The Efficacy of the ESP on Cordwood Stoves

Appendix G: Analysis of Device Performance

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Appendix G. Analysis of Device Performance

To provide a basis to understand the performance of the ESP device, the TEOM and ESP operational data were combined and processed to permit a graphical display of emissions performance on a consistent basis during the test. The work was performed by Rincon Ranch Consulting under subcontract to Trinity Consultants and is included here at the request of ADEC and FNSB.

The TEOM measurements of particulate emissions were reported on a minute-by-minute basis by ClearStak. For the two cordwood stoves, the data include baseline emission rates measured before the ESP was installed and test run emission rates measure at the outlet of the ESP, both in units of g/hr. The ESP operational data are the device's diagnostic information reported on a second-by-second basis through a data-logging interface to Microsoft Excel. Many different parameters are reported, but for this analysis the key data fields are voltage (V), current (μA), and power (mW). These values indicate whether the ESP is in operation or not and provide the chief measures of its instantaneous operational state.

Arcing events can have a large impact on emissions exiting the ESP. Arcing events are instants in time when the voltage, current and power fall to zero as the high-voltage electrode is shorted to ground by accumulated PM. Two types of arcing events were coded. The device itself may report a trouble code of 8 to indicate that an event has occurred. In addition to such Reported Arcing Events, Suspected Arcing Events were coded whenever the power fell to zero but a trouble code of 8 was not reported. For either type, an event begins when a second with zero power occurs and will continue until such time as power rises above zero. Reported and Suspected Arcing Events are mutually exclusive and both may influence stack emissions.

The TEOM was placed into operation when the IDC test procedure began; start and end times were recorded for each test. The ESP datalogging was started independently and could be initiated before the test began, when it began, or shortly thereafter since the ESP turns itself on automatically after a delay of a few to several minutes from starting the test. The first step in the analysis was to align the ESP operational data according to the test start and end times associated with the TEOM data. Then, the second-by-second operational data were reduced to minute or sub-minute averages in order to facilitate graphical display. During the processing, it was determined that the second-by-second data frequently fail to report a second or may report data with a duplicate timestamp. This logging irregularity results in missing 1.8 seconds of each minute on average; most minutes consist of 57-59 entries with duplicated timestamps in some cases. Because of this, the second-by-second entries were treated as generic "entries" that are assumed to be evenly

spaced throughout the minute. The difference between this treatment and the true (but unknown) time base of seconds is too small to be detectable in the graphs.

Arcing events are very short-term events that last at most a few seconds. The full second-by-second data show these events clearly along with intra-minute detail on the operational parameters during more normal operation, but the data are unwieldy to display because the IDC test spans a total of several hours. To address this, while retaining the short-term visualization of arcing events, minute-by-minute averages of voltage, current and power were computed to correspond to the TEOM data, but the computation switched to a second-by-second basis whenever an arcing event (of either type) occurred. The data were then reported on a second-by-second basis through the end of the minute in which the arcing event ends. Emissions and operational data were then plotted on an X, Y basis where X can be an integer minute or a decimal value representing a sub-minute average or a single second in time.

Two graphs were created to display a range of operational parameters and emission rates. The set of four graphs were produced for the entire test cycle and for its phases: Startup, High Fire, Maintenance Fire and Overnight Fire. The phase durations are not a static length in minutes, but are variable based on how rapidly the stove burns the prescribed fuel load. An abbreviated test procedure was used with Stove 19, which terminated the IDC cycle after minute 30 of the Maintenance Fire phase due to the stove's low emission levels. For Stove 9, graphs are shown for the entire run, the Startup, High Fire, Maintenance, and Overnight phases. ESP Run 3 was not analyzed as the ESP errored out during testing and the ESP operational data could not be saved. For Stove 19, graphs are for shown for the entire run, the Startup, High Fire, and an abbreviated Maintenance Fire phase, which ends after 30 minutes.

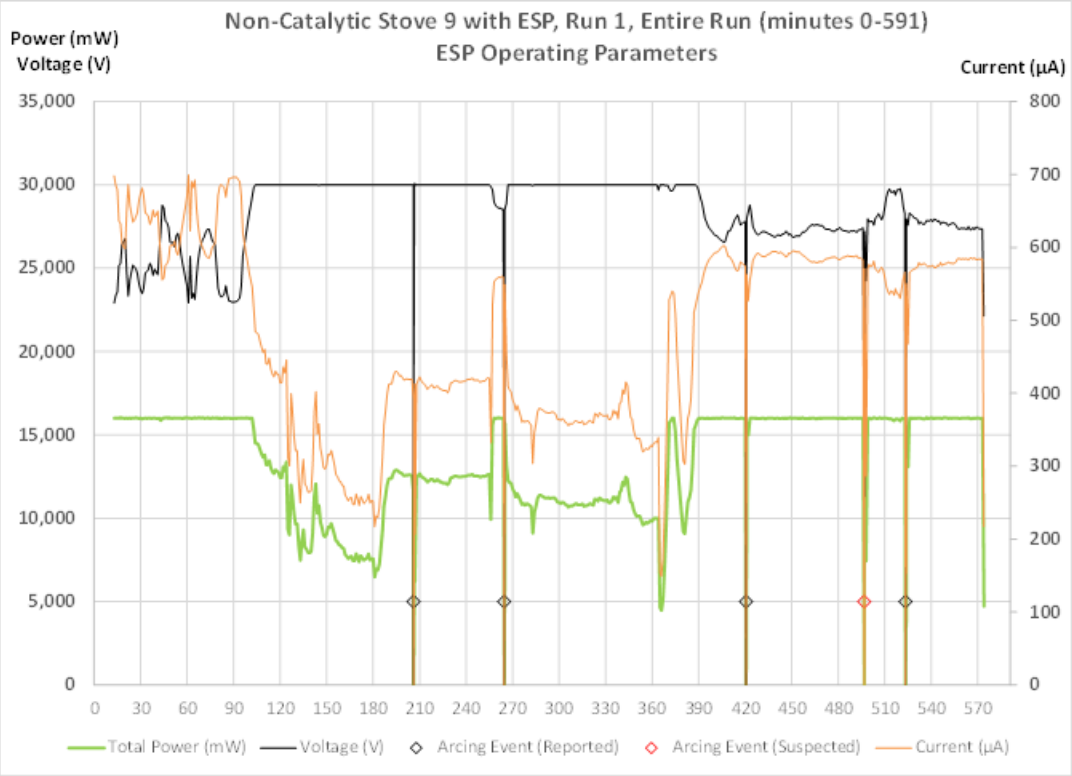
The graphs and variables displayed in them are the following:

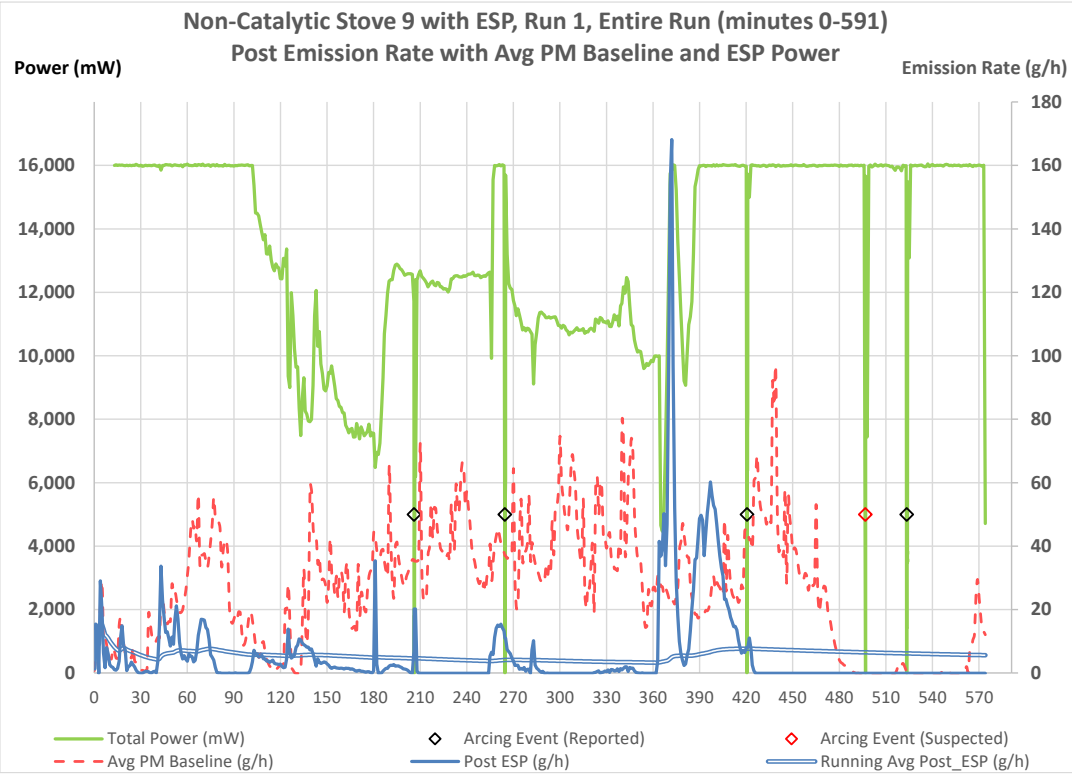
- ESP Operational Parameters: graph of ESP Power, Voltage and Current during the test. Arcing events are indicated by black and red diamonds and overlaid on the graph at the level of 5,000V (an arbitrary position chosen for clarity).
- Average Baseline and Post-ESP Emission Rate with ESP Power: graph of PM emissions measured during the Baseline testing, on average, and after the ESP during the test run to. Power and arcing events are also shown as in the first graph.

An important caveat should be noted in the use and interpretation of the graphs. In this testing, emissions from the stove were not measured concurrently with emissions from the ESP. The red lines labeled Avg Baseline are those measured on average during the Baseline tests. They reflect the stove emissions on a minute-by-minute basis *during the Baseline testing* and are shown for reference versus the emissions out

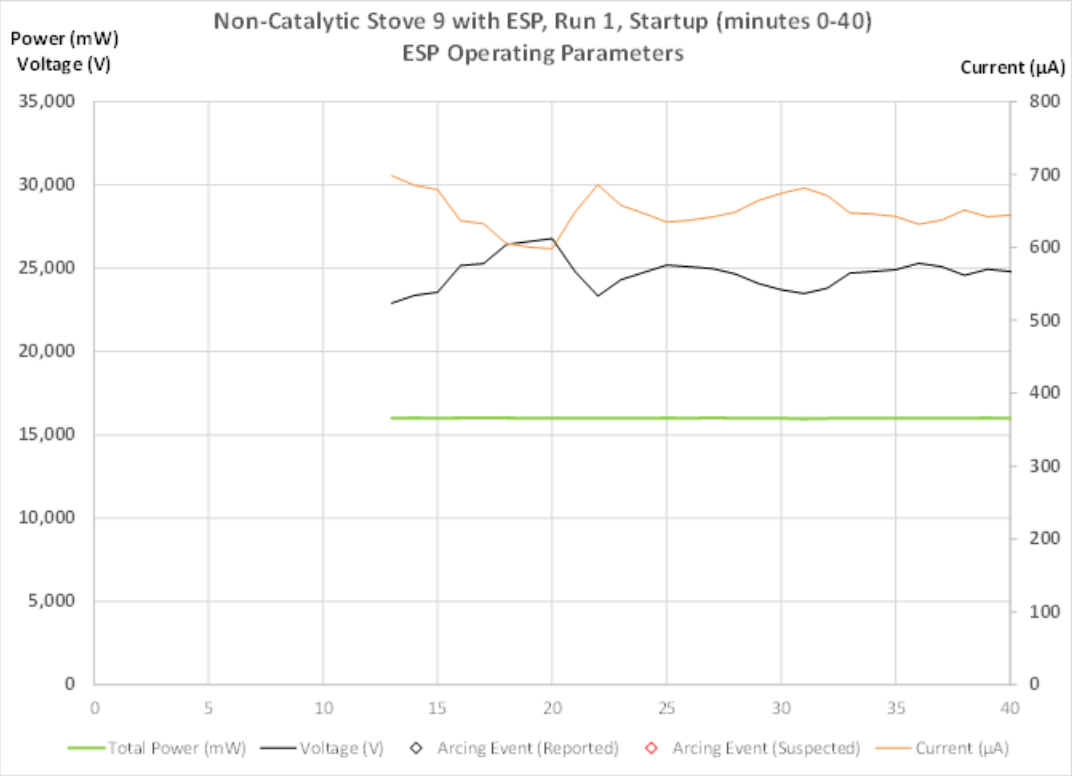
of the ESP during the test run. The Avg Baseline does not represent stove-out emissions *during the ESP testing* and, thus, does not match up minute by minute with ESP-out emissions.

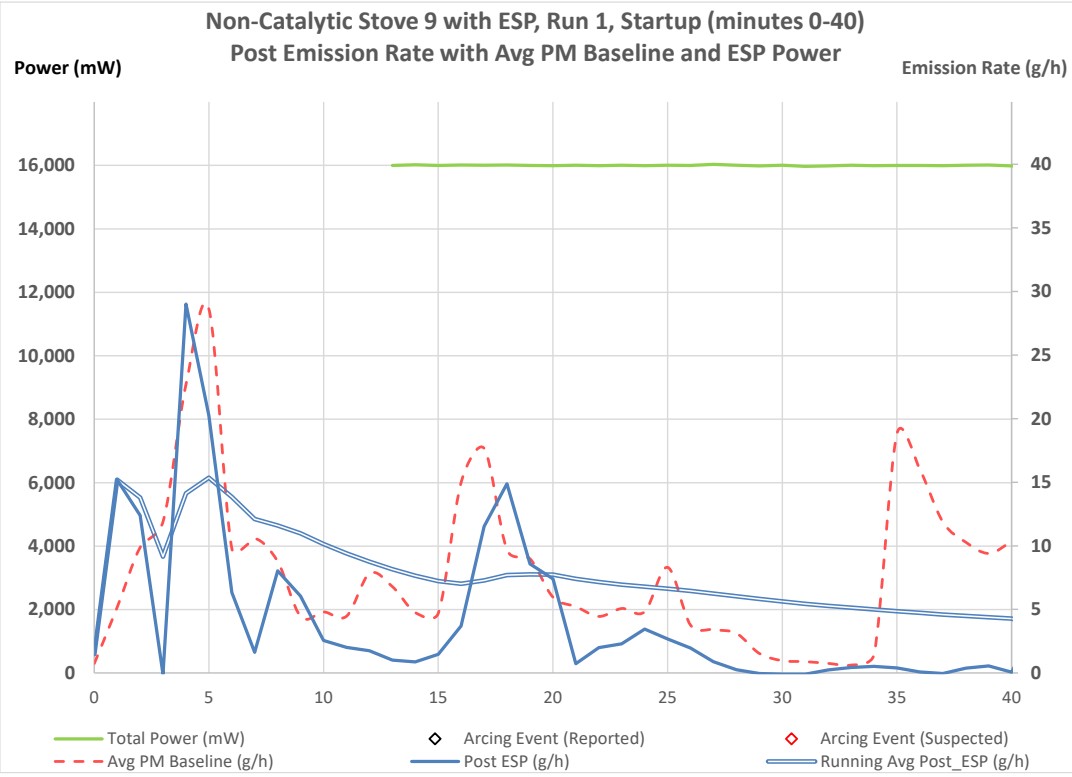
Cordwood Stove 9 with ESP, Run 1, Entire Run



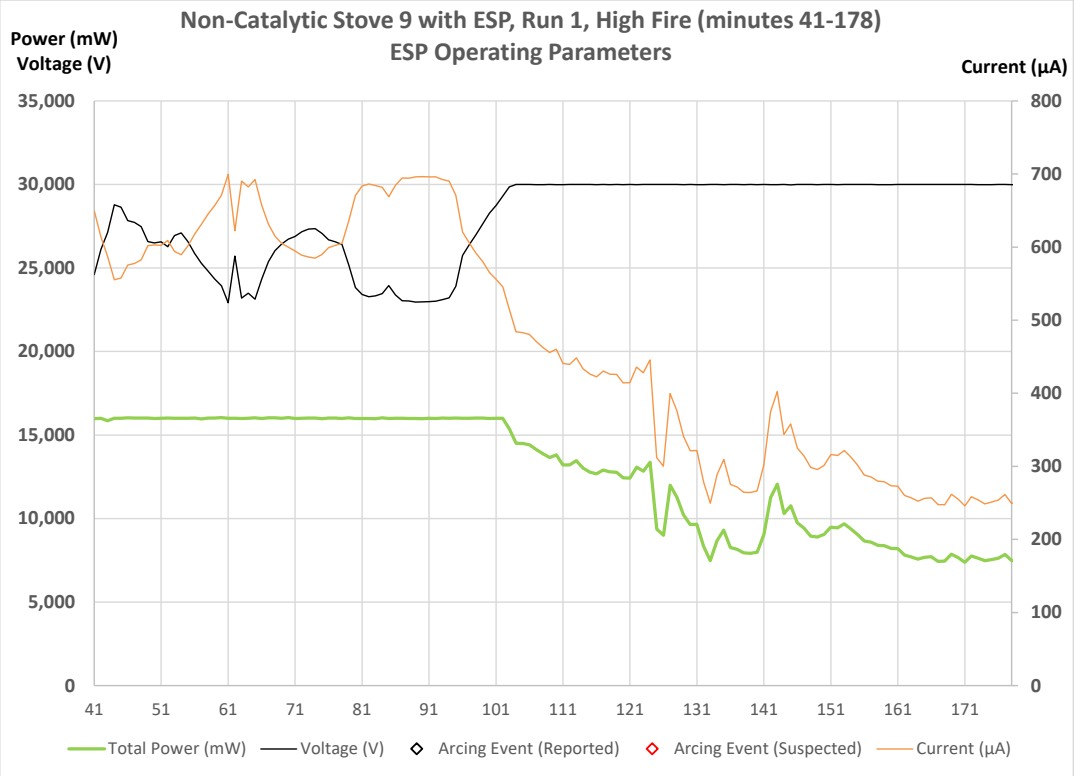


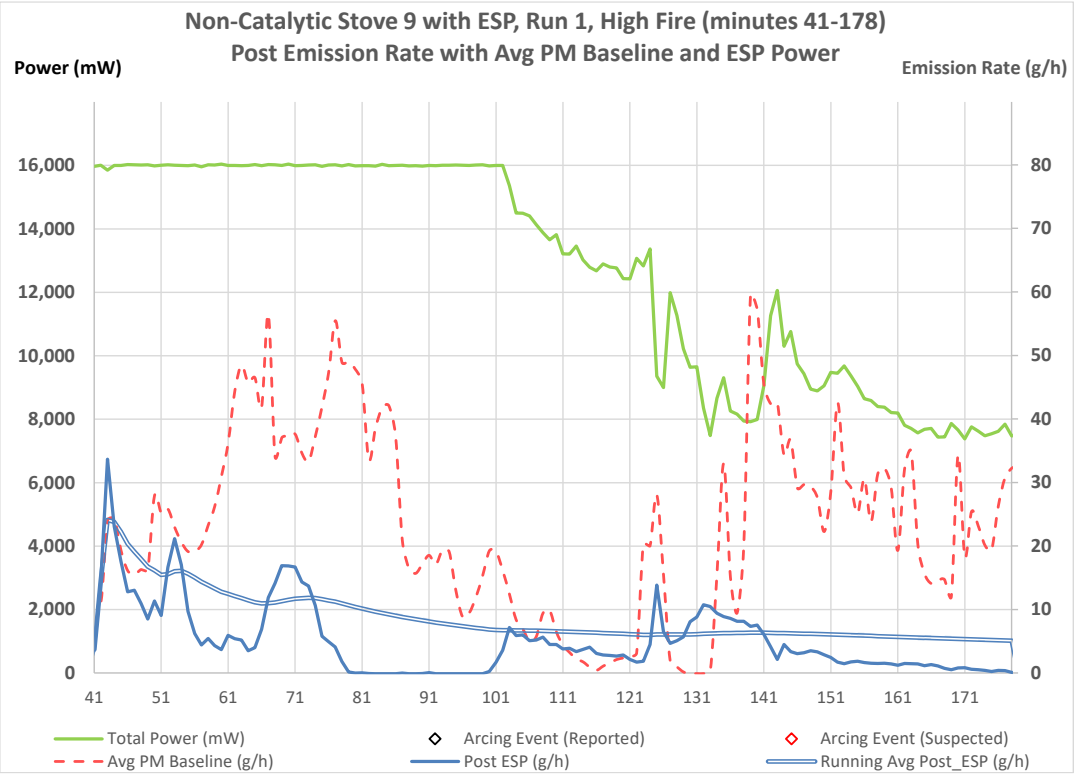
Cordwood Stove 9 with ESP, Run 1, Start-up



