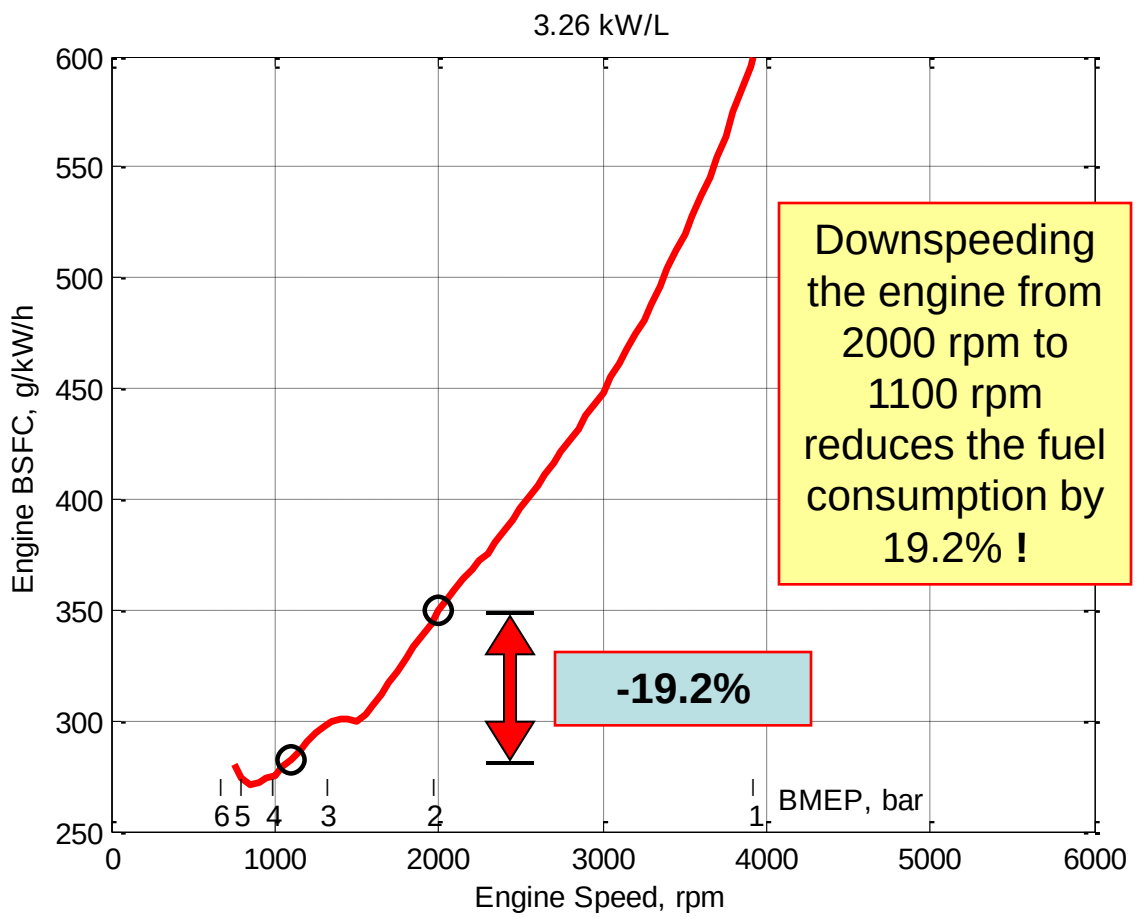
Op. Issues: The Engine as part of a larger system

- For the two EPA cycles, few test points fall in the minimum BSFC island
  - For the example shown, vehicle power demand is not that high
- Proposed analysis:
  - Examine BSFC at a constant power level of 3.26 kW / L



