Engine Parametric Study

+/- 10kW range with a step of 1kW

For DOT/VOLPE

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Results Summary

For conventional vehicles, increasing/decreasing the engine power by 10kW leads to an increase/decrease in fuel consumption by a range of:

- 3.1% and 3.3% for Eng01
- 2.8% and 3.2% for Eng02
- 2.7% and 3.0% for Eng03
- 2.0% and 2.3% for Eng04

DOHC

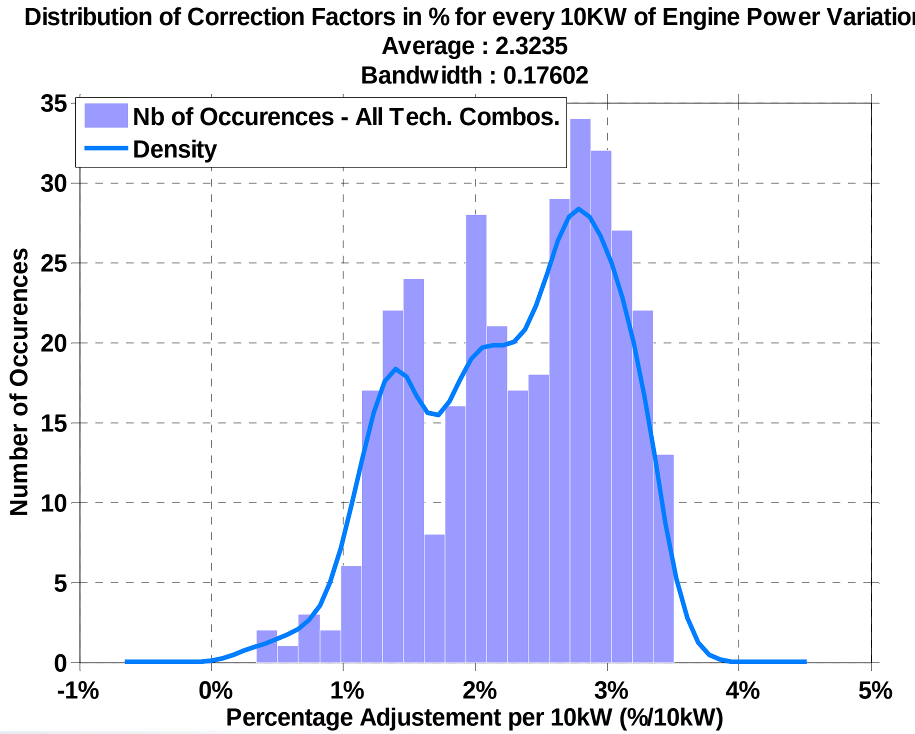
- 3.3% and 3.4% for Eng5a
- 3.1% and 3.3% for Eng5b
- 3.0% and 3.1% for Eng5c
- 2.7% and 3.0% for Eng6a
- 2.5% and 2.9% for Eng6b
- 2.5% and 2.9% for Eng7a
- 2.4% and 2.8% for Eng7b
- 1.8% and 2.2% for Eng8a
- 1.7% and 2.0% for Eng8b

SOHC

- 1.9% and 2.2% for Eng12
- 1.0% and 1.6% for Eng13
- 1.1% and 1.6% for Eng14
- 1.4% and 1.5% for Eng15
- 1.5% and 1.7% for Eng16
- 2.2% and 3.1% for Eng17

TURBO | DIESEL

- We show that electrification level, transmission technology and speed selection has little to no impact on Adjustment Factors variations.
- We show that Adjustment Factors variations are mainly driven by Engine Technology.
- We show that it is possible to attain better performance results with minimal fuel consumption penalty.
- See conclusion for other findings.



Objective & Background

The objective is to evaluate the impact of engine power variation on fuel consumption results to mimic engine inheritance effects

- Generate Fuel Consumption Adjustment Factors to answer:
  - By how much do fuel consumption results need to be adjusted if engines are kept constant across multiple classes?
  - Do the adjustment factors depend on the technological combinations?

Approach
Engine Power Variation

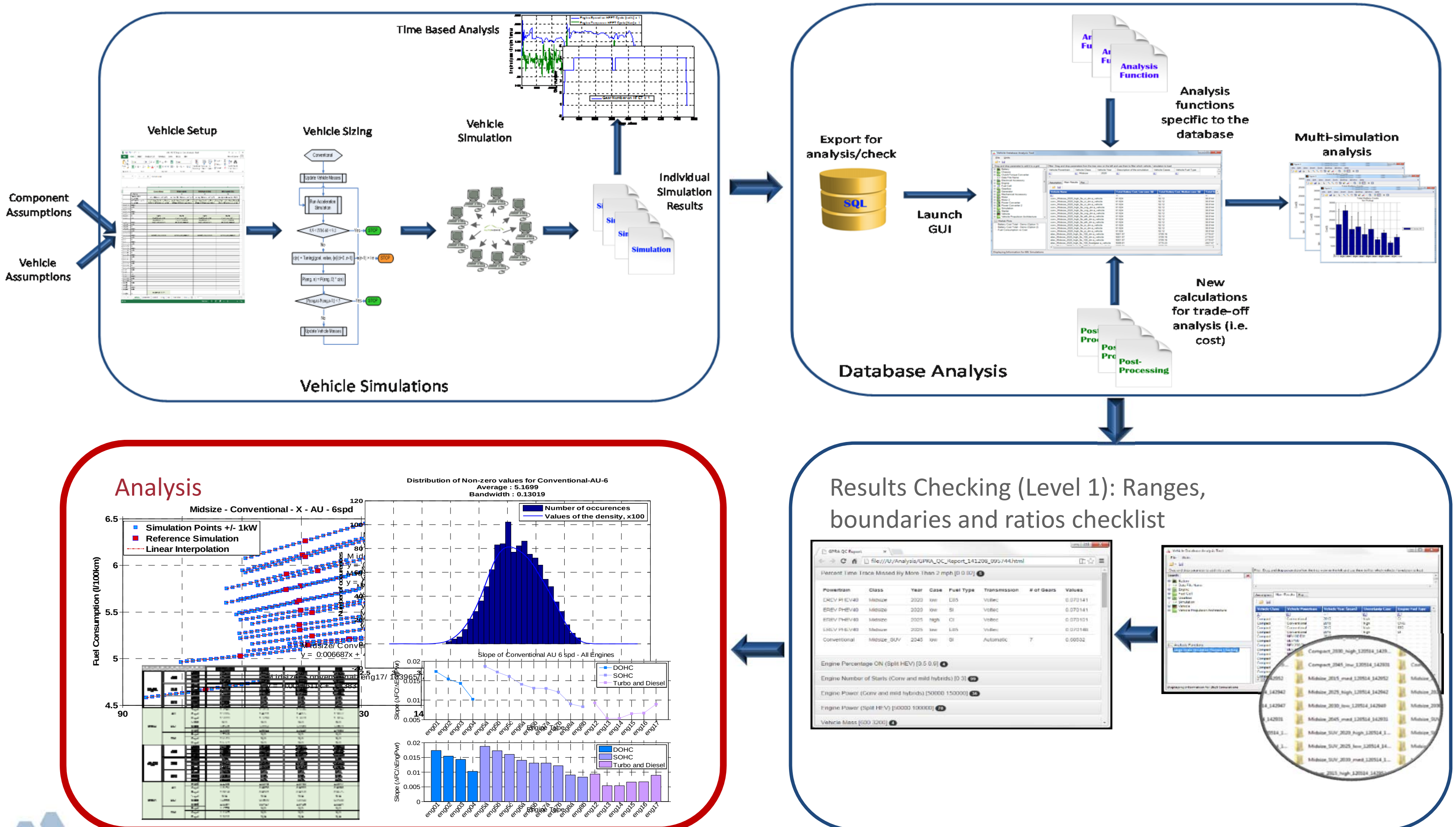
- Study done on one class: Midsize.
- All vehicle technological combinations have been selected except for those that embed linear proprieties such as Mass, Aerodynamic and Rolling resistance reductions:
  - 19 engine technologies (IAV engines)
  - 4 no/low electrification levels (Conventional, Micro Hybrid, BISG, CISG)
  - 9 transmission technologies (AU/DCT/DM, 5/6/8 speed)
  - 1 light-weighting levels (MR0)
  - 1 rolling-resistance levels (ROLL0)
  - 1 aerodynamic levels (AERO0)
- Parametric study by varying a *reference** engine power over a range of +/- 10kW with a step of 1kW. Each vehicle combination selected requires 20 simulations.
  - Develop the relationships and extract adjustment factors

~ 14,000 vehicles simulated

(*) Reference: vehicles with engine powers that provide similar performance results (sized vehicles)

Methodology

- The Large Scale Simulation Process was re-used to complete this parametric study.
- The flexibility of the process allow us to easily run, create a database, check the results, generate specific plots for the analysis, and extract adjustment factors.



