TECHNICAL NOTE

A Primer to Understanding Fuel Cell Power Module Life

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Executive Summary

Information with respect to how we operate the fuel cells in our Energy Servers is generally not publicly available, and given that, we want to provide some insight on the operating life cycle of our fuel cells. To that end, we have prepared this report to describe how we continuously track the performance of our fleet of solid oxide fuel cell ("SOFC") power modules ("PMs")[1], how we define the economic life in the field of our PM's through a median time to replacement ("MTTR") metric and how we apply this framework to publicly available data.

We utilize our fleet-wide monitoring data to clearly demonstrate year-over-year improvements to the MTTR of our PMs, from a median of 1.9 years for the fleet of PMs that reached commencement of operations ("COO")[2] in 2011 (the "2011 Vintage"), to 4.7 years for our 2015 Vintage.

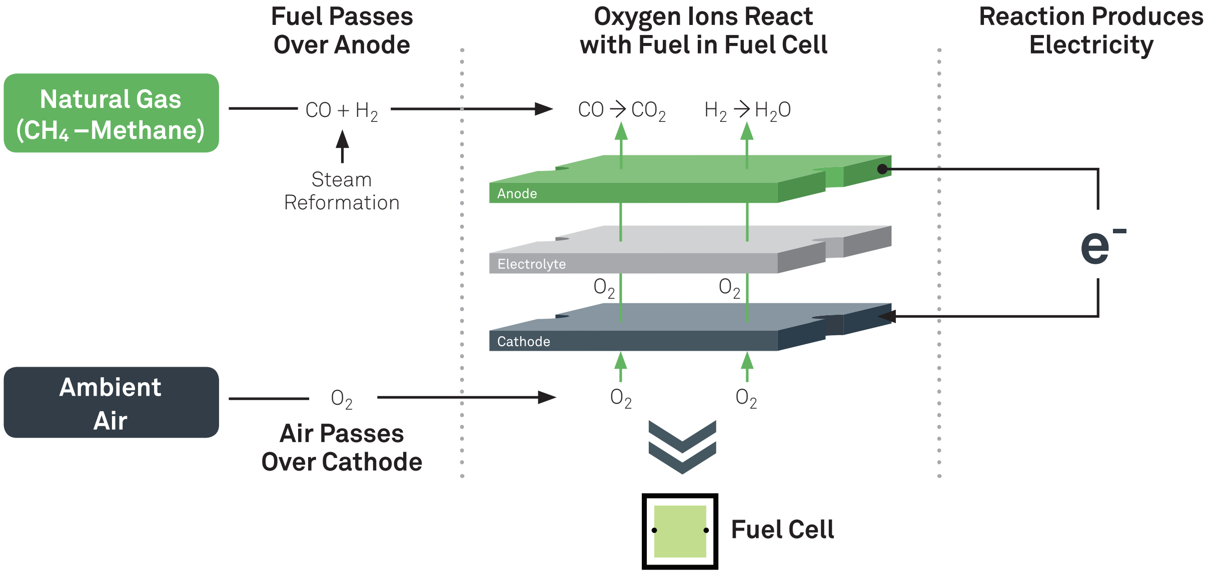
Vintage years beyond 2015 have not yet reached their respective MTTRs, and so estimating this value requires forecasting beyond the lifetime already demonstrated by actual run time in the field. We do so by (i) comparing like time periods between Vintages (i.e., the first year of performance of the 2015 Vintage vs. improved performance observed for the same period of the 2018 Vintage); and (ii) utilizing data from the extensive testing we conduct before releasing improvements to our stack and system design into the field. On the basis of these data, we estimate that the 2018 Vintage and later will have an expected MTTR of at least 5 years.

Finally, we show why certain publically available data — particularly those from the NYSERDA program — have incomplete data related to incorrect COO dates and efficiency calculations. However, these errors are easily corrected and can be bridged to demonstrate how the data provided for those systems lines up with those that have already demonstrated a 4.7 year MTTR for our 2015 Vintage fleet.