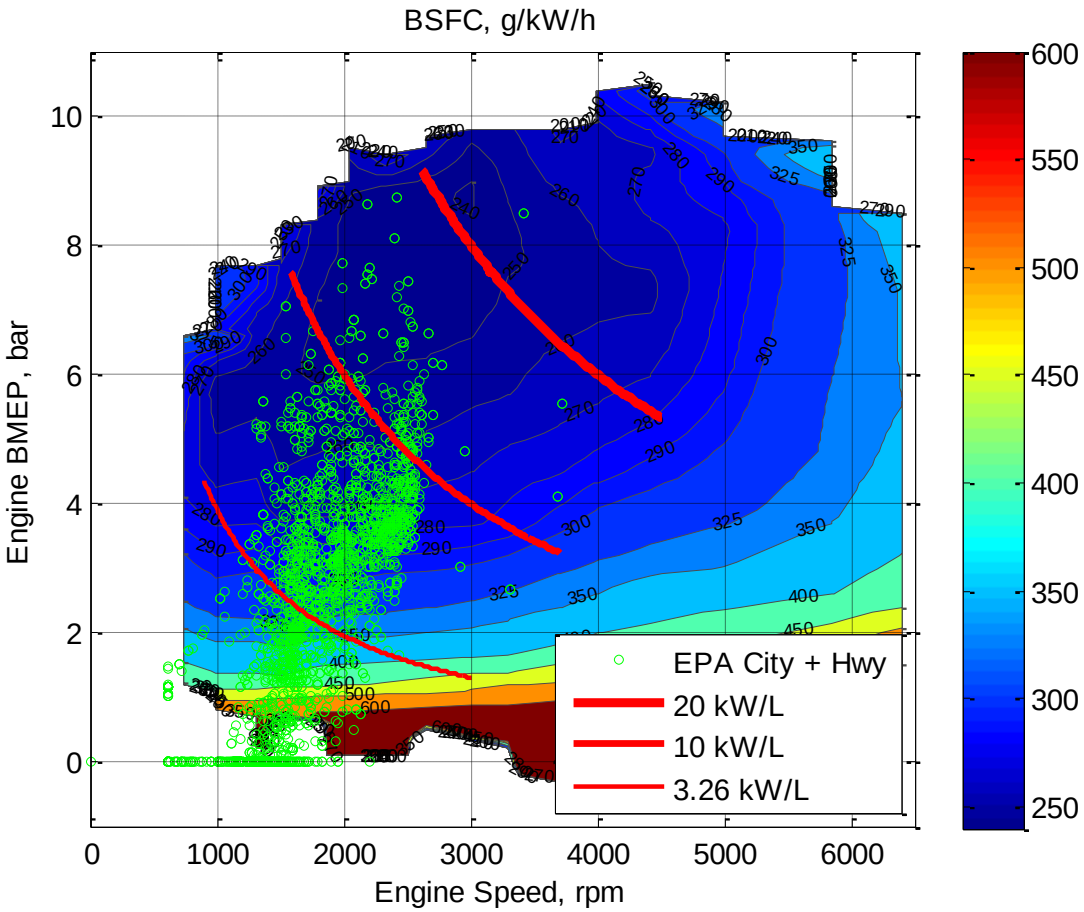
Op. Issues: BSFC at 3.26 kW / L

- Why 3.26 kW / L?
  - Normalizing power by displacement is required to plot power on a speed / BMEP basis
  - 3.26 kW/L is within 2% of many "world points" (e.g., 2000 rpm / 2 bar)
- Note the large BSFC sensitivity
  - There are issues though… more later



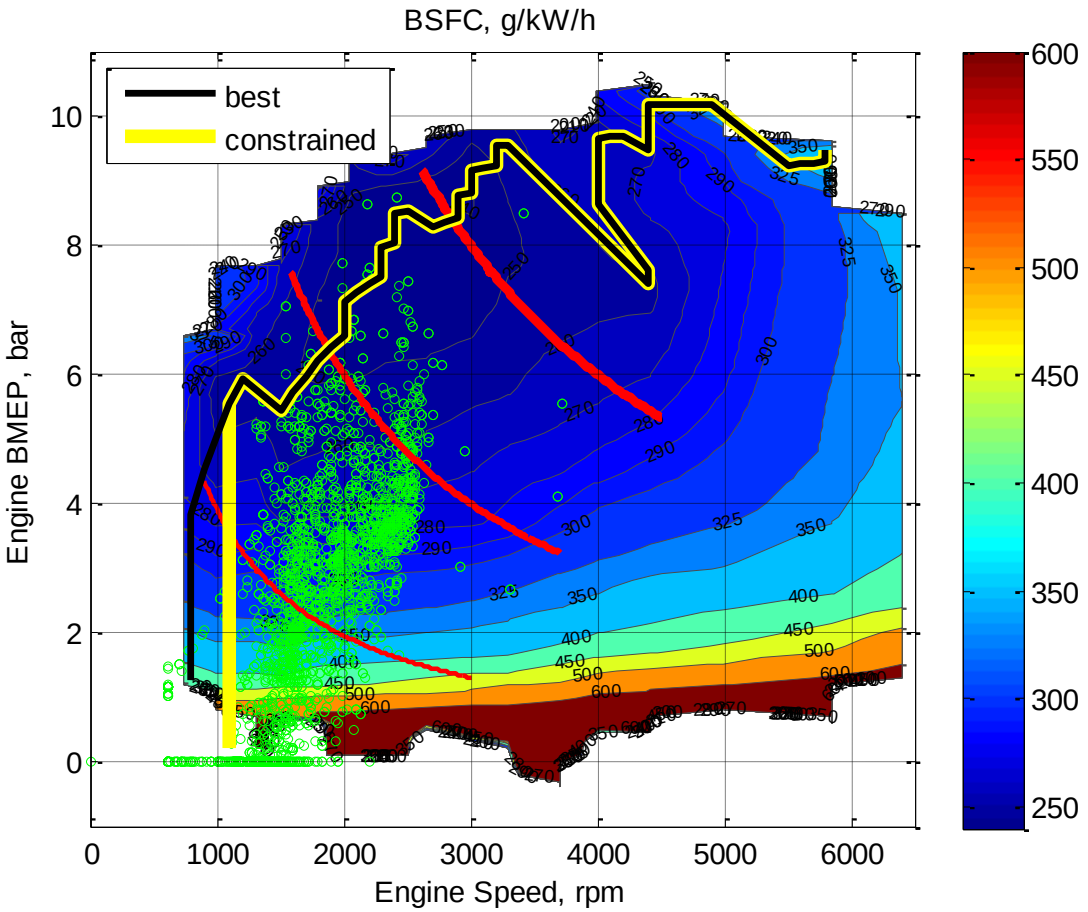
Metric Def'n: Extending the 3.26 kW / L Analysis

