Project Report

Active Stop-Start^{TM} hybrid technology

Port Authority of New York – New Jersey

APM Terminal Demonstration Project

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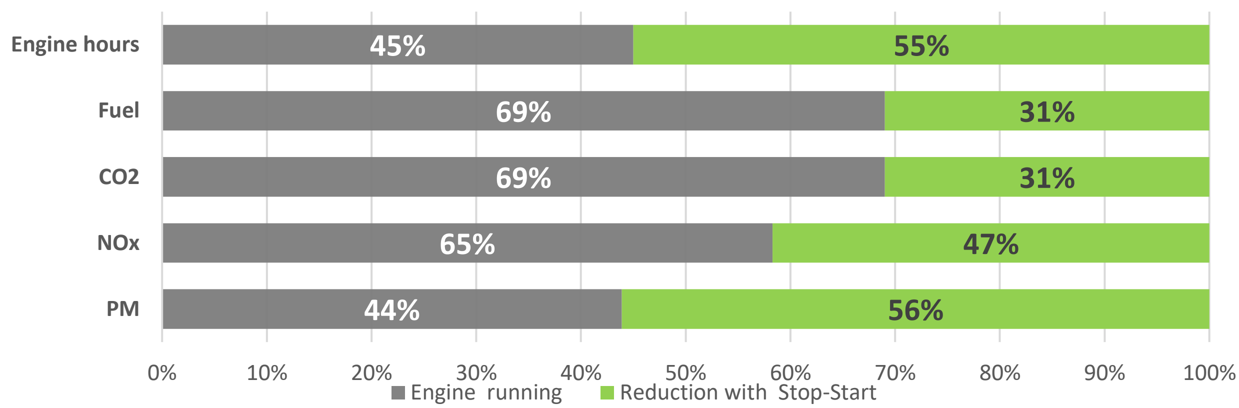
Summary

This report shows the progression of the demonstration of the Active Stop-Start technology™ on two terminal tractors at APM terminal (40451 and 40490). The technology virtually eliminates idle and therefore creates value by significantly reducing engine operating hours and corresponding fuel consumption, emissions and maintenance. The results of laboratory testing with the New York City Department of Sanitation are presented herein and show that beyond reducing fuel and related greenhouse gas emissions, stop-start operation also reduces criteria pollutants such as NOx, VOC and PM by an even greater extent.

Field deployment data collected over 36 operating days on tractor 40490 between November 1st and December 31st, 2018 show that by reducing engine run time by 55%, the Active Stop-Start™ system reduced fuel consumption and related GHG emissions by 31% and reduced NOx and PM emissions by 47% and 56%, respectively.



Because the tractors operate on a mix of one and two shift schedules, annual savings were calculated based on 12 operating hours per day. Considering 260 operating days per year, the yearly savings with the technology are:

1,718	816	8.3	353	2.12
ENGINE HOURS	GALLONS	TONS OF GHG	POUNDS OF NOX	POUNDS OF PM

Finally, a cost-effectiveness analysis reveals that, for new vehicle acquisitions, the Active Stop-Start™ technology is between 3 and 4.5 times more cost-effective than a full electric chassis on a per ton cost comparative and neglecting charging infrastructure. For a retrofit scenario of Tier 3 and Tier 4 Interim trucks, the technology again proves to be very cost-effective with $7,092 to $10,606 per weighted ton of criteria pollutant reduced, or $352 to $246 per metric ton of GHG eliminated.

1 About the technology

BENEFITS

- 40-50% fewer engine hours
- 15-30% fuel savings
- 12-30 tons CO_2/yr saved
- Reduced maintenance on engine and DPF
- Quiet operation

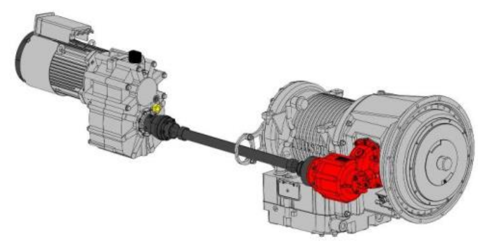
KEY FEATURES & SPECS

- Automatic, seamless idle off operation with no effect on cab comfort
- Vehicle equipment electrically powered with engine off
- Optional electric A/C with engine off
- Parallel system
- Weight: 640 lbs / 290 kg
- Wireless real-time vehicle monitoring

THE EFFENCO ACTIVE STOP-START™ TECHNOLOGY

Effenco's Active Stop-Start™ technology is an electric system designed to shut down the engine of vocational trucks when they are stationary and to provide electric power to the vehicle equipment, cab and chassis accessories including the HVAC system. Since these vehicles spend a large proportion of their operating time immobile, the Active Stop-Start™ technology creates value by reducing engine operating hours and corresponding fuel consumption, emissions and maintenance.

