Comparison of VECTO and GEM

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Deep Dive to Support Heavy-Duty Vehicle Efficiency Labeling and Standards Meeting #2

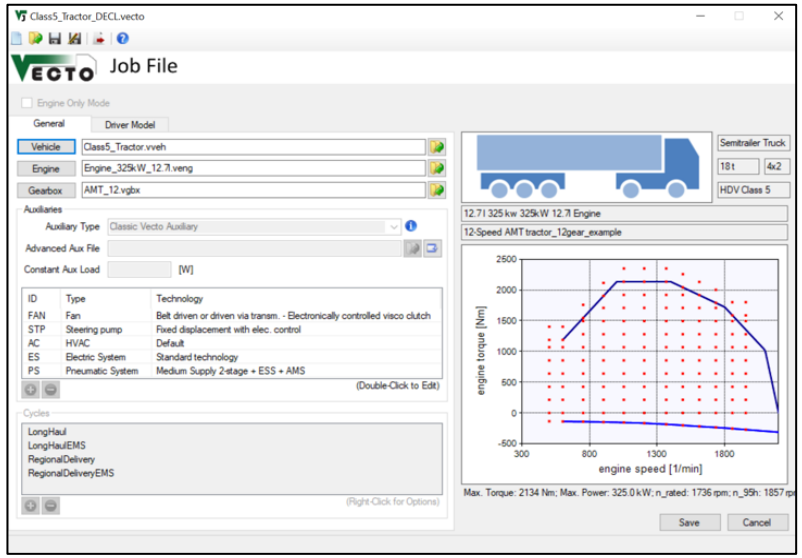
icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

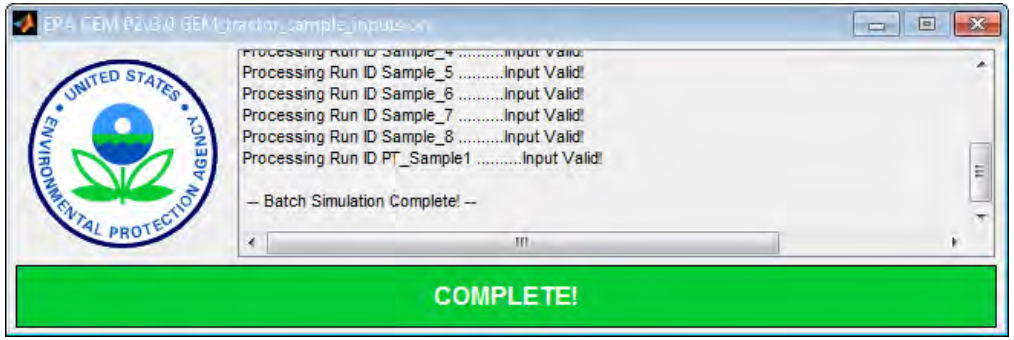
”Heavy-duty vehicle fuel-efficiency simulation: A comparison of US and EU tools” (2015)

- ICCT conducted a comparison of GEM 2.0 (Phase 1) and VECTO (2.0.3) in 2015
- Since then both tools have been updated to GEM 3.0 (Phase 2) and VECTO (3.2.1), resulting in changes to the required model inputs and the resulting fuel consumption simulation.
- Nevertheless, ICCT’s 2015 report is a good reference document for understanding:
  - Forward vs. backward models
  - VECTO’s shifting strategy
  - VECTO’s look ahead coasting
  - VECTO’s file structure

Franco, V., Delgado, O., & Muncrief, R. (2015). *Heavy-duty vehicle fuel-efficiency simulation: A comparison of US and EU tools*. ICCT. http://www.theicct.org/heavy-duty-vehicle-fuel-efficiency-simulation-comparison-us-and-eu-tools

”The Present of EU’s Vehicle Energy Consumption Calculation Tool (VECTO), and Recommendations for the Future” (2018)





- A new comparison study of the latest releases of GEM and VECTO
- Although focused on VECTO, it describes the model architectures of both GEM and VECTO
- The results of this new study are the focus of this presentation
- Publication expected in February 2018