- The preceding process can be repeated at multiple power levels
  - 10 and 20 kW / L added for example



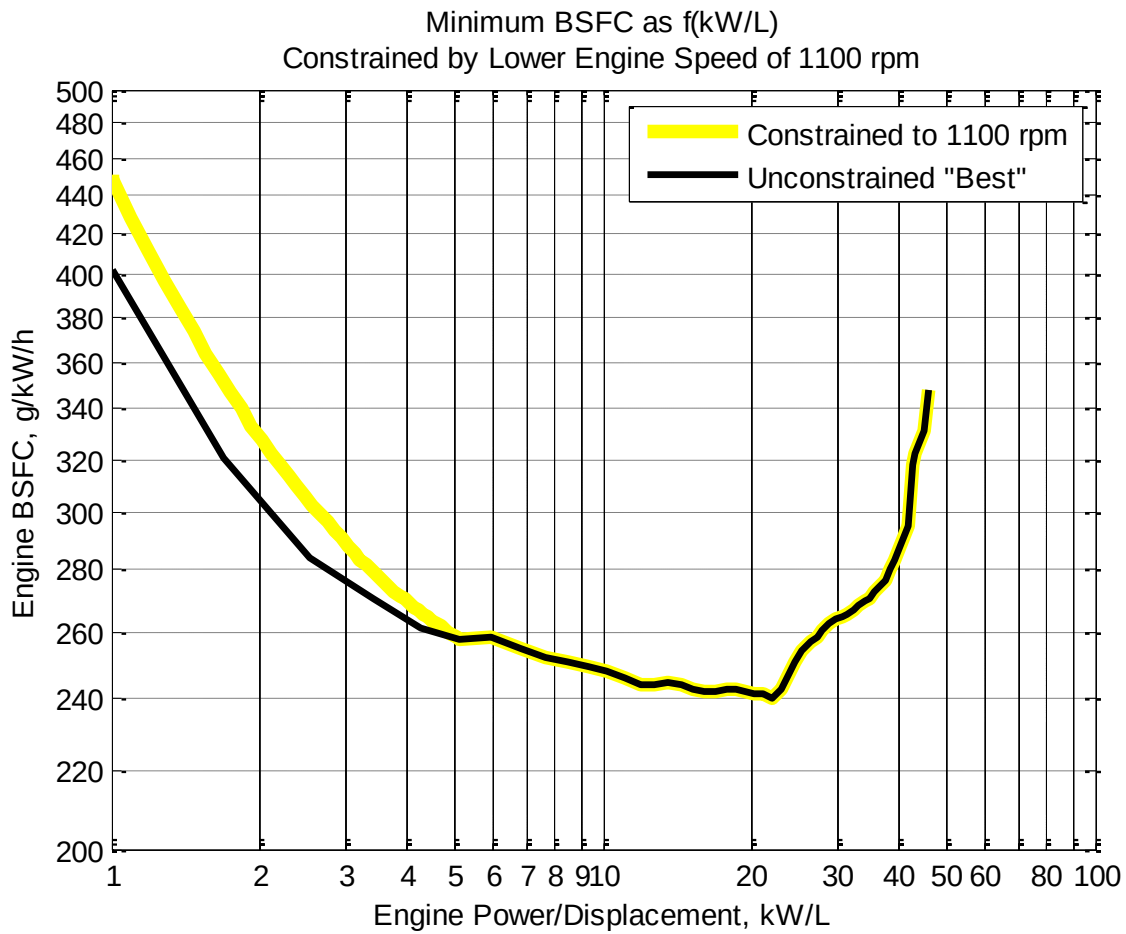
Metric Def'n: Extending the 3.26 kW / L Analysis

- The added lines:
  - "best" connects the minimum at all power levels
  - "constrained" applies a more realistic, but still aggressive lower engine speed limit of 1100 rpm
- Advanced trans-missions will strive to operate here
  - Hybrids may get even closer