Reminder: IAV Engine Technologies

Increased efficiency

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

Diesel

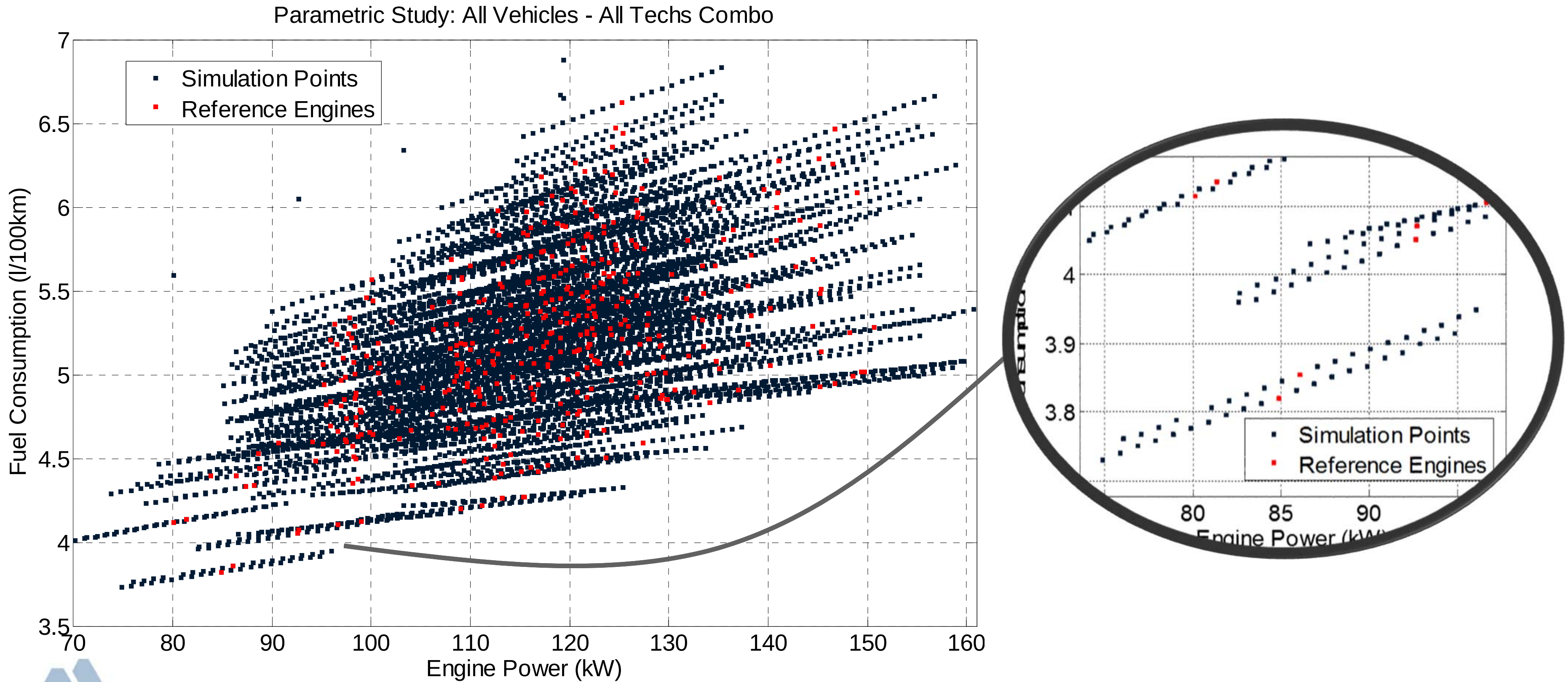
17. Diesel engine → 2.2l, 4cyl

*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

Results

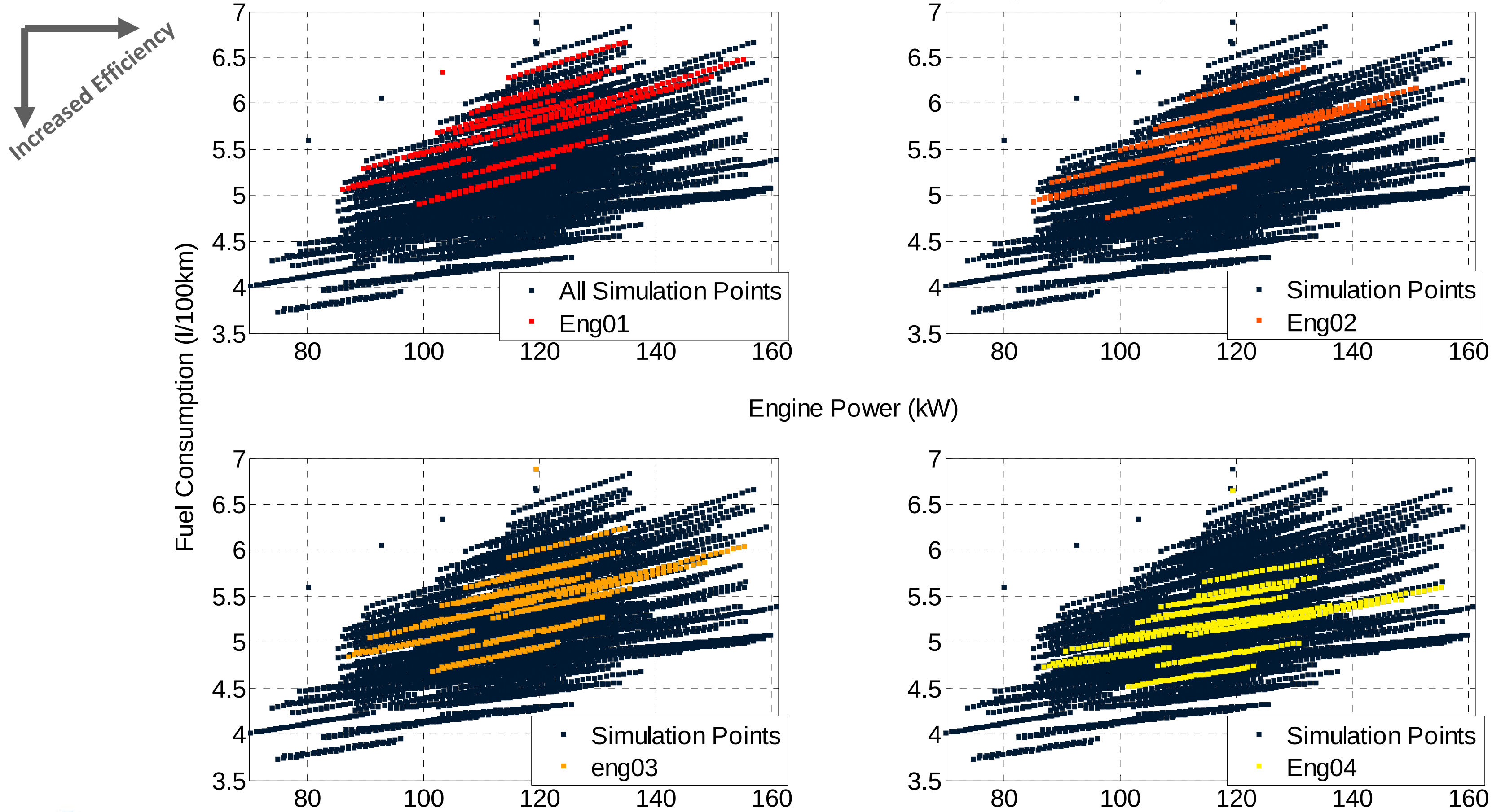
All Technology Combinations

- Each vehicle combination was run with ranging the engine power by +/- 10kW with a step of 1kW.
- Linear behaviors are emerging for the simulation results, regardless of the combo.
- Slopes appear to be varying with technology, which would lead to different adjustments (adjustment factors)



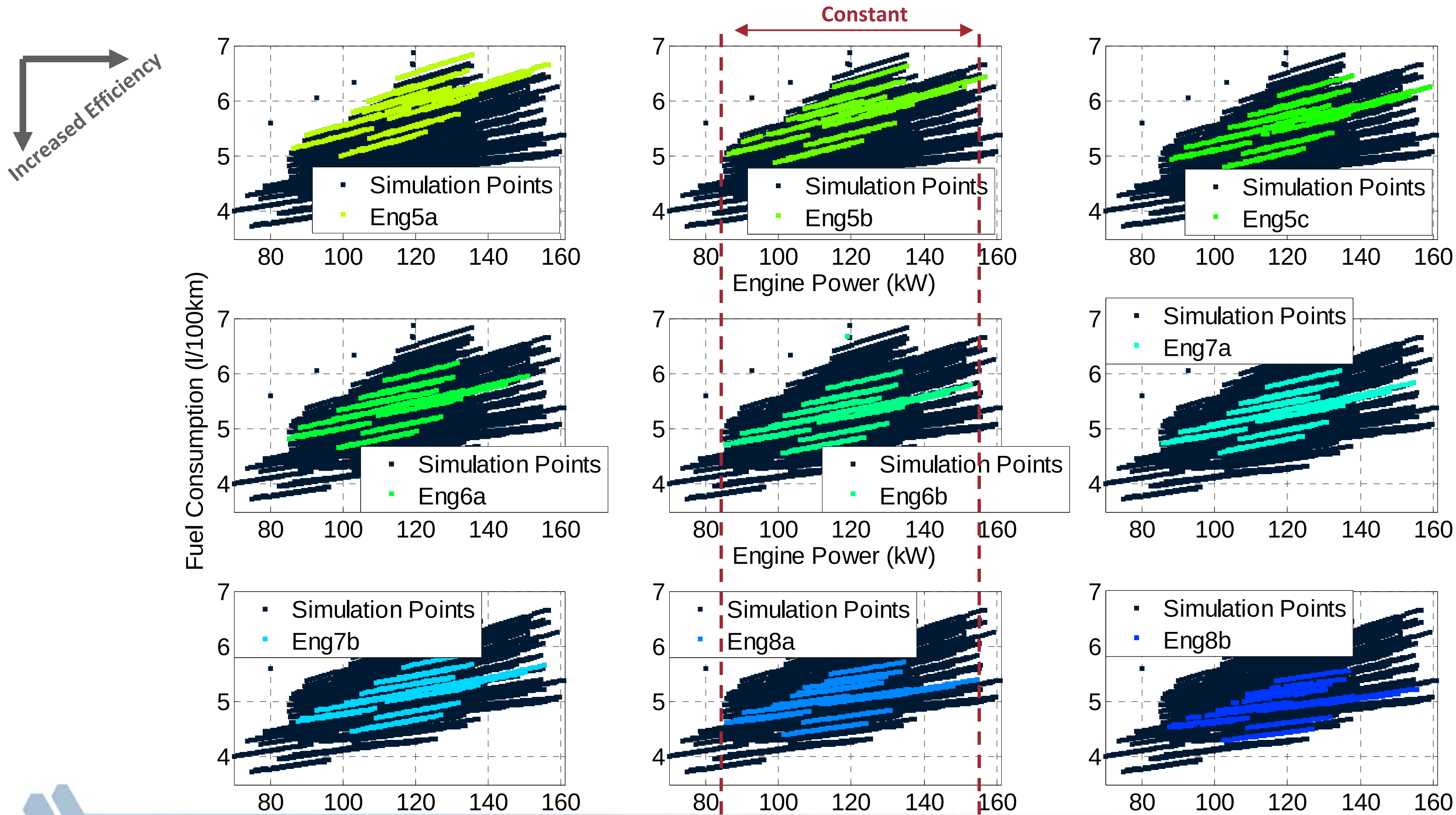
Evolution of Engine Technology - DOHC

- Eng01 to Eng04: DOHC engines (refer to IAV engine report/description)
- One engine at a time / fixed engine – All Combos
- Improvement in engine technology appear to affect the parametric sensitivity as the slope of the lines are reduced with lower highlighted regions.