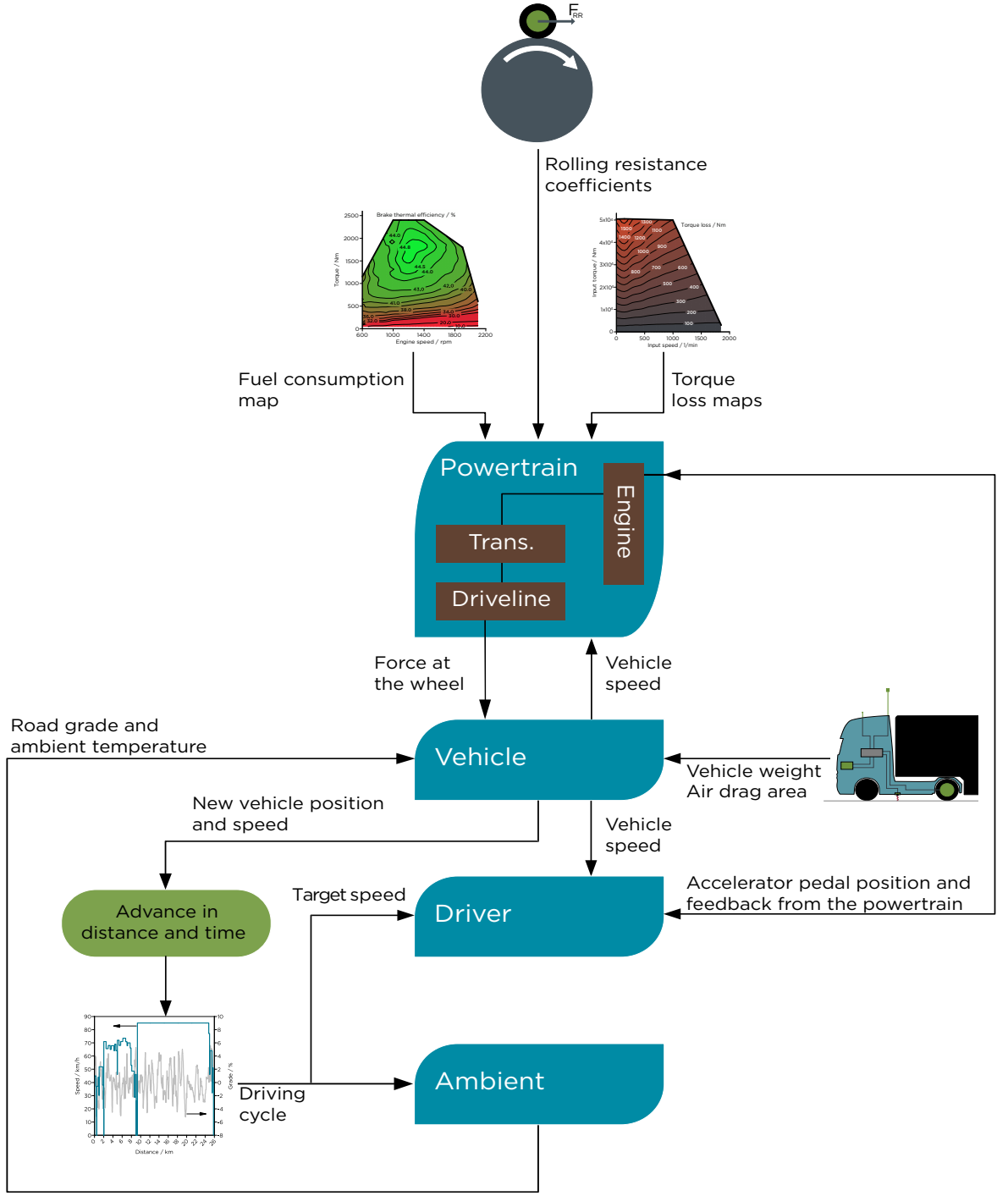
Rodríguez, F. (2018). *The Present of EU’s Vehicle Energy Consumption Calculation Tool (VECTO), and Recommendations for the Future* (Publication pending). International Council on Clean Transportation.

Input comparison between GEM and VECTO

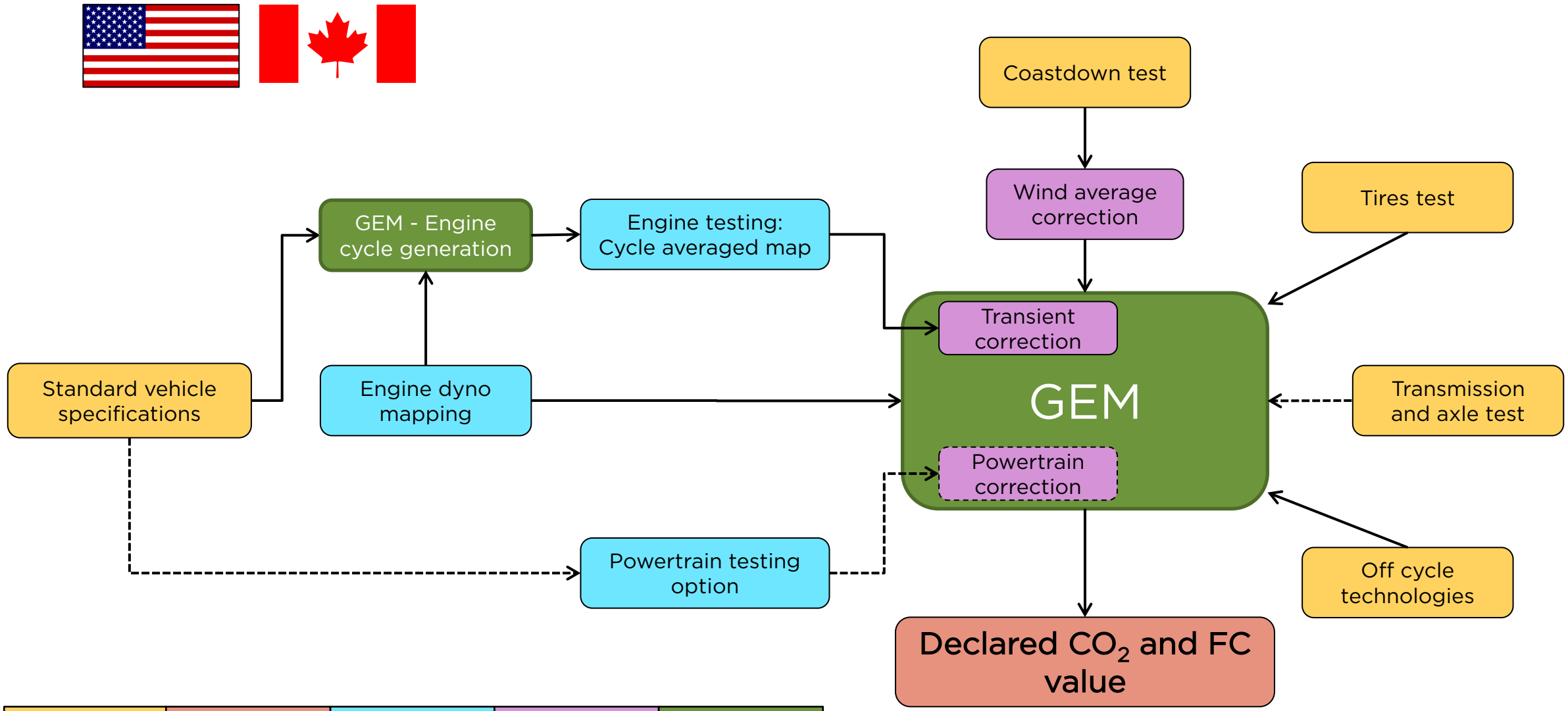
Component	VECTO input	GEM input
Engine	Displacement, idle speed, fuel consumption map, full load torque curve, motoring friction curve, **brake-specific fuel consumption over the Worldwide Harmonized Transient Cycle (WHTC)**	Displacement, idle speed, fuel consumption map, full load torque curve, motoring friction curve, **fuel consumption over the ARB Transient Drive Cycle for 9 different vehicle configurations**
Transmission	Transmission type, gear ratios, **torque loss map as a function of torque and speed** for each gear, maximum torque and speed per gear	Transmission type, gear ratios, and maximum torque per gear. **Optional: Power loss map** as a function of torque and speed for each gear
Axle	Axle ratio and **torque loss map as a function of torque and speed**	Axle ratio **Optional: Power loss map** as a function of torque and speed
Aerodynamic drag	Air drag area as determined during the **constant speed procedure.** For rigid trucks, a standard box is used. For tractors, a standard trailer is used.	Air drag area as determined by the **coastdown methodology.** Standard trailers are used for tractor modeling.
Tires	Tire dimensions, **rolling resistance coefficient (Crr),** and load applied during the rolling resistance test for each axle	**Rolling resistance coefficient (Crr)** for each axle, and drive tire revolutions per mile
Vehicle	**Curb vehicle weight,** gross vehicle weight rating, and axle configuration	**Vehicle weight reduction** (sum of standardized weight reductions per component), vehicle regulatory subcategory (e.g., Class 8, sleeper cabin, high roof), and axle configuration
Other	**Auxiliaries:** Technology used for the following auxiliaries: cooling fan, steering system, electric system, pneumatic system, A/C system (whether it is present or not), and power take-off	**Off-cycle technologies:** Improvements through the application of the following technologies: Speed-limiter, neutral-idle, intelligent controls, accessory load reduction, extended idle reduction, tire pressure system, and other technologies.