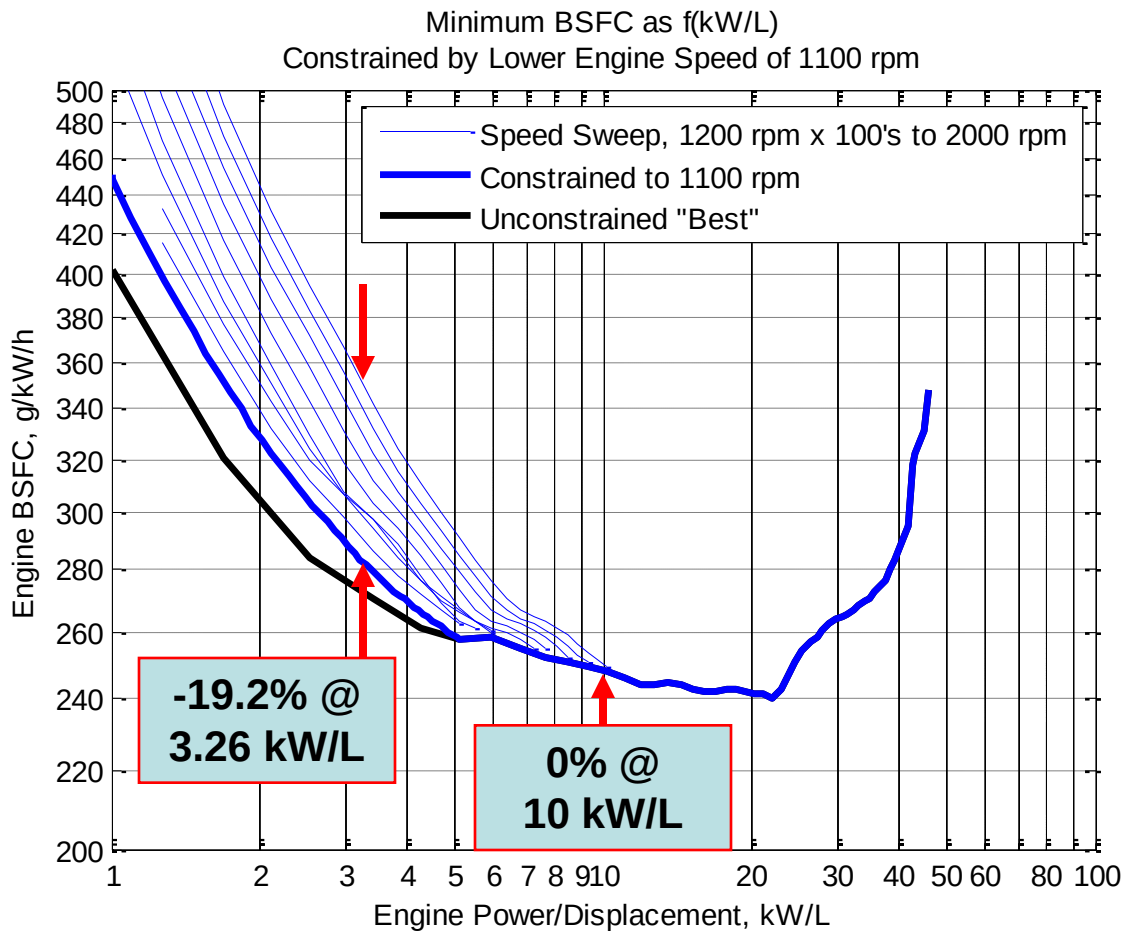
The Metric: $BSFC_{min}$ as f(kW/L)

- Same data as shown on previous slide
  - Now plotted in kW/L domain
- Enables 2D comparisons of 3D data
  - In a way that is relevant to how the engine will be used in the larger system