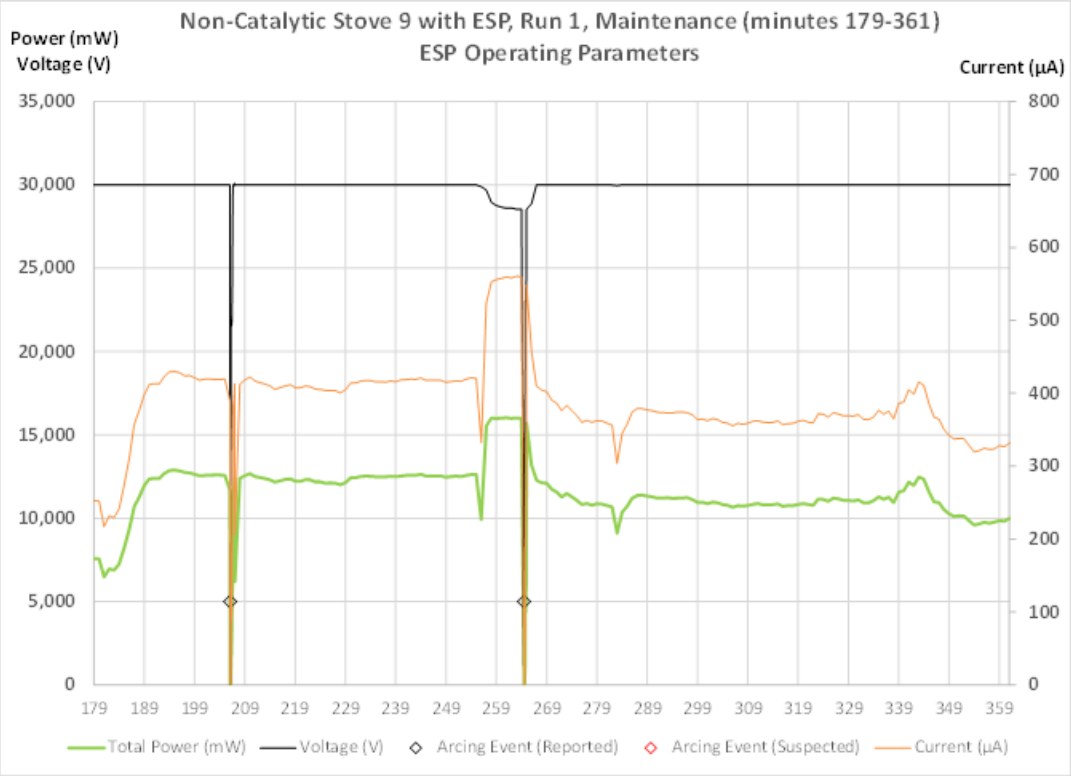


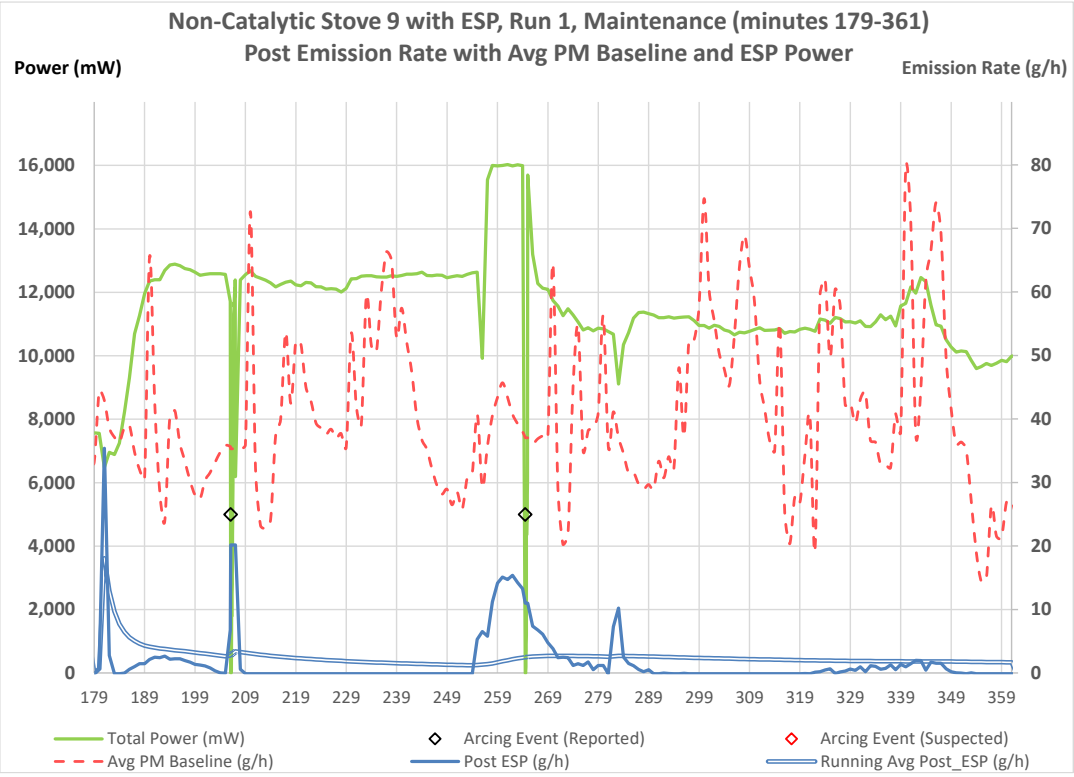
Cordwood Stove 9 with ESP, Run 1, High Fire



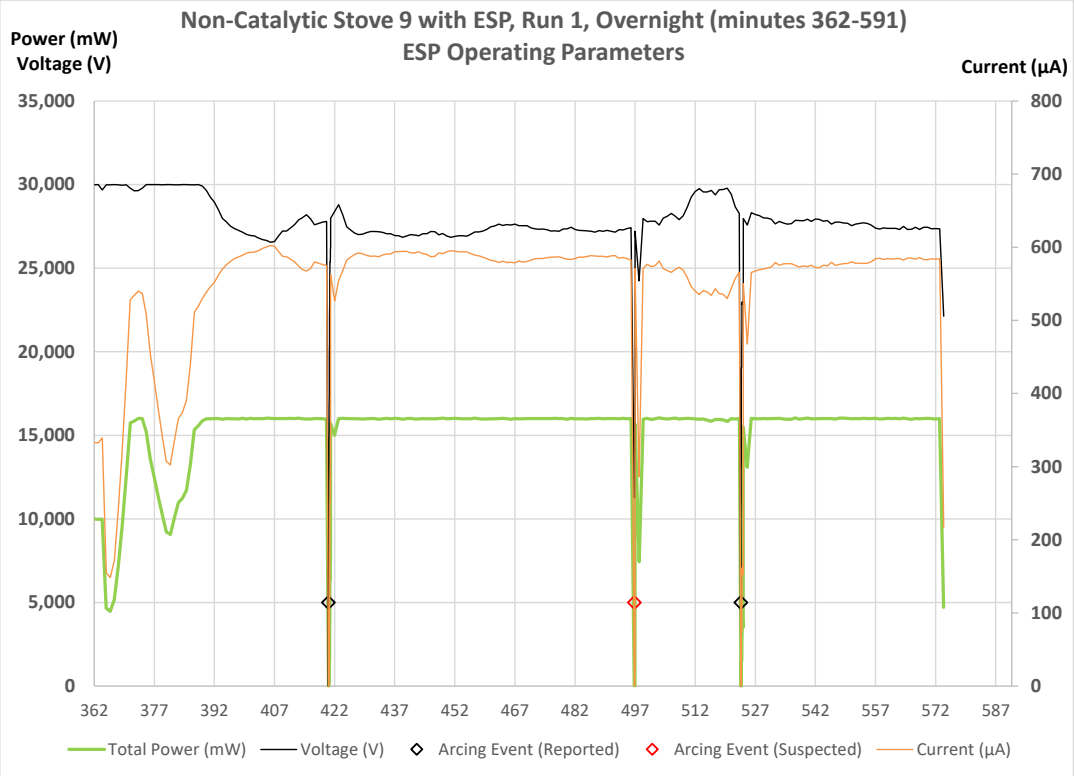


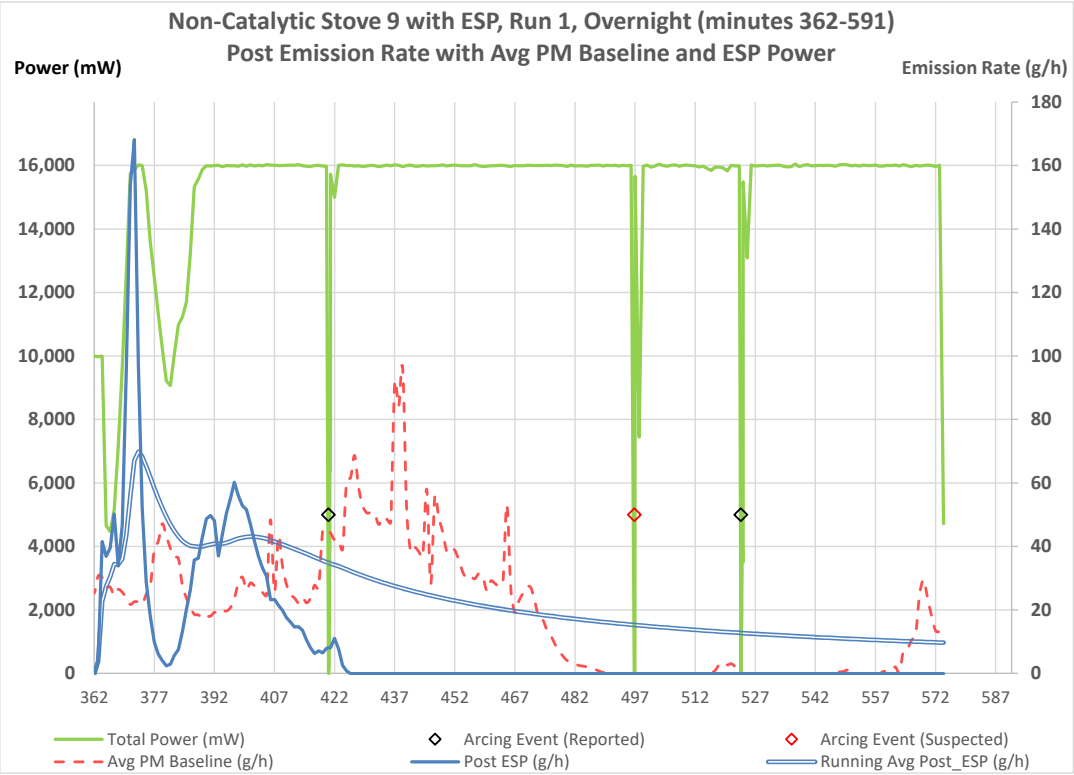
Cordwood Stove 9 with ESP, Run 1, Maintenance Fire



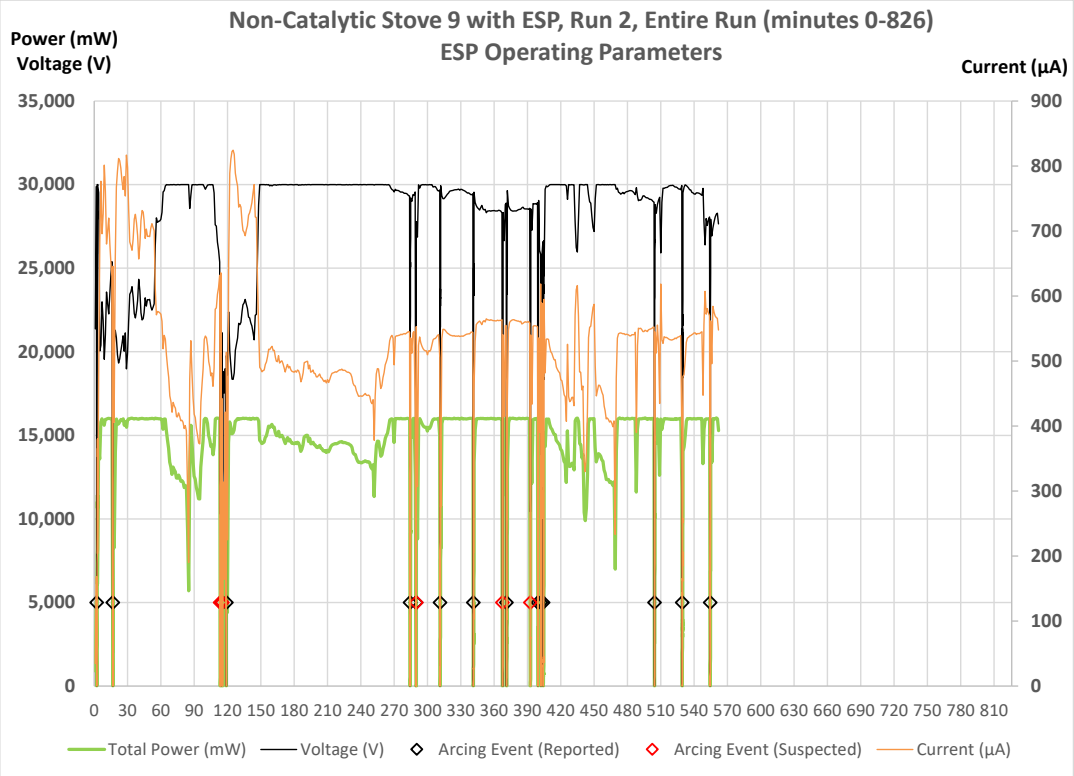


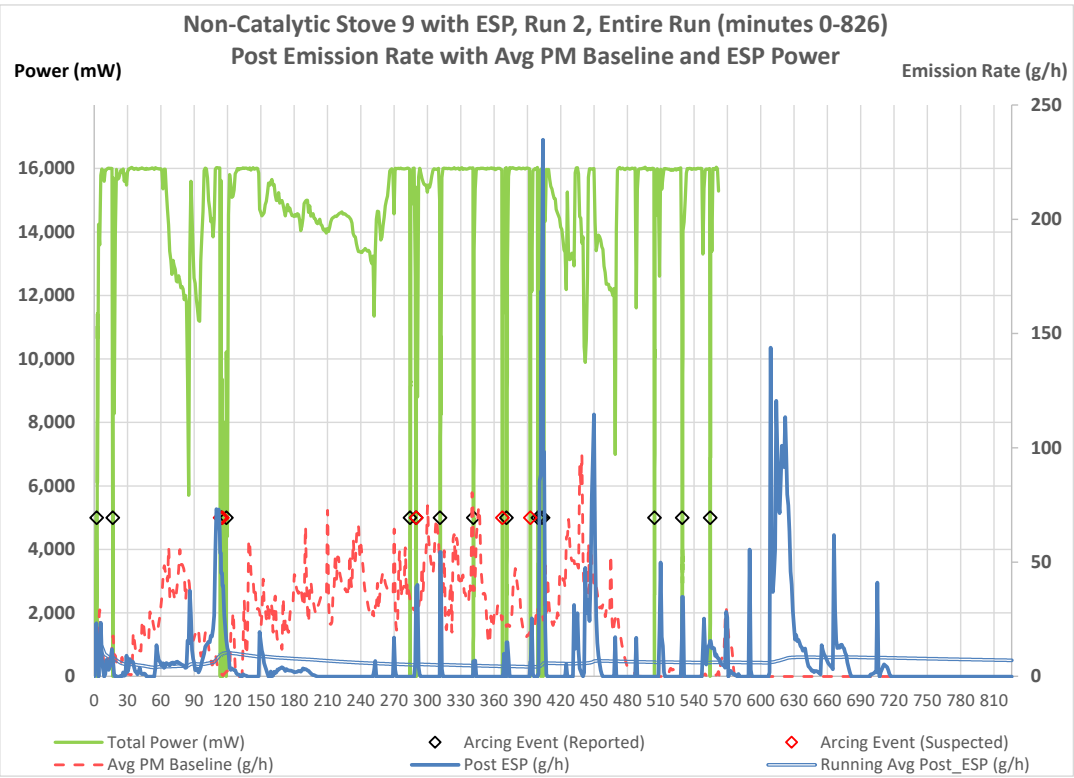
Cordwood Stove 9 with ESP, Run 1, Overnight Fire



