Sandia LTGC Engine Fuel Efficiency Impact on Regulatory Cycles

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Vehicle Assumptions

2015 baseline vehicle used as reference to estimate engine benefits

Transmission	GR1	GR2	GR3	GR4	GR5	GR6	*Final Drive for Baseline*	*Final Drive for LTC*
6-AU	4.074	2.4867	1.6241	1.135	0.8487	0.679	*3.65*	*3.2*

Frontal Area	m^2	2.35
Drag Coefficient	-	0.3
Rolling Resistance	-	0.009
0-60mph Performance Time	s	9 (*)
Vehicle curb weight	kg	1607
Vehicle class	-	Midsize
Powertrain Considered	-	Conv.

(*) Vehicles are sized to meet target 0-60mph along with other performance metrics .

Final drive reduction ratio was adjusted as compression ignition engines can operate efficiently at relatively lower speeds and higher loads compared to SI engines.

Engine Sizing to Meet Vehicle Technical Specifications (VTS)

All vehicles meet or exceed all VTS metrics

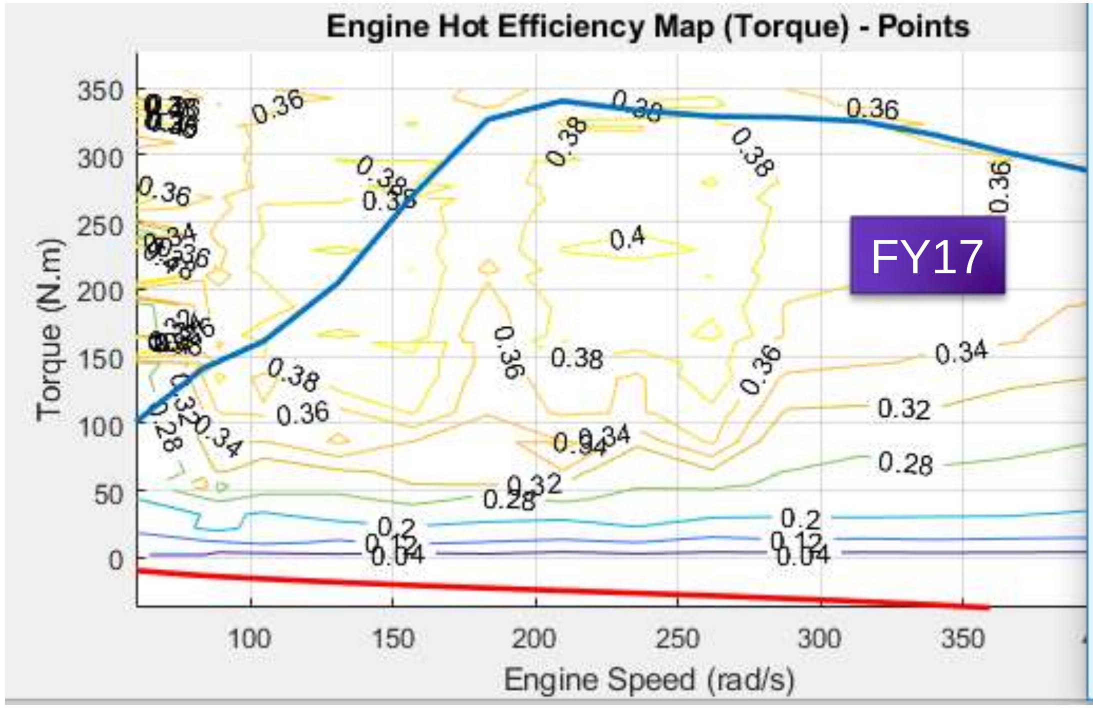
- The desired engine power is 117kW.
  - The single cylinder test data is scaled up to meet the power requirements (default scaling algorithms in Autonomie are used for this)
  - Turbo charging is expected in regions above 6 bar
  - The lag associated with turbo charging in performance tests results in slightly larger engine
    - Reducing the lag will enable us to use a 113kW engine to meet the same performance

