Pellet Stove Retrofit Emission Control Device Emission Reduction Testing

Appendix I. Analysis of Device Performance

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Appendix I. 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 determine the device's PM removal efficiency and to permit a graphical display of emissions performance on a consistent basis during the test. This work was performed by Rincon Ranch Consulting under subcontract to Trinity Consultants and is included here at the request of FNSB.

The TEOM PM emission measurements and the ESP operational data were combined and processed to permit a graphical display of emissions performance on a consistent basis during the tests. The TEOM measurements of particulate emissions were reported on a minute basis by ClearStak. For the pellet stove, the data include emission rates measured before and after the ESP device in units of g/h. 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. Two types of arcing events were coded. The device itself may report a trouble code of 8 to the data-logging interface 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 voltage 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 ASTM E2779 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 ASTM E2779 test spans a total of 25,200 seconds (420 minutes). To address this, while retaining the short-term visualization of arcing events, minute-by-minute averages of voltage, current and power were usually computed to correspond to the TEOM data, but the computation switched to a second-by-second basis whenever an arcing event (of either type) occurs. 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.

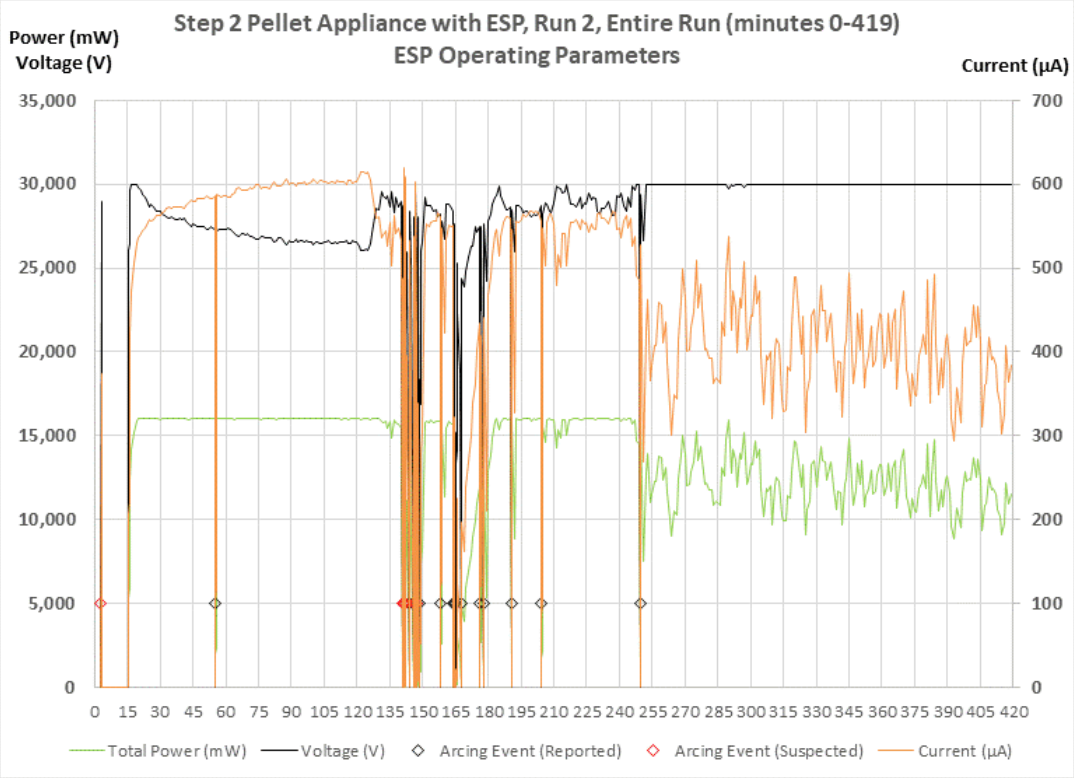
Four different graphs were created to display a range of operational parameters, emission rates, and computed emission removal rates and removal efficiencies for the device. The set of four graphs were produced for the entire test cycle and for its four phases: Startup (minutes 0-60); High Burn (minutes 61-120); Medium Burn (minutes 121-240); and Low Burn (minutes 241-419).

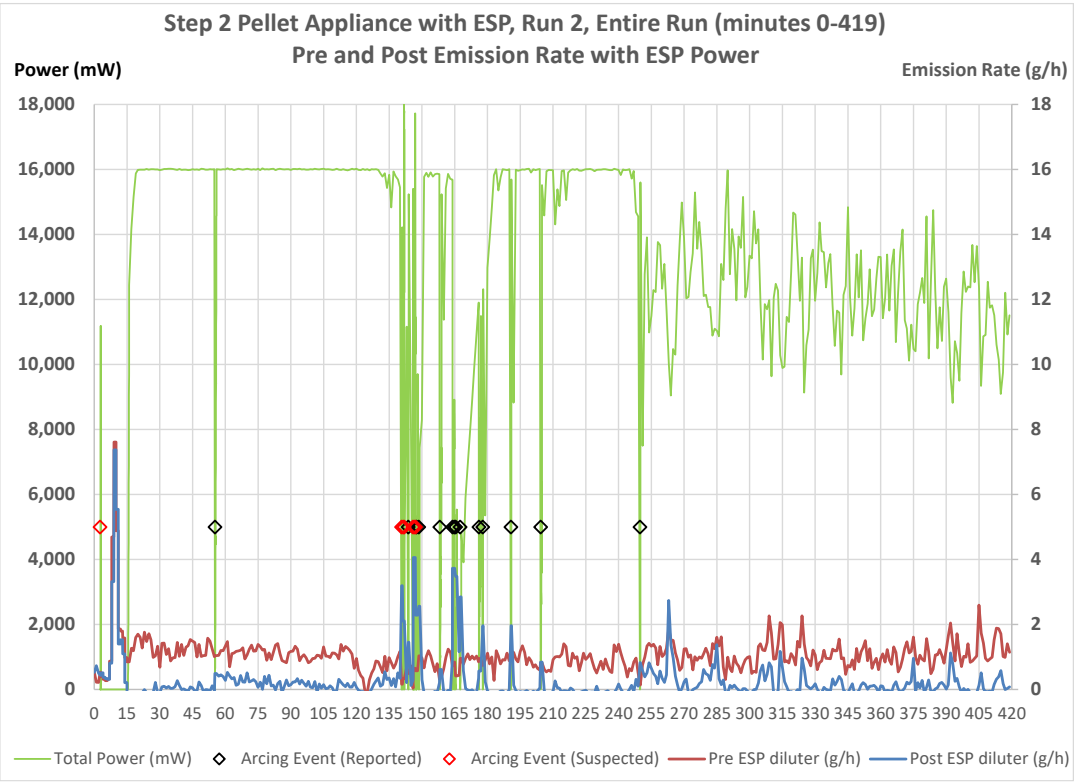
The graphs and variables displayed in them are the following:

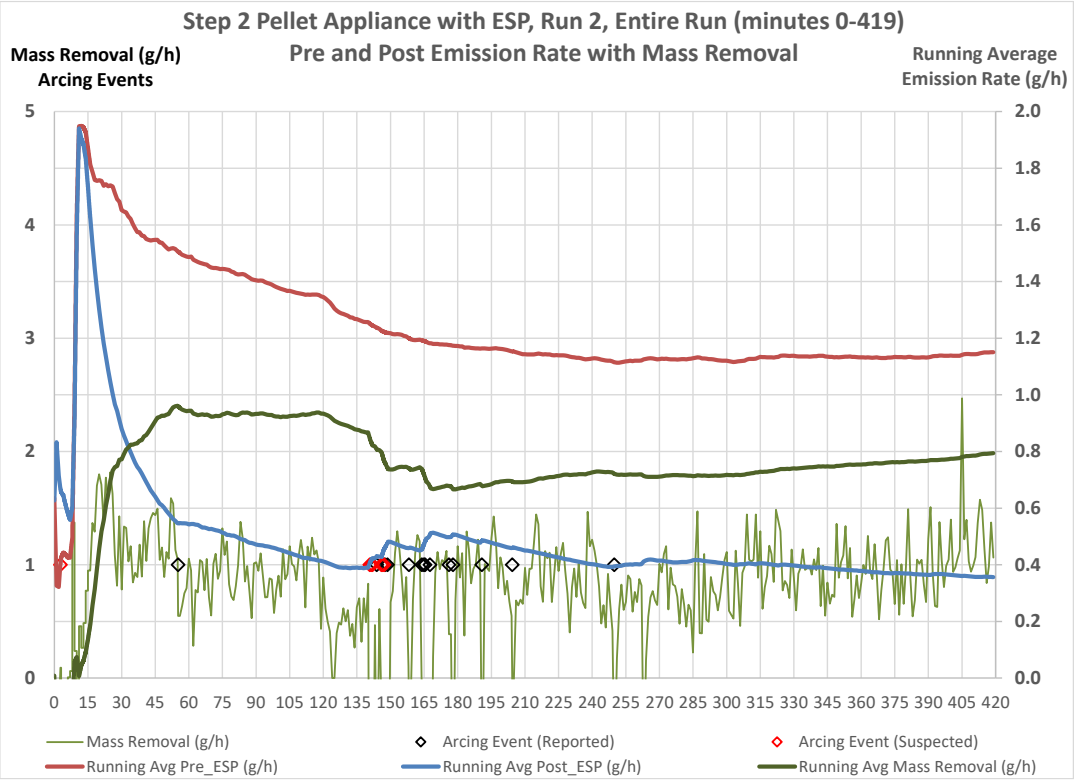
- ESP Operational Parameters: graph of ESP Power, Voltage and Current during the test. Arcing events are indicated by black and red diamonds and overlaid on the graph at the level of 5,000V (an arbitrary position chosen for clarity).
- Pre and Post Emission Rate with ESP Power: graph of PM emissions measured before and after the ESP to show the pollutant removal by the device. Power and arcing events are also shown as in the first graph.
- Pre and Post Emission Rate with Mass Removal: graph of the instantaneous mass removal rate (g/h) on the left axis, with running averages of the pre- and post- emission rates and mass removal rate on the right axis. For the graphs of the entire test, the running averages begin with minute 0 and end with minute 419. For the graphs of phases of the test, the running averages begin and end with the minutes that define the phase. Arcing events are overlaid at the 1 level (arbitrary).

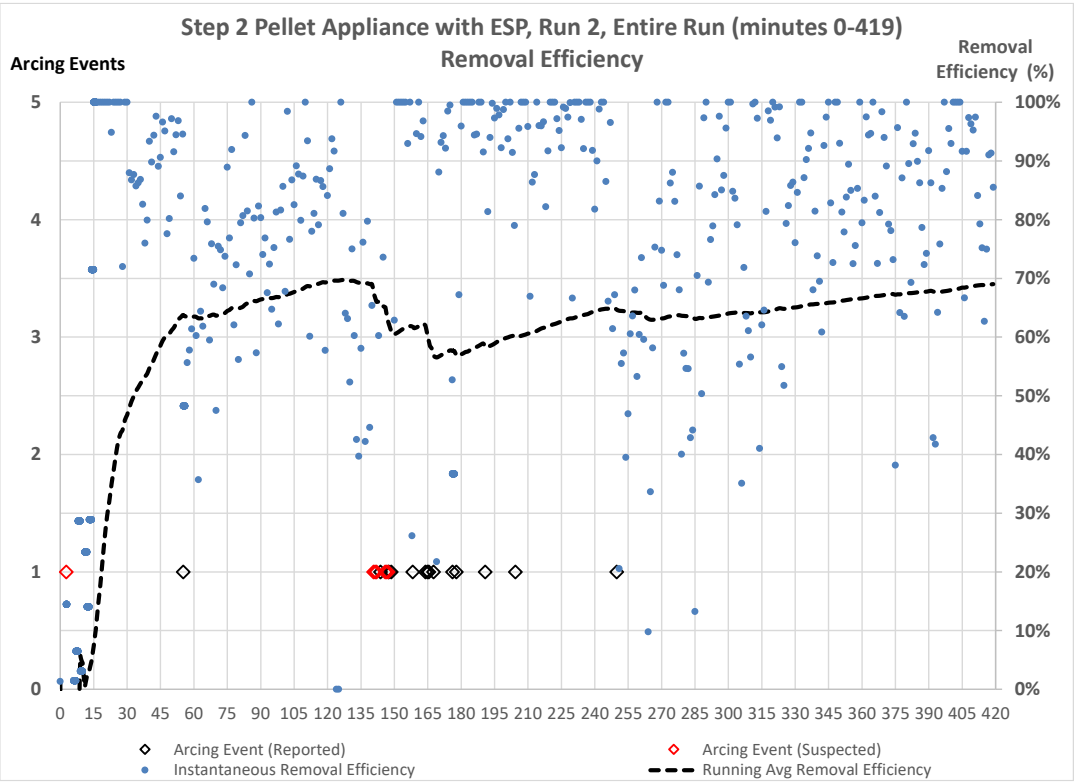
- Removal Efficiency: graph of instantaneous removal efficiency (blue circles) and running average removal efficiency (black line) along with an overlay of arcing events. The running average begins and ends with the test segment shown in the graph.

Step 2 Pellet Appliance with ESP, Run 2, Entire Run

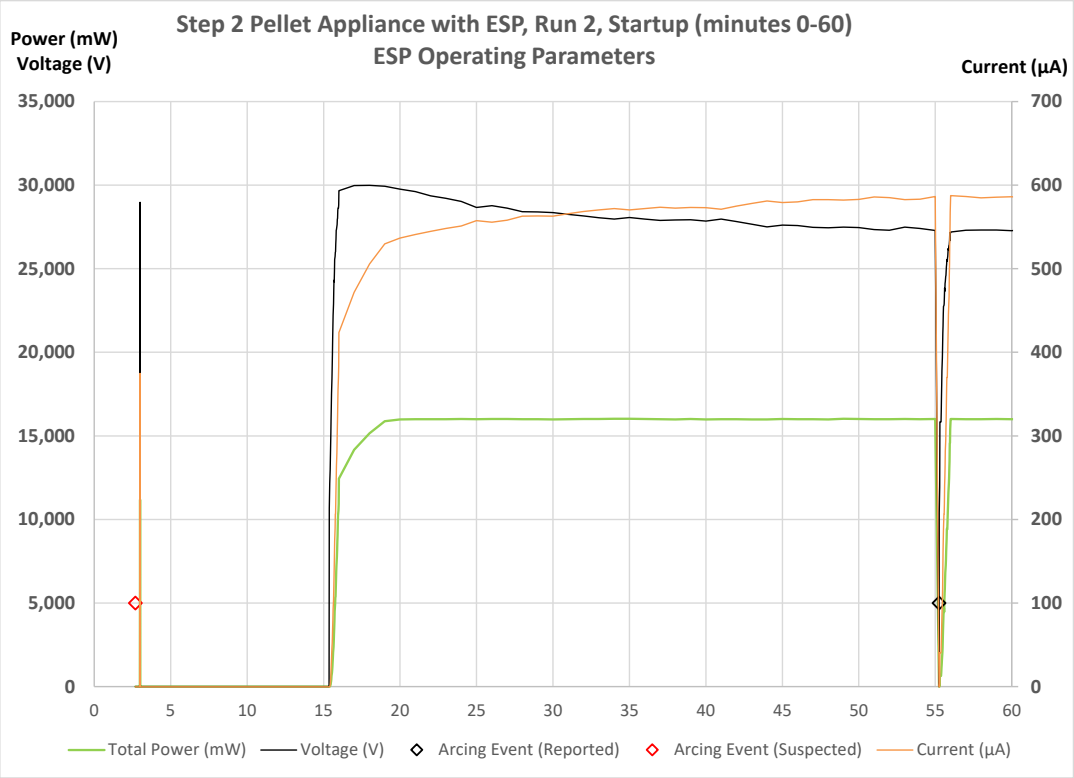


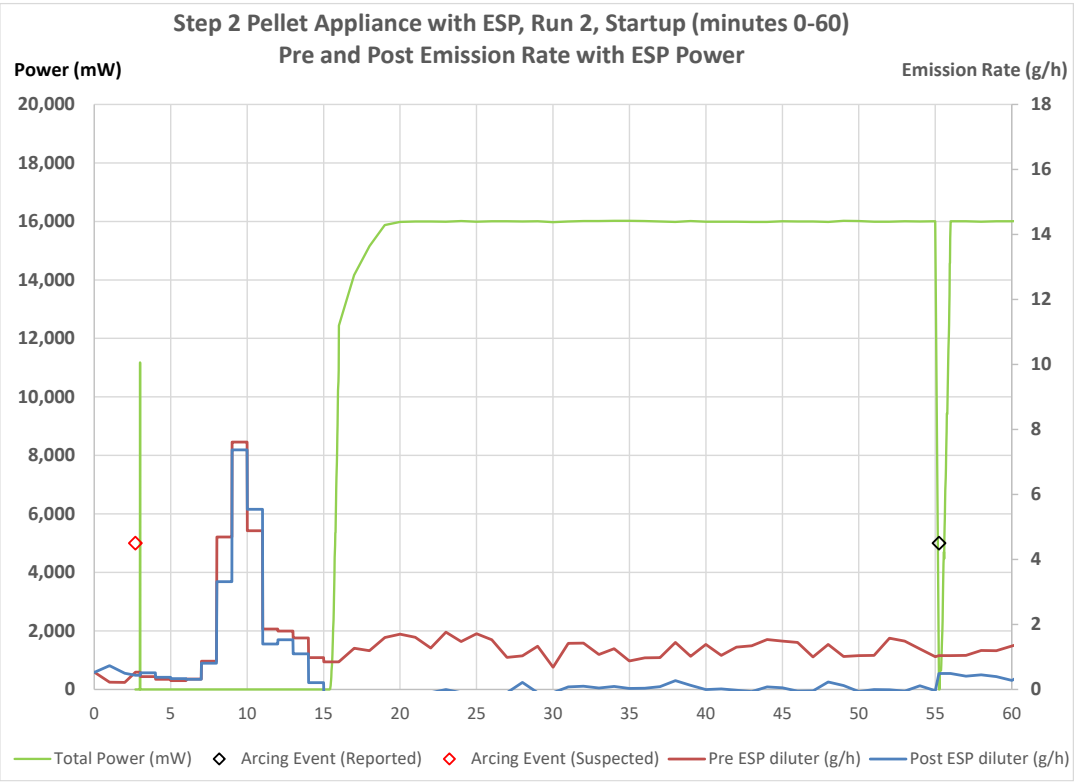


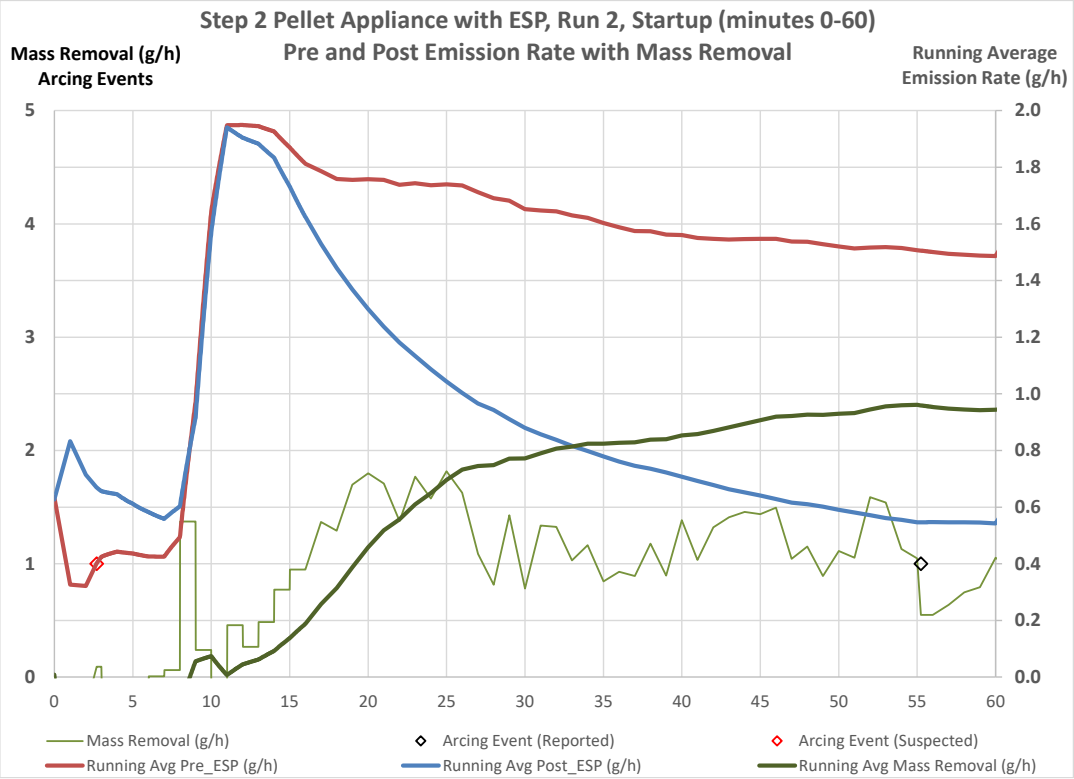

Step 2 Pellet Appliance with ESP, Run 2, Entire Run (minutes 0-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

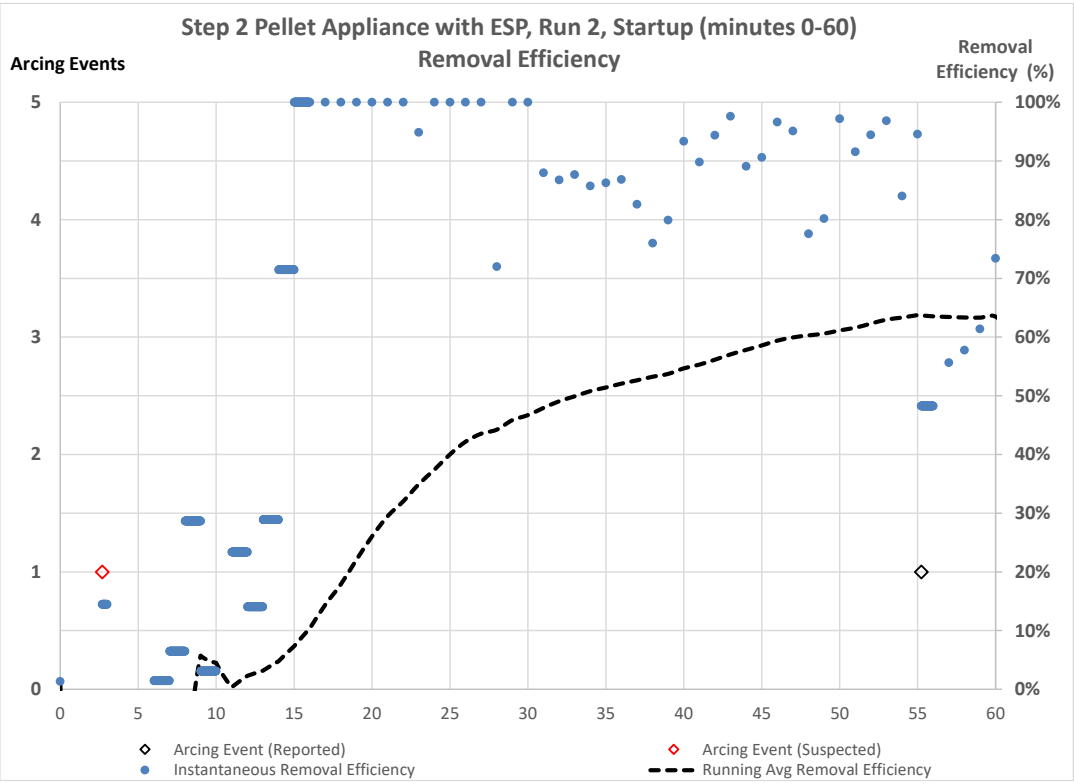

Step 2 Pellet Appliance with ESP, Run 2, Entire Run (minutes 0-419)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 2, Startup

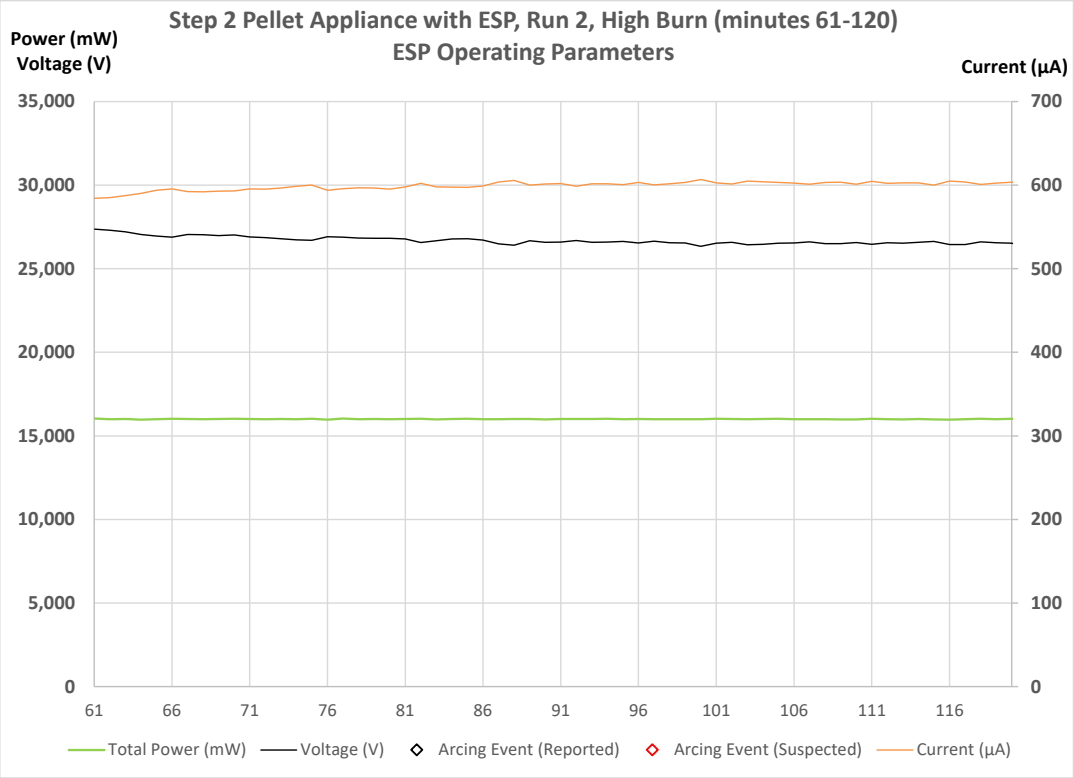


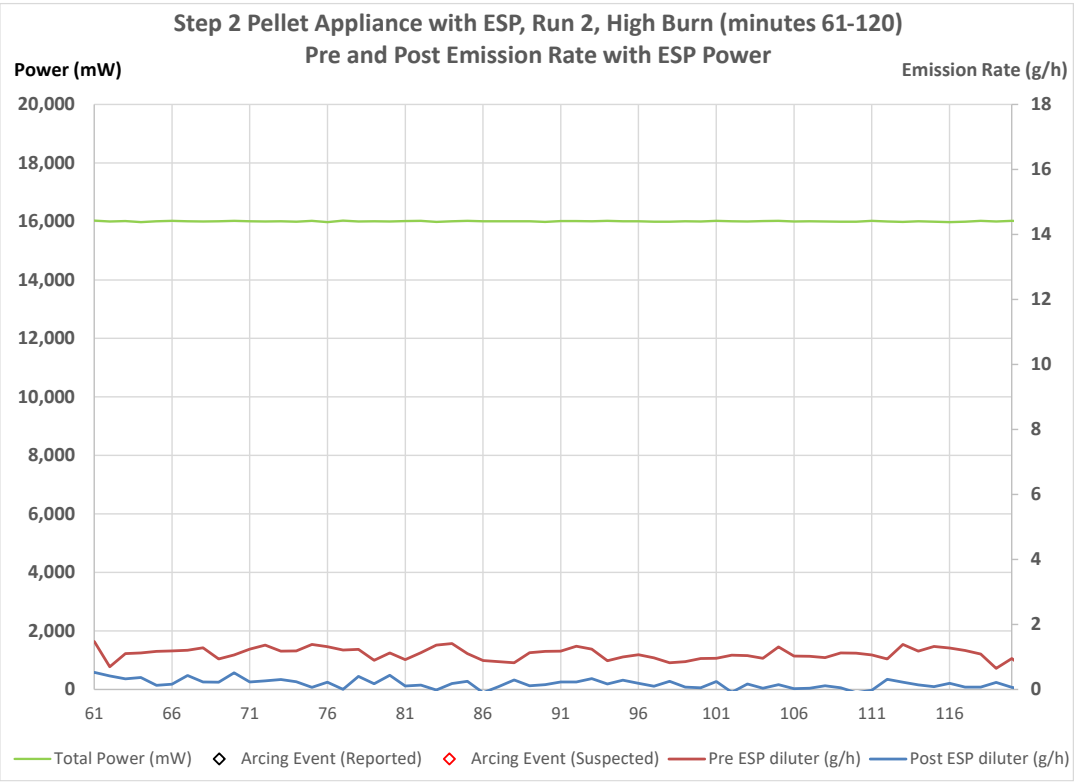


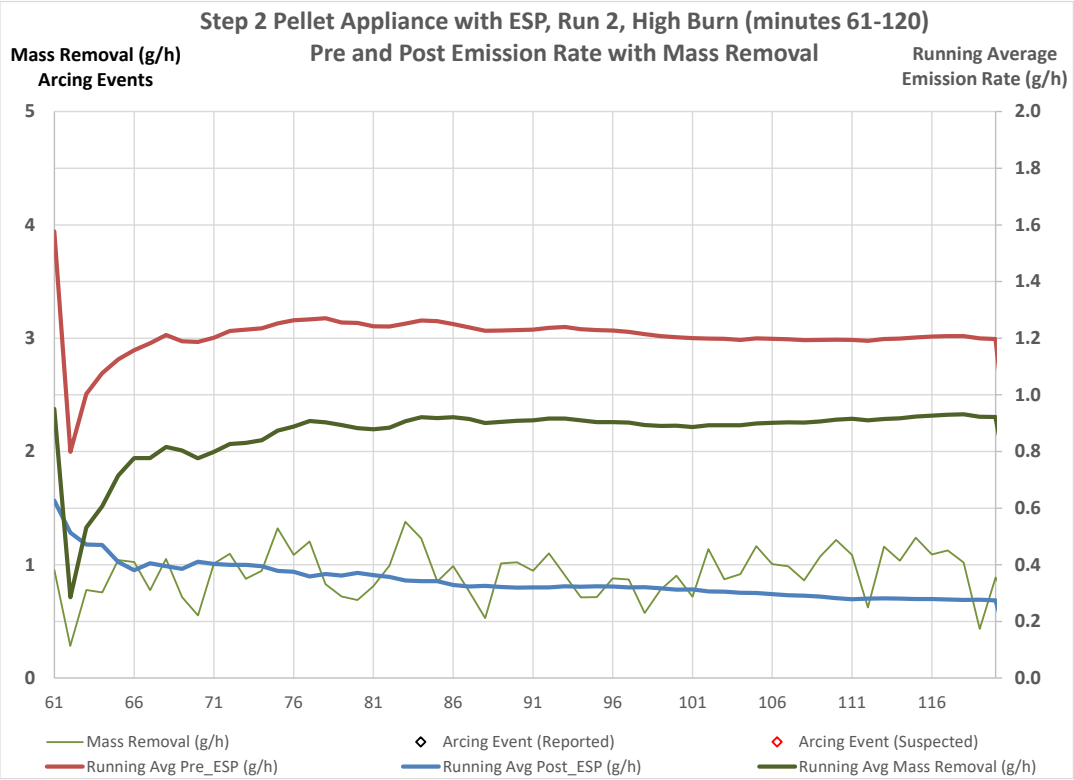

Step 2 Pellet Appliance with ESP, Run 2, Startup (minutes 0-60)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

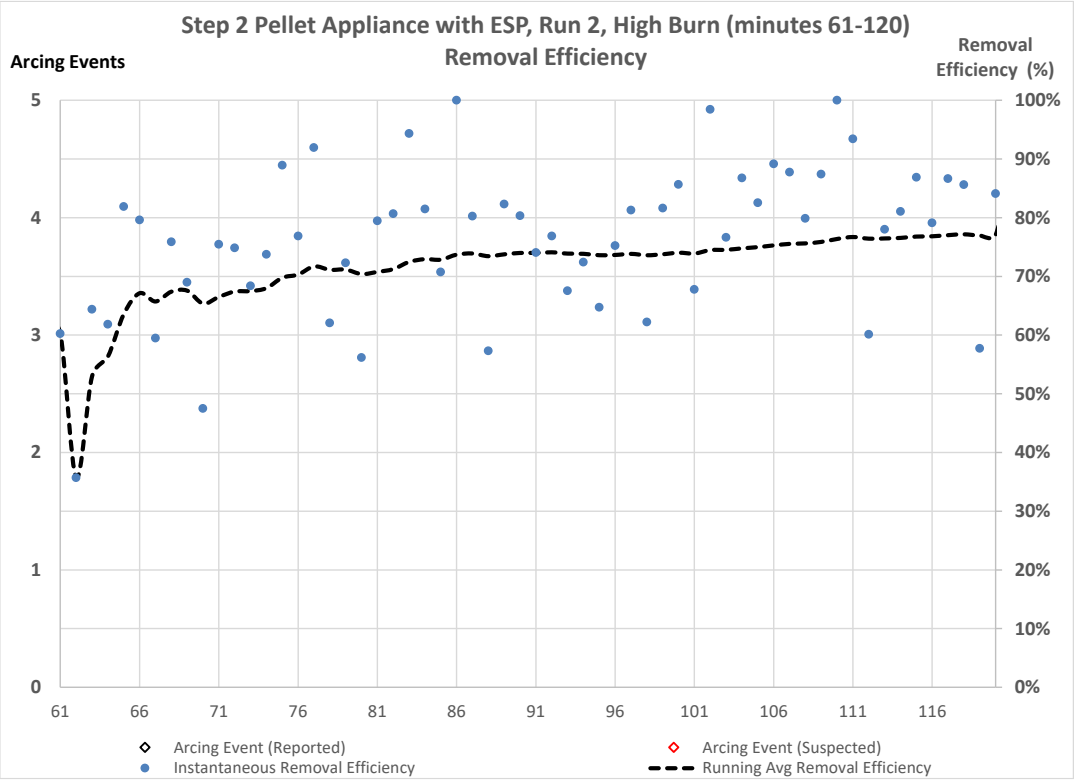

Step 2 Pellet Appliance with ESP, Run 2, Startup (minutes 0-60)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
5
10
15
20
25
30
35
40
45
50
55
60
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 2, High Burn

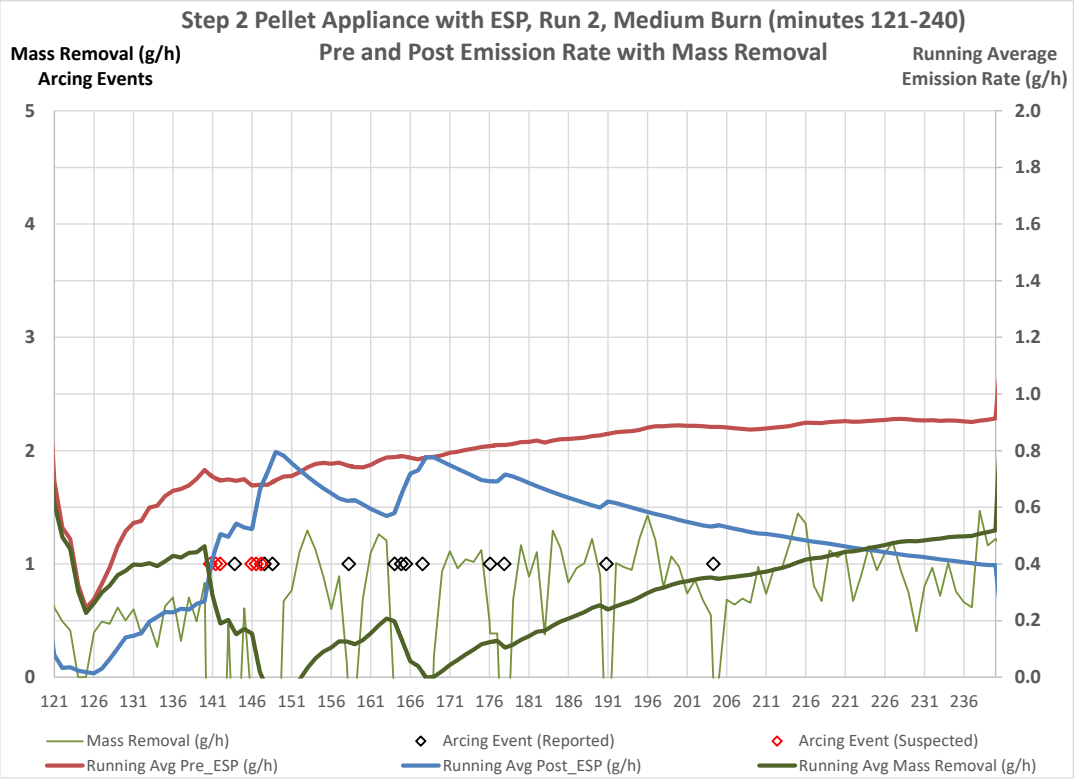


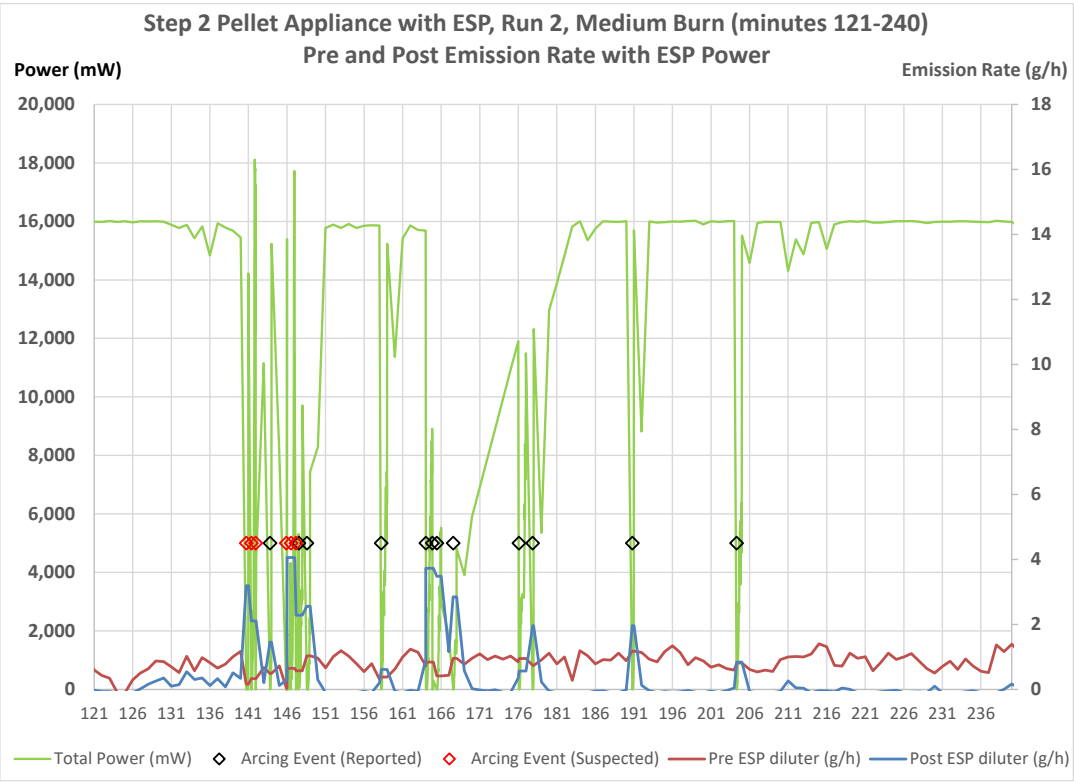


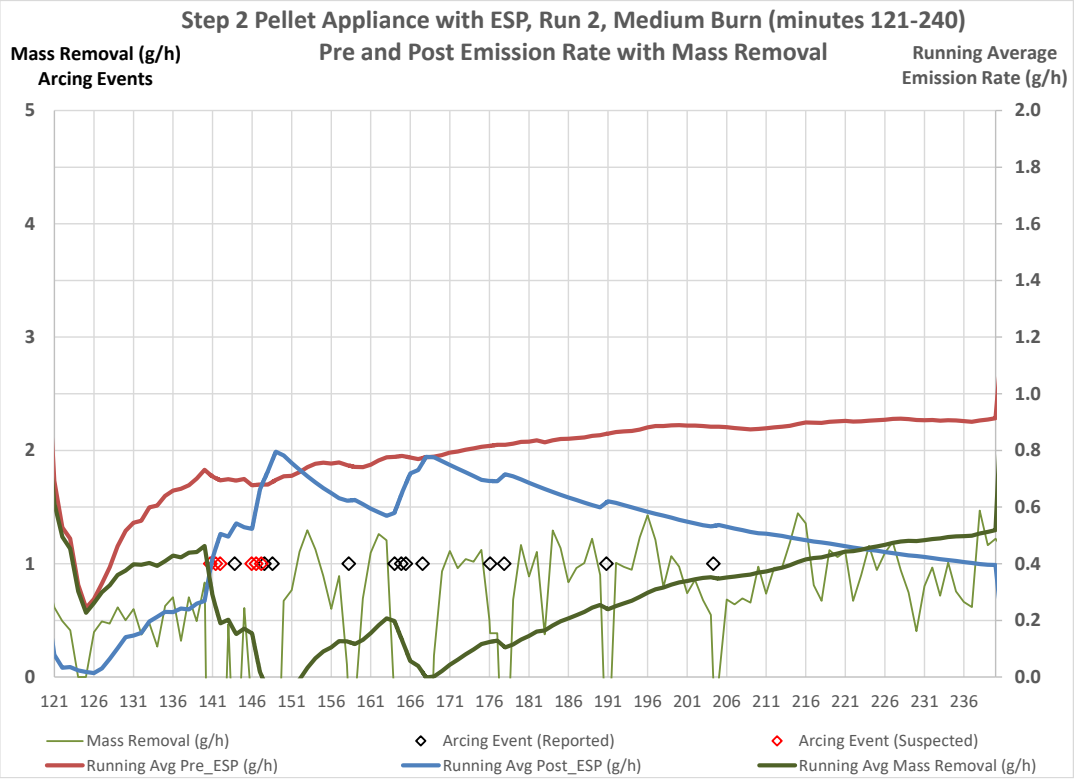

Step 2 Pellet Appliance with ESP, Run 2, High Burn (minutes 61-120)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
61
66
71
76
81
86
91
96
101
106
111
116
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

