INTERNATIONAL
ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION

Benefits of Electrified Powertrains for Medium & Heavy Duty Vehicles

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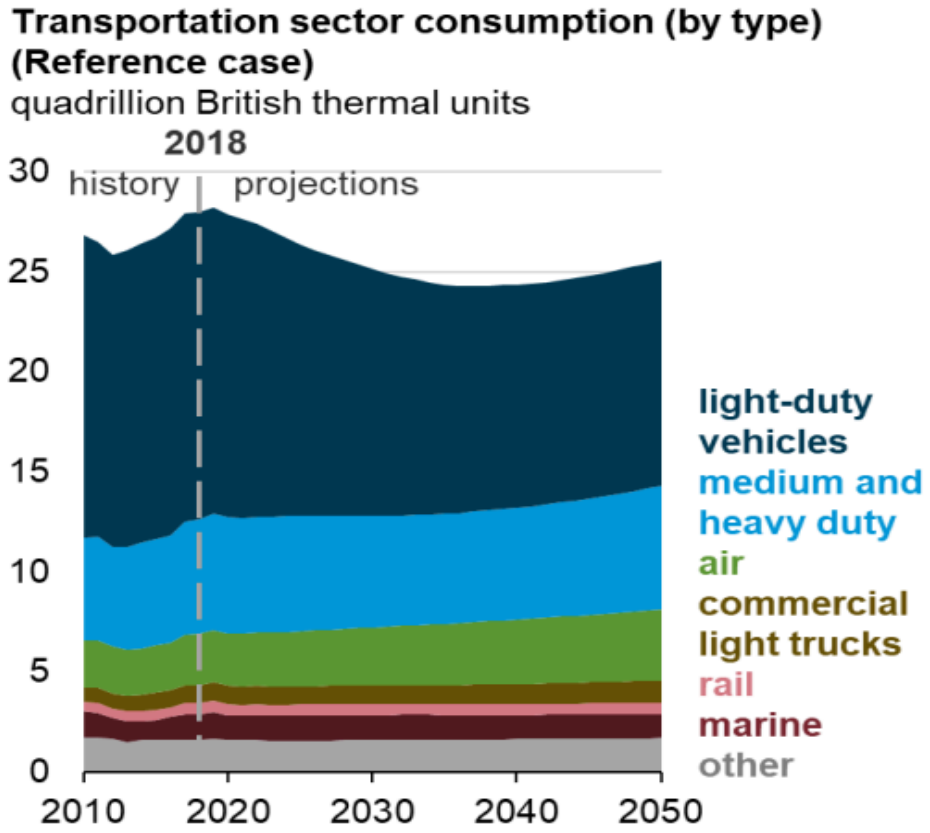
Medium and Heavy Duty Vehicles Account for 26% of US Petroleum Consumption



US EIA, Annual Energy Outlook

- **Impact of advanced powertrains on Medium and Heavy Duty (MDHD) vehicles is not as well understood as in case of Light Duty (LD) vehicles.**
- **This study quantifies the fuel saving potential of electrified powertrains for medium and heavy duty vehicles**
- **Powertrains**
  - **Conventional**
  - **Start stop**
  - **Pretrans HEV**
  - **Series PHEV**
  - **Battery Electric**

Multiple Vehicle Classes & Vocations Are Needed To Represent Medium and Heavy Duty Applications

Vehicle Class	Purpose
Class 2b: 6000–10,000 lb.	Small Van
Class 3: 10,001–14,000 lb.	Enclosed Van
Class 3: 10,001–14,000 lb.	Service, Utility Truck
Class 4: 14,001–16,000 lb.	Walk-In, Multi-Stop, Step Van
Class 5: 16,001–19,500 lb.	Utility, Tow Truck
Class 6: 19,501–26,000 lb.	Construction, Dump Truck
Class 7: 26,001–33,000 lb.	School Bus
Class 7: 26,001–33,000 lb.	Day Cab
Class 8: > 33,000 lb	Sleeper
Class 8: > 33,000 lb	Sleeper Aero
Class 8: > 33,000 lb	Day Cab

- Sleeper cabs were found to be diverse enough to include two representative vehicles.
  - 15L engine, 6x4 axle representing average trucks
  - 12L engine, 6x2 axle, and more aftermarket aero improvements to represent more fuel efficient trucks.
- Class 7&8 day cabs represents other types of heavy trucks that are used for shorter hauls.

