AN ATTEMPT TO RE-COMPUTE ECN IN THE FCA INSTRUMENT

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INTRODUCTION

This report is a continuation of an earlier report submitted to CIMAC (WG), titled "A Contrarian Approach to the Recommendations Made on Ignition Quality in the Proposed ISO 8217:2010 Standards". This approach did not agree that the ECN values given by the FCA instrument were consistent with engine performance, and therefore the instrument was to be discarded. This approach took a stand that there is nothing wrong with the instrument and a re-computation of ECN would fix the problem. Taking the approach that the ECN has to be re-computed, we made several efforts to arrive at an algorithm/formula to use the measurement parameters thrown by the instrument to arrive at the new ECN, hereafter known as NECN.

Please note that all the results and computations have been carried out on the FIA instrument model 100/3. Viswa Lab does have the new version of this instrument, FCA. However, since the data used for computation was old, generated by the 100/3 instrument, the entire working has utilized this old data. Suitable data points can be obtained for FCA and the formula can be modified, essentially to do the same work that this formula does.

We have totally considered 44 data points. Of these, there were about 8 cases where piston ring breakages were reported. In all these cases the ECN was above average (20-25, a number considered satisfactory). On the other hand, there were 6 data points from Santos fuels which have incredibly low ECN (<5). Interestingly, these fuels performed well in the engine without any problem or damage. This is the anomaly that prompted us to take a new look at the computation of ECN. This approach does not believe that the engine make and model have a major impact on the behavior of the actual fuel in the engine.

CONCEPT AND PURPOSE OF NEW ECN

The purpose of the Fuel-Tech instrument was to replace CCAI. It was clear that CCAI was not indicating the correct ignition property of marine fuels since these had undergone secondary refining properties instituted in the refineries. The instrument was initially designed for distillate and heavy fuels. Subsequently, the distillate fuel component was eliminated, and the instrument was to be used specifically for heavy fuels only. The ECN is a direct function of SMC or MCD. While this may have been correct for distillate fuels, it was incorrect to use the same equation to calculate ECN for heavy fuels. Heavy fuels have two, distinct, independent properties namely ignition and combustion. In slow speed marine diesel engines this distinction was critical. In other words, what may ignite fast (good ignition property) may not combust fast. Alternately, what may ignite very slowly (long ignition delay and long SMC), may combust properly. It all depends on the

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proportion of the paraffinic, naphthenic and aromatic proportions in the fuel. Since marine fuel does not define this proportion, the supplies from different parts of the world come with very different proportions of these constituents and therefore very different ignition and combustion properties. The question that we have to ask is: "What is expected of this instrument?" It will be ideal if this instrument can flag problem fuels and benchmark quality of all fuels. Unfortunately, the marine fuel is a lot more complicated. Less than 10ppm of organic chlorides can ruin the diesel engine fuel pump and nozzles. Presence of any acids or other refinery wastes and contaminants such as DCPD and styrene can choke up the filter, and cause enormous problems to the functioning of the engine. This instrument cannot flag these problems. What this instrument can do is to flag fuels which may cause problem strictly from the ignition and combustion point of view. This will be the MCR in the fuel, the asphaltene content in the fuel, and the paraffinic, naphthenic and aromatic contents of the fuel. From a quality point of view, it would be nice if this instrument can benchmark the ignition and combustion property of the fuel, so that the user can compare and also use the data for blending. Further study of the instrument and correlating with engine performance, may lead to this.

Out of the two considerations above, we have attempted to re-compute the ECN primarily to detect problem fuels. In this process there is also a benchmarking feature that the results are able to show. Both these will be described in detail below.

METHOD FOR NEW COMPUTATION & RESULTS

To arrive at the new formula for calculating a more representative equivalent cetane number (NECN), the parametric values available from the FIA-100 instrument were considered for use. This consists of the ignition delay (ID), start of main combustion (SMC), combustion period (CP), maximum rate of heat release (max ROHR), and time of max ROHR (max ROHR position). The instrument also provides a plot of the chamber pressure over time, and a second plot of the rate of change of pressure over time.