GEM's model architecture

- GEM does not feature a graphical user interface.
- GEM was developed in Matlab Simulink as a forward-looking model: The simulation runs from the accelerator pedal to the wheels.
- The GEM architecture is comprised of four main modules: Powertrain, Vehicle, Driver, and Ambient.
- The Driver module is a closed-loop controller

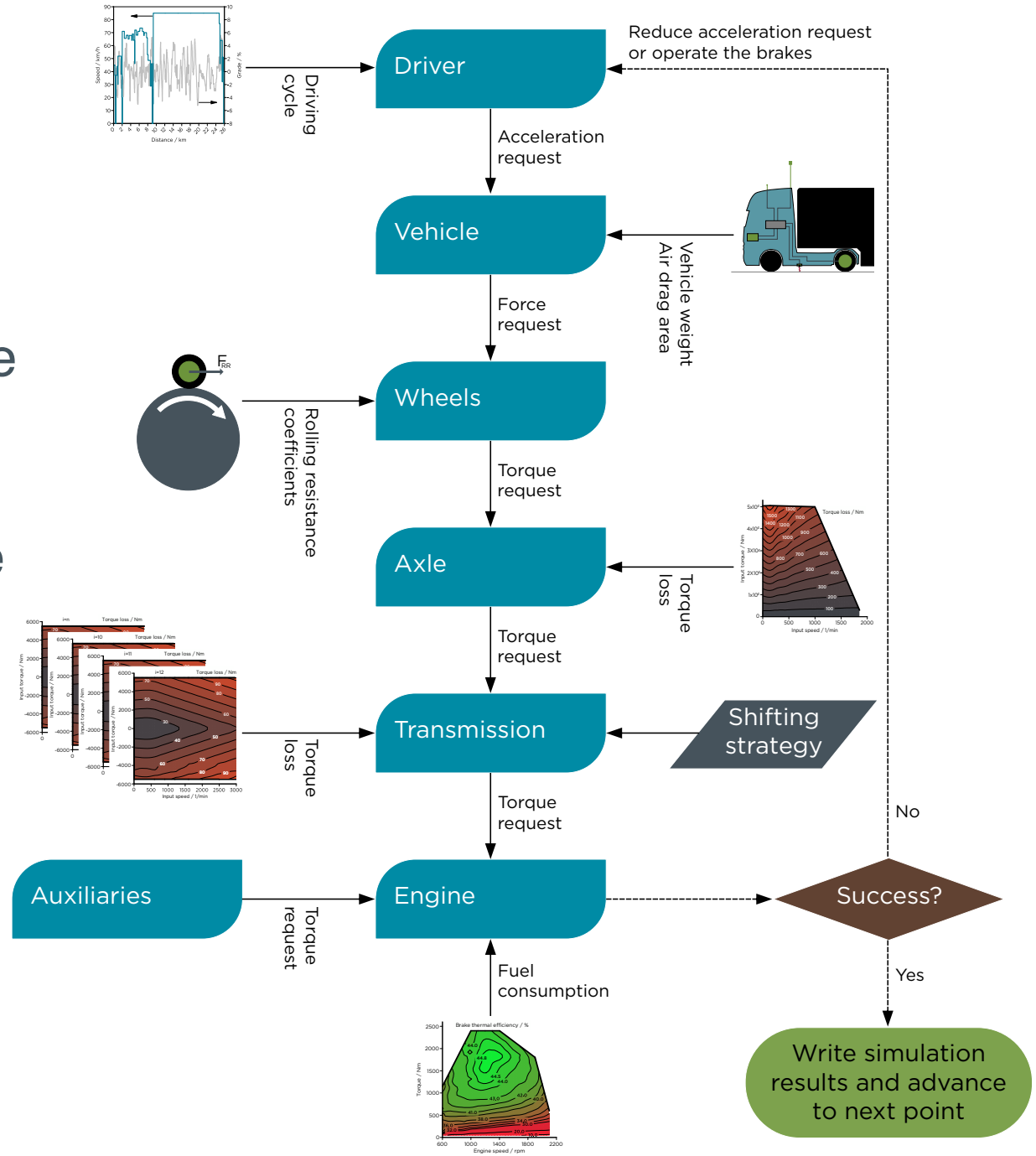


US and Canada HDV fuel consumption certification

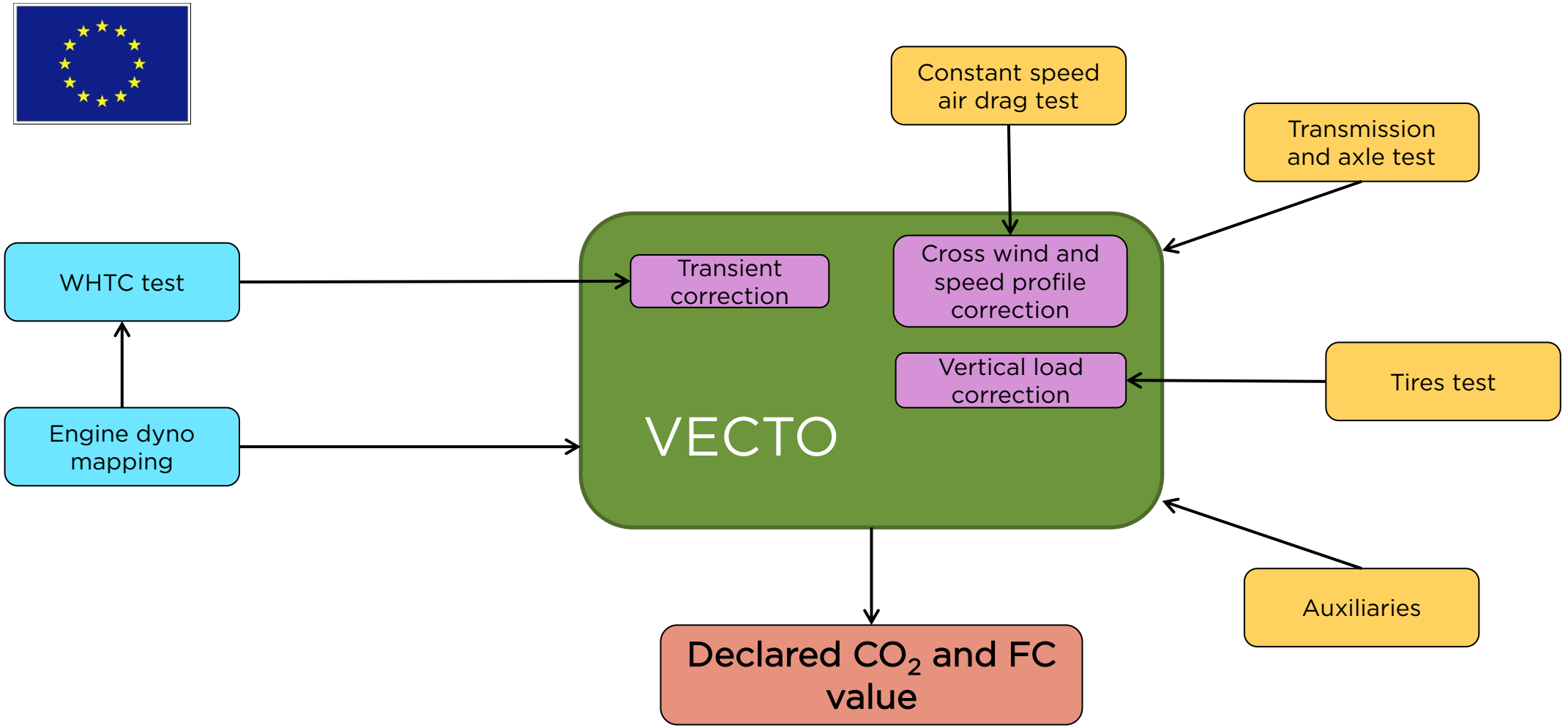


VECTO's model architecture

- VECTO was developed in C# as a backward-looking model: the simulation flow occurs in the opposite direction to the way it takes place in the actual vehicle.
- The Driver Model converts the drive cycle information into an acceleration request, to ultimately locate an appropriate operating point in the engine fuel map
- Once a valid engine operating point is found, the simulation moves to the next point in the driving cycle.



