Working Paper No. **HDH-07-09**
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Heavy-Duty GHG Overview and Hybrid System Testing

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Agenda

- Overview of the HD GHG Rulemaking
- Advanced Technology Flexibility Provisions in the Rule
- Pre-transmission Powerpack Test Procedures
- Post-transmission Powerpack Test Procedures
- Complete Vehicle Chassis Test for Hybrid Systems
- HD GHG Implementation

Program Description

- Vehicles covered by this program make up the transportation segment's second largest contributor to oil consumption and GHG emissions.
- This comprehensive program is designed to address the urgent and closely intertwined challenges of dependence on oil, energy security, and global climate change.
- The HD National Program has been developed with support from industry, the State of California, and environmental stakeholders, and is a key component of the agencies' response to a Presidential Memorandum issued in May 2010.[1]
- The combined standards will reduce CO2 emissions by about 270 million metric tons and save about 530 million barrels of oil over the life of vehicles built for the 2014 to 2018 model years, providing $49 billion in net program benefits.
- A second phase of regulations is planned for model years beyond 2018.

Regulation Structure & Requirements

Subcategory → Family → Subfamily → Vehicle Configuration → Vehicle

Subcategory

9 Subcategories which are based on GVWR, roof height, and cab (day or sleeper)

Compliance with Standard

Family

Typically one conventional vehicle family per subcategory.

Additional families for tractors with advanced or innovative technologies.

A Certificate is issued for each family

Certification Fees are paid for each certificate

Subfamily

A subfamily is a group of vehicle configurations with the same FEL.

In the case of GHG emissions, potential subfamilies are determined by the potential whole number g/ton-mile results for the family.

Approximately 20-40 subfamilies per family.

Each subfamily has its own FEL which is the standard for every vehicle in the subfamily

Vehicle Configuration

A vehicle configuration is a set of vehicles with the same set of component configurations.

An aero configuration consists similar body components with the same aero bin and a similar CdA

A tire configuration consists of a single tire model

A weight configuration consists of the same set of weight reduction technologies

An AES configuration consists of a single shutdown strategy, including expiration setting

A VSL configuration consists of a single VSL setting, including expiration and soft top settings

Amend a Certificate

Vehicle

Each tractor produced is a vehicle with its own VIN

Each vehicle has its own label

Record keeping is required for each vehicle

In-use, Audit

Recall

GHG and Fuel Consumption Standards

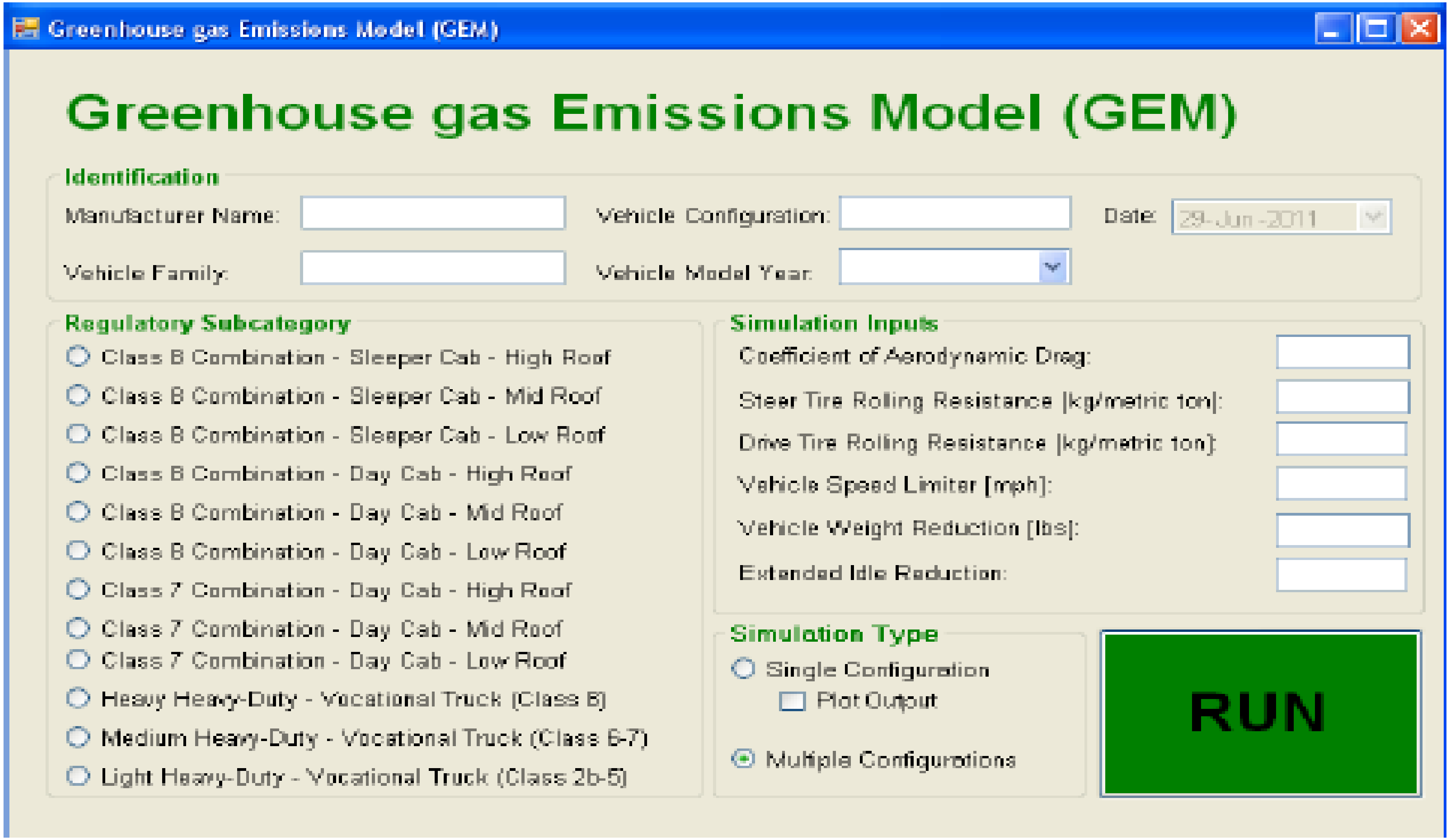
Table 1: MY 2017 Combination Tractor Standards