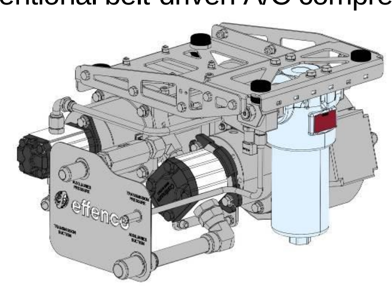
PTO MOUNTED ELECTRIC HYBRID STARTER



Because of the high stopping frequency of vocational trucks, the system is equipped with a powerful electric hybrid starter linked to the engine through a constant mesh PTO connection. The system uses this starter to restart the engine and does not add any load or wear to the existing electric starter and batteries. On releasing the brakes, the PTO mounted electric hybrid starter takes less than half a second to take the engine from a stop to idle speed making the vehicle as responsive as it would have been if the engine had been running.

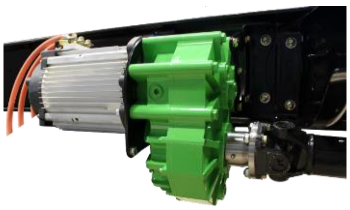
ELECTRIC ASSISTANCE WITH THE ENGINE OFF

When immobile, the system turns the engine off automatically and supplies power to equipment that would normally draw power from the engine. The system includes an electric motor-driven hydraulic pump (below left) which allows keeping the transmission engaged even if the engine is turned off. To keep the cab comfortable with the engine off, an optional electric A/C compressor can be added in parallel to the conventional belt-driven A/C compressor (right).



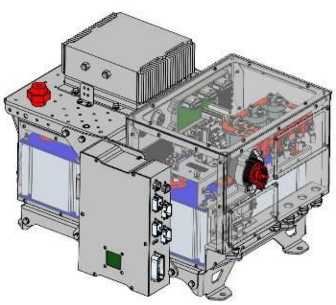
ELECTRIC HYBRID STARTER

- AC 3 Phases, 18kW peak power
- Passive gearbox
- CV joint automotive drive shaft



ULTRACAPACITORS

- 144V maximum voltage
- +10 year lifespan
- Not sensitive to temperature
- Totally enclosed, easily and safely serviceable



COMPATIBILITY

- Class 6-8 chassis
- Allison 3000, 4000, Contact Effenco for other models
- Diesel or CNG engines

ULTRACAPACITOR BASED ENERGY STORAGE

An electric power pack provides power to the electric hybrid starter as well as the vehicle equipment when the engine is off. This pack houses three 48V ultracapacitor modules from Maxwell Technologies featuring the new DuraBlue™ Advanced Shock and Vibration Technology. Recognized for their ruggedness, high cycle life, and resistance to temperature fluctuations, ultracapacitors are the best fit for the trucking industry. The electric power pack is enclosed in a rail mounted assembly which contains all the system's main components (below right).

ENERGY MANAGEMENT AND BENEFITS

The electric hybrid starter can operate as a motor or a generator. In generator mode it harvests power while the vehicle brakes. If braking energy is insufficient, it takes some power of the engine when at its best efficiency point. The Active Stop-Start™ system uses its stored energy to create value by virtually eliminating idle and low power operation of the combustion engine. The most exhaustive assessment of the performance of Effenco's system was carried out by New York City in their Vehicle Testing and Analysis Facility on a refuse truck. These tests confirmed that the Active Stop-Start™ technology eliminates idle fuel consumption with no parasitic losses.

SYSTEM INTEGRATION AND INSTALLATION

The Effenco Active Stop Start™ technology can be integrated to most vocational truck applications and configurations. Its modular packaging makes it suitable for retrofit or factory installation.

2 Converted vehicles

The vehicle converted are described below.

APM Terminal

Units	40451, 40490
Make	Ottawa Kalmar
Model	T2
Year	2016
Engine	Cummins B6.7
Engine Technology	Tier 4 Final
Transmission	Allison 3500
Deployed	August 3rd, 2018

3 Laboratory testing

This document provides a brief description of laboratory testing conducted to assess and measure the fuel savings and emission reductions generated by the Active Stop-Start™ electric hybrid technology for a port terminal tractor application.