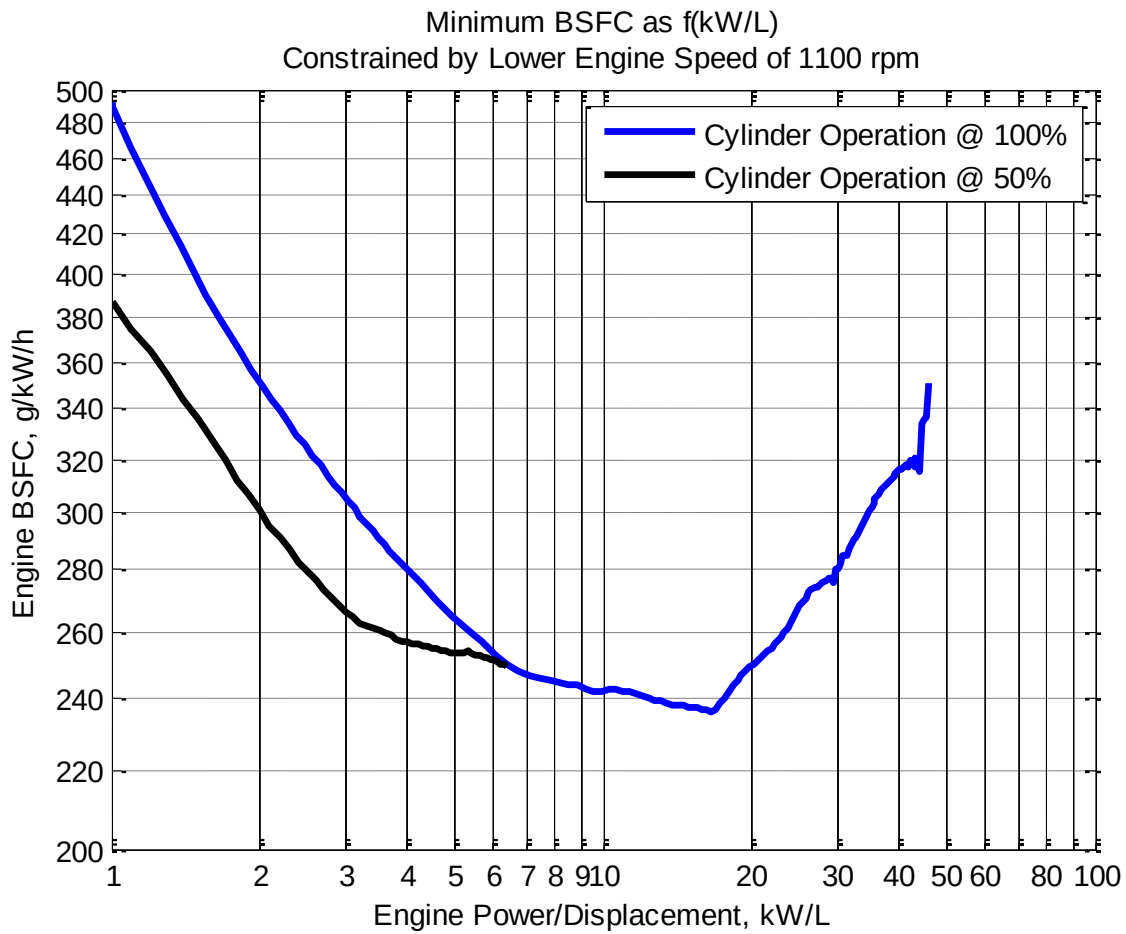
Tech Ex. 1: Potential of Downspeeding

- Same data as shown before
- Downspeeding sensitivity wrt load is now evident
  - Large benefit at low loads
  - No benefit at high loads
- Issues:
  - NVH
  - Trans. Ratio Range
  - Torque Reserve



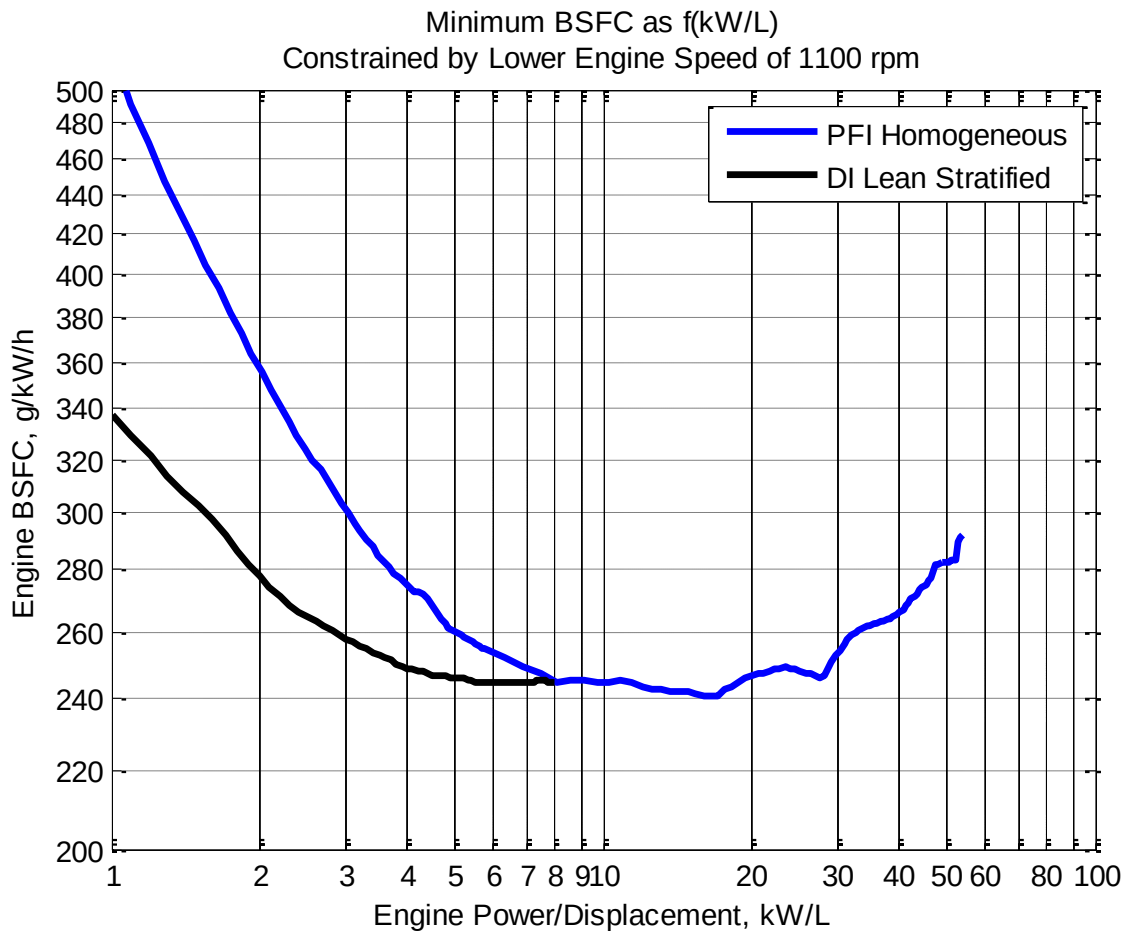
Tech Ex. 2: Potential of Cylinder Deactivation

- Cylinder deactivation further reduces pumping losses
  - Benefit goes to zero at higher loads, where the pumping losses are naturally reduced *via* less intake throttling, and due to knock
- Issues:
  - NVH
  - Vehicle Integration