	EPA Emissions Standards (g CO2/ton-mile)			NHTSA Fuel Consumption Standards (gal/1,000 ton-mile)		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Day Cab Class 7	104	115	120	10.2	11.3	11.8
Day Cab Class 8	80	86	89	7.8	8.4	8.7
Sleeper Cab Class 8	66	73	72	6.5	7.2	7.1

Table 2: MY 2017 Vocational Vehicle Standards

	EPA Full Useful Life Emissions Standards (g CO2/ton-mile)	NHTSA Fuel Consumption Standards (gal/1,000 ton-mile)
Light Heavy Class 2b-5	373	36.7
Medium Heavy Class 6-7	225	22.1
Heavy Heavy Class 8	222	21.8

GEM



Greenhouse gas Emissions Model (GEM)
Greenhouse gas Emissions Model (GEM)
Identification
Manufacturer Name:
Vehicle Configuration:
Date:
29-Jun-2011
Vehicle Family:
Vehicle Model Year:
Regulatory Subcategory
Class 8 Combination - Sleeper Cab - High Roof
Class 8 Combination - Sleeper Cab - Mid Roof
Class 8 Combination - Sleeper Cab - Low Roof
Class 8 Combination - Day Cab - High Roof
Class 8 Combination - Day Cab - Mid Roof
Class 8 Combination - Day Cab - Low Roof
Class 7 Combination - Day Cab - High Roof
Class 7 Combination - Day Cab - Mid Roof
Class 7 Combination - Day Cab - Low Roof
Heavy Heavy-Duty - Vocational Truck (Class 8)
Medium Heavy-Duty - Vocational Truck (Class 6-7)
Light Heavy-Duty - Vocational Truck (Class 2b-5)
Simulation Inputs
Coefficient of Aerodynamic Drag:
Steer Tire Rolling Resistance [kg/metric ton]:
Drive Tire Rolling Resistance [kg/metric ton]:
Vehicle Speed Limiter [mph]:
Vehicle Weight Reduction [lbs]:
Extended Idle Reduction:
Simulation Type
Single Configuration
Plot Output
Multiple Configurations
RUN

HD Pickup Truck & Van CO2 Standards

1037.104

- The HD Pickup Truck and Van CO2 emissions standards:
  - Begin in 2014MY
  - Are CO2 standards, not CREE
  - Represent a fleet-average standard where all vehicles in this category form a single averaging set

$$\text{Fleet-Average Standard} = \frac{\sum[\text{Target}_i \times \text{Volume}_i]}{\sum[\text{Volume}_i]}$$

  - The GHG emission standards for these vehicles apply for a weighted average of 55% FTP City and 45% Highway test cycle where the vehicle is tested at Adjusted Loaded Vehicle Weight (ALVW)

HD Pickup Truck & Van CO_2 Standards

1037.104

Spark Ignition

CO_2 Target (g/mile) = 0.0440 x WF + 339

Compression Ignition

CO_2 Target (g/mile) = 0.0416 x WF + 320

$$WF = 0.75 \times (GVWR - Curb\ Weight + xwd) + 0.25 \times (GCWR - GVWR)$$

Where:

xwd = 500 pounds if the vehicle has four-wheel drive or all-wheel drive; xwd = 0 pounds for all other vehicles.

HD Pickup Truck & Van GHG Phase-in

1037.150(b)

Table 1 to 1037.150

Model Year and Engine Cycle	Alternate CO_2 Target (g/mile)
2014 Spark-Ignition	[0.0482 × (WF)] + 371
2015 Spark-Ignition	[0.0479 × (WF)] + 369
2016 Spark-Ignition	[0.0469 × (WF)] + 362
2017 Spark-Ignition	[0.0460 × (WF)] + 354
2014 Compression-Ignition	[0.0478 × (WF)] + 368
2015 Compression-Ignition	[0.0474 × (WF)] + 366
2016 Compression-Ignition	[0.0460 × (WF)] + 354
2017 Compression-Ignition	[0.0445 × (WF)] + 343

Table 2 to 1037.150

Model Year and Engine Cycle	Alternate CO_2 Target (g/mile)
2014 Spark-Ignition	[0.0482 × (WF)] + 371
2015 Spark-Ignition	[0.0479 × (WF)] + 369
2016-2018 Spark-Ignition	[0.0456 × (WF)] + 352
2014 Compression-Ignition	[0.0478 × (WF)] + 368
2015 Compression-Ignition	[0.0474 × (WF)] + 366
2016-2018 Compression-Ignition	[0.0440 × (WF)] + 339

HD Pickup Truck and Van N_2O and CH_4 Standards

1037.104(c)

- The GHG emission standards for these vehicles apply for a weighted average of 55% FTP City and 45% Highway test cycle

HD Pickup Truck and Van Standards (g/mile):

Model Years	CH_4 Emissions	N_2O Emissions
2014 and Later	0.05	0.05

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HFC Standards

1037.115(c)

- HFC emissions are controlled through a leakage standard, not a credit program
- No averaging, banking, or trading of HFC credits is allowed
- The leakage of refrigerant from an A/C system may not exceed 1.50 percent per year
  - For systems with refrigerant capacities less than 734 grams, the leakage may not exceed 11.0 grams per year

Dual, Multi, or Flex Fuel Vehicles

1037.104(d)(10)

- Perform exhaust testing on each fuel type
- Use either the conventional fueled CO_2 emission rate or a weighted average of the emission results as specified in 40 CFR 600.510-12(k)
- May not exceed the N_2O or CH_4 standard on either fuel

Flexibility Provisions

Earning CO2 Credits

Sum of four independent calculations (calculated separately for each averaging set) = total credits in a model year