The data consists of fuel samples with a wide range of projected FIA-CN values that Viswa Lab has taken from March 2009 and later. For each sample, the ID, SMC, CP, max ROHR, and max ROHR position were readily available from FIA tests, as well as micro-carbon residue (MCR), density, viscosity, and asphaltene details.

Two additional variables of significance were derived for use in deducing the NECN. The first is the ratio CP/SMC, calculated by simply dividing a particular fuel sample's CP by its SMC. This is consistent with our approach that there is a distinct difference in the ignition and combustion properties of the fuel, and in order to arrive at a representative NECN, both factors have to be considered. The second variable is the rate of heat release at the SMC or dP/dt@SMC; it indicates the rate of chamber pressure increase when combustion begins. This is critical to understanding how the fuel transitions from ignition stage to combustion stage. Its calculation is shown in Appendix A.1.

With all the available measures in hand, data sorting provides useful trends. For example, the majority of fuels that caused piston rings to break (PRB fuels) had SMC's between 11.0 and 12.0 ms, while Santos fuels had much longer SMC values (above 19ms). Trends like these are useful in determining the final equation for the NECN. In reality, the PRB fuels with higher ECN caused machinery problems, while the Santos fuels with very low ECN's cause no problems in the engine. Our attempt was to re-compute ECN so that it will truly represent the properties of the fuel as it behaved in the engine.

By a trial-and-error process, the dependence of each of the variables was determined. The key to the equation is to accentuate the characteristics of the data such that the desired number is found. That is, the trends that are seen in the data, when sorting according to each variable, are exploited in determining the universal NECN equation. The key was to introduce coefficients (A-G) that could scale the contribution level of each variable.

The final equation is:

$$NECN = \frac{A}{SMC^2} + \frac{B}{(5*CP)^2} + \frac{C}{(ROHRpos)^2} + 10 \cdot D \cdot mROHR +$$

$$E \cdot \left(\frac{CP}{SMC} - 1\right)^2 + F \cdot \left(\frac{dP}{dt}_{SMC}\right)^2 + \frac{G}{(2 \cdot MCR)^2} \ - 75$$

Where the parameters have the following values:

Table 1 NECN equation parameter values

Parameter	A	B	C	D	E	F	G
Value	0.2	0	0.1	0.8	20	13	1000

The structure of this equation shows that the NECN is simply a summation of the contributions from the SMC, CP/SMC, etc. As mentioned above, the order of dependence for each variable was found by a trial and error process; essentially it became an optimization problem where the contributions must be balanced such that the NECN's for the PRB fuels ended up lower than the corresponding FIA-CN's, and those of the Santos fuels became higher.

Plots of the individual functions, e.g. A/SMC^2, provided a strong visual aid to help assess the quality of the equation. These can be found in the Appendix A.3. The plots help to see which characteristics of the fuel's data can be manipulated to suit this purpose. Our best results were seen when we set the orders of dependence as the following:

Table 2 Order of dependence of ECN on each variable

Variable	SMC	CP	ROHRpos	mROHR	CP/SMC	$dP/dt|_{SMC}$	MCR
Order	-2	0	-2	1	2	2	-2

Earlier it was stated that the aim of the NECN is to utilize only information available from the FIA instrument. However an external variable, the micro-carbon residue (MCR), has been used in this analysis. The reason behind this is that the MCR is a major parameter affecting engine performance, and fuels with high MCRs are likely to experience problems. In determining the equation, it was found that simply using the ignition and combustion data was not enough to create enough of a spread or difference between the NECNs of regular and PRB fuels. After further review of this equation, if the MCR remains as a variable to calculate the NECN, then the instrument operators will have to manually feed this number to the instrument for the result.