3.1 Laboratory equipment

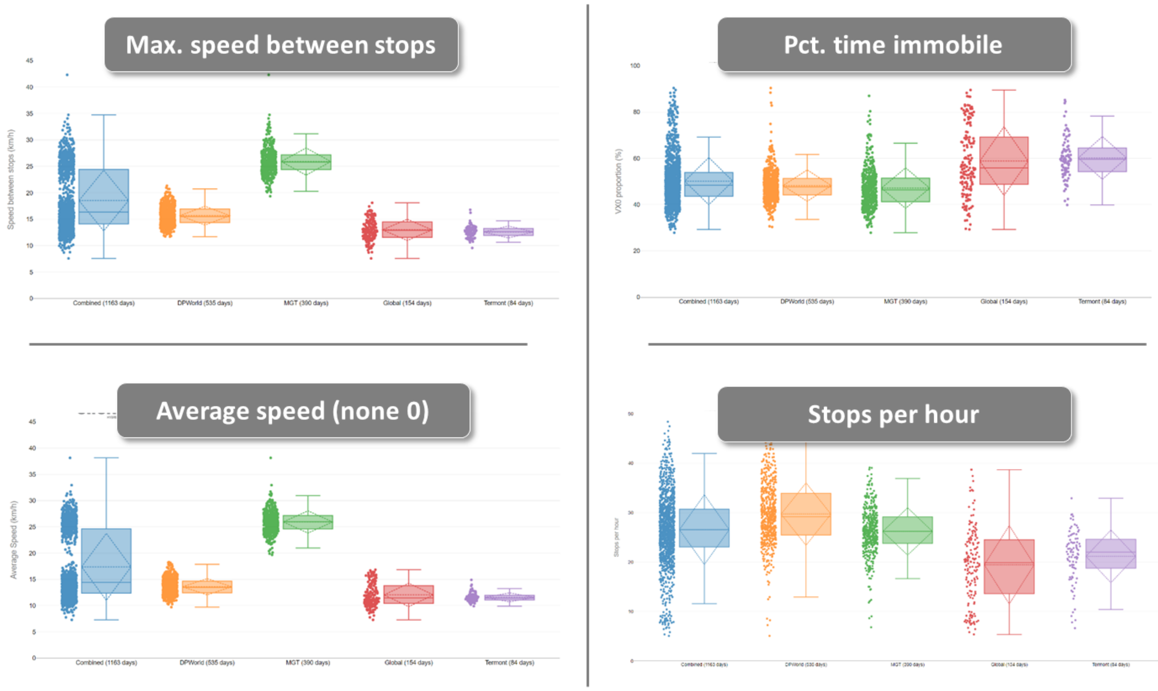
The assessment of Effenco's Active Stop-Start™ hybrid technology performance was carried out by New York City Sanitation Department at their Vehicle Testing and Analysis Facility. The department operates a state of the art, EPA certified level, heavy duty vehicle emissions testing laboratory with a HORIBA MEXA 7200 DTR emissions analyzer. The tests involved a 2014 Kalmar-Ottawa 4X2 port tractor operated by Global Container Terminal – New York. The vehicle was equipped with a Tier 4 Interim Alt NOx Cummins B6.7 engine rated at 173hp (ARB Executive Order U-R-002-0600, Engine Code 3098:FR92558).

Test cell doors

Hybrid truck on the dynamometer

3.2 Duty Cycle

The first step was to determine a baseline duty cycle that would represent typical operating conditions of a port terminal tractor. The speed cycle used for the laboratory testing was based on the analysis of 1163 days of operating data collected on 16 Effenco equipped terminal tractors deployed over four terminals. This data was swept to benchmark candidate repetitive micro cycles against the overall data using four key metrics; average speed, stops per hour, maximum speed reach between stops and idle time.



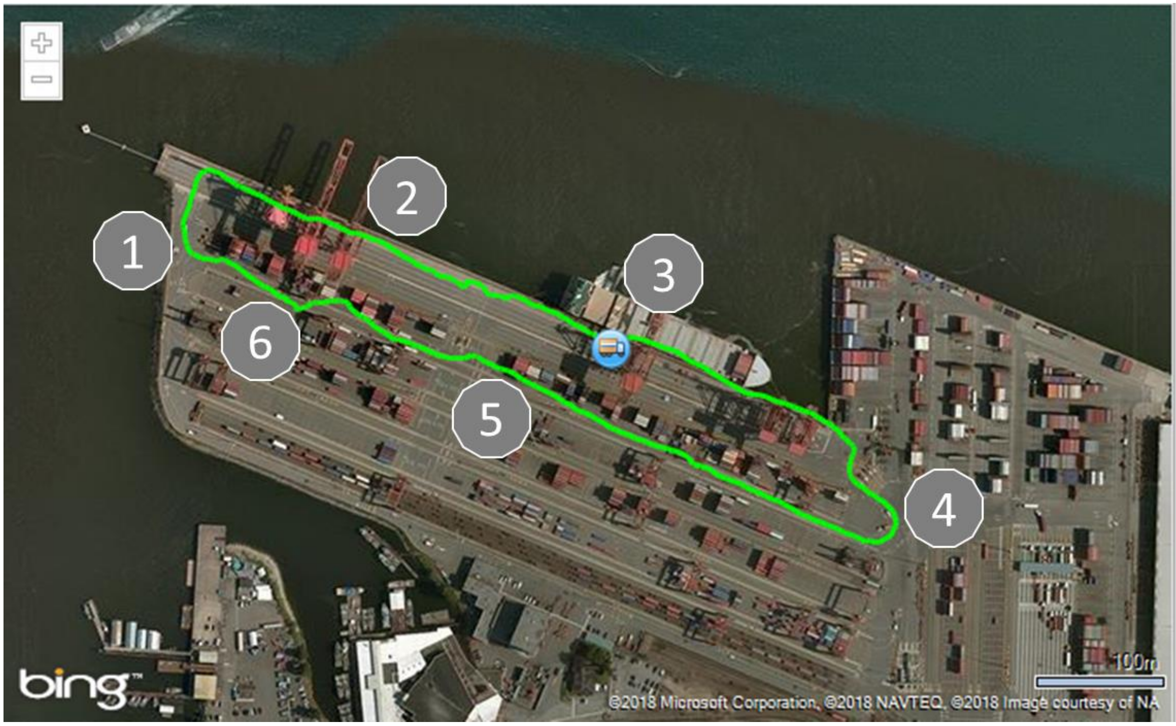
Statistical analysis of 1163 operating days based on four key metrics