Europe HDV fuel consumption certification



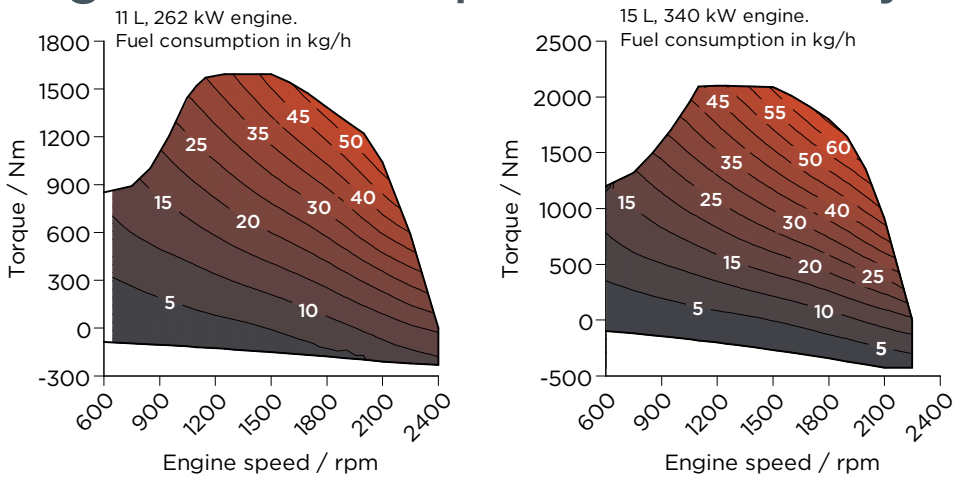
Input data | Output data | Dyno testing | Correction | Simulation

GEM-VECTO comparison: Definition of base vehicle

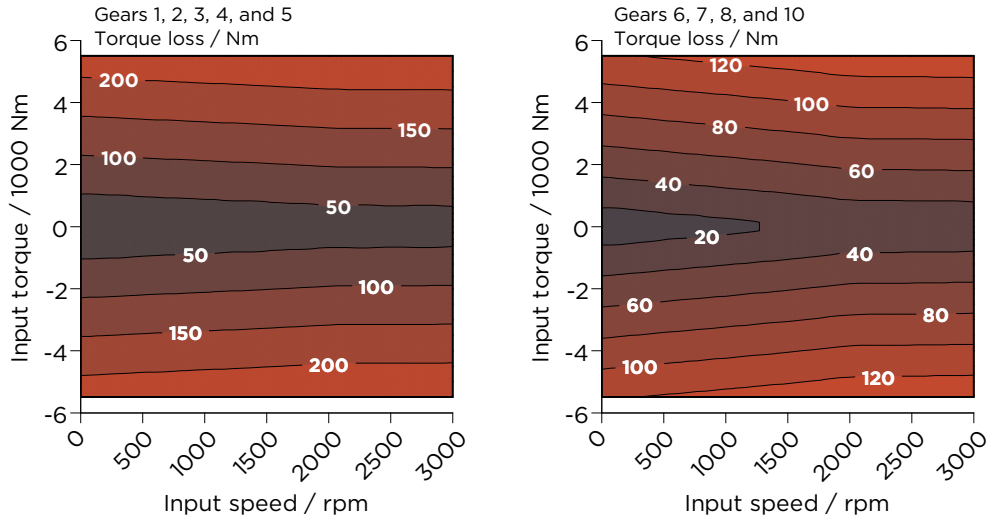
Component	Parameter	4x2 tractor-trailer	6x2 tractor-trailer
Engine	Displacement	11.0 liters	15.0 liters
	Idle speed	650 rpm	600 rpm
	Power	262 kW @ 1715 rpm	340 kW @ 1726 rpm
	Transient correction	None	None
Transmission and axle	Transmission type	10 speed, AMT	10 speed, AMT
	Axle ratio	**Between 3:1 and 4:1**	**Between 3:1 and 4:1**
Aerodynamic drag	**C_dA**	**Between 4 and 6 m^2**	**Between 4 and 6 m^2**
	Cross-wind correction	None	None
Tires	**Crr steering axle**	**Between 4 and 7 N/kN**	**Between 4 and 7 N/kN**
	Crr drive/tandem axles	**Between 4 and 7 N/kN**	**Between 4 and 7 N/kN**
	C_{rr} trailer axles	6 N/kN	6 N/kN
	Tire dynamic radius	512 mm	512 mm
Accessories	Accessory power	3500 W (constant)	3500 W (constant)
	Acc. load reduction	None	None
Vehicle	Base vehicle mass	9570 kg	14741 kg
	Base payload	11340 kg	17237 kg
	Vehicle weight reduction	**Up to 2000 kg**	**Up to 3000 kg**
	Total number of axles	4	5