Similarly, asphaltenes are also a significant, known contributor to engine problems. Fuels with high asphaltene content (>7%) are likely to clog piston rings and gaps which may result in breakage and high wear. Of the "regular" fuel samples in the data, asphaltene values were not readily available. In terms of averages, the asphaltene content for 2009 PRB fuels is 9.2%, that of older PRB fuels is 10.1%, only 4 values were available for the regular fuels averaging 6.2%, and lastly the Santos fuels contained ~4.5%. Though there are only 4 data points of regular fuels available to us, we can project this trend to state that future work on defining a universal ECN should certainly include the asphaltene content as an additional variable. In fact, asphaltene content could even replace MCR in future study.

This study is performed over a total of 44 data points, of which 6 points are new 2009 PRB fuel cases, 4 points are older PRB fuel cases, and 6 are Santos fuels. The table below summarizes the average NECN values that results for each fuel group. Please see Appendix A.2 for an expanded data table showing values for each data point.

Table 3 Average variable and NECN values for the different fuel types

Fuel Type	ID (ms)	SMC (ms)	CP (ms)	mROHR pos(ms)	mROHR (bar/ms)	CP/ SMC	dP/dt @ SMC (bar/ms)	MCR (%)	Asphalt enes	NECN
PRB	8.3	11.6	15.8	12.0	1.5	1.36	1.08	14.5	9.2	8.8
PRB Old	7.8	10.5	17.6	10.6	1.9	1.67	1.29	15.5	10.1	15.0
Regular	8.9	12.4	17.2	13.0	1.5	1.40	1.10	12.8	6.2	24.1
Santos	11.9	19.5	24.0	19.4	0.8	1.24	0.52	11.5	4.5	69.6

As seen, the NECN equation assigns the lowest values to the PRB fuels, and higher values for good fuels. The plot below summarizes the scattering of the results. It shows the NECN against the SMC. The '09 PRB data is mainly gathered between SMC's of 11 and 12 ms, with NECN values ranging from ~1 to ~16. The problem fuels have an NECN below 17, with a majority under 10. The regular fuels on which there are no reports of machinery problems have an average of 24.1, while the Santos fuels had a much higher number of 69.

Figure 1 Plot of NECN vs. SMC for all data points, distinguishing fuel type

ASSUMPTIONS AND CONDITIONS

It is important to note that the Viswa Lab samples considered for this study were all evaluated using the older FIA 100/3 instrument. This may not be the latest model of the instrument, however the concept suggested here will hold true for the new version as well.

Consider table 4, which is an extract from the data table in appendix A.2.

Table 4 Data for PRB fuels ordered by increasing NECN, including the FIA-CN

Fuel Sample ID	ID (ms)	SMC (ms)	CP (ms)	FIA Cetane #	CP/SMC	dP/dt @ SMC (bar/ms)	MCR (%)	Asphaltenes (%)	NECN
F090516221	7.90	11.65	16.50	17.50	1.416	0.978	17.55	9.7	1.5
F090931026	8.15	11.45	15.20	19.60	1.328	1.087	16.38	9.5	3.6
F090724534	8.30	11.80	15.70	16.40	1.331	1.031	13.86	11.0	7.7
F090204768	8.50	12.15	17.80	15.90	1.465	0.990	15.29	10.4	9.4
F090103177	8.30	11.15	14.50	20.60	1.300	1.229	14.16	na	10.1
F090410717	8.90	12.70	19.20	14.70	1.512	0.949	17.25	na	10.7
F090100492	8.80	12.45	15.40	15.80	1.237	0.986	13.40	na	10.8
F090517096	7.95	10.70	16.60	22.20	1.551	1.273	15.55	na	11.0
PB8	7.35	9.95	16.40	24.80	1.648	1.351	15.61	8.9	12.2
F090102587	8.35	11.45	16.10	17.80	1.406	1.141	14.20	na	12.5
F090932405	8.80	12.55	18.00	14.60	1.434	0.963	14.38	na	13.6
F090929882	8.25	11.05	13.10	21.00	1.186	1.247	12.04	6.7	14.2
F090828589	9.05	13.35	17.40	11.60	1.303	0.853	13.46	na	14.9
PB1	8.25	11.25	19.00	20.60	1.689	1.176	16.23	10.7	15.0
F090308975	8.60	11.95	20.50	17.30	1.715	1.064	15.40	na	15.4
PB6	8.00	10.75	17.10	22.00	1.591	1.273	14.78	10.3	16.0
F090413186	8.50	11.65	16.60	17.40	1.425	1.123	11.58	7.7	16.2
F090102378	8.05	10.95	16.40	21.30	1.498	1.215	13.07	na	16.3
PB7	7.55	10.15	17.70	24.10	1.744	1.346	15.29	10.4	16.6