Performance and Range Requirements

Performance of market leading conventional vehicles are simulated. Range is based on data from VIUS & Fleet-DNA

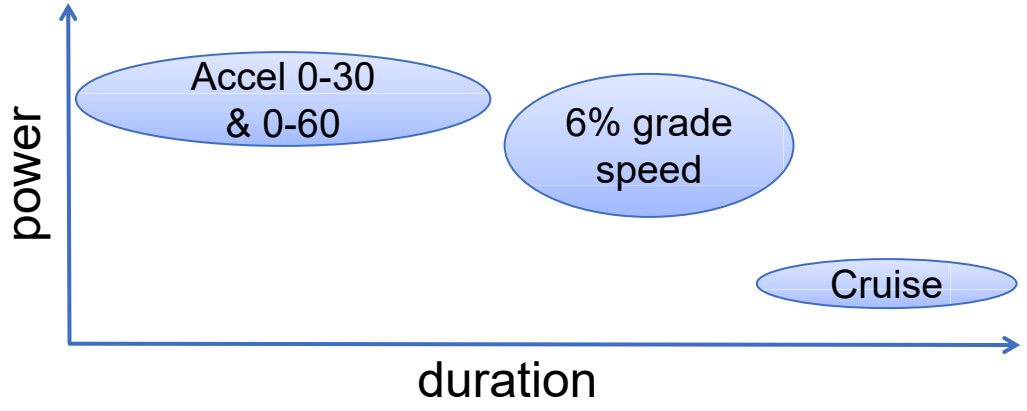
Class	Purpose	0-30 mph (s)	0- 60 mph (s)	Grade Speed 6% (mph)	Cruise Speed (mph)	90 % Daily Driving Range (Miles)
2	Van	7	21.5	65	70	200
3	Service	5.8	18	65	70	150
3	Van	6.4	24	49	70	200
4	WalkIn	7.5	35	40	70	150
5	Utility	9	24	65	65	150
6	Construction	11.6	46.5	27	65	150
7	DayCab	18	66	31	65	250
7	School	18.5	60	30	60	150
8	DayCab	18	66	31	65	250
8	Sleeper	18	60	32	65	500

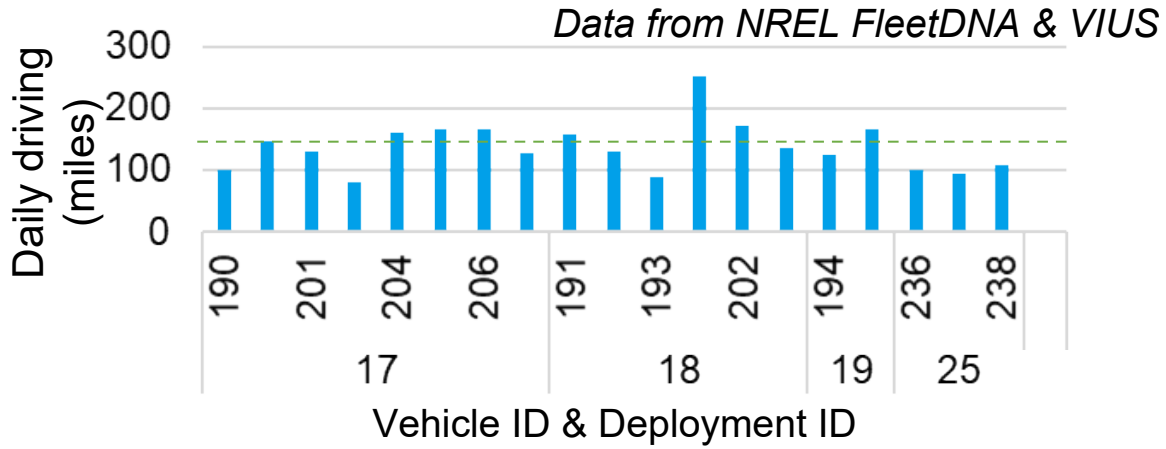
- Cargo load is set based on EPA's regulatory testing procedures
- Vehicle weight is estimated by Autonomie based on component sizes
- All powertrain variants are sized to meet the same vehicle requirements