The selected micro cycle is illustrated below and corresponds to a complete typical load-unload cycle of a port terminal tractor that involves the following phases:

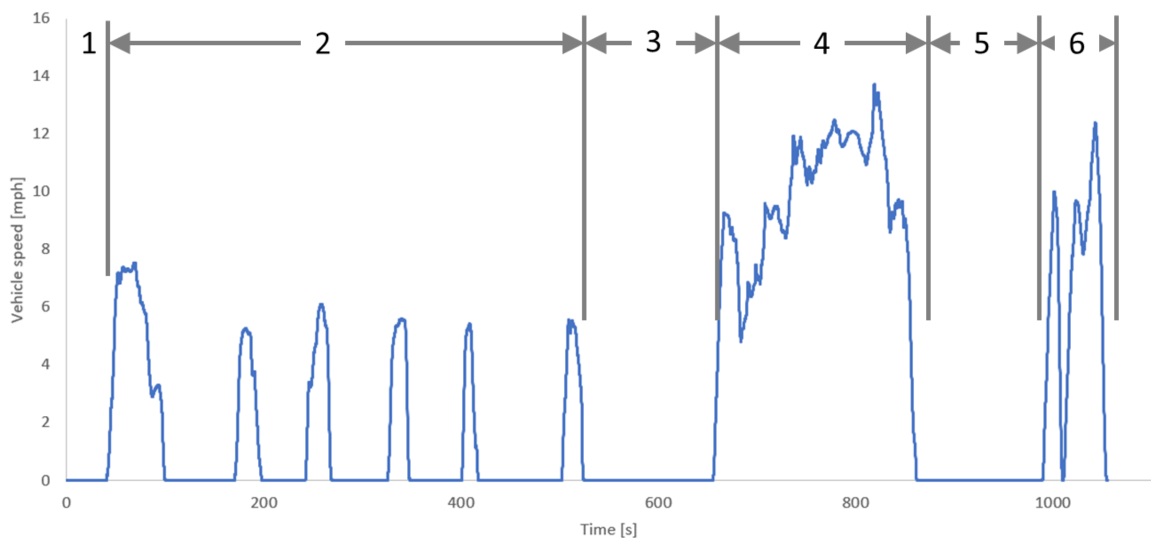
1. Queuing: Tractor is waiting in line to start a cycle
2. Approach: Tractor is creeping and performing several stops while approaching the vessel
3. Loading: Tractor is immobile while the container is being loaded from the ship
4. Transit 1: Tractor is transiting to the unloading site
5. Unloading Tractor is immobile while the container is being lifted from the chassis
6. Transit 2 Tractor is transiting back to the waiting line

The parameters of the speed cycle selected are listed below and the four key metrics (average speed, stops per hour, maximum speed reach between stops and idle time) are representative to the data base used for benchmarking.

Parameter	Unit	Value
Duration	s	1056
Distance	mile	0.87
Average speed	mph	2.96
Average speed in movement	mph	6.9
Stops per hour	-	30
Average max. speed between stops	mph	7.8
Time immobile	s	603
Proportion time immobile	%	57
Time idle, gear in drive	s	303
Proportion in drive at idle	%	50