Solid Oxide Fuel Cells Overview

SOFCs generate power by electrochemically reacting fuel with oxygen ions harvested from ambient air. As shown in *Figure 1* below, SOFCs are comprised of three layers of solid state materials: an anode, an electrolyte and a cathode (together, a "cell"). In addition, "interconnect" plates are sandwiched between the cells to manage fuel and air flows and to conduct current through repeated cell layers (for simplicity, interconnects are not pictured below).

Figure 1: **Solid Oxide Fuel Cell Technology**



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[1] Our modular Energy Server design enables us to replace one PM, while the entire Energy Server remains in operation. Thus, our unit of replacement is at the PM level, and we therefore analyze the frequency thereof in this report.

[2] This value is generally very close to, or the same as, the "acceptance" date we use to recognize the revenue associated with the sale of an Energy Server.

One cell produces approximately 25W of electricity. Stacked, alternating layers of cells and interconnects constitutes a fuel cell "stack." Fuel cell PMs are comprised of multiple stacks and produce 50 kW at the beginning of life for the current product generation. A group of several PMs form a single Bloom Energy Server.

Bloom's SOFC system architecture is shown below in *Figure 2*.

Figure 2: **Energy Server Architecture**

Cells, interconnects and the interfaces between them all have intrinsic ionic and electrical conductive resistance. The increase in resistance over time is a key variable affecting degradation in efficiency and our MTTR.

Field Life: Calculating, Forecasting and Utilizing MTTR

Our SOFC's have a "life cycle" similar to that of an aircraft engine. They start their lives as newly manufactured stacks in a PM. They are installed at a customer site and achieve COO. They generate power for a certain period of time and at some point, our Remote Monitoring and Control Center ("RMCC") determines that the PMs need to be removed and refurbished. Once removed, the PM's are sent to our Repair and Overhaul Center, where we harvest the majority of the materials to refurbish the unit and return it to the field for continued generation of power.

For a given PM, we define time to replacement (TTR) as the time between the COO date and the replacement for repair date. That calculation is:

$$\text{TTR (years)} = (\text{replacement date} - \text{COO date})/365$$

For a Vintage of PMs that reached COO in a given year, we calculate the median TTR (or MTTR) for that Vintage as the age by which 50% of the PMs in that fleet have been replaced (and, by extension, 50% of the PMs continue to operate in the field).

Our PMs do not generally experience sudden "catastrophic failure" in the field. Instead, we schedule their replacement, well into the future for a variety of reasons. We replace PMs considering not only the performance of the individual PM, but also that of its neighbors at a site and, in many instances, across a number of sites or fleet level ("Portfolio"). Our decision to remove an individual PM is therefore a function of the performance of a large group of PMs and Energy Servers in a Portfolio, as our performance commitments are generally set at the Portfolio level.

We have developed algorithms to optimize our replacement and refurbishment strategy to generate the highest performance at the lowest cost by analyzing a number of variables that include:

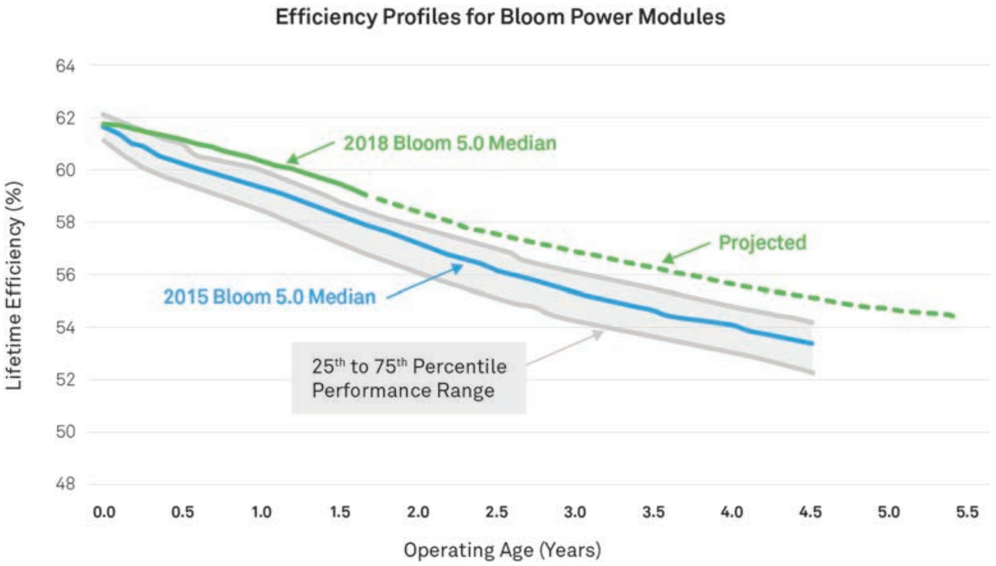
- Individual PM, site-level and Portfolio-level electrical efficiency
- Individual PM, site-level and Portfolio-level electrical output
- Site level resiliency commitments
- Service labor optimization (i.e. minimizing drive times and maximizing service impact on a per-trip basis)
- Preventative maintenance
- Diagnostic benefits (i.e., removing a laggard from service early to begin the work on root cause analysis)
- Estimated costs for a given replacement date (i.e., some failure modes are less expensive when caught early)