1. Averaging, Banking, and Trading – 1037.705
2. Innovative Technology Credits – 1037.610
3. Early Credits – 1037.150(a)
4. Advanced Technology Credits – 1037.615

Credits are always rounded to the nearest whole megagrams (Mg)

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Subcategory, Averaging Set, Service Class

Subcategory

Standards are based on Subcategory

9 Tractor Subcategories
- Cl. 7 Low Roof Day Cab
- Cl. 7 Mid Roof Day Cab
- Cl. 7 High Roof Day Cab
- Cl. 8 Low Roof Day Cab
- Cl. 8 Mid Roof Day Cab
- Cl. 8 High Roof Day Cab
- Cl. 8 Low Roof Sleeper Cab
- Cl. 8 Mid Roof Sleeper Cab
- Cl. 8 High Roof Sleeper Cab

3 Vocational Vehicle Subcategories
- Light Heavy –Duty Vehicles (Cl. 2b-5)
- Medium Heavy-Duty Vehicles (Cl. 6-7)
- Heavy Heavy-Duty Vehicles (Cl. 8)

4 Engine Subcategories
- Light Heavy-Duty CI Engines (Cl. 2b-5)
- Medium Heavy-Duty CI Engines (Cl. 6-7)
- Heavy Heavy-Duty CI Engines(Cl. 8)
- Spark Ignited Engines

Averaging Set

ABT, Early, and Innovative Credits must stay within an Averaging Set

3 Vehicle Averaging Sets
- Light Heavy –Duty Vehicles (Cl. 2b-5)
- Medium Heavy-Duty Vehicles (Cl. 6-7)
- Heavy Heavy-Duty Vehicles (Cl. 8)

4 Engine Averaging Sets
- Light Heavy-Duty CI Engines (Cl. 2b-5)
- Medium Heavy-Duty CI Engines (Cl. 6-7)
- Heavy Heavy-Duty CI Engines(Cl. 8)
- Spark Ignited Engines

Service Class

Advanced Technology credits may move among averaging sets, but moves from one service class to another are restricted to 60,000 Mg

3 Service Classes
- SI Engines, Light Heavy –Duty Vehicles and CI Engines (Cl. 2b-5)
- Medium Heavy-Duty Vehicles and CI Engines (Cl. 6-7)
- Heavy Heavy-Duty Vehicles and CI Engines (Cl. 8)

GHG Credit Programs

<u>Early Credits – 1037.150 (a):</u>
•2013 MY only (except electric vehicles)
•Entire regulatory subcategory
-or-
•Difference between 2012 MY and 2013 MY SmartWay designated high roof sleeper cab sales
•1.5x multiplier

<u>Restrictions:</u>
•Credits stay in averaging set – 1037.740(a)
•5 year credit life - 1037.740(c)
•Only a single 1.5x multiplier may be used for early credits which are also eligible for Advanced Technology Credits - 1037.150 (i)

<u>Advanced Technology Credits – 1037.615:</u>
•Vehicles with Rankine cycle, electric vehicles, fuel cell vehicles, and hybrid powertrains
•Only a single certifier (either of the engine or the vehicle) may establish credits for a hybrid powertrain
•1.5x multiplier – 1037.150(i)

<u>Restrictions:</u>
•Credits can go into any averaging set, except only 60,000 Mg CO2 credits can come into a service class from another service class - 1037.740(b)
•5 year credit life – 1037.740(c)

<u>Innovative Technology Credits – 1037.610:</u>
•Vehicle or engine technology which is not captured on test (GEM) and not in common use in 2010 MY for heavy-duty vehicles
•Preapproval of test method required
•No multiplier

<u>Restrictions:</u>
•Credits stay in averaging set – 1037.740(a)
•5 year credit life - 1037.740(c)

Implementation Workshop

- The workshop will be held November 3, 2011 in the auditorium of the Morris J. Lawrence Building at Washtenaw Community College
- Located at 4800 E. Huron River Drive, Ann Arbor, MI 48105.
- Maps and driving directions can be found at http://www.wccnet.edu/about-us/visiting/.
- Please email questions to complianceinfo@epa.gov by October 12, 2011 for EPA consideration.
- EPA will only take questions on index cards during the workshop and may not have time to answer them that day.
- For other questions, you may contact us at: Compliance Information Hotline at 734.214.4343 or omplianceinfo@epa.gov

Hybrid Testing Procedures

Advanced Technology Demonstration
1037.510, 1037.525, 1037.550, 1066

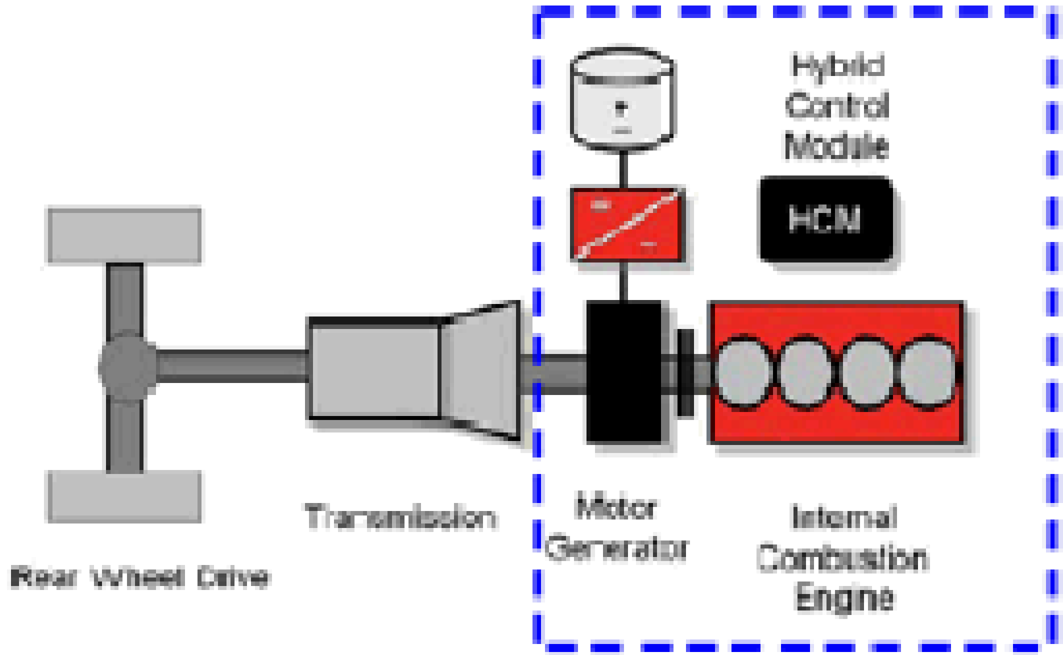
- The testing consists of both a conventional vehicle and a hybrid vehicle. The results from the two vehicles will be used to determine an improvement factor