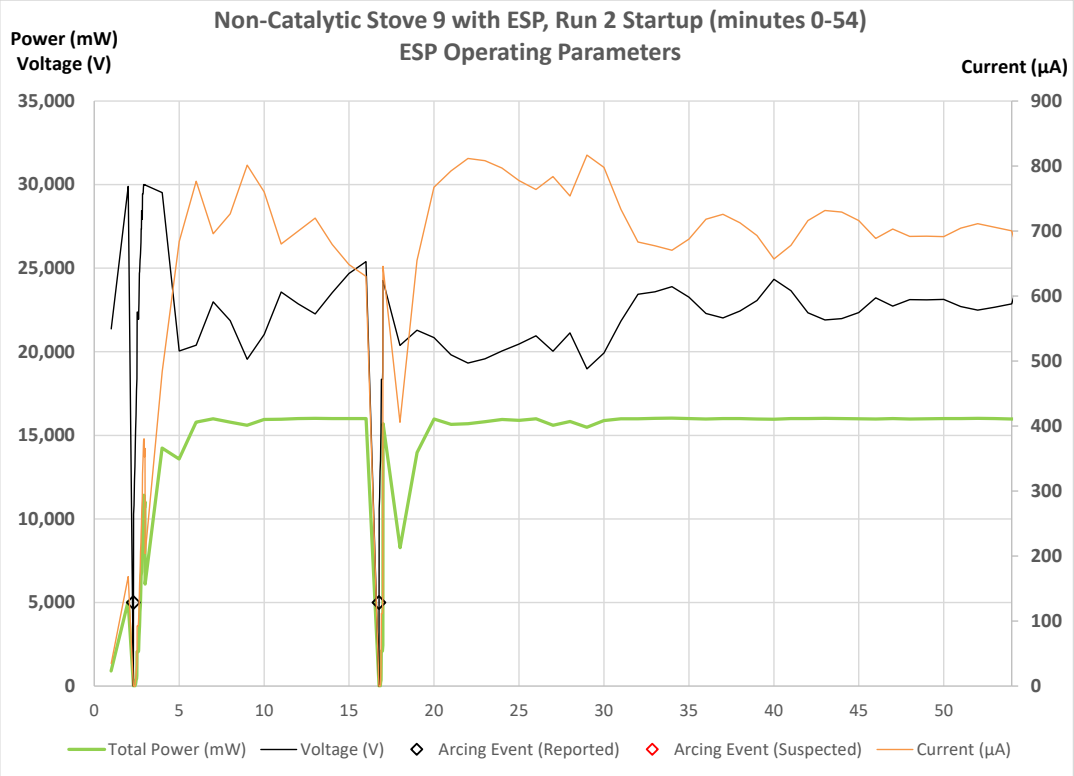


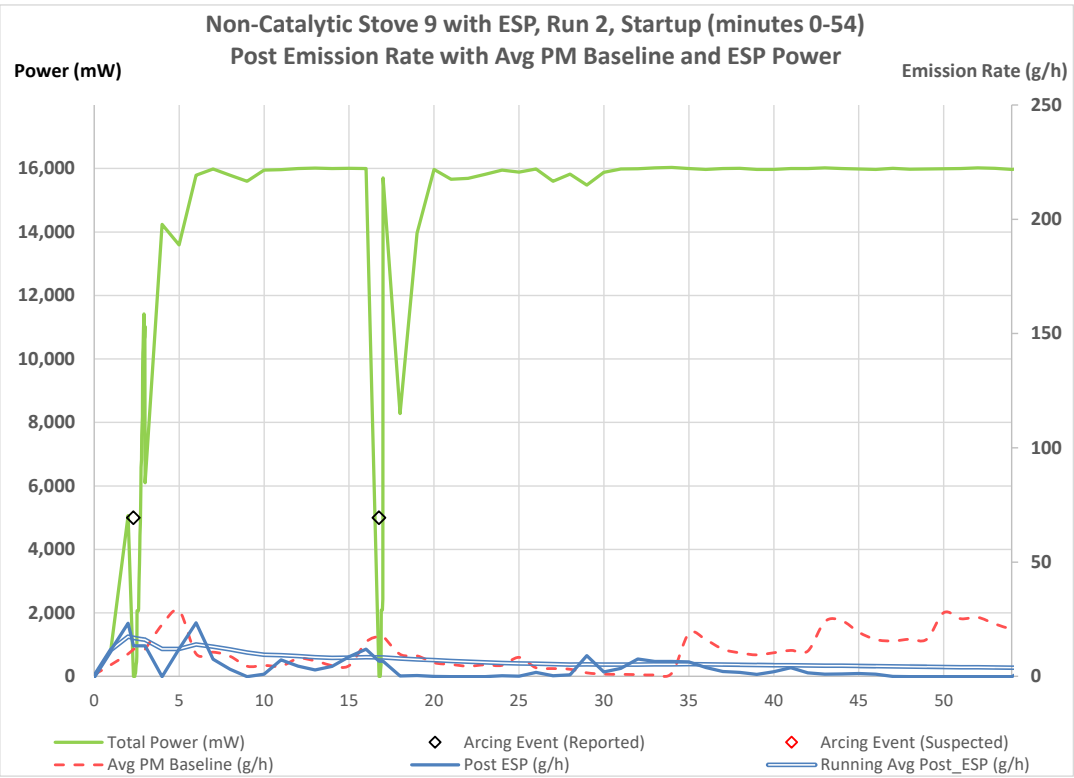
Cordwood Stove 9 with ESP, Run 2, Entire Run



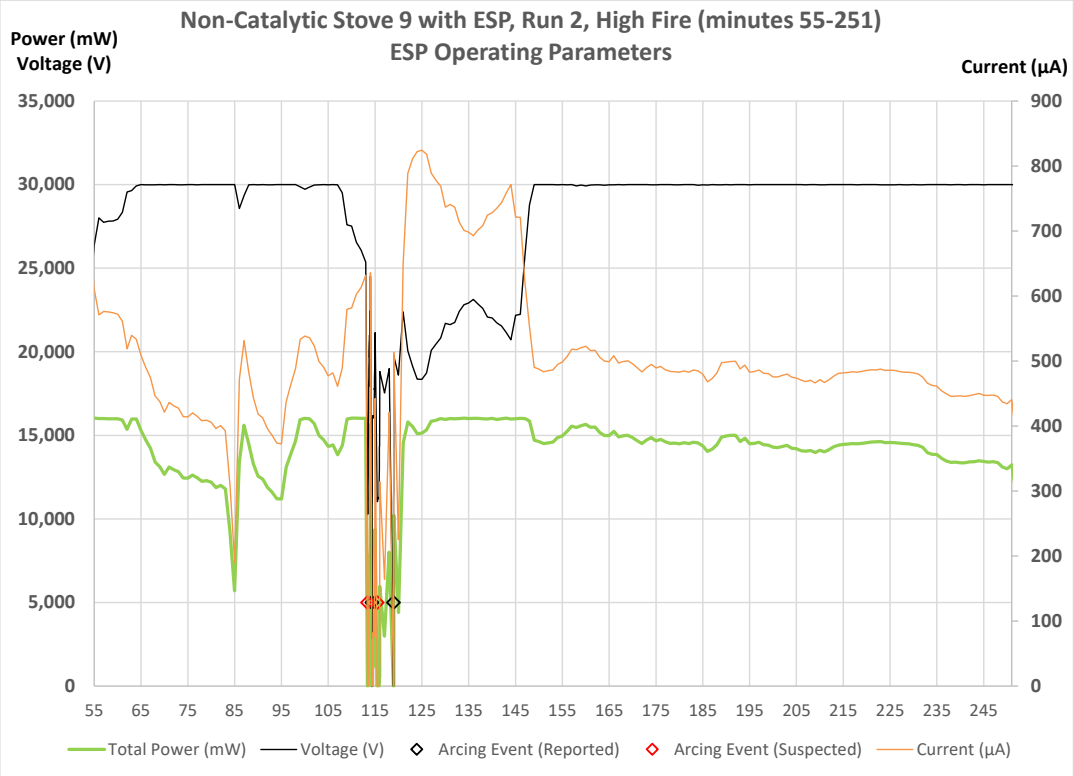


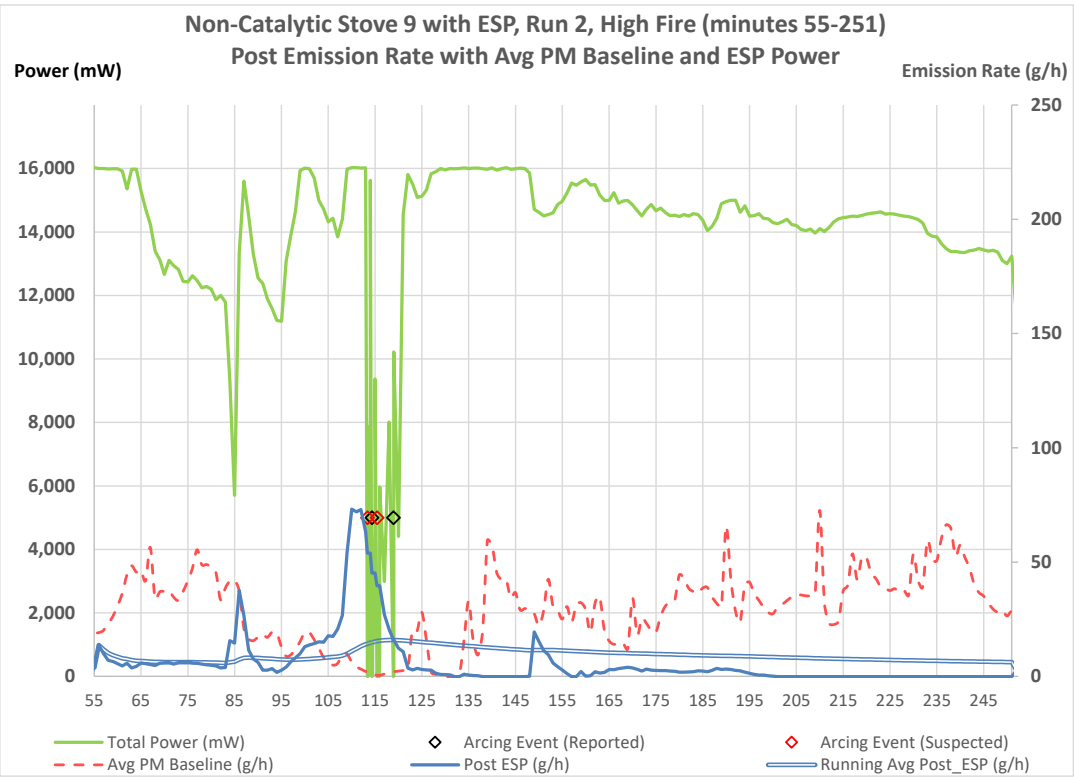
Cordwood Stove 9 with ESP, Run 2, Start-up



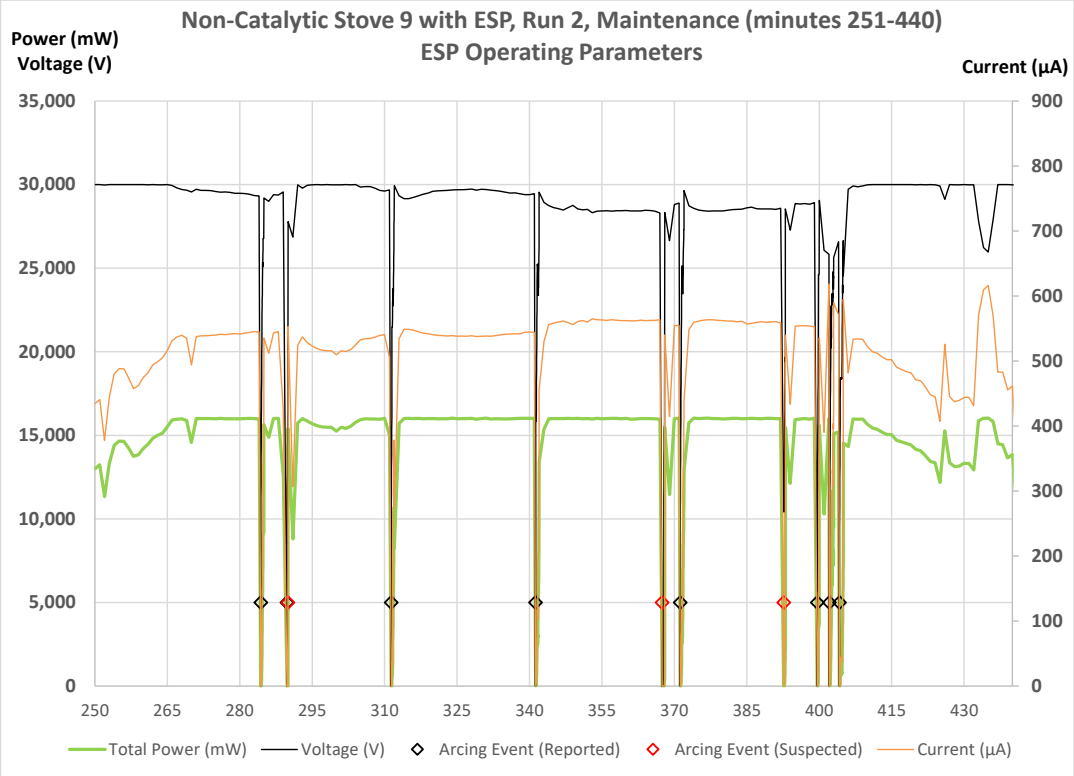


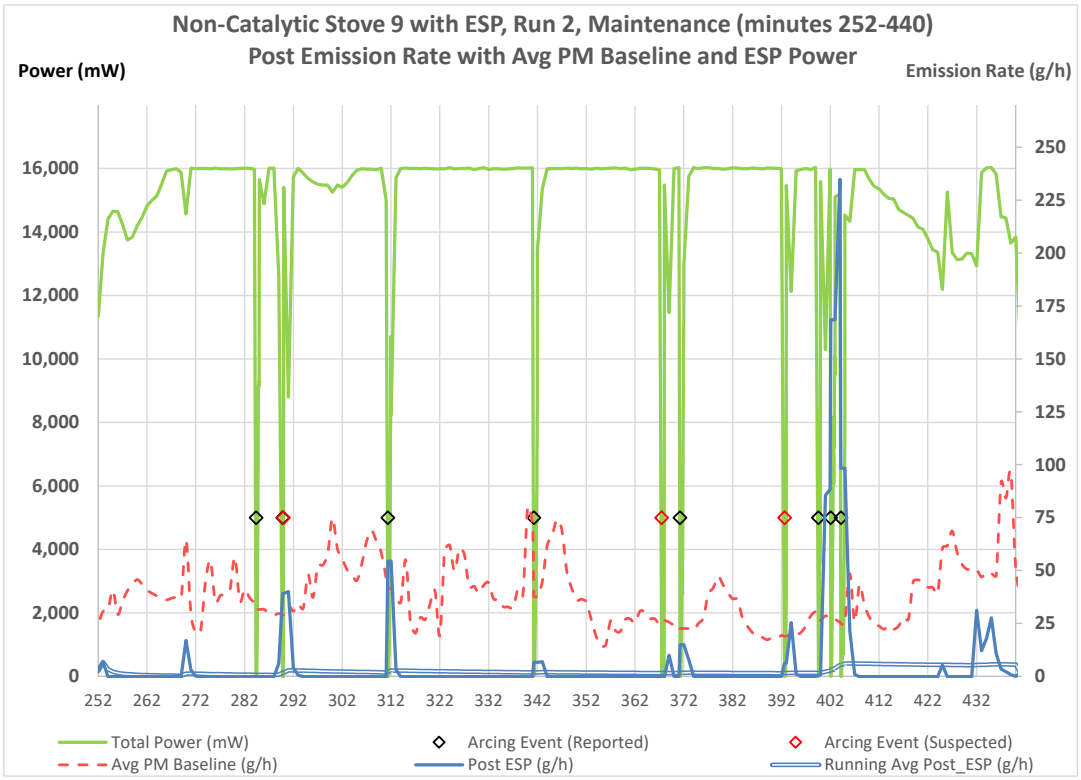
Cordwood Stove 9 with ESP, Run 2, High Fire