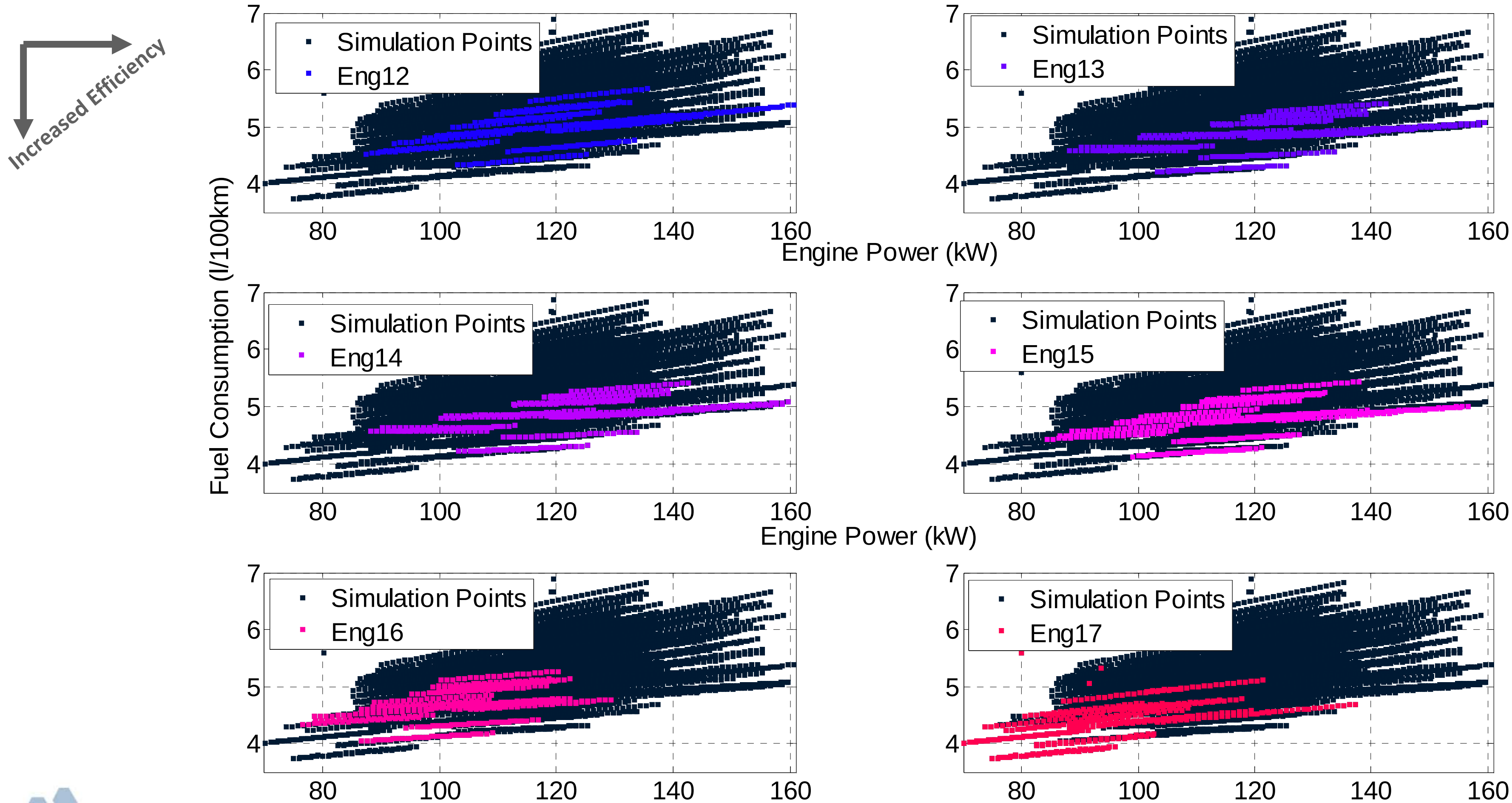
Evolution of Engine Technology - SOHC

- Eng5a to Eng8b: SOHC engines.
- Improved engines understandably provide lower fuel consumption results. The power span seems to remain constant across engines, but rather fuel consumption is less sensitive to power change.
- Eng5a lines show an obvious bigger slope than Eng8b.



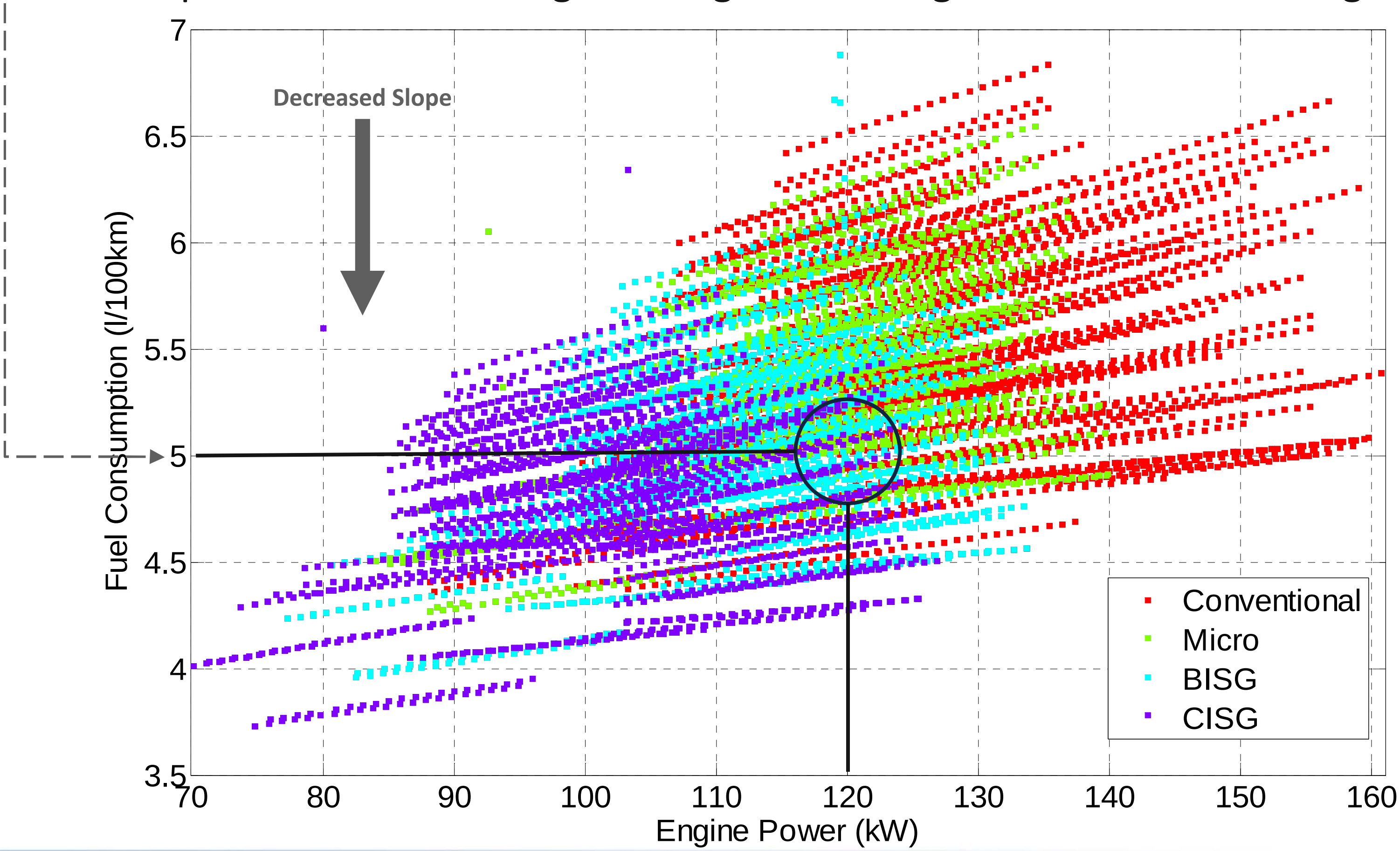
Evolution of Engine Technology – Turbo

- Eng12 to Eng16: Turbo engines, Eng17: Diesel engine
- Turbo engines slopes lean towards flat behaviors.
- Diesel engine vehicles reveal the more fuel efficient and the least powerful vehicles, but sensitivity seem to increase again as the slope gets steeper (Eng17)



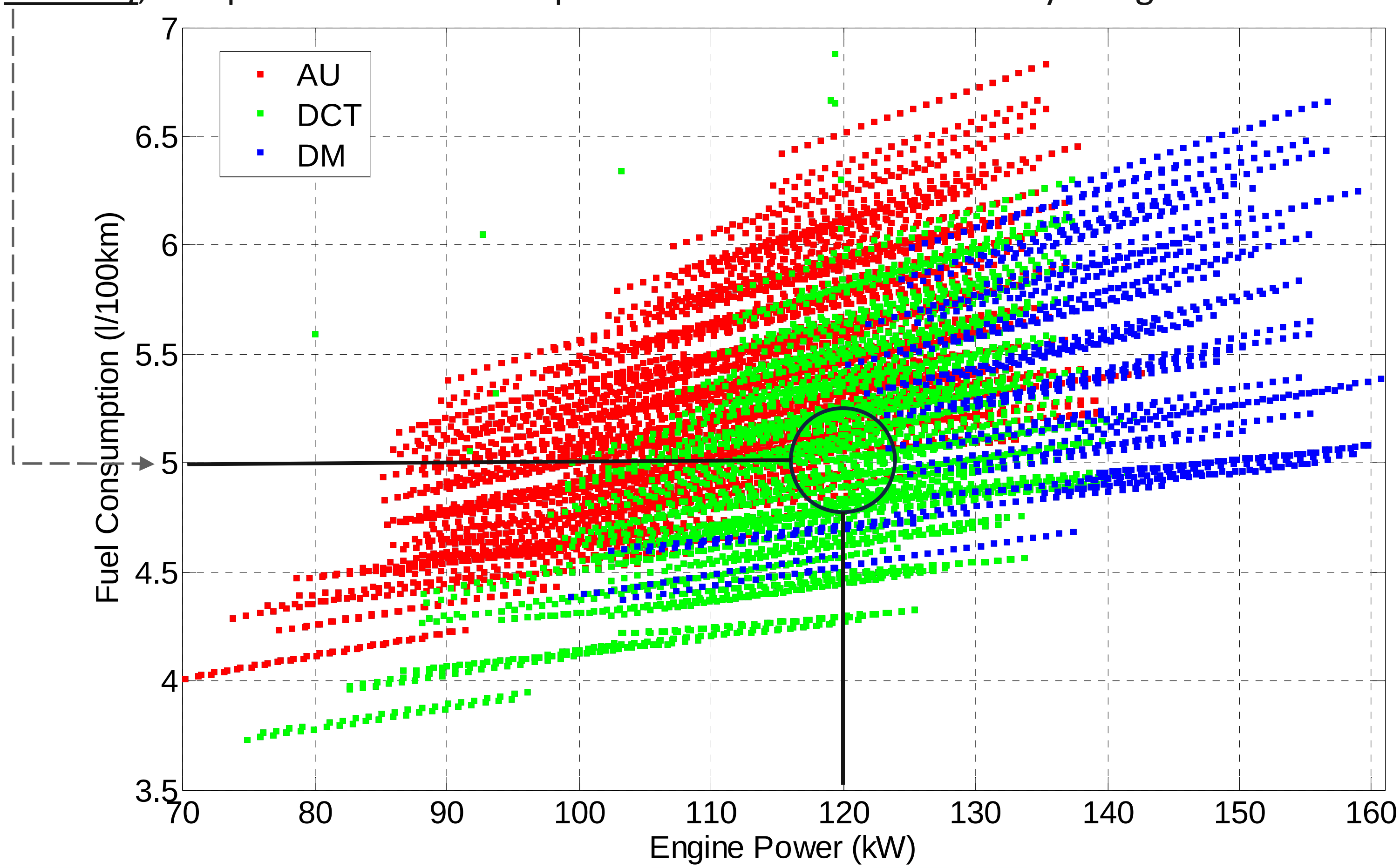
Evolution of Powertrain Technology

- The breakdown per powertrain clearly shows the different operating powers as well as the decrease in fuel consumption for progressive technologies (Conv. to CISG)
- It has been established that the slope decreases moving downwards.
- Side note: It appears that similar fuel consumption results can be attained by using different powertrain technologies along with the right tech. combo. for a given power.