Performance Based Powertrain Sizing Ensures Fair Comparison

Sizing Assumptions

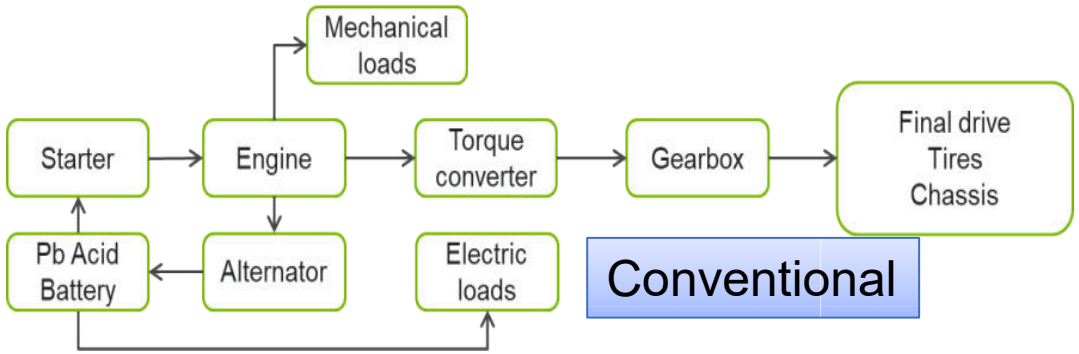
- **No trade off on payload or performance**
  - Fixed payload across all powertrains
  - Match or better the conventional vehicle in performance
- BEVs range will depend on the application. (150 miles assumed in this study)
- PHEVs will have 50 % all electric range as the BEV.



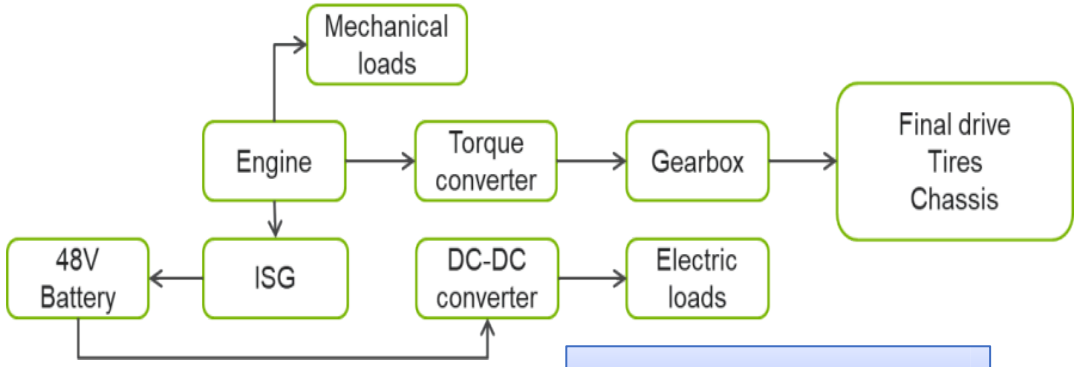


As performance parameters are not widely published for heavy vehicles, the baseline values are estimated through simulations.