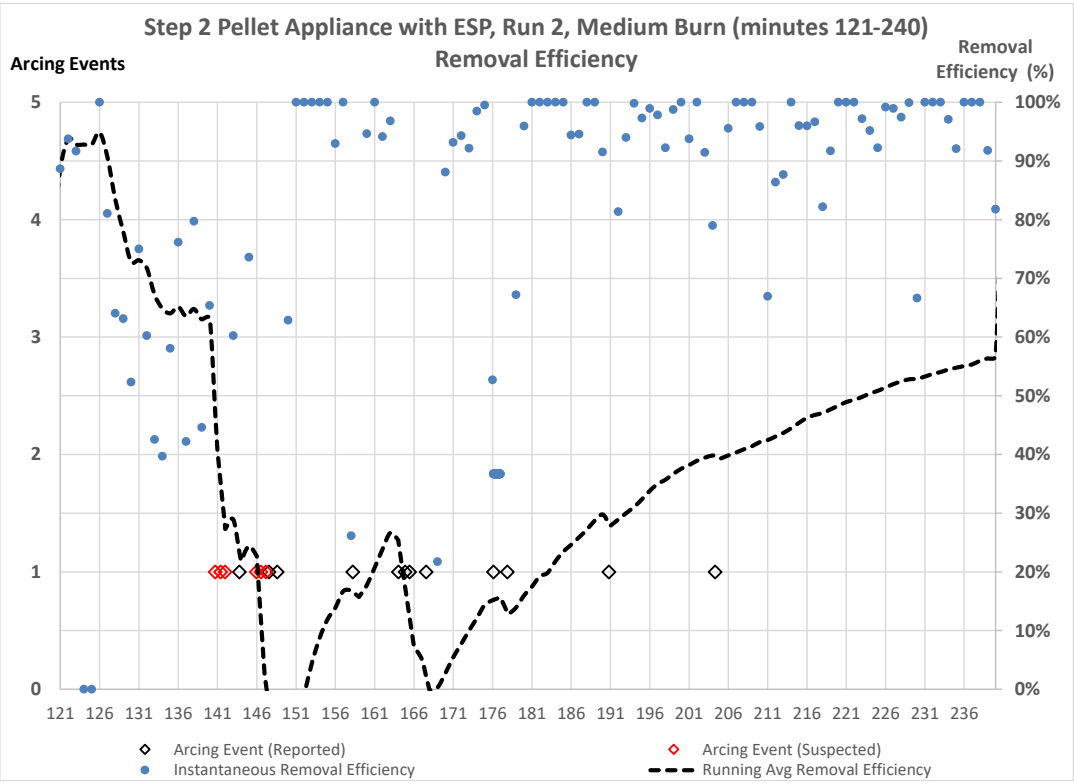

Step 2 Pellet Appliance with ESP, Run 2, High Burn (minutes 61-120)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
61
66
71
76
81
86
91
96
101
106
111
116
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 2, Medium Burn

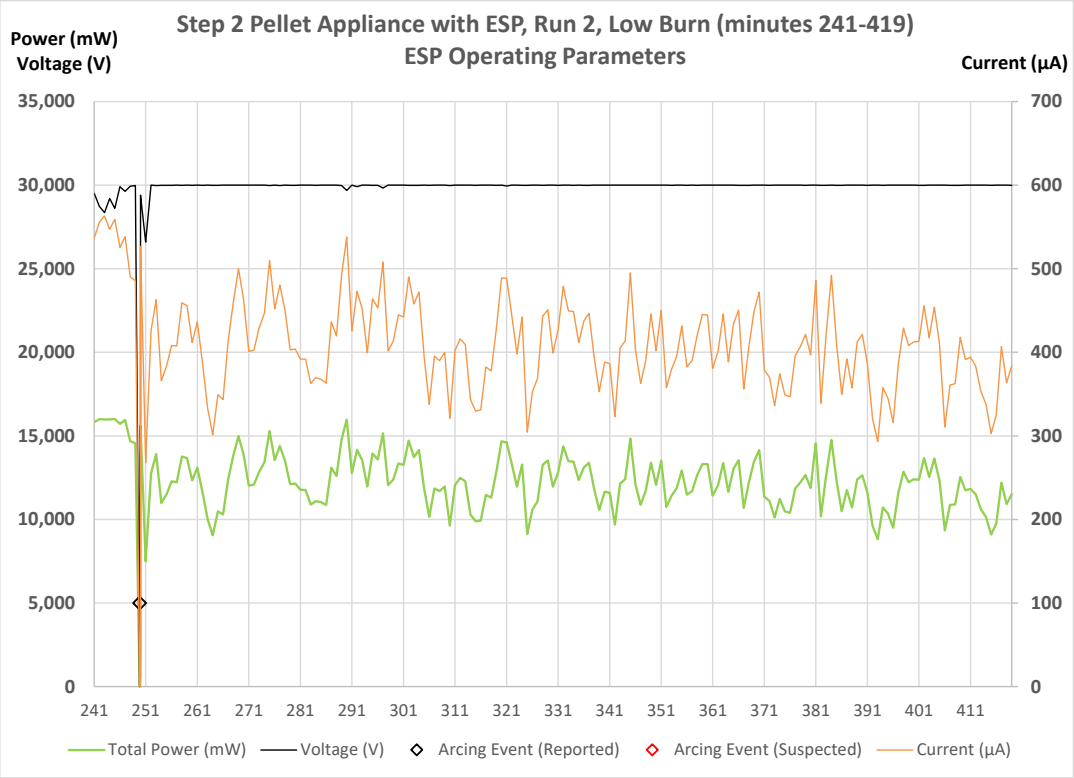


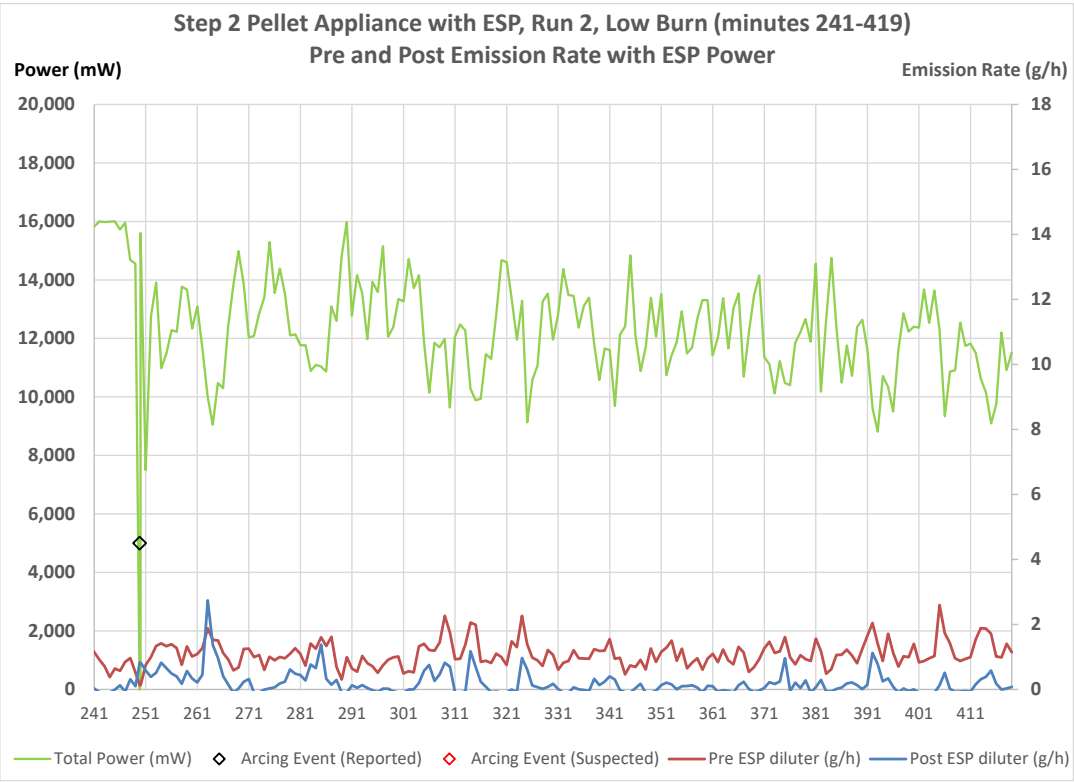


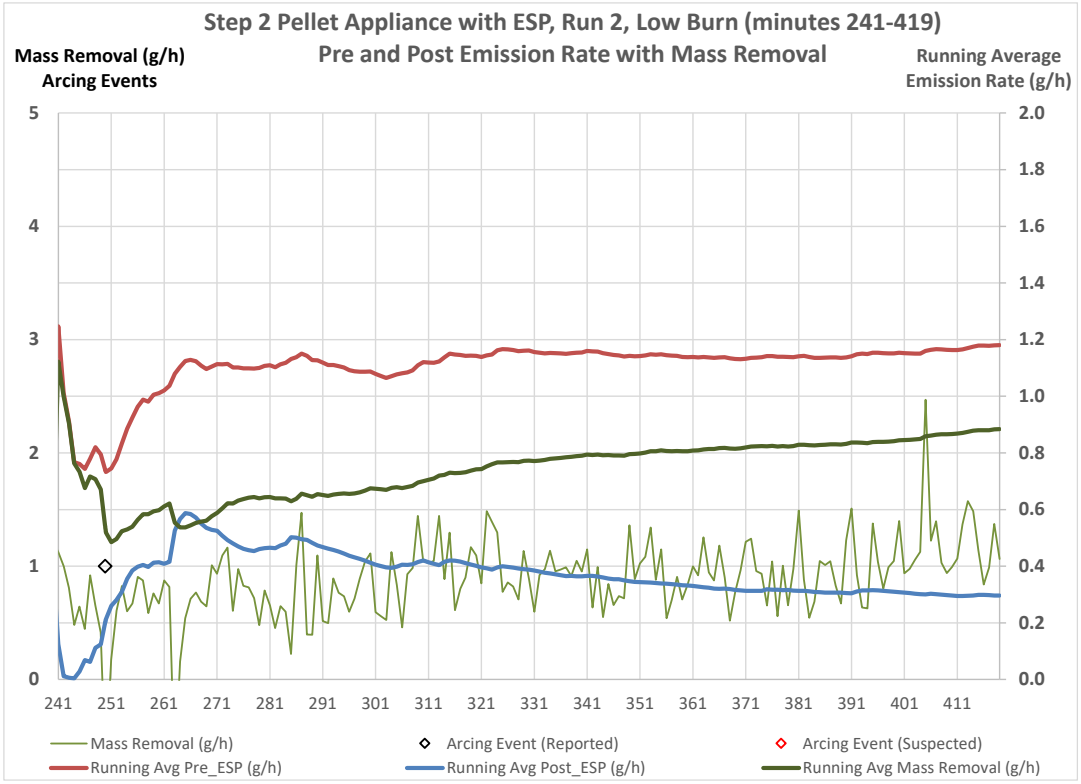

Step 2 Pellet Appliance with ESP, Run 2, Medium Burn (minutes 121-240)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
121 126 131 136 141 146 151 156 161 166 171 176 181 186 191 196 201 206 211 216 221 226 231 236
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

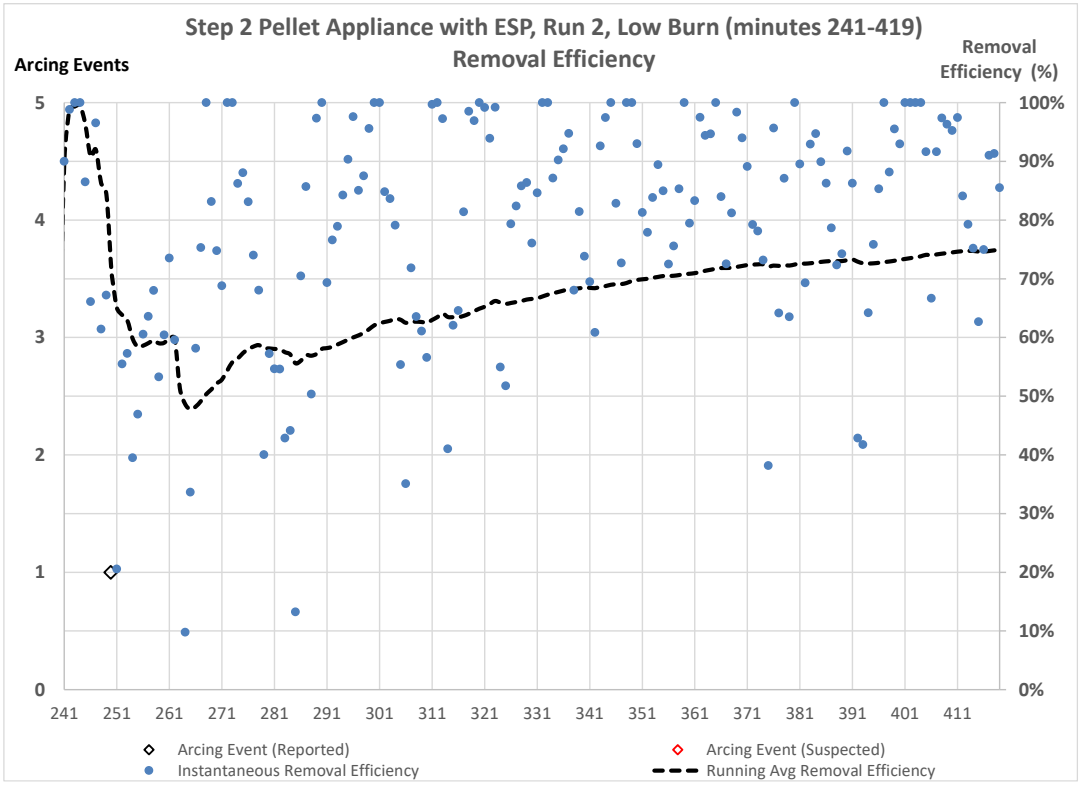

Step 2 Pellet Appliance with ESP, Run 2, Medium Burn (minutes 121-240)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
121 126 131 136 141 146 151 156 161 166 171 176 181 186 191 196 201 206 211 216 221 226 231 236
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 2, Low Burn

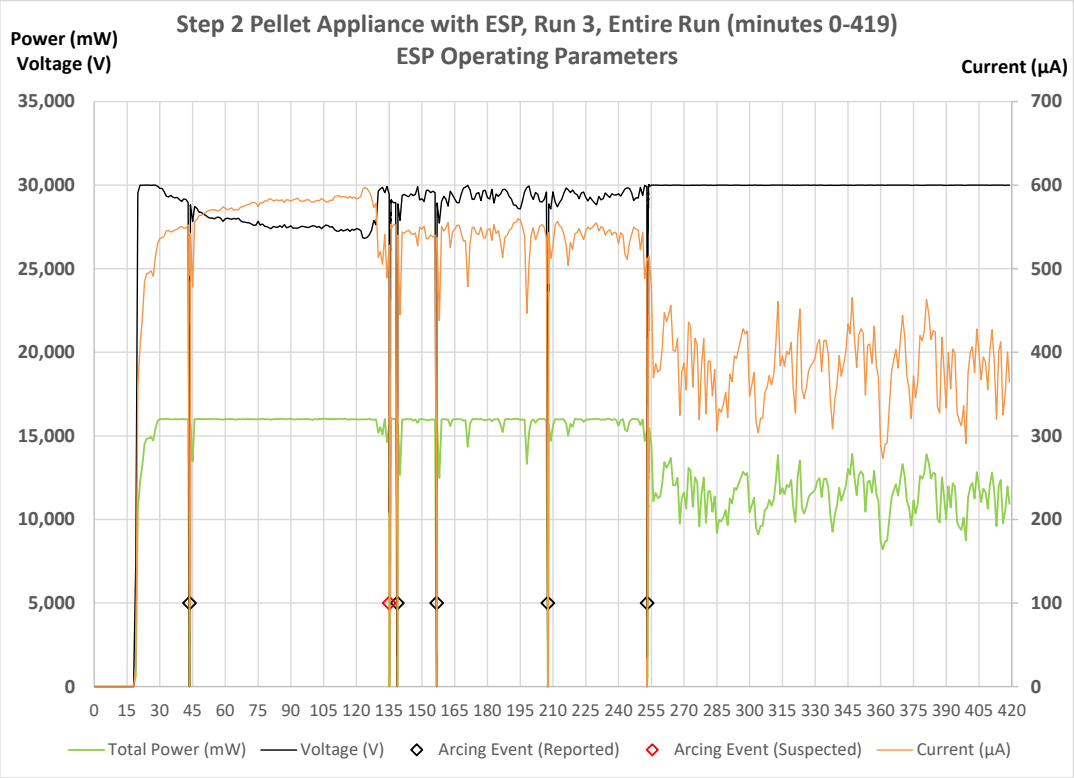


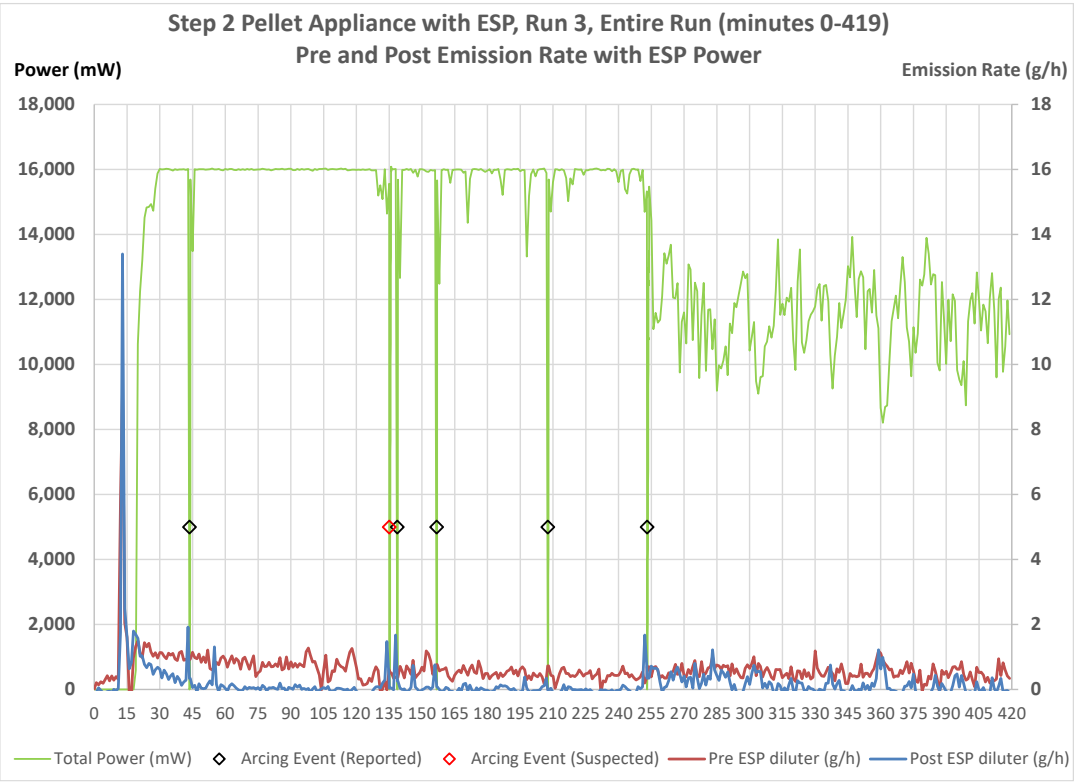


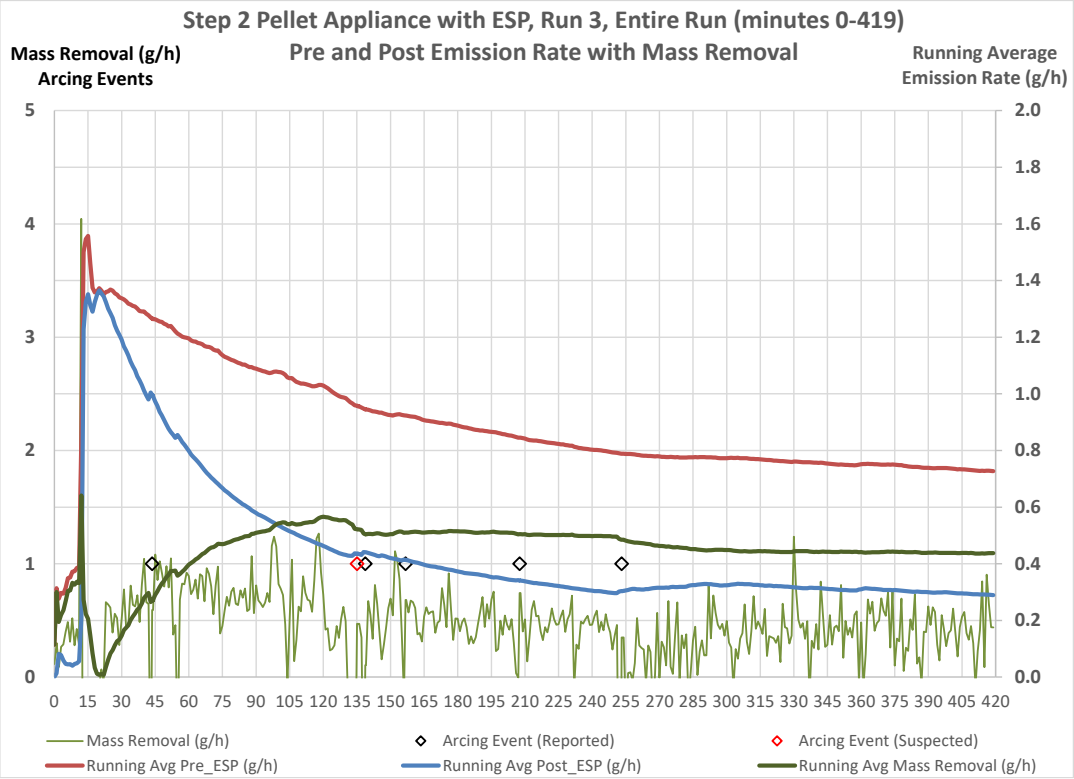

Step 2 Pellet Appliance with ESP, Run 2, Low Burn (minutes 241-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

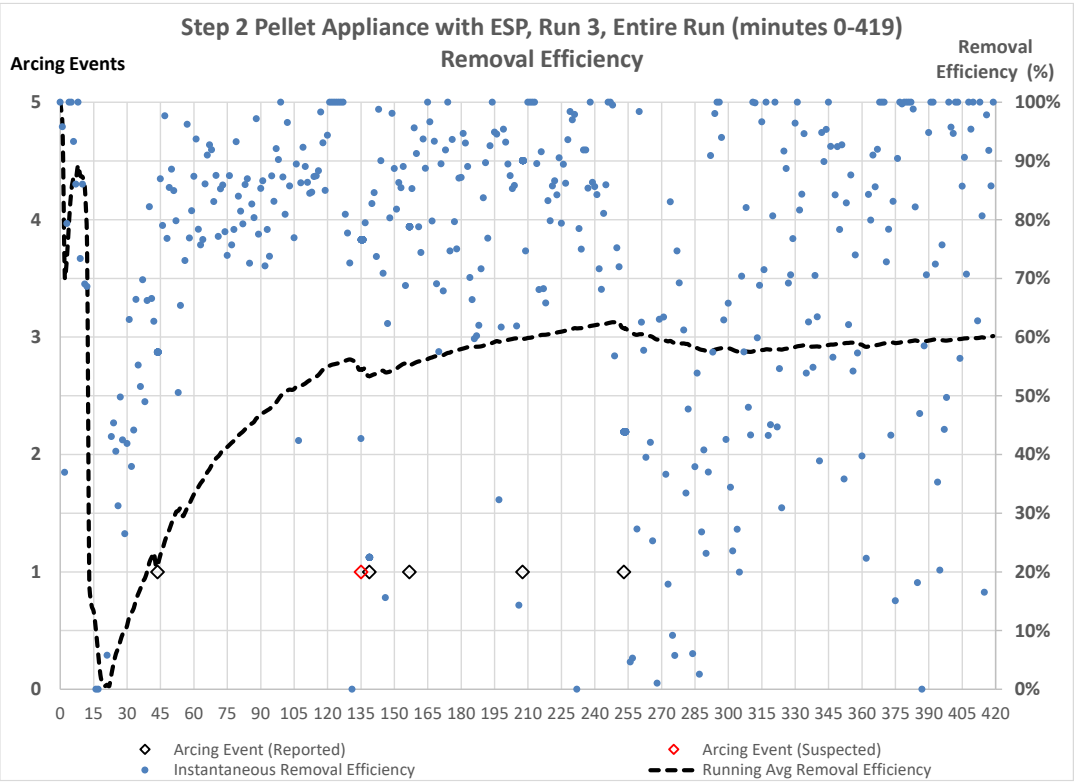

Step 2 Pellet Appliance with ESP, Run 2, Low Burn (minutes 241-419)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 3, Entire Run

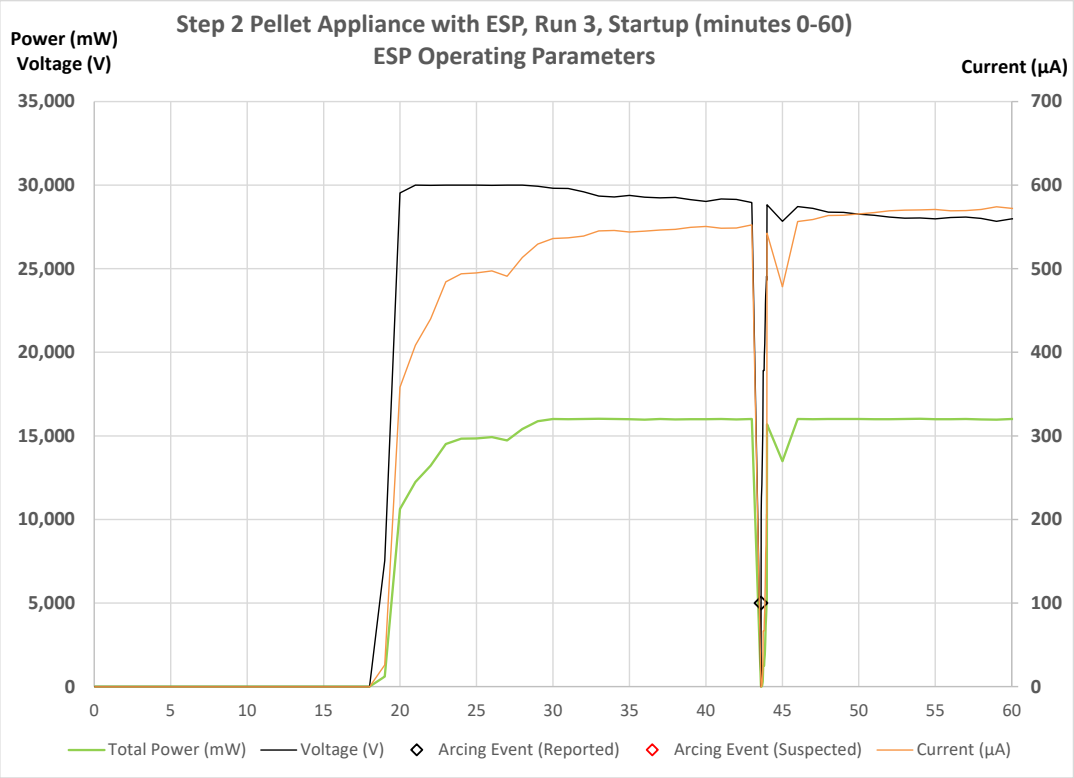


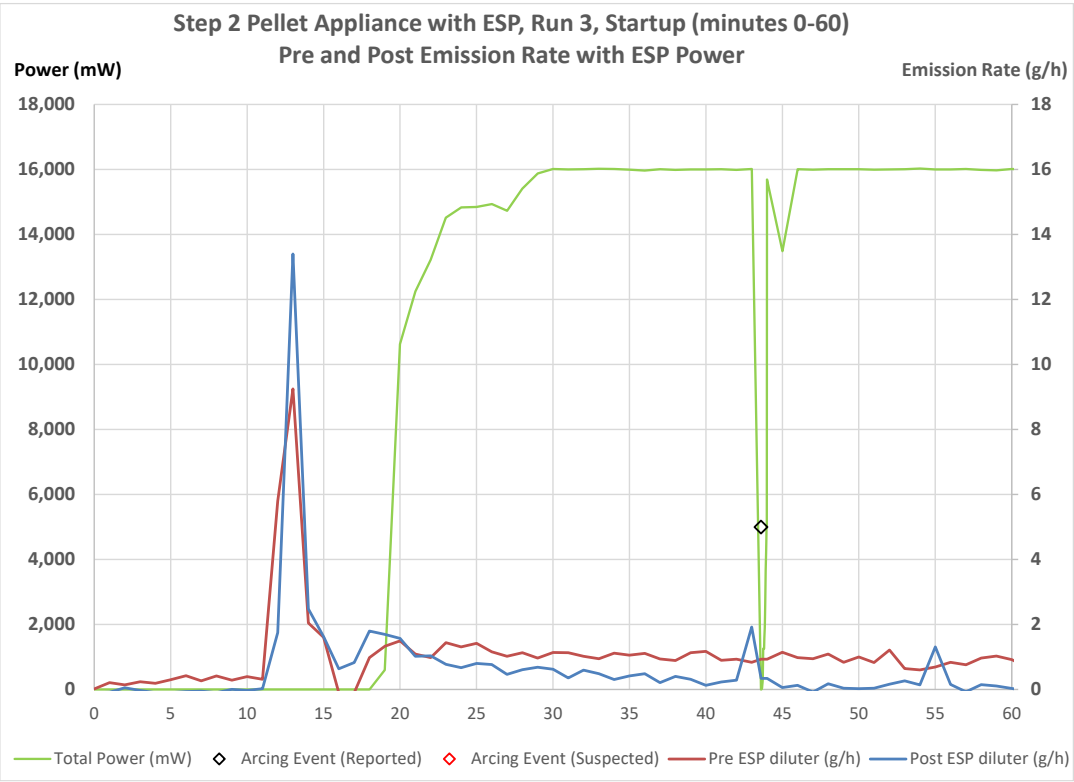


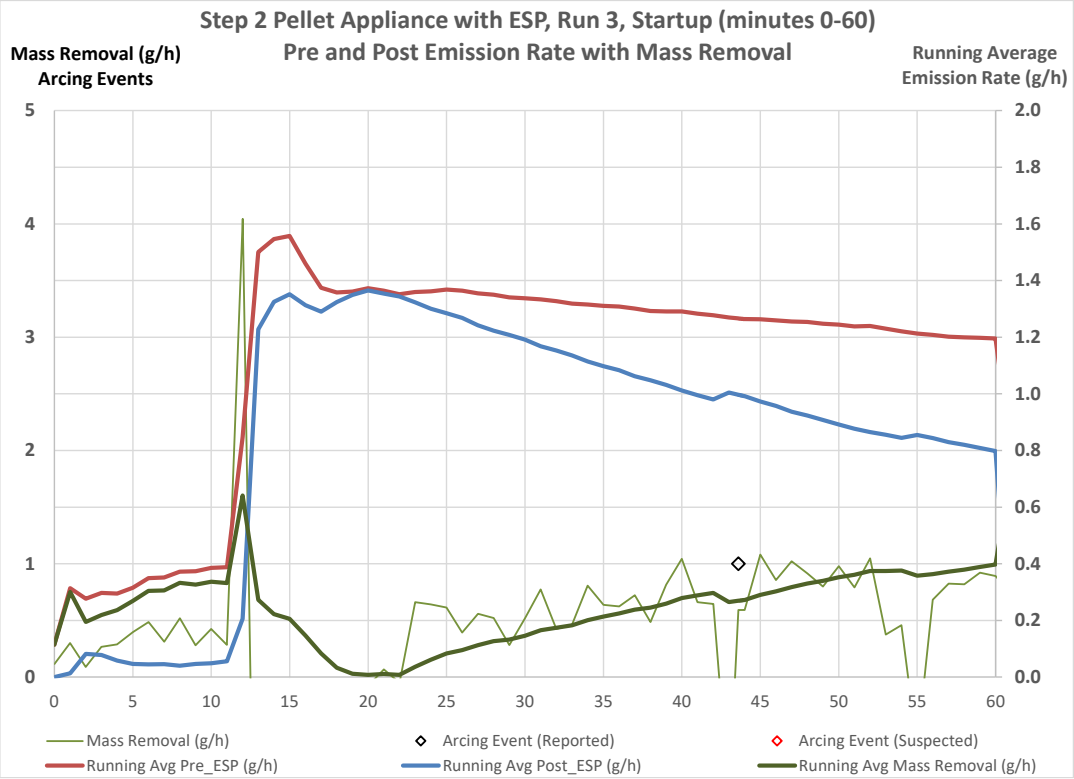

Step 2 Pellet Appliance with ESP, Run 3, Entire Run (minutes 0-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

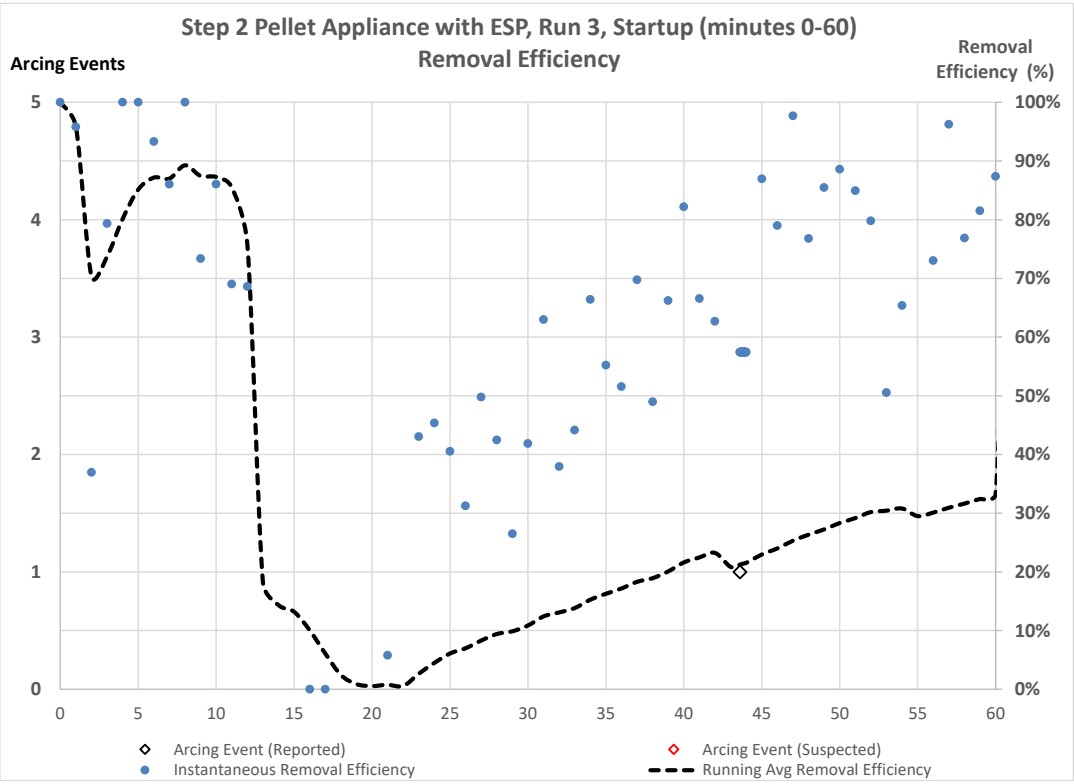

Step 2 Pellet Appliance with ESP, Run 3, Entire Run (minutes 0-419)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 3, Startup