Note that the PBX Fuel Sample ID's indicate older than 2009 PRB fuel samples. If we consider only the 2009 PRB fuels then in descending order the NECN values are: 16.2, 14.2, 9.4, 7.7, 3.6 and 1.5. With a total of 29 regular fuel data points, if 16.2 is considered the limit for determining bad or good fuels, then there are 8 regular fuel data points that are interspersed with the PRB fuel data (values less than 16.2). How to explain 8 regular fuel data points which are in the same range as problem fuels? We tried to look into the asphaltene content of these regular fuels. We got results for only 5 of them. In all of them the asphaltene content was below 6.8%. Therefore, the problem fuels are distinguished by 4 factors: A) NECN (values below 16.2), B) SMC (11-12ms), C) MCR (>12.0%), and D) Asphaltene (>9%). When all four filters are applied, we can identify the problem fuel with reasonable accuracy. Even if we identify it with 85% correlation accuracy, it should be considered acceptable. We also feel that asphaltene could replace MCR in the equation, based on a future extended study. The thumb rule that asphaltene is two-third's of MCR is no longer valid; asphaltene content has to be determined experimentally.

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CONCLUSIONS

This instrument truly represents the ignition and combustion properties of the fuel. It is indicative of how the fuel will behave in the engine. So far the problem has been in interpreting the data, arriving at a suitable computation process to determine the correct ECN number. This is what has been attempted in this paper. It is accepted that the validity of this computation has to be checked with a huge number samples and data points. Suitable modifications may have to be made to the algorithm based on bulk data. In fact, the asphaltene content in the fuel should form part of the equation. At the end of all this exercise, the user will get an ECN which is truly representative of the ignition and combustion property of the fuel – more particularly, the damage potential of the fuel. In addition the new ECN gives a benchmark rating of the ignition and combustion property of the fuel, however, this has to be validated by the actual performance of this fuel in a standard engine. In other words, the same engine under same conditions should produce more power for a fuel with a higher NECN than one with a lower NECN. This part of the work remains to be completed.

Also to be noted is that this instrument will not identify presence of chemical waste, contaminants, or adulterants which may not affect the ignition and combustion properties, but may ruin the engine through excessive wear. Therefore at best, this instrument will represent one important facet of the fuel quality, namely ignition and combustion. Other means have to be employed to identify other facets of marine fuel quality. We are confident that, for this limited purpose, a newly computed ECN taking into consideration a much larger database and using the FCA instrument will provide the right answer.

DISCLAIMER

Please note that procedure and results suggested here are by no means the fantastic panaceas to grade all fuels. Rather, it is an individual attempt at reconciling the discrepancies between real world evaluation of a fuel and its FIA interpretation. The inherent accuracy of the instrument is beyond doubt; rather we must correctly process the data into accurate information of use to us. This work is intended to spur more complete and effective study, into the correct translation of the instrument's data specifically for use in evaluating marine fuels.