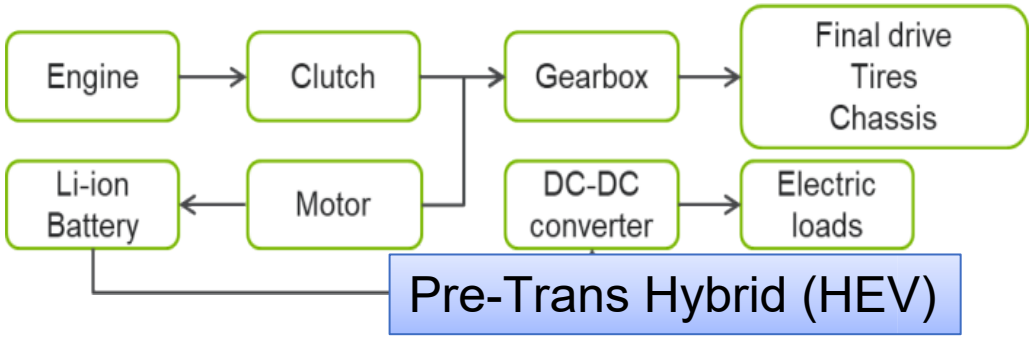
Architectures Considered



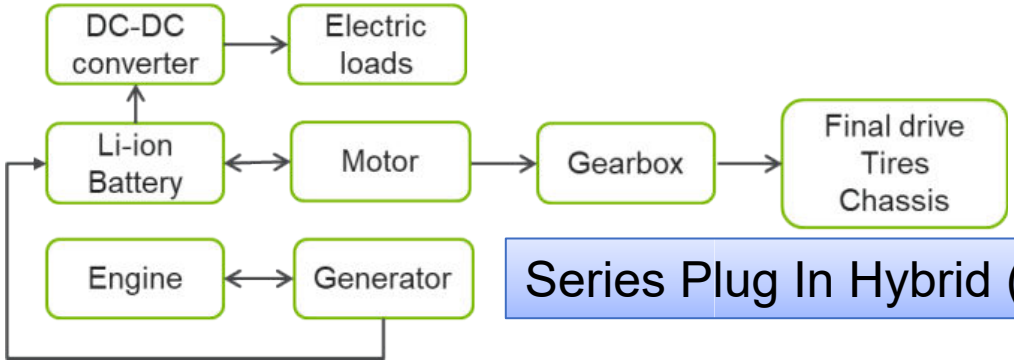
Conventional



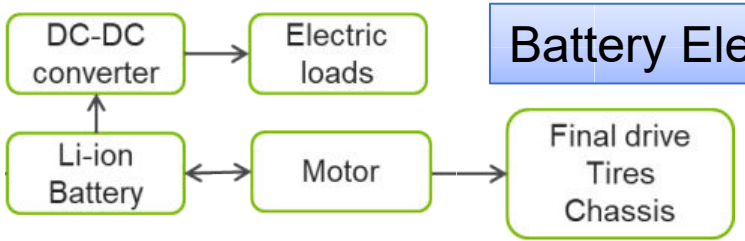
Mild Hybrid (ISG)



Pre-Trans Hybrid (HEV)



Series Plug In Hybrid (PHEV)



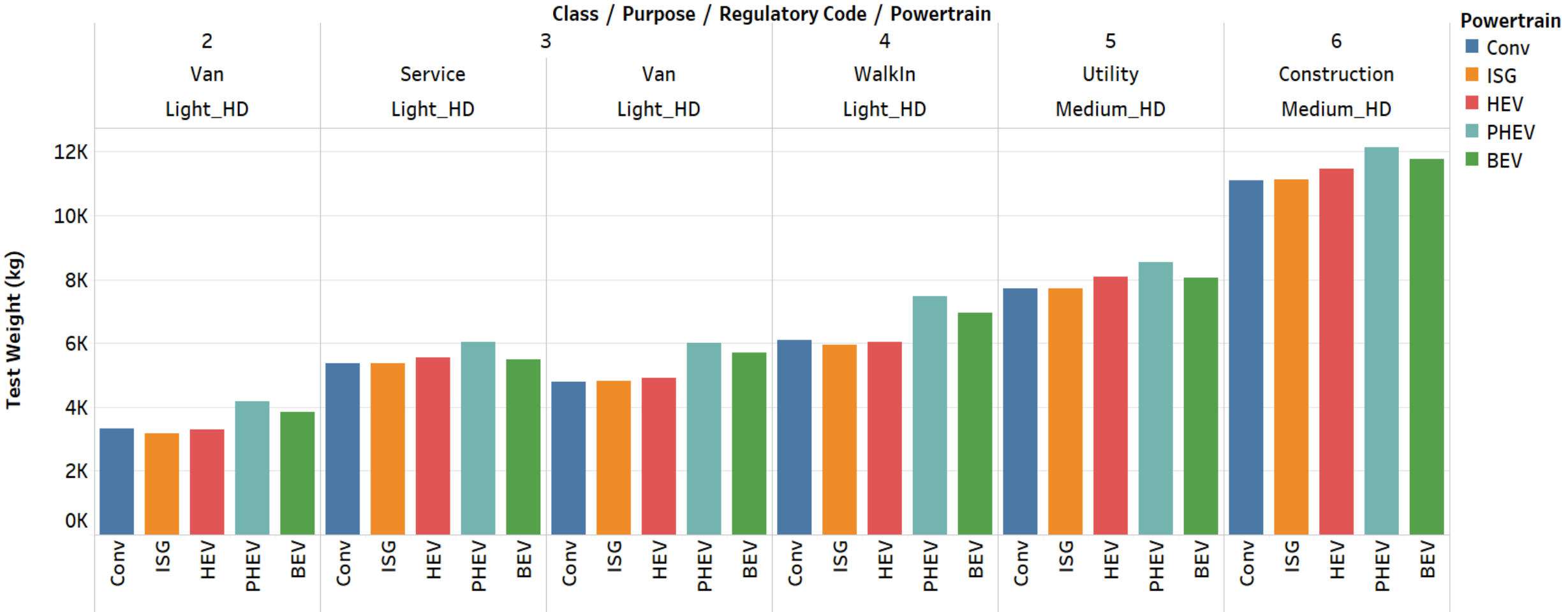
Battery Electric (BEV)