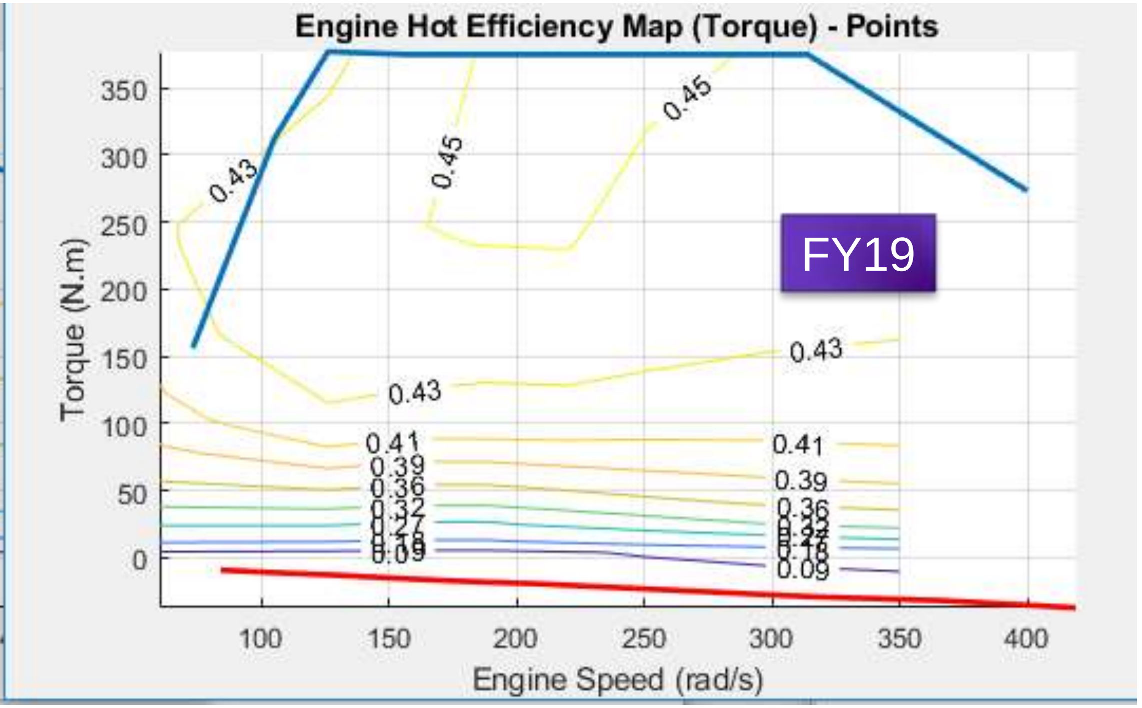
FY19 Engine Data Shows 5 to 8 Percentage Point Improvements over Previous Data (FY17).

The New Data Demonstrates Large Regions over 40% Efficiency

Improvements observed on engine sizing and vehicle evaluation:

- Increased peak torque (BMEP from 16bar to 20bar).
  – This helps further engine downsizing.
- Additional test data is available:
  – Speeds: 600, 1200, 1800, 2400, 2100, 2400 rpm and 3-6 torque points for each speed.