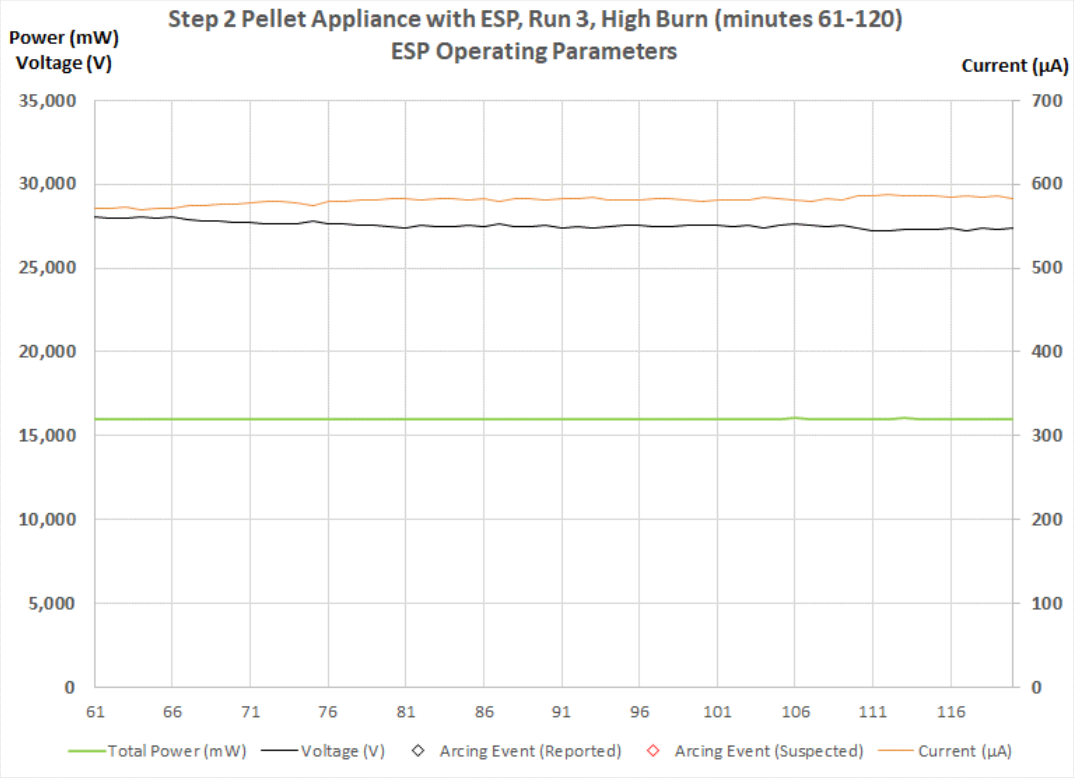


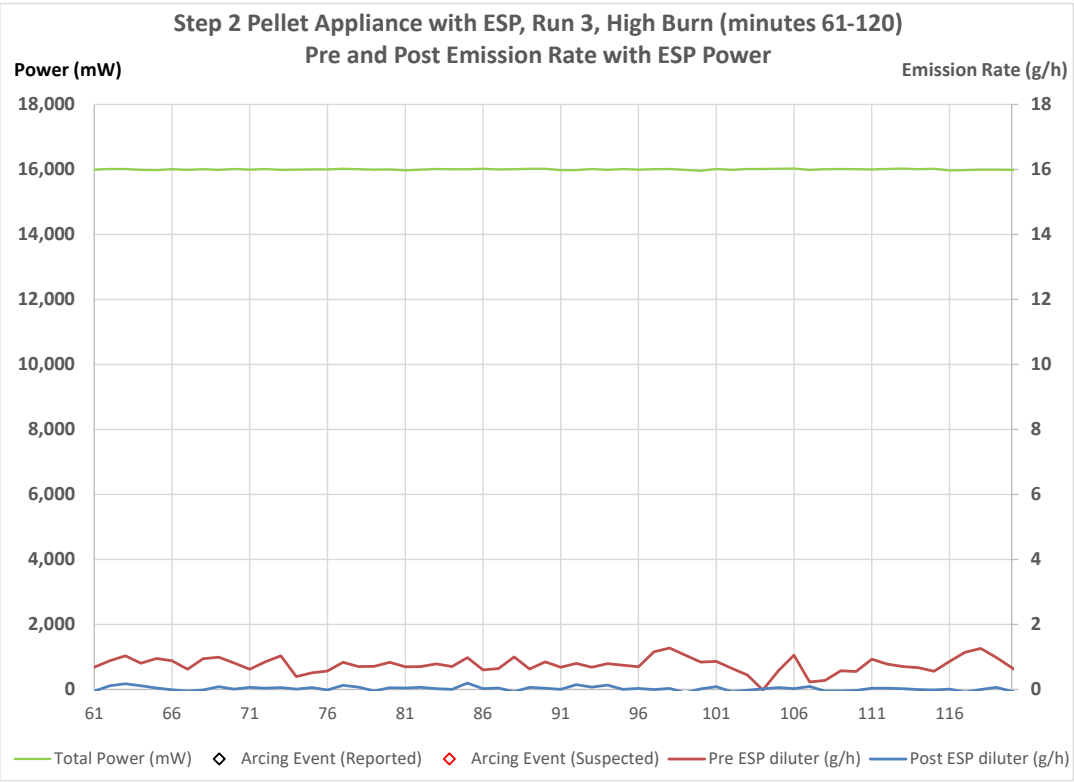


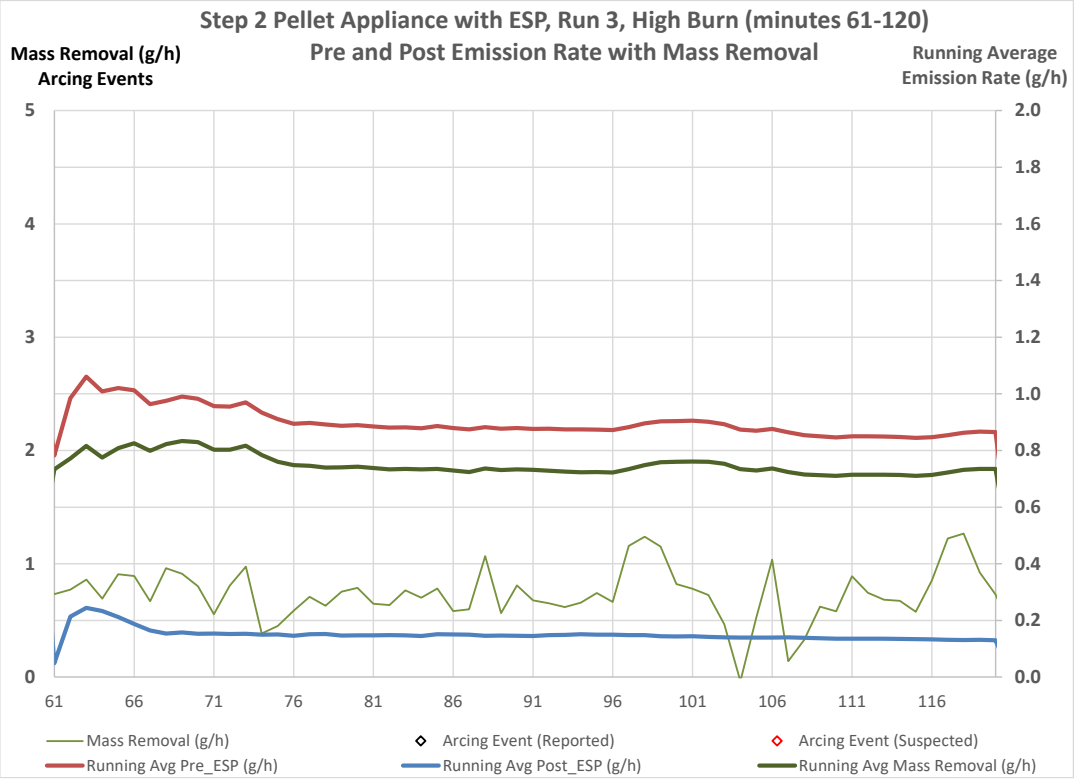

Step 2 Pellet Appliance with ESP, Run 3, Startup (minutes 0-60)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 5 10 15 20 25 30 35 40 45 50 55 60
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

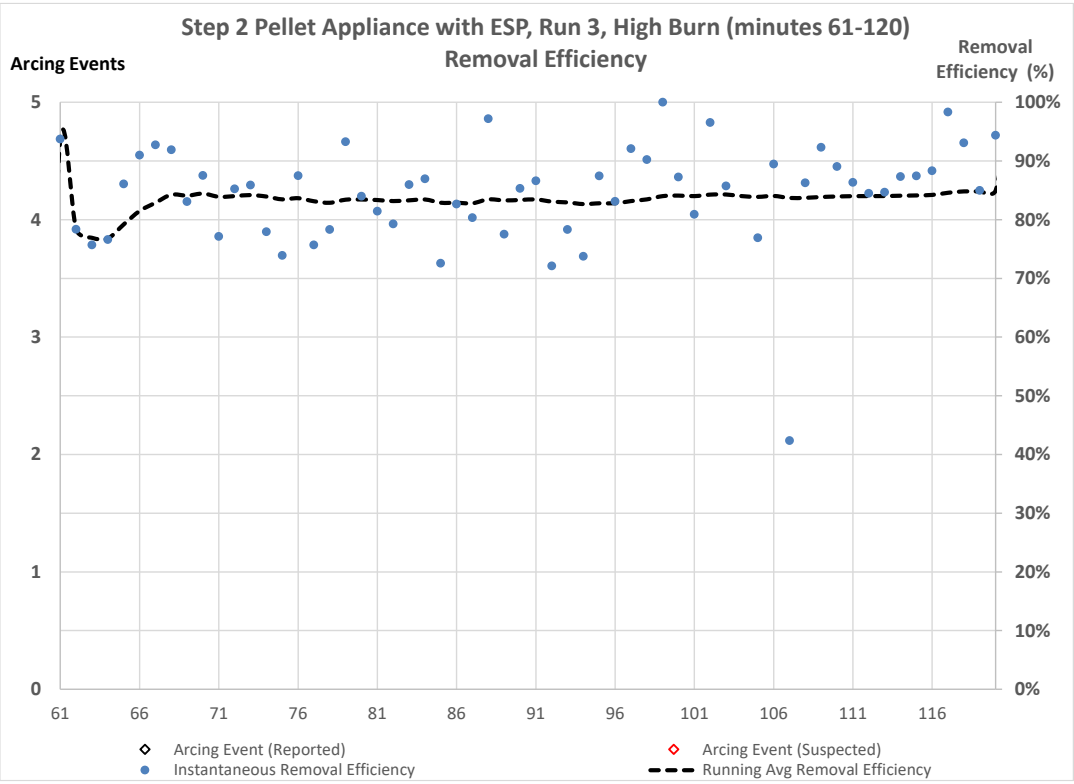

Step 2 Pellet Appliance with ESP, Run 3, Startup (minutes 0-60)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 5 10 15 20 25 30 35 40 45 50 55 60
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 3, High Burn

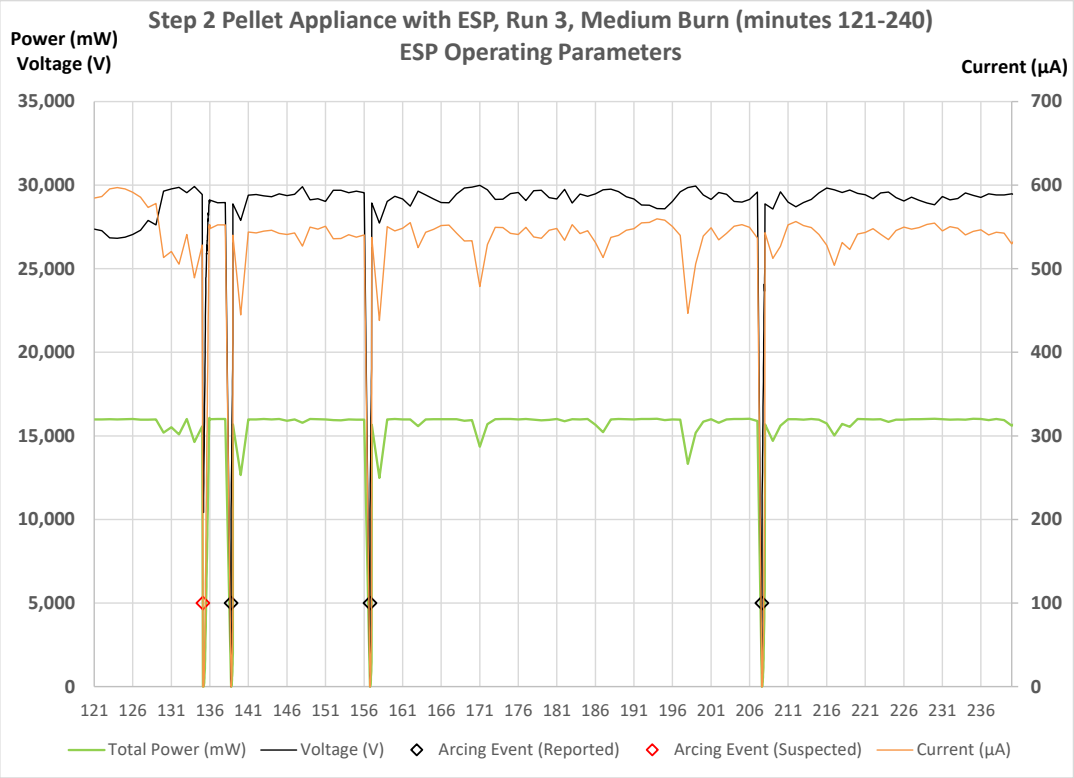


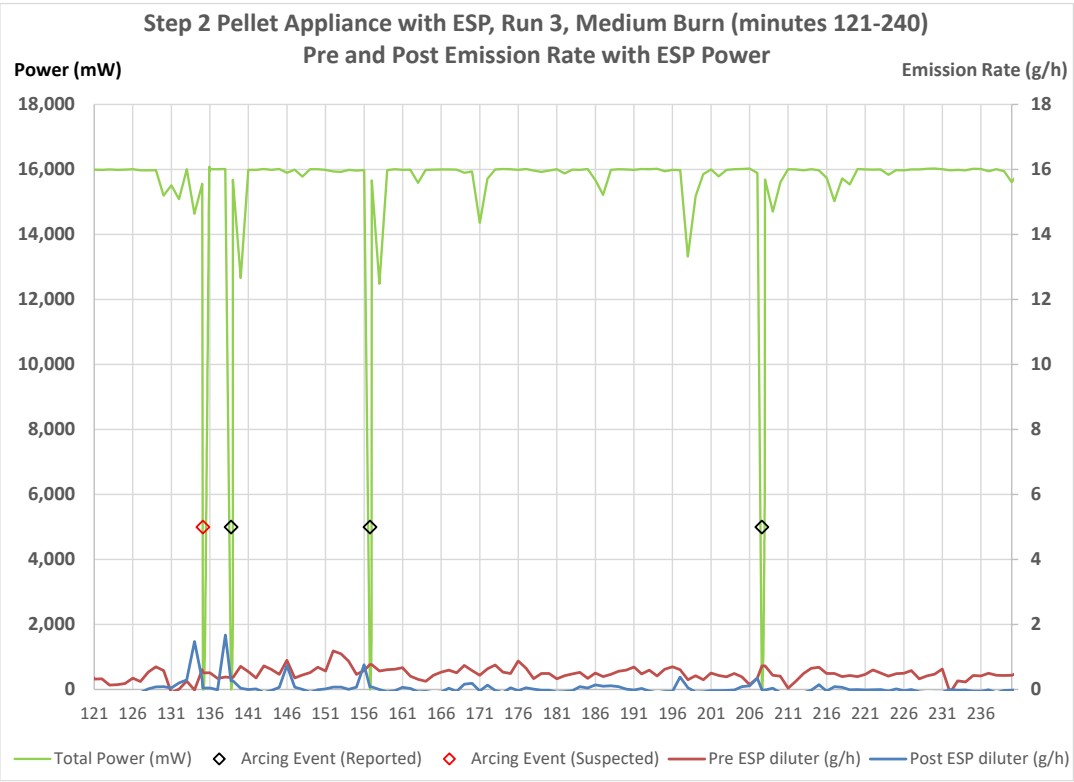


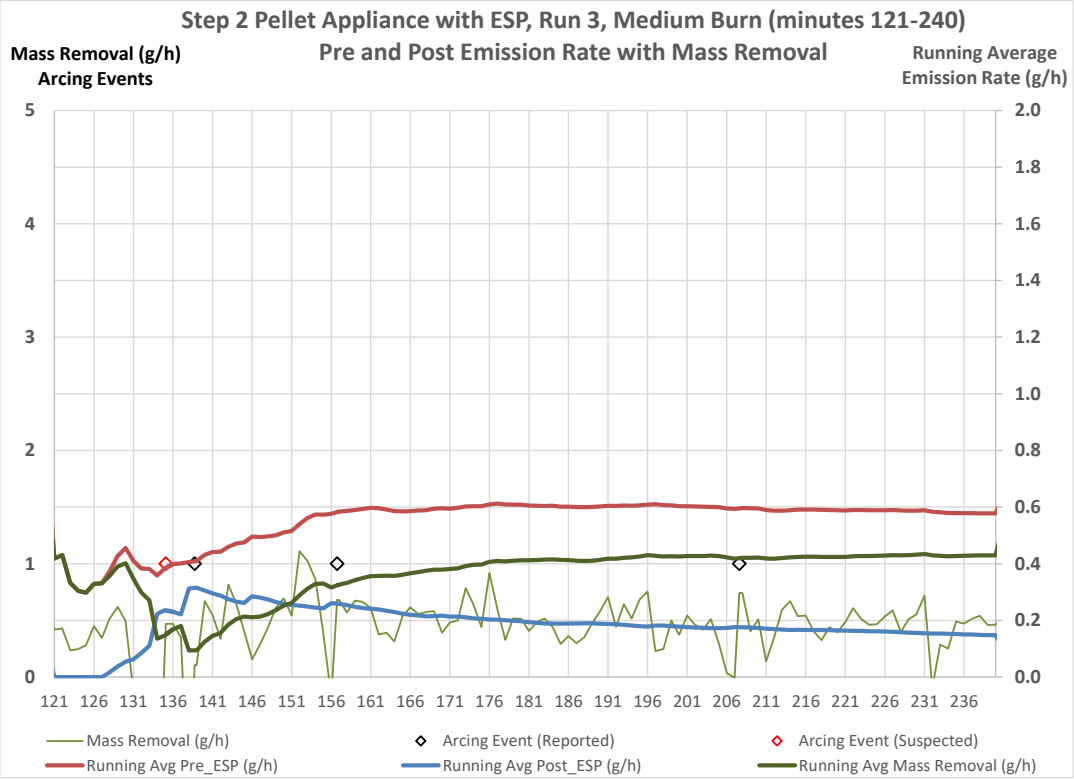

Step 2 Pellet Appliance with ESP, Run 3, High Burn (minutes 61-120)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
61
66
71
76
81
86
91
96
101
106
111
116
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

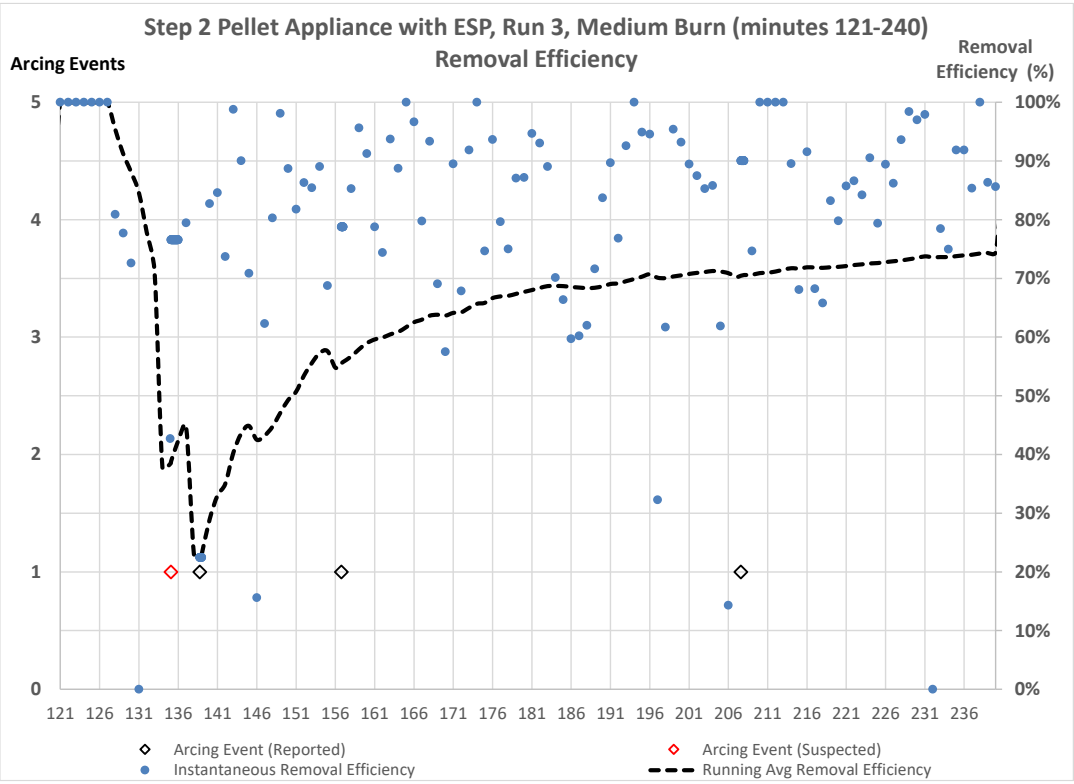

Step 2 Pellet Appliance with ESP, Run 3, High Burn (minutes 61-120)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
61
66
71
76
81
86
91
96
101
106
111
116
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 3, Medium Burn

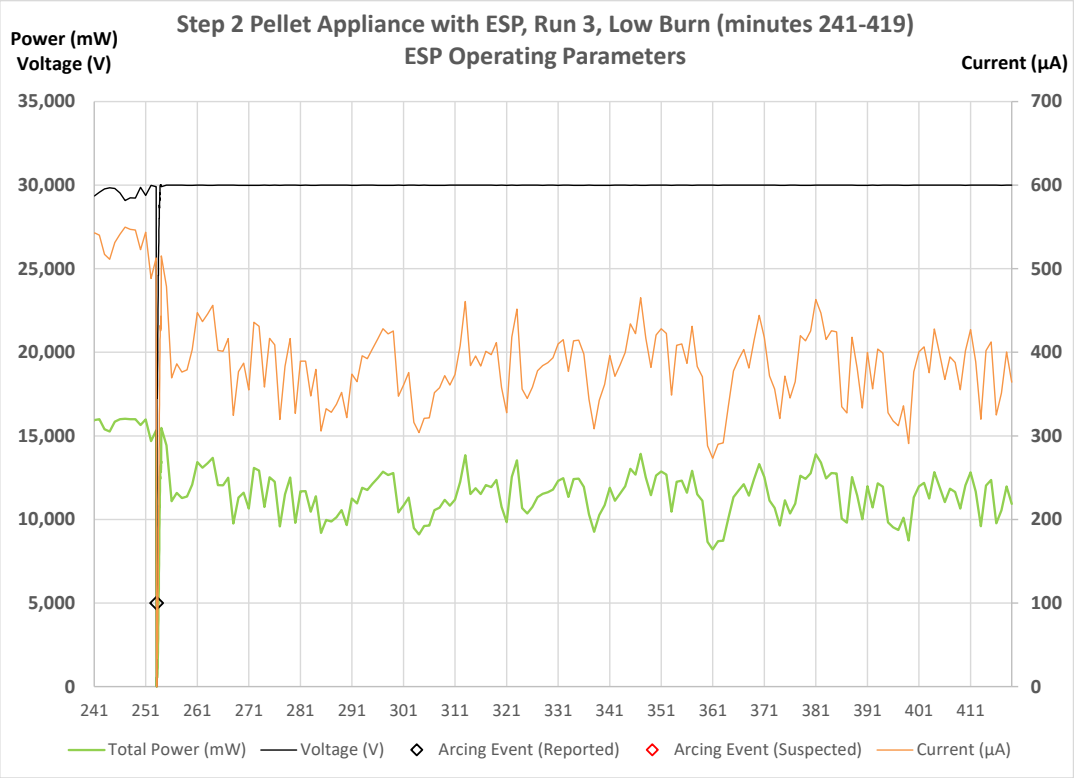


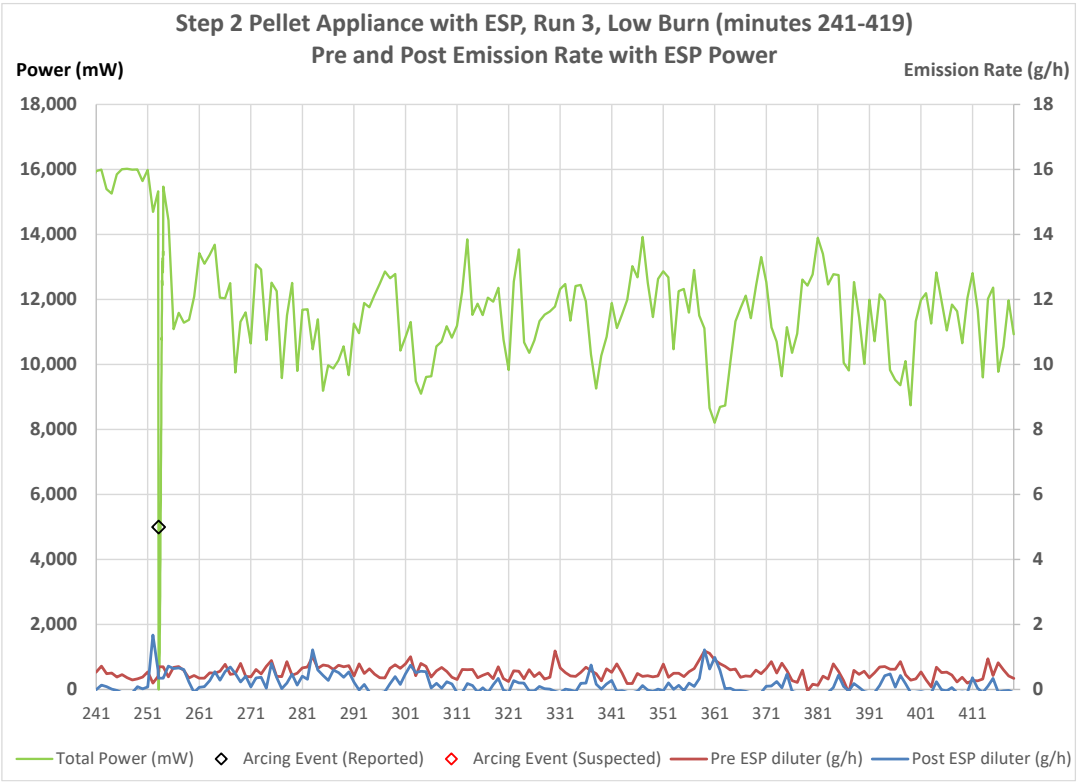


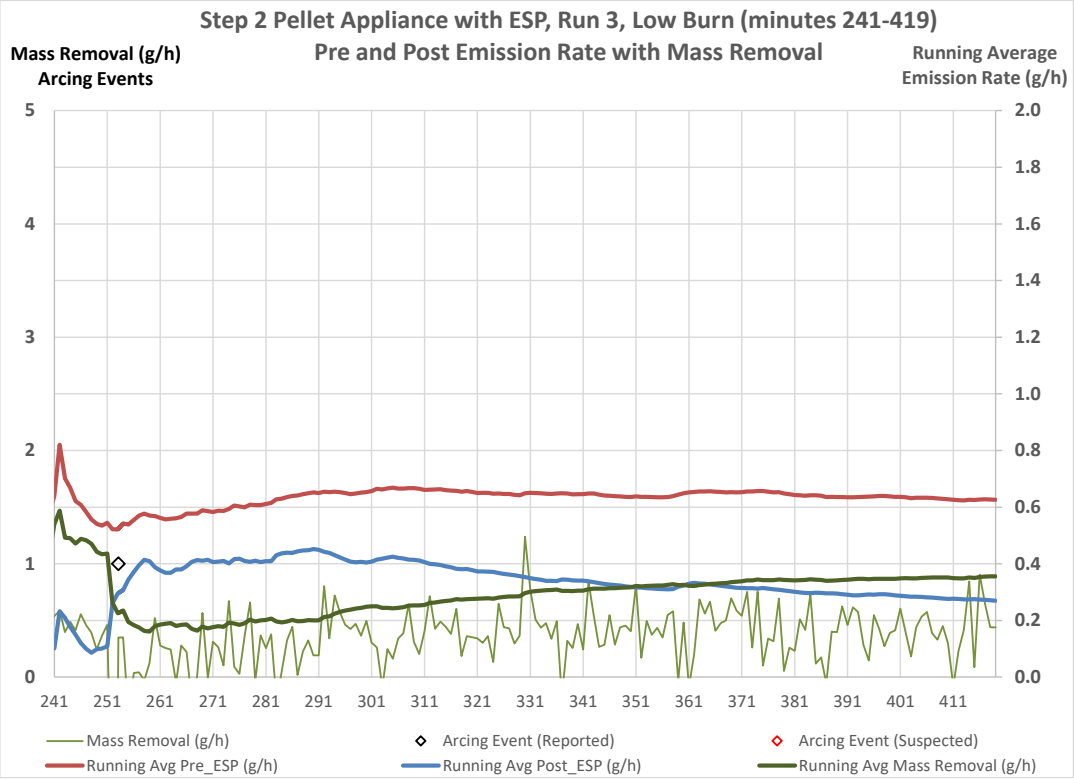

Step 2 Pellet Appliance with ESP, Run 3, Medium Burn (minutes 121-240)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
121 126 131 136 141 146 151 156 161 166 171 176 181 186 191 196 201 206 211 216 221 226 231 236
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

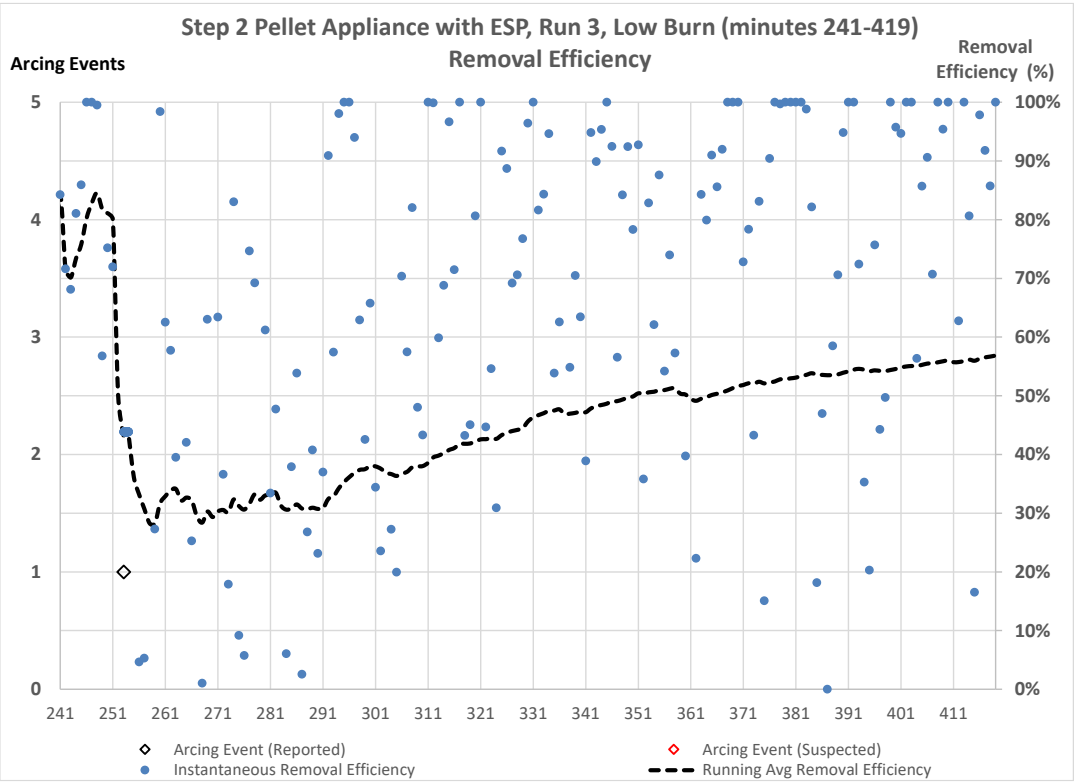

Step 2 Pellet Appliance with ESP, Run 3, Medium Burn (minutes 121-240)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
121 126 131 136 141 146 151 156 161 166 171 176 181 186 191 196 201 206 211 216 221 226 231 236
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 3, Low Burn

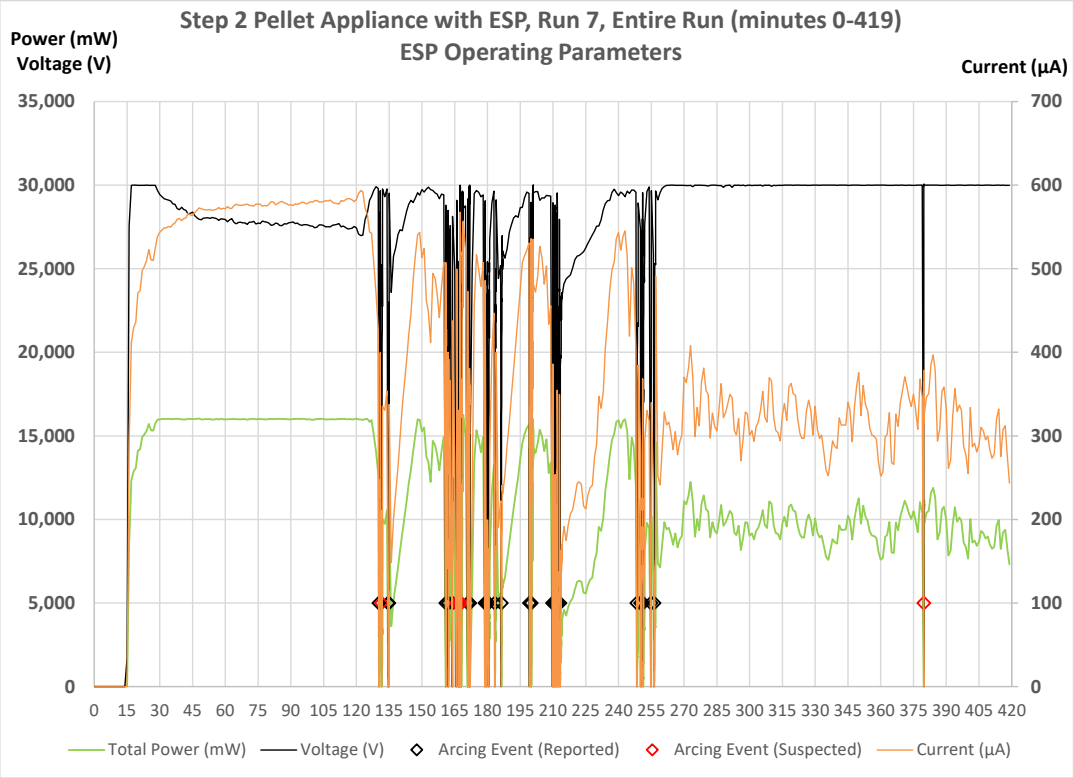


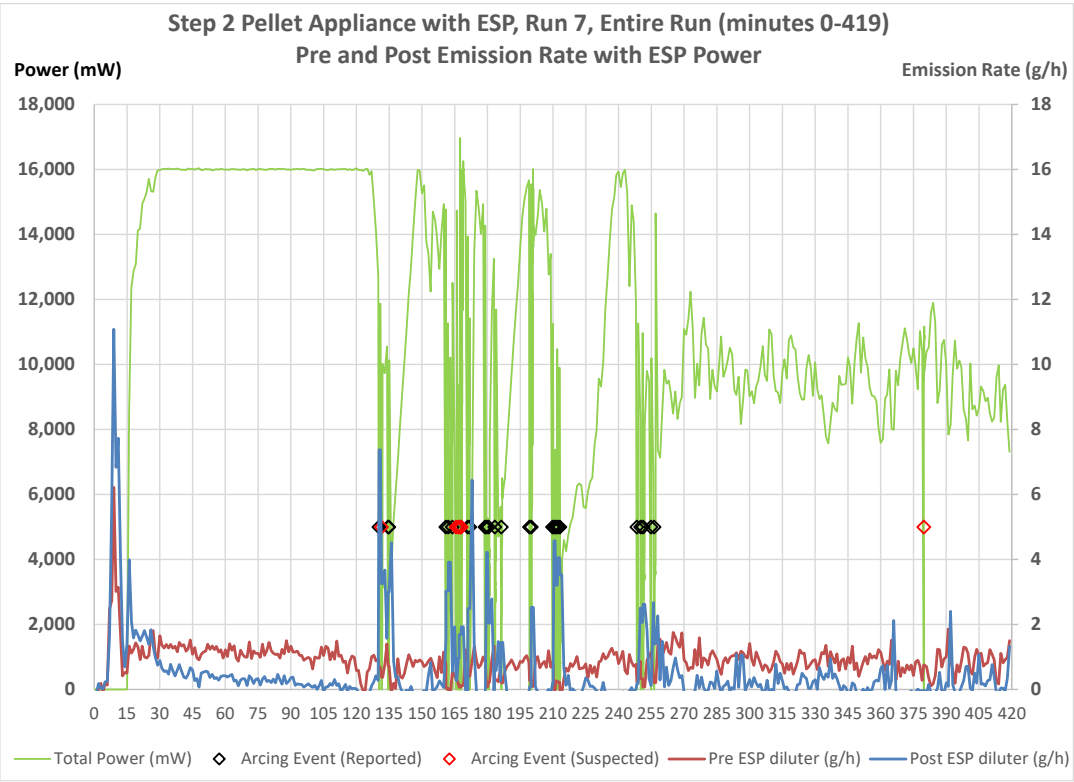


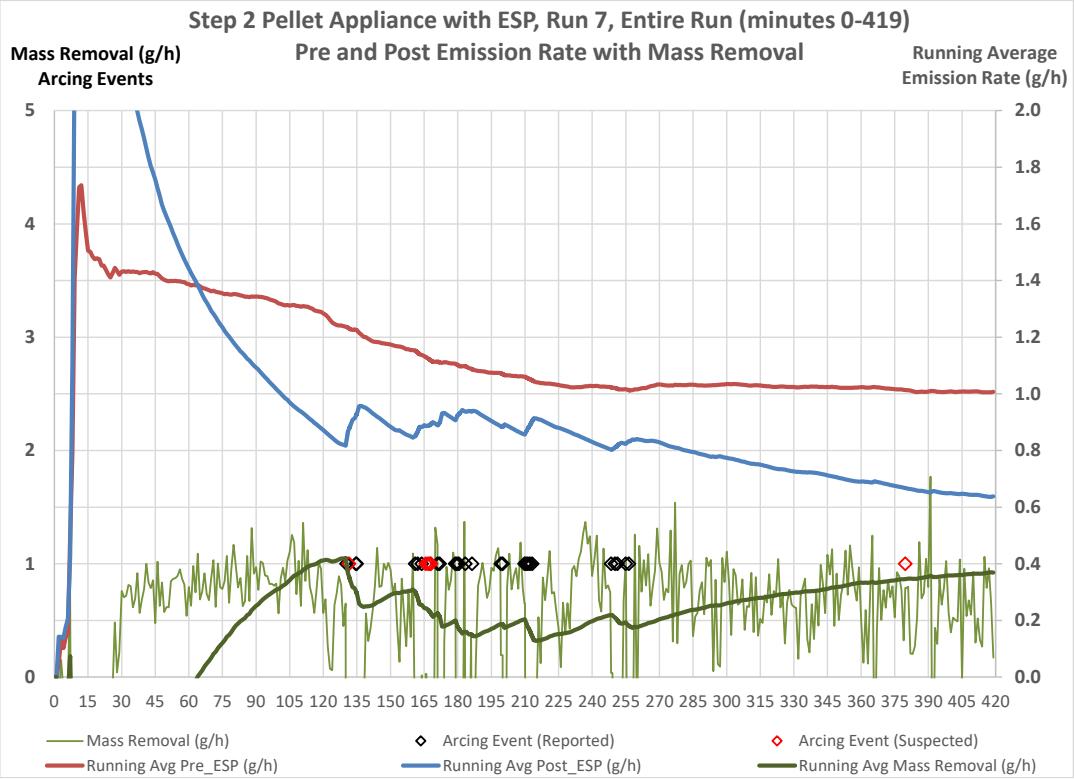

Step 2 Pellet Appliance with ESP, Run 3, Low Burn (minutes 241-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

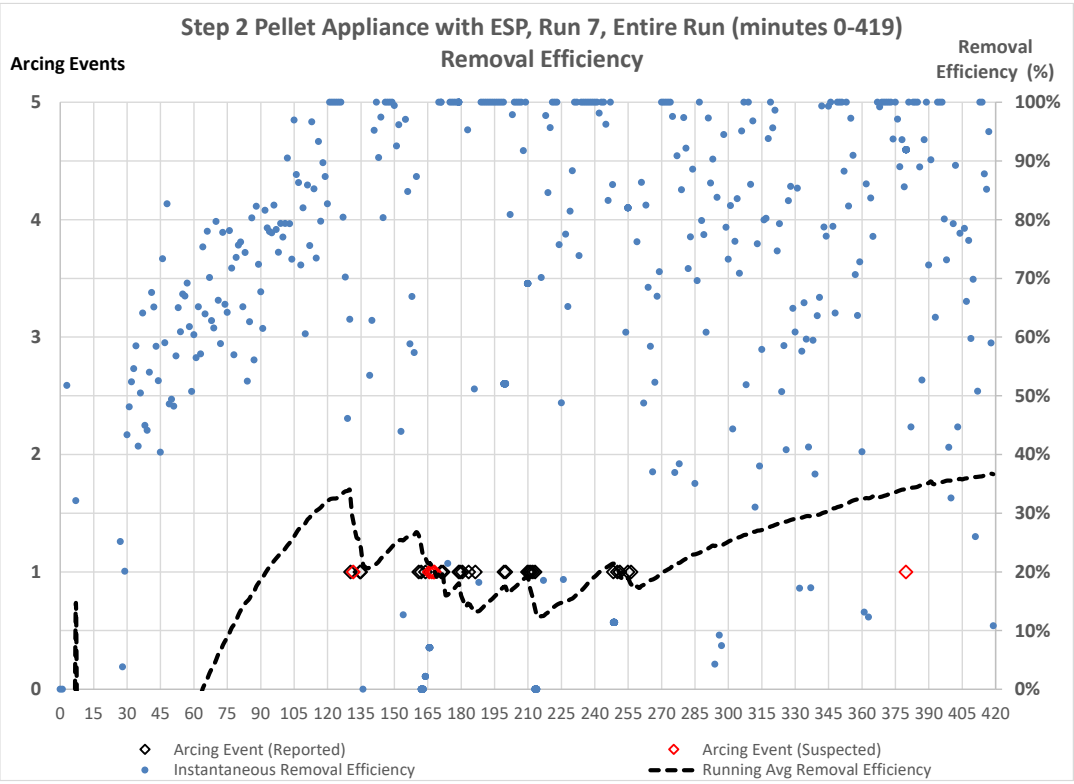

Step 2 Pellet Appliance with ESP, Run 3, Low Burn (minutes 241-419)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 7, Entire Run