Performance Based Sizing Logic

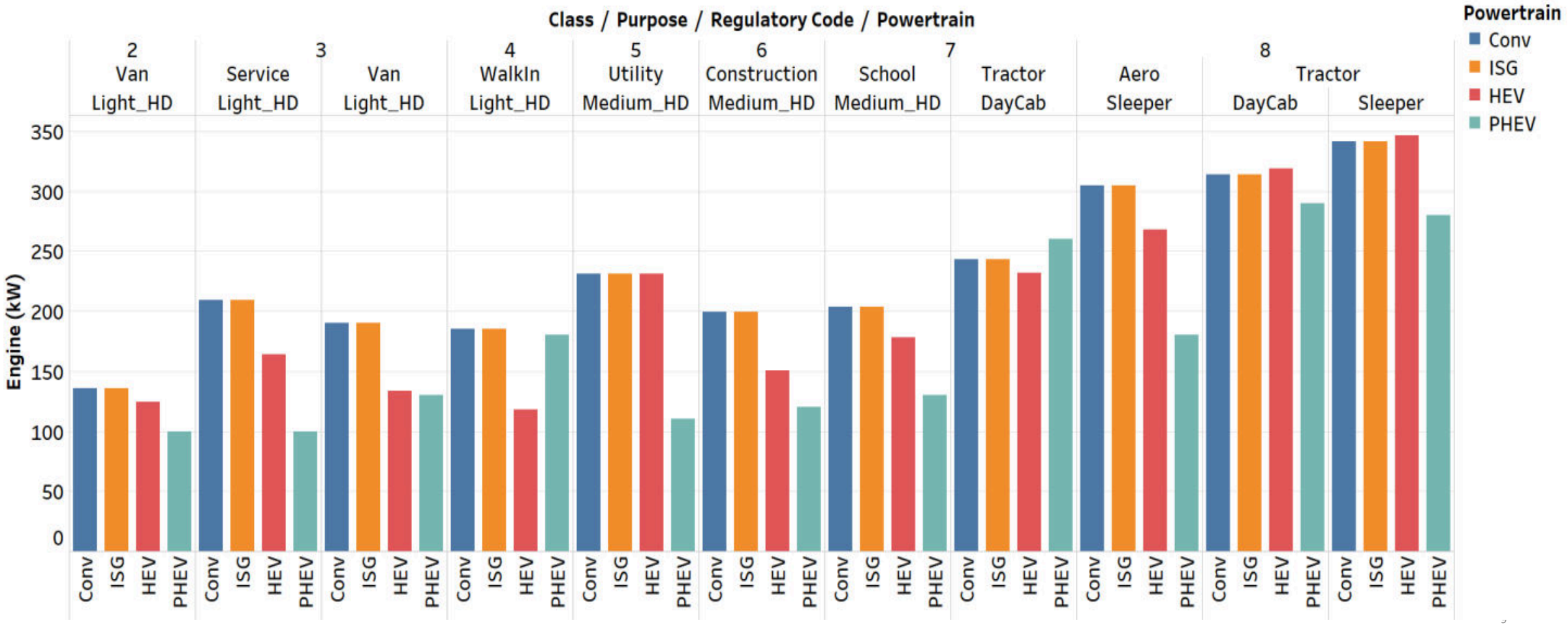
- Component power requirements vary with powertrain architecture
- Goal of sizing
  - To find minimum component sizes needed to meet performance targets
  - To reduce fuel consumption (not optimization).
  - Fully utilize the components available in architecture

Powertrain	Engine	Motor	Battery
Conventional	Acceleration Grade & Cruise		
ISG		Size based on Starter & Alternator	Energy: Sustain electric loads for at least 1 minute*
HEV		Maximize regen in ARB Transient	Power: to sustain peak motor output
PHEV	Grade & Cruise	Acceleration Grade & Cruise	Energy: Electric Range Driving Range in EPA 65. Power: Sufficient power to support motor & aux loads
BEV			