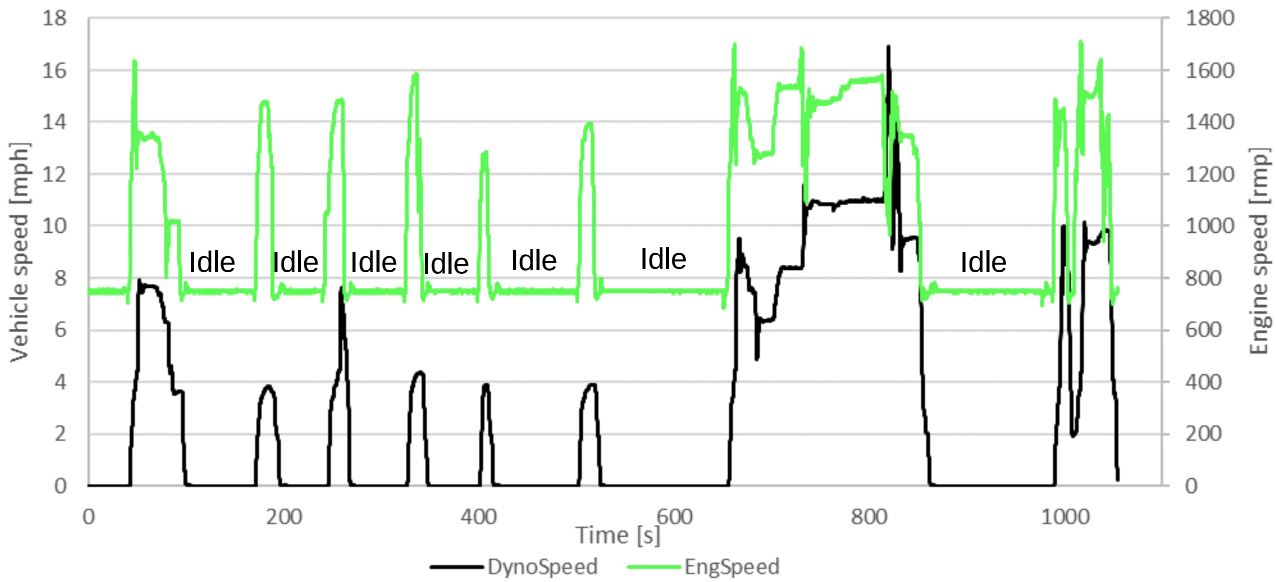
GPS trace of the selected micro cycle



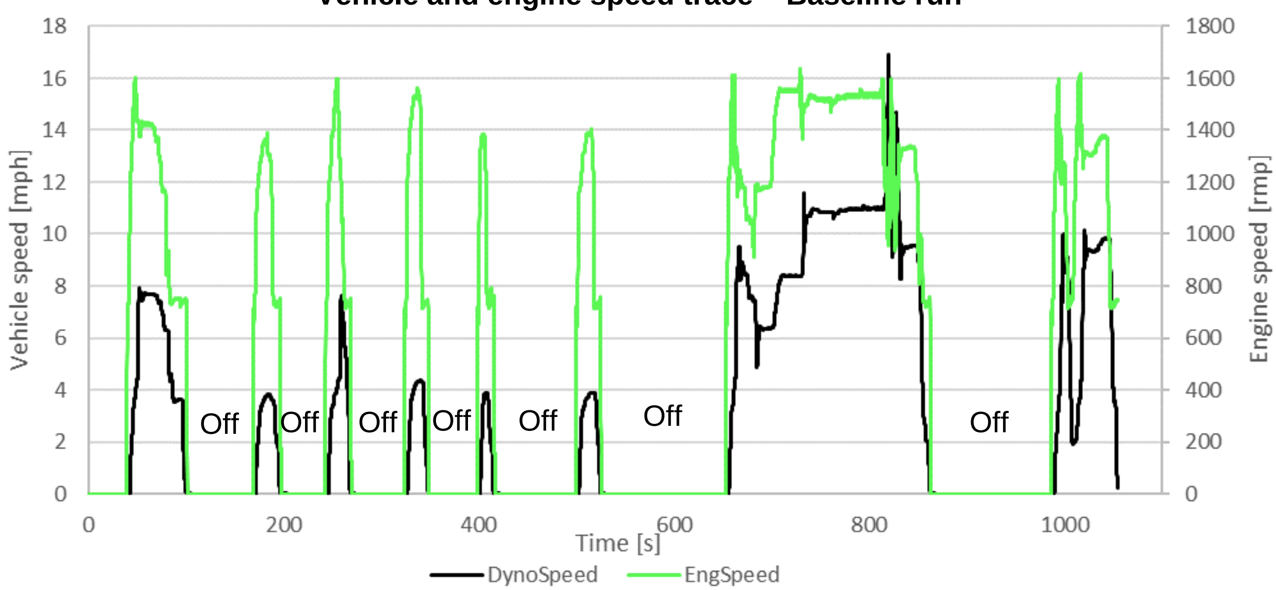
Speed profile of the selected micro cycle

3.3 Test runs

To measure the savings from the Active Stop-Start™ hybrid technology, tests were performed on the VTAF's dynamometer test bench with the system activated and deactivated where a HORIBA MEXA 7200 DTR emissions analyzer was used for exhaust gas analysis with an accuracy of ±2%. Two sets of 4 runs with the hybrid system deactivated and activated were alternatively conducted following the selected speed cycle to respectively determine the baseline and stop-start vehicle fuel consumption and emissions. Comparing the two graphics below, one can see how the technology eliminates the use of the engine as its rotational speed systematically goes to zero at every stop.



Vehicle and engine speed trace – Baseline run



Vehicle and engine speed trace – Hybrid run

3.4 Results

Results of this testing session are summarized in the table below. By reducing the engine run time by 56%, the technology allowed reducing fuel consumption and related CO2 emissions by 32%. The technology also allowed reducing NOx emissions by 48% (1.5 times fuel savings), HC, or VOC, emissions by 55% (1.72 times fuel savings) and PM emissions by 58% (1.81 times fuel savings). It should be noted that the test was run with little payload simulated which resulted in less fuel used for propulsion and a bigger proportion of idle fuel consumption than what is observed for in-use data. However, operating conditions that are meaningful to stop-start operation such as the number of restarts per hour and the overall idle time were perfectly simulated. Therefore, the measurements of absolute savings (fuel and emissions) related to idle elimination are valid. Also, the relative reductions (ratio) in NOx, HC and PM in comparison to CO2 are accurate and the tests demonstrated that the intensity of these emissions is higher at idle than when the engine is loaded.