- Advanced technology demonstrations for vehicles with hybrid powertrains would typically occur through either chassis testing or powerpack testing

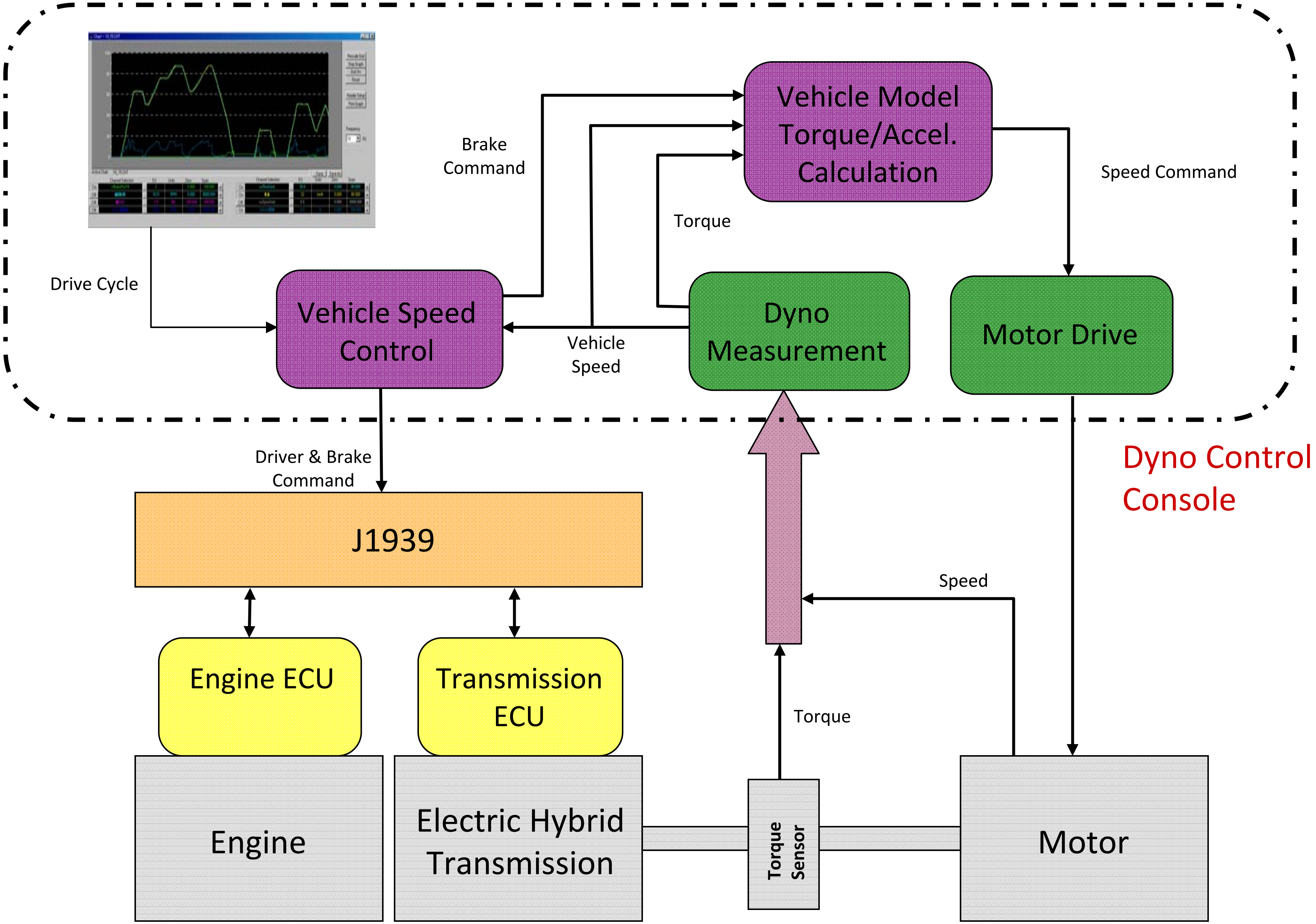
- Chassis testing
  - Refer to procedures in 1037.510, including the weighting factors for the duty cycles
  - Provisions for vehicles with a power take-off (PTO) are included in 1037.525

- Powerpack testing
  - Refer to procedures in 1037.550

Pre-Transmission Hybrid Control Volume



Source: Cummins Incorporated's White Paper: Regulation of emissions from commercial hybrid vehicles, August 9, 2010



Performance specifications for system variables defined in Table 1 40 CFR 106.5.205

Pre-Transmission Powerpack / Hybrid Engines

- Criteria pollutant certified engine
- GHG certified hybrid system including the hybrid components
- Defined as an engine system that includes features that recover and store energy during engine motoring operation.
- Include features that recover and store energy from braking unrelated to engine motoring operation.
  - Features that recover energy between the engine and transmission are considered ‘‘related to engine motoring’’

Testing Hybrid Engines

- The hardware that must be included in these tests includes:
  - Engine
  - Hybrid electric motor
  - Rechargeable energy storage system (RESS)
  - Power electronics between the hybrid electric motor and the RESS
- You may ask us to modify the provisions of this section to allow testing non-electric hybrid vehicles
- Measure emissions using the same procedures that apply for testing non-hybrid engines unless specified otherwise
- Deactivate the hybrid features when testing using the SET

Five Unique Test Procedures for Hybrid Engines

- They are related to
  - Engine mapping,
  - Engine shutdown during the test cycle,
  - Calculating work,
  - Limits on braking energy, and
  - State of charge constraints

Torque Maps

- Separate torque maps for the engine with and without the hybrid features active.
  - For transient testing denormlization should include the map which incorporates the hybrid features
  - For steady state testing, denormalization should include the map which does not incorporate the hybrid features

Idle Shutdown

- If the engine will be configured in actual use to shut down automatically during idle operation, you may let the engine shut down during the idle portions of the test cycle.