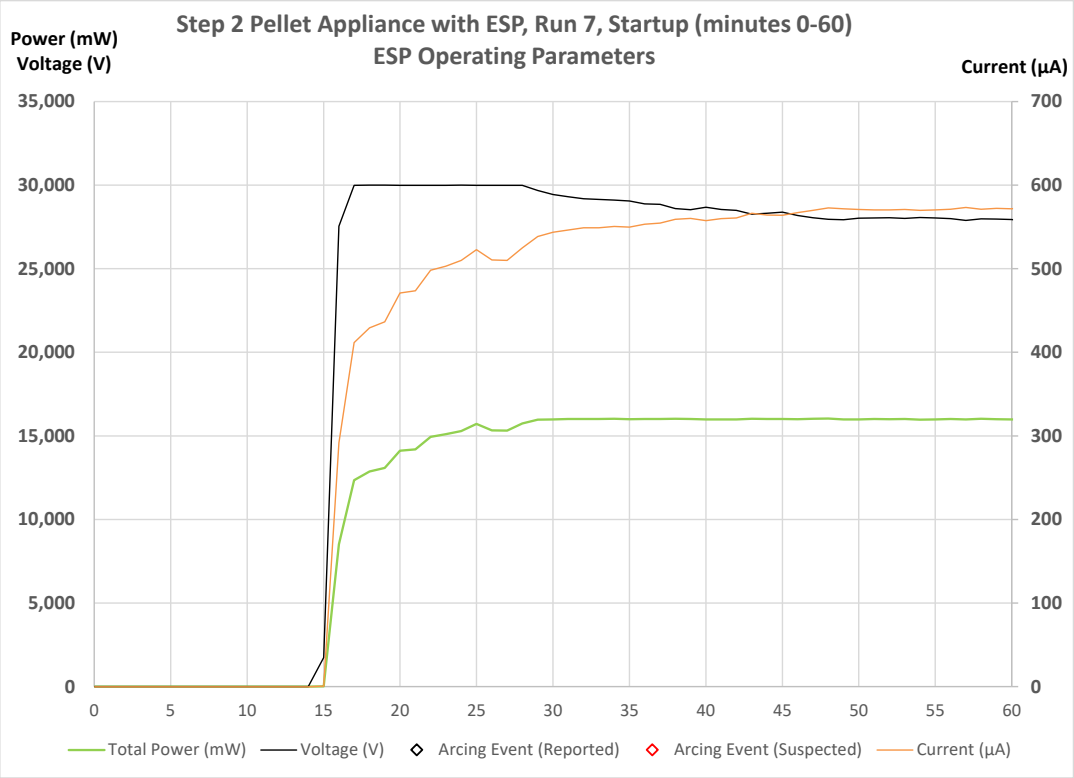


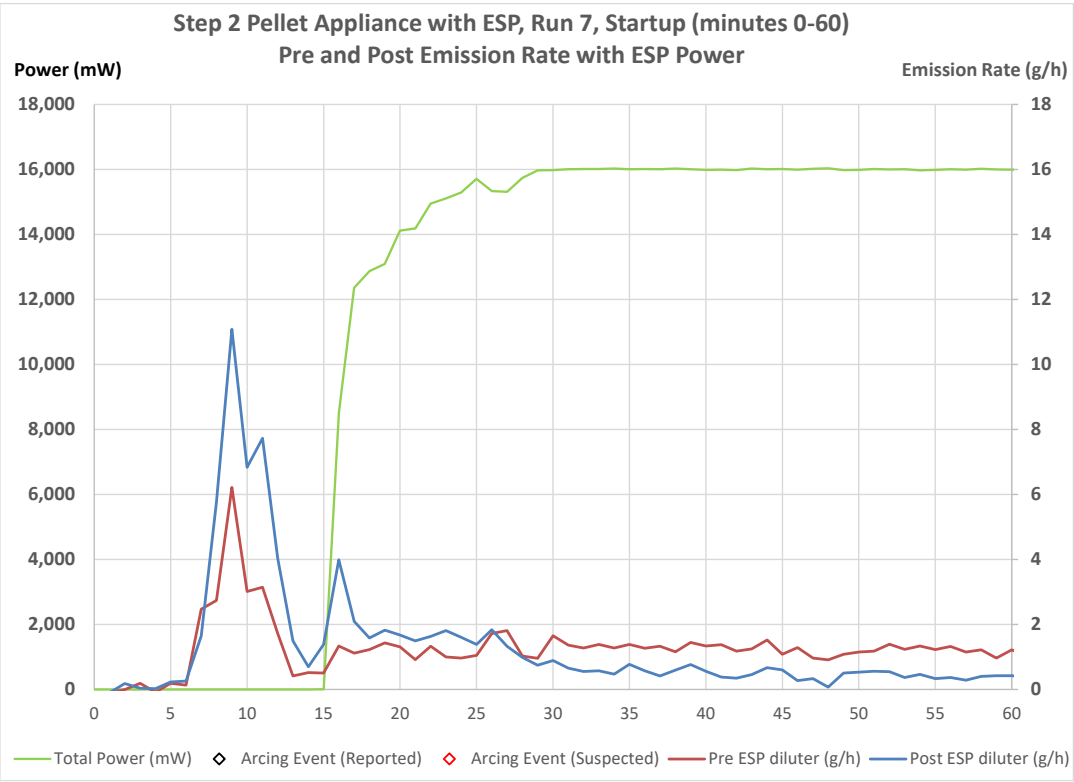


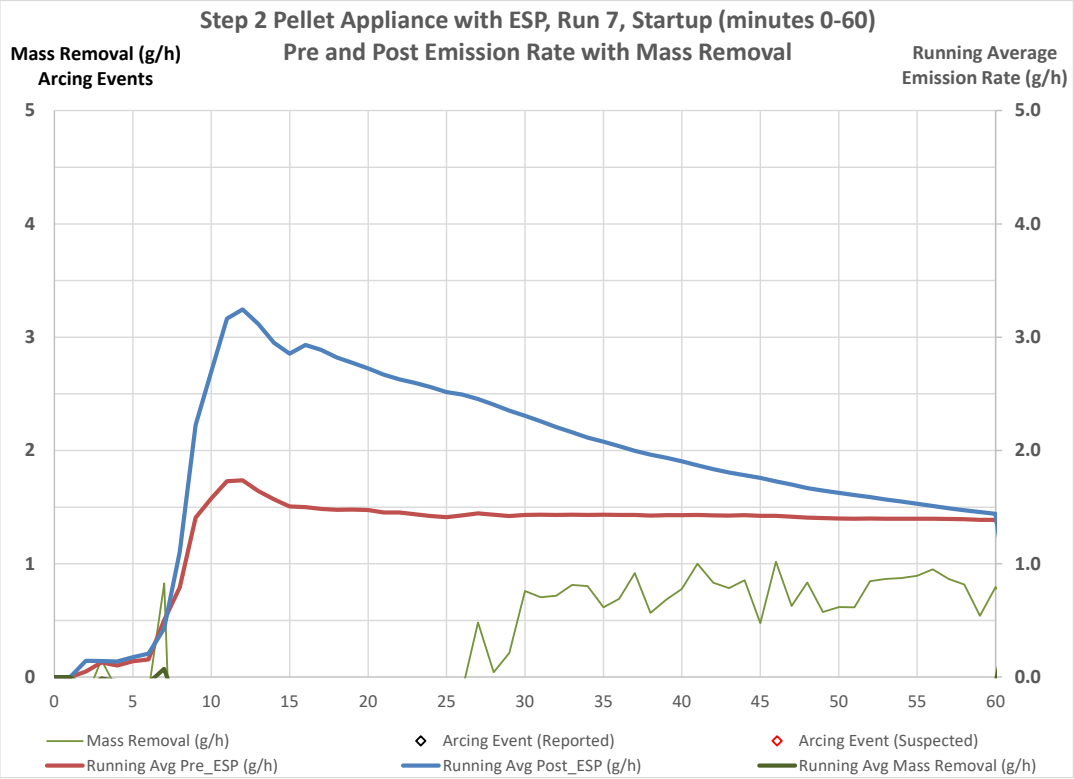

Step 2 Pellet Appliance with ESP, Run 7, Entire Run (minutes 0-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

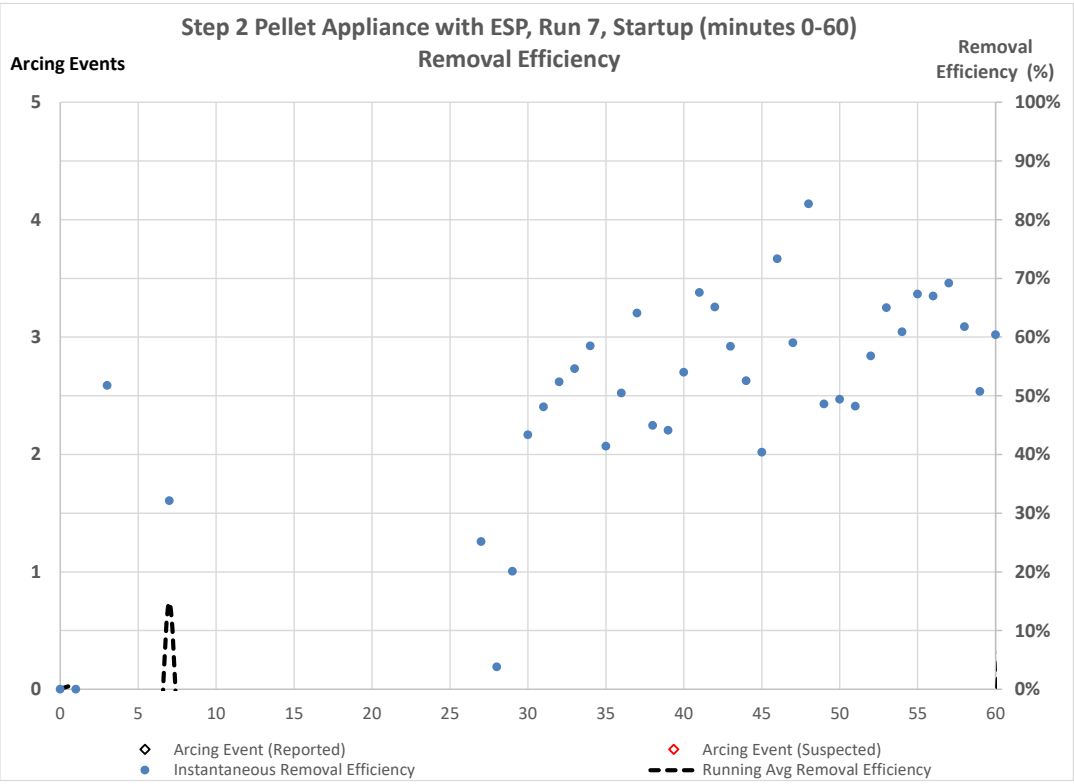

Step 2 Pellet Appliance with ESP, Run 7, Entire Run (minutes 0-419)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 7, Startup

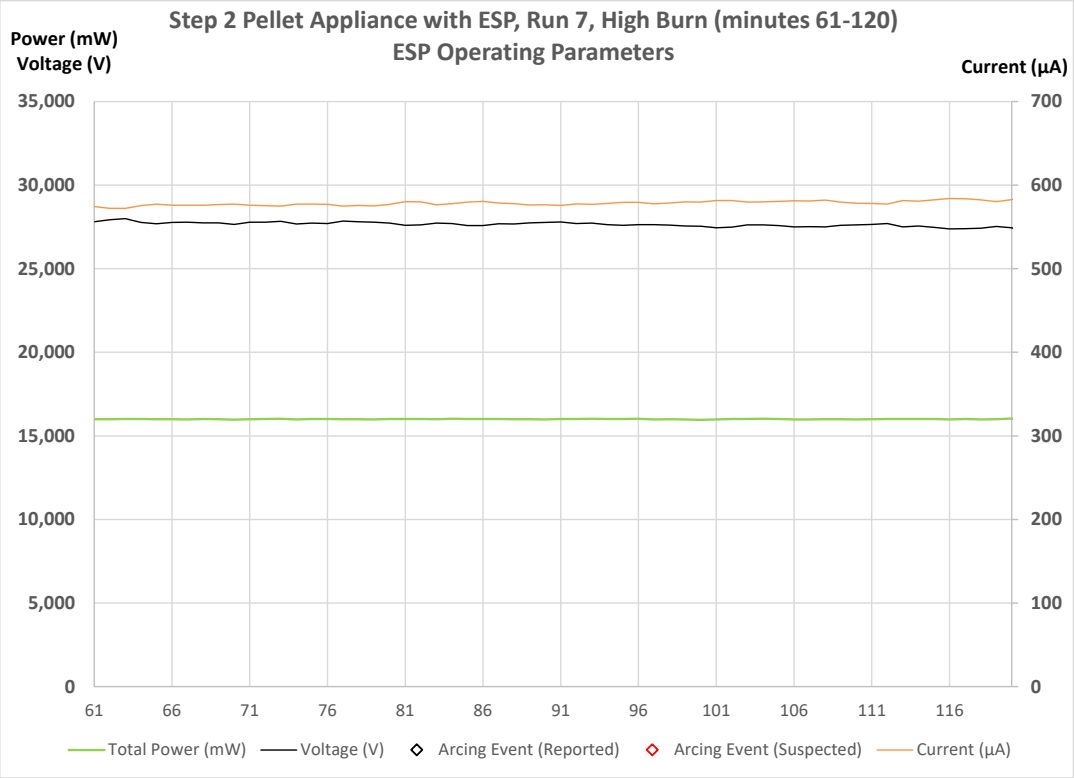


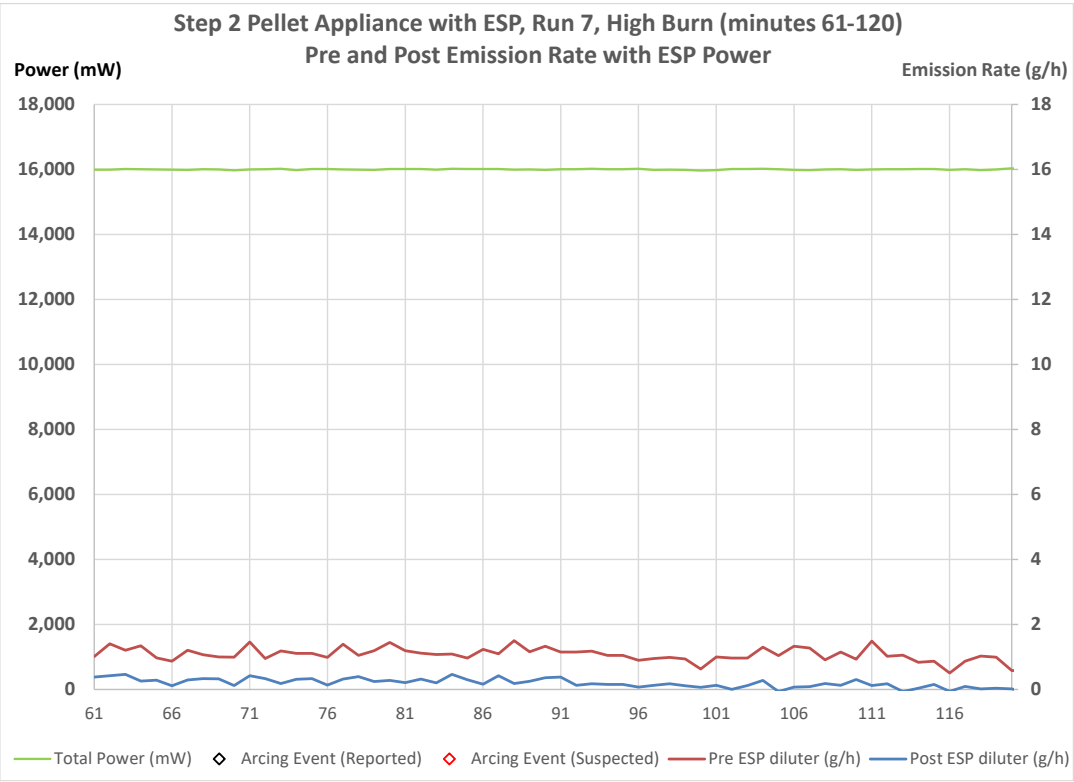


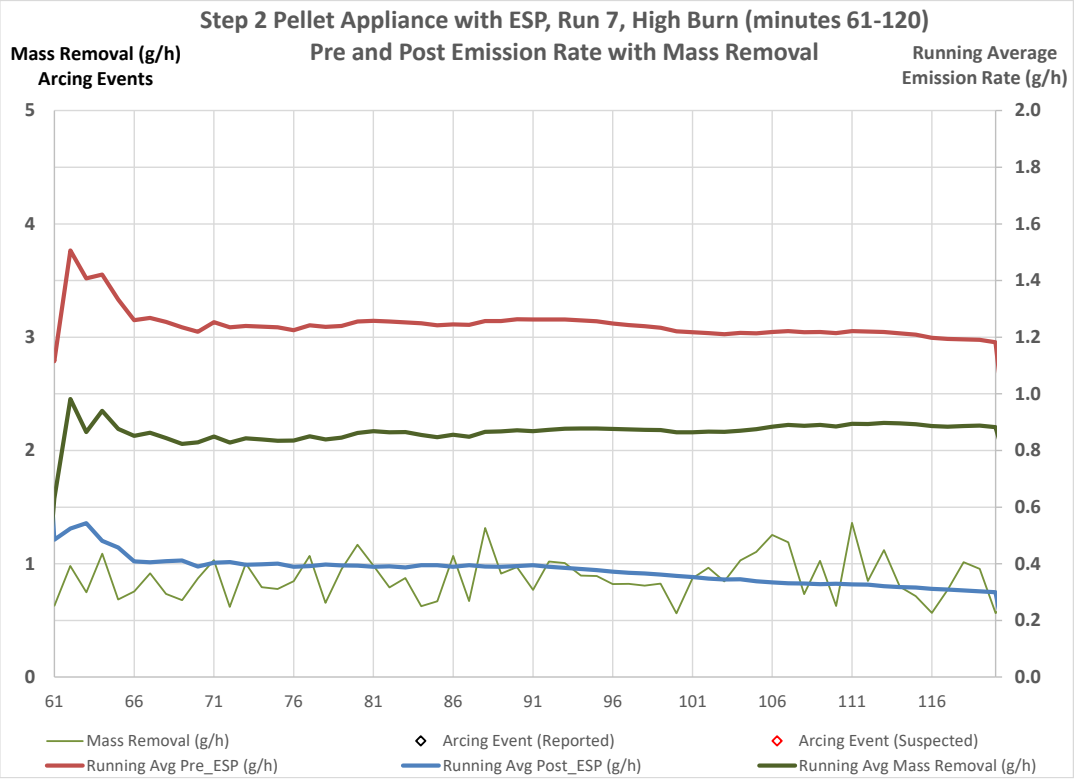

Step 2 Pellet Appliance with ESP, Run 7, Startup (minutes 0-60)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
5.0
4.0
3.0
2.0
1.0
0.0
0 5 10 15 20 25 30 35 40 45 50 55 60
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

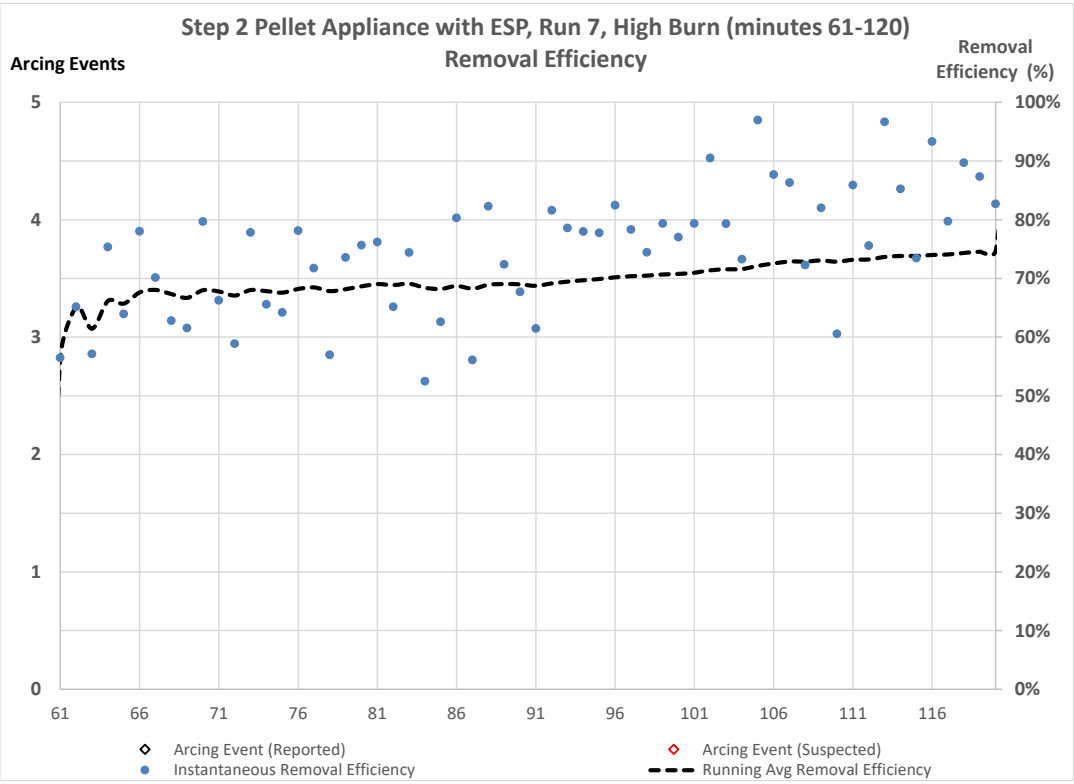

Step 2 Pellet Appliance with ESP, Run 7, Startup (minutes 0-60)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 5 10 15 20 25 30 35 40 45 50 55 60
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 7, High Burn

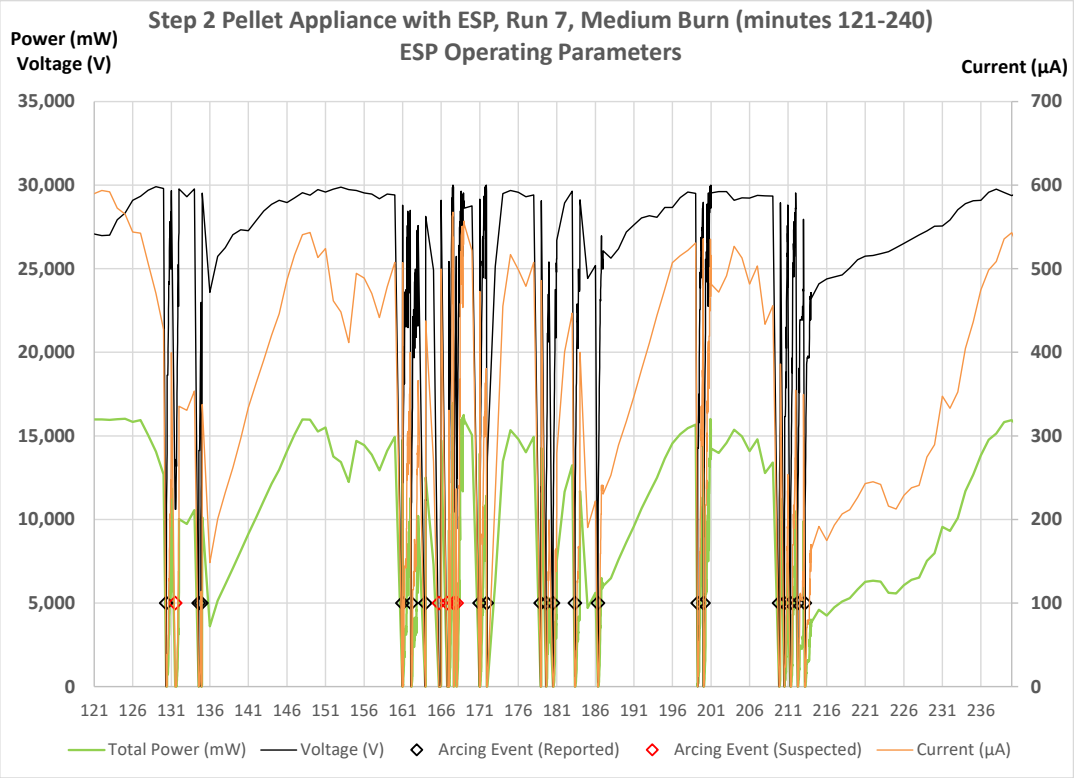


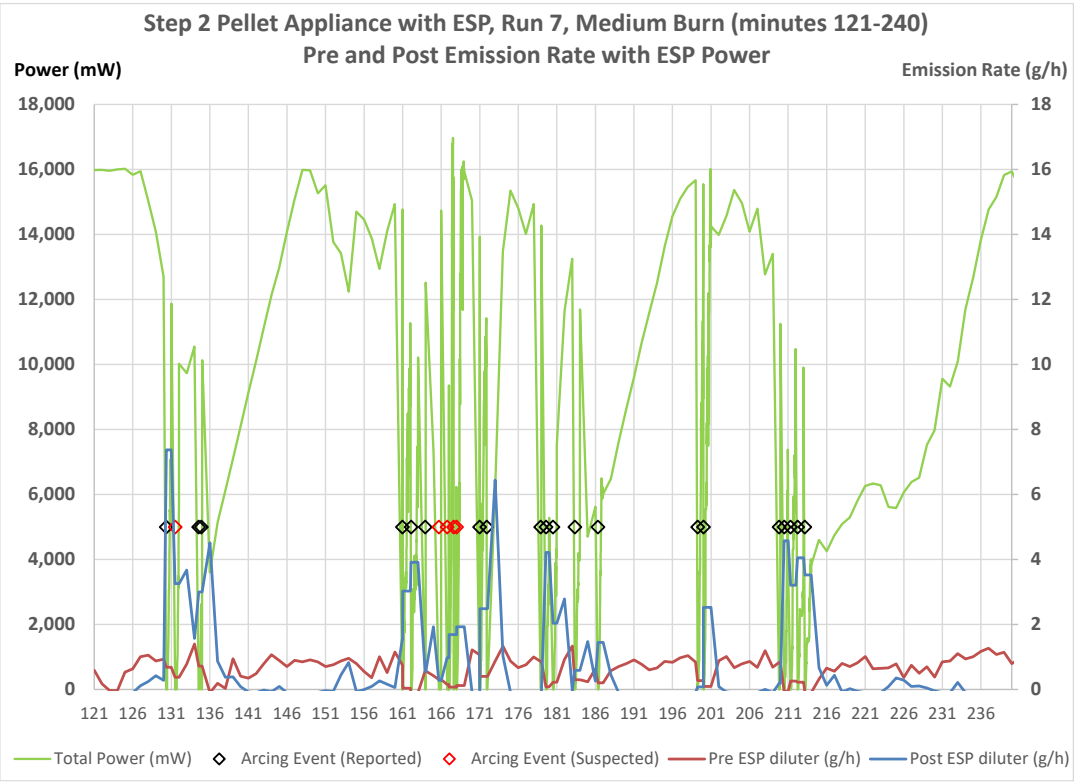


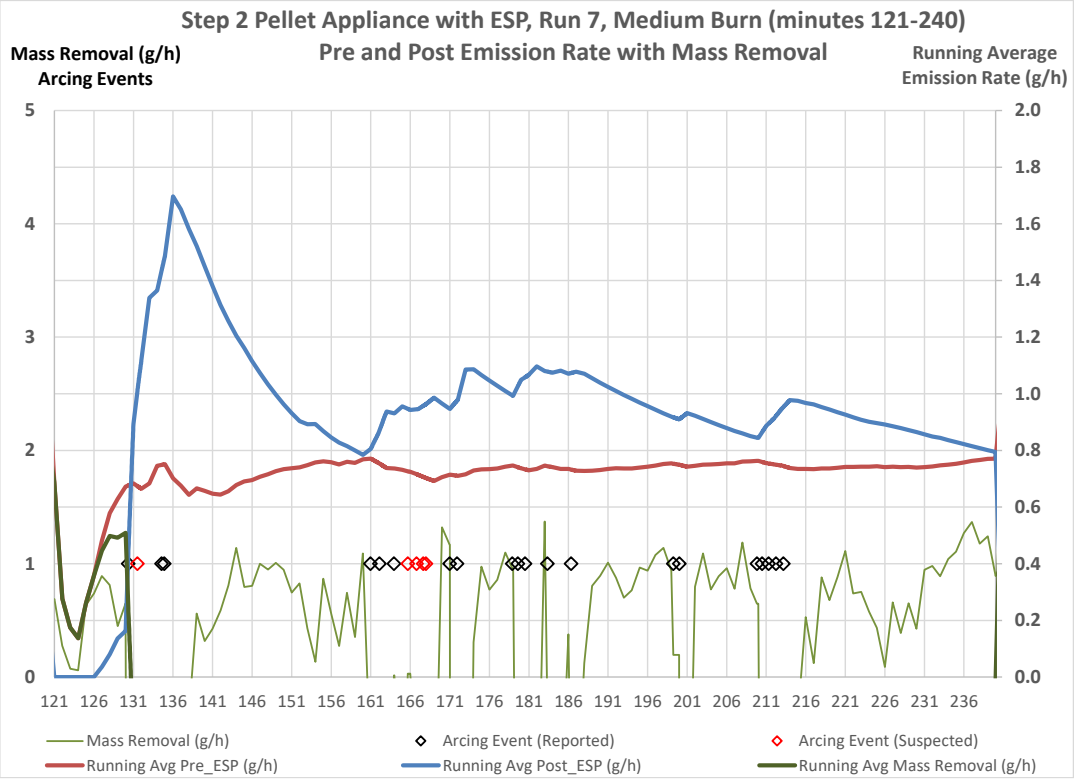

Step 2 Pellet Appliance with ESP, Run 7, High Burn (minutes 61-120)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
61
66
71
76
81
86
91
96
101
106
111
116
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

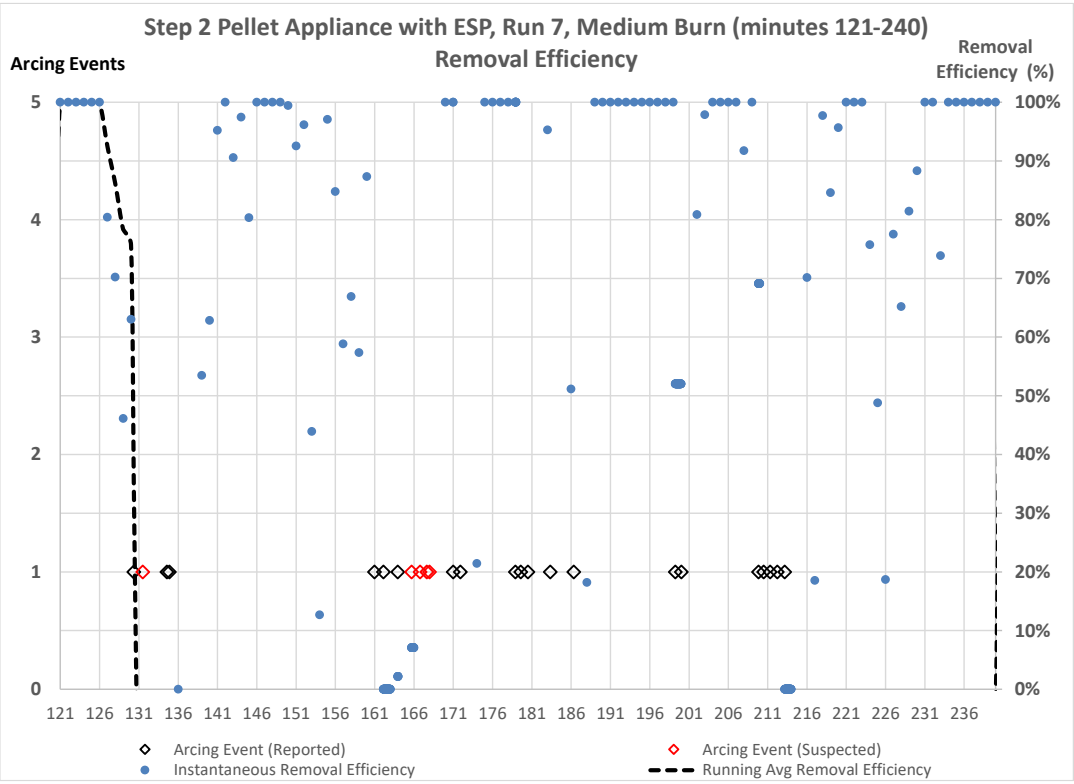

Step 2 Pellet Appliance with ESP, Run 7, High Burn (minutes 61-120)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
61
66
71
76
81
86
91
96
101
106
111
116
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 7, Medium Burn

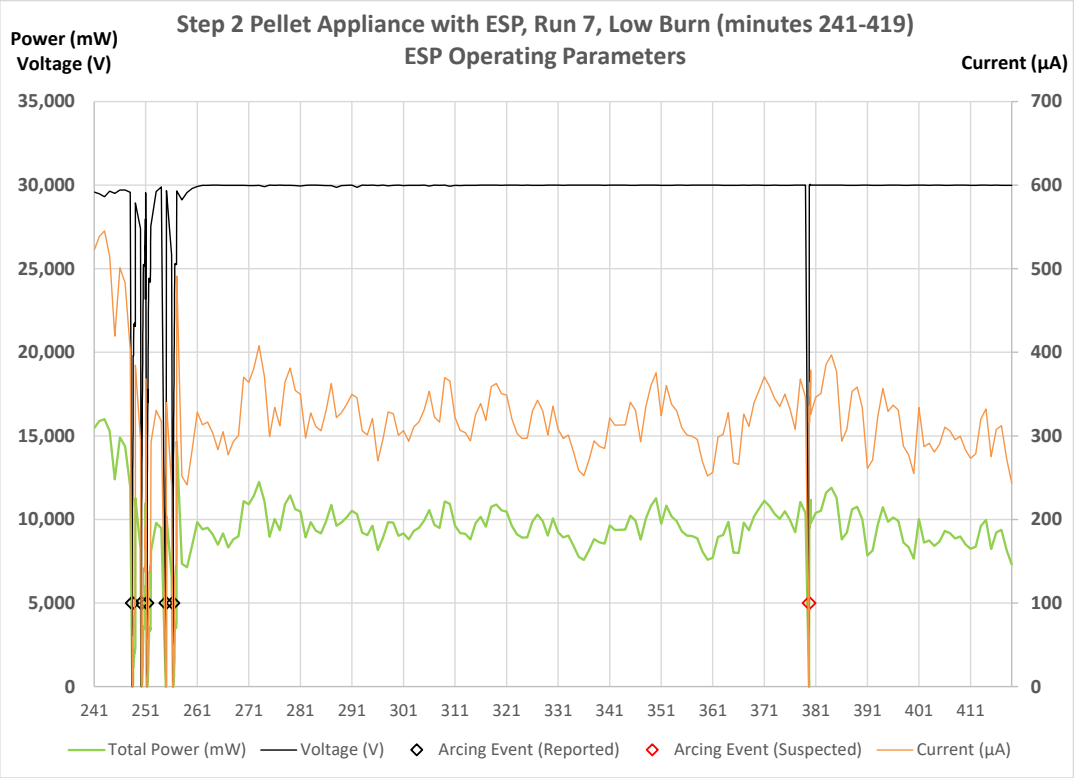


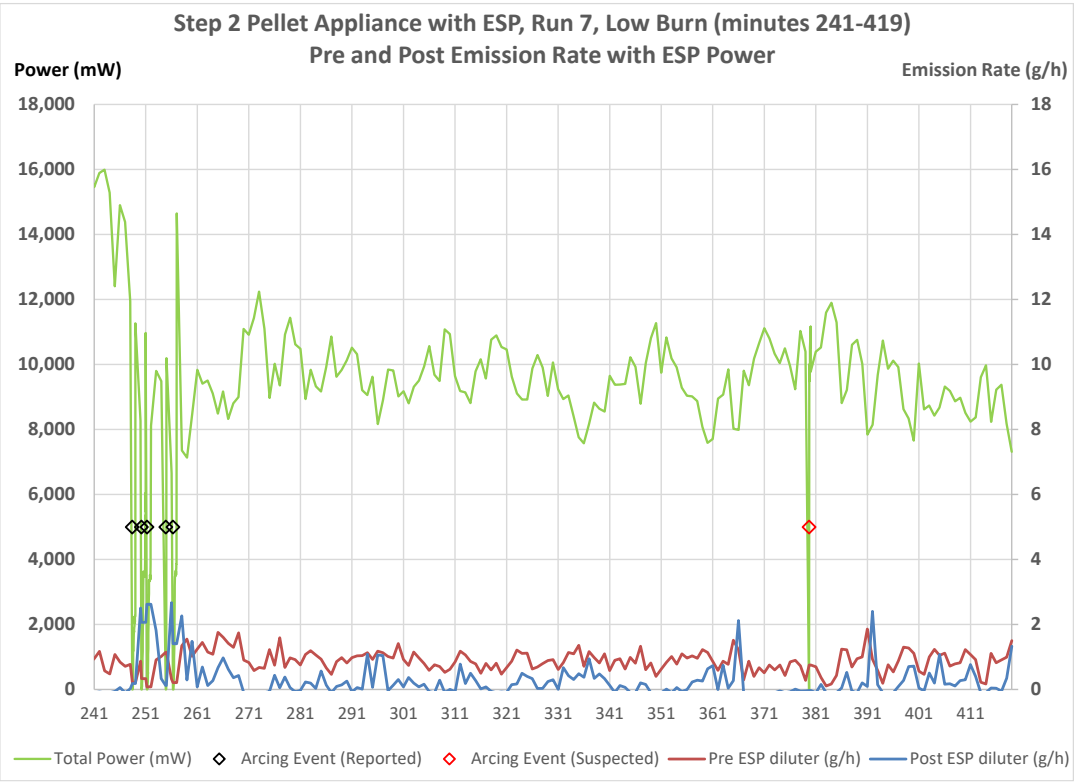


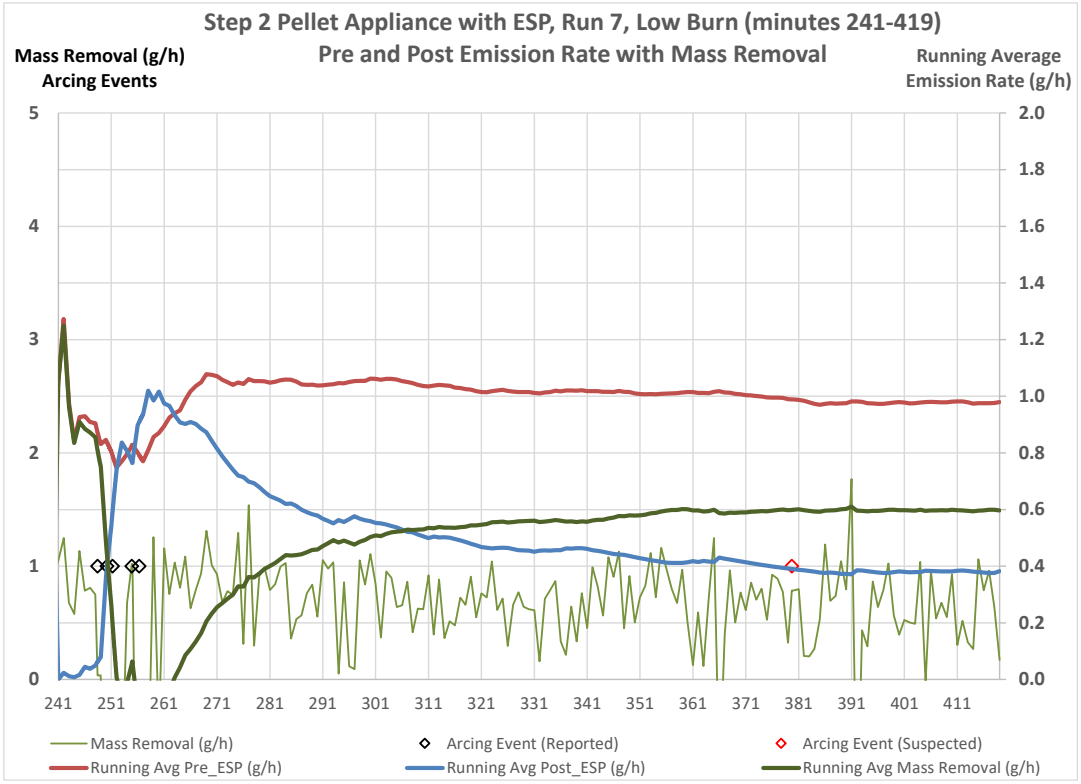

Step 2 Pellet Appliance with ESP, Run 7, Medium Burn (minutes 121-240)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
121 126 131 136 141 146 151 156 161 166 171 176 181 186 191 196 201 206 211 216 221 226 231 236
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