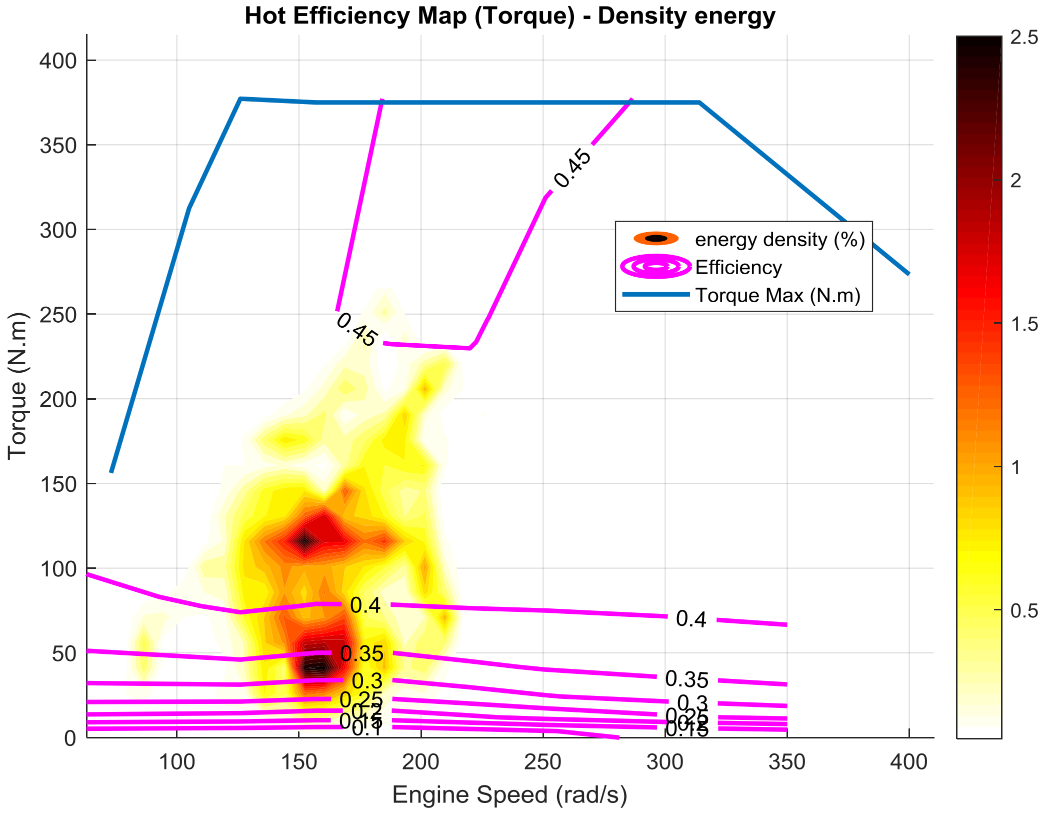
Data taken at ANL by Ciatti *et al.*

Data taken at SNL by Dec *et al.*

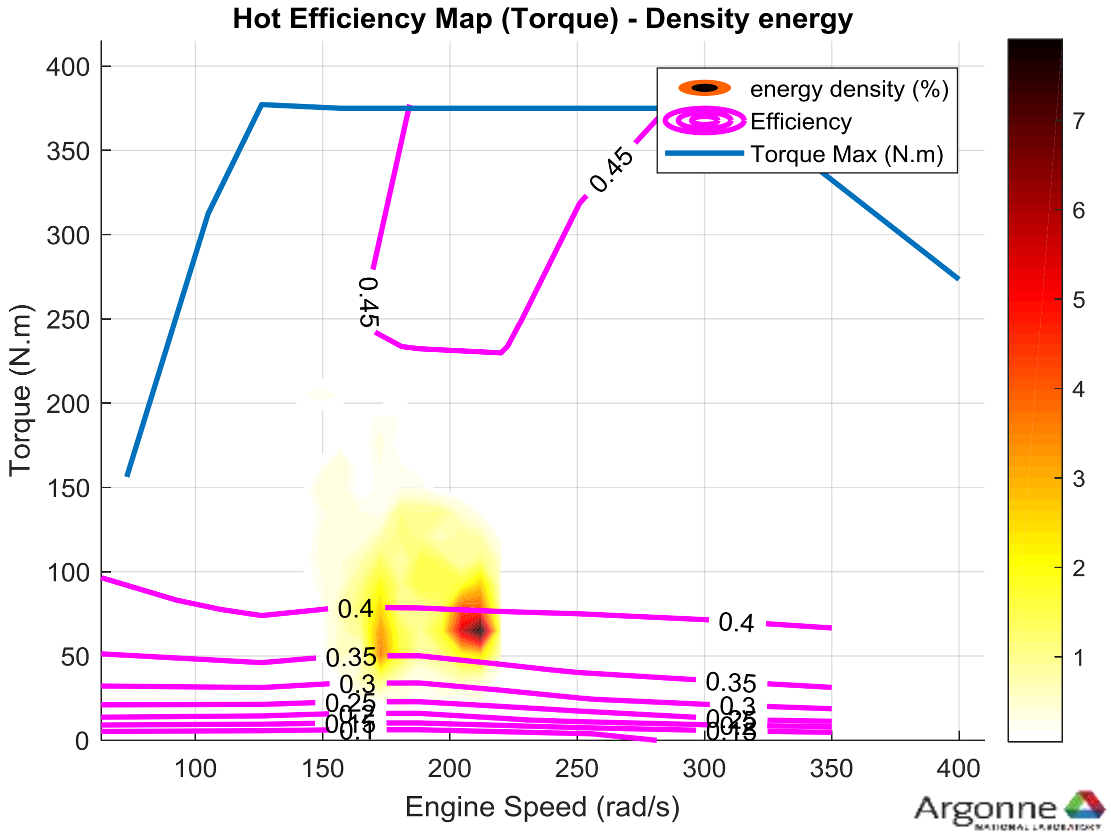
LTGC Summary (Operating points)

- For the conventional vehicle, the engine is mostly used at low loads on the regulatory cycles
- Hybridization could downsize the engine further and let it operate at higher loads even in regulatory cycles, resulting in higher average cycle efficiency.

UDDS avg. eff. 33.8%



HWFET avg. eff. 38%



Summary

- Combined unadjusted fuel economy of 43mpg is observed on the US Standard driving cycles for the FY19 LTGC engine on a conventional midsize sedan with a 6 speed gearbox.
- Over 19% increase in mpg is observed w.r.t 2015 baseline, because of engine improvements.
- Further evaluations are underway to quantify the impact with more advanced transmissions and powertrains.

	2015 Baseline downsized turbo**	2019 LTGC Turbo**
UDDS	31.8	37.3
HWFET	43.0	53.0
Combined*	36.0	43.0
% imp. w.r.t 2015 baseline	0.0%	19.4%

* Unadjusted
** 4 cyl, 6 AU