Cycle Work

Cycle Work

- Follow 40 CFR 1065.650(d) to calculate cycle work, except as follows:
  - For positive work over the cycle, set negative power from hybrid to zero
  - For the negative work over the cycle set the positive power to zero and set the non-hybrid power to zero.

$$x_b = \left| \frac{W_{neg}}{W_{pos}} \right|$$

Eq. 1036.525-1

$$x_{bl} = 4.158 \cdot 10^{-4} \cdot P_{max} + 0.2247$$

Eq. 1036.525-2

$$W_{cycle} = W_{pos} - \left(\left| W_{neg} \right| - x_{bl} \cdot W_{pos} \right)$$

Eq. 1036.525-3

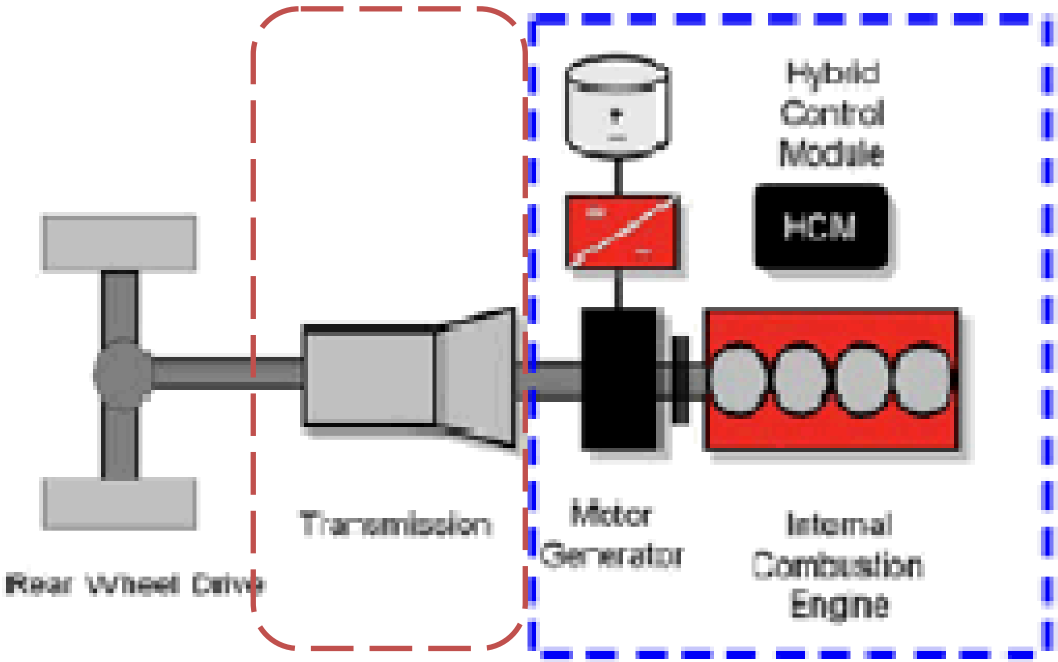
xb *= the brake energy fraction.*
Wneg *= the negative work over the* cycle.
Wpos *= the positive work over the* cycle.
xbl *= the brake energy fraction limit.*
Pmax *= the maximum power of the* engine with the hybrid system engaged (kW).
Wcycle *= the work over the cycle when xb is greater than xbl.*

Brake Energy Fraction

- Calculate brake energy fraction, *xb, as the integrated negative work over* the cycle divided by the integrated positive work over the cycle according to Equation 1036.525–1.
- Calculate the brake energy limit for the engine, *xbl,* according to Equation 1036.525–2. If *xb* is less than *xbl, use the integrated* positive work for your emission calculations.
- If the *xb is greater than xbl* use Equation 1036.525–3 to calculate the positive work done over the cycle.
- Use *Wcycle as the integrated positive* work when calculating brake-specific emissions.
- To avoid the need to delete extra brake work from positive work you may set an instantaneous brake target that will prevent *xb from being larger* than *xbl.*

X b = absolute value of (W negative / W positive) is the brake energy fraction
X bl = 4.158X10-E-04 x Pmax +.2247 is the brake energy fraction cap

Post-Transmission Hybrid Control Volume



Source: Cummins Incorporated's White Paper: Regulation of emissions from commercial hybrid vehicles, August 9, 2010

Post-transmission Powerpack

40 CFR§ 1037.550

- Criteria pollutant certified engine
- GHG certified hybrid system including hybrid system components and the transmission
- The procedure for simulating a chassis test with a post-transmission hybrid system for A to B testing.
- The hardware that must be included in these tests is the engine, the transmission, the hybrid electric motor, the power electronics between the hybrid electric motor and the RESS.
- Set-up the engine consistent with 40 CFR 1065.110 for work inputs and outputs and accessory work.
- Collect CO2 while operating the system over the duty cycles of 1037.510

Post-Transmission Powerpack Test Procedures

- Collect and measure emissions as described in 40 CFR part 1066. Calculate emission rates in grams per ton-mile without rounding. Determine values for *A, B, C,* and *M* for the vehicle being simulated as specified in 40 CFR part 1066. If you will apply an improvement factor or test results to multiple vehicle configurations, use values of *A, B, C, M,* k_d, and *r* that represent the vehicle configuration with the smallest potential reduction in greenhouse gas emissions as a result of the hybrid capability.