PMs that remain in service by definition do not have a replacement date, and so there is no MTTR to be calculated. However, we can estimate the expected MTTR ("MTTRe") by estimating the impact that design improvements will have in increasing the MTTR of a newer vintage compared to the baseline of an older one.

To do so, we utilize field data from our RMCC to verify that design improvements are functioning as expected. As we improve the electrochemistry of our cells and stacks, as well as improve the operating environment and balance of plant that surrounds the cells and stacks, the rate of change in the resistance of the components subsides. This manifests as a reduced rate of performance degradation over time, which can be observed in the data in a number of ways.[3] These improvements are first measured in the lab as we establish design of experiments ("DOEs") to isolate beneficial changes to our cell, stack and PM hardware. We then validate these DOEs with field performance data to ensure that the improvements are operating as anticipated under field conditions. As we see these improvements manifest across many PMs, we update our MTTRe algorithms, as well as run model simulations, and we can conclude that the improvements versus older Vintage baselines will result in longer MTTRs.

For example, *Figure 3* below demonstrates the slower rate of efficiency degradation[4] for our 2018 Vintage as compared to our 2015 Vintage.

Figure 3: **2015 Bloom 2.5 Fleet Cumulative Efficiency Profiles**



One of the advantages of having a large operating fleet is that we can identify both statistical outperformers and laggards. This in turn helps us uncover the root causes of both longer- and shorter-than-median TTRs for any given PM. We utilize this data to create critical improvement programs to increase MTTR and reduce service costs both within current generation technology and our next generation technologies..

We utilize all of these data (historical MTTR values, current MTTRe values, as well as our engineering judgment for improvements currently underway) when pricing our operating and maintenance ("O&M") contracts to ensure that a contract's service revenues are sufficient to cover the required replacement and other necessary service activities.[5]

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[3] The most precise of these is a metric that measures the area-normalized rate of change in resistance (or "area specific resistance degradation" (ASRD)) in the cell. As this resistance degradation slows, the cell's deviation from its initial performance slows and the expected MTTR will increase.

[4] Note that the Y-axis is in cumulative lifetime efficiency, which we show here as (i) this is generally the metric used in our O&M contracts (see below); and (ii) this normalizes for site level changes that include changes in gas composition and the inclusion of ancillary equipment such as gas pressure boosters. Also of note is that the rate of change of efficiency isn't linear but rather "levels out" with longer operation, due to changes in the operating current.

[5] Though PM replacement is the majority of the O&M cost, we also use similar estimating methods to calculate the future anticipated non-replacement costs associated with a given O&M contract.