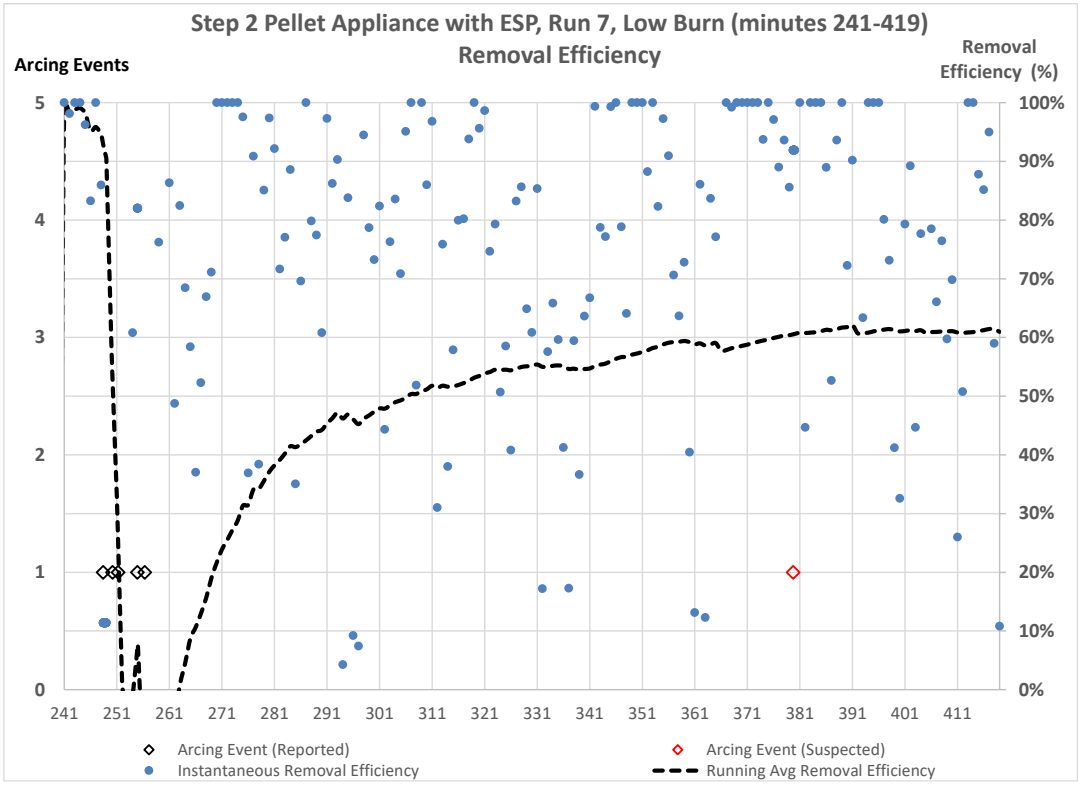

Step 2 Pellet Appliance with ESP, Run 7, Medium Burn (minutes 121-240)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
121 126 131 136 141 146 151 156 161 166 171 176 181 186 191 196 201 206 211 216 221 226 231 236
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 7, Low Burn

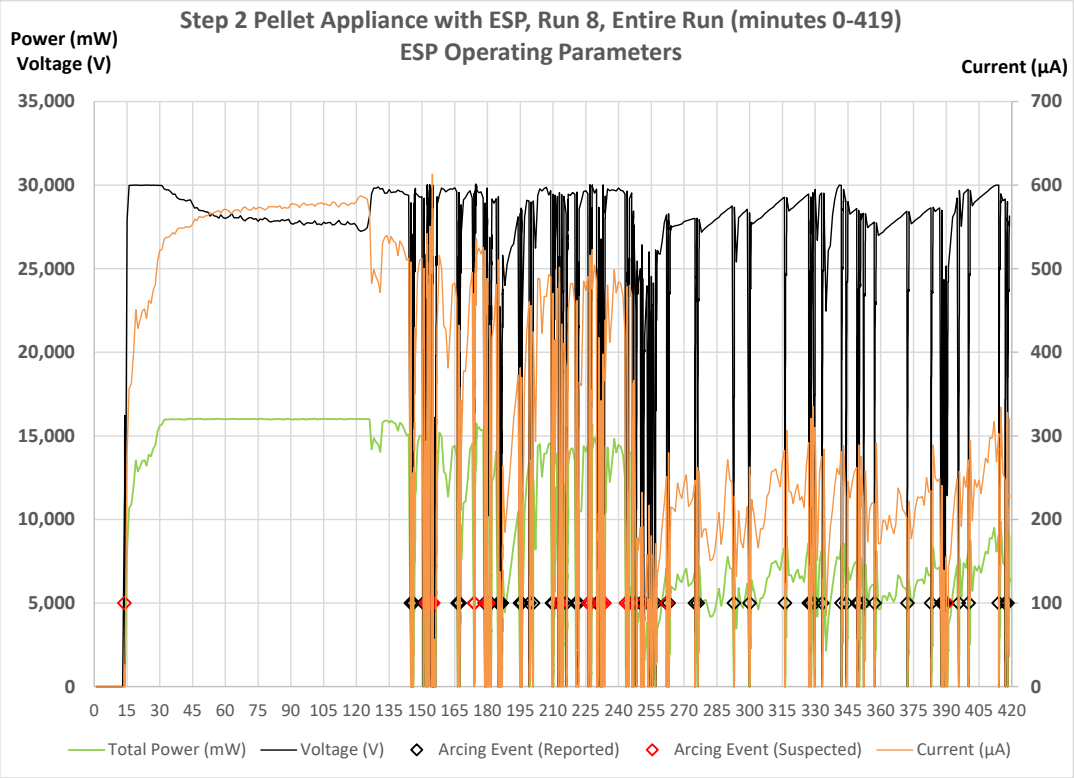


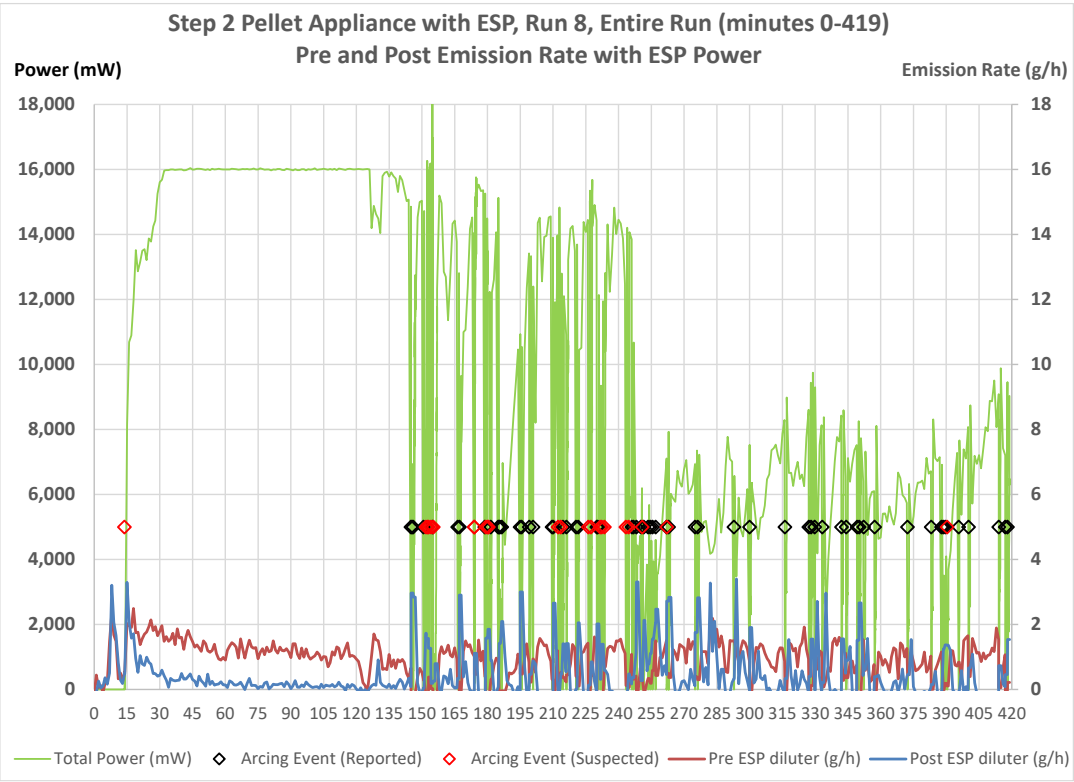


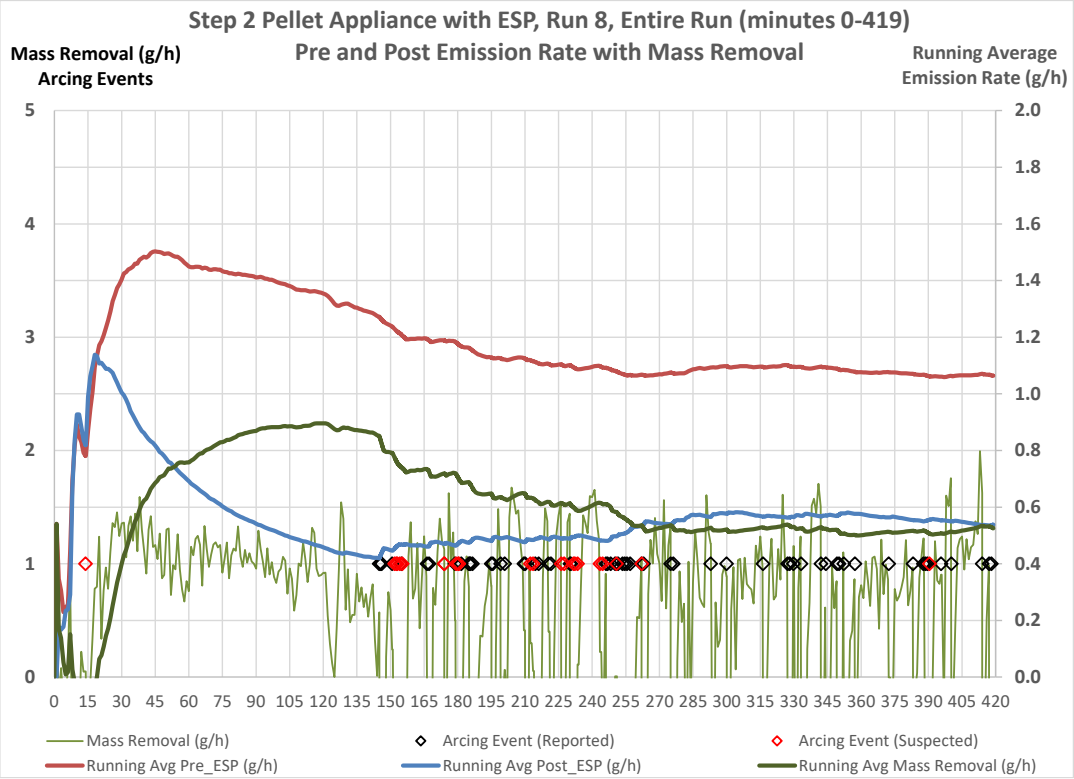

Step 2 Pellet Appliance with ESP, Run 7, Low Burn (minutes 241-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

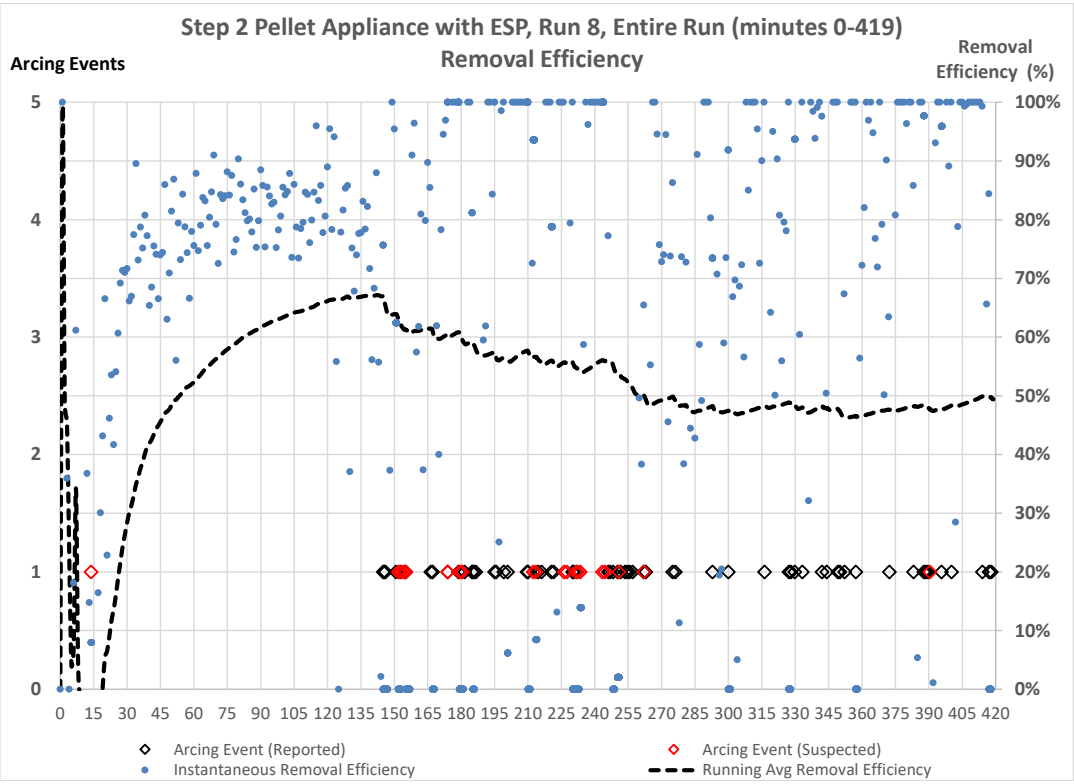

Step 2 Pellet Appliance with ESP, Run 7, Low Burn (minutes 241-419)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 8, Entire Run

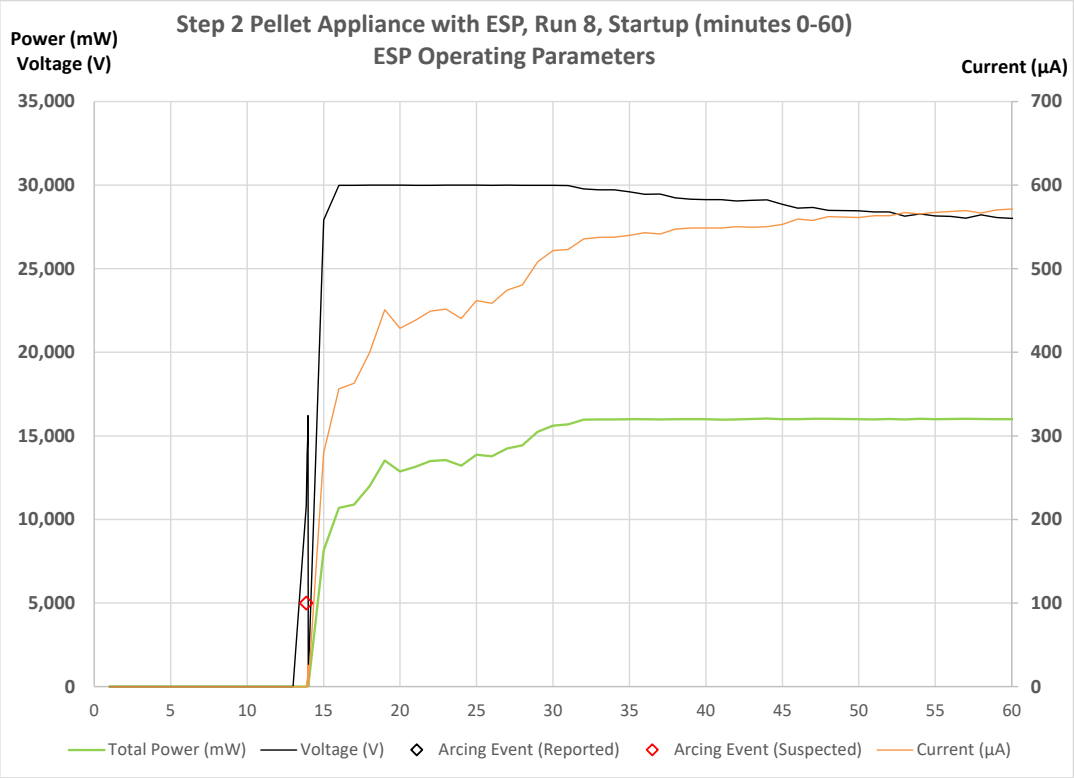


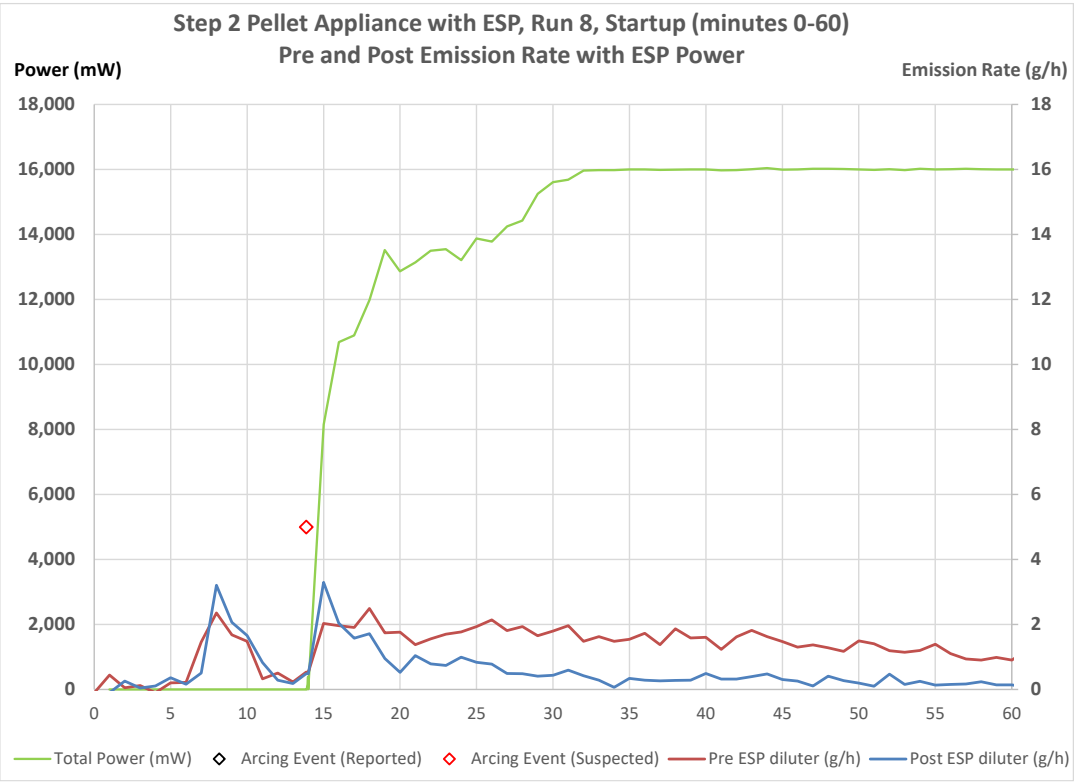


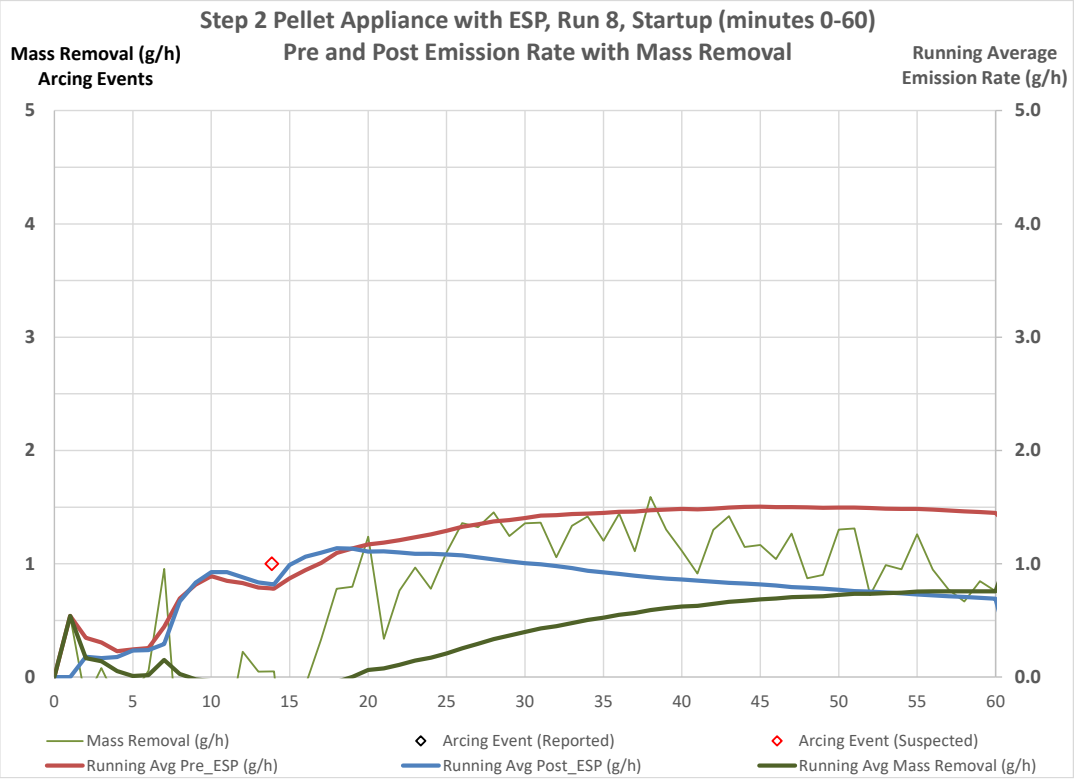

Step 2 Pellet Appliance with ESP, Run 8, Entire Run (minutes 0-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

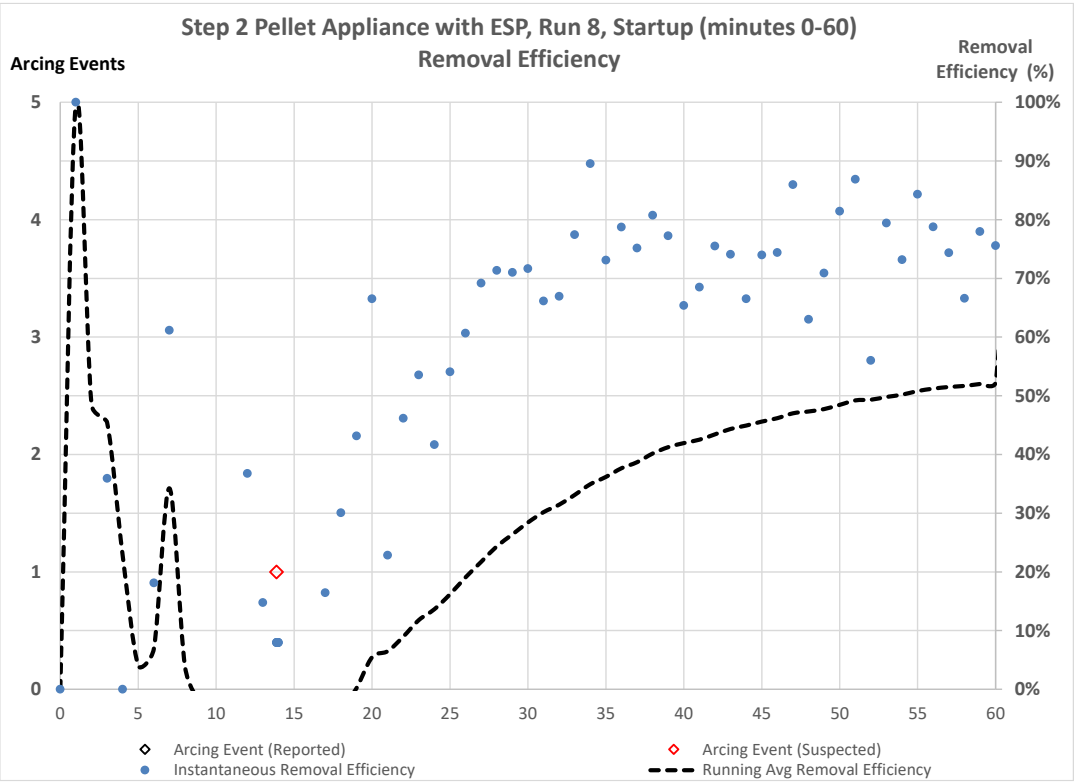

Step 2 Pellet Appliance with ESP, Run 8, Entire Run (minutes 0-419)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 8, Startup

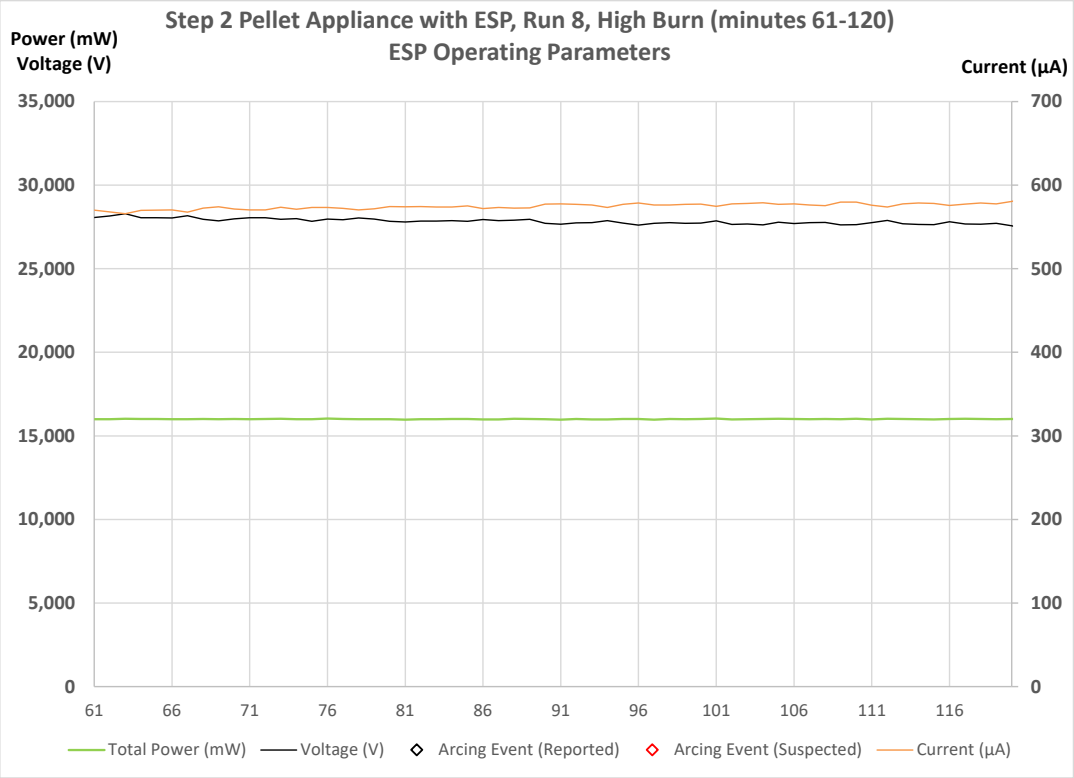


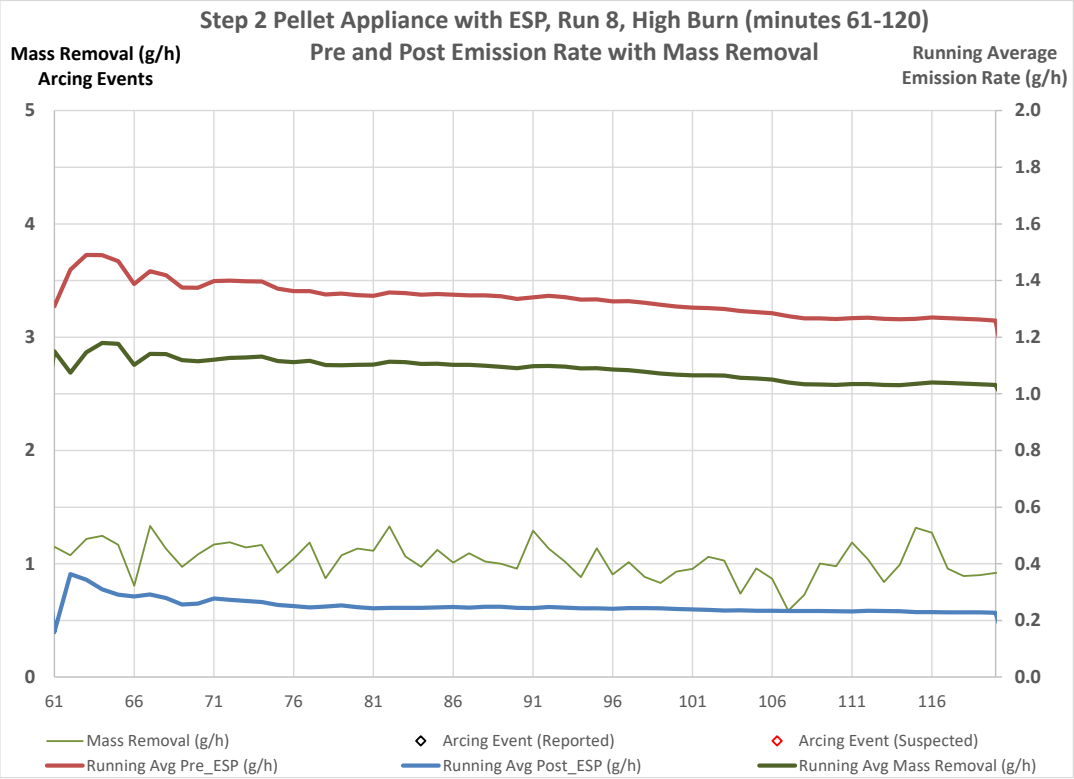


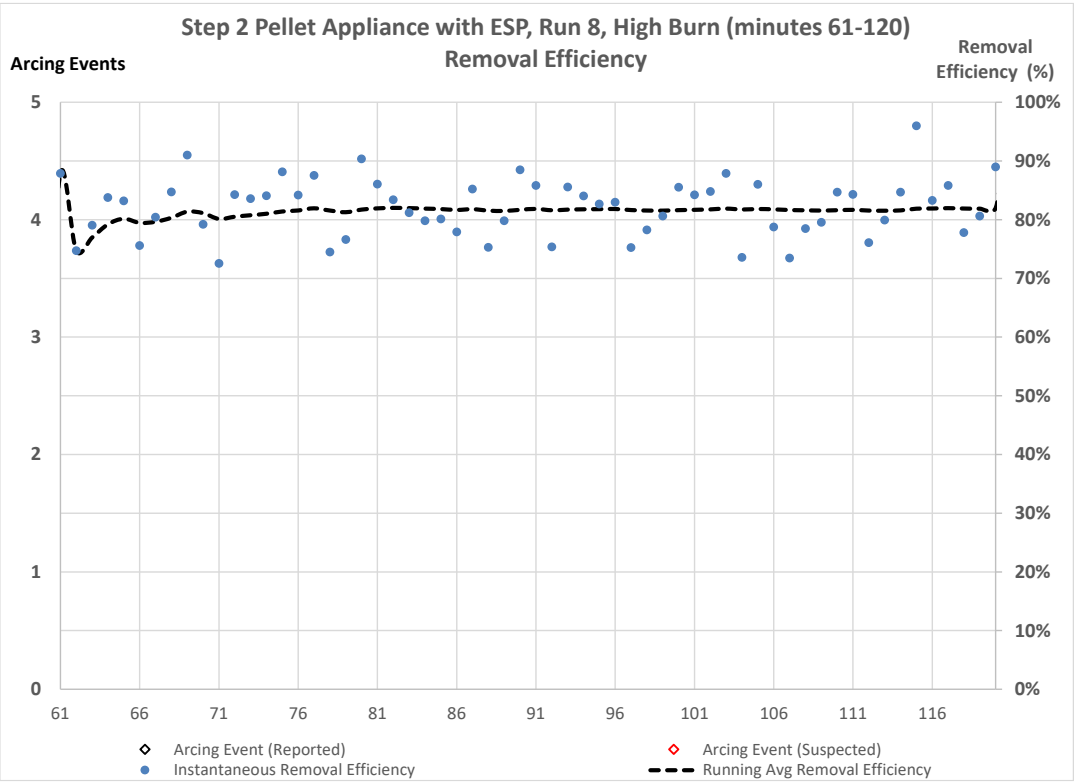

Step 2 Pellet Appliance with ESP, Run 8, Startup (minutes 0-60)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
5.0
4.0
3.0
2.0
1.0
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)


Step 2 Pellet Appliance with ESP, Run 8, Startup (minutes 0-60)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
5
10
15
20
25
30
35
40
45
50
55
60
Arcing Event (Reported)
Instantaneous Removal Efficiency
Arcing Event (Suspected)
Running Avg Removal Efficiency

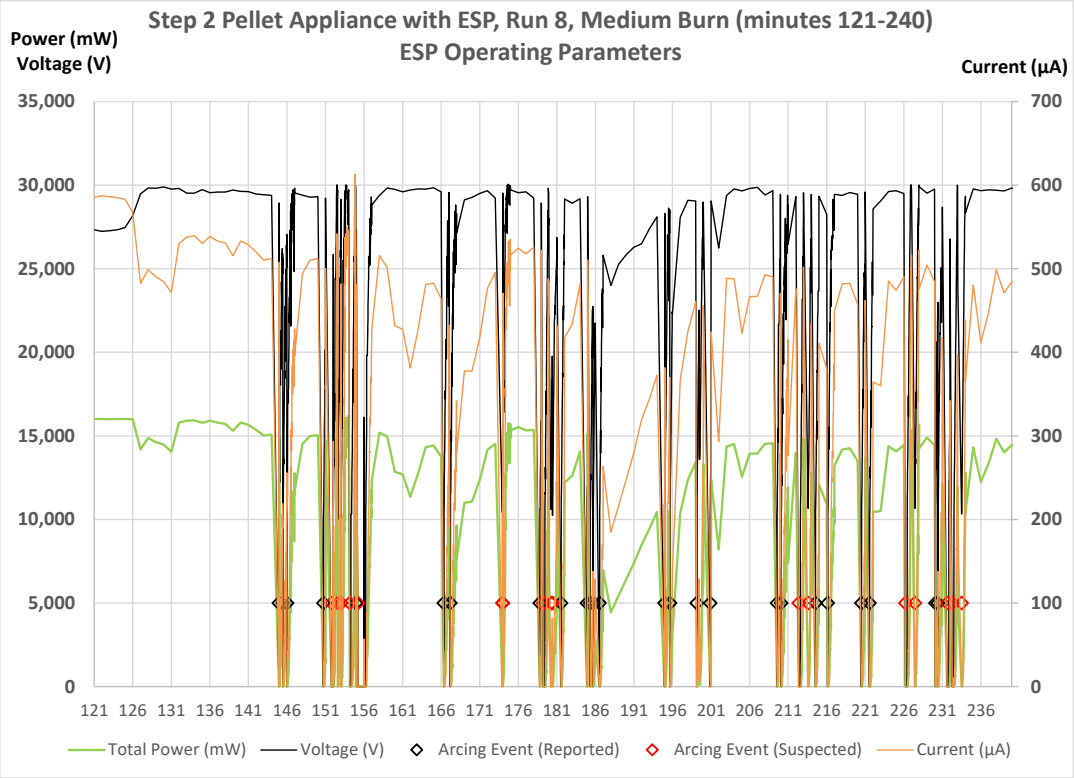
Step 2 Pellet Appliance with ESP, Run 8, High Burn

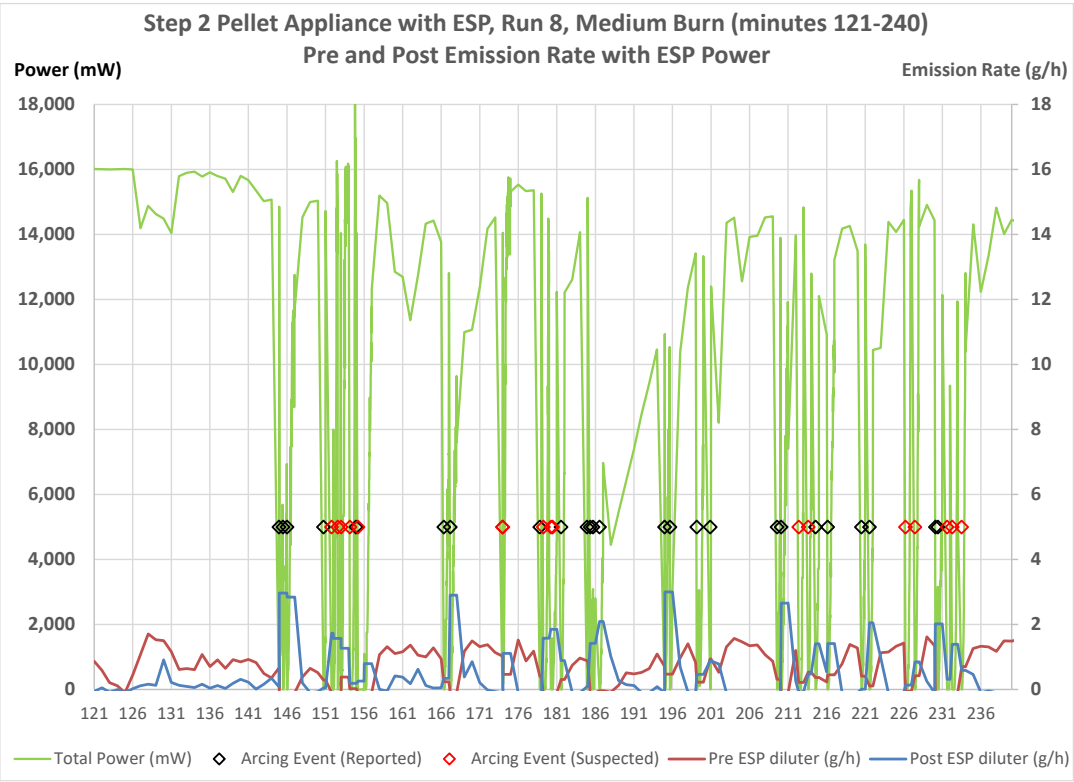


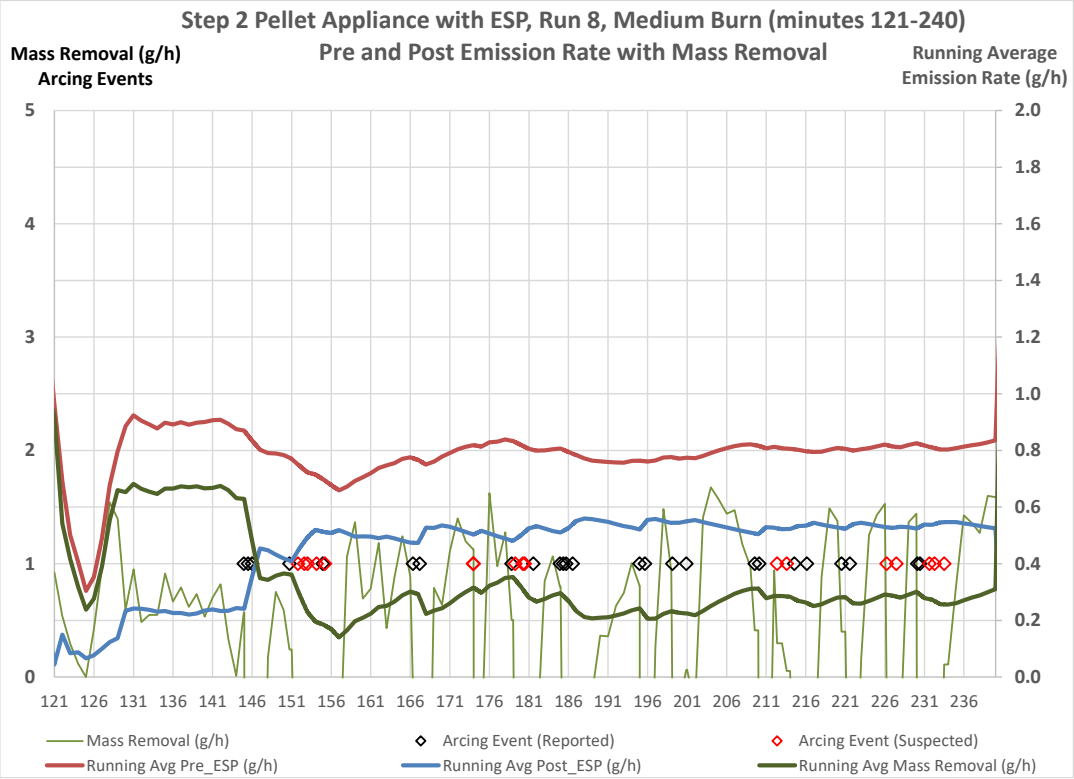

Step 2 Pellet Appliance with ESP, Run 8, High Burn (minutes 61-120)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
61
66
71
76
81
86
91
96
101
106
111
116
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