GEM-VECTO comparison: Powertrains

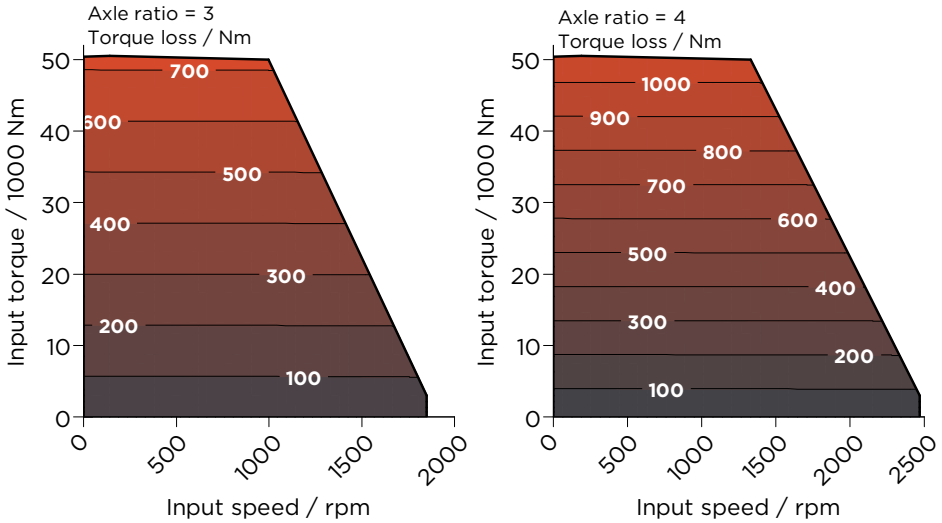
Engine: ~ 46% peak efficiency

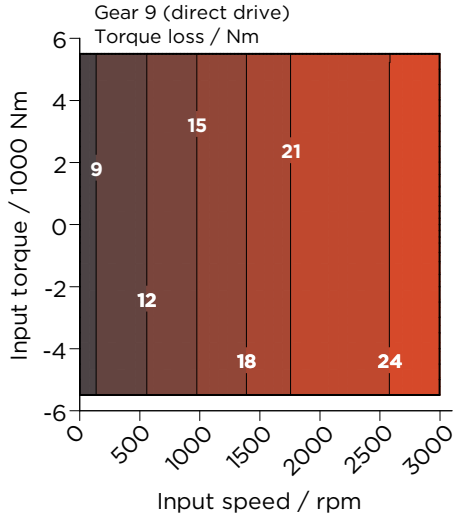


Transmission: ~95-99% mech. efficiency



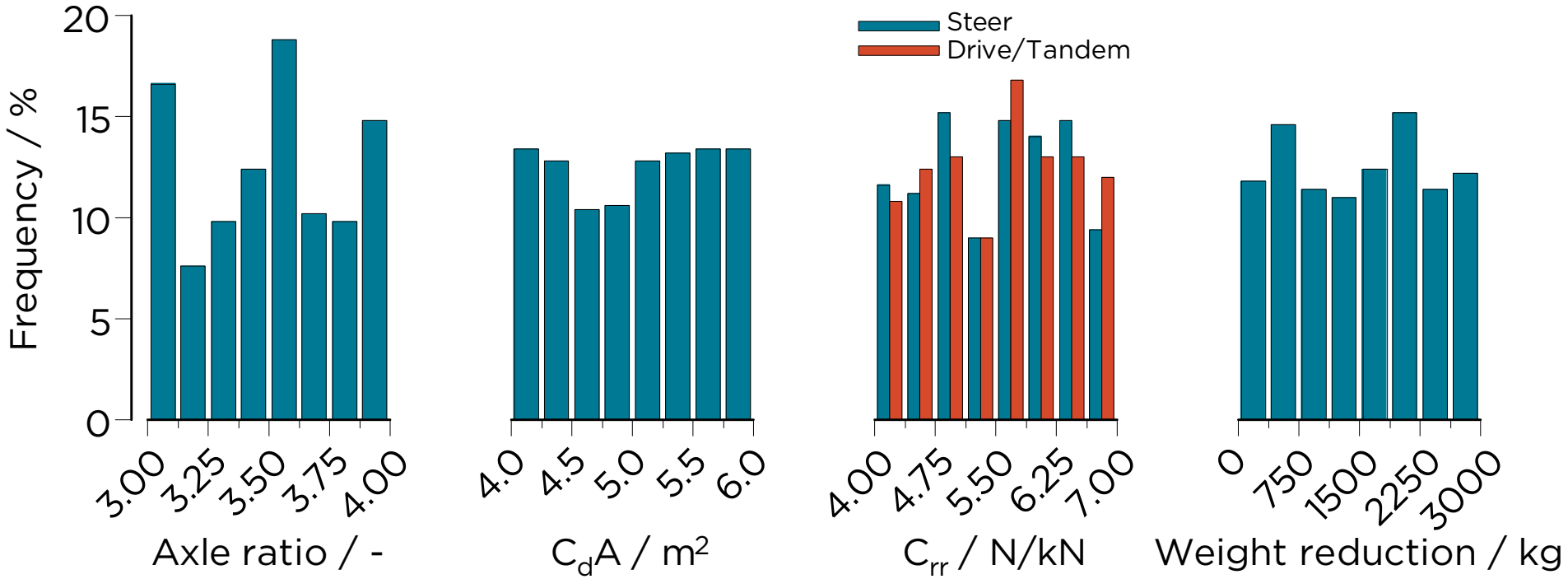
Axle: ~ 98% mechanical efficiency





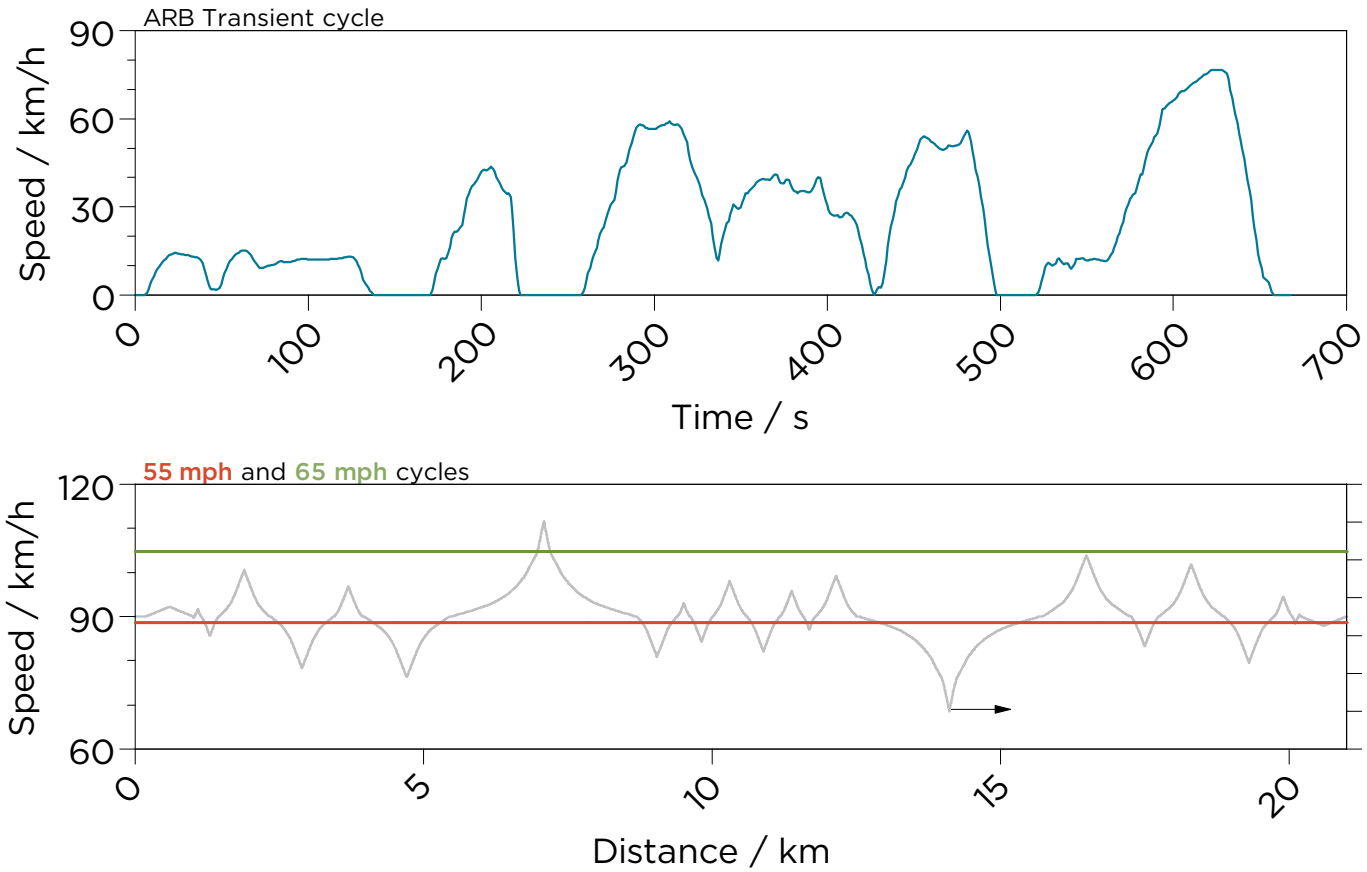
GEM-VECTO comparison: Randomized vehicle generation