NYC VTAF – Dynamometric test bench results – Port Terminal Tractor Cycle

Parameter	Unit	Baseline avg. 4 runs	Stop-Start avg. 4 runs	Difference
Time	s	1056.2	1057.0	0.1%
Distance	mile	0.82	0.83	1.4%
Average speed	mph	2.79	2.83	1.3%
Engine run time	s	1056.2	590.5	-56.0%
Fuel used	gallon	0.27	0.18	-32.4%
Fuel Economy	mpg	3.00	4.51	50.0%
CO2 Emissions	g	2774.1	1875.1	-32.4%
NOx Emissions	g	36.03	18.69	-48.1%
HC Emissions	g	0.82	0.37	-54.8%
PM Emissions	g	0.18	0.08	-58.4%

3.5 Emission factors

Based on the results obtained above, the following emission factors were deduced for in-use calculation of emission reduction for a port terminal tractor equipped with a Tier 4 Interim Alt NOx Cummins B6.7 engine rated at 173hp. The base unit is pounds of emission reduced per gallon of fuel saved at idle with the technology.

Emission factors in pounds per gallon of fuel saved with the Stop-Start technology

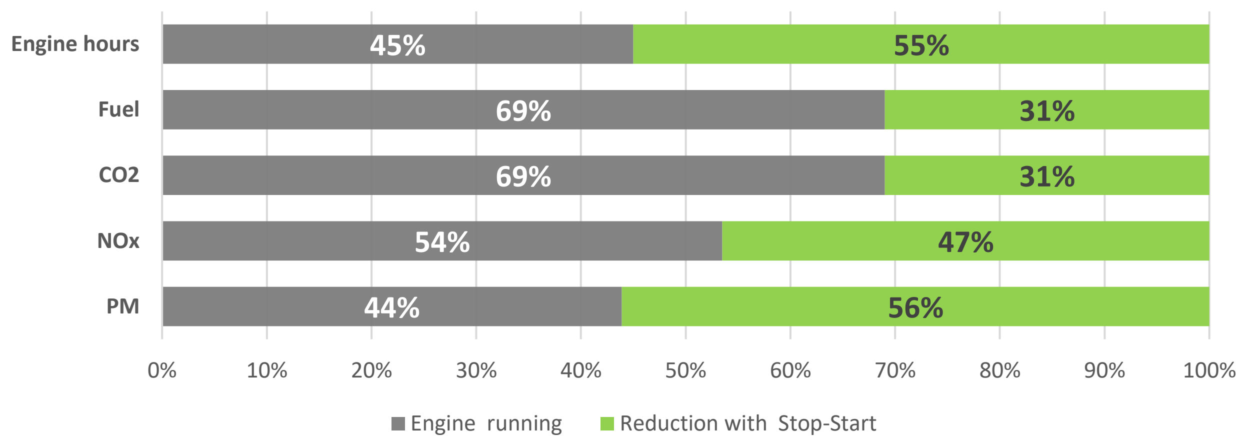
Emission factors	Values
CO2	22.39
NOx s	0.4320
VOC (HC)	0.0113
PM	0.0026

4 Field results

This section highlights the operating and performance statistics of APM terminal tractor 40490 equipped with Effenco's Active Stop-Start™ technology for the period between November 1st and December 31st, 2018. Our remote monitoring device recorded data for 36 days of operation during that period. In order to reflect typical operating conditions, days with irregular operating statistics (e.g. less than 2 hours of operation, 100% stationary due to maintenance, etc.) were discarded for data analysis. Note that no hybrid data were collected for tractor 40451 during this period as the system is presently waiting for a noise reduction device prototype.

Performance summary

The graphic below highlights how the Active Stop-Start™ technology performed considering only the days the system was fully functional during the period (30 days in total). By reducing engine run time by 55%, the Active Stop-Start™ system reduced fuel consumption and related GHG emissions by 31% on average and reduced NOx and PM emissions by 47% and 56%, respectively.



Annualized savings

Considering 260 operating days per year of an expected 12 hours a day, the yearly savings with the technology are:

1,718	816	8.3	353	2.12
ENGINE HOURS	GALLONS	TONS OF GHG	POUNDS OF NOX	POUNDS OF PM

Daily average operating and performance statistics

The table below presents under which conditions the vehicle operated and how the system performed for each of the 36 operating days recorded. As the system is still being fine tuned for the operation, the system has not been fully functional for some days (shown in light gray below). Consequently, the overall system availability has been of 84% bringing the effective fuel saving to 27% so far.