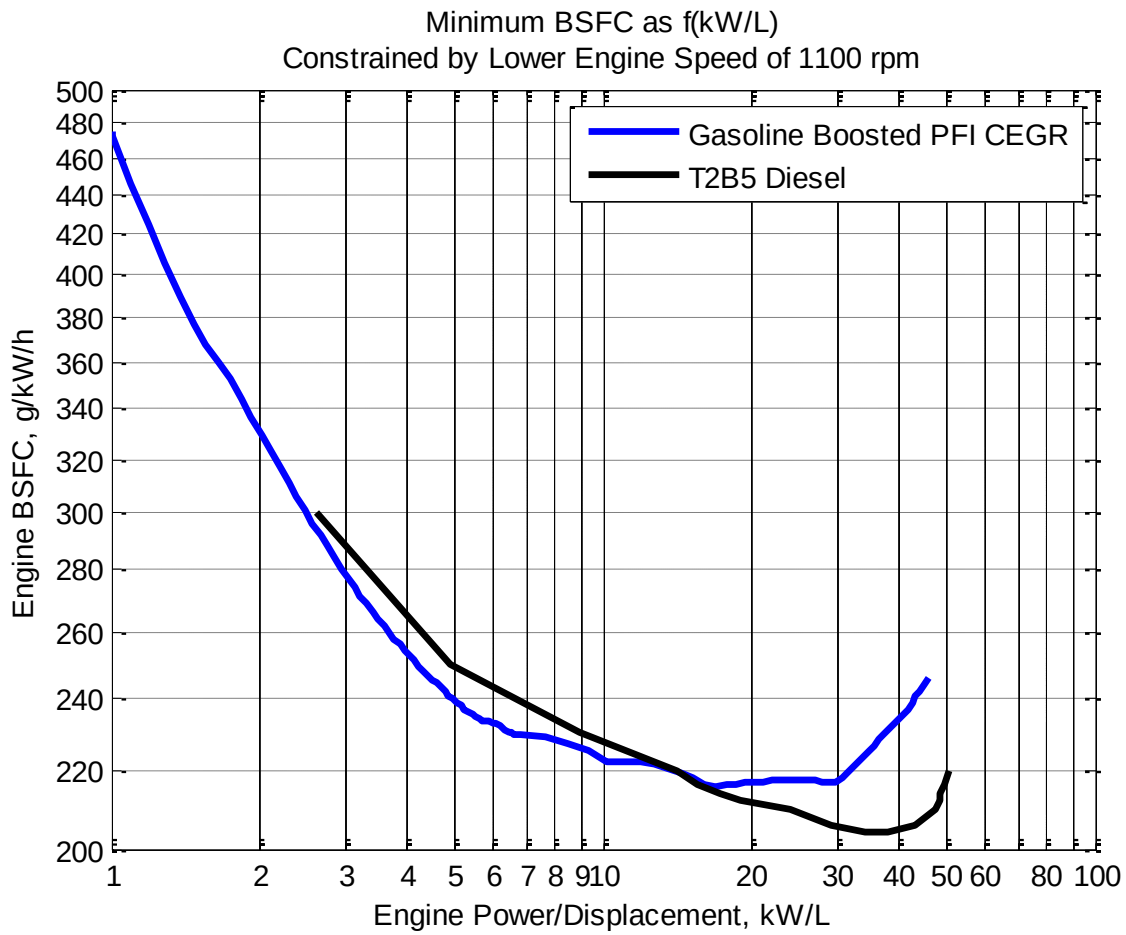
Tech Ex. 3: Potential of DI Lean Stratified

- Similar benefit to cylinder deactivation
  - Magnitude, and range of benefit is larger
  - Likely best or near best of all pumping loss reduction techs
- Issues:
  - Emissions aftertreatment cost and complexity
  - Fuel Quality