- (d) Calculate the transmission output shaft's angular speed target for the driver model, $f_{nref,driver}$, from the linear speed associated with the vehicle cycle using the following equation:

$$f_{nrefi,driver} = \frac{S_{i,cycle} \cdot k_d}{2 \cdot \pi \cdot r}$$

- Where:
- S_{cyclei}= vehicle speed of the test cycle for each point *i* .
- k_d= final drive ratio (the angular speed of the transmission output shaft divided by the angular speed of the drive axle), as declared by the manufacturer.
- *r* = radius of the loaded tires, as declared by the manufacturer.

- (e) Use either speed control or torque control to program the dynamometer to follow the test cycle, as follows:

Post-Transmission Powerpack Test Procedures

- (1) *Speed control.* Program dynamometers using speed control as described in this paragraph (e)(1). We recommend speed control for automated manual transmissions or other designs where there is a power interrupt during shifts. Calculate the transmission output shaft's angular speed target for the dynamometer, $f_{nref,dyno}$, from the measured linear speed at the dynamometer rolls using the following equation:

$$f_{nref,dyno} = \frac{S_{i,ref} \cdot k_d}{2 \cdot \pi \cdot r}$$

- Where:

$$S_{i,ref} = \left(FR_{meas,i} - \left(A + B \cdot S_i + C \cdot S_i^2\right)\right)\frac{t_i - t_{i-1}}{M} + S_{i,ref-1}$$

- t = elapsed time in the driving schedule as measured by the dynamometer, in seconds.
- Let $t_{i-1} = 0$.

$$FR_{meas,i} = \frac{k_d \cdot T_i}{r}$$

- Where:

$$S_i = \frac{2 \cdot \pi \cdot r \cdot f_{n,i}}{k_d}$$

- T_i= instantaneous measured torque at the transmission output shaft.
- $f_{n,i}$= instantaneous measured angular speed of the transmission output shaft.
- (2) *Torque control.* Program dynamometers using torque control as described in this paragraph (e)(2).
- (i) Calculate the transmission output shaft's torque target, T_{refi}, using the following equation:

$$T_{ref,i} = \frac{r \cdot FR_i}{k_d}$$

- Where:
- FR_i= total road load force at the surface of the roll, calculated using the equation in 40 CFR 1066.210(d)(4), as specified in paragraph (e)(2)(ii) of this section.
- (ii) Calculate the total road load force based on instantaneous speed values, S_i, calculated from the equation in paragraph (e)(1) of this section.

Post-Transmission Powerpack Test Procedures

- (3) For each test, validate the measured transmission output shaft's speed or torque with the corresponding reference values according to 40 CFR 1065.514(e).

- You may delete points when the vehicle is braking or stopped. Perform the validation based on speed and torque values at the transmission output shaft.

- For steady-state tests (55 mph and 65 mph cruise), apply cycle-validation criteria by treating the sampling periods from the two tests as a continuous sampling period.

- Perform this validation based on the parameters for speed and torque control defined in Table 1 of §1037.550 (shown later).

Post-Transmission Powerpack Test Procedures

- (f) Send a brake signal when throttle position is equal to zero and vehicle speed is greater than the reference vehicle speed from the test cycle.
  - The brake signal should be turned off when the torque measured at the transmission output shaft is less than the reference torque.
  - Set a delay before changing the brake state using good engineering judgment to prevent the brake signal from dithering.

- (g) The driver model should be designed to follow the cycle as closely as possible and must meet the requirements of 40 CFR 1066.430(e) for transient testing and §1037.510 for steady-state testing.

- (h) Correct for the net energy change of the energy storage device as described in 40 CFR 1066.501.

- (i) Follow the provisions of §1037.510 to weight the cycle results and §1037.615 to calculate improvement factors and benefits for advanced technologies.

Powerpack Validation

- Validation from the rulemaking focused on comparison of Powerpack and complete vehicle improvement factors
  - Testing at NVFEL, CARB, and Environment Canada
- Additional validation testing using the Powerpack and chassis dynamometer testing at Environment Canada is planned
- “Real signals” from chassis dynamometer testing used to validate control strategies and facilitate improvements in vehicle simulation
- Driver model and drive train simulation based on the specific vehicle for which the powerpack testing would be applied at the manufacturer’s discretion.

Complete Hybrid Vehicle GHG Certification

- Perform coastdown testing to develop road load coefficients consistent with the provisions of 40 CFR 1066
- Coastdown requirements are largely based on SAE J1263 with some modifications
- Detailed procedures are available in 40 CFR 1066.310
- Duty Cycles include the 55 mph, 65 mph, and transient duty cycle.
- To correct fuel economy or emission results for Net Energy Change of the RESS, use the procedures specified for charge-sustaining operation in SAE J2711 (incorporated by reference in § 1066.710).
- Calculate your total mass of emissions over a test cycle as specified in 40 CFR 86.144 or 40 CFR part 1065, subpart G.

Cycle Weighting

$$Emissions\left(\frac{g}{ton-mile}\right)=\frac{1}{payload\,(tons)}\cdot\left(\frac{w_{transient}\cdot m_{transient}}{D_{transient}}+\frac{w_{55}\cdot m_{55}}{D_{55}}+\frac{w_{55}\cdot m_{65}}{D_{65}}\right)$$

- Where:
- *payload* = the standard payload, in tons, as specified in §1037.705.
- *w* = weighting factor for the appropriate test cycle, as described in paragraph (c) of this section.
- *m* = grams of CO_2 emitted over the appropriate test cycle.
- *D* = miles driven over the appropriate test cycle.
- (c) Apply weighting factors specific to each type of vehicle and for each duty cycle as described in the following table:

Table 1 to § 1037.510_Weighting Factors for Duty Cycles

	Transient (%)	55 mph cruise (%)		65 mph cruise (%)
Vocational..	42	21		37
Vocational Hybrid Vehicles.......................	75	9		16
Day Cabs...	19	17		64
Sleeper Cabs..	5	9		86

Advanced Technology Credit Determination for Post-Transmission Hybrids and Complete Vehicles