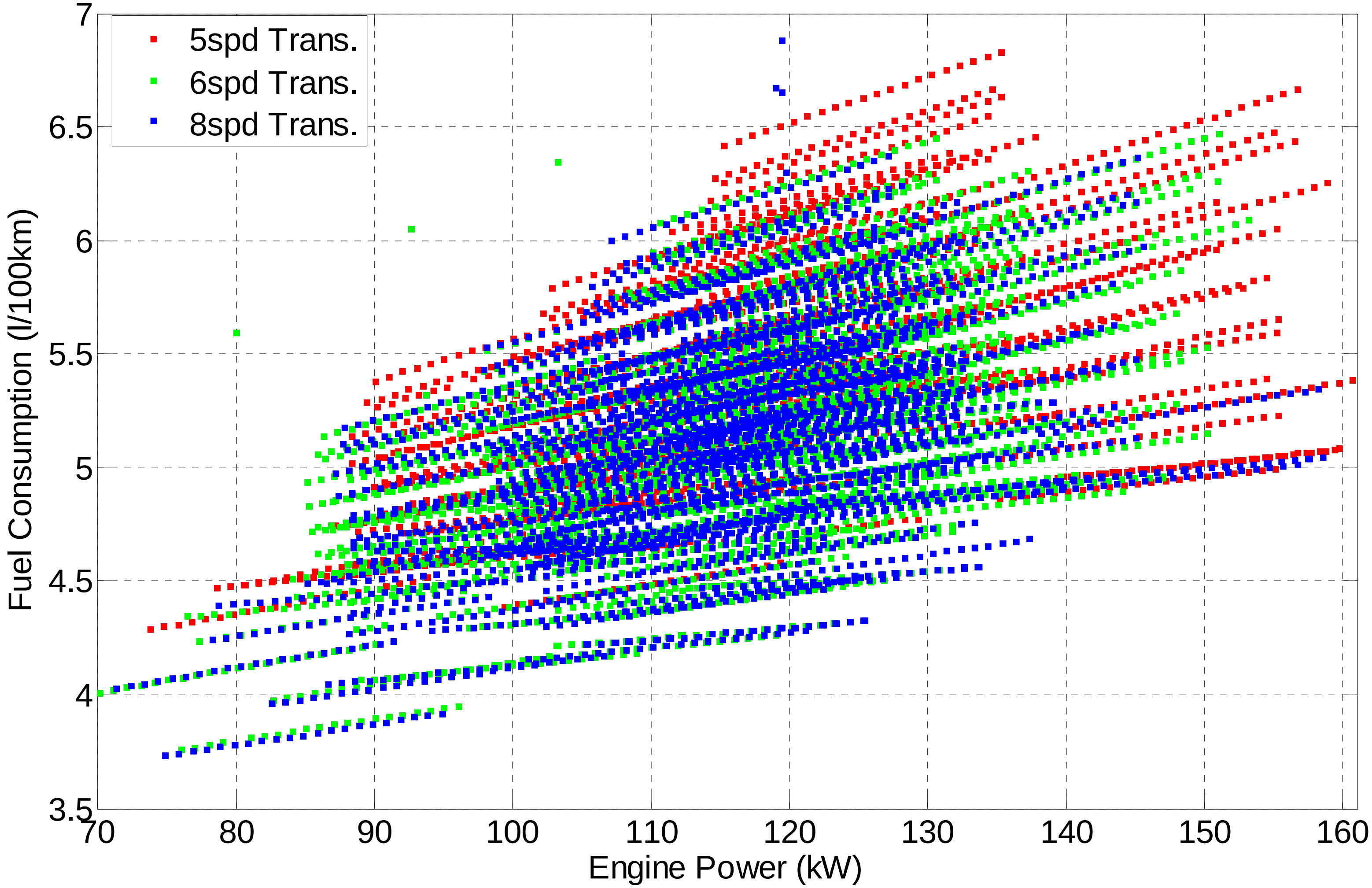
Evolution of Transmission Technology

- Automatic transmissions vehicles have the lowest engine power requirement as opposite to Manual transmissions. This is the result of performance vehicle sizing.
- The torque converter help automatic transmissions to achieve better performances leading to lower engine powers. Dual Clutch transmission provide the best fuel efficiency for a given power.
- Similarly, comparable fuel consumption results can be attained by using different Trans. Tech.



Evolution of Transmission Speed

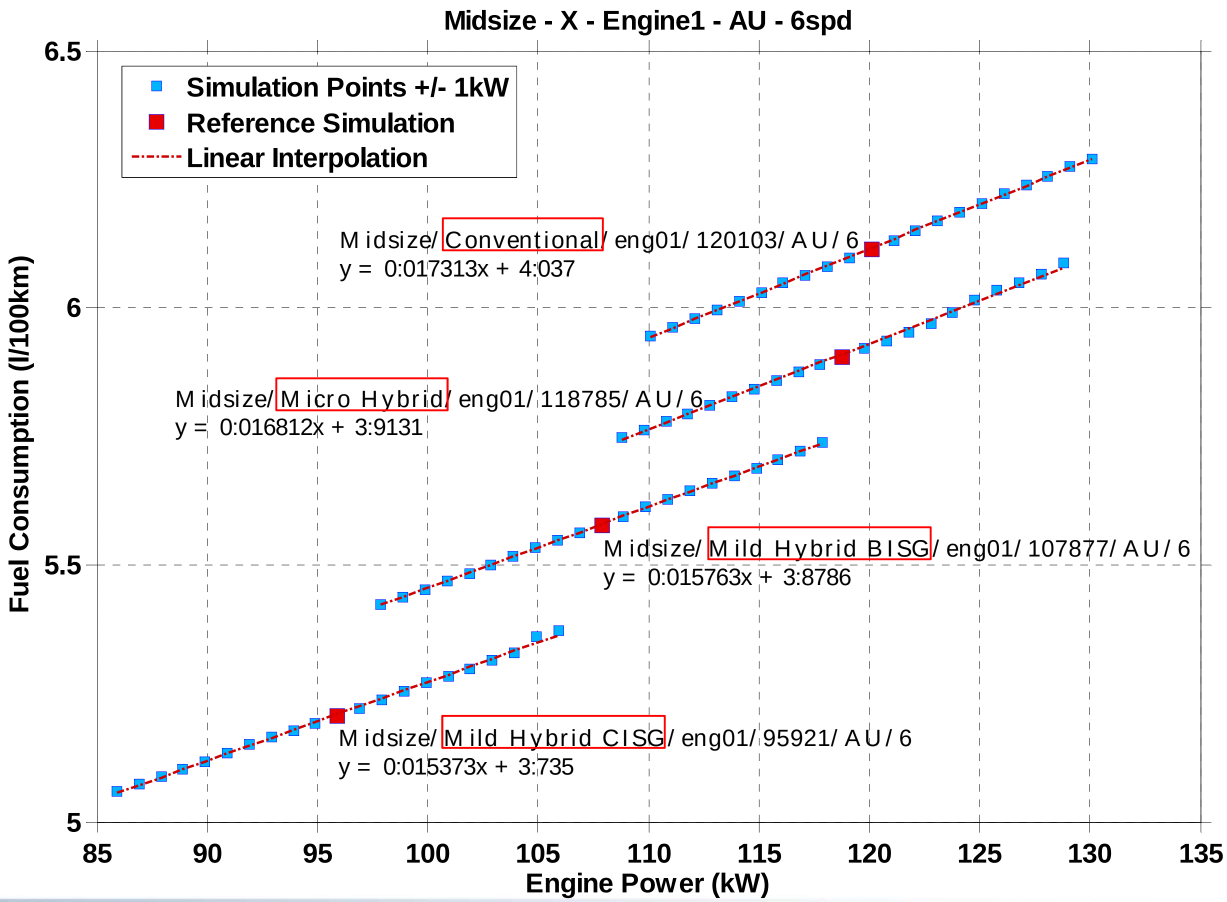
- No intelligible pattern seem to arise from the selection of different transmission speeds.
- Diverse Trans. Speeds can be used to achieve similar fuel consumption results.



Subset: Fixed Combo (All Pwt.)

Eng01-AU-6 speed

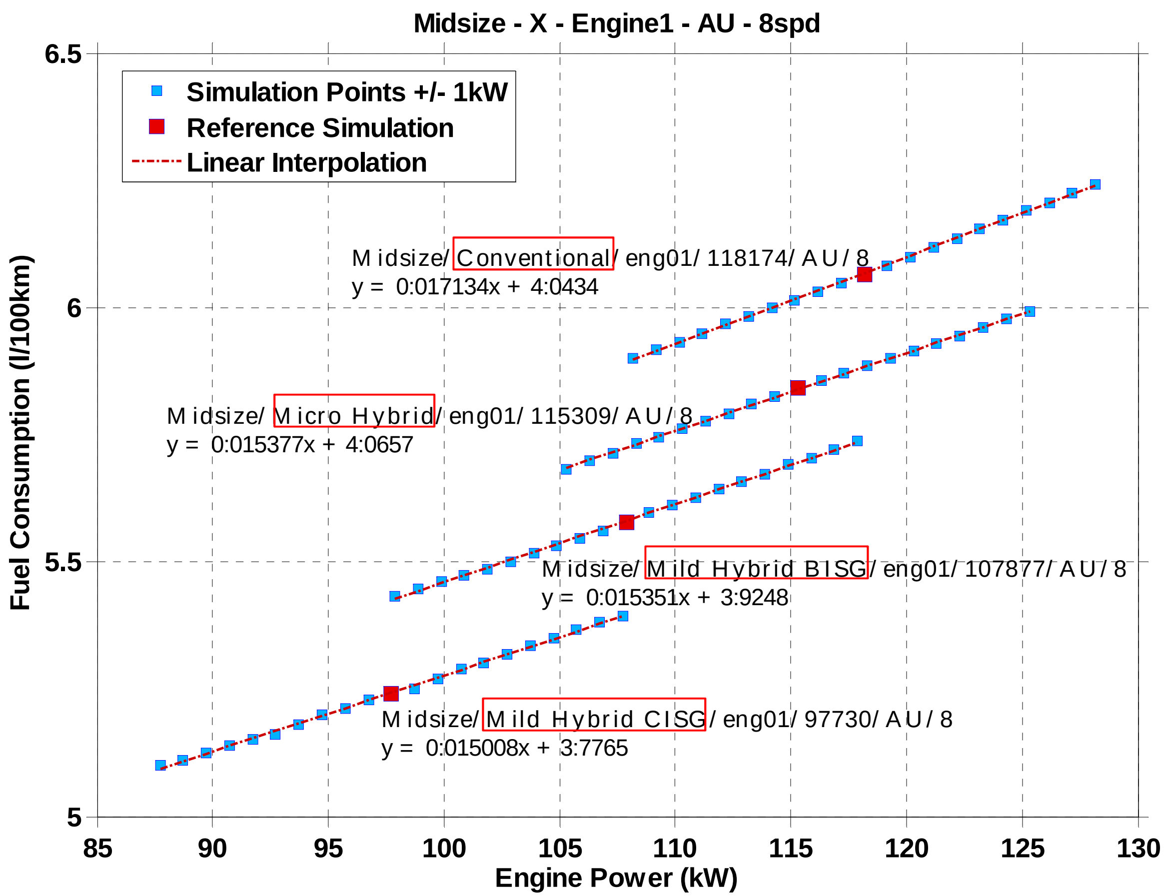
- Fuel consumption decreases with advanced powertrain
- Power Requirement decreases with advanced powertrain.
- The slope *slightly* decreases with advanced powertrain (very small impact)



Subset: Fixed Combo (All Pwt.)