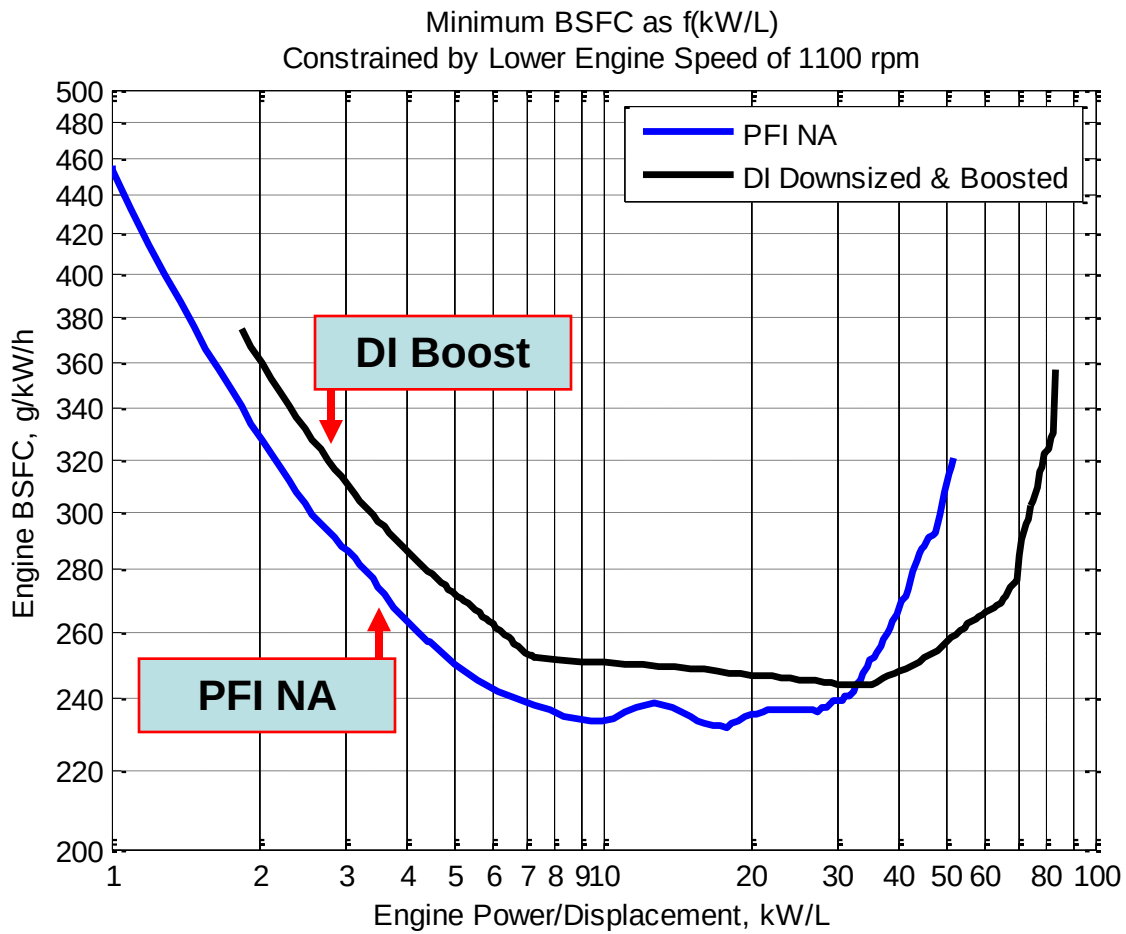
Tech Ex. 4: Potential of CEGR v. T2B5 Diesel

- Gasoline engines w/ boosting and cooled EGR
  - Discussed as a competitor to modern diesels
  - CEGR minimum BSFC is best of those shown for gasoline engines
  - Lower load benefit for CEGR potentially due to higher η_m
- Issues: TBD



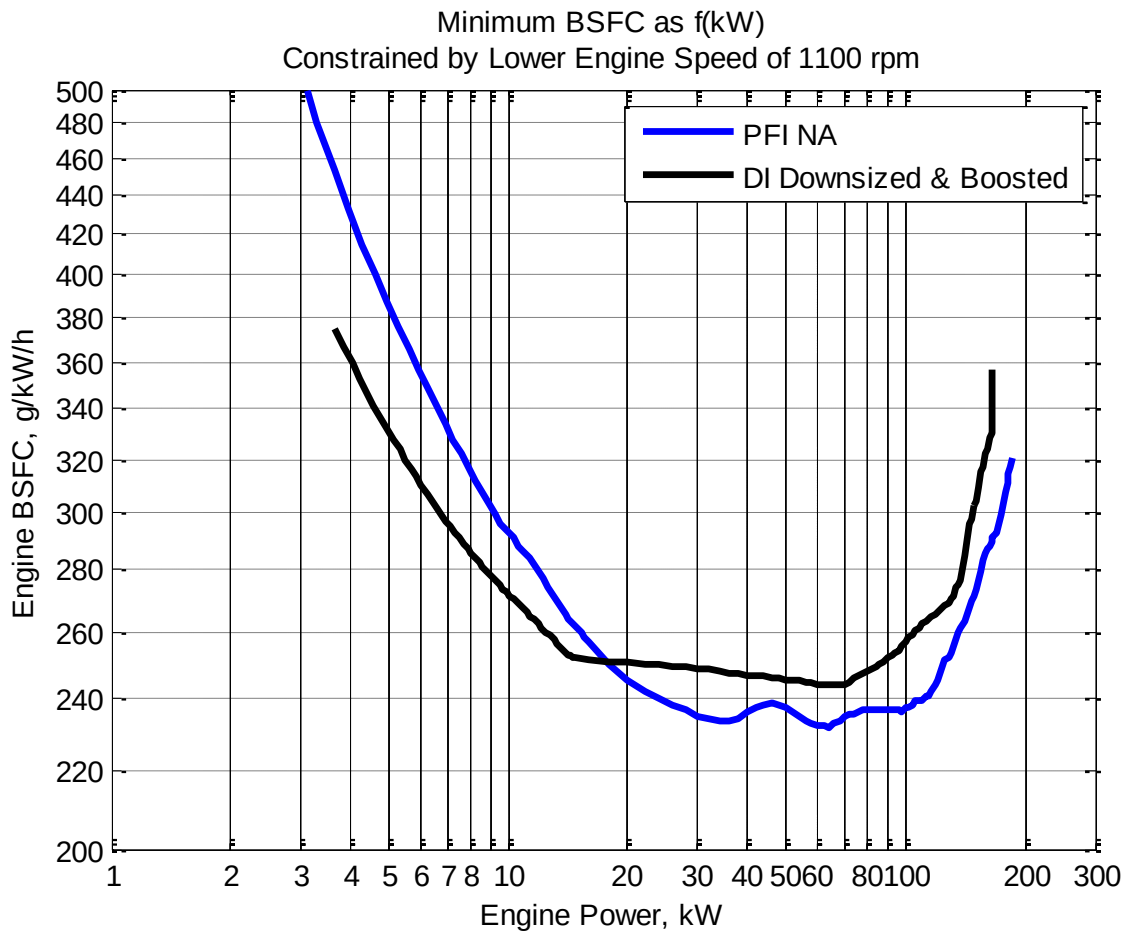
Tech Ex. 5: Potential of Downsizing and Boosting