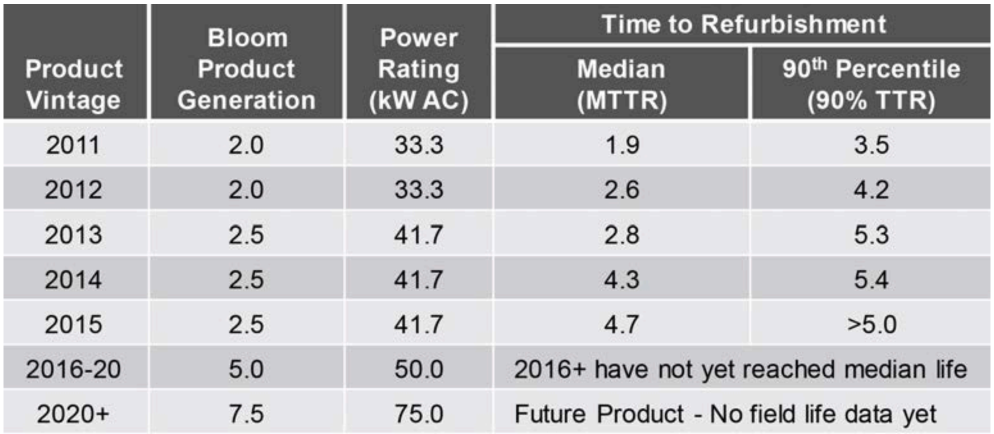
MTTR Field Data

Figure 4 below shows our Remote Monitoring and Control Center (RMCC) in San Jose, CA where we monitor our global installed fleet (the “Global Fleet”) and continuously gather and analyze operating data down to the individual stack level to evaluate health and to optimize performance. For each PM, we monitor over 200 distinct variables or over 1,200 variables for a 300 kW Energy Server. We also have a mirror site in Mumbai, India, that provides both redundancy and resiliency of our RMCC operations as well as 24 x 7 hour coverage of our fleet.

Figure 4: **Bloom’s Remote Monitoring and Control Center in San Jose, CA**

We have aggregated performance data in *Table 1* below, which summarizes MTTR for all of our Vintages since 2011. This shows progressive improvement in MTTR year-after-year from 2011 through 2015 where an MTTR of 4.7 years has been reached. 2015 is the most recent vintage where MTTR can be directly calculated from field experience. Note the 90th percentile TTR is also shown indicating the top 10% of each Vintage from 2013 through 2015 has already exceeded 5 years.

Table 1: **Bloom Power Module Product Advancements**



Product Vintage	Bloom Product Generation	Power Rating (kW AC)	Time to Refurbishment	
			Median (MTTR)	90th Percentile (90% TTR)
2011	2.0	33.3	1.9	3.5
2012	2.0	33.3	2.6	4.2
2013	2.5	41.7	2.8	5.3
2014	2.5	41.7	4.3	5.4
2015	2.5	41.7	4.7	>5.0
2016-20	5.0	50.0	2016+ have not yet reached median life	
2020+	7.5	75.0	Future Product - No field life data yet	

It is also worth noting that 85% of our Global Fleet consists of PMs that reached COO between 2016 and 2019, and the remaining 15% of the Global Fleet is from 2014 and 2015 Vintage PMs. The earlier Vintages that had shorter MTTRs have been refurbished with all of the improvements and upgrades developed through continuous improvement programs to deliver the MTTR of our latest product vintages.

Comparison of Global Fleet Data to Sub-sets of Publically Available Data

A number of public sources of data exist that contain limited amounts of Energy Server performance data. These include 21 sites in the northeast covered by the NY State Energy Research and Development Authority (NYSERDA) program.

With respect to the NYSERDA data, the lifetime efficiency reported through the NYSERDA portal is not complete and incorrectly reports key variables for 75% of the sites due to a delay in the start of NYSERDA metering by 15 to 538 days. This means the NYSERDA cumulative efficiency calculation does not include the highest efficiency performance at the beginning of life resulting in errors ranging from 0.2% to 2.9% for these sites.