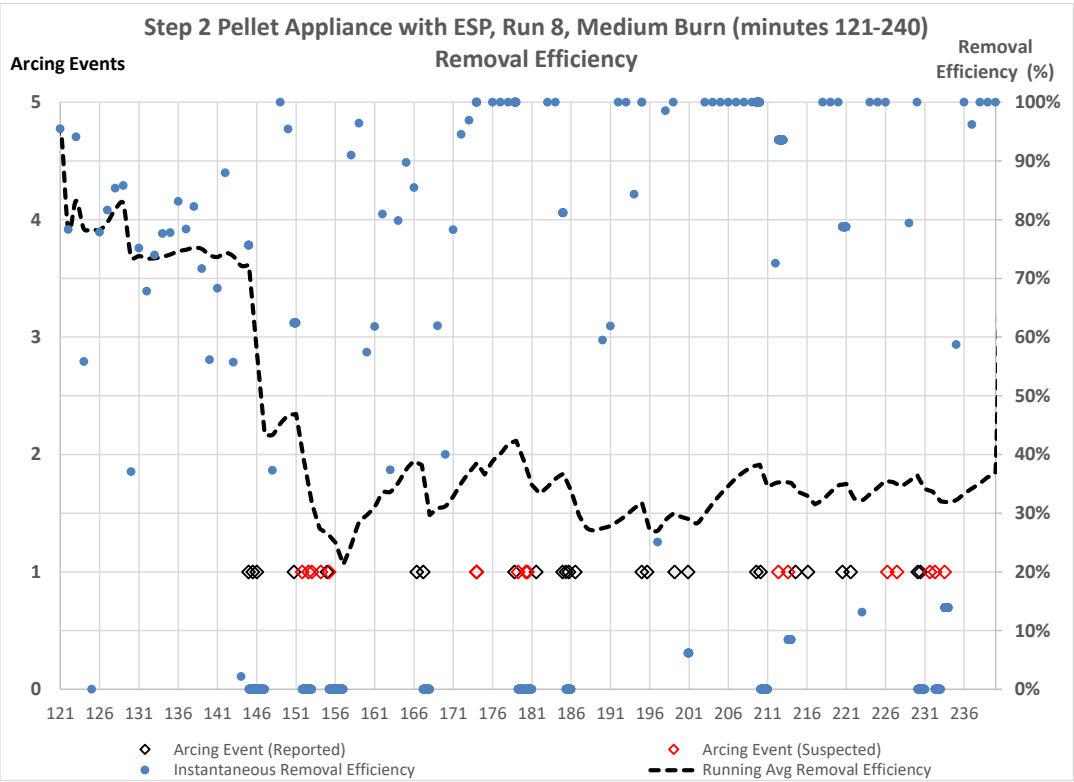

Step 2 Pellet Appliance with ESP, Run 8, High Burn (minutes 61-120)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
61
66
71
76
81
86
91
96
101
106
111
116
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 8, Medium Burn

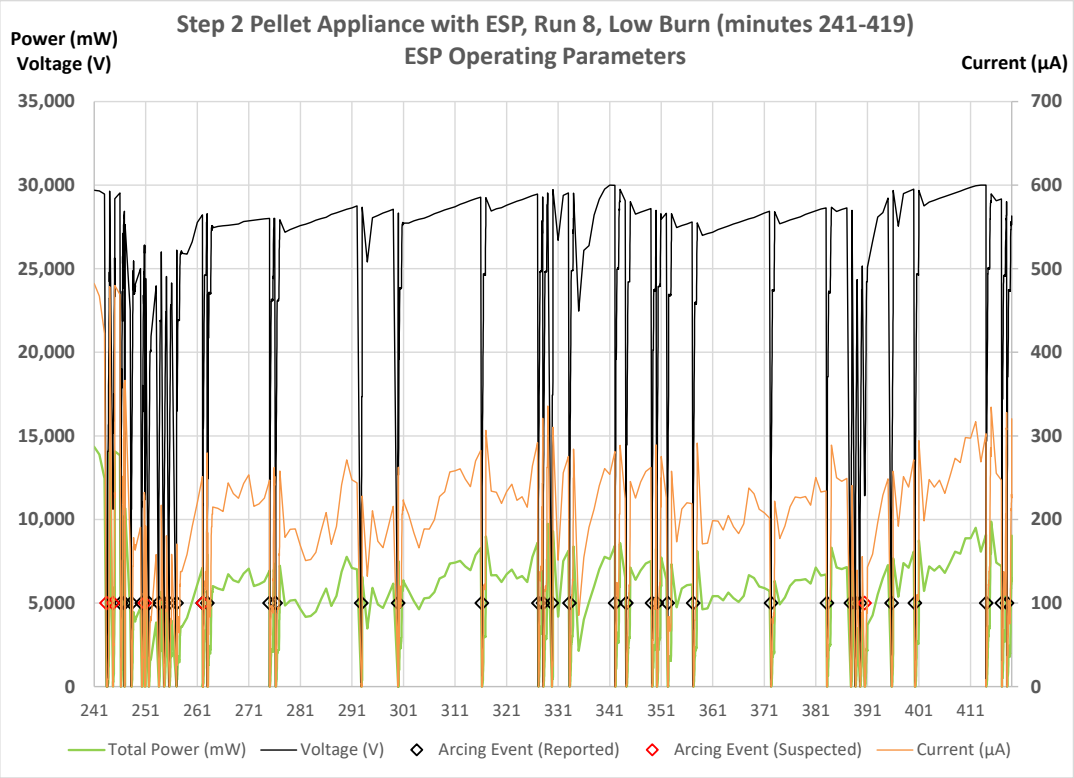


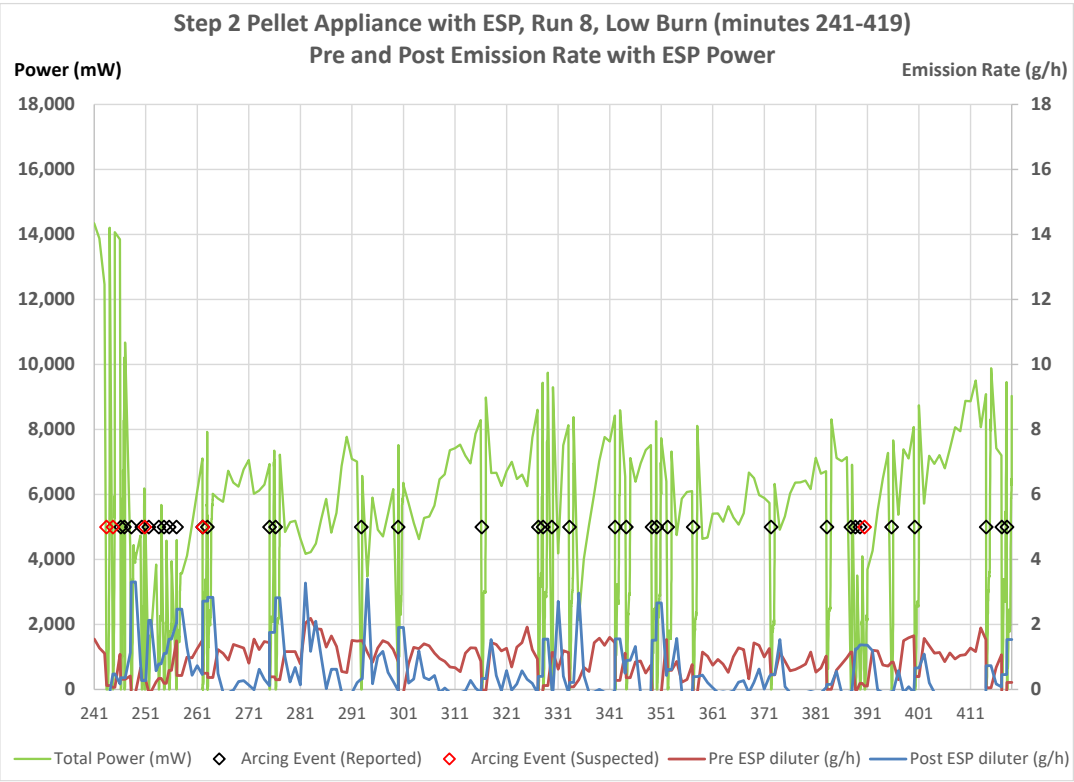


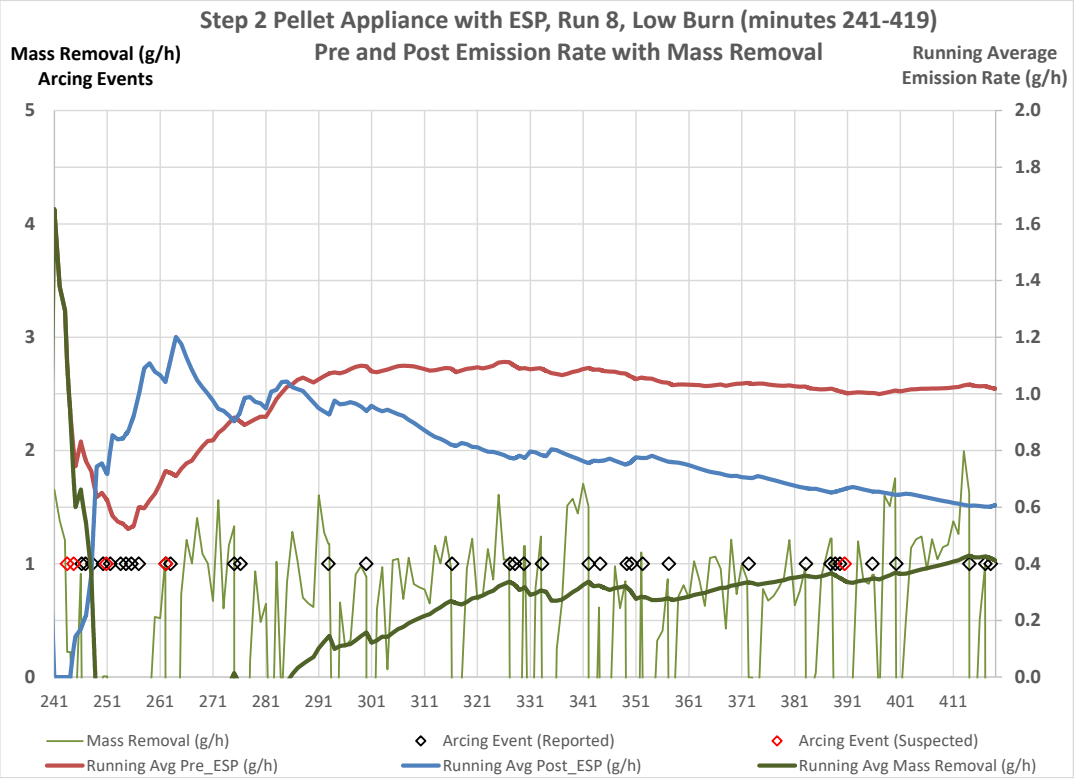

Step 2 Pellet Appliance with ESP, Run 8, Medium Burn (minutes 121-240)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

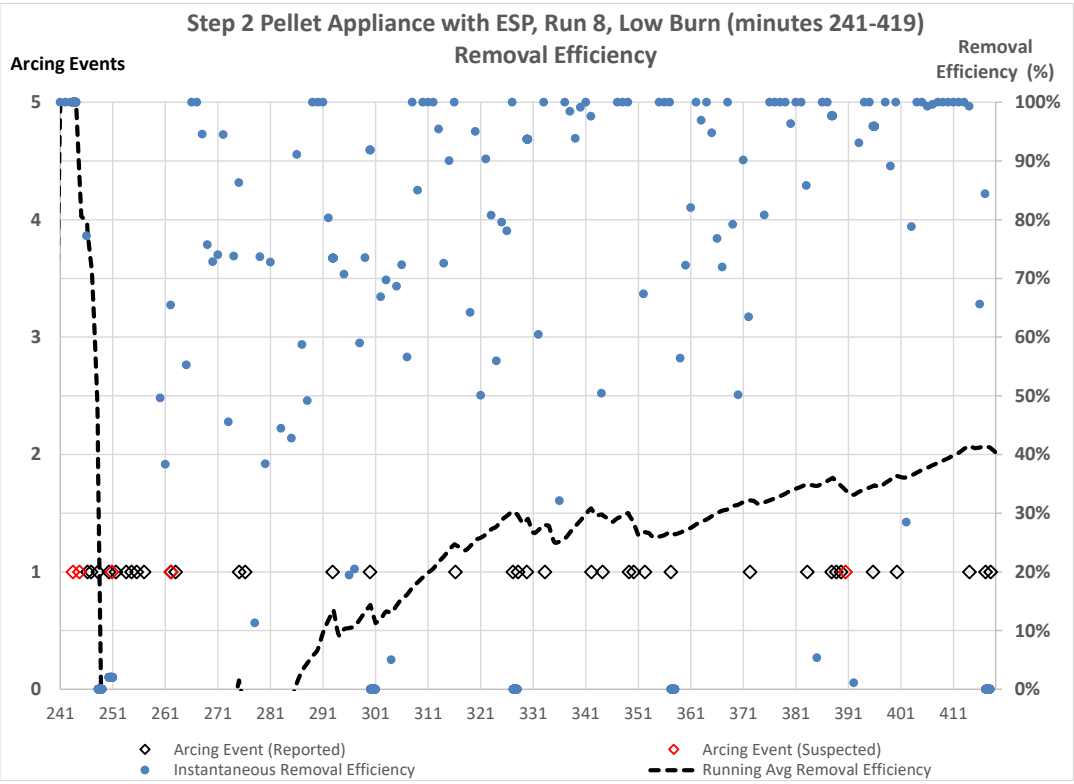

Step 2 Pellet Appliance with ESP, Run 8, Medium Burn (minutes 121-240)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 8, Low Burn






Step 2 Pellet Appliance with ESP, Run 8, Low Burn (minutes 241-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)


Step 2 Pellet Appliance with ESP, Run 8, Low Burn (minutes 241-419)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 9, Entire Run

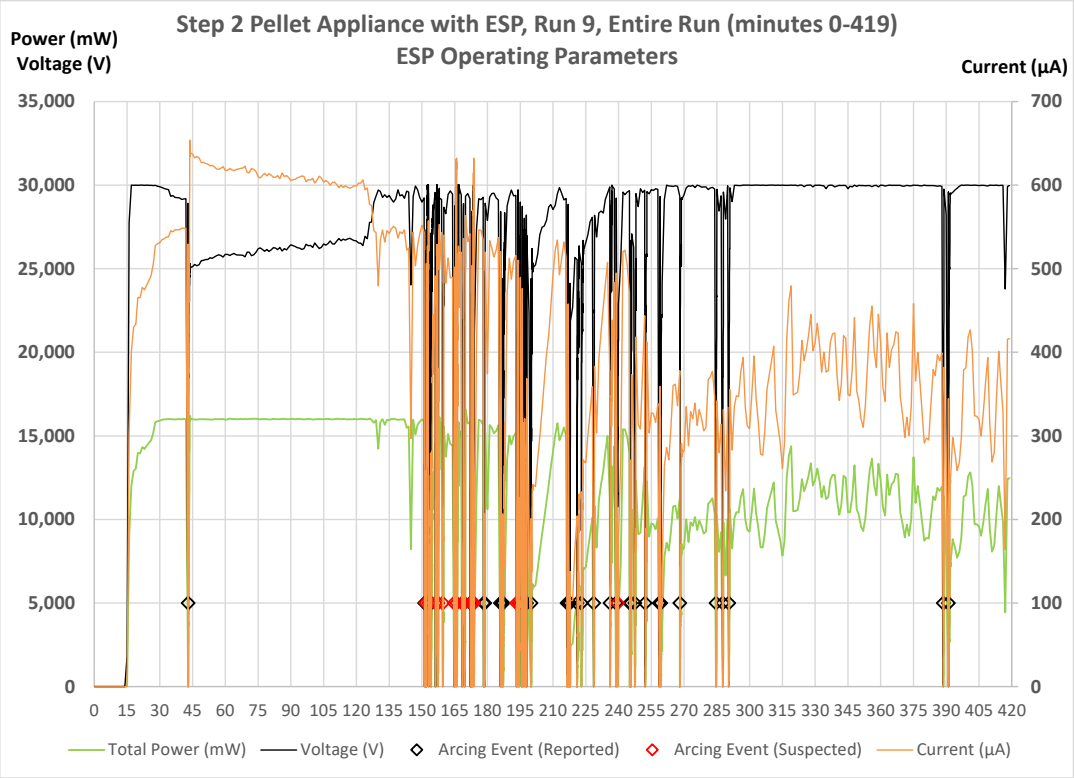
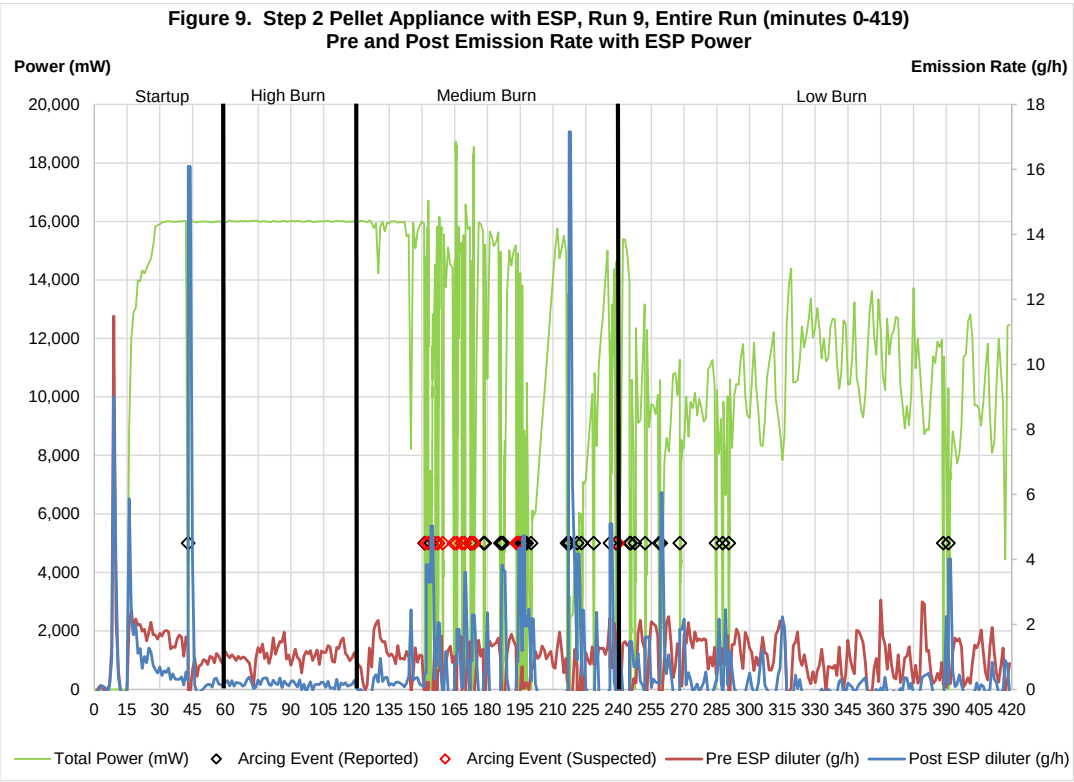


Figure 9. Step 2 Pellet Appliance with ESP, Run 9, Entire Run (minutes 0-419)
Pre and Post Emission Rate with ESP Power



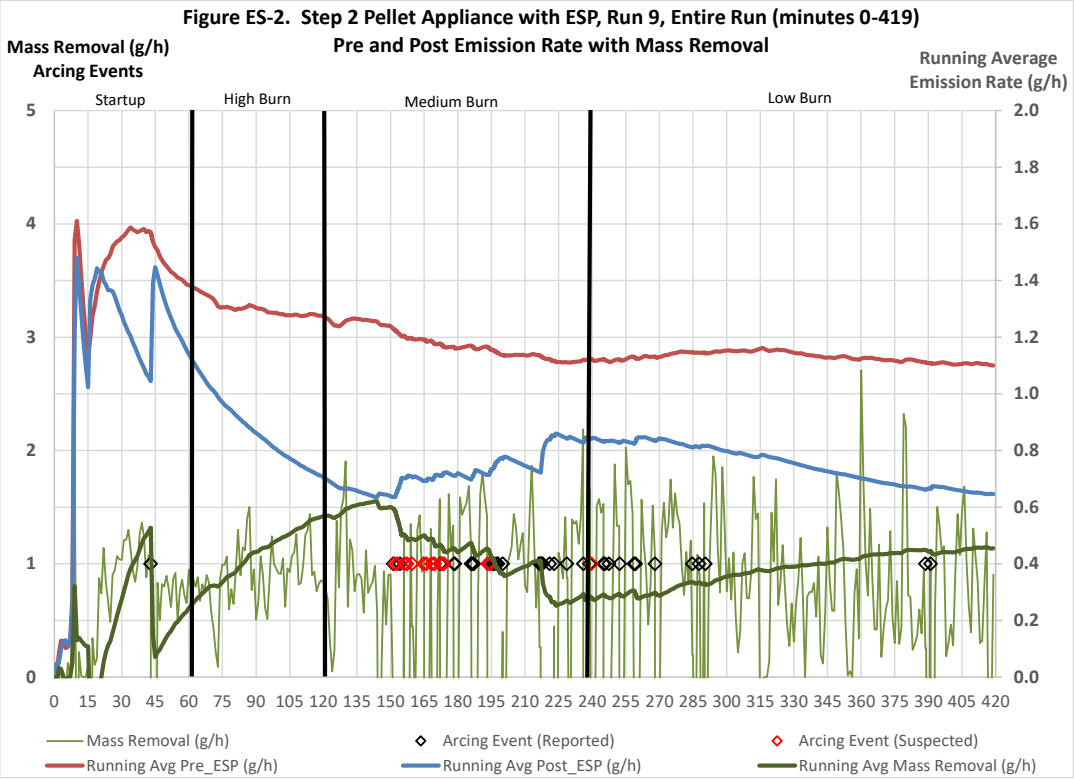
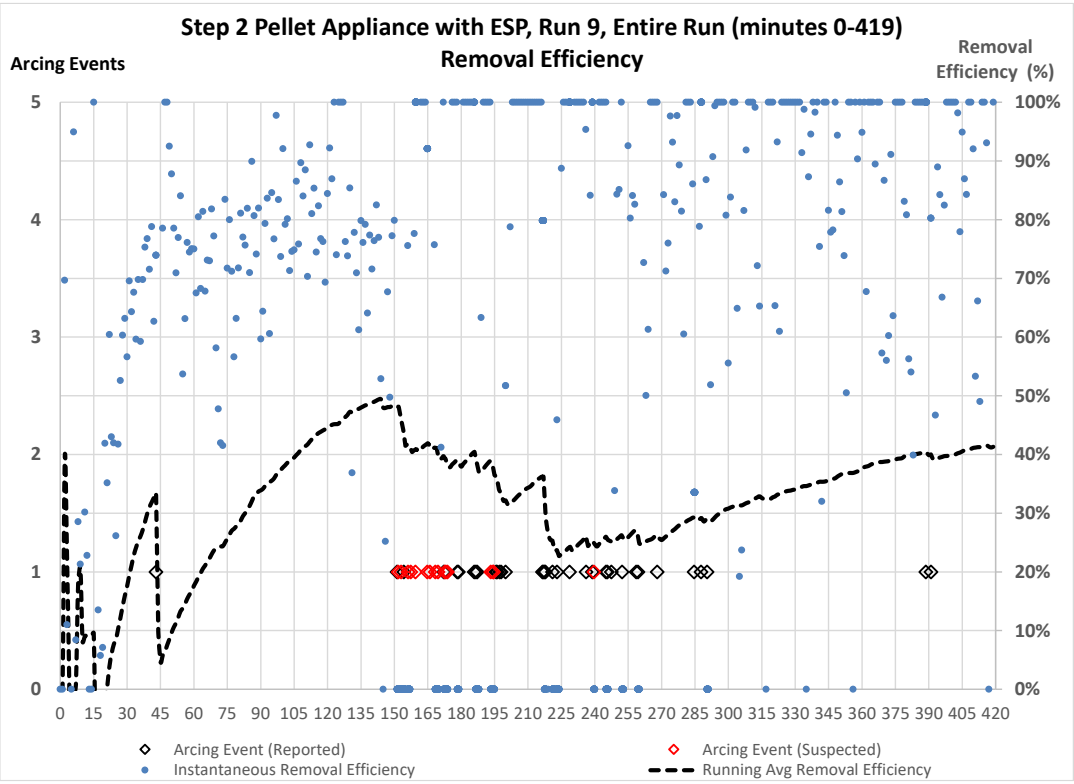
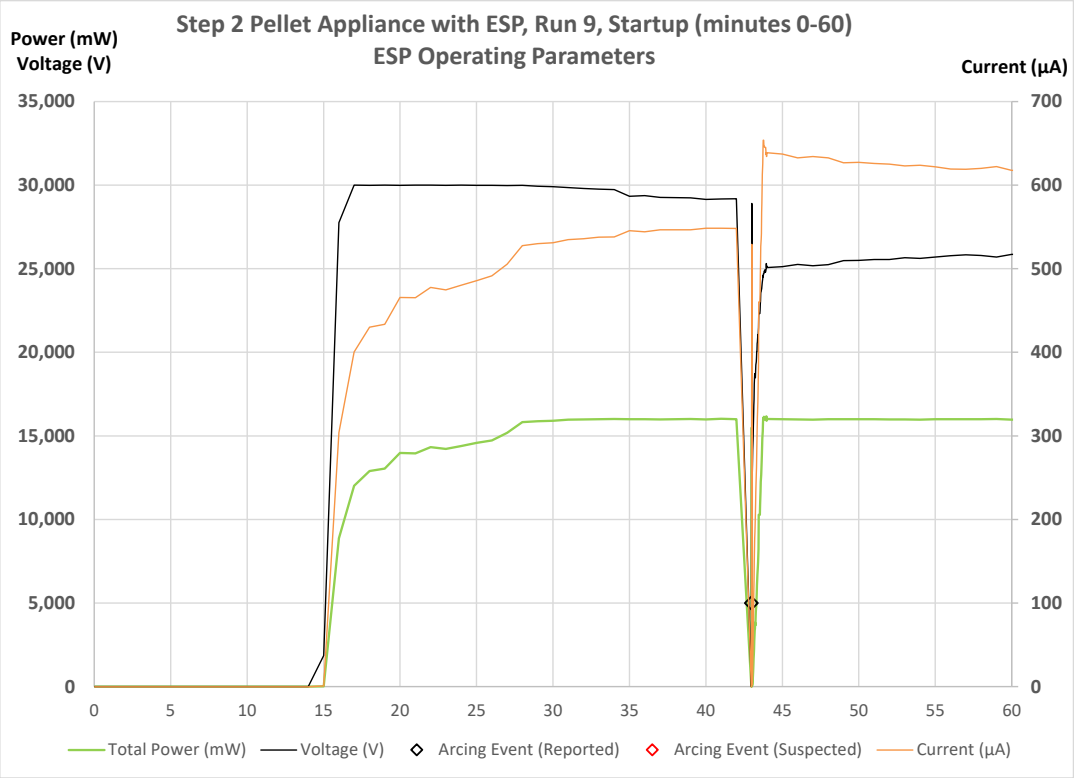
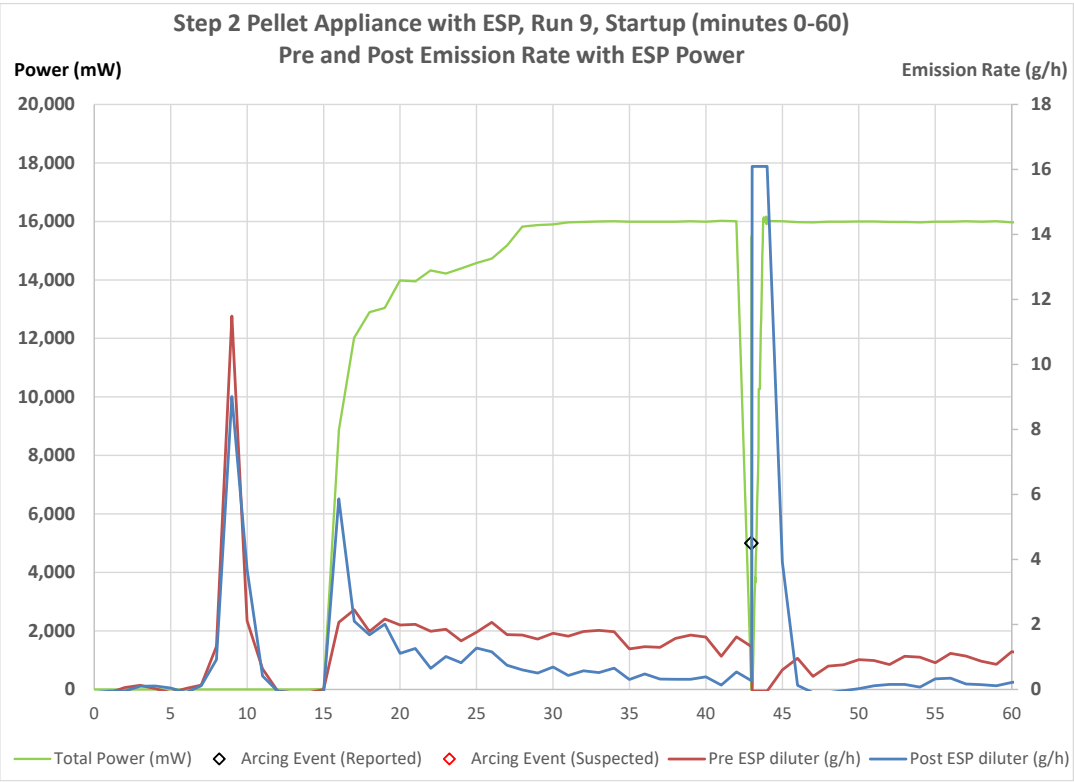


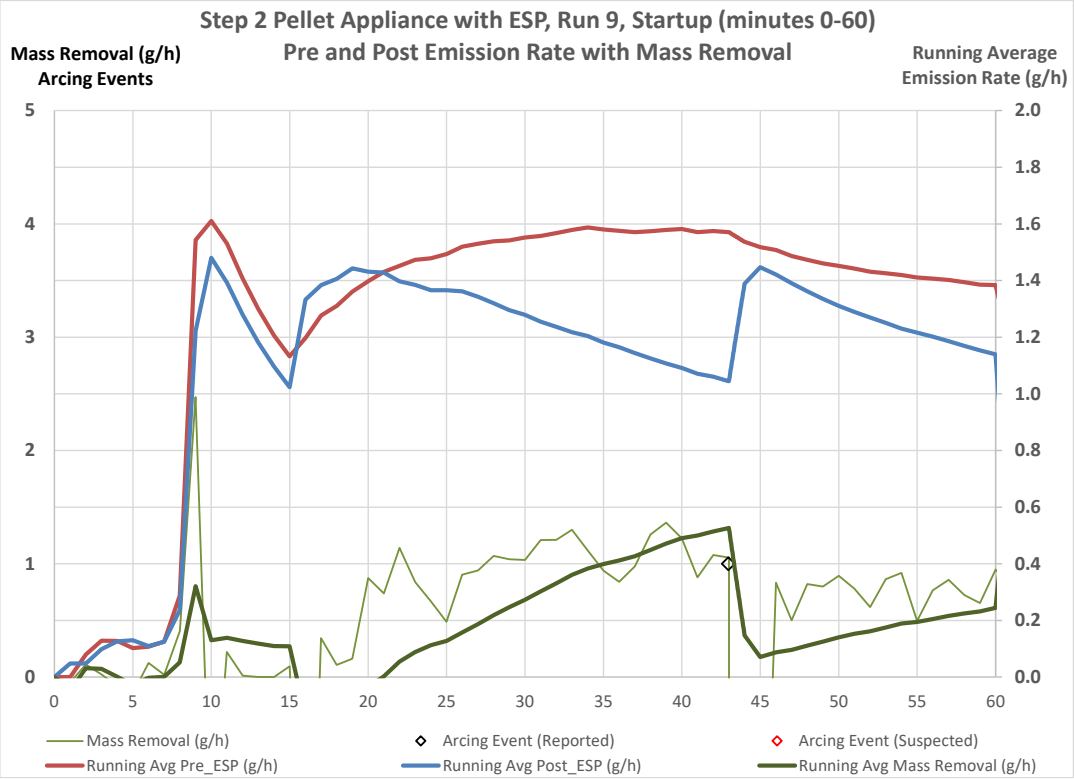
Figure ES-2. Step 2 Pellet Appliance with ESP, Run 9, Entire Run (minutes 0-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
Startup
High Burn
Medium Burn
Low Burn
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

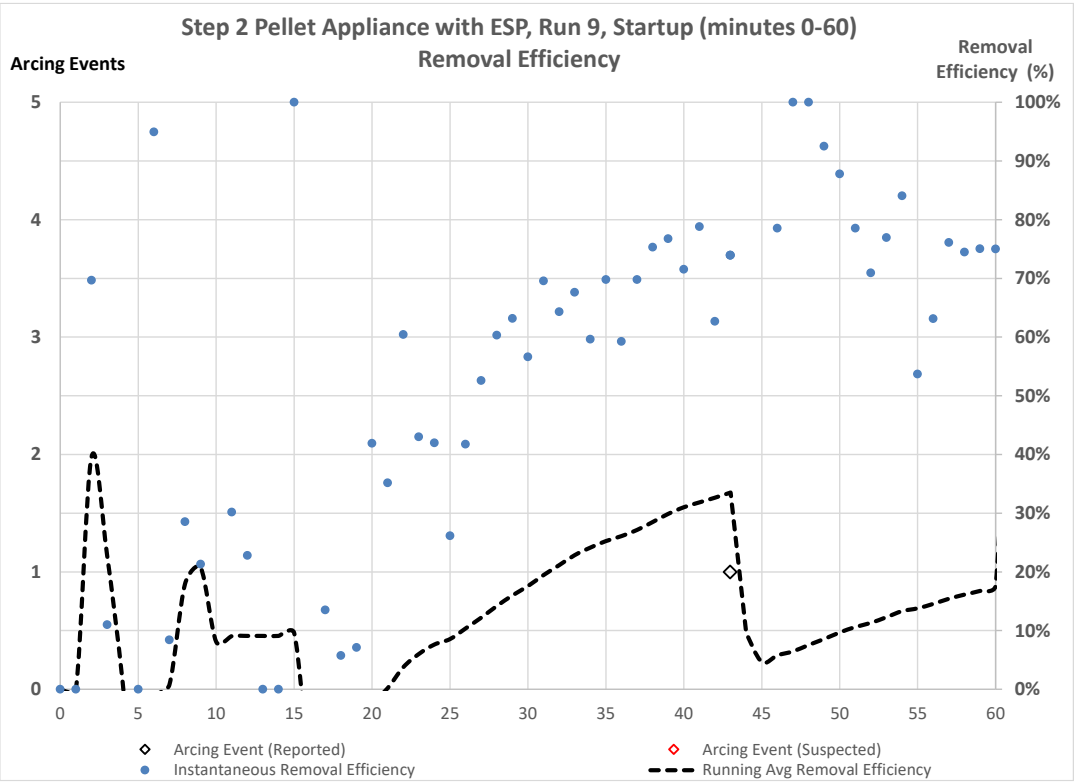

Step 2 Pellet Appliance with ESP, Run 9, Entire Run (minutes 0-419)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 9, Startup

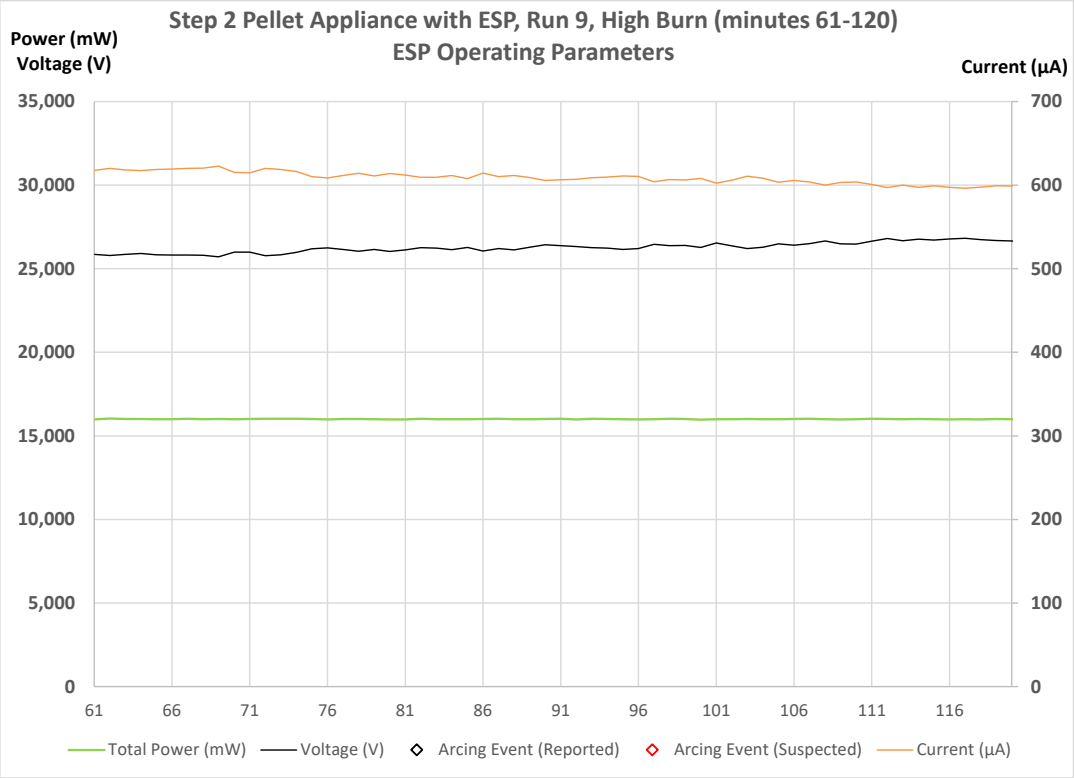


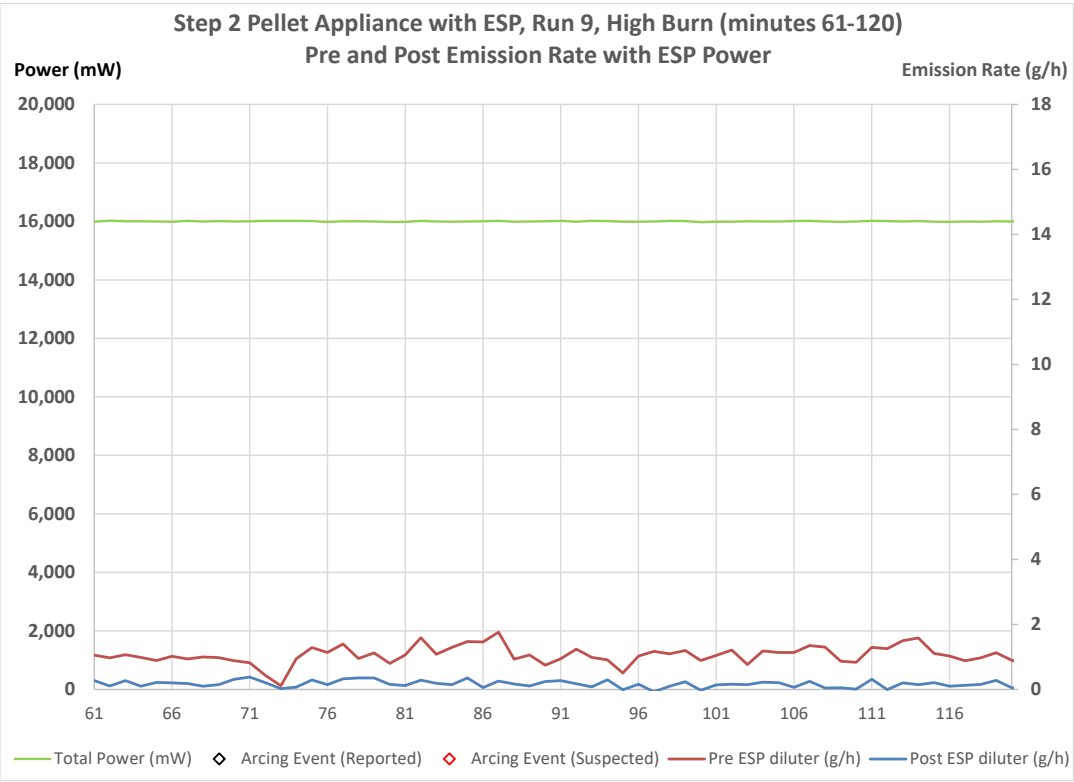


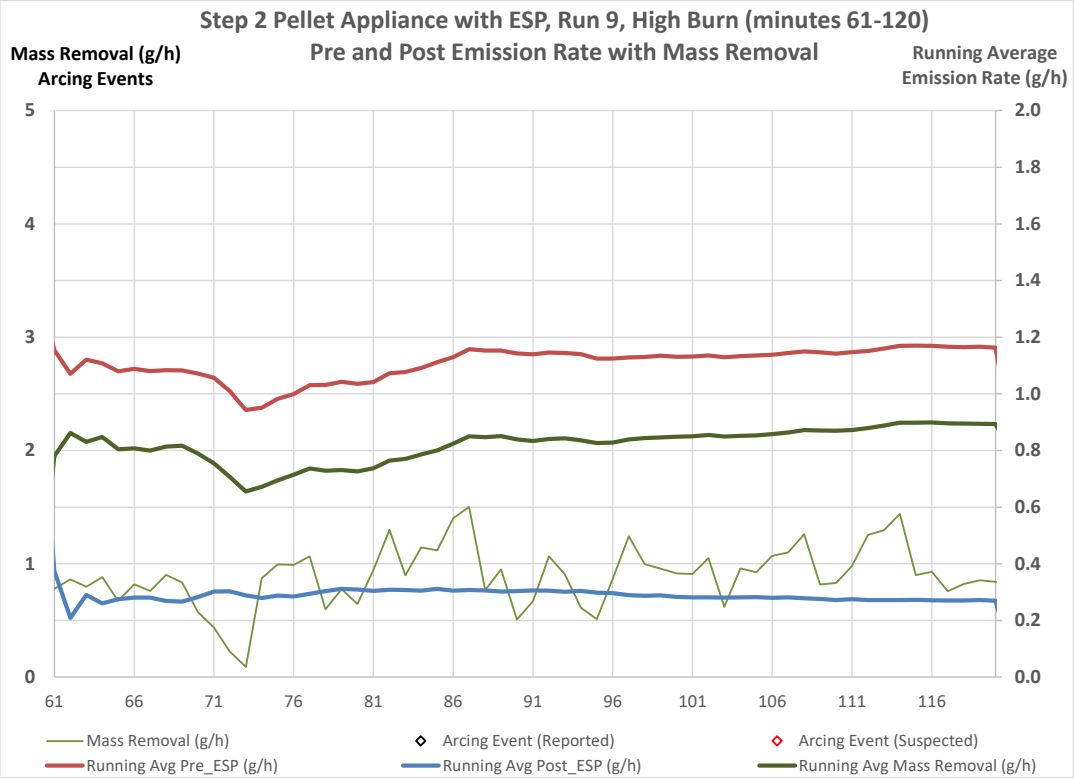

Step 2 Pellet Appliance with ESP, Run 9, Startup (minutes 0-60)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