APPENDIX

A.1: Calculation of CP/SMC and dP/dt @ SMC

Consider the following fuel sample:

Table 5 Sample data point showing all variables

Fuel Sample ID	ID (ms)	SMC (ms)	FIA Cetane #	CP (ms)	max ROHR position (ms)	max ROHR (bar/ms)	Density (kg/m3)	Viscosity (cSt)	MCR (%)
F090517096	7.95	10.70	22.20	16.60	10.60	1.80	990.50	368.60	15.55

To calculate the **CP/SMC**:
x = CP/SMC = 16.60ms / 10.70ms = 1.551

To calculate the **dP/dt @ SMC**:
We desire an equation for dP/dt i.e. an equation to describe the plot of ROHR against time. To find this, we use the 3 known points at time t=0, t=ID, and t=SMC.

- At time t=0, the pressure is equal to the reference chamber pressure, P=45bar.
- The ignition delay is the point at which the pressure has risen to 0.2 bars above the reference pressure.
- The start of main combustion is the timestamp when the pressure has risen to 3 bars above the reference pressure.

In short:

Time (ms)	0.00	7.95	10.70
Pressure (bar)	0.0	45.2	48.0

There is only one specific 2nd order polynomial equation that connects these 3 points, and using the regression option in Microsoft Excel, it is found to be:
$P = 0.09028*t^2 – 0.7127*t + c$, bar

The derivative of this equation is thus: $dP/dt = 0.1856*t – 0.7127$, bar/ms

And it is evaluated at the SMC:

$dP/dt|_{SMC} = 0.1856*(10.70ms) – 0.7127 = 1.273$ bar/ms

A.2: Data Tables

Table 6 Values of all variables for each data point, including the NECN

Fuel Sample ID	ID (ms)	SMC (ms)	CP (ms)	mROHR pos (ms)	mROHR (bar/ms)	CP/ SMC	dP/dt @ SMC	MCR (%)	Asphalte nes (%)	NECN
F090516221	7.90	11.65	16.50	11.90	1.40	1.416	0.978	17.55	9.7	1.5
F090931026	8.15	11.45	15.20	12.00	1.40	1.328	1.087	16.38	9.5	3.6
F090724534	8.30	11.80	15.70	12.10	1.40	1.331	1.031	13.86	11.0	7.7
F090204768	8.50	12.15	17.80	12.60	1.40	1.465	0.990	15.29	10.4	9.4
F090103177	8.30	11.15	14.50	11.30	1.70	1.300	1.229	14.16	na	10.1
F090410717	8.90	12.70	19.20	13.00	1.40	1.512	0.949	17.25	na	10.7
F090100492	8.80	12.45	15.40	12.60	1.40	1.237	0.986	13.40	na	10.8
F090517096	7.95	10.70	16.60	10.60	1.80	1.551	1.273	15.55	na	11.0
PB8	7.35	9.95	16.40	9.90	1.90	1.648	1.351	15.61	8.9	12.2
F090102587	8.35	11.45	16.10	11.60	1.90	1.406	1.141	14.20	na	12.5
F090932405	8.80	12.55	18.00	12.80	1.60	1.434	0.963	14.38	6.4	13.6
F090929882	8.25	11.05	13.10	11.40	1.70	1.186	1.247	12.04	6.7	14.2
F090828589	9.05	13.35	17.40	13.40	1.40	1.303	0.853	13.46	na	14.9
PB1	8.25	11.25	19.00	11.20	1.90	1.689	1.176	16.23	10.7	15.0
F090308975	8.60	11.95	20.50	12.30	1.40	1.715	1.064	15.40	na	15.4
PB6	8.00	10.75	17.10	10.80	2.10	1.591	1.273	14.78	10.3	16.0
F090413186	8.50	11.65	16.60	11.90	1.40	1.425	1.123	11.58	7.7	16.2
F090102378	8.05	10.95	16.40	11.20	2.00	1.498	1.215	13.07	na	16.3
PB7	7.55	10.15	17.70	10.60	1.80	1.744	1.346	15.29	10.4	16.6
F090412169	9.50	13.65	20.00	13.80	1.10	1.465	0.874	13.60	na	17.9
F090205382	7.30	9.75	15.60	10.10	2.00	1.600	1.423	12.92	5.2	18.7
F090514205	9.65	13.20	19.30	13.40	1.50	1.462	0.996	14.19	6.4	19.4
F091034688	7.70	10.00	13.30	10.30	2.00	1.330	1.491	11.99	6.3	20.1
F090722393	7.70	9.85	11.90	10.10	2.10	1.208	1.581	12.25	6.8	21.4
F091240063	8.95	12.15	16.80	12.40	1.30	1.383	1.100	10.54	na	21.5
F090308729	9.80	14.41	19.20	14.90	1.20	1.332	0.794	13.16	na	23.2
F091136326	7.05	9.20	14.10	9.80	2.10	1.533	1.601	11.31	na	26.9
F090205786	8.60	12.75	20.00	19.50	0.90	1.569	0.887	17.16	na	27.9
F090514528	10.75	15.65	20.10	16.00	1.10	1.284	0.744	14.22	na	29.6
F090101966	8.30	10.80	15.80	11.00	2.30	1.463	1.374	10.44	na	30.6
F090724161	9.85	14.35	17.20	14.90	1.10	1.199	0.810	10.18	na	30.6
F090205787	9.50	15.15	19.70	15.20	0.90	1.300	0.672	10.53	na	31.4
F090517153	7.20	9.35	15.70	9.80	2.20	1.679	1.595	11.30	na	31.6
F090101603	6.80	8.80	13.30	8.90	2.00	1.511	1.711	10.22	na	31.6
F090515888	10.65	14.95	19.50	15.60	1.20	1.304	0.833	11.79	na	32.5
F091136725	12.45	16.50	19.60	16.40	1.10	1.188	0.856	11.93	na	42.9
F090931851	10.85	16.90	21.50	17.60	0.90	1.272	0.622	12.37	na	43.1
F090930752	11.25	17.70	19.80	17.50	0.80	1.119	0.585	11.33	na	48.9
F091137007	9.75	12.85	16.20	13.20	1.40	1.261	1.116	7.09	na	53.9
F090930254	11.40	17.60	22.20	17.60	0.90	1.261	0.606	10.27	5.1	55.0
F090827898	12.10	19.50	24.10	19.50	0.80	1.236	0.517	11.61	na	68.6
F090828626	12.55	19.80	27.00	19.50	0.80	1.364	0.522	12.44	na	70.2
F090828209	11.90	21.50	24.70	21.00	0.60	1.149	0.415	11.41	4.2	88.2
F090828208	12.55	21.65	24.60	21.20	0.50	1.136	0.431	10.62	4.1	92.6

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Table 7 Contributions of each parameter/variable group for all data points in the study