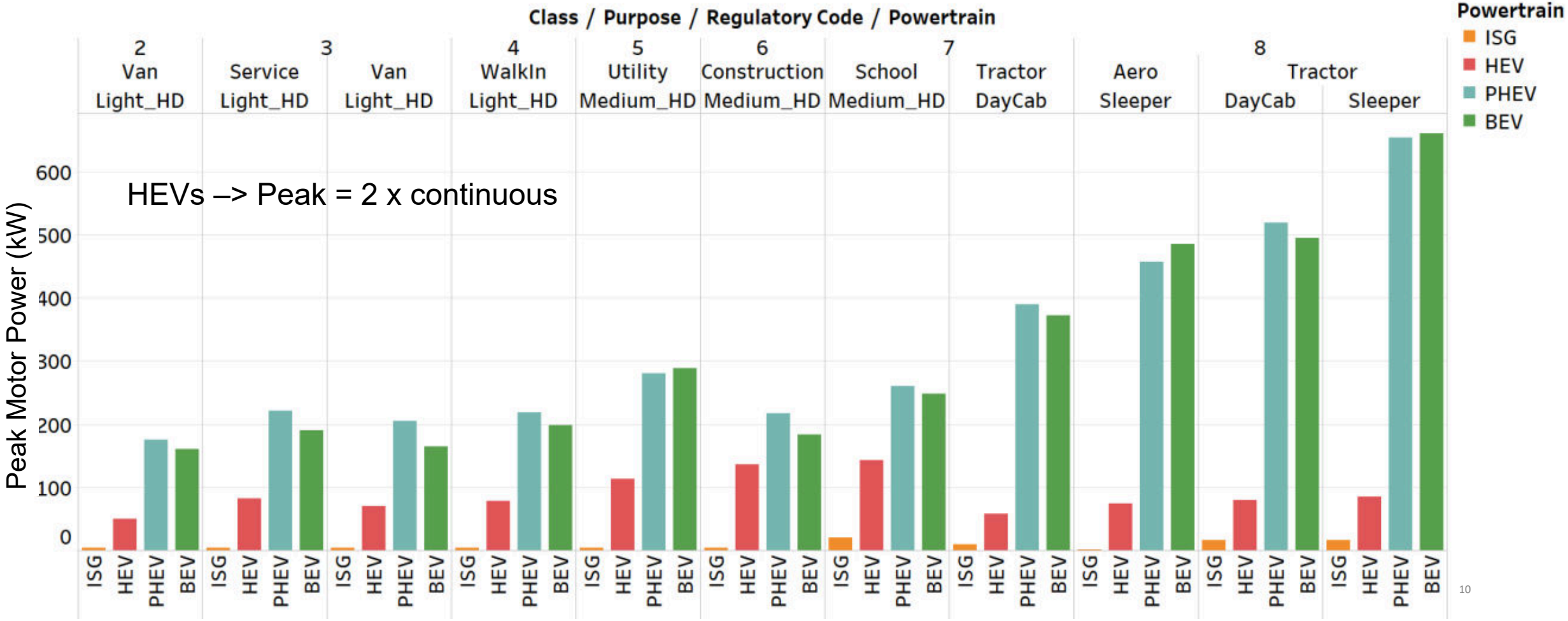
Test Weight Increase for Hybrid Powertrains is Minimal, Unlike for PHEVs and BEVs



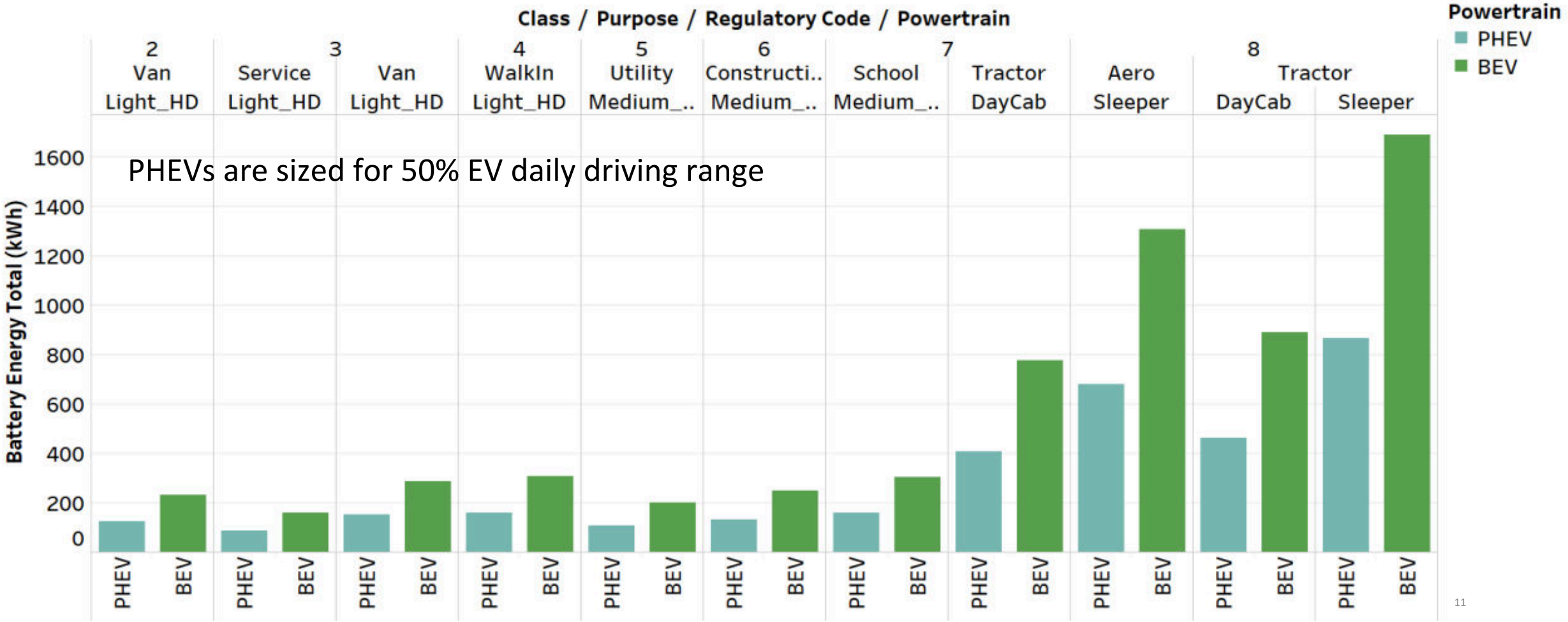
Smaller Vehicles Enable Engine Power Reduction with Hybridization.