Eng01-AU-8 speed

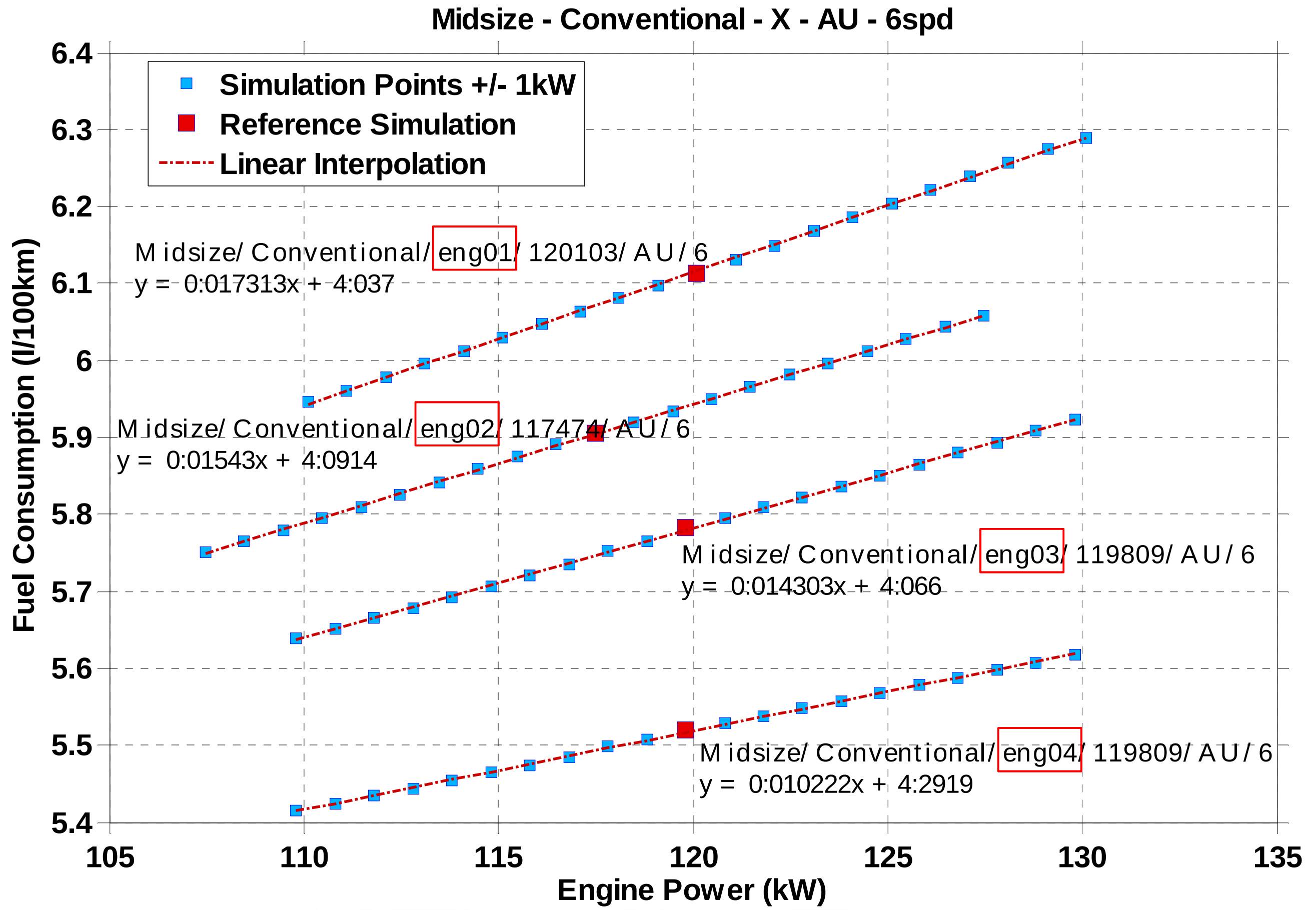
- Similar behavior (previous slide) is seen for different transmission speed selection.



Subset: Fixed Combo (All DOHC)

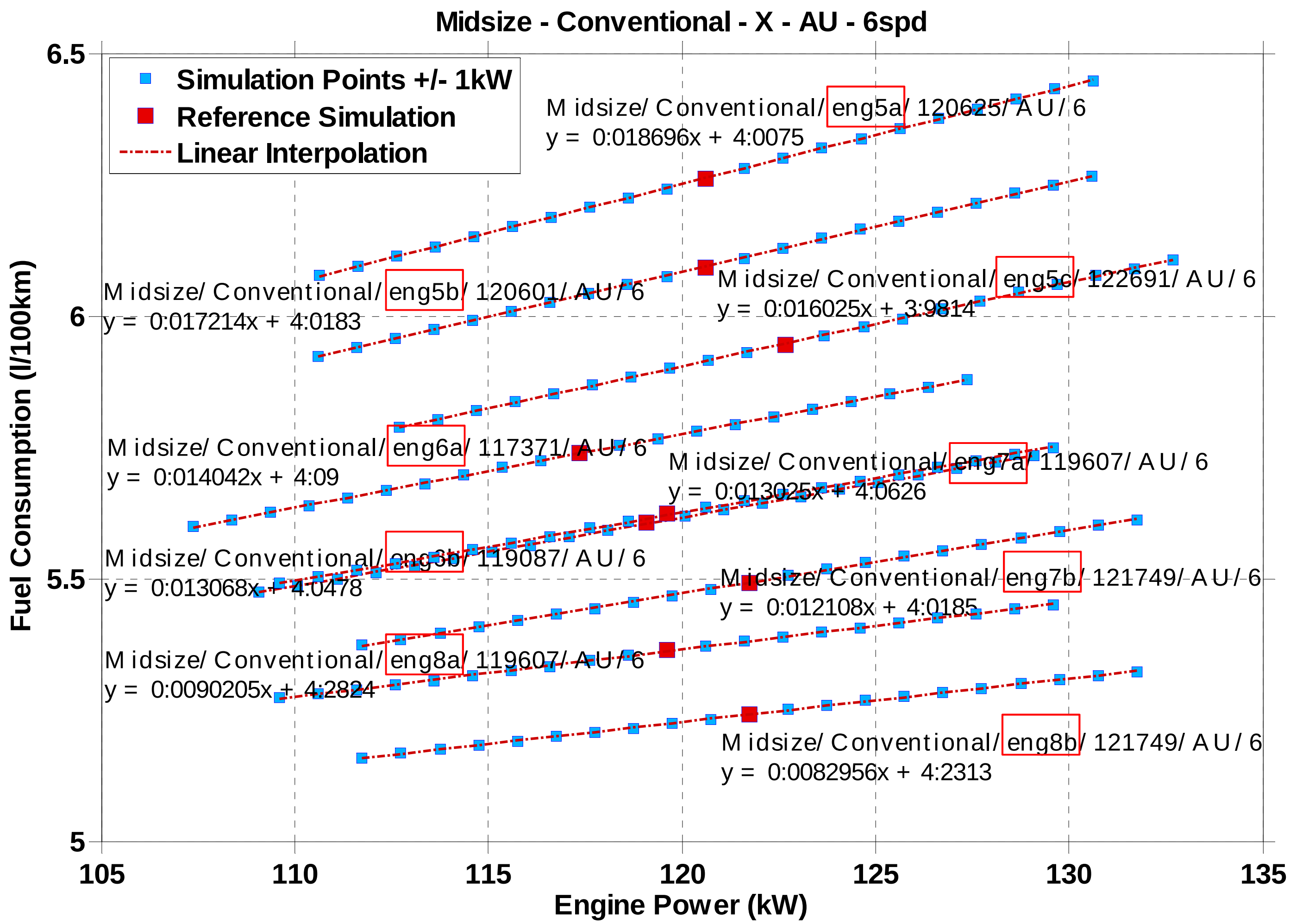
Conv-AU-6 speed

- Fuel consumption decreases with advanced engines.
- Power Requirement seem to stay constant with advanced engines.
- The slope decreases with advanced engines.



Subset: Fixed Combo (All SOHC)
Conv-AU-6 speed

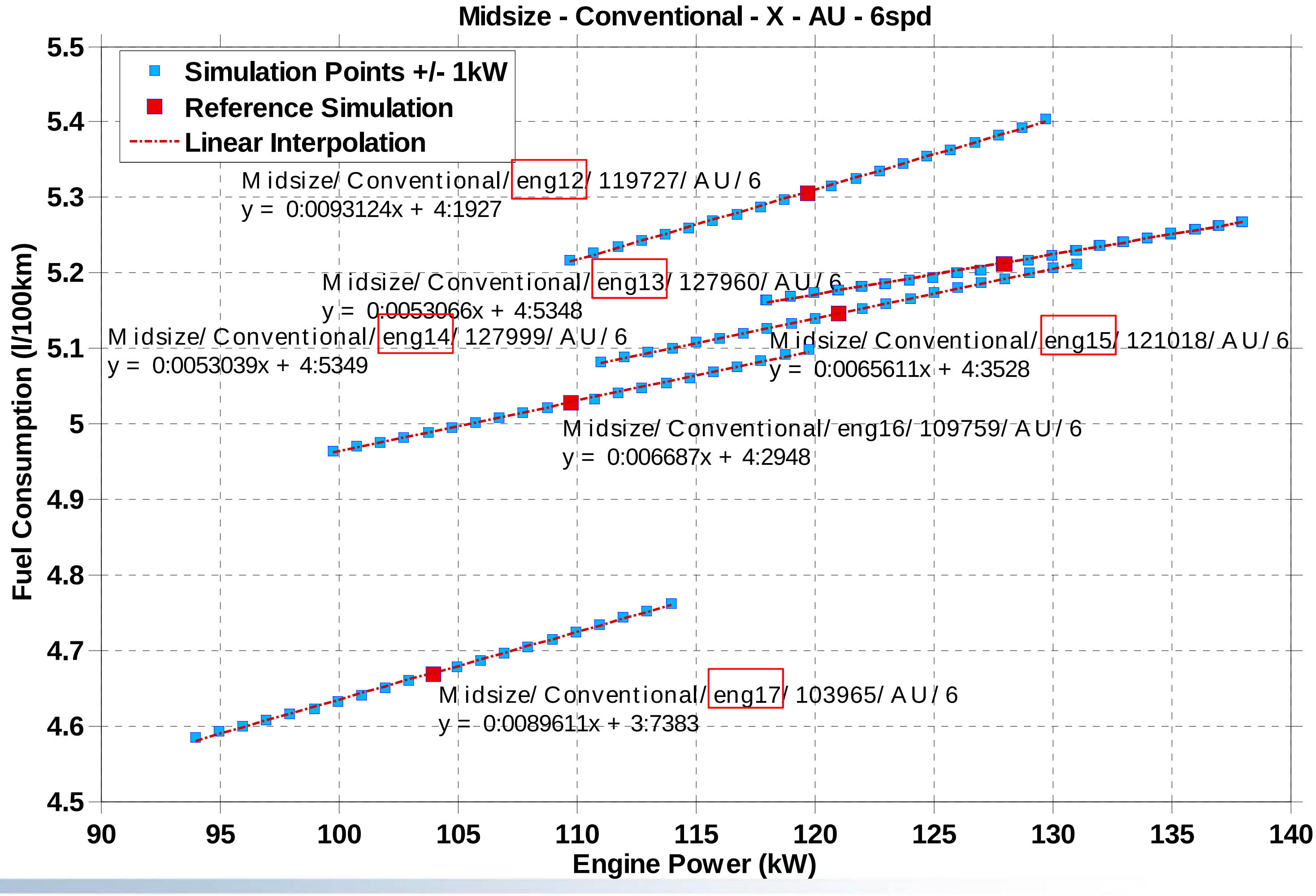
- Similar trend (previous slide)