Fuel Sample ID	A/ SMC	C/ max ROHR position	D/ max ROHR	E/ CP/SMC	F/ dP/dt	G/ MCR	Sum
F090516221	27.14	14.16	11.20	3.47	12.45	8.12	**1.535**
F090931026	26.22	14.40	11.20	2.15	15.36	9.32	**3.641**
F090724534	27.85	14.64	11.20	2.18	13.82	13.01	**7.711**
F090204768	29.52	15.88	11.20	4.32	12.75	10.69	**9.372**
F090103177	24.86	12.77	13.60	1.81	19.62	12.47	**10.127**
F090410717	32.26	16.90	11.20	5.24	11.72	8.40	**10.716**
F090100492	31.00	15.88	11.20	1.12	12.63	13.92	**10.751**
F090517096	22.90	11.24	14.40	6.08	21.07	10.34	**11.028**
PB8	19.80	9.80	15.20	8.40	23.74	10.26	**12.202**
F090102587	26.22	13.46	15.20	3.30	16.94	12.40	**12.510**
F090932405	31.50	16.38	12.80	3.77	12.07	12.09	**13.611**
F090929882	24.42	13.00	13.60	0.69	20.22	17.25	**14.170**
F090828589	35.64	17.96	11.20	1.84	9.46	13.80	**14.905**
PB1	25.31	12.54	15.20	9.49	17.97	9.49	**15.005**
F090308975	28.56	15.13	11.20	10.24	14.71	10.54	**15.378**
PB6	23.11	11.66	16.80	6.98	21.05	11.44	**16.050**
F090413186	27.14	14.16	11.20	3.61	16.41	18.64	**16.166**
F090102378	23.98	12.54	16.00	4.95	19.18	14.63	**16.289**
PB7	20.60	11.24	14.40	11.07	23.56	10.69	**16.558**
F090412169	37.26	19.04	8.80	4.33	9.93	13.52	**17.878**
F090205382	19.01	10.20	16.00	7.20	26.32	14.98	**18.714**
F090514205	34.85	17.96	12.00	4.27	12.89	12.42	**19.381**
F091034688	20.00	10.61	16.00	2.18	28.88	17.39	**20.062**
F090722393	19.40	10.20	16.80	0.87	32.51	16.66	**21.439**
F091240063	29.52	15.38	10.40	2.93	15.73	22.50	**21.468**
F090308729	41.53	22.20	9.60	2.21	8.20	14.44	**23.175**
F091136326	16.93	9.60	16.80	5.67	33.30	19.54	**26.850**
F090205786	32.51	38.03	7.20	6.47	10.23	8.49	**27.921**
F090514528	48.98	25.60	8.80	1.62	7.19	12.36	**29.557**
F090101966	23.33	12.10	18.40	4.29	24.55	22.94	**30.605**
F090724161	41.18	22.20	8.80	0.79	8.52	24.12	**30.620**
F090205787	45.90	23.10	7.20	1.80	5.87	22.55	**31.428**
F090517153	17.48	9.60	17.60	9.22	33.08	19.58	**31.569**
F090101603	15.49	7.92	16.00	5.23	38.04	23.94	**31.615**
F090515888	44.70	24.34	9.60	1.85	9.02	17.99	**32.496**
F091136725	54.45	26.90	8.80	0.71	9.53	17.57	**42.947**
F090931851	57.12	30.98	7.20	1.48	5.03	16.34	**43.148**
F090930752	62.66	30.63	6.40	0.28	4.45	19.48	**48.890**
F091137007	33.02	17.42	11.20	1.36	16.20	49.73	**53.943**
F090930254	61.95	30.98	7.20	1.37	4.77	23.70	**54.969**
F090827898	76.05	38.03	6.40	1.11	3.48	18.55	**68.615**
F090828626	78.41	38.03	6.40	2.64	3.54	16.15	**70.171**
F090828209	92.45	44.10	4.80	0.44	2.24	19.20	**88.236**
F090828208	93.74	44.94	4.00	0.37	2.42	22.17	**92.645**

Figure 2 Plot of NECN vs SMC for all data points

Figure 3 Plot of NECN vs SMC for all data points, distinguishing fuel group

Figure 4 Plot of coefficient group A's contribution to the NECN vs SMC

Figure 5 Plot of coefficient group B's contribution to the NECN vs SMC

Figure 6 Plot of coefficient group C's contribution to the NECN vs SMC

Figure 7 Plot of coefficient group D's contribution to the NECN vs SMC

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Figure 8 Plot of coefficient group E's contribution to the NECN vs SMC

Figure 9 Plot of coefficient group F's contribution to the NECN vs SMC

Figure 10 Plot of coefficient group G's contribution to the NECN vs SMC

Figure 11 Superimposed plot of each of the coefficient groups' contribution to the NECN, vs SMC