Cordwood Stove 9 with ESP, Run 2, Maintenance Fire





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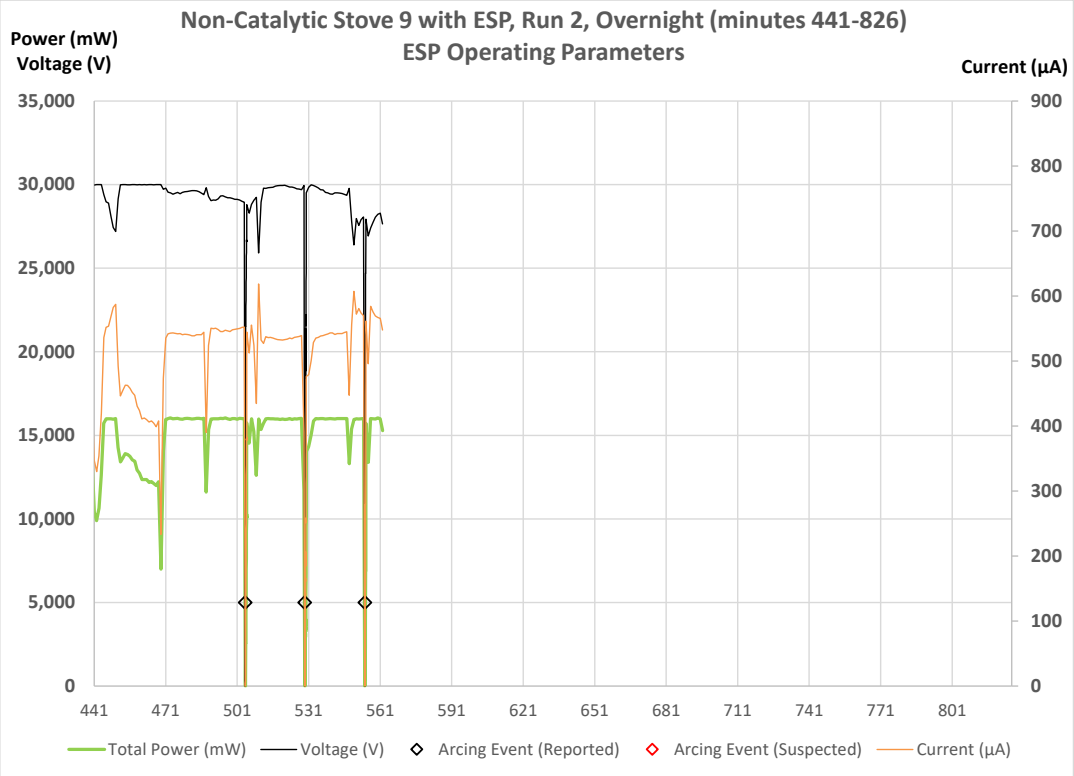
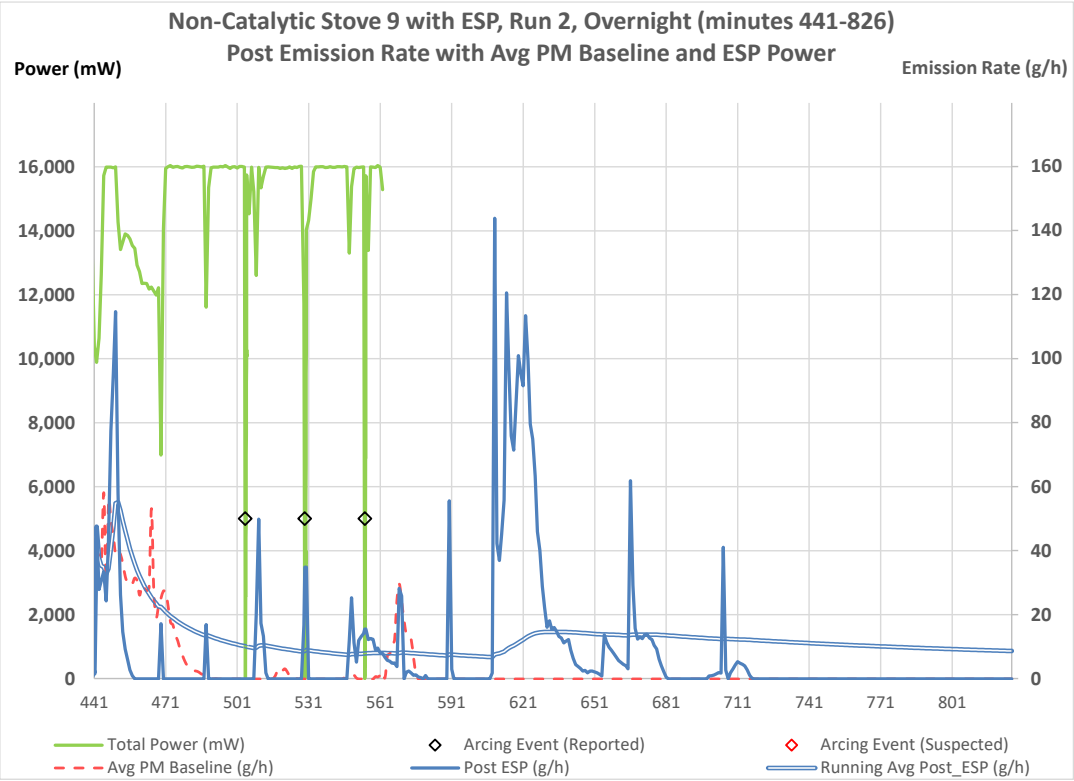
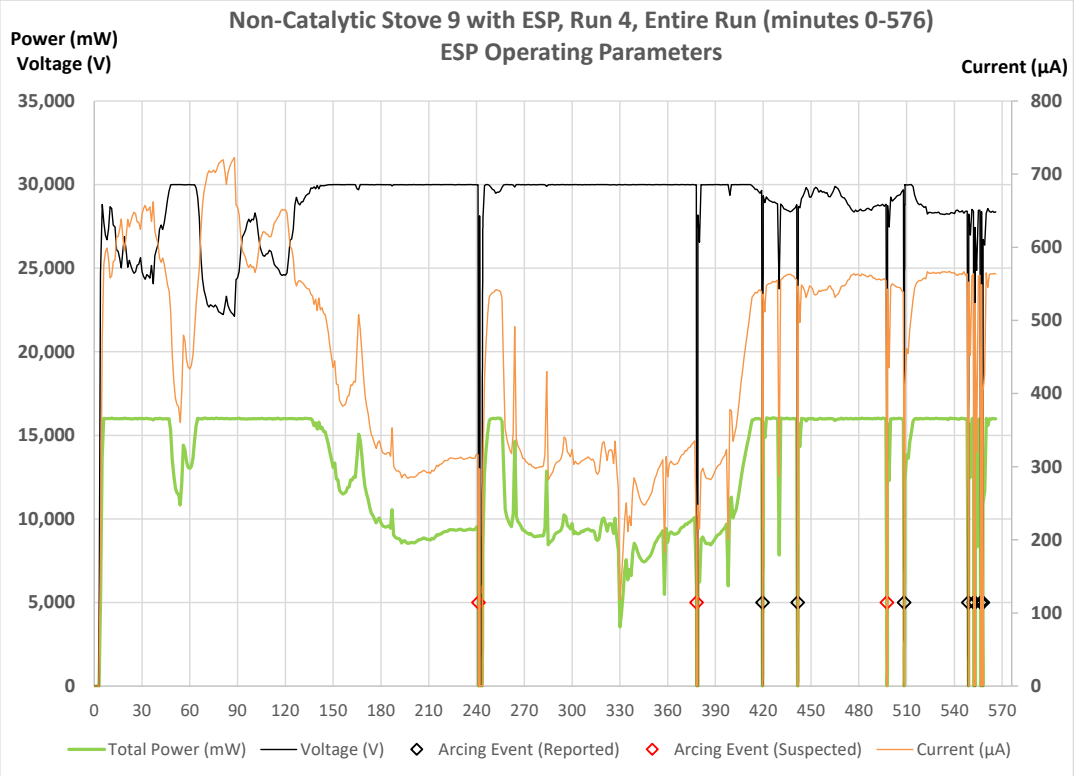
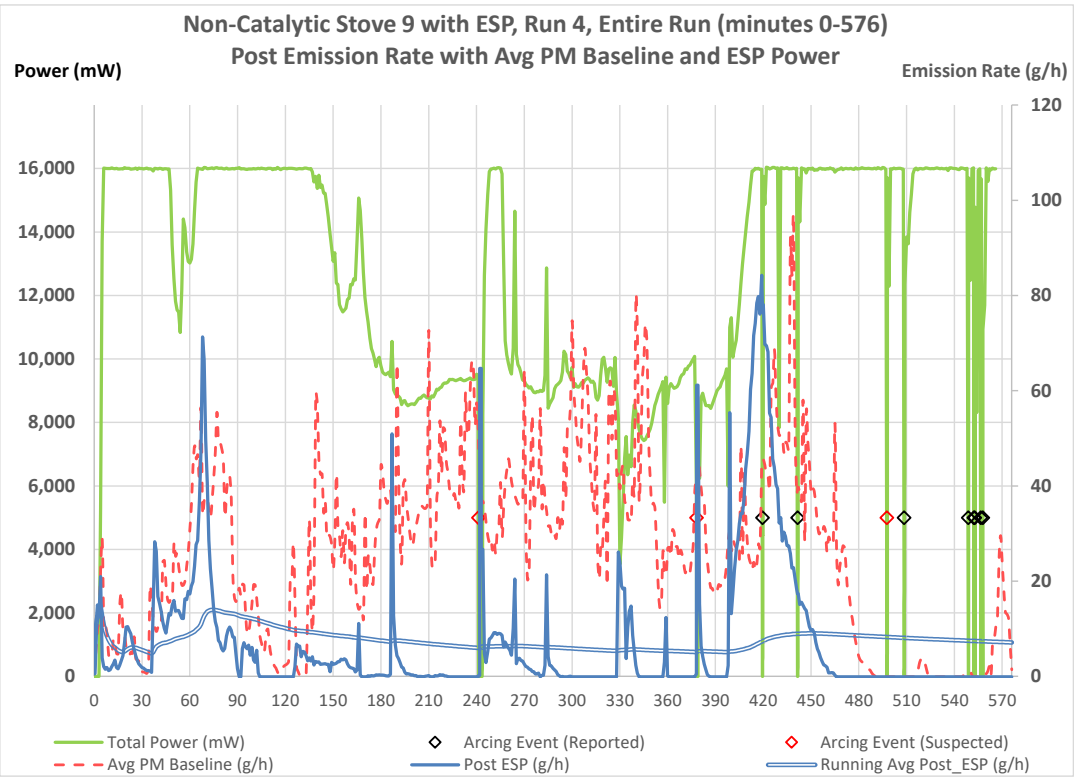


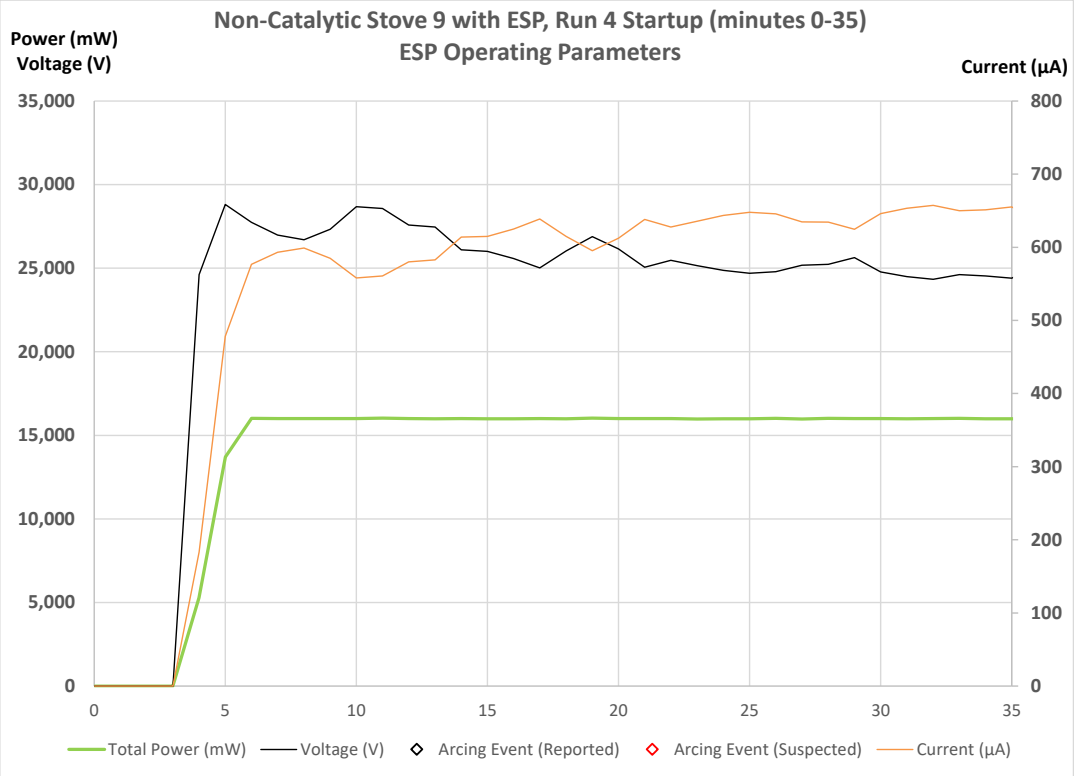


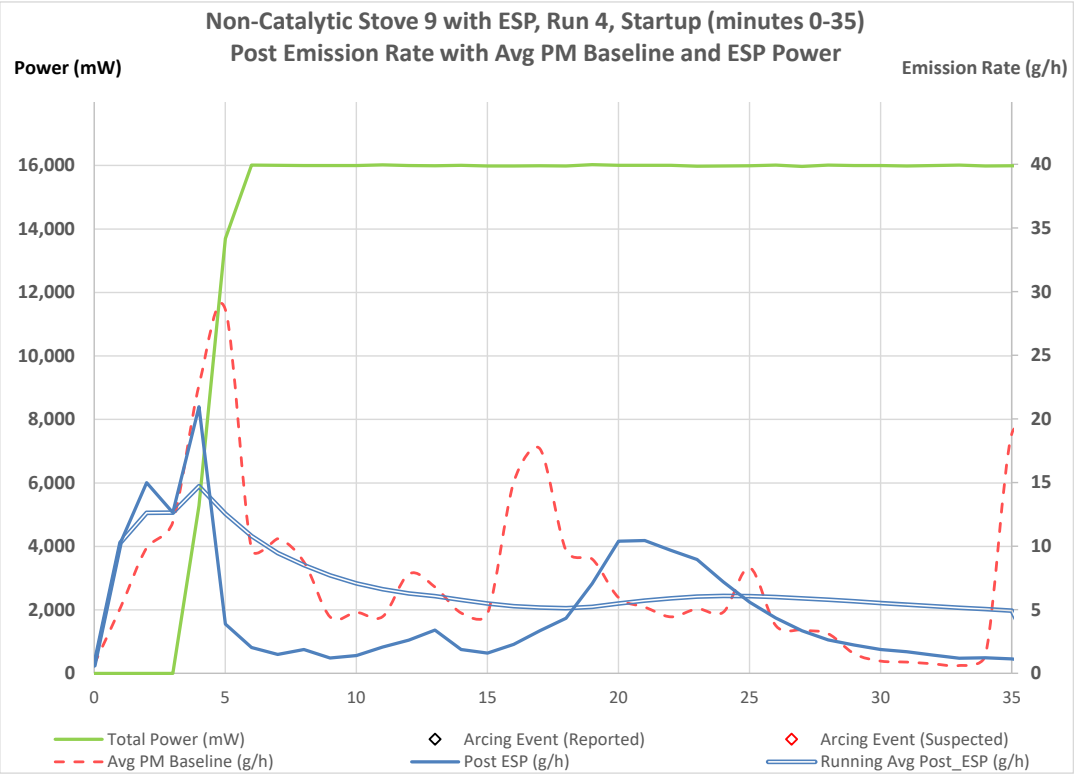
Cordwood Stove 9 with ESP, Run 4, Entire Run



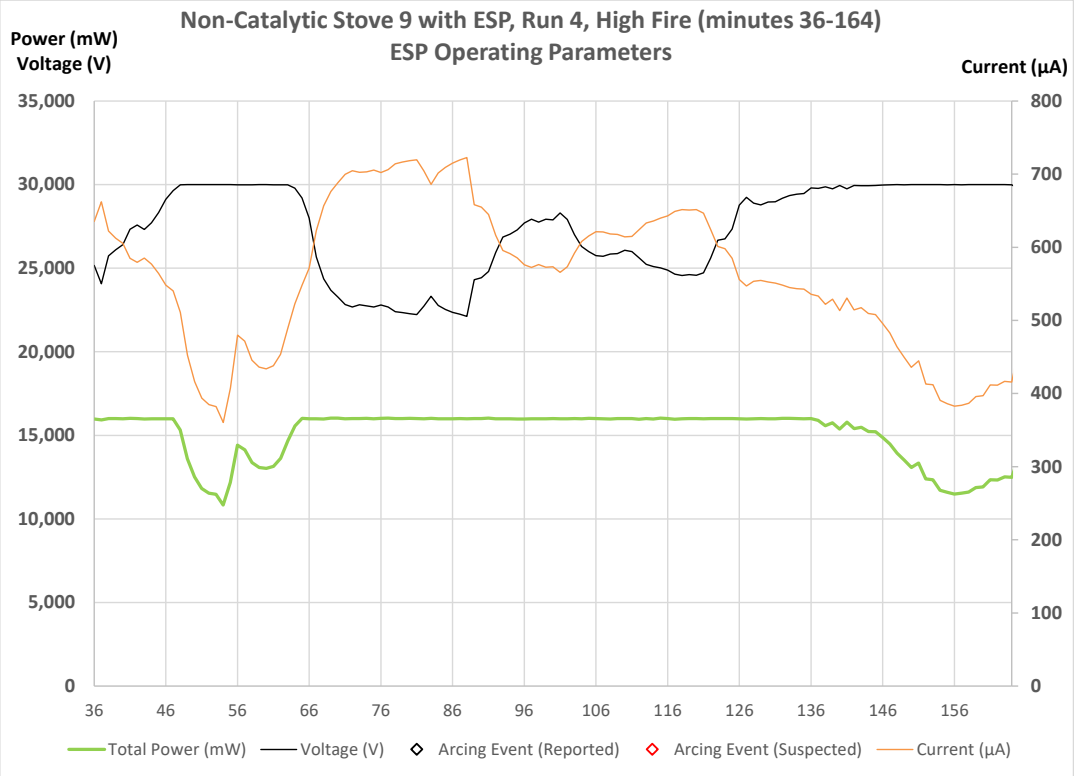


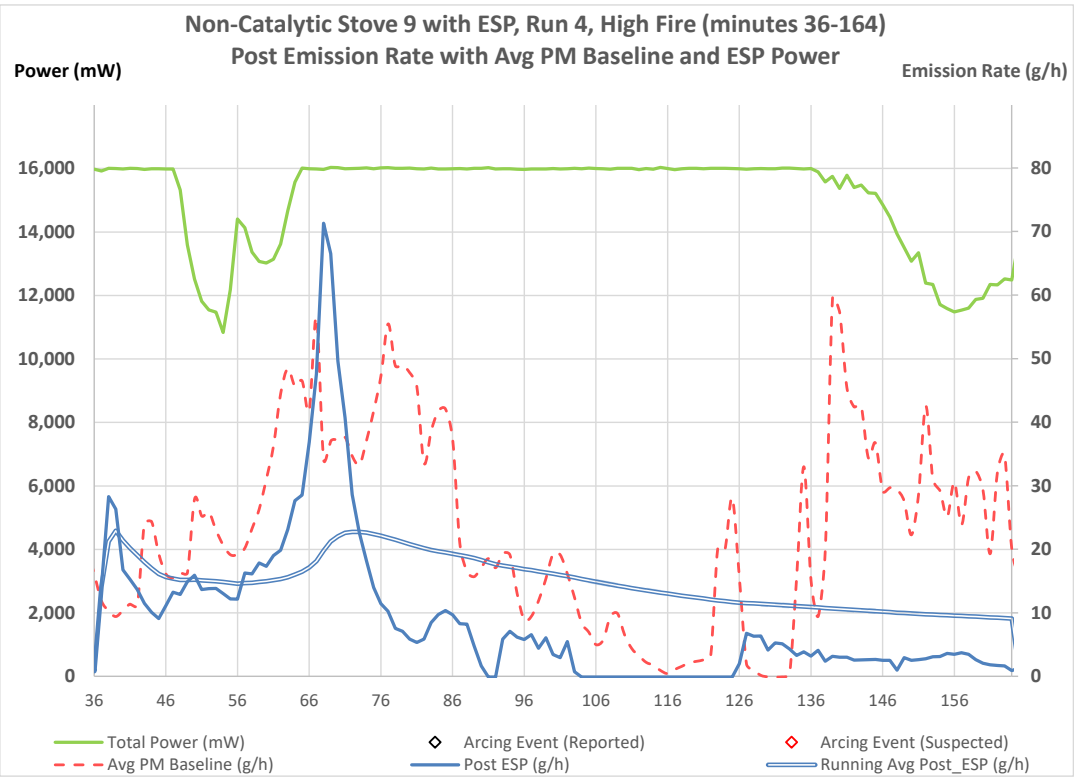
Cordwood Stove 9 with ESP, Run 4, Start-up