Subset: Fixed Combo (All Turbo)

Conv-AU-6 speed

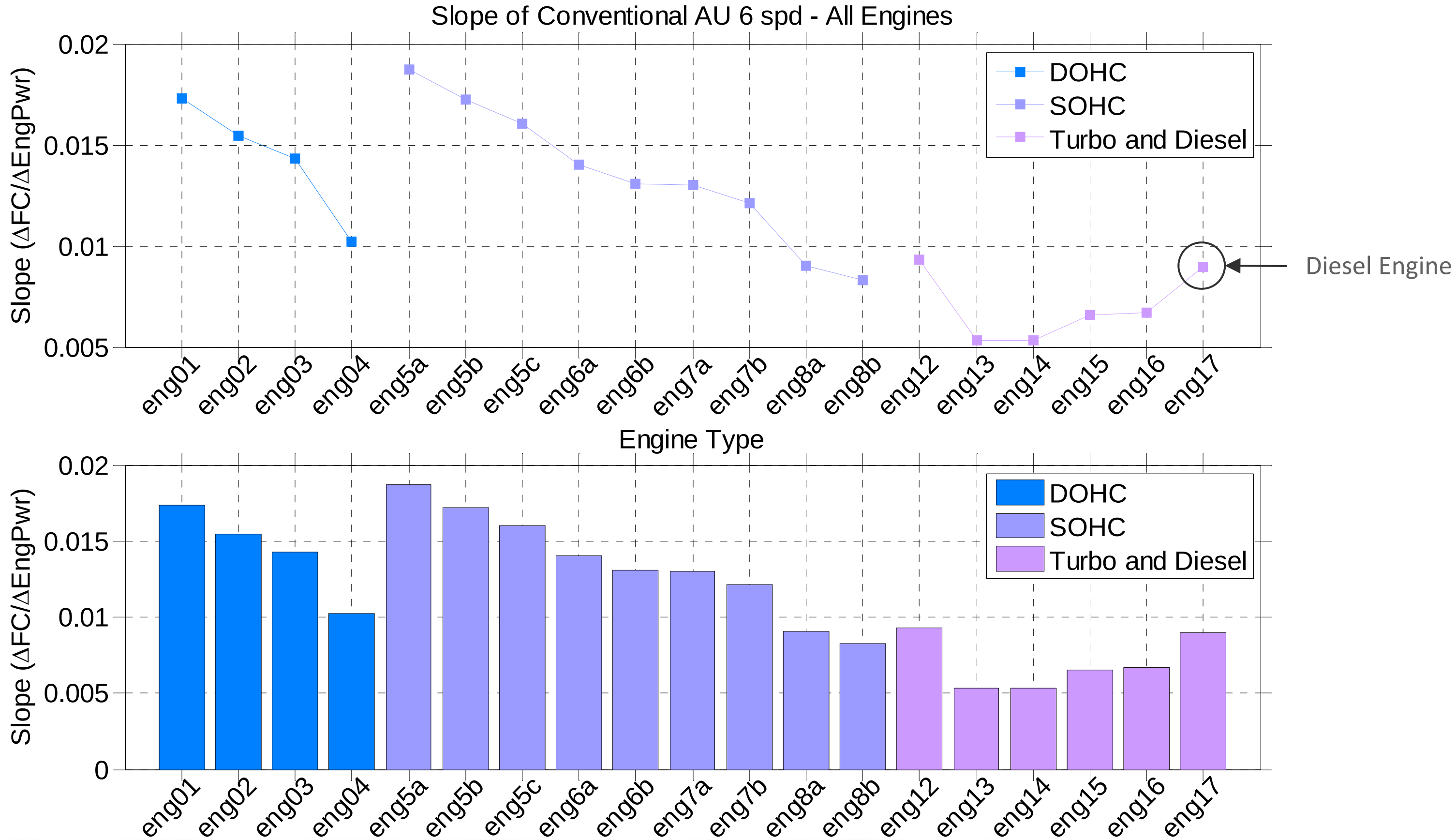
- For turbo the trend seem to be reversed as the slope increases with turbo engine evolution.



Slope Analysis - Fixed combo (All Engines)

Conv-AU-6 speed

- For DOHC and SOHC engines, advanced technologies are less sensitive to engine power variation. Sensitivity decreases within each engine group as the slope is strictly decreasing (slope going down as the engine technology gets better).
- Turbo engines slope values are overall lower than SOHC and DOHC engines. The engine is highly downsized and it is operating at high BMEP efficiency, hence a lower sensitivity level. However, the trend is not the same.

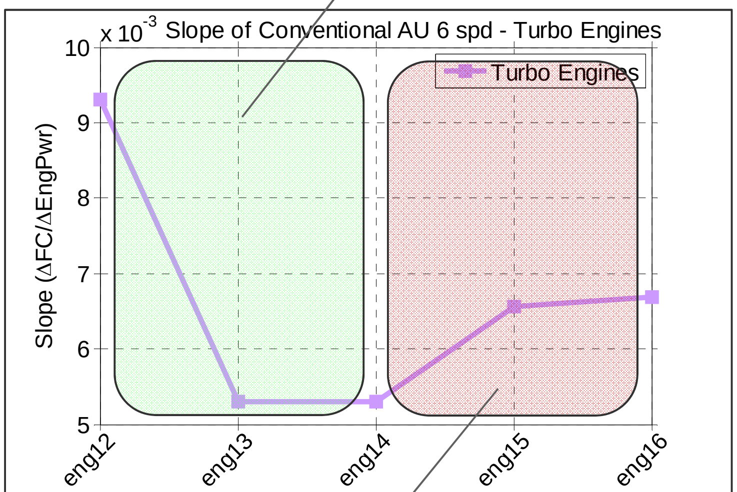


Slope Analysis – Fixed combo (Turbo Engines)

Conv-AU-6 speed

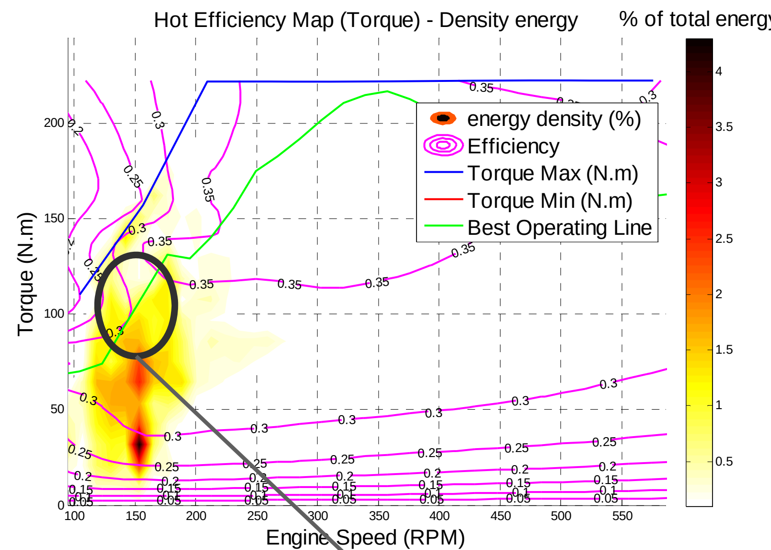
1 **2**

This area shows a normal trend from Eng12 to Eng13 (decrease) and from Eng13 to Eng14



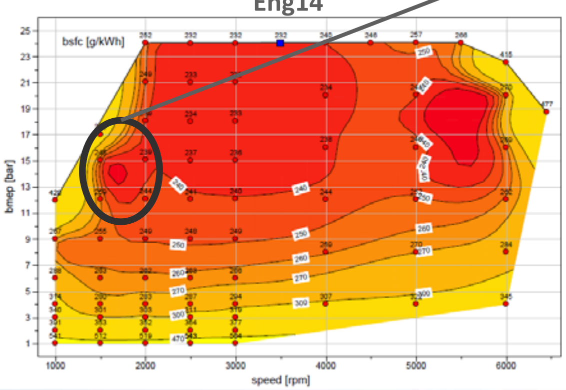
This area shows a suspicious trend from Eng14 to Eng16 (increase in slope) due to data uncertainty.

Note: Eng13 and Eng14 are equivalent, flat slope is plausible (refer to IAV description)

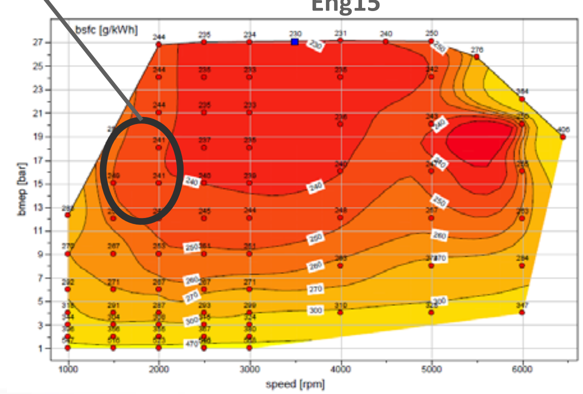


It has been established that better efficiency engines lowers the slope. Eng14 shows a high efficiency region (data uncertainty/anomaly) compared to Eng15 leading to swap in the trend.