Days	Operating time [h]	Net fuel used [gal.]	Distance [miles]	Avg speed movement [mph]	Stops per hour	Immobile time [%]	Engine runtime reduction [%]	Fuel avoided [gal.]	Fuel savings [%]
11/9/2018	4.3	3.0	12.0	2.8	12	72	52	1.1	25.8
11/10/2018	8.6	4.5	15.5	1.8	8	78	60	2.5	35.6
11/15/2018	10.2	6.4	19.8	1.9	20	74	61	3.1	32.6
11/16/2018	9.4	6.2	15.2	1.6	10	80	44	1.9	23.3
11/17/2018	5.8	2.9	8.2	1.4	11	80	55	1.5	34.2
11/19/2018	9.0	5.0	14.8	1.6	13	73	54	2.3	31.5
11/20/2018	11.5	7.1	22.2	1.9	14	75	57	3.1	30.1
11/21/2018	11.1	10.0	17.2	1.5	11	80	17	0.9	8.4
11/23/2018	12.6	9.6	18.4	1.5	11	78	45	2.5	21.0
11/26/2018	11.3	7.4	19.7	1.7	15	71	58	3.1	29.9
11/27/2018	11.8	9.8	21.7	1.8	19	71	35	2.0	16.7
11/28/2018	12.6	5.7	16.3	1.3	13	78	66	3.9	40.2
11/29/2018	11.9	5.8	18.2	1.5	14	76	60	3.4	37.2
11/30/2018	9.9	7.9	18.7	1.9	24	66	28	1.3	14.3
12/3/2018	8.7	4.7	15.0	1.7	15	71	56	2.3	32.7
12/4/2018	12.3	7.4	21.4	1.7	16	73	50	2.9	28.5
12/5/2018	13.4	4.1	8.7	0.6	8	89	73	4.6	53.0
12/6/2018	8.5	4.4	12.3	1.4	14	76	62	2.4	35.2
12/7/2018	9.0	6.2	19.1	2.1	9	73	40	1.6	20.4
12/8/2018	2.7	4.9	16.8	6.3	33	39	25	0.3	5.6
12/10/2018	9.3	5.4	12.0	1.3	10	83	65	2.7	33.4
12/11/2018	8.6	2.9	8.3	1.0	8	86	71	2.9	49.5
12/12/2018	11.9	6.1	12.0	1.0	9	85	56	3.1	33.8
12/13/2018	11.2	6.5	13.0	1.2	8	84	52	2.7	29.5
12/14/2018	6.7	4.6	14.4	2.1	18	67	56	1.8	27.7
12/15/2018	4.2	2.8	7.8	1.9	15	71	52	1.0	27.1
12/17/2018	10.2	6.3	14.7	1.4	10	81	39	1.9	22.9
12/18/2018	9.8	5.2	13.0	1.3	11	82	60	2.6	33.6
12/19/2018	10.2	8.3	21.4	2.1	19	72	51	2.3	21.4
12/20/2018	9.6	4.8	11.8	1.2	10	80	63	2.7	35.5
12/21/2018	9.6	8.7	18.9	2.0	17	69	30	1.3	13.0
12/26/2018	9.2	6.1	17.9	1.9	17	69	56	2.4	28.2
12/27/2018	8.5	4.4	12.8	1.5	10	77	68	2.7	38.3
12/28/2018	7.2	5.0	18.4	2.6	15	63	43	1.4	22.1
12/30/2018	19.0	26.3	61.7	3.3	17	53	2	0.2	0.6
12/31/2018	6.5	9.0	23.4	3.6	20	54	10	0.3	3.5
Overall Avg.	**9.6**	**6.5**	**17.0**	**1.9**	**14.0**	**73.5**	**49.2**	**2.2**	**27.1**
100% Hybrid	**9.3**	**5.5**	**15.0**	**1.8**	**13.2**	**75.1**	**55.1**	**2.4**	**30.7**

Graphical representation of the trucks' operating cycle.

The figure below shows the course of a tractor during a day of operation (in white) and in which places and how long it stopped. The location of the colored spots indicates the stopping points while their respective size and intensity of red indicate the duration of these stops. This image shows how the immobile time is divided according to the different modes of operation during the day. We can see the truck being stopped at the cranes, at the containers stack and at the garage for example.

5 Deployment benefits and cost effectiveness

The benefits of the technology and its cost-effectiveness for two deployment scenarios, new tractors or retrofits, are presented here.

5.1 Emission calculations

Based on the fuel savings obtained with the field deployment so far at APM Terminal NY and considering the ratios to CO_2 reduction obtained for reduction of NOx, HC (VOC) and PM in laboratory, the respective expected emission reductions expressed in percentages are shown in the table below.