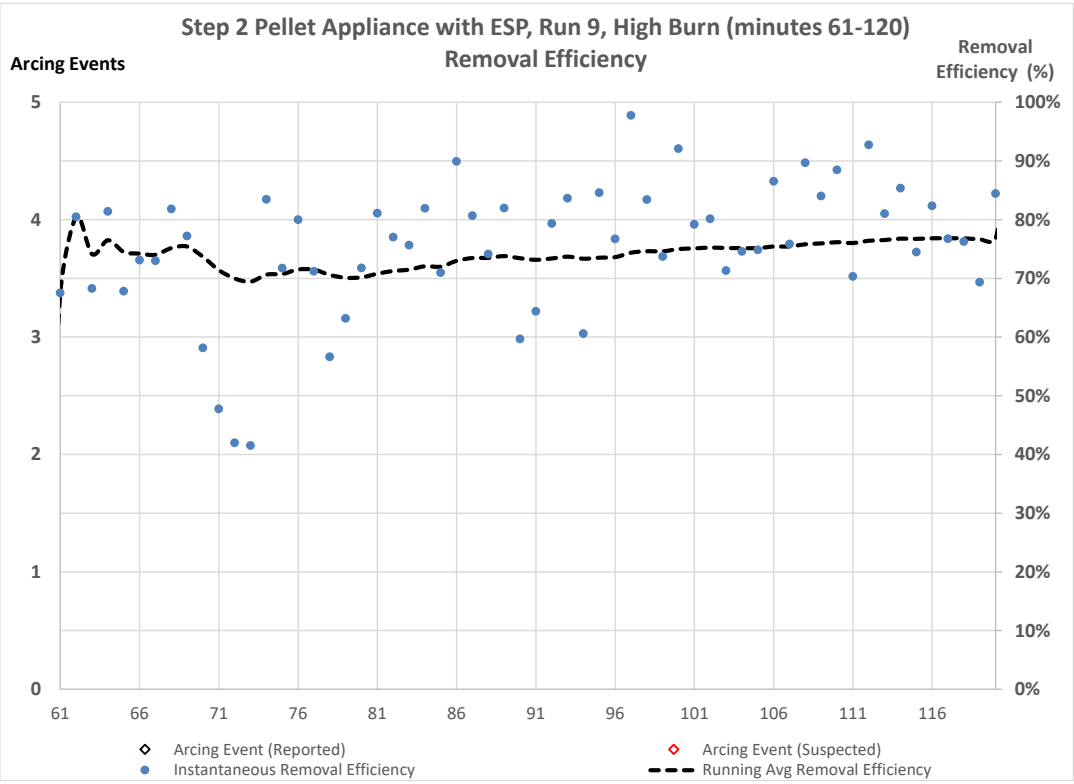

Step 2 Pellet Appliance with ESP, Run 9, Startup (minutes 0-60)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
5
10
15
20
25
30
35
40
45
50
55
60
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 9, High Burn

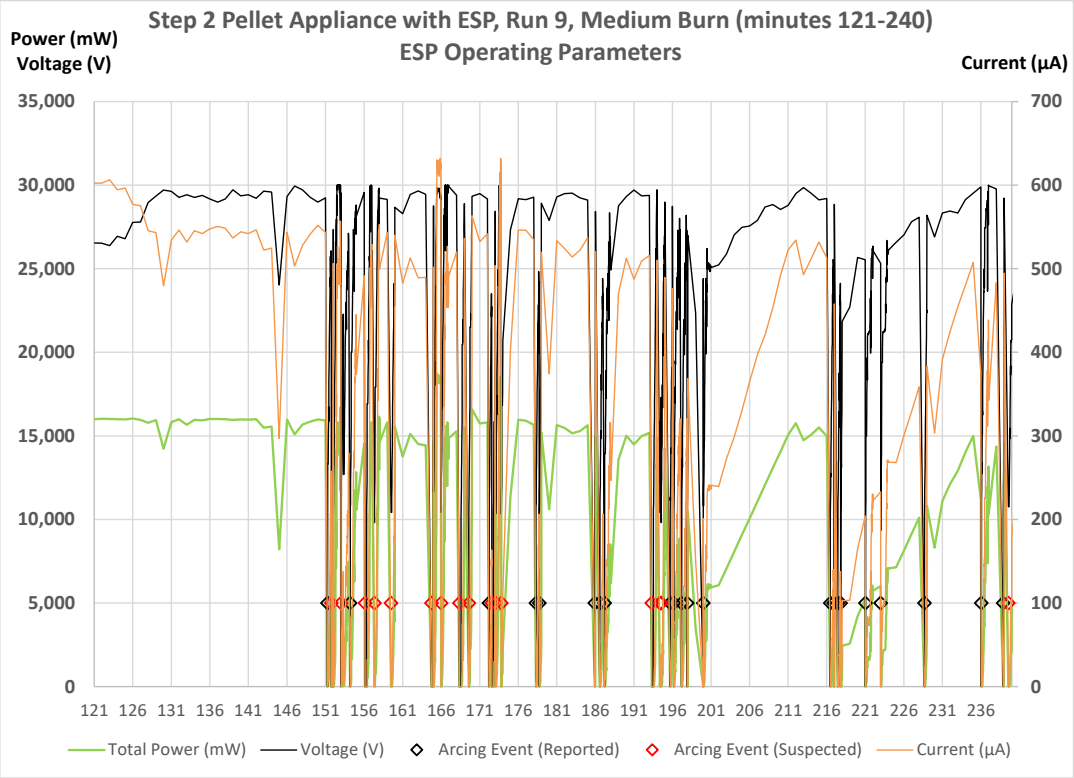


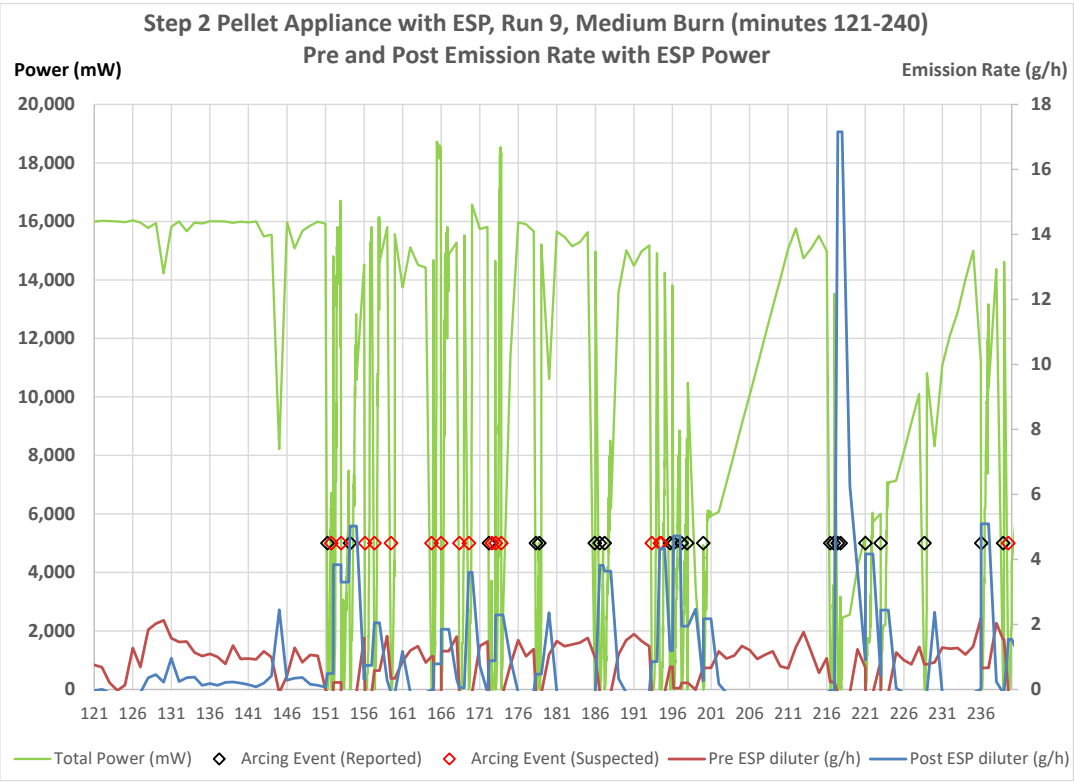


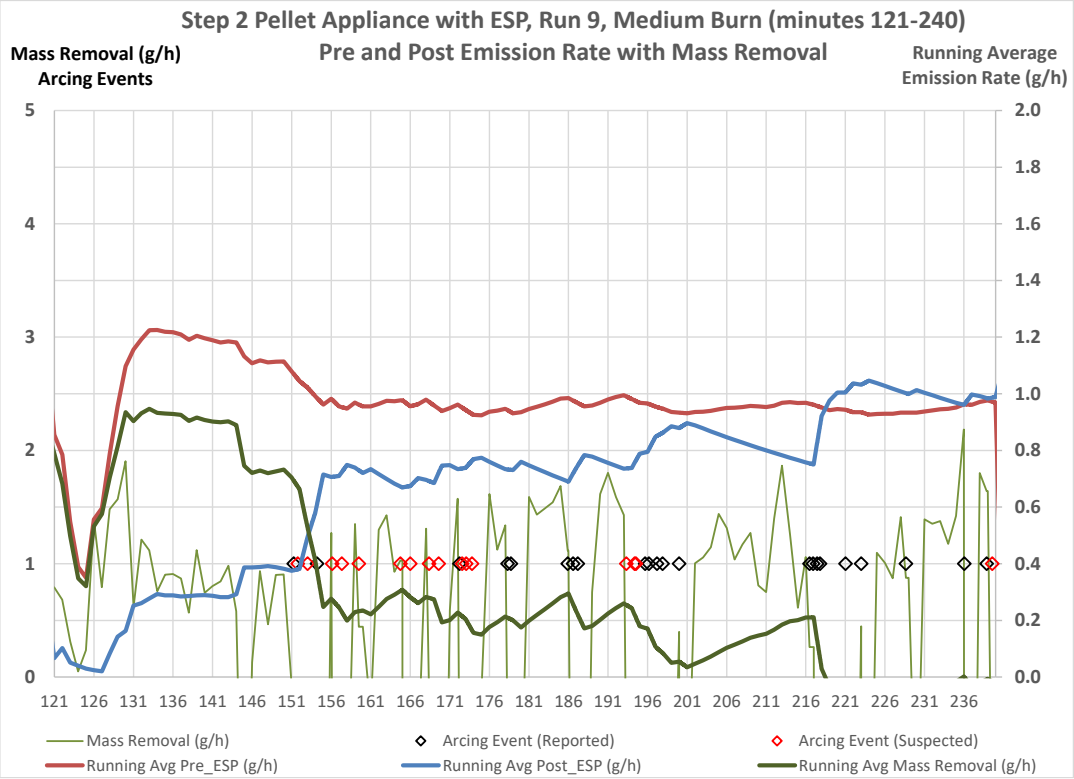

Step 2 Pellet Appliance with ESP, Run 9, High Burn (minutes 61-120)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
61
66
71
76
81
86
91
96
101
106
111
116
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

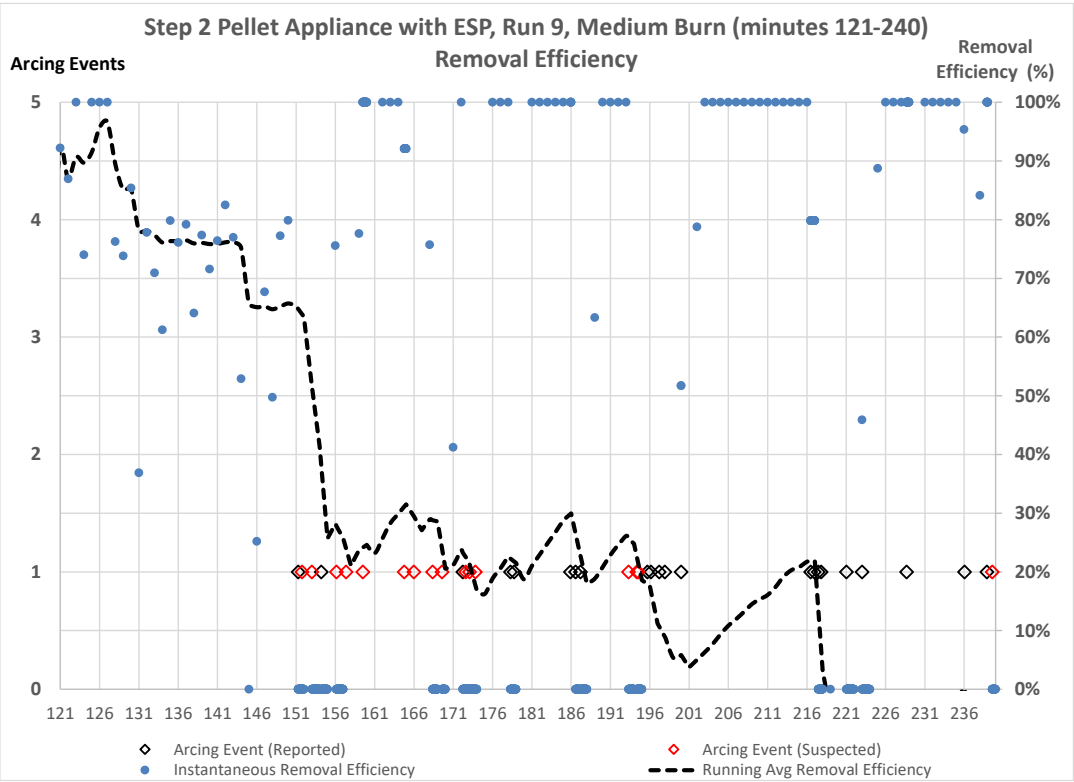

Step 2 Pellet Appliance with ESP, Run 9, High Burn (minutes 61-120)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
61
66
71
76
81
86
91
96
101
106
111
116
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 9, Medium Burn

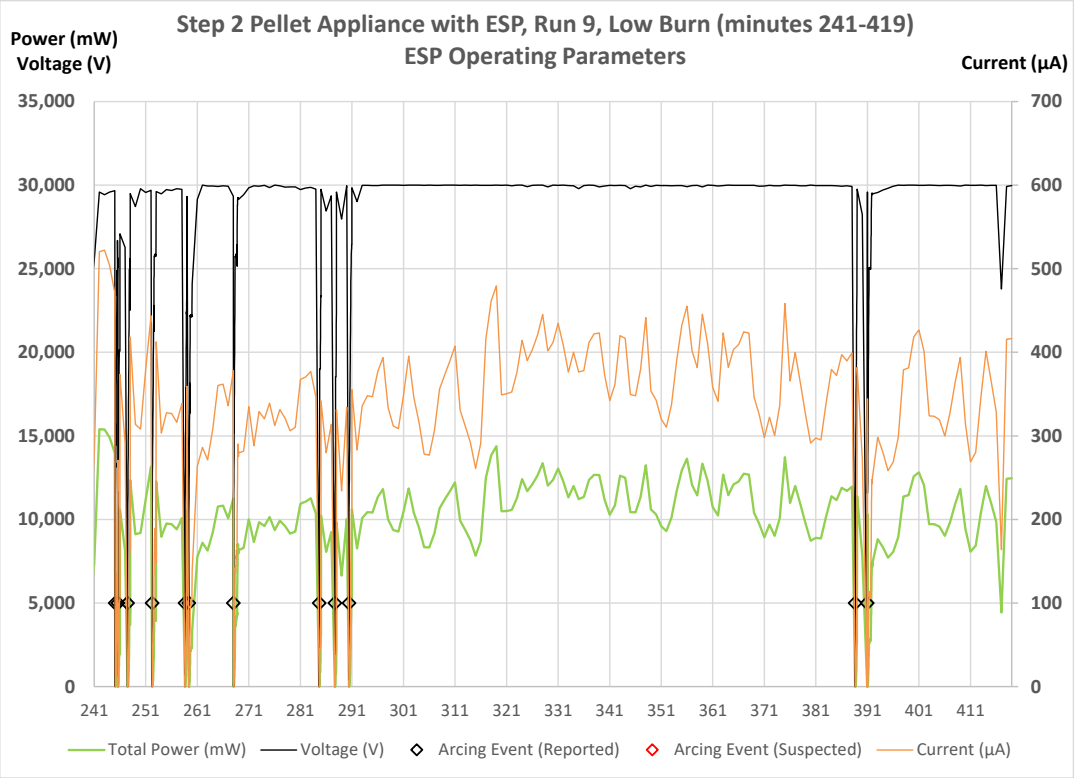


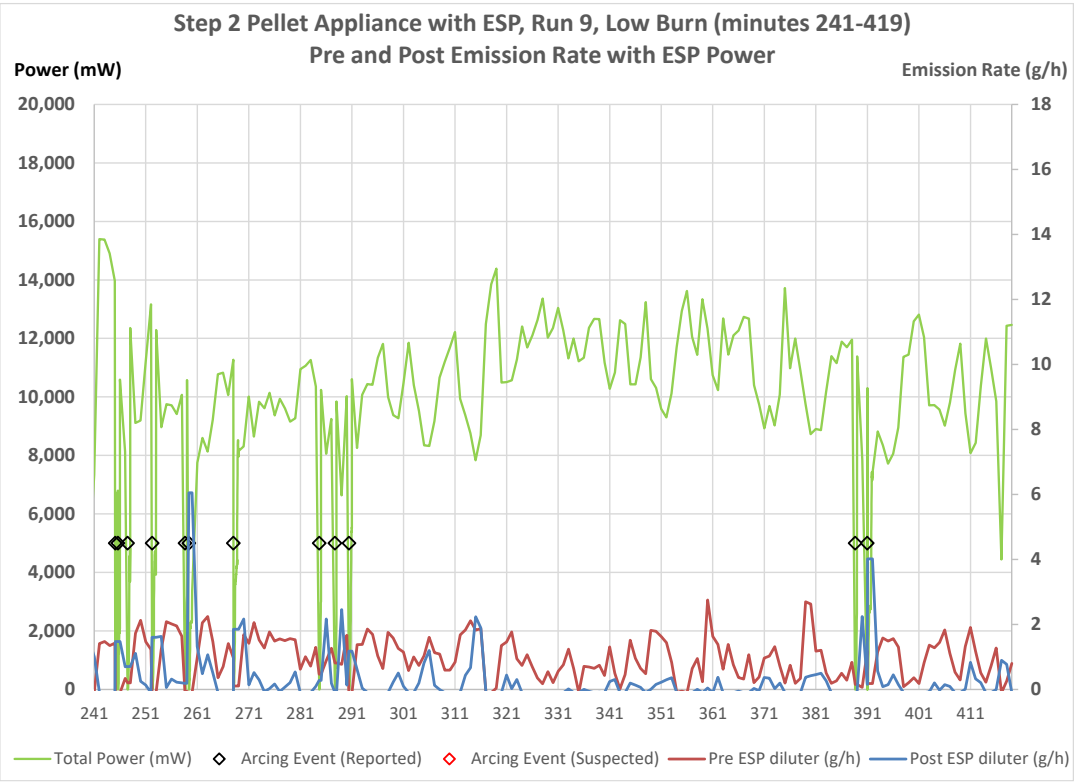


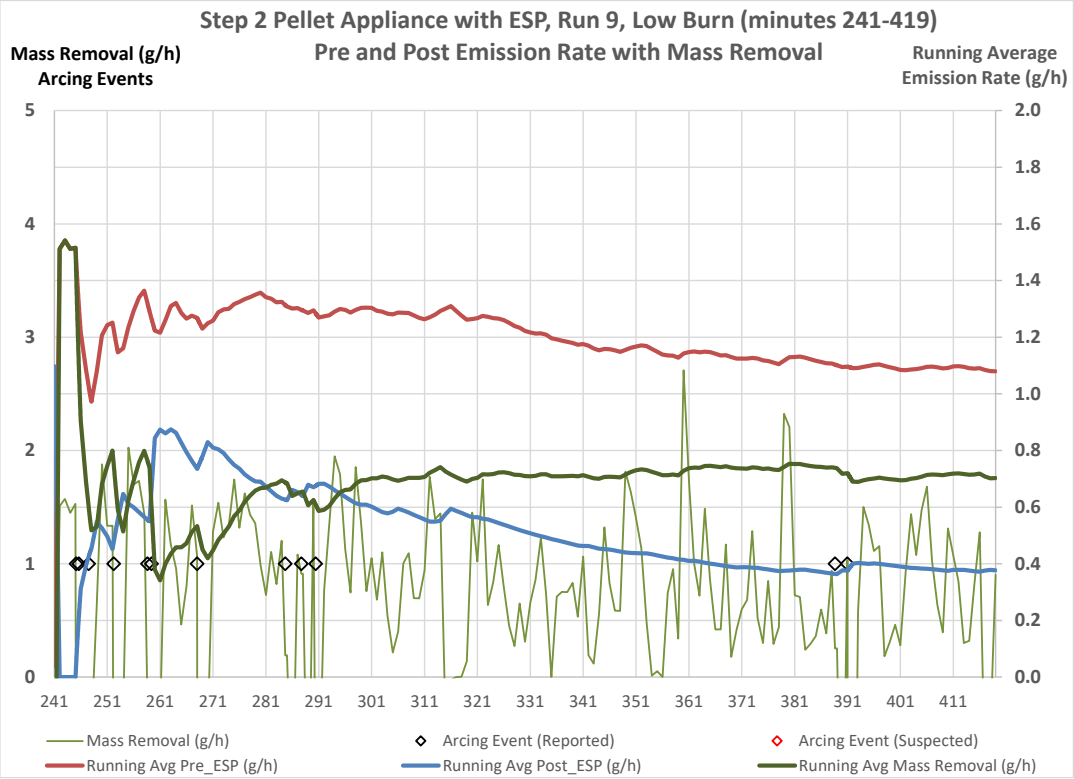

Step 2 Pellet Appliance with ESP, Run 9, Medium Burn (minutes 121-240)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

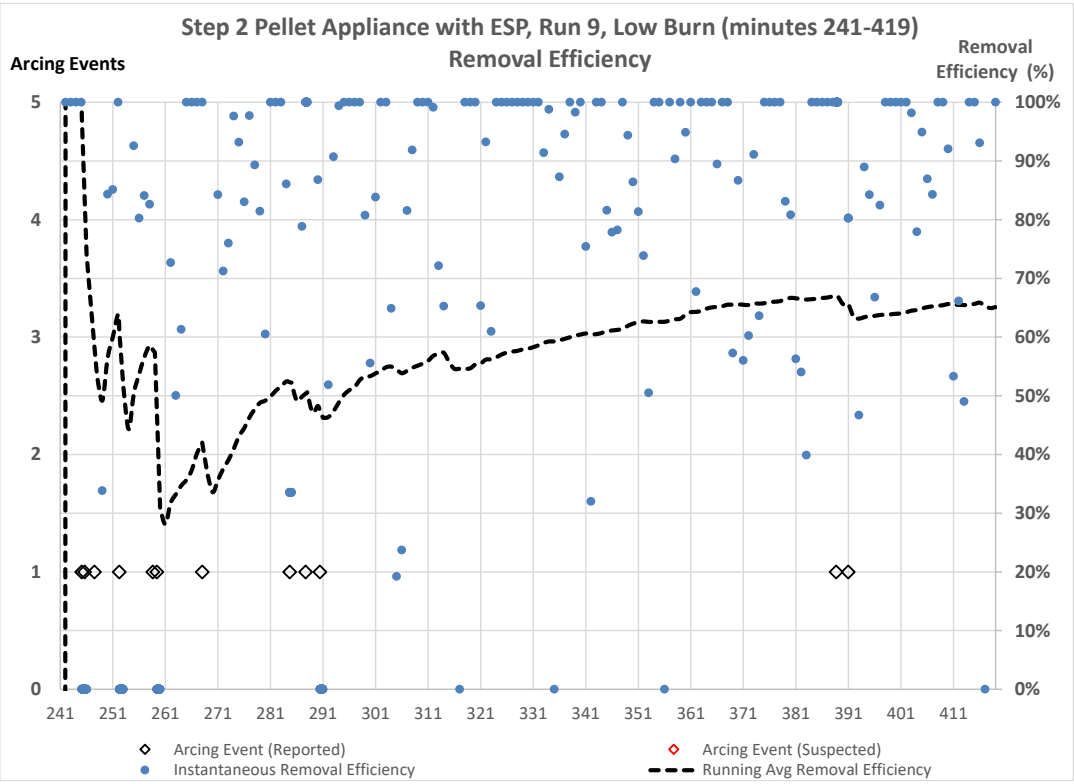

Step 2 Pellet Appliance with ESP, Run 9, Medium Burn (minutes 121-240)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 9, Low Burn

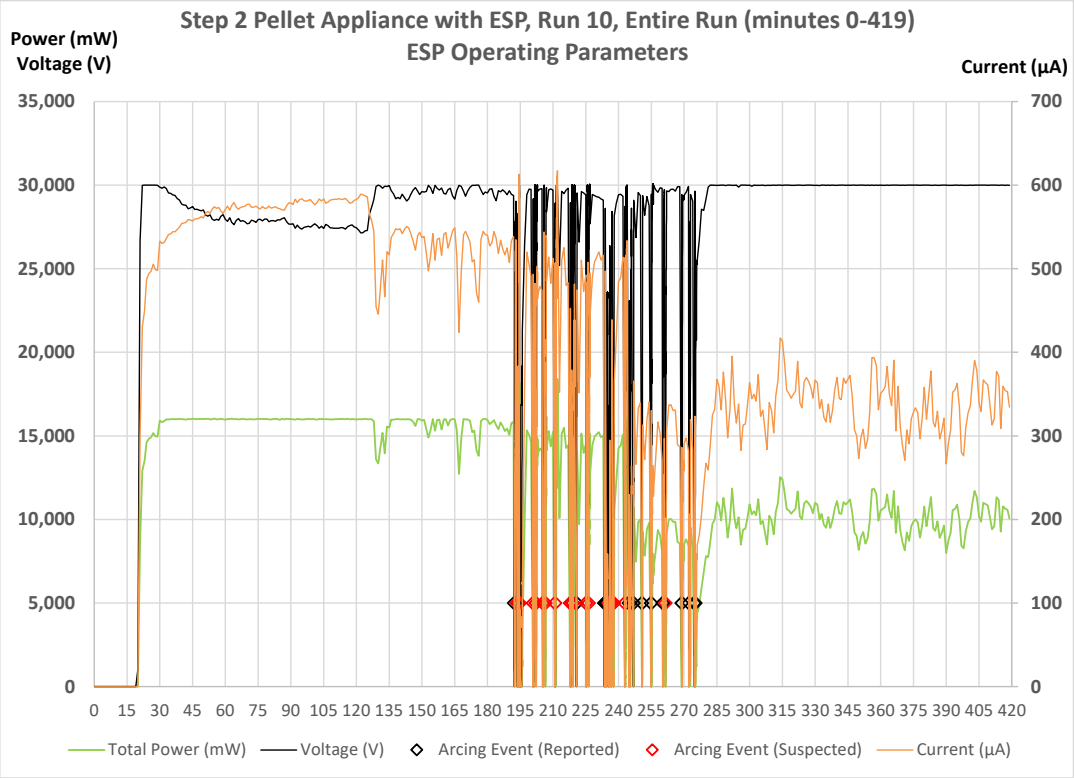


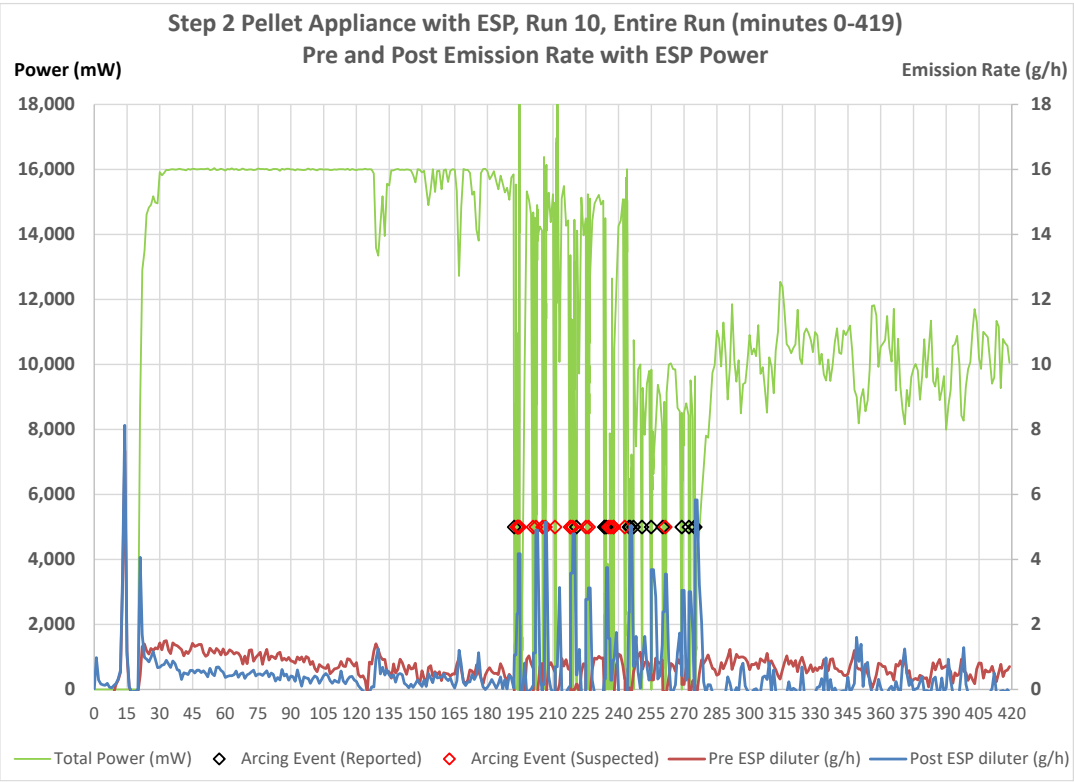


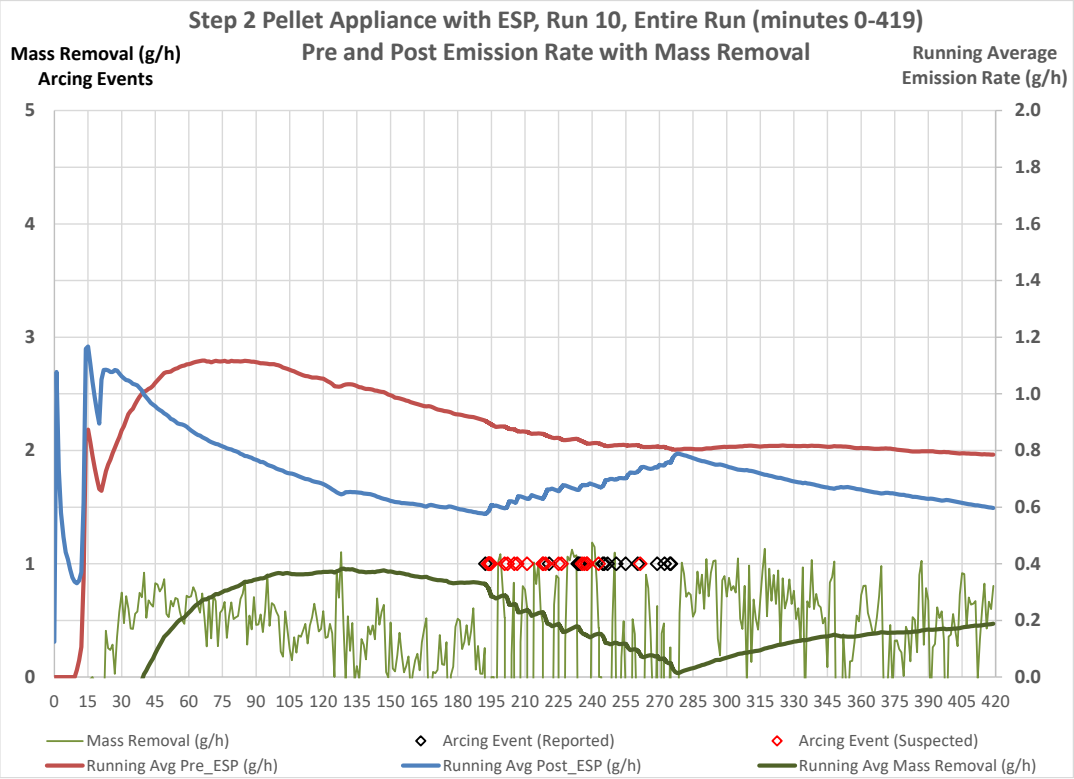

Step 2 Pellet Appliance with ESP, Run 9, Low Burn (minutes 241-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

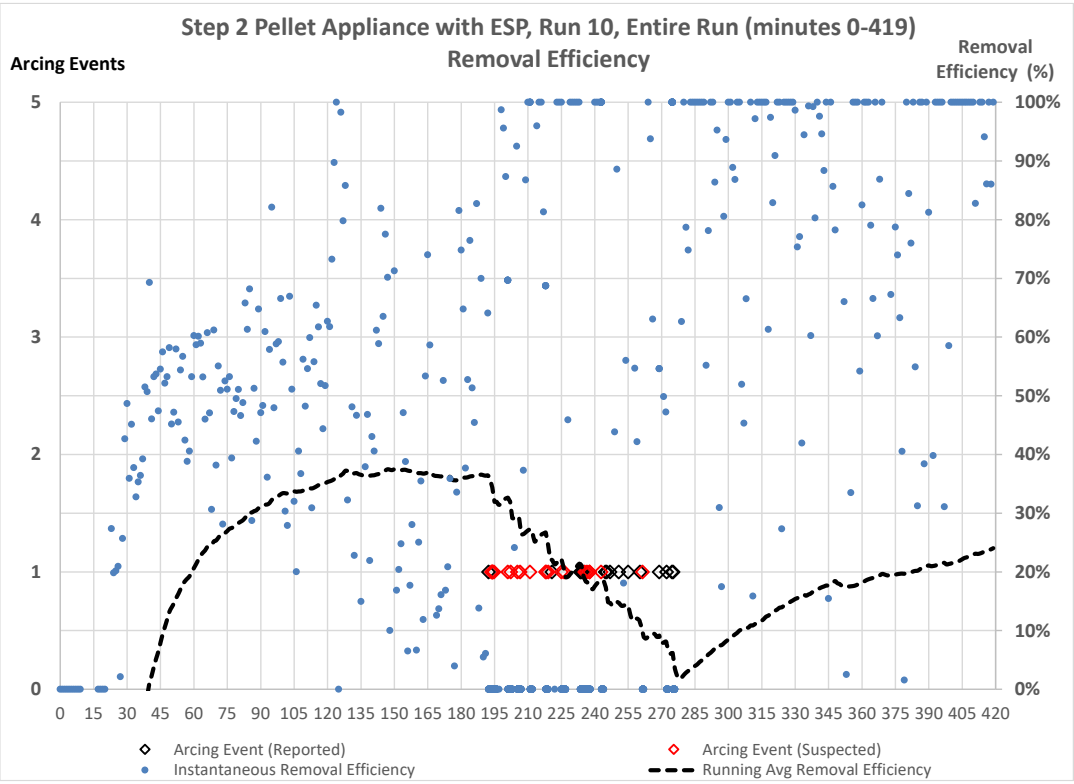

Step 2 Pellet Appliance with ESP, Run 9, Low Burn (minutes 241-419)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 10, Entire Run