Eng14

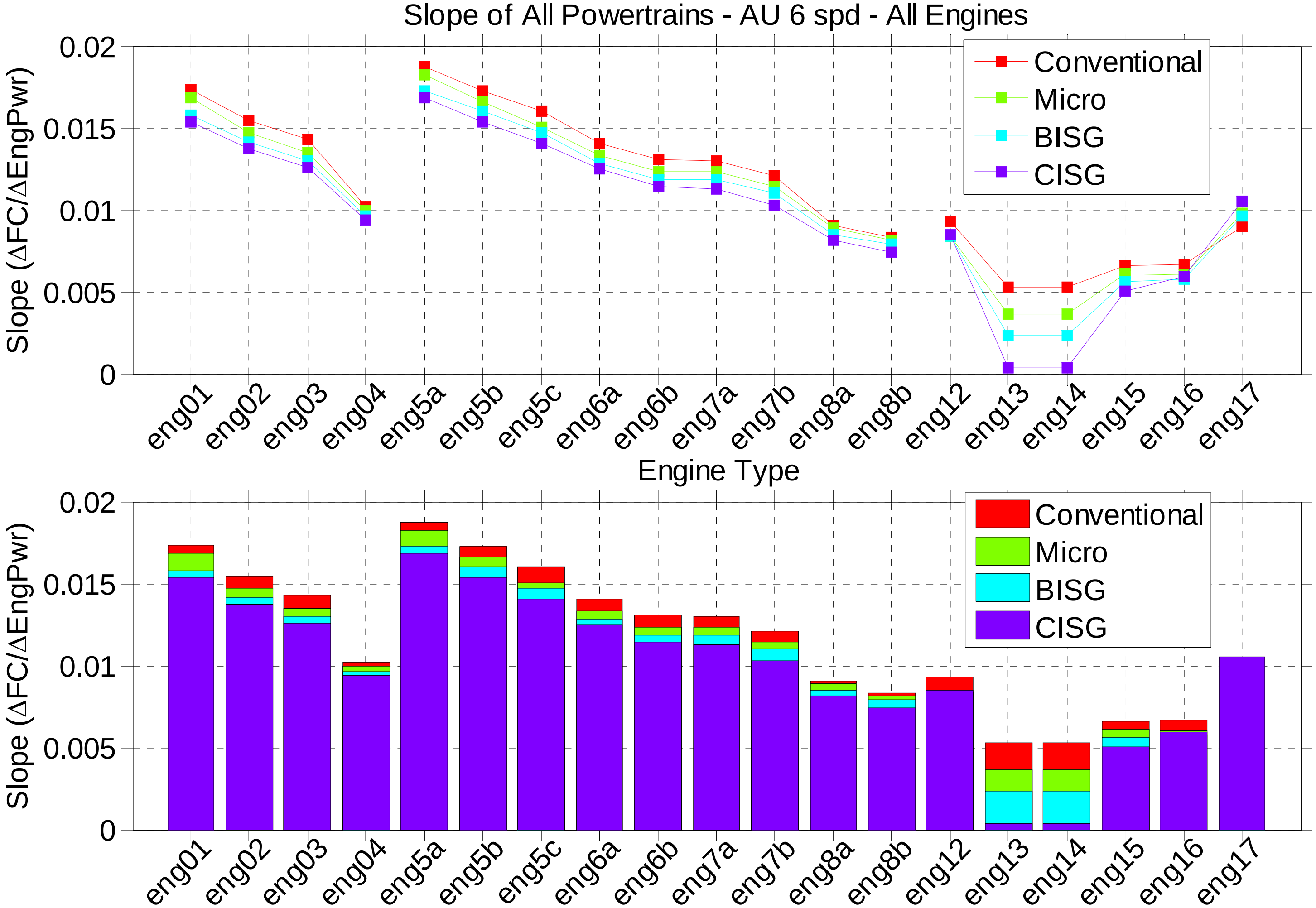


Eng15



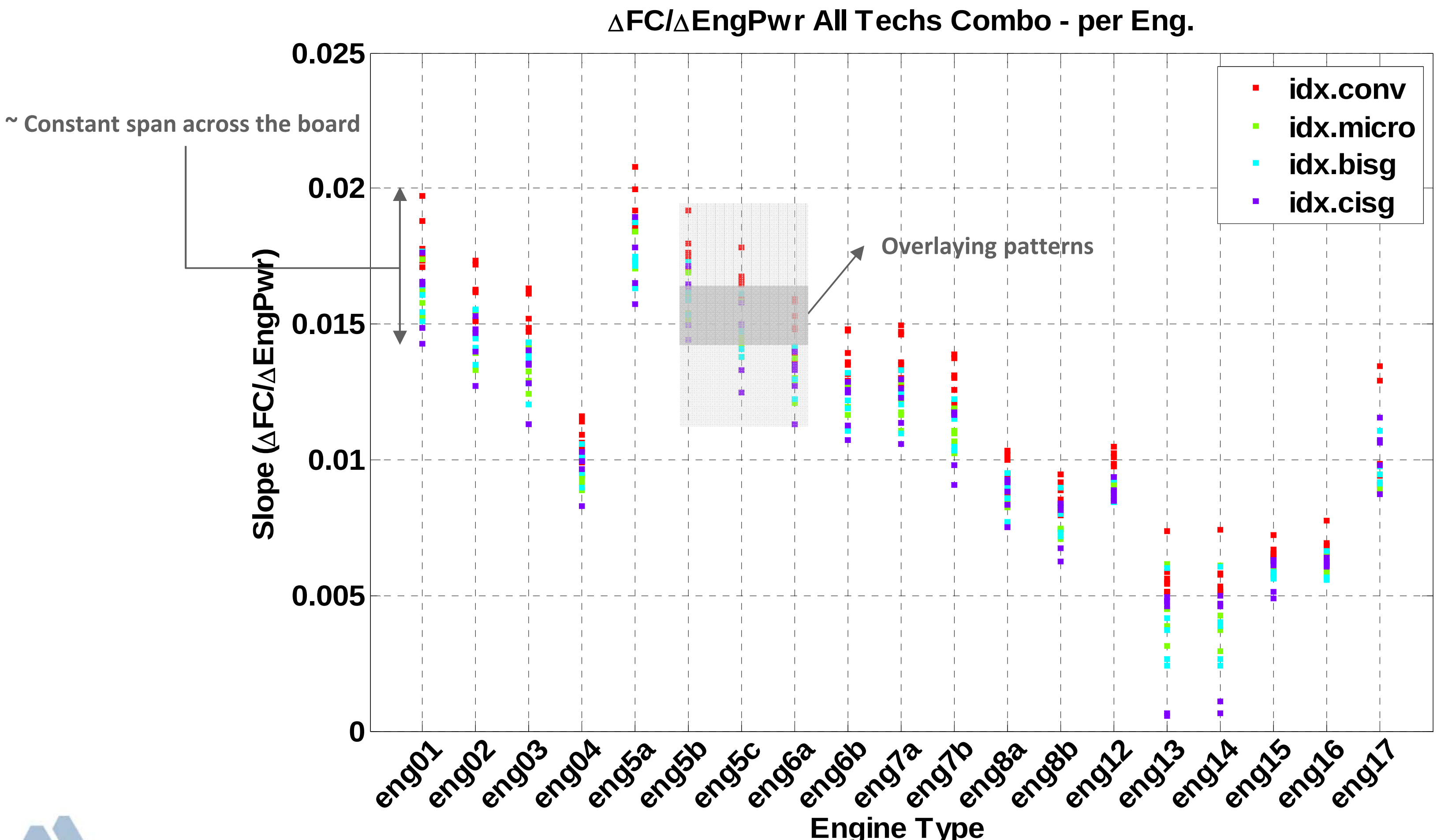
Slope Analysis – All Pwt. (fixed combo)

- The slope tend to *slightly* decrease with powertrain electrification, following the same logic: more efficient technologies, less fuel consumption sensitivity to power variation.



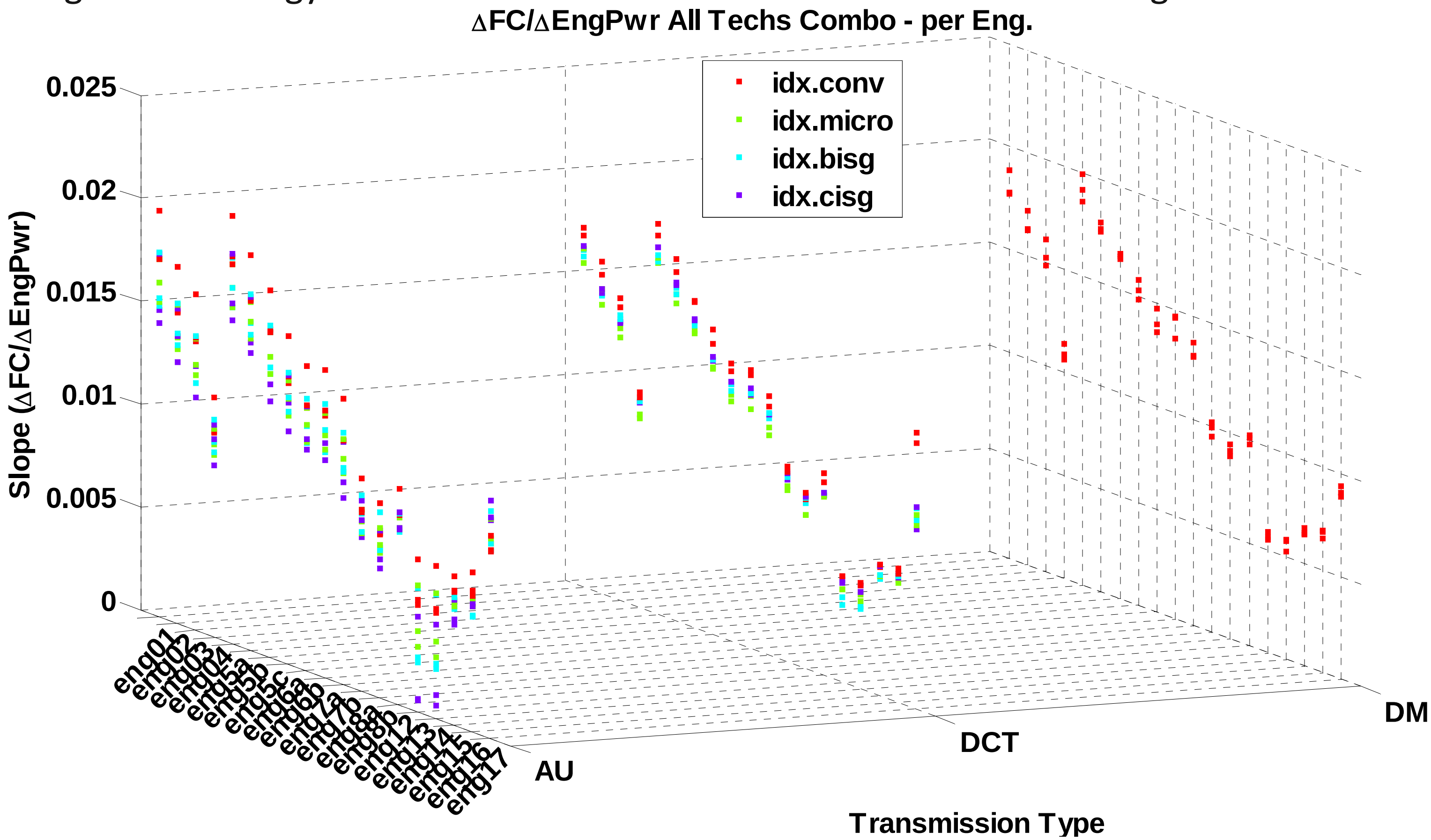
Slope Analysis – All Pwt. (All combo)

- The overall engine evolution trend is preserved regardless of the technology combination selected.
- The slope span for each engine is more or less maintained.
- The powertrain ordering is roughly consistent with previous findings.
- The overlaying behavior reappears: similar slopes for different combos, a sign for efficiency cross over.