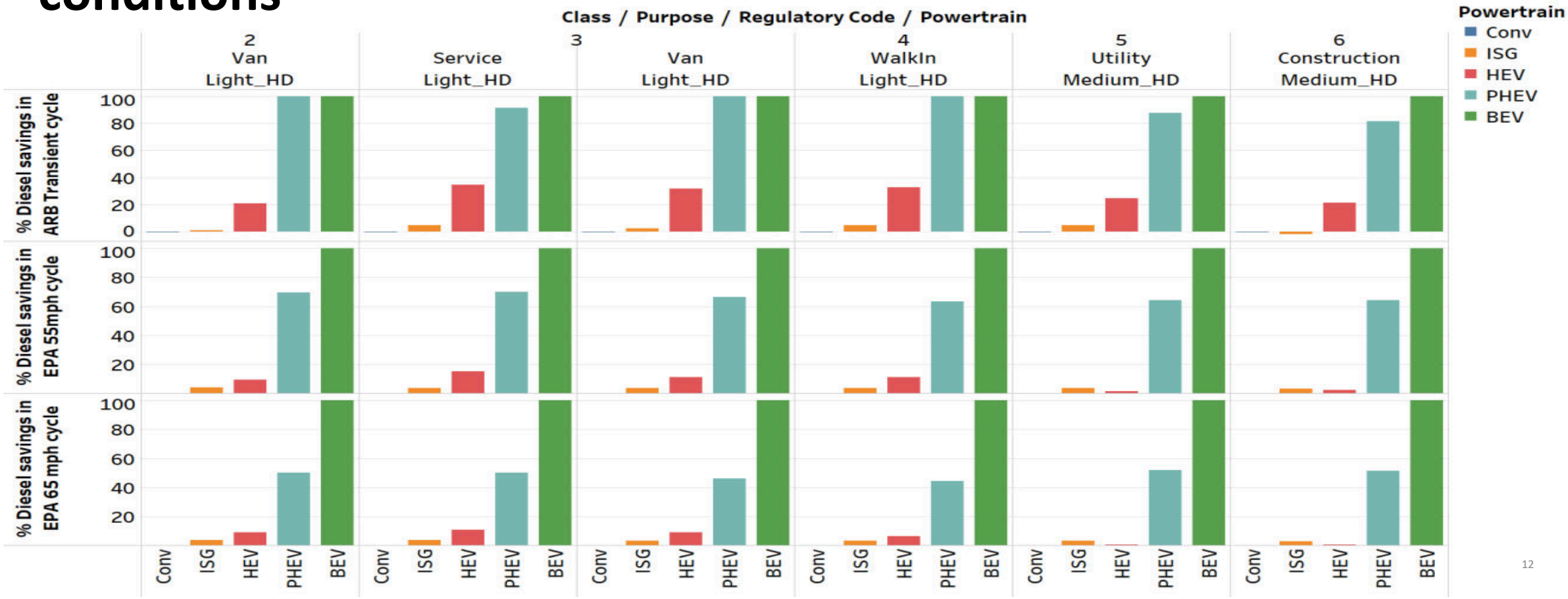
Electric Machine Requirements Vary Greatly Across Class and Powertrains