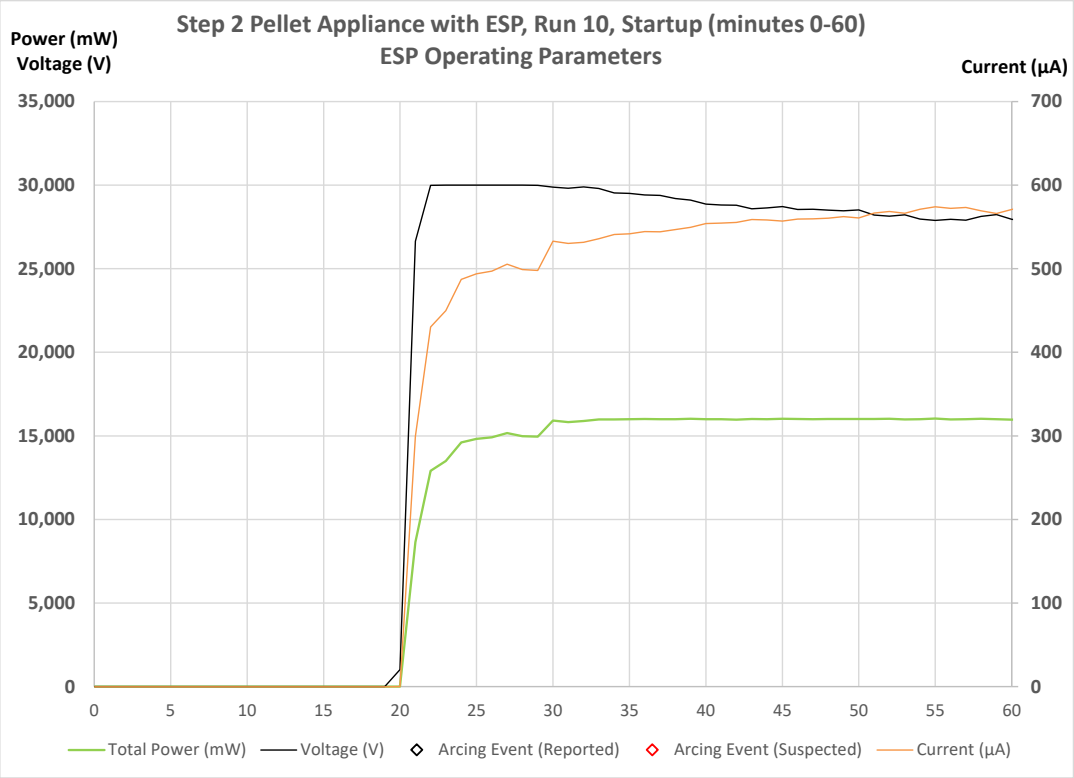


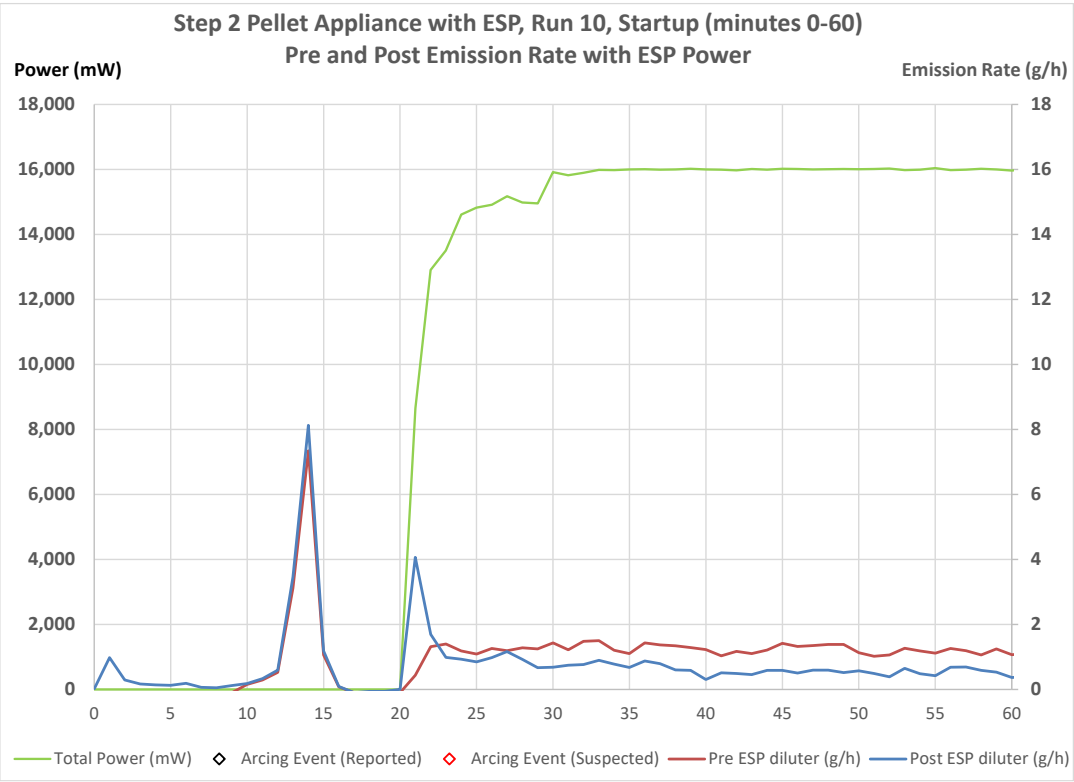


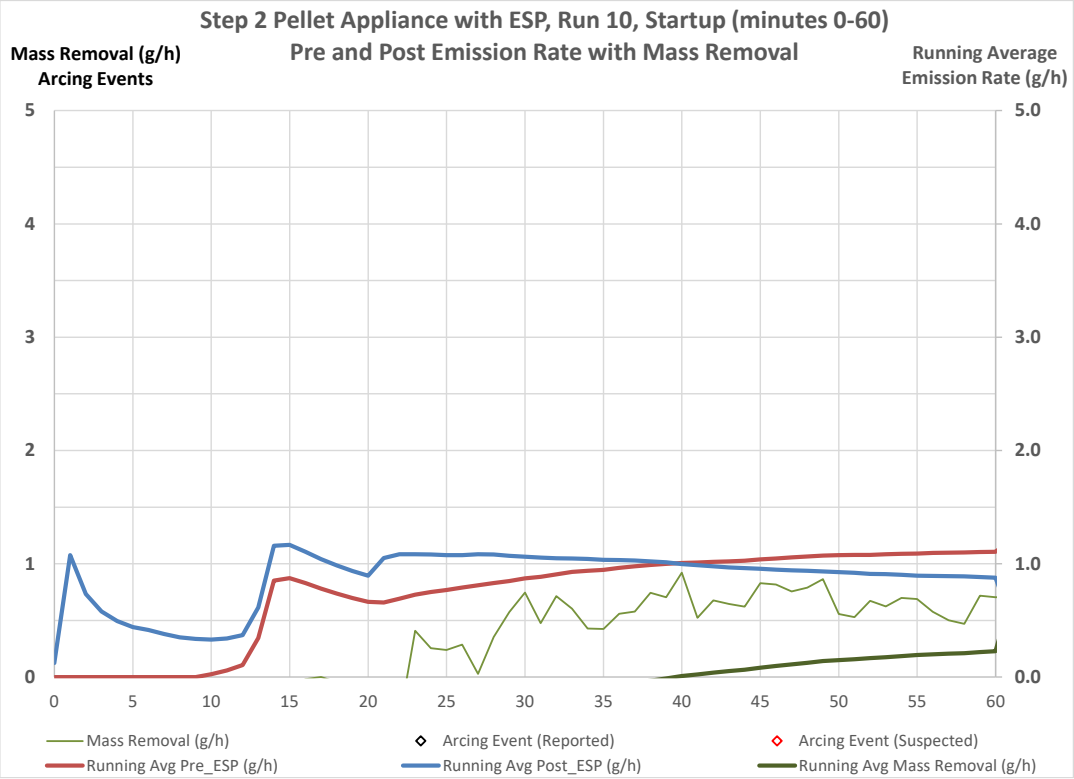

Step 2 Pellet Appliance with ESP, Run 10, Entire Run (minutes 0-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

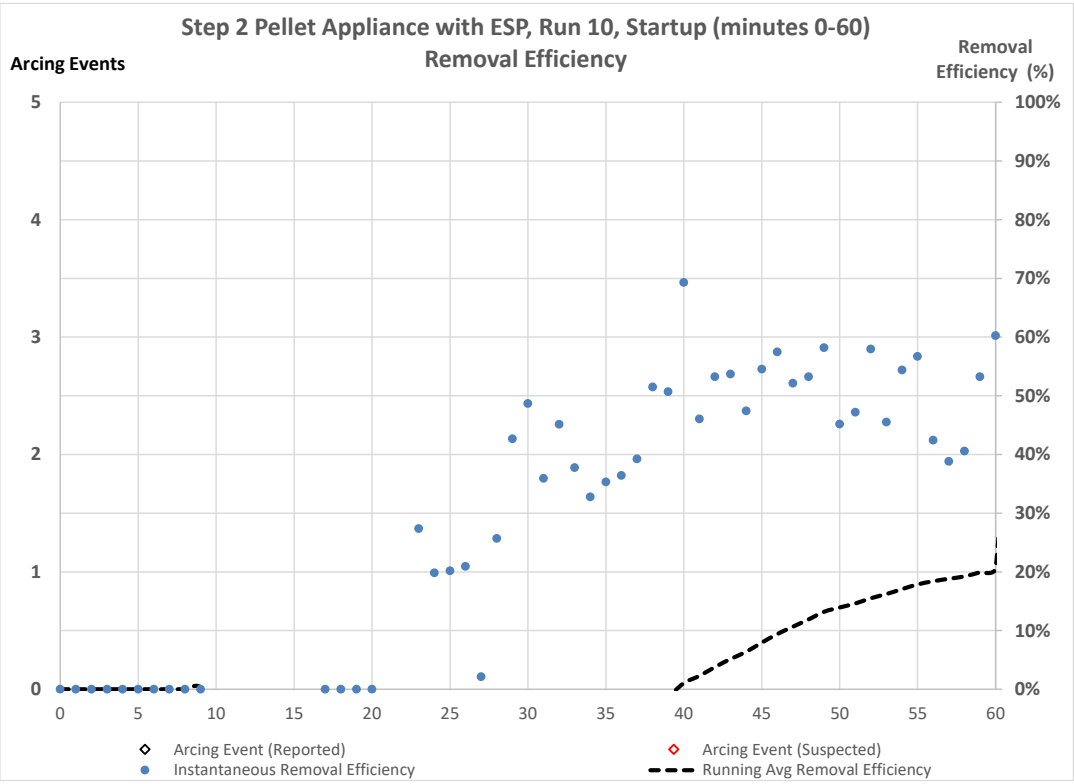

Step 2 Pellet Appliance with ESP, Run 10, Entire Run (minutes 0-419)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360 375 390 405 420
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 10, Startup

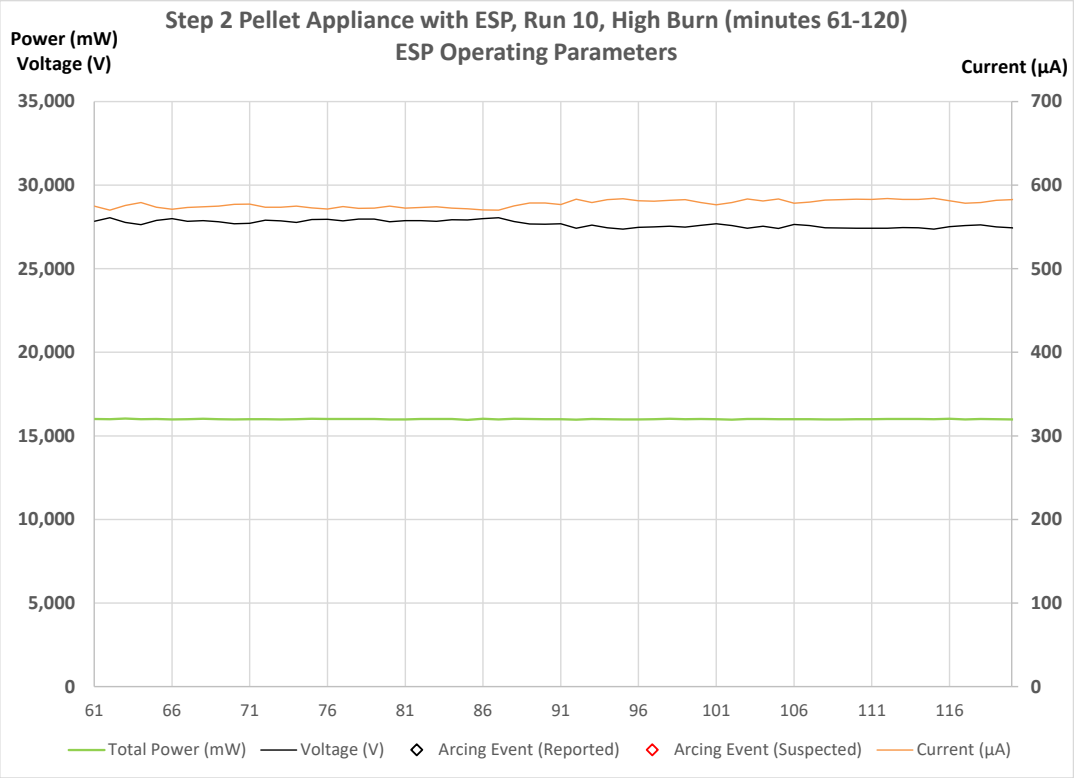


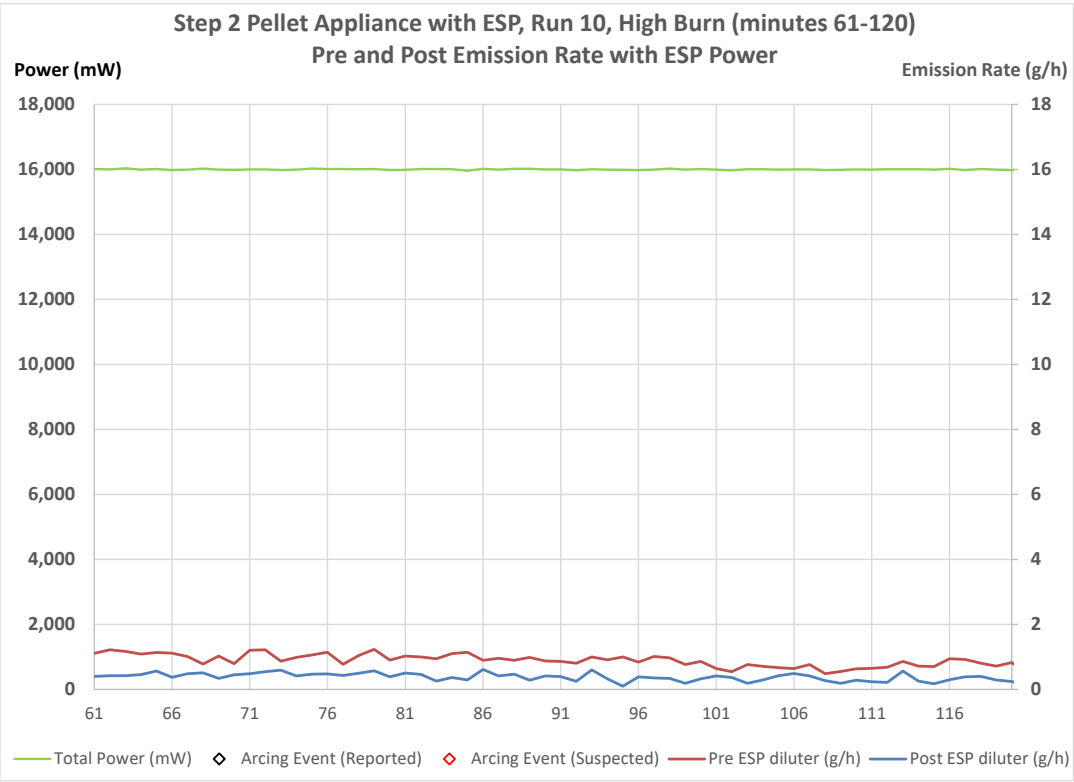


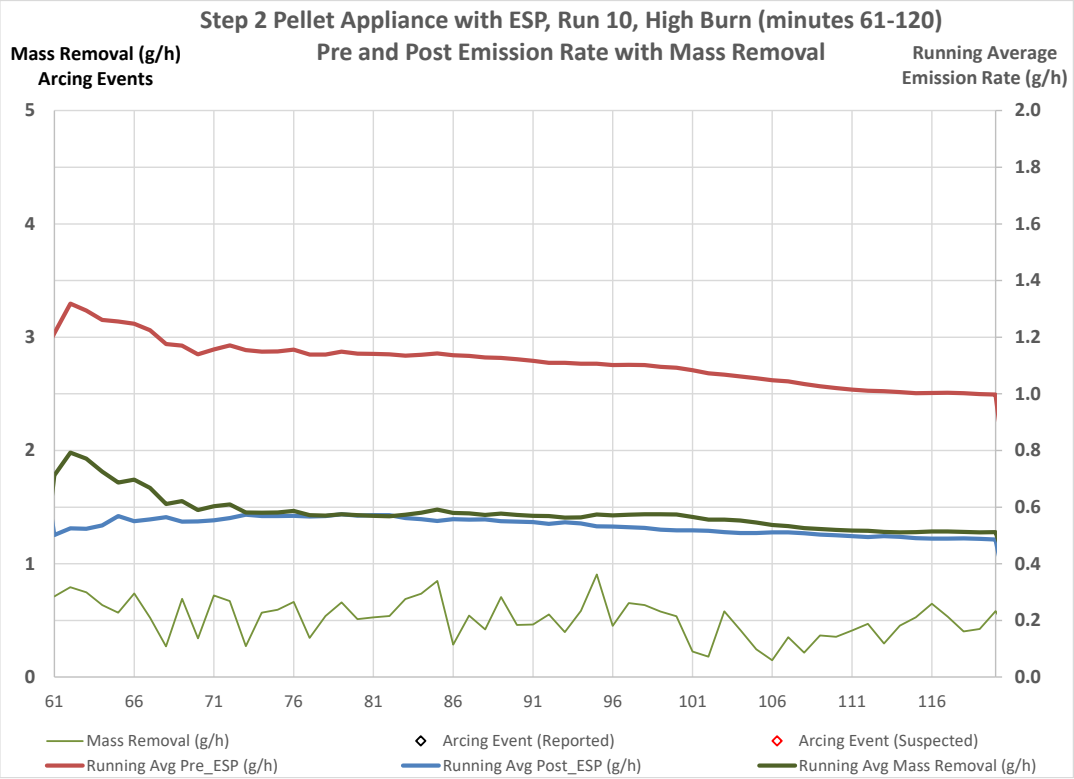

Step 2 Pellet Appliance with ESP, Run 10, Startup (minutes 0-60)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
5.0
4.0
3.0
2.0
1.0
0.0
0 5 10 15 20 25 30 35 40 45 50 55 60
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

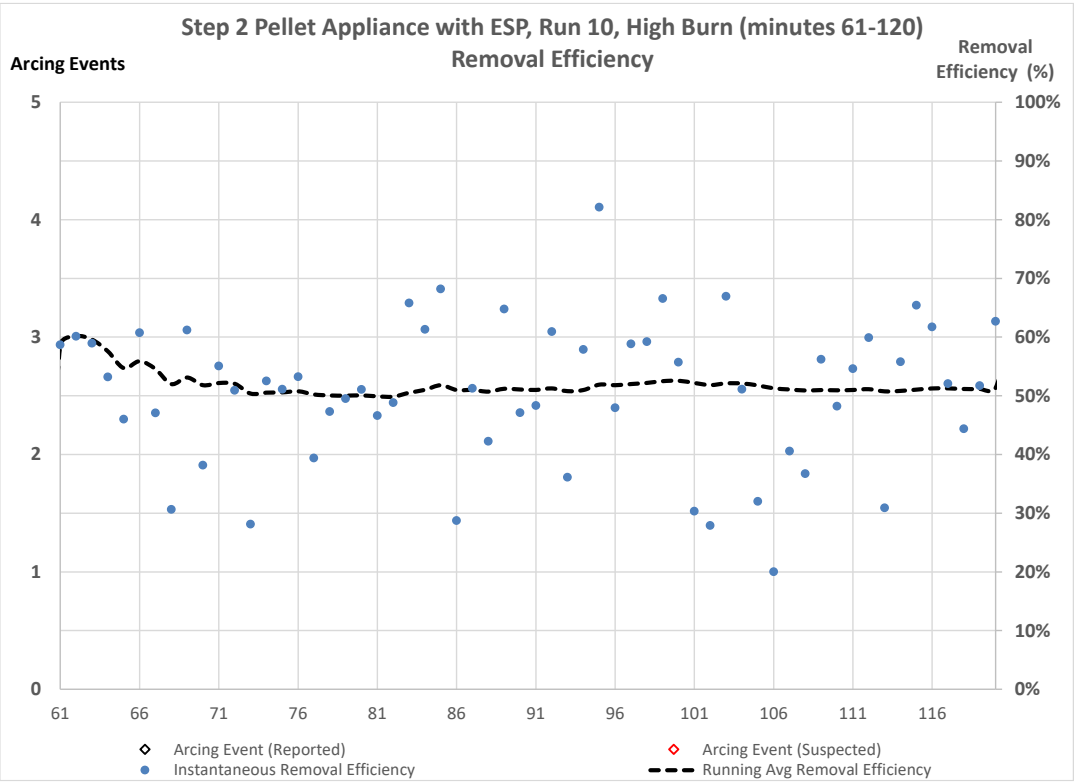

Step 2 Pellet Appliance with ESP, Run 10, Startup (minutes 0-60)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 5 10 15 20 25 30 35 40 45 50 55 60
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 10, High Burn

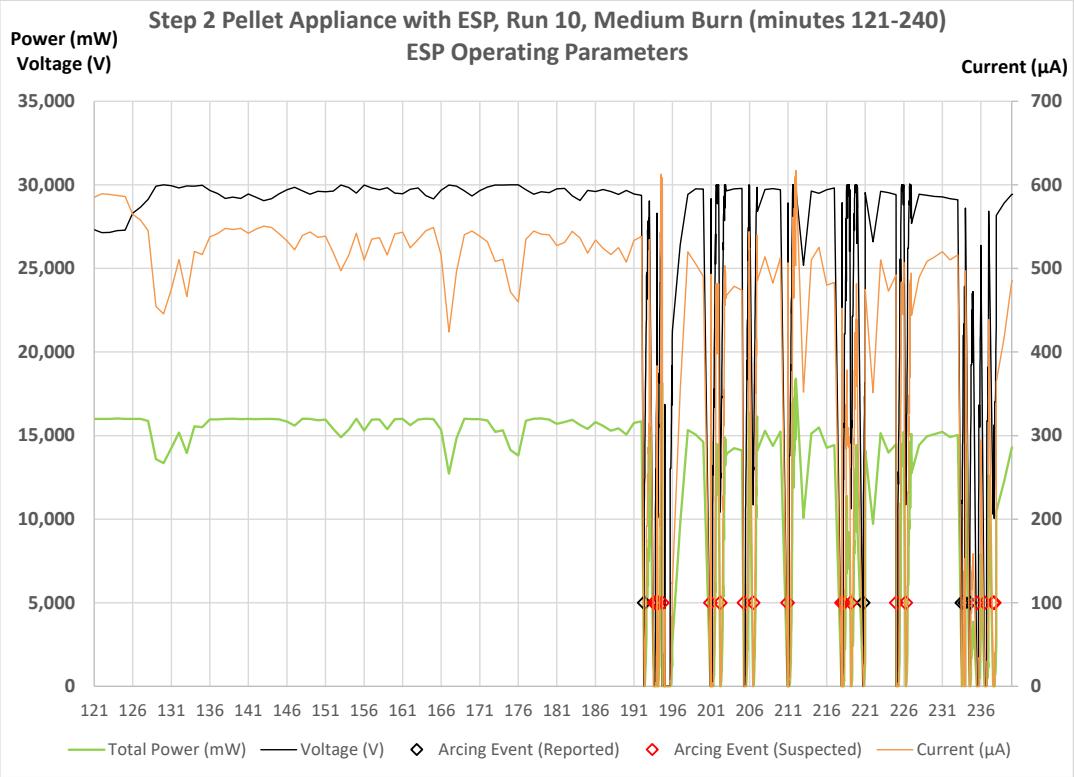


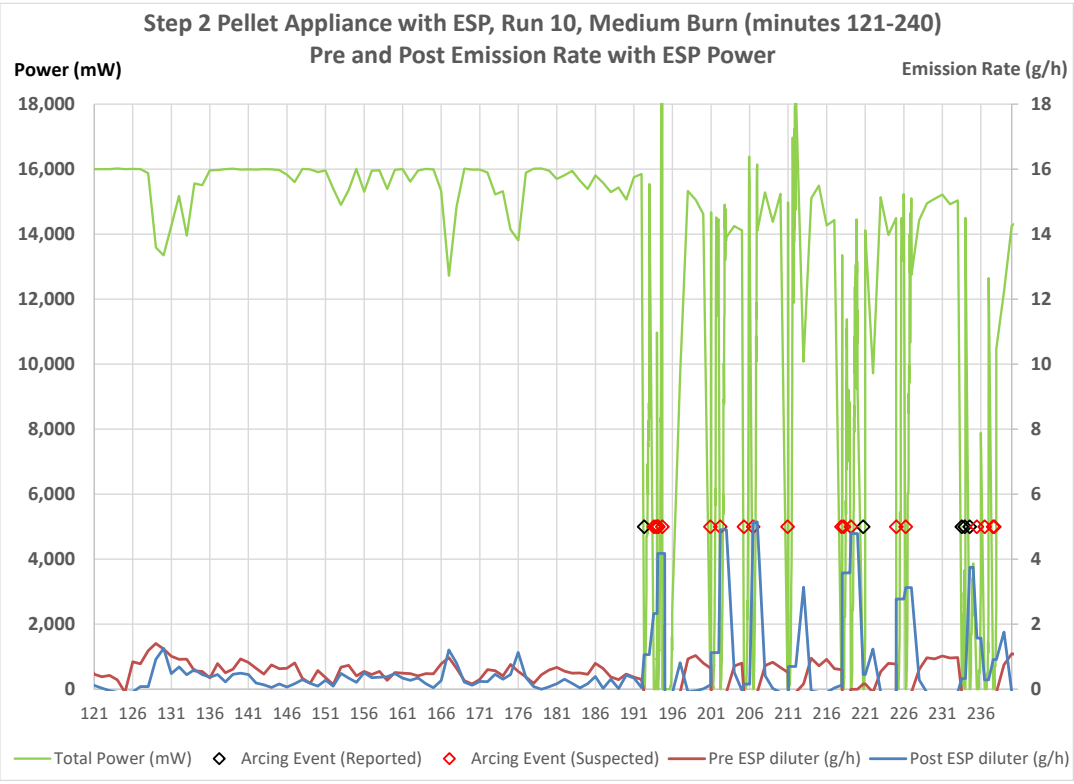


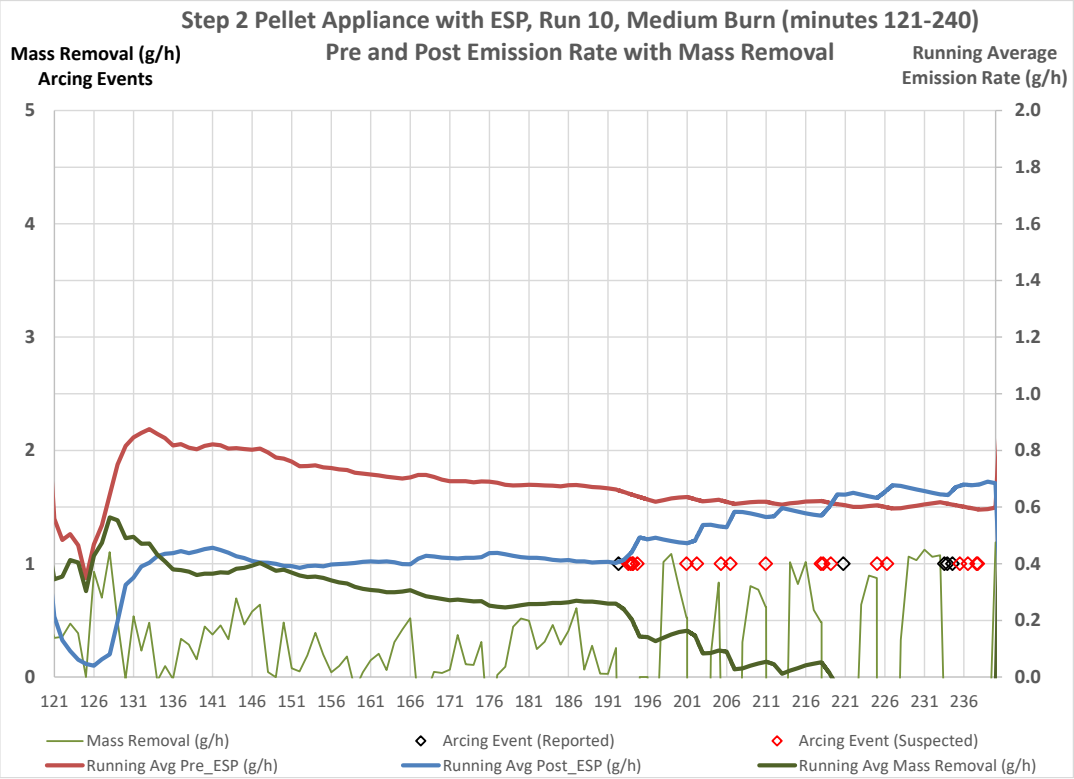

Step 2 Pellet Appliance with ESP, Run 10, High Burn (minutes 61-120)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
61
66
71
76
81
86
91
96
101
106
111
116
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

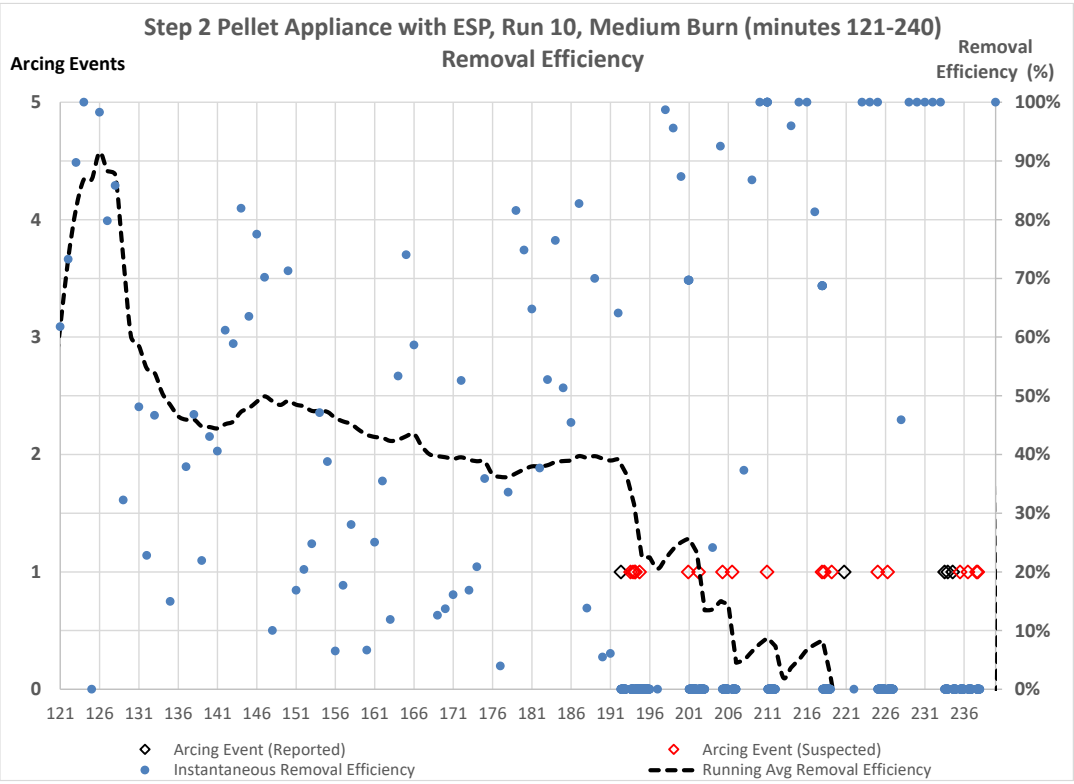

Step 2 Pellet Appliance with ESP, Run 10, High Burn (minutes 61-120)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
61
66
71
76
81
86
91
96
101
106
111
116
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 10, Medium Burn

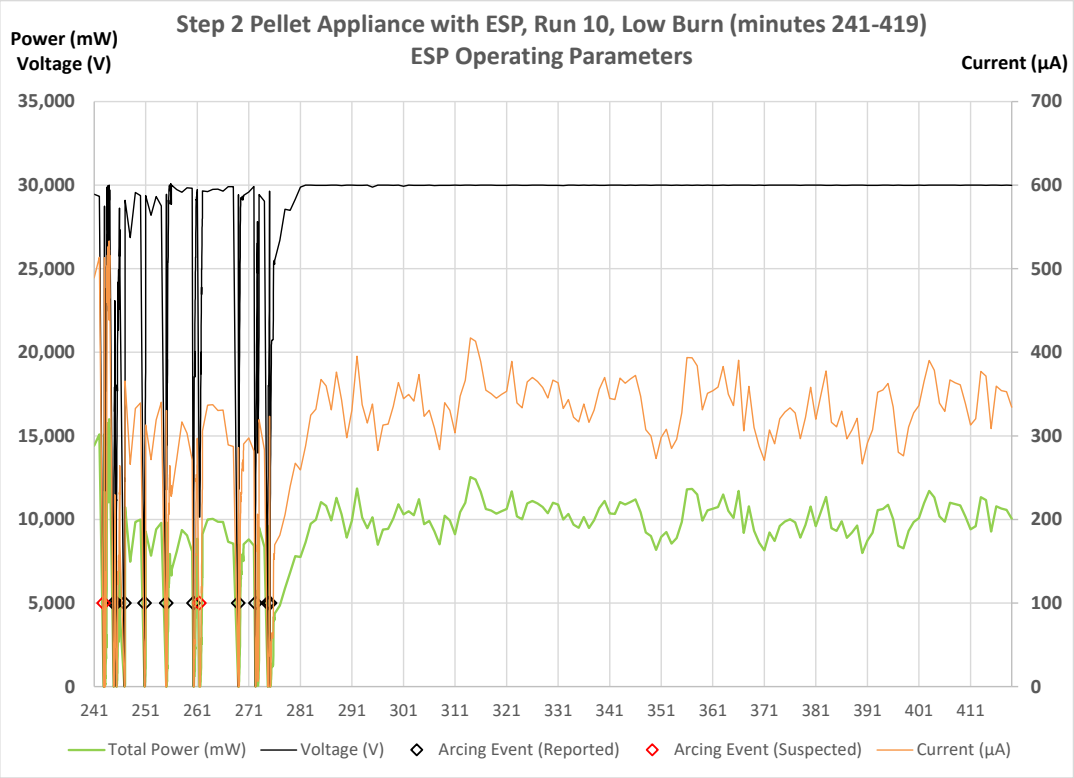


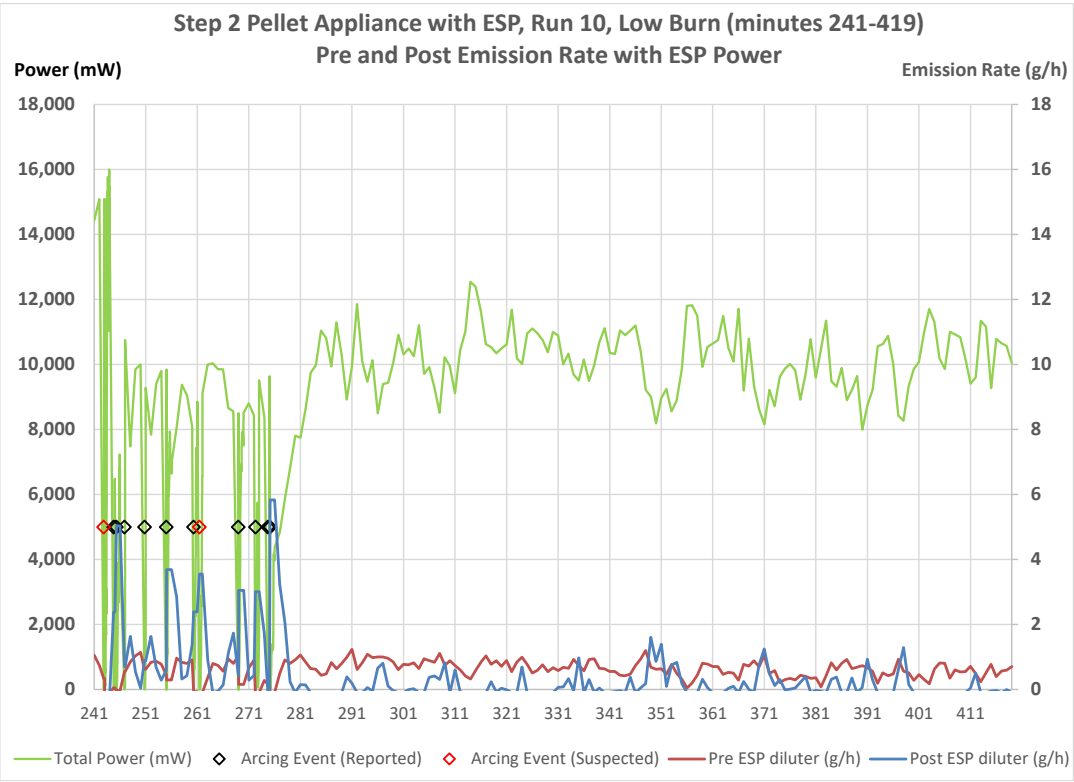


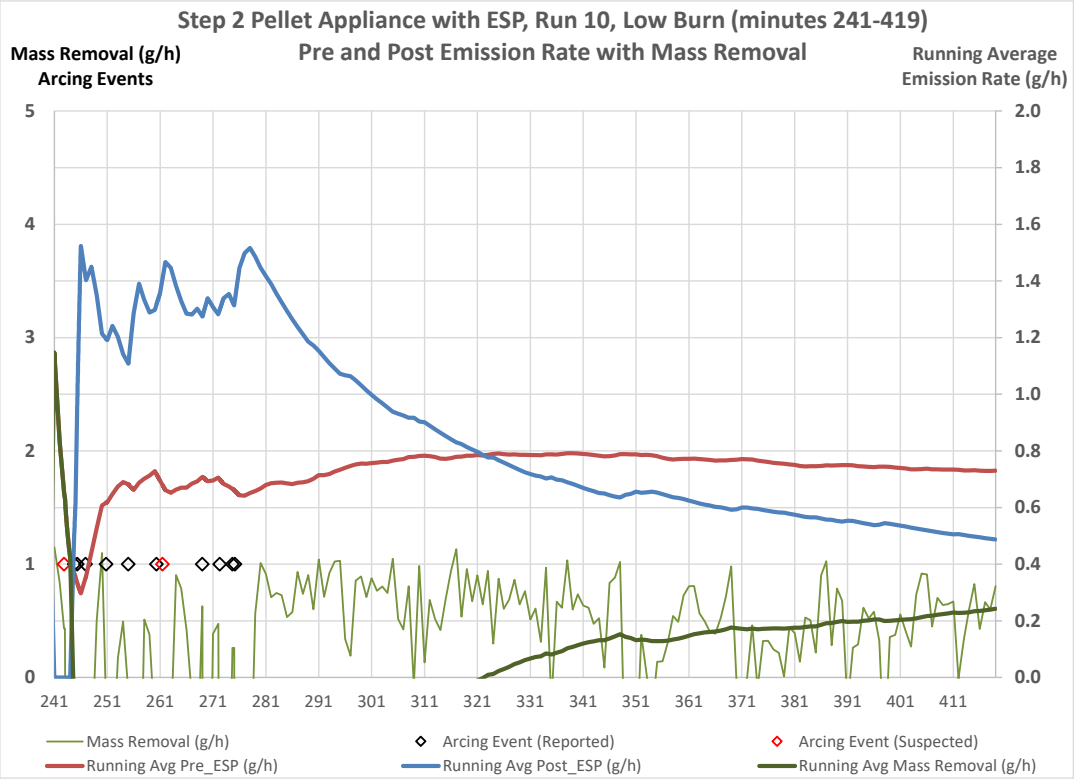

Step 2 Pellet Appliance with ESP, Run 10, Medium Burn (minutes 121-240)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average Emission Rate (g/h)
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)

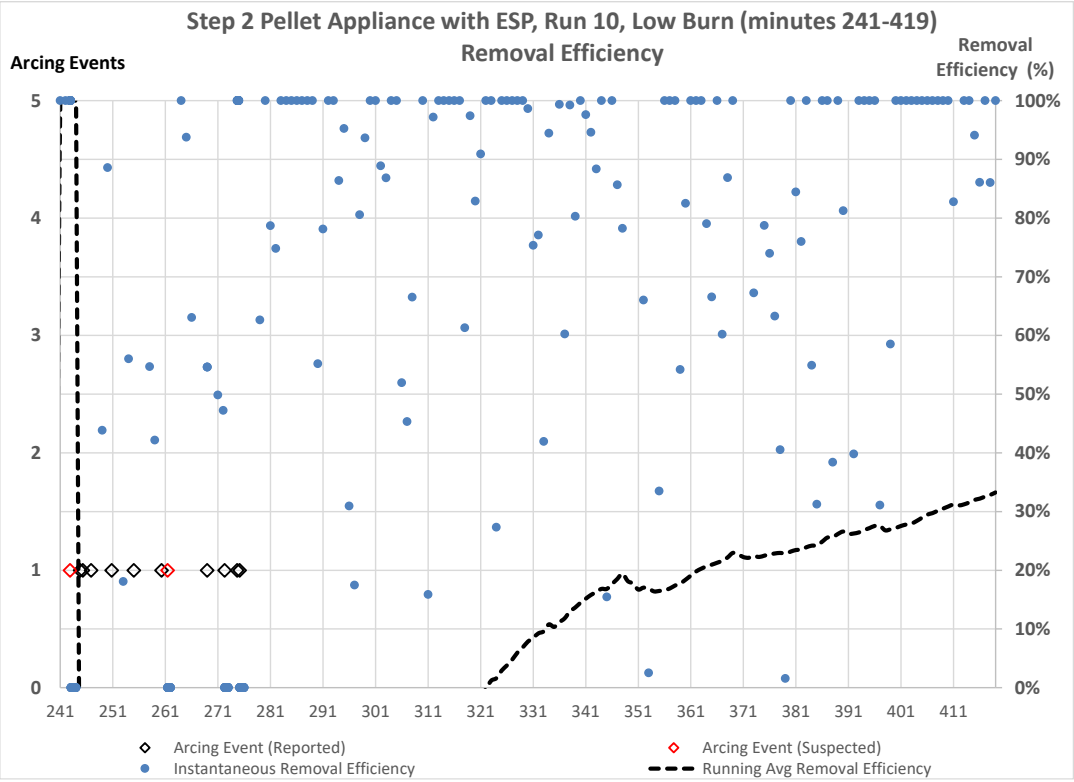

Step 2 Pellet Appliance with ESP, Run 10, Medium Burn (minutes 121-240)
Removal Efficiency
Arcing Events
Removal Efficiency (%)
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

Step 2 Pellet Appliance with ESP, Run 10, Low Burn






Step 2 Pellet Appliance with ESP, Run 10, Low Burn (minutes 241-419)
Pre and Post Emission Rate with Mass Removal
Mass Removal (g/h)
Arcing Events
Running Average
Emission Rate (g/h)
5
4
3
2
1
0
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Mass Removal (g/h)
Arcing Event (Reported)
Arcing Event (Suspected)
Running Avg Pre_ESP (g/h)
Running Avg Post_ESP (g/h)
Running Avg Mass Removal (g/h)


Step 2 Pellet Appliance with ESP, Run 10, Low Burn (minutes 241-419)
Removal Efficiency
Arcing Events
Removal
Efficiency (%)
5
4
3
2
1
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
241 251 261 271 281 291 301 311 321 331 341 351 361 371 381 391 401 411
Arcing Event (Reported)
Arcing Event (Suspected)
Instantaneous Removal Efficiency
Running Avg Removal Efficiency

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