A total of 500 unique vehicle configurations were randomly generated for each one of the two vehicle types. As an example, the distribution of the values for the 500 different 6x2 tractor-trailers simulated are below



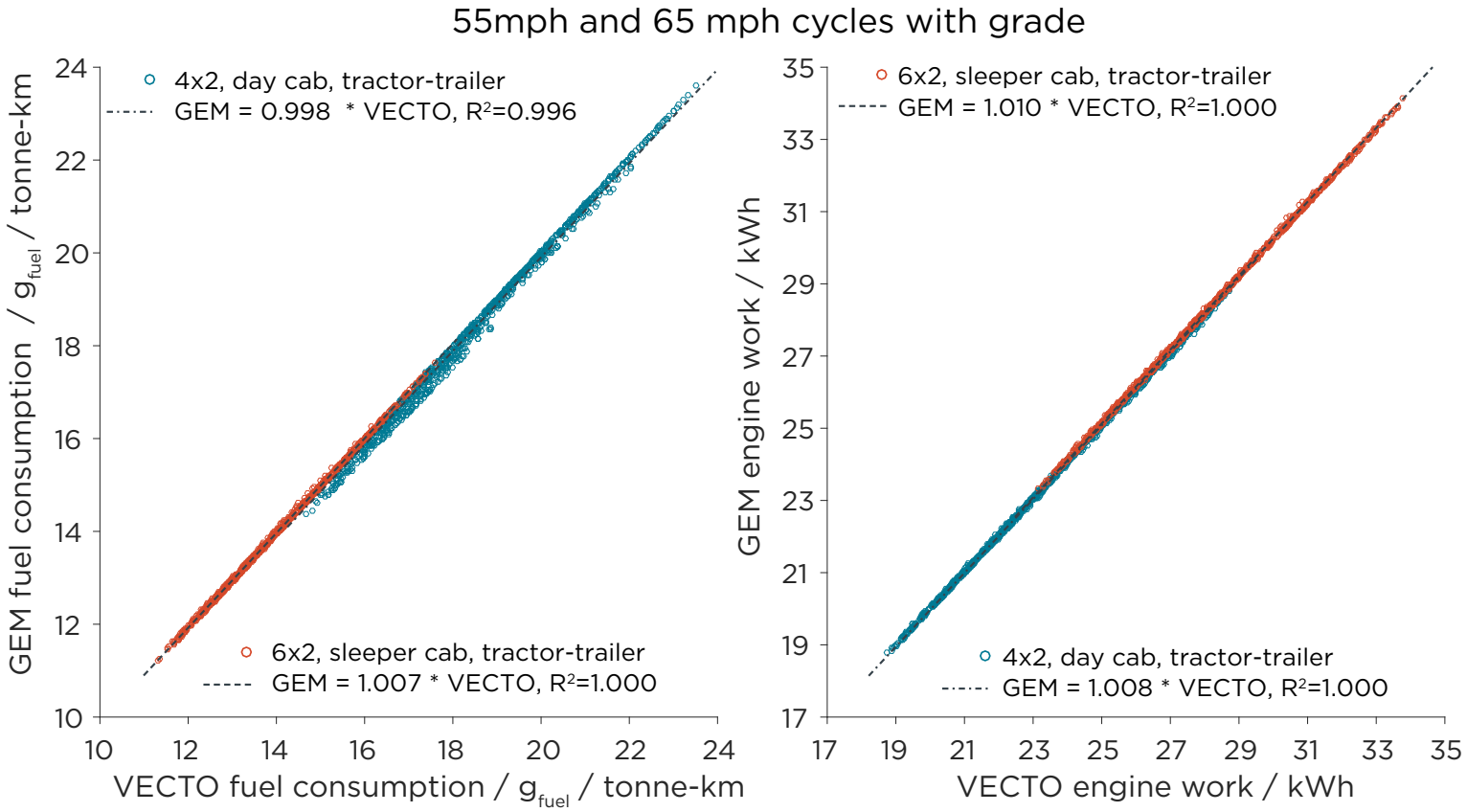
The US GHG Phase 2 cycles were used for the comparison