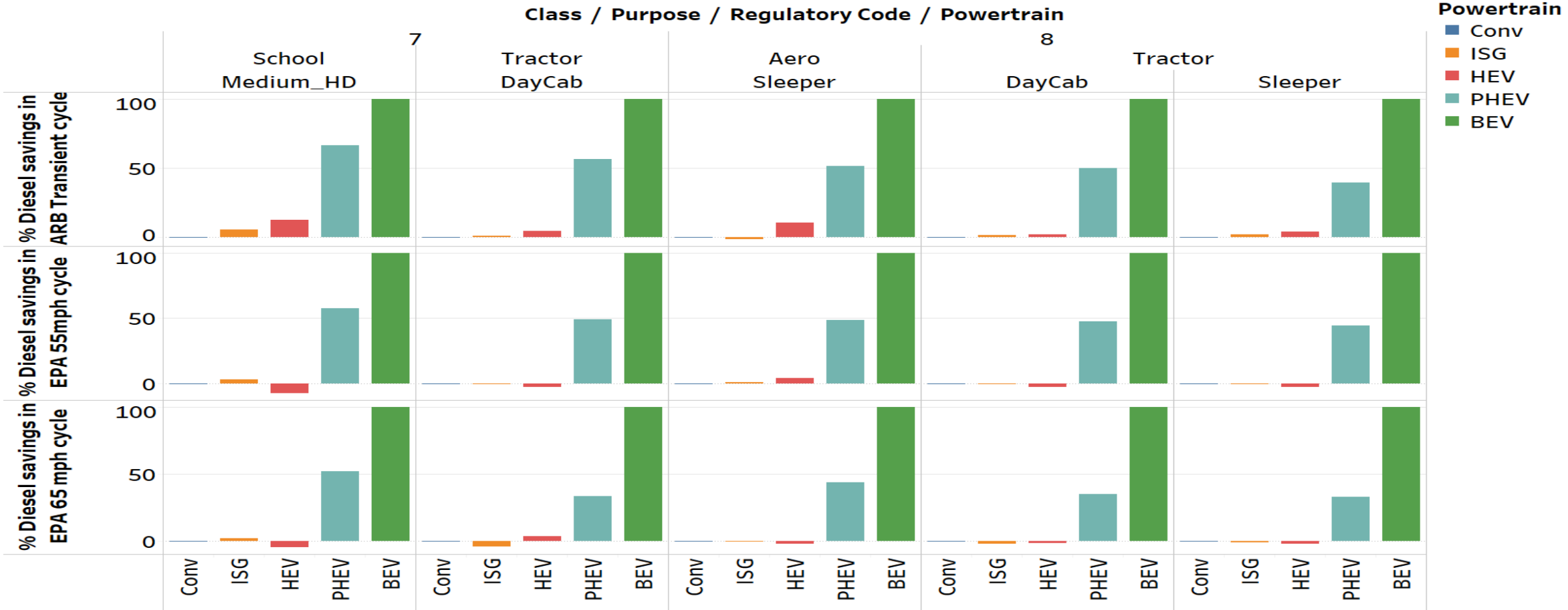
Usable Battery Energy Requirements for PHEVs and BEVs



For Class 2-6, on ARB Transient, HEV could save 20-30% and PHEVs 80-100% fuel while displacing significant amounts on highway driving conditions



Heavy duty, due to practical limitations in regenerative braking, benefits less from HEVs. PHEVs & BEVs are the primary choices for achieving petroleum displacement in this segment.



Summary and Next Steps

- Under the current assumptions, this study demonstrated that
  - HEVs are an attractive choice for medium duty trucks operating in urban conditions.
  - For heavier vehicles or those operating mostly on highways, significant fuel savings are achieved through PHEV or BEV variants.
- Next steps:
  - Many powertrains are sized for specific rather than average conditions. Since, for example, Class 4 walk-in trucks are typically not designed for highway driving, the energy savings for different vehicle specifications should be considered.
  - Examine sizing and benefits under real world cycles as an alternative to regulatory cycles
  - Consider additional vehicle classes/variations

Additional Classes/Variations Already Available for Future Work

Class	Vocation	Conv			ISG			HEV			PHEV			BEV	FCHEV
		Diesel	CNG	Gas	Diesel	CNG	Gas	Diesel	CNG	Gas	Diesel	CNG	Gas		
2b	Small Van														
3	Enclosed Van														
3	School Bus														
3	Service, Utility Truck														
4	Walk In, Step Van														
4	Light HD	+			+			+			+			+	+
5	Utility, Tow Truck														
6	Construction, Dump Truck														
6	Medium HD	+			+			+			+			+	+
7	School Bus														
7	DayCab (3)	+			+			+			+			+	+
7	Medium HD	+			+			+			+			+	+
8	Construction, Dump Truck														
8	Sleeper NACFE	*													*
8	Refuse, Cab over type														
8	Tractor Trailer														
8	40’ Transit Bus														
8	Heavy HD	+			+			+			+			+	+
8	DayCab (3)	+			+			+			+			+	+
8	Sleeper (3)	+			+			+			+			+	+

+ denotes the cases currently considered