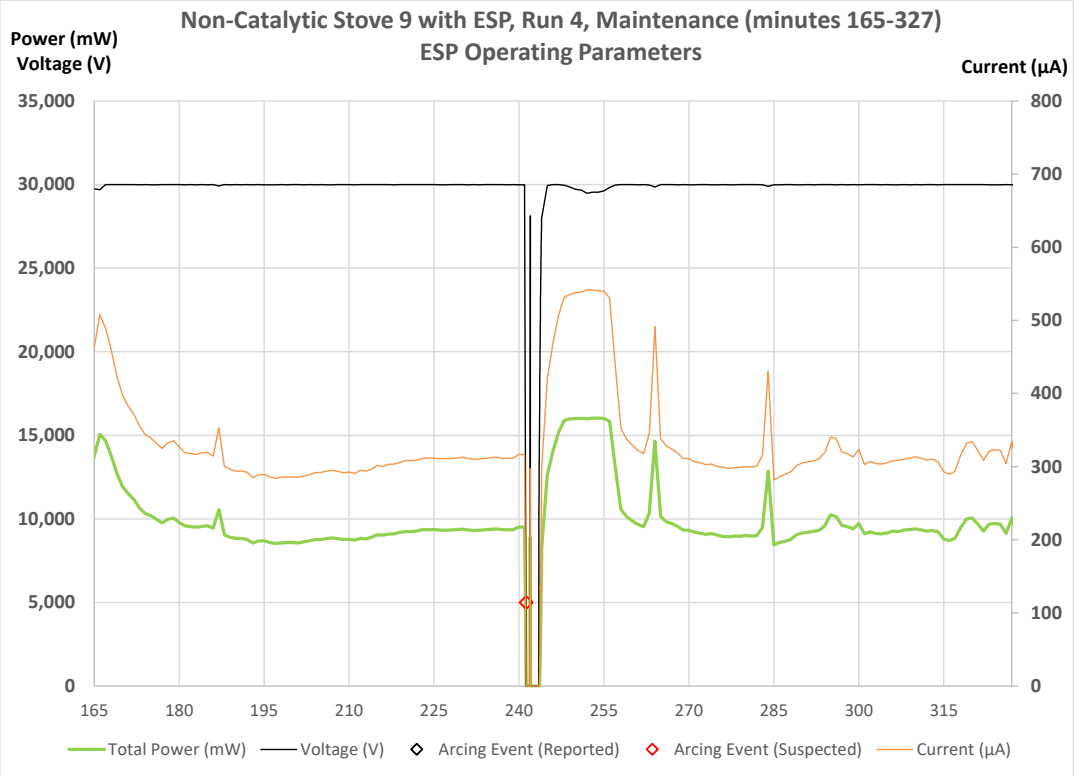


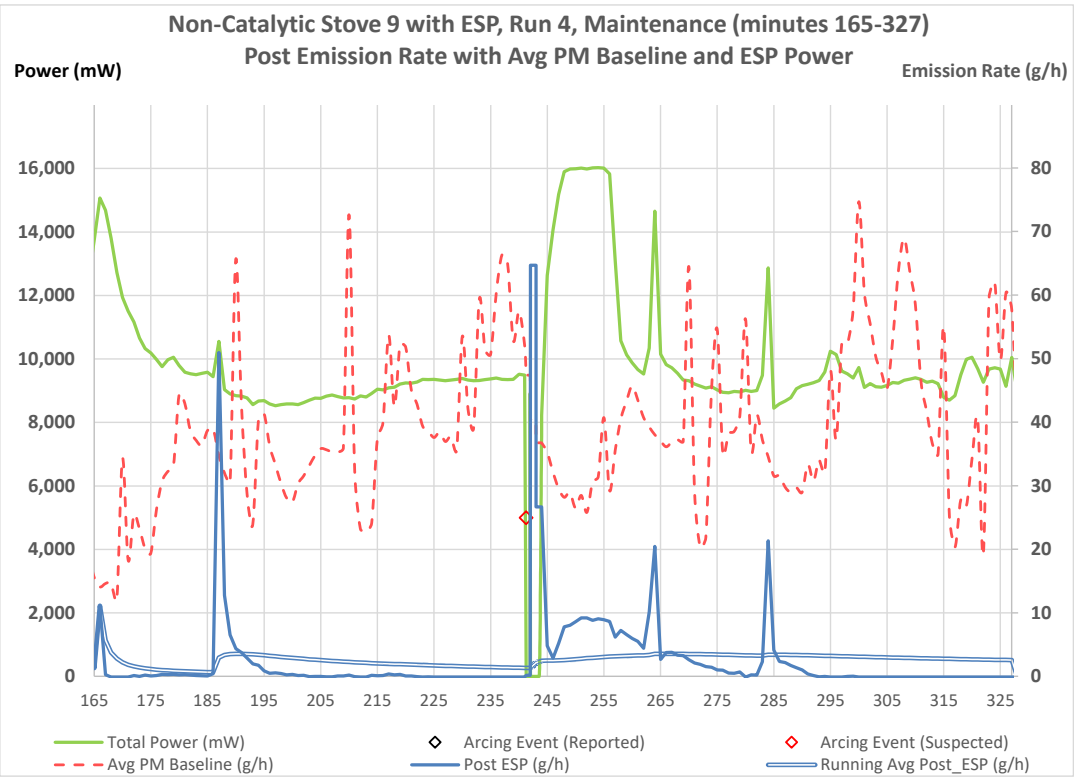
Cordwood Stove 9 with ESP, Run 4, High Fire



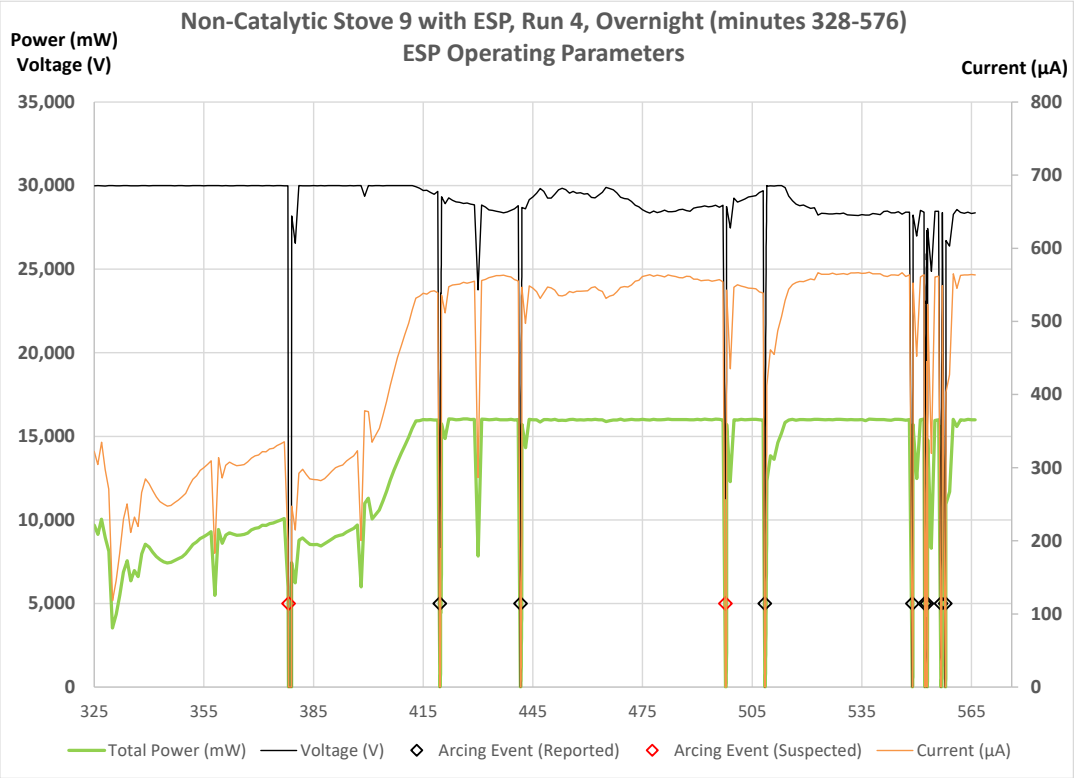


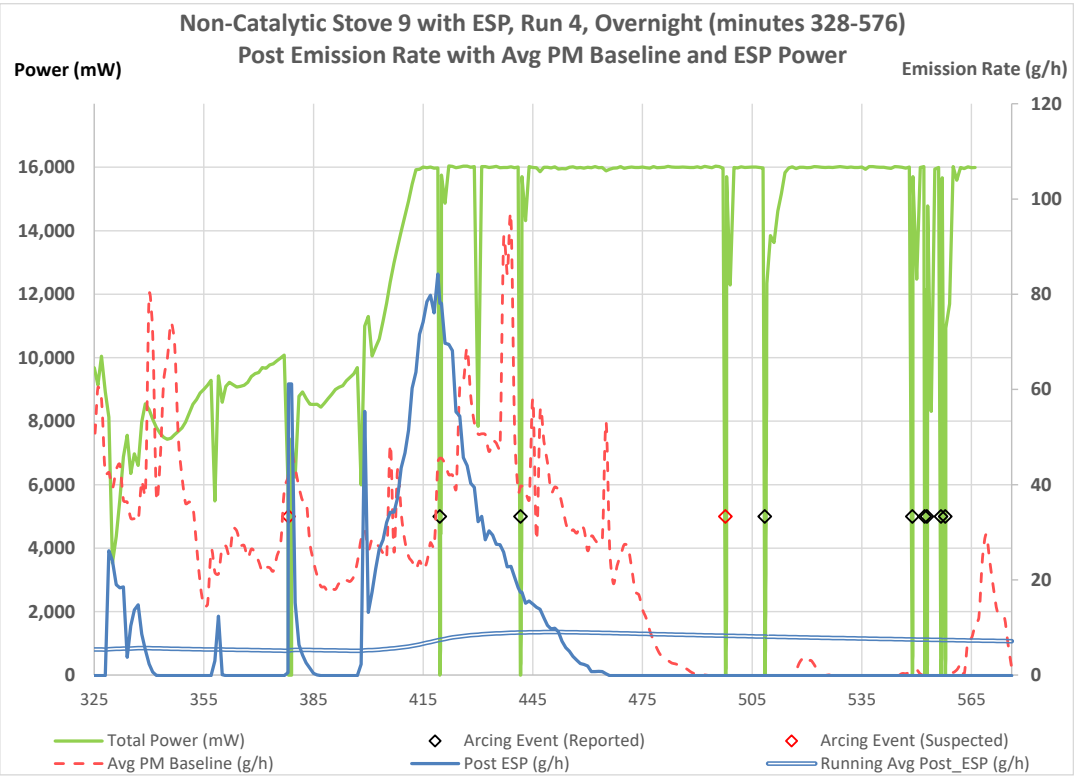
Cordwood Stove 9 with ESP, Run 4, Maintenance Fire



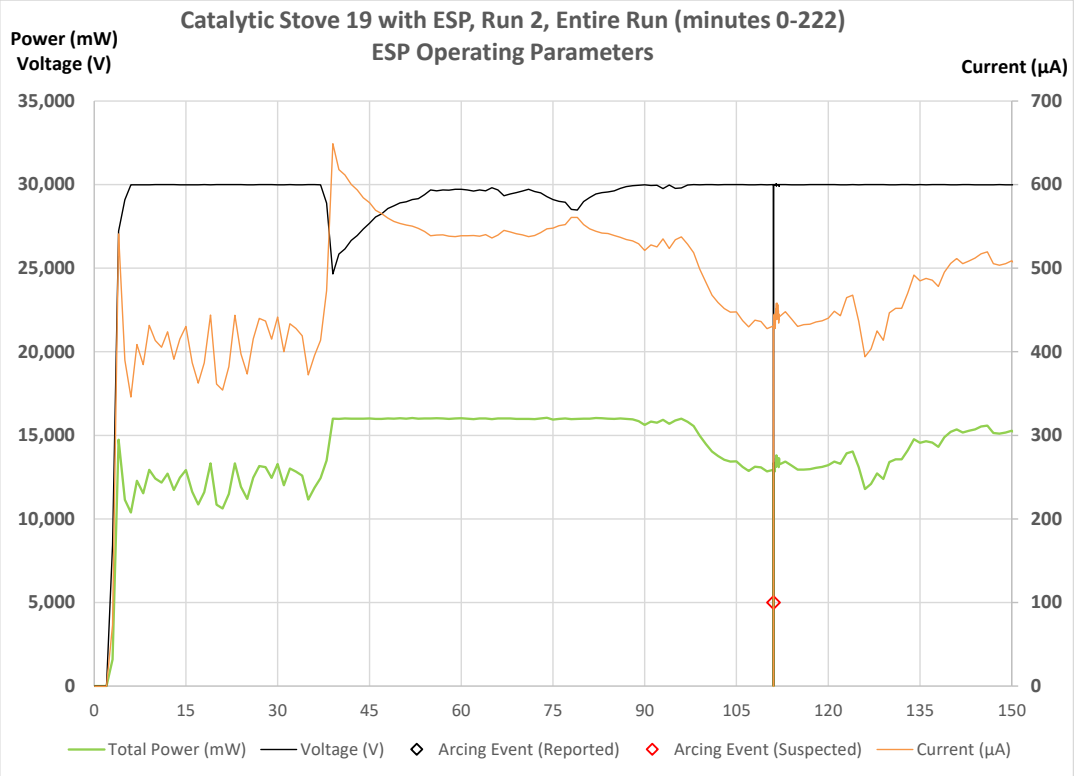


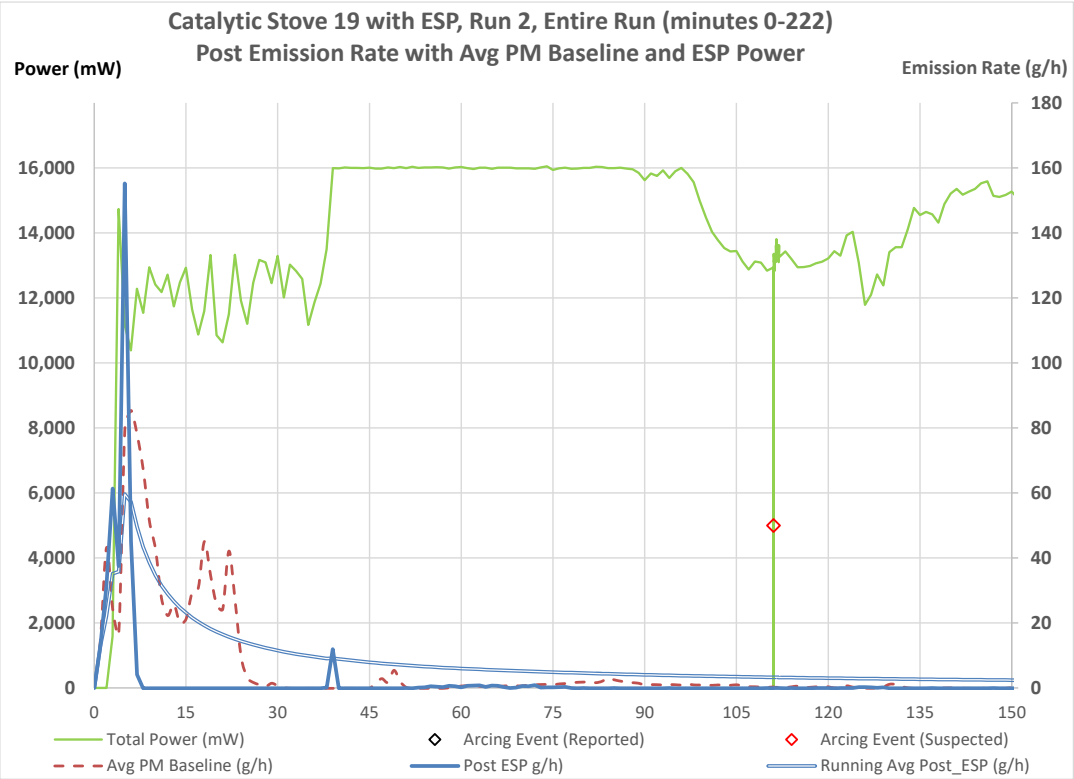
Cordwood Stove 9 with ESP, Run 4, Overnight Fire