- The regulatory cycles for the US GHG Phase 2 standard were used, since they cannot be changed in GEM.
- The 55 mph and 65 mph cycles are distance-based cycles with grade.
- The ARB Transient cycle is a time-based cycle without grade



Comparison results: Constant speed cycles with grade

Absolute error: 0.64%

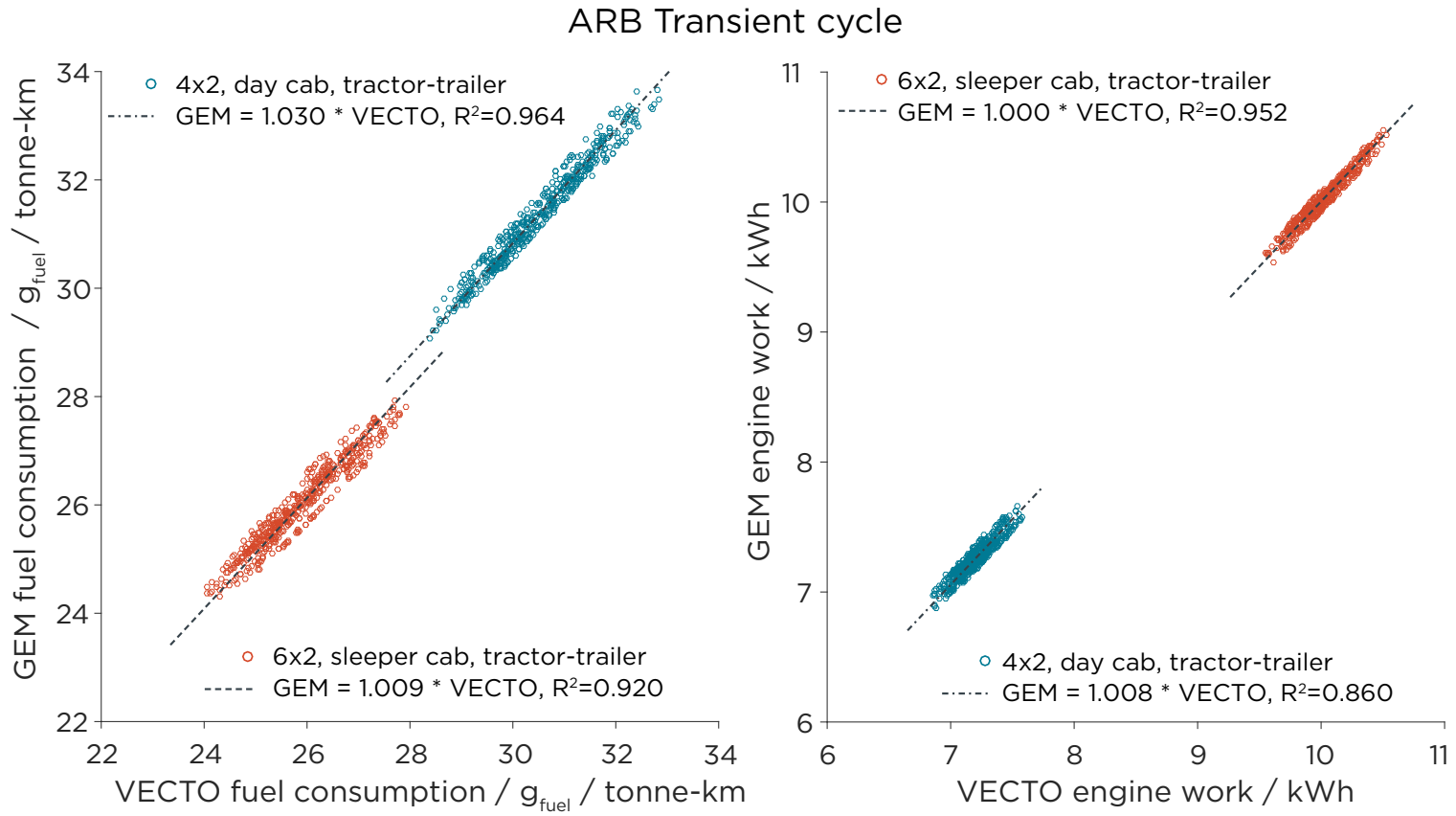


- The engine work is useful to gauge the agreement in energy flows observed by the engine.
- The fuel consumption is useful to assess the impact of the shifting strategies. For a given engine work, the shifting strategy determines the regions of the engine map.

Comparison results: Transient cycle

- Despite the differences in model architecture (forward vs backward-looking), driver model, and shifting strategy; both VECTO and GEM produce similar results in terms of engine work and fuel consumption.

Absolute error: 2.03%



Takeaway messages

- **VECTO and GEM show very good agreement** when simulated over a large set of identical vehicles

- The accurate simulation of CO_2 emissions of HDVs is more dependent on the component input data than on the selected model (VECTO vs GEM). **Harmonization of component certification benefits the implementation of future regulatory measures.**

- **Both GEM and VECTO can be adapted to account for the differences across regions.** VECTO's engineering mode provides a user friendly interface to modify drive cycles, payloads, and vehicle details. GEM can also be modified accessing the source code, however, this implies more effort.