Slope Analysis – All Pwt. (All combo)

- Transmission technology change does not perturb the trending behavior, nor slope values (little influence). The engine implication on the slope and therefore fuel efficiency is sustained.
- The engine technology has a dominant effect on the results and the findings.



Generation of Adjustment Factors are only relevant across powertrain and engine technology progress, especially engines.

Adjustment Factors – in %/10kW

- Complete table: *"ANL - Eng. Param. Study - Adjustment_Factors.xlsx"*
- Subset: the table represents the percentage of fuel consumption adjustments needed for 10kW.

Units: %/10kW ------ ΔFuel. Cons. /Δ Eng. Pwr.

			Conventional	Micro	BISG	CISG
Eng01	AU	5 spd	3.33%	3.21%	3.34%	3.58%
		6 spd	3.14%	3.36%	3.16%	3.44%
		8 spd	3.19%	2.86%	3.14%	3.19%
	DCT	5 spd	N/A.	N/A.	N/A.	N/A.
		6 spd	3.29%	2.30%	3.31%	3.23%
		8 spd	3.31%	2.77%	3.28%	3.62%
	DM	5 spd	3.35%	N/A.	N/A.	N/A.
		6 spd	3.28%	N/A.	N/A.	N/A.
		8 spd	3.27%	N/A.	N/A.	N/A.
Eng02	AU	5 spd	3.07%	2.77%	3.05%	3.25%
		6 spd	2.84%	2.97%	2.92%	3.29%
		8 spd	2.89%	2.64%	2.90%	2.91%
	DCT	5 spd	N/A.	N/A.	N/A.	N/A.
		6 spd	3.09%	2.93%	2.73%	3.31%
		8 spd	3.11%	2.80%	3.03%	3.34%
	DM	5 spd	3.10%	N/A.	N/A.	N/A.
		6 spd	3.15%	N/A.	N/A.	N/A.
		8 spd	3.11%	N/A.	N/A.	N/A.
Eng03	AU	5 spd	2.92%	2.68%	2.90%	3.08%
		6 spd	2.72%	2.74%	2.78%	3.14%
		8 spd	2.77%	2.43%	2.69%	2.74%
	DCT	5 spd	N/A.	N/A.	N/A.	N/A.
		6 spd	2.99%	2.49%	2.90%	3.11%
		8 spd	2.97%	2.61%	2.90%	3.13%
	DM	5 spd	2.97%	N/A.	N/A.	N/A.
		6 spd	3.00%	N/A.	N/A.	N/A.
		8 spd	3.04%	N/A.	N/A.	N/A.
Eng04	AU	5 spd	2.17%	1.96%	2.20%	2.37%
		6 spd	2.01%	2.09%	2.13%	2.48%
		8 spd	2.07%	1.79%	2.07%	2.10%
	DCT	5 spd	N/A.	N/A.	N/A.	N/A.
		6 spd	2.26%	1.87%	2.21%	2.35%
		8 spd	2.24%	1.94%	2.21%	2.39%
	DM	5 spd	2.23%	N/A.	N/A.	N/A.
		6 spd	2.28%	N/A.	N/A.	N/A.
		8 spd	2.34%	N/A.	N/A.	N/A.

Adjustment Factors – in l/100km/kW

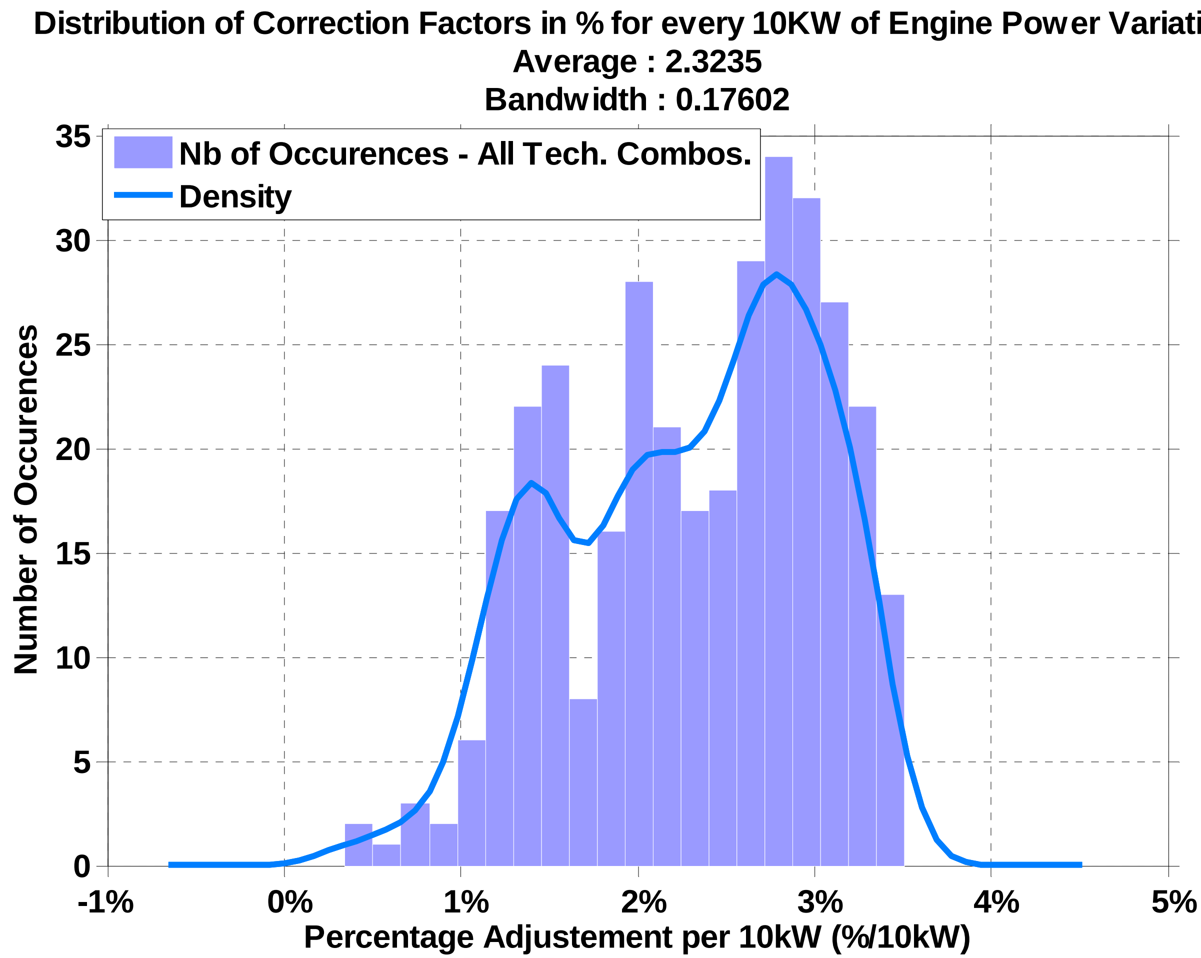
- Complete table: *"ANL - Eng. Param. Study - Adjustment_Factors.xlsx"*
- Subset: the table represents the amount of fuel consumption adjustments needed per unit of power in kW.

Units: l/100km/kW ------ ΔFuel. Cons. /Δ Eng. Pwr.

			Conventional	Micro	BISG	CISG
Eng01	AU	5 spd	0.0196	0.0178	0.0175	0.0175
		6 spd	0.0172	0.0170	0.0158	0.0156
		8 spd	0.0171	0.0155	0.0153	0.0147
	DCT	5 spd	N/A.	N/A.	N/A.	N/A.
		6 spd	0.0177	0.0191	0.0162	0.0174
		8 spd	0.0172	0.0156	0.0167	0.0164
	DM	5 spd	0.0191	N/A.	N/A.	N/A.
		6 spd	0.0178	N/A.	N/A.	N/A.
		8 spd	0.0180	N/A.	N/A.	N/A.
Eng02	AU	5 spd	0.0172	0.0152	0.0155	0.0154
		6 spd	0.0153	0.0147	0.0141	0.0139
		8 spd	0.0151	0.0137	0.0138	0.0131
	DCT	5 spd	N/A.	N/A.	N/A.	N/A.
		6 spd	0.0159	0.0145	0.0145	0.0146
		8 spd	0.0156	0.0139	0.0152	0.0146
	DM	5 spd	0.0172	N/A.	N/A.	N/A.
		6 spd	0.0165	N/A.	N/A.	N/A.
		8 spd	0.0164	N/A.	N/A.	N/A.
Eng03	AU	5 spd	0.0161	0.0141	0.0146	0.0143
		6 spd	0.0142	0.0134	0.0130	0.0128
		8 spd	0.0141	0.0125	0.0126	0.0117
	DCT	5 spd	N/A.	N/A.	N/A.	N/A.
		6 spd	0.0149	0.0134	0.0138	0.0136
		8 spd	0.0145	0.0130	0.0141	0.0137
	DM	5 spd	0.0164	N/A.	N/A.	N/A.
		6 spd	0.0155	N/A.	N/A.	N/A.
		8 spd	0.0153	N/A.	N/A.	N/A.
Eng04	AU	5 spd	0.0116	0.0100	0.0108	0.0106
		6 spd	0.0102	0.0099	0.0096	0.0097
		8 spd	0.0101	0.0091	0.0094	0.0087
	DCT	5 spd	N/A.	N/A.	N/A.	N/A.
		6 spd	0.0107	0.0097	0.0101	0.0099
		8 spd	0.0104	0.0094	0.0104	0.0102
	DM	5 spd	0.0116	N/A.	N/A.	N/A.
		6 spd	0.0111	N/A.	N/A.	N/A.
		8 spd	0.0111	N/A.	N/A.	N/A.

Distribution of Adjustment Factors

- Most of the percentage values stand around 3%, still a reasonable number of vehicles show percentage at around 2% and 1.5%.
- Those 3 groups of percentages mimic the 3 engine categories (DOHC, SOHC and Turbo) we demonstrated in the previous slides.



Conclusion

- A parametric study was done on multiple vehicle tech. combinations by varying a reference engine power over a range of +/- 10kW with a step of 1kW.
- The impact of engine power on fuel consumption results was assessed to mimic engine inheritance effects.
- Each vehicle combination selected required extra 20 simulation, resulting to a total of 14,000 points.
- Change in engine power leads to linear impact on fuel consumption with relation depending on engine technology and powertrain configurations (minimal).
- It has been demonstrated that vehicle fuel consumption sensitivity to power change is mainly influenced by the powertrain and the engine technology. Transmission technology and speed selection have little to no impact.
- It has been proven that the ΔFuel Consumption/ΔEngine Power (the slope of the parametric study points) minimally decreases with advances in powertrain or engine technology (better efficiency levels). The slope is the sensitivity level representing how much engine power variations affect fuel consumption results.
- Adjustment factors have been generated to allow vehicle fuel consumption adjustments with possible future change in engine power requirement/performance requirement.