- Where's the benefit ?
  - NA has better BSFCs at low and mid loads
  - Boosted has higher specific output
- To show in-vehicle benefit, need to account for displacement and move to absolute power



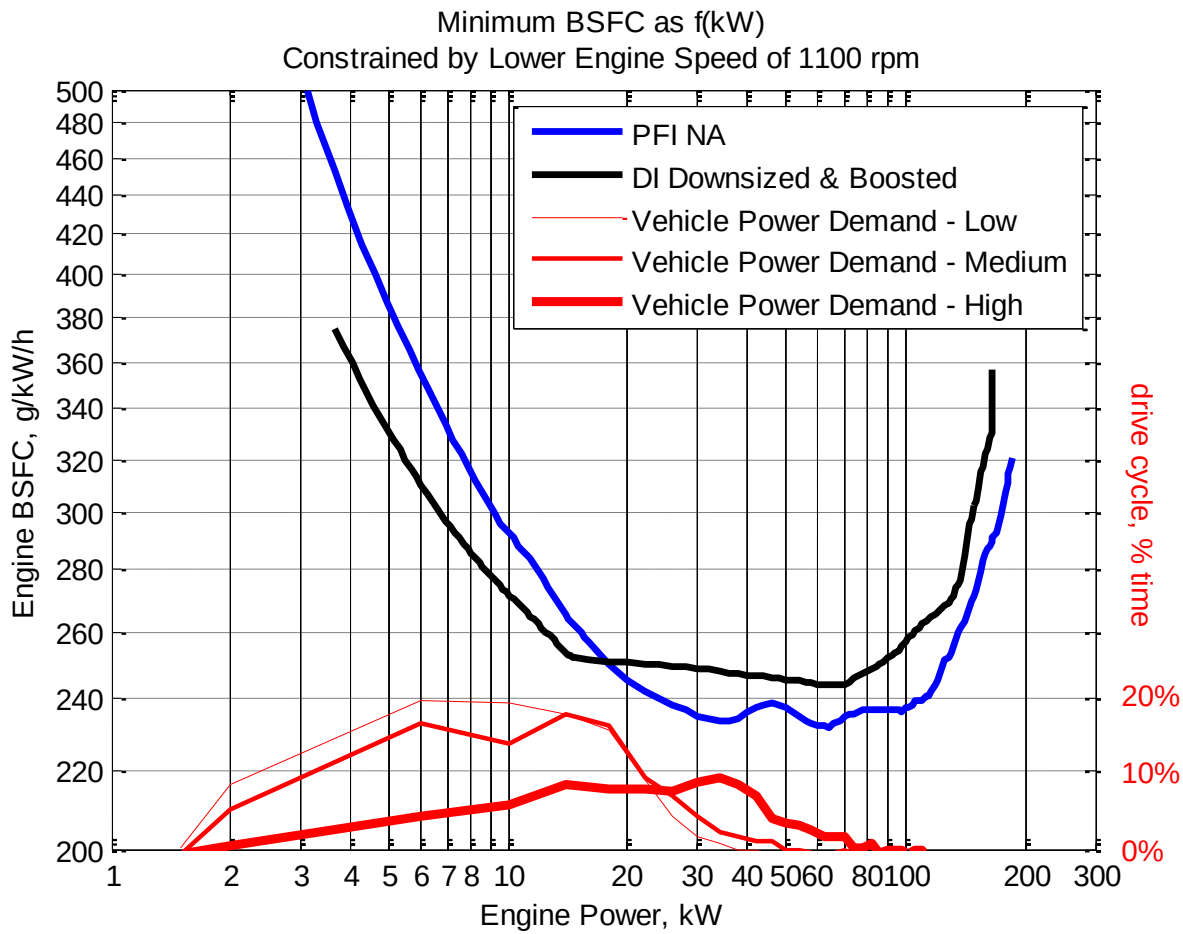
The other Metric: $BSFC_{min}$ as f(kW)

- The comparison is now valid
  - Benefit will be highest on low power demand cycles
  - Fuel consumption for the d/s boosted engine will be worse at the higher power demands
- Issues:
  - Benefit will vary depending on how the customer drives



The other Metric: $BSFC_{min}$ as f(kW) w/ Demand

- The benefit will also vary by vehicle application
  - Three "sizes" of vehicles are shown
  - Size is denoted by power demand
- For this example:
  - Small vehicles will see a sizeable benefit
  - Large vehicles may see no benefit, and may even be worse



Summary

- There is no clear, single solution
- Technologies which further reduce IC engine losses are worthy of future research
- The end decision as to what succeeds will be decided by the customer, and will be based upon:
  - Cost, Comfort
  - Dynamic Response, and Overall Performance
- We can significantly influence the customers decision
  - By working together developing technologies to address the above factors

Thank you for your attention

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