Conventional Vehicle

Curb wt: 21k lbs

Payload: 1k lbs

Test wt: 22k lbs

Coastdown Wt: 22k lbs

GVWR: 33k lbs

A Test

Hybrid Vehicle

Curb wt: 22k lbs

Payload: 1k lbs

Test wt: 23k lbs

Coastdown Wt: 23k lbs

GVWR: 33k lbs

B Test

1. $(CO_{2\_A} - CO_{2\_B}) / (CO_{2\_A})$ = ______ (Improvement Factor)
2. Improvement Factor x GEM Result B = ___ (g/ton mile benefit)

A – Conventional Vehicle

B - Hybrid Vehicle Counterpart

GEM Result B – Non-hybrid vehicle components modeled emissions

LHD Hybrid Testing

- Based on SAE J1711 Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid Electric Vehicles, Including Plug-in Hybrid Vehicles

- Testing consistent with charge sustaining testing as defined for LD vehicles

- Duty cycles used for LHD testing are consistent with LD vehicle testing

PTO Testing

- If you produce a hybrid engine designed with power take-off capability and sell the engine coupled with a transmission, you may calculate a reduction in CO_2 emissions resulting from the power take-off operation as described in 40 CFR 1037.525.

Equation 3-1: Cycle-Weighted PTO Emissions Results

Emissions (g/ton-mile) = (PTO emissions (g/hour) * 0.01435 (hr/mile) / payload (tons)) + 0.30 Transient (g/ton-mile) + 0.15 * 55 mph (g/ton-mile) + 0.27* 65 mph (g/ton-mile)

PTO Test Procedure

- This is a procedure for quantifying the reduction in greenhouse gas emissions as a result of running power take-off (PTO) devices with a hybrid powertrain
- Test the PTO so that all the energy is produced with the engine
- The full test for the hybrid vehicle is from a fully charged renewable energy storage system (RESS) to a depleted RESS and then back to a fully charged RESS.
- These procedures may be used for whole vehicles or with a post-transmission hybrid system.
- When testing just the post-transmission hybrid system, you must include all hardware for the PTO system.

Vehicle Selection for PTO Testing

- Select a vehicle with a hybrid powertrain to represent the vehicle family
- Select the vehicle type with the maximum number of PTO circuits that has the smallest potential reduction in greenhouse gas emissions
- Select an equivalent conventional vehicle as specified in §1037.615.

PTO Test Protocol

- 1) Without adding any additional restrictions, instrument the vehicle with pressure transducers at the outlet of the hydraulic pump for each circuit.

- (2) Operate the PTO system with no load for at least 15 seconds. Measure the pressure and record the average value over the last 10 seconds (p_{min}). Apply maximum operator demand to the PTO system until the pressure relief valve opens and pressure stabilizes; measure the pressure and record the average value over the last 10 seconds (p_{max}).

- (3) Denormalize the PTO duty cycle in Appendix II of part 1037 using the following equation:

- $p_{refi} = NP_i \cdot (p_{max} - _{min}) + p_{min}$

- Where:
- p_{refi}= the reference pressure at each point *i* in the PTO cycle.
- NP_i= the normalized pressure at each point *i* in the PTO cycle.
- p_{max}= the maximum pressure measured in paragraph (b)(2) of this section (1037.550).
- p_{min}= the minimum pressure measured in paragraph (b)(2) of this section(1037.550).

PTO Test Protocol (continued)

- (4) If the PTO system has two circuits, repeat paragraph (b)(2) and (3) for the second PTO circuit.
- (5) Install a system to control pressures in the PTO system during the cycle.
- (6) Start the engine.
- (7) Operate the vehicle over one or both of the denormalized PTO duty cycles, as applicable. Collect CO_2emissions during operation over each duty cycle.
- (8) Use the provisions of 40 CFR part 1066 to collect and measure emissions. Calculate emission rates in grams per test without rounding.
- (9) For each test, validate the pressure in each circuit with the pressure specified from the cycle according to 40 CFR 1065.514. Measured pressures must meet the specifications in Table 1 for a valid test:

PTO Test Protocol (continued)

- (10) Continue testing over the three vehicle drive cycles, as otherwise required by this part.
- (11) Calculate combined cycle-weighted emissions of the four cycles as specified in paragraph (d) of this section.
- (c) Measure PTO emissions from the fully warmed-up hybrid vehicle
- (d) Calculate combined cycle-weighted emissions of the four cycles for vocational vehicles
- (e) Follow the provisions of §1037.615 to calculate improvement factors and benefits for advanced technologies.

Statistical Criteria for Validating PTO Cycles

Table 1 of § 1037.525_Statistical Criteria for Validating Duty Cycles	

Parameter Pressure	

Slope, [verbar]a1[verbar]................... 0.950 [le] a1 [le] 1.030.	
Absolute value of intercept, [bond]a0[bond]. [le] 2.0% of maximum mapped pressure.	
Standard error of estimate, SEE............. [le] 10% of maximum mapped pressure.	
Coefficient of determination, r\2\......... >= 0.970.	

HD Hybrid OBD

- Legacy systems may delay OBD compliance until 2017

- New hybrid – engine systems must be fully compliant with OBD in 2016

- Legacy products represent those engine-hybrid systems in production prior to Model Year 2013.