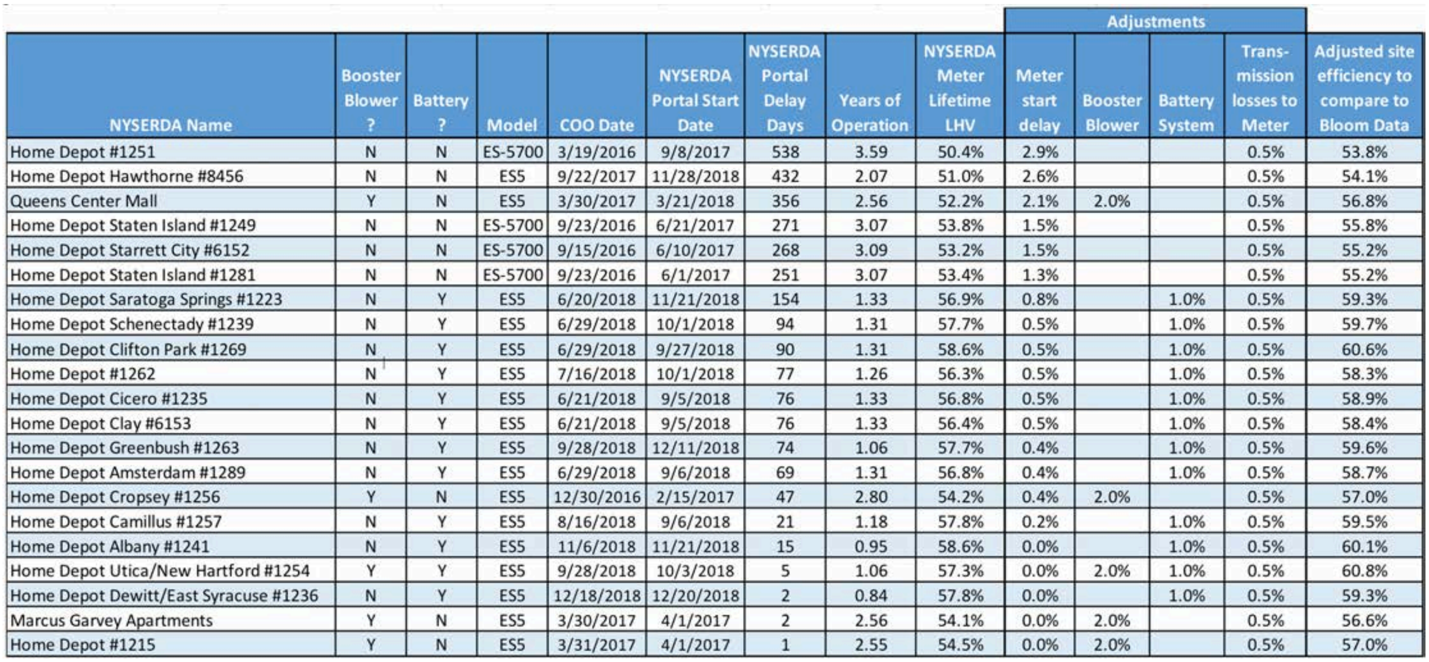
In addition, the reported efficiencies of the Energy Servers are impacted by the existence of certain ancillary equipment such as:

- Gas pressure booster blowers used to increase low gas supply pressures in the region which introduce added electrical loads outside of the Energy Server reducing efficiency by approximately 2%; and
- The use of Batteries for customer required resiliency solutions that reduce efficiency by about 1% due to the round trip efficiency losses for charging and discharging the batteries.

This ancillary equipment (booster blowers and batteries) are currently present in less than 5% of Bloom Energy Servers and thus are unique and not representative of the overall Bloom fleet. In the case of the NYSERDA sites, these ancillary loads have no effect on either the MTTR of the Energy Servers, or the rate of performance degradation described above. As noted above, efficiency alone does not dictate the MTTR. Given all of this, the uncorrected NYSERDA data cannot be used to calculate MTTR.

Table 2 below shows the adjustments necessary to correct for NYSERDA metering delays and the presence of ancillary equipment to compare the NYSERDA data to the 2015 Vintage efficiency data discussed previously. In addition to the adjustments described above, there is also a 0.5% adjustment made to account for transmission losses from the Bloom Energy Server to the NYSERDA meter.