	Emissions			
	CO_2	NOx	HC (VOC)	PM
Expected in-use reductions	31%	47%	53%	56%

In order to compare the benefits of cost effectiveness for different engine technologies, the 2017 Moyer Program Guidelines were used to quantify the emission reductions. A sample calculation is presented below based for a Tier 4 Interim (Alt NOx) engine, the same engine that was used for the laboratory testing. The load factor for a yard tractor of 0.39 was obtained from table D-7 of Appendix D of the Guidelines. As for the emission factors of 2.15, 0.08 and 0.009 g/bhp-hr for, respectively, NOx, ROG (or VOC) and PM10 emissions, they were drawn from Table D-9, same section. Hence, using formula C-6 for calculating estimated annual emissions based on hours of operation as indicated in the Guidelines and neglecting the deterioration product for simplicity for this proposal, the respective annual NOx, ROG (VOC) and PM10 emissions were calculated as follow:

Annual NO_x emissions:

$$2.15\frac{g}{bhp \cdot hr} \times 173\ hp \times 0.39 \times \frac{12\ hours}{day} \times \frac{260\ days}{year} \times \frac{ton}{907{,}200g} \times 47\% = 0.234\ \frac{tons\ NO_x}{year}$$

Annual ROG(VOC) emissions:

$$0.08\frac{g}{bhp \cdot hr} \times 173\ hp \times 0.39 \times \frac{12\ hours}{day} \times \frac{260\ days}{year} \times \frac{ton}{907{,}200g} \times 53\% = 0.010\ \frac{tons\ ROG}{year}$$

Annual PM10 emissions:

$$0.009\frac{g}{bhp \cdot hr} \times 173\ hp \times 0.39 \times \frac{12\ hours}{day} \times \frac{260\ days}{year} \times \frac{ton}{907{,}200g} \times 56\% = 0.001\ \frac{tons\ PM10}{year}$$

Formula C-3 was used to calculate the weighted emission reductions as follow:

$$Weighted\ Emission\ Reductions = NO_x reductions\ \left(\frac{tons}{yr}\right) + ROG\ reductions\ \left(\frac{tons}{yr}\right) + \left[20 \times PM\ reductions\left(\frac{tons}{yr}\right)\right]$$
$$= 0.264\frac{ton}{year \cdot tractor}$$

The same calculations were performed for Tier 3 and Tier 4 Final engines using their respective emission factors and with the assumption that in-use reductions of NOx, ROG and PM10 emissions would follow the same pattern as observed in laboratory for the Tier 4 Interim engine technology. The respective emission and weighted emission reductions with Stop-Start per tractor for all three engine technologies are summarized in the table below.

Emission standards	NOx	VOC (ROG)	PM	Weighted emission reductions
Tier 3	0.253	0.011	0.015	0.564
Tier 4 Interim	0.234	0.010	0.001	0.264
Tier 4 Final	0.028	0.006	0.001	0.054

5.1.1 GHG reduction calculations

The following calculations were performed according to the Methodology for determining emissions reductions and Cost-Effectiveness from the Mobile Source Control Division of CARB. Considering the estimated annual baseline fuel consumption of 2,674 gallons for the tractor 40490, the annual GHG emissions per tractor is thus given by:

$$GHG\ Reduction = 102.01\frac{gCO_2e}{MJ} \times 134.47\frac{MJ}{gal} \times 4{,}217\frac{gal}{year} \times \frac{metric\ ton\ CO_2e}{1{,}000{,}000\ gCO_2e} = 36.7\frac{metric\ ton\ CO_2e}{year}$$

5.2 New truck replacement scenario

To determine the cost-effectiveness of the Active Stop-Start technology for a new truck replacement, a tractor with a Tier 4 Final engine technology is used as the baseline. Also, to benchmark the cost-effectiveness of the Active Stop-Start technology, it is here compared against a full electric terminal tractor and considering the following parameters and assumptions:

- Vehicle lifespan: 14 years
- Incremental cost of Active Stop-Start technology: $ 25,000
- Incremental cost of electric tractor vs new tractor: $ 180,000
- Midlife replacement battery cost: $ 50,000
- Electricity consumption: 3.5kWh/mile
- Electricity CO2 intensity (NY State): 512 lbs/MWh
- Annual distance: 5,200 miles
- Annual CO2 emissions from electricity (electric tractor): 4.23 metric tons

Hence, the cost-effectiveness of both technologies in regard to criteria pollutants (weighted emissions) and GHG emissions are given in the table below. The Active Stop-Start is 4.5 times more cost efficient for the former metric and more than 3 times for the latter **without considering the cost of infrastructure required for the electric tractor.**

Technology	Cost effectiveness	
	Weighted emissions (NOx, VOC and PM) [$/ton]	GHG [$/metric ton]
Active Stop-Start	33,069	156
Full electric	148,005	506

5.3 Retrofit scenario

The Active Stop-Start technology has the particularity of being retrofittable, giving the opportunity to immediately reduce emissions from existing trucks that should remain in service for several years. The table below shows the cost-effectiveness of retrofits for both Tier 3 and Tier 4 Interim technologies considering a 14-year vehicle lifespan and 28,000$ for the cost of a retrofit.

Engine technology	Remaining service years	Cost effectiveness [$/ton]	
		Weighted emissions (NOx, VOC and PM) [$/ton]	GHG [$/metric ton]
Tier 3	7	7,092	352
Tier 4 Interim	10	10,606	246