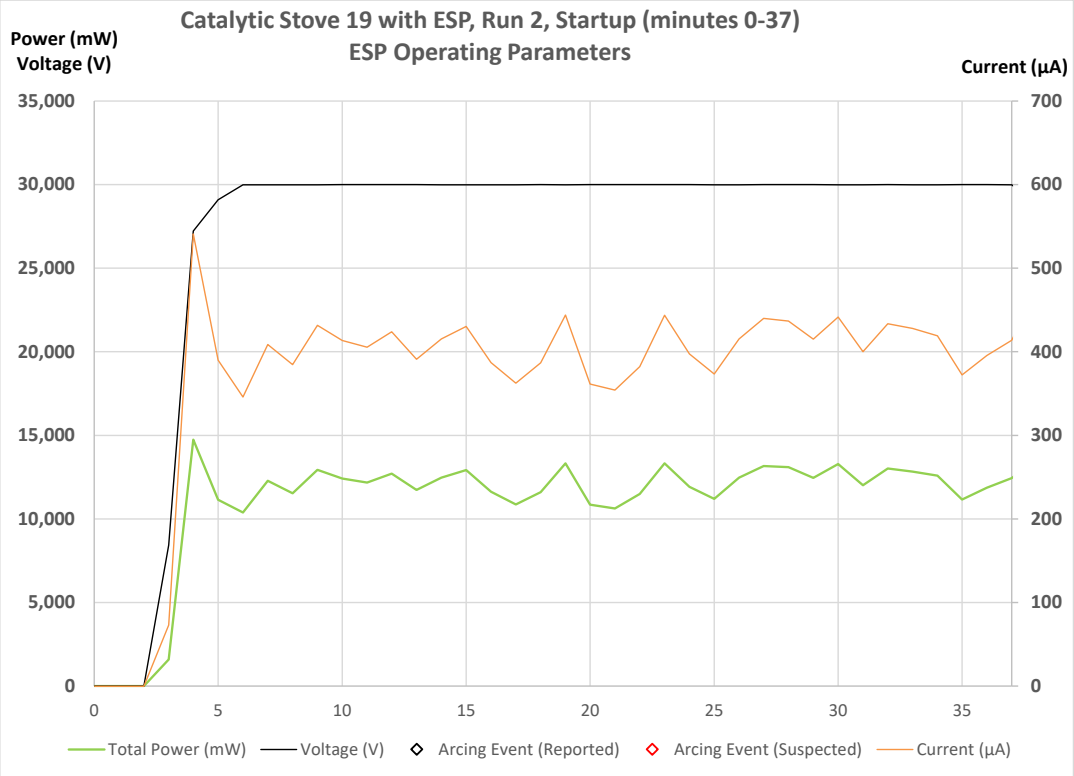


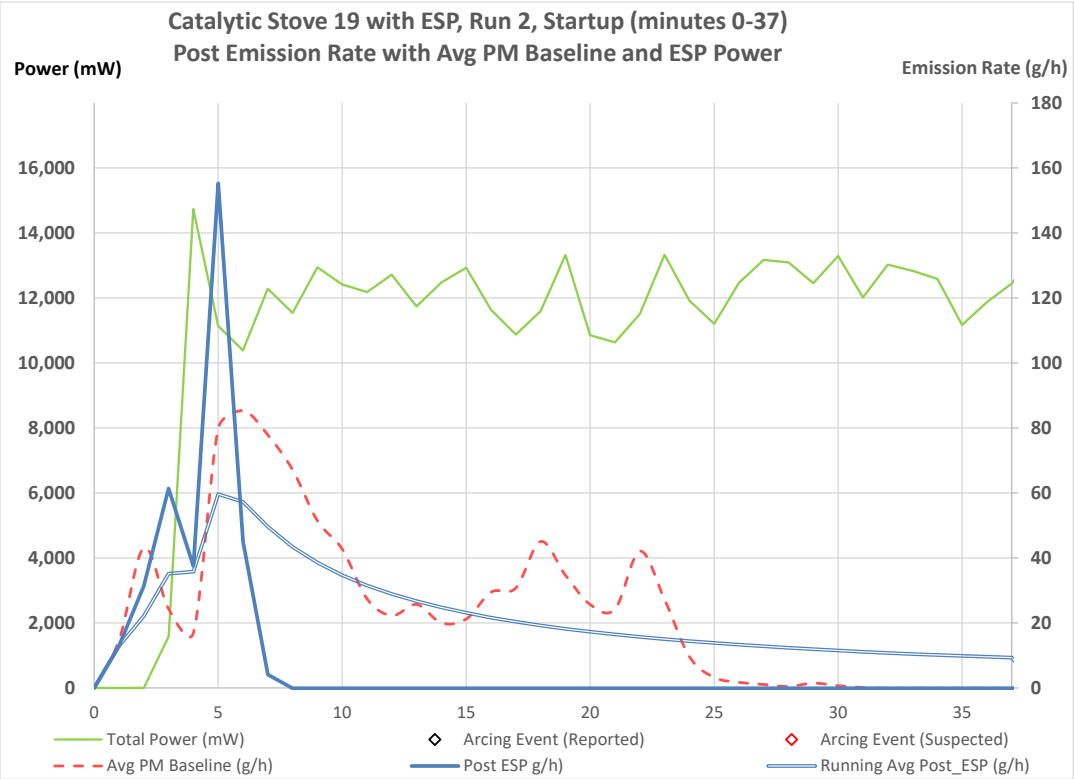
Catalytic Stove 19 with ESP, Run 2, Entire Run



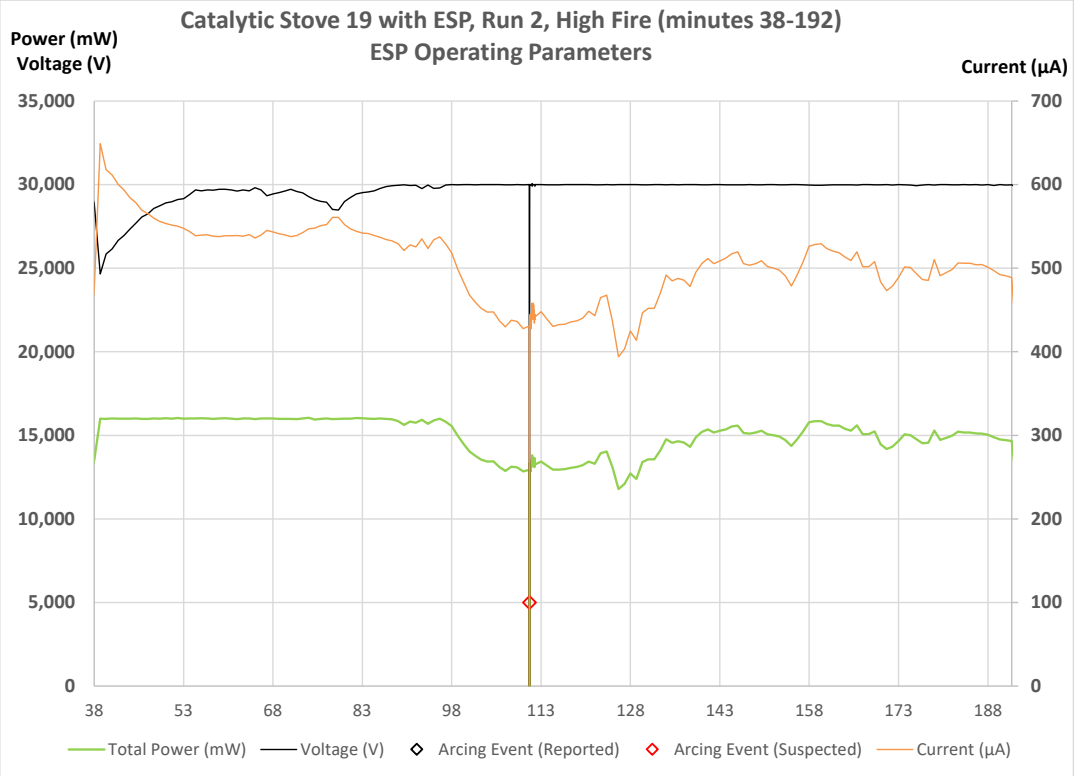


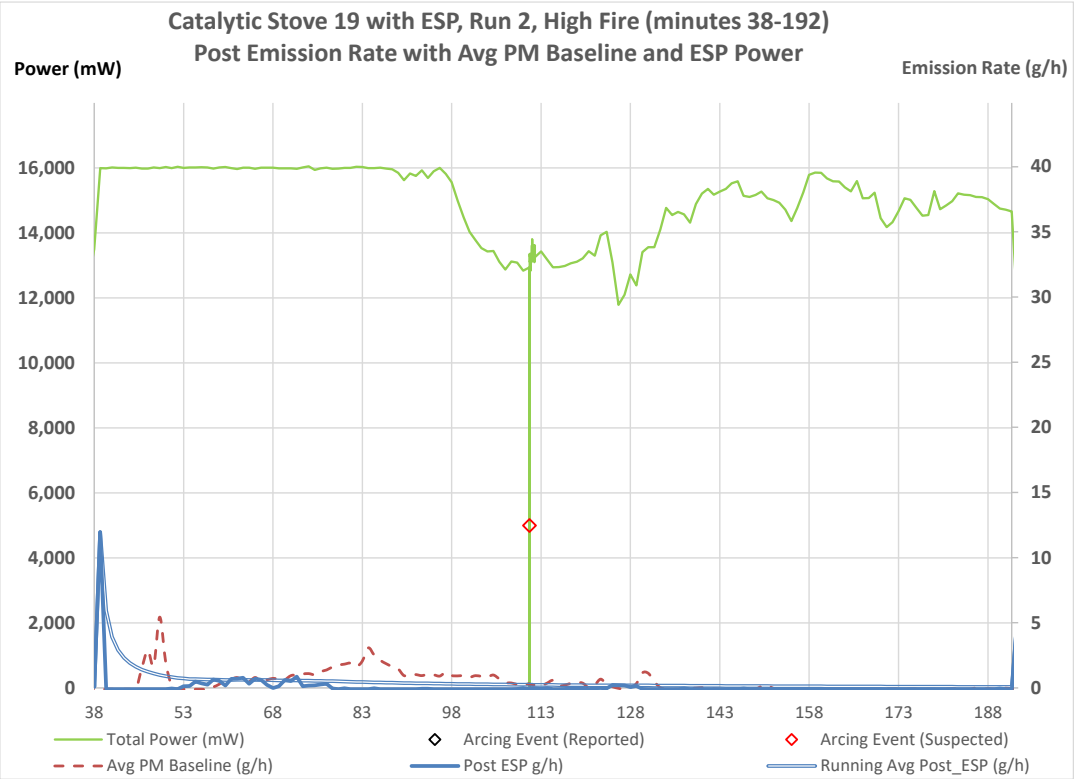
Catalytic Stove 19 with ESP, Run 2, Start-up



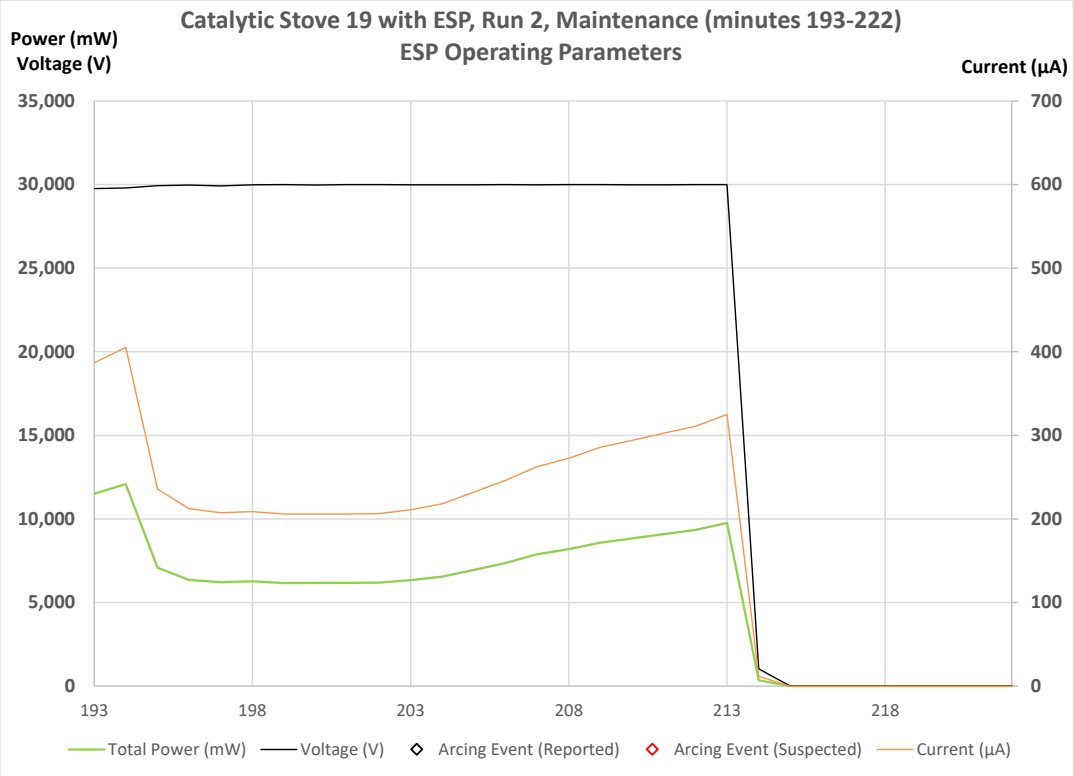


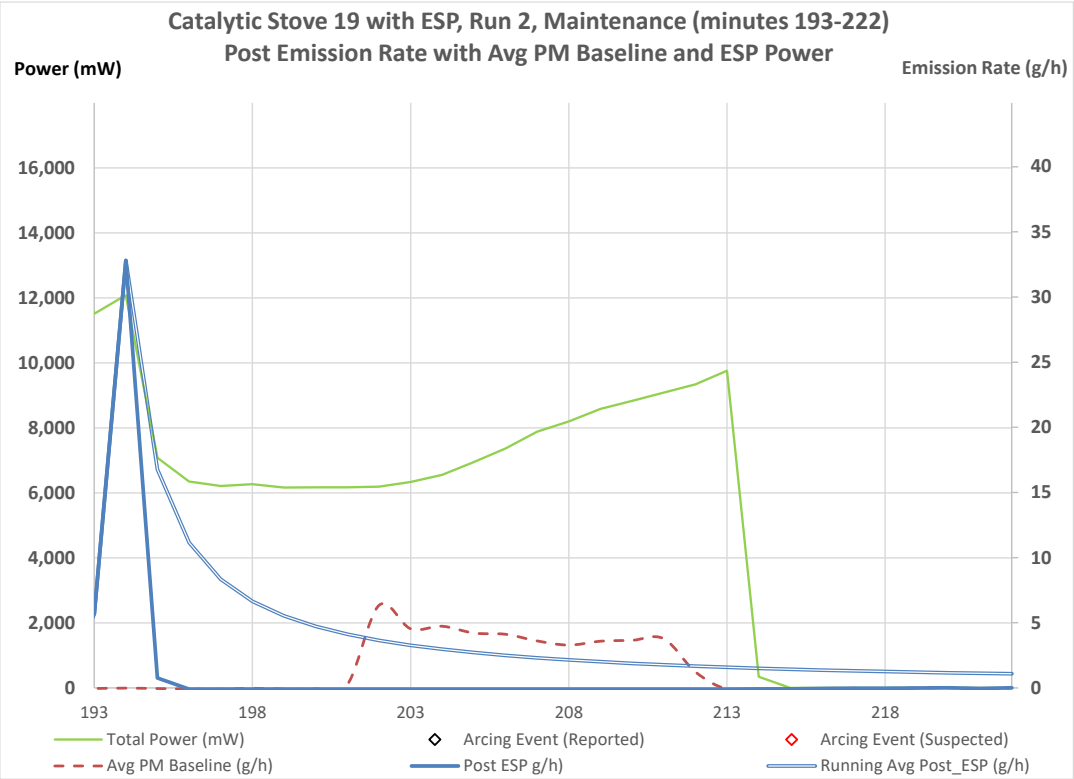
Catalytic Stove 19 with ESP, Run 2, High Fire