Implementation Workshop

- The workshop will be held November 3, 2011 in the auditorium of the Morris J. Lawrence Building at Washtenaw Community College
- Located at 4800 E. Huron River Drive, Ann Arbor, MI 48105.
- Maps and driving directions can be found at http://www.wccnet.edu/about-us/visiting/.
- Please email questions to complianceinfo@epa.gov by October 19, 2011 for EPA consideration.
- EPA will only take questions on index cards during the workshop and may not have time to answer them that day.
- For other questions, you may contact us at: Compliance Information Hotline at 734.214.4343 or omplianceinfo@epa.gov

Appendix

Payload

Table 3-19: Combination Tractor Total Weight

MODEL TYPE	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 7	CLASS 7	CLASS 7
Regulatory Subcategory	Sleeper Cab High Roof	Sleeper Cab Mid Roof	Sleeper Cab Low Roof	Day Cab High Roof	Day Cab Mid Roof	Day Cab Low Roof	Day Cab High Roof	Day Cab Mid Roof	Day Cab Low Roof
Tractor Tare Weight (lbs)	19,000	18,750	18,500	17,500	17,100	17,000	11,500	11,100	11,000
Trailer Weight (lbs)	13,500	10,000	10,500	13,500	10,000	10,500	13,500	10,000	10,500
Payload (lbs)	38,000	38,000	38,000	38,000	38,000	38,000	25,000	25,000	25,000
Total Weight (lbs)	70,500	66,750	67,000	69,000	65,100	65,500	50,000	46,100	46,500

Table 3-20: Vocational Vehicle Total Weights

REGULATORY SUBCATEGORY	LIGHT HEAVY	MEDIUM HEAVY	HEAVY HEAVY
Truck Tare Weight (lbs)	10,300	13,950	27,000
Payload (lbs)	5,700	11,200	15,000
Total Weight (lbs)	16,000	25,150	42,000

Power Take Off Testing Overview

- The EPA comissioned Southwest Research Institute to study the potential applications for hybrid PTO vehicles in industry and to determine what typical PTO operation would be.

- Survey of industry indicated PTO hybrids were being investigated and developed for utility and refuse applications.

- SwRI obtained a utility truck and a refuse truck, instrumented them, and sent them to their owner for field operation

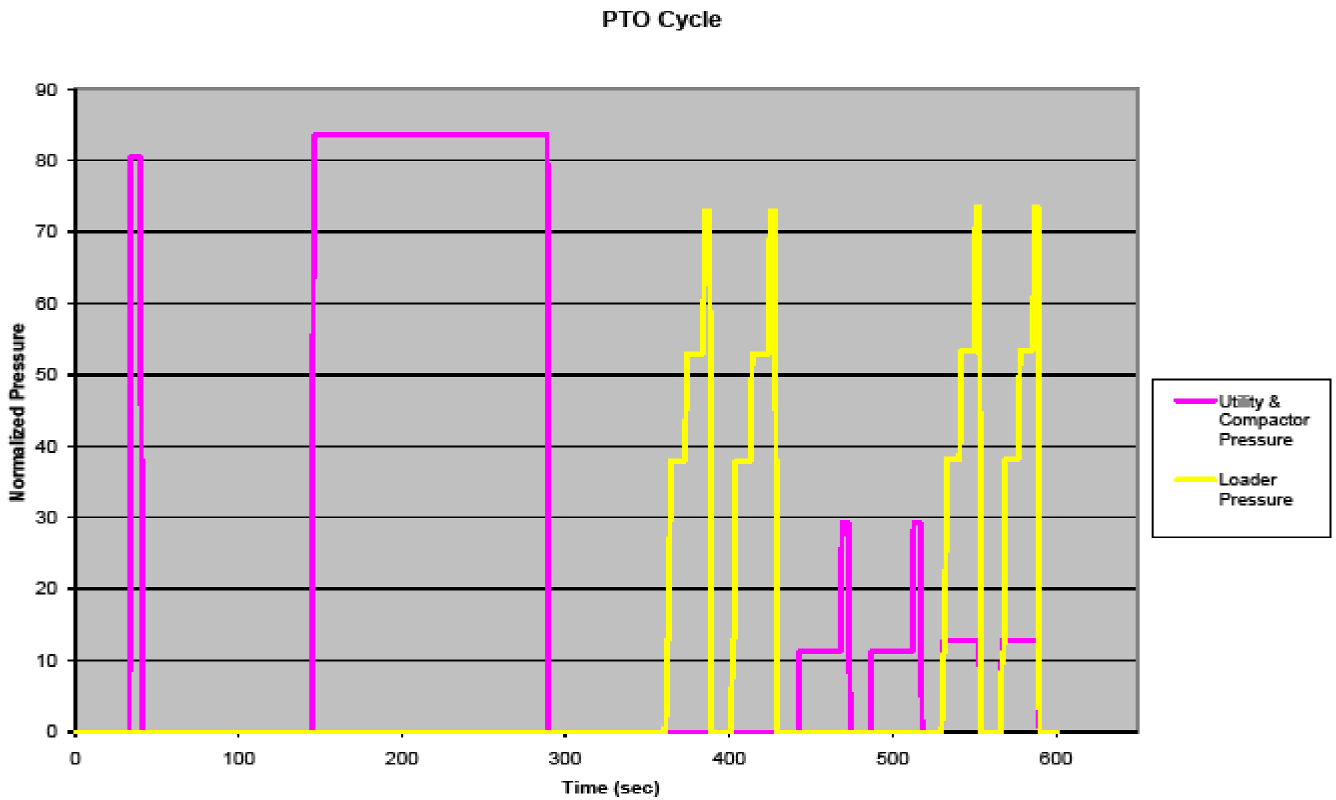
- The refuse truck was operated for a week on a variety of routes
  - The vehicle was a class 8 residential vehicle with a automated side-load-arm (SLA). This vehicle was owned by a large refuse company.

- The utility truck was operated for two weeks in two different locations
  - The vehicle was a class 8 vehicle with a bucket. This vehicle was in a rental fleet during testing.

Power Take Off Testing Overview

- The testing showed that the utility truck had different duty cycles depending upon the operator and location of the vehicle.
- The testing showed that the refuse truck duty cycle was similar day-to-day for the routes it covered.
- SwRI analyzed the data and using cluster analysis to determine the most appropriate pump operation modes based upon the data for both vehicles.
- Two sub-cycles were developed, one for utility and one for refuse operations. These were combined into one cycle, weighted for time wihtin the cycle based on unit sales.

Power Take Off Testing Overview



Power Take Off Testing Overview

Hybrid Powertrain Testing Overview

- The test rig can test a two-loop or single-loop PTO system.
- The subject vehicle will be put near an emission analyzer and connected to the PTO rig.
- The vehicle will be operated over the cycle while measuring emissions.
- A conventional system will be tested and compared to the hybrid system. The difference will be used to calculate emission credits.