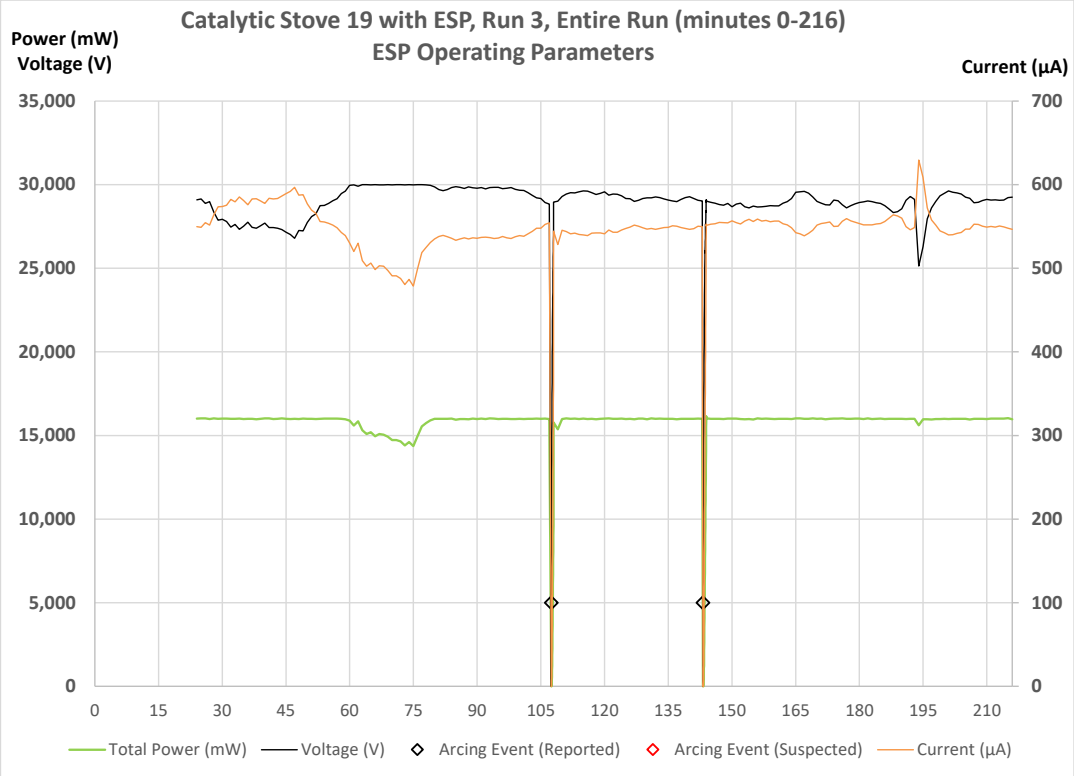


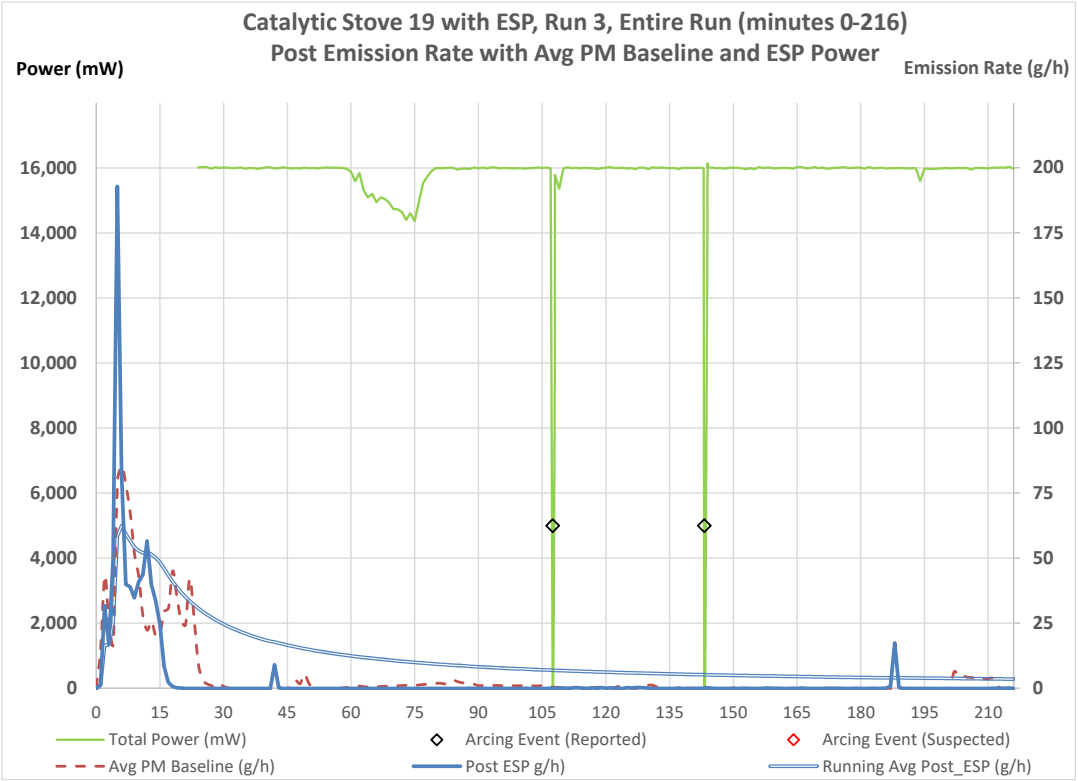
Catalytic Stove 19 with ESP, Run 2, Maintenance Fire



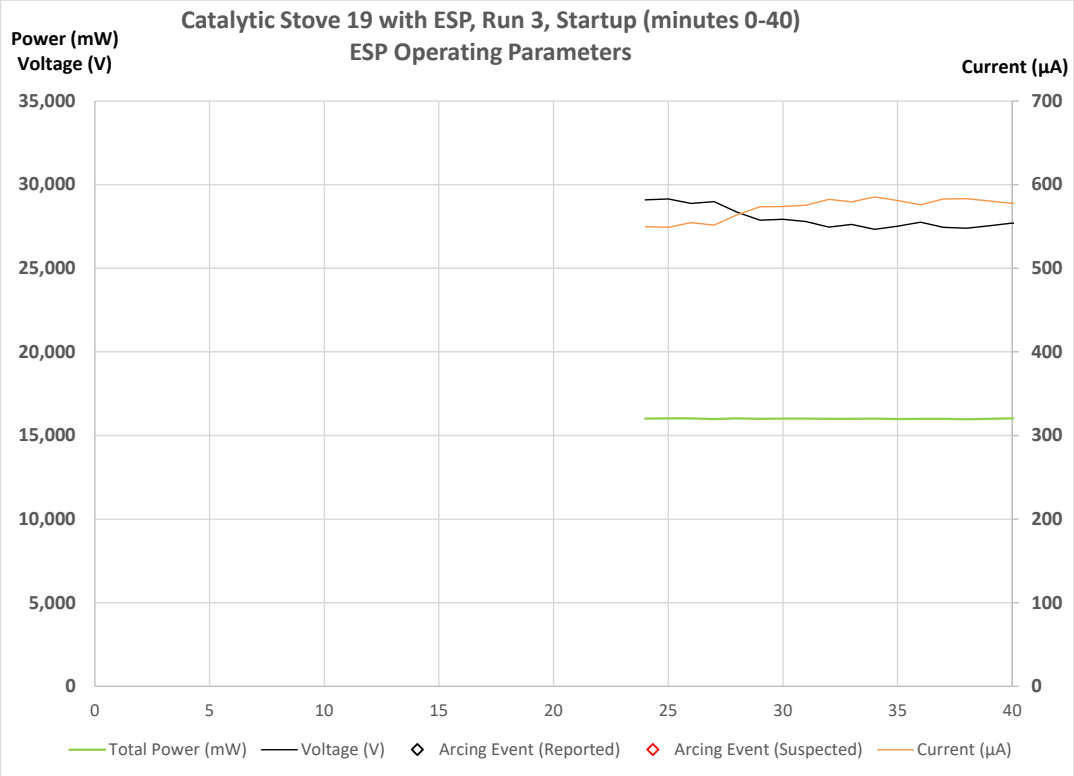


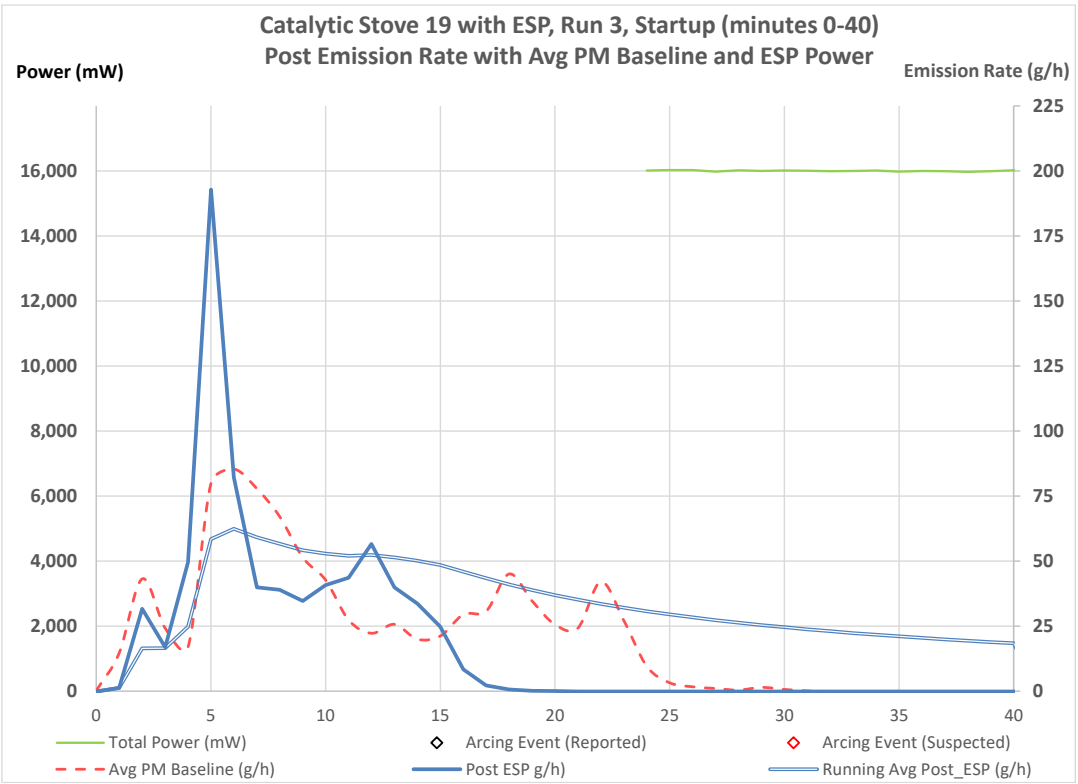
Catalytic Stove 19 with ESP, Run 3, Entire Run



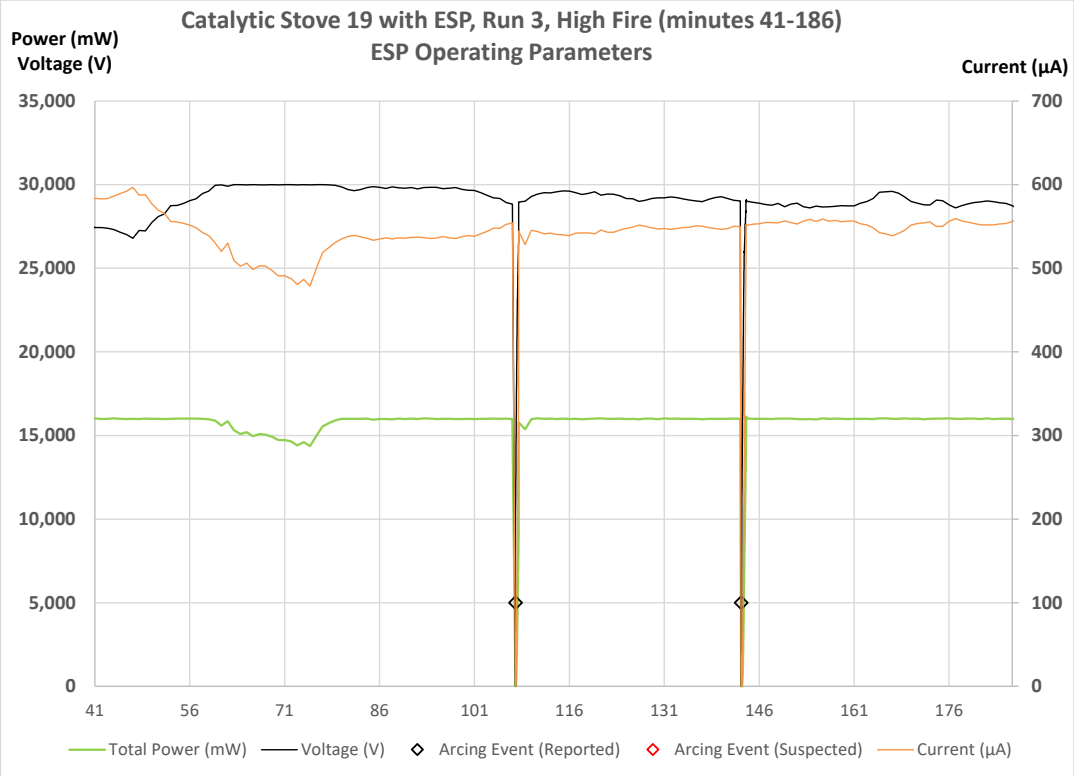


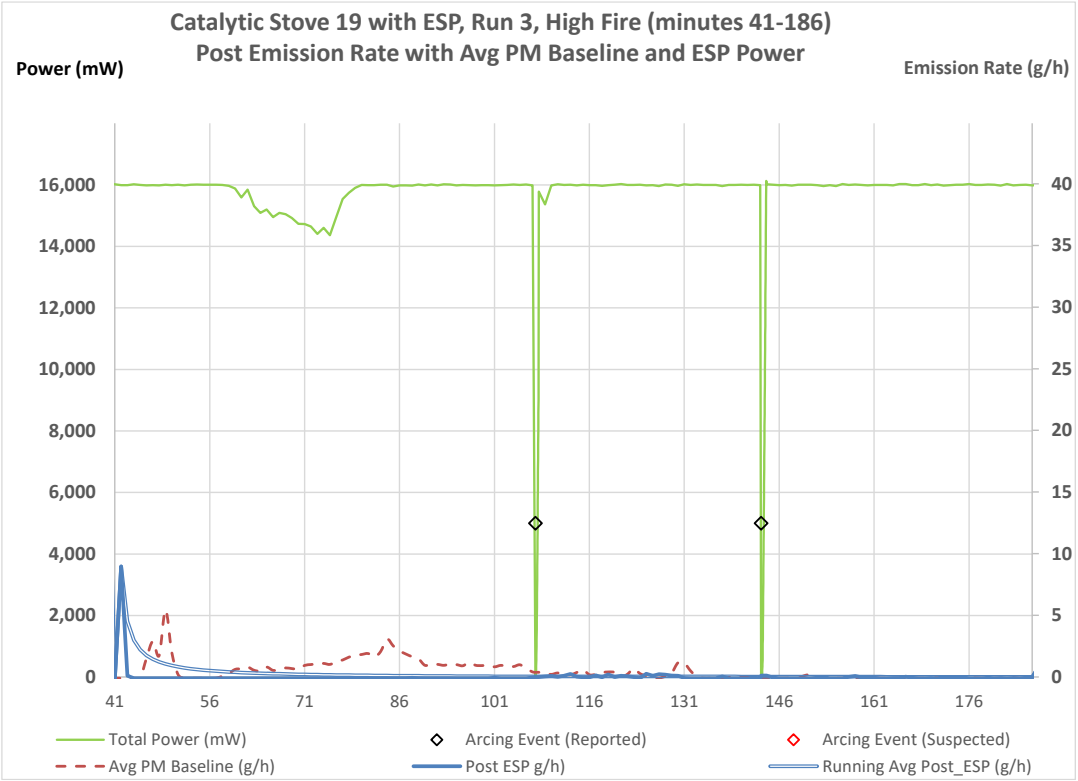
Catalytic Stove 19 with ESP, Run 3, Start-up



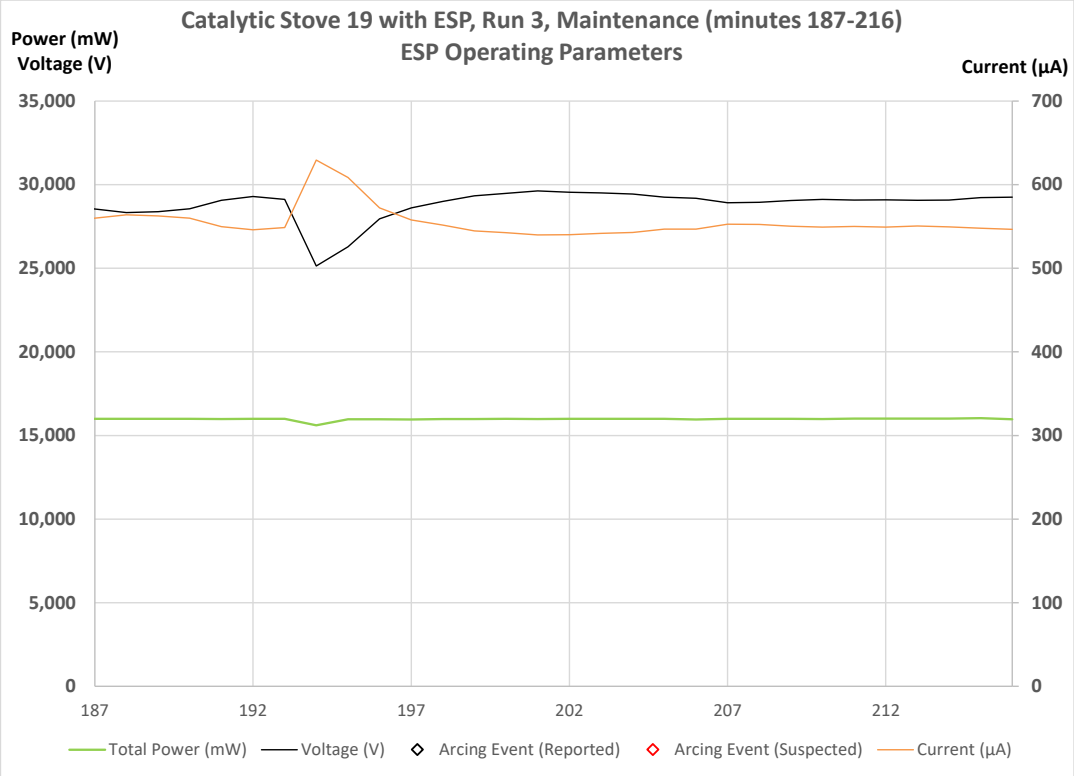


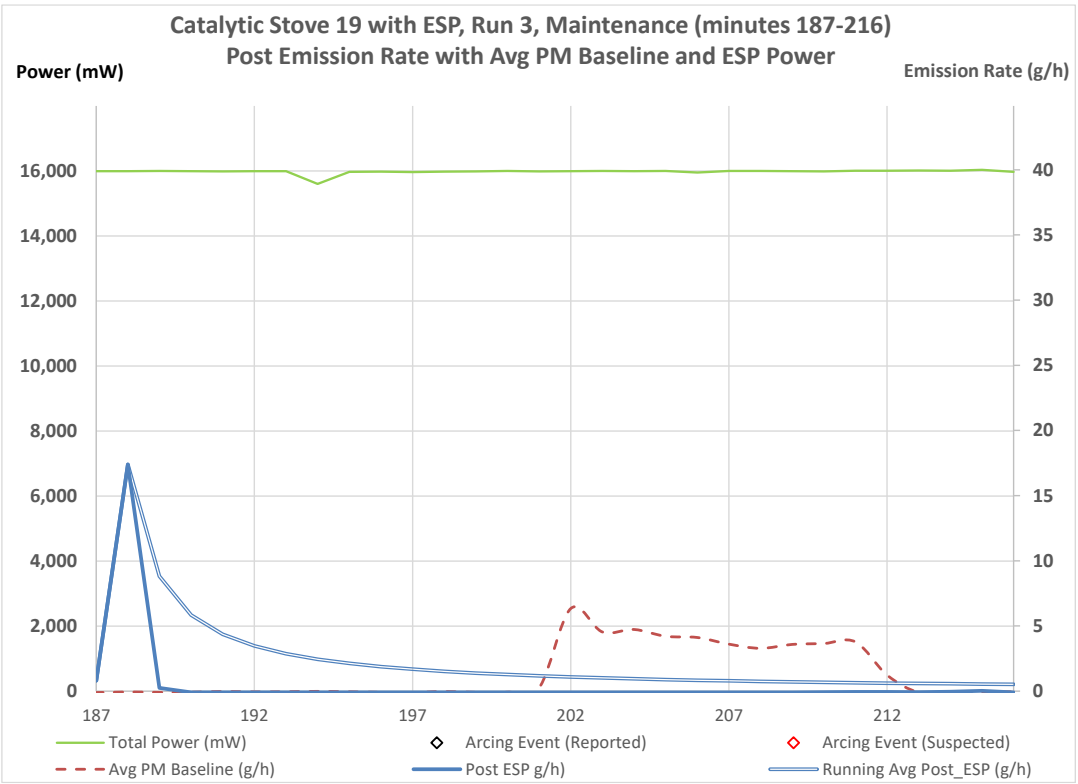
Catalytic Stove 19 with ESP, Run 3, High Fire



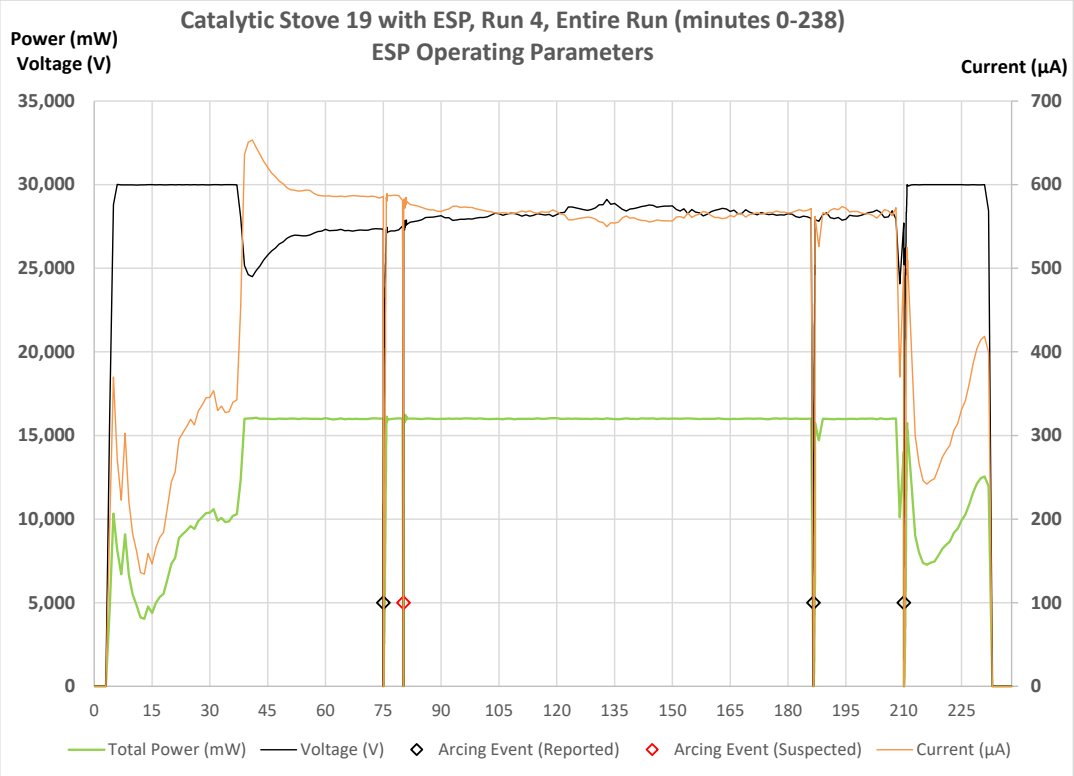


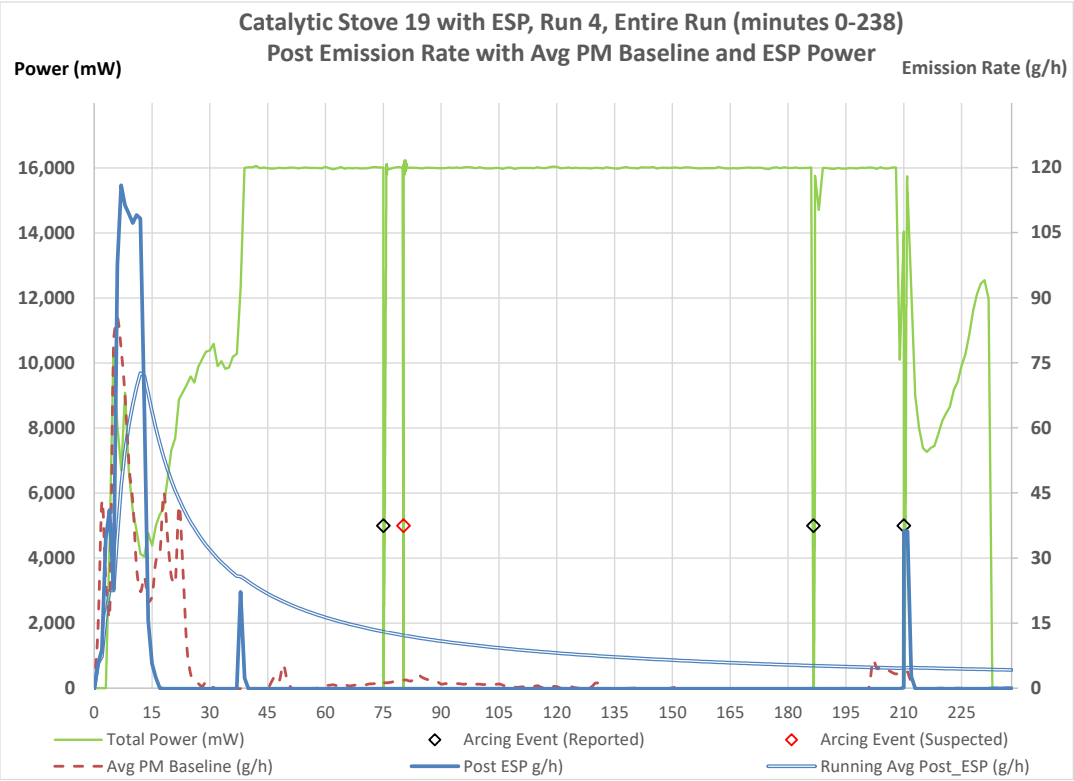
Catalytic Stove 19 with ESP, Run 3, Maintenance Fire



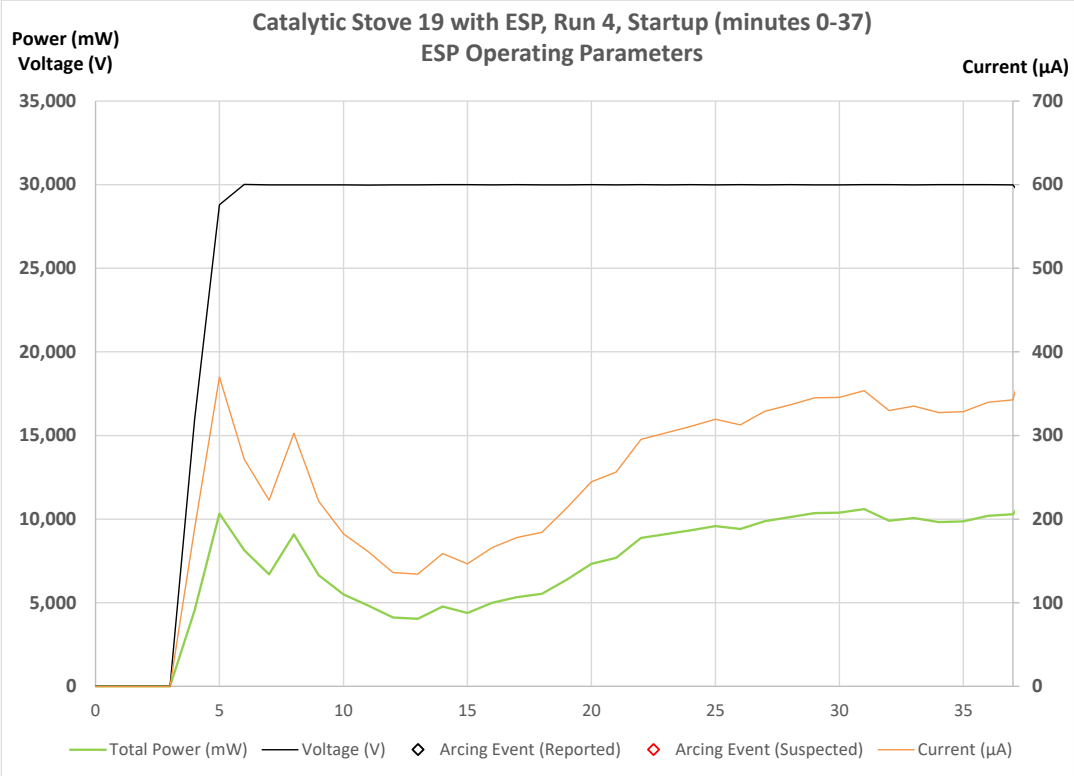


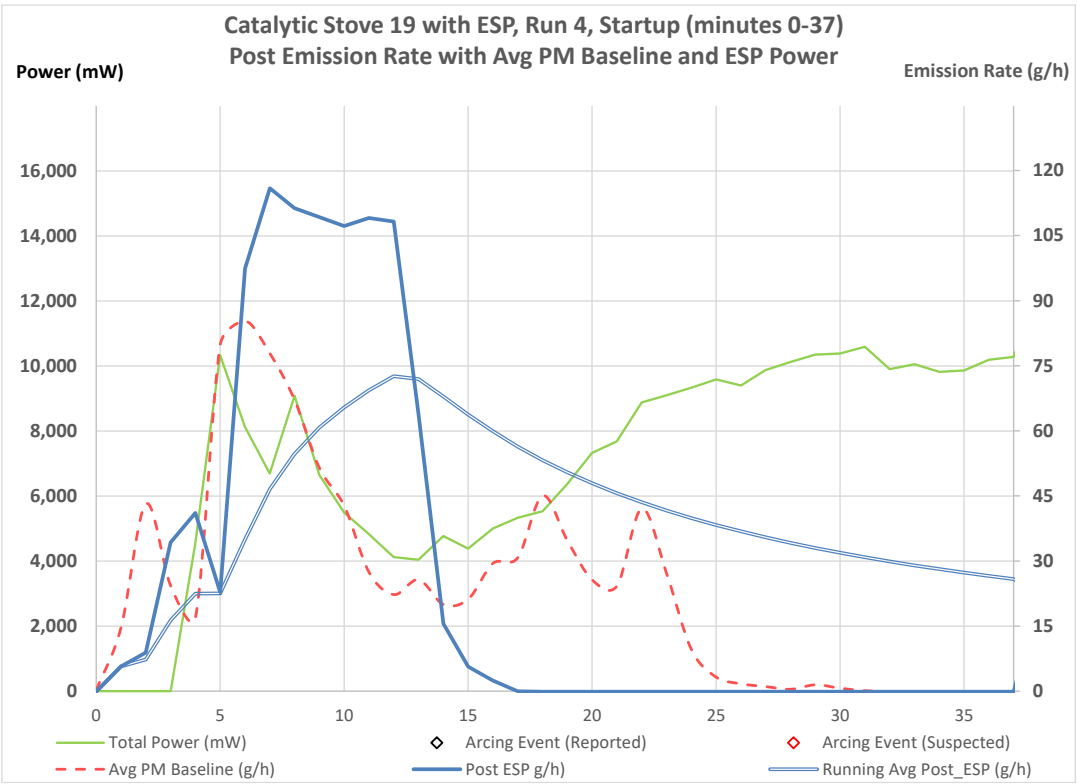
Catalytic Stove 19 with ESP, Run 4, Entire Run



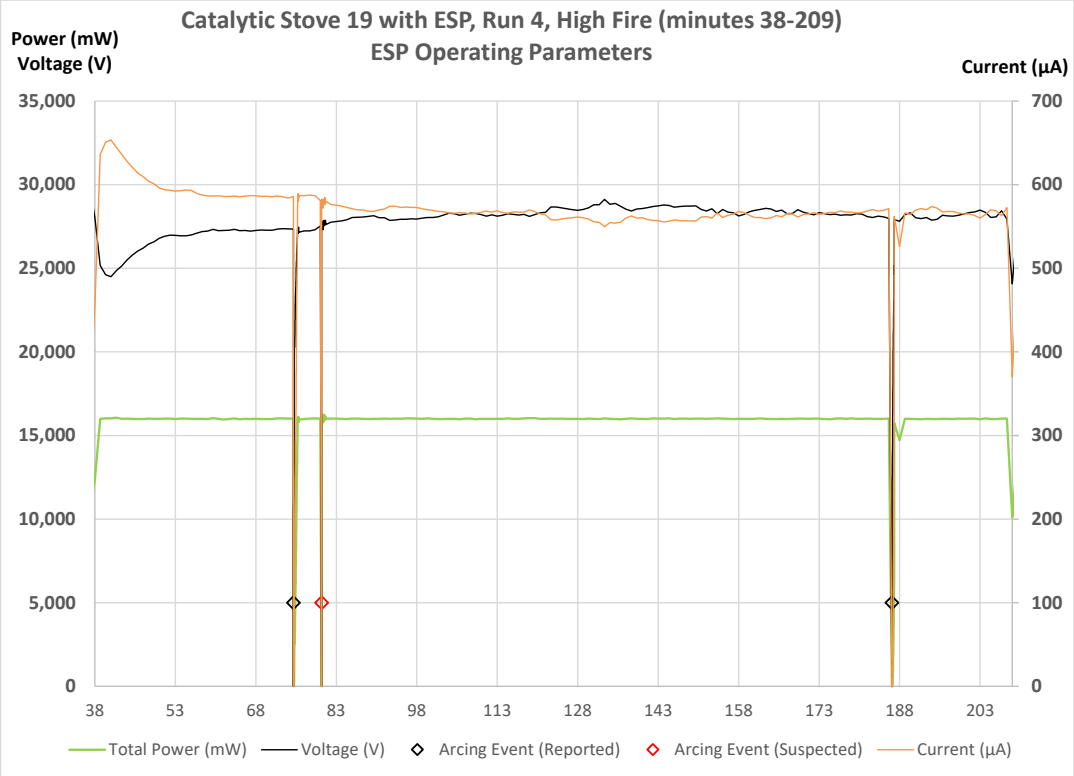


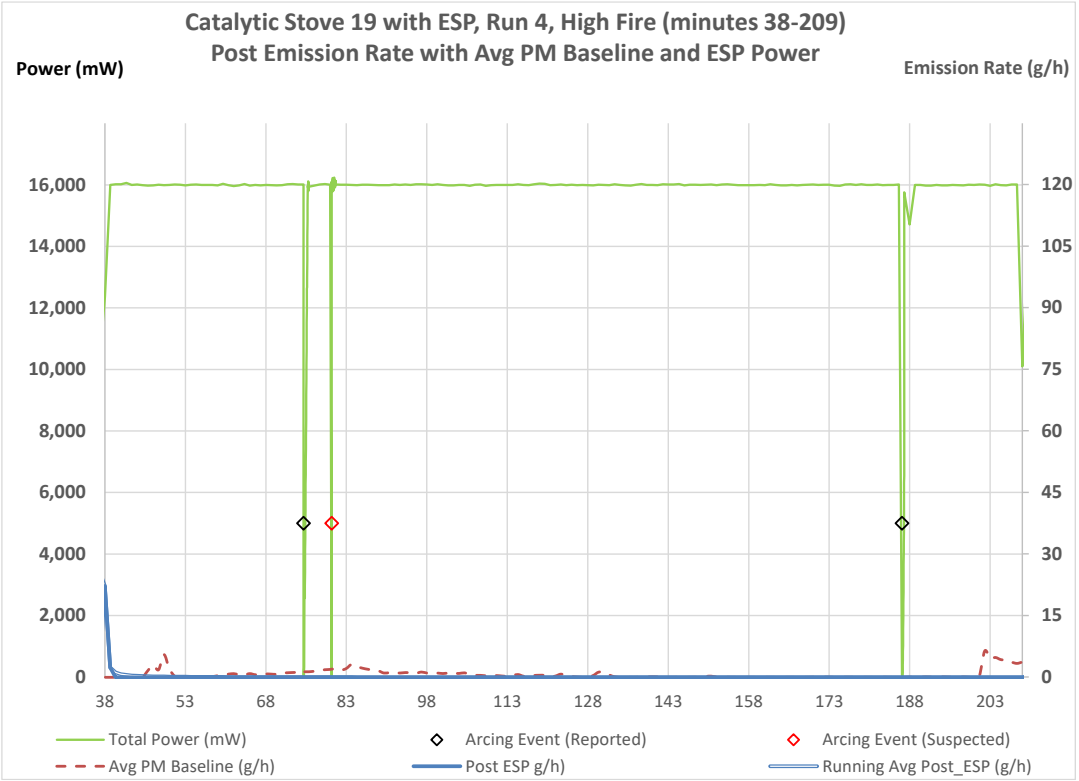
Catalytic Stove 19 with ESP, Run 4, Start-up





Catalytic Stove 19 with ESP, Run 4, High Fire





Catalytic Stove 19 with ESP, Run 4, Maintenance Fire