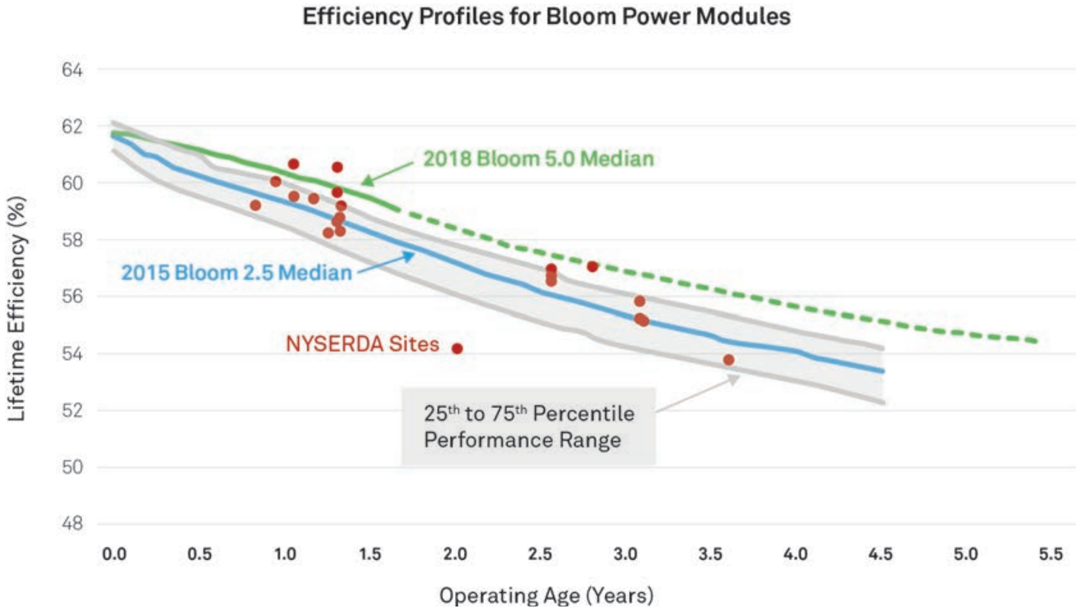
***Table 2:* Corrections of NYSERDA Efficiency Data**



									Adjustments				
NYSERDA Name	Booster Blower ?	Battery ?	Model	COO Date	NYSERDA Portal Start Date	NYSERDA Portal Delay Days	Years of Operation	NYSERDA Meter Lifetime LHV	Meter start delay	Booster Blower	Battery System	Trans-mission losses to Meter	Adjusted site efficiency to compare to Bloom Data
Home Depot #1251	N	N	ES-5700	3/19/2016	9/8/2017	538	3.59	50.4%	2.9%			0.5%	53.8%
Home Depot Hawthorne #8456	N	N	ES5	9/22/2017	11/28/2018	432	2.07	51.0%	2.6%			0.5%	54.1%
Queens Center Mall	Y	N	ES5	3/30/2017	3/21/2018	356	2.56	52.2%	2.1%	2.0%		0.5%	56.8%
Home Depot Staten Island #1249	N	N	ES-5700	9/23/2016	6/21/2017	271	3.07	53.8%	1.5%			0.5%	55.8%
Home Depot Starrett City #6152	N	N	ES-5700	9/15/2016	6/10/2017	268	3.09	53.2%	1.5%			0.5%	55.2%
Home Depot Staten Island #1281	N	N	ES-5700	9/23/2016	6/1/2017	251	3.07	53.4%	1.3%			0.5%	55.2%
Home Depot Saratoga Springs #1223	N	Y	ES5	6/20/2018	11/21/2018	154	1.33	56.9%	0.8%		1.0%	0.5%	59.3%
Home Depot Schenectady #1239	N	Y	ES5	6/29/2018	10/1/2018	94	1.31	57.7%	0.5%		1.0%	0.5%	59.7%
Home Depot Clifton Park #1269	N	Y	ES5	6/29/2018	9/27/2018	90	1.31	58.6%	0.5%		1.0%	0.5%	60.6%
Home Depot #1262	N	Y	ES5	7/16/2018	10/1/2018	77	1.26	56.3%	0.5%		1.0%	0.5%	58.3%
Home Depot Cicero #1235	N	Y	ES5	6/21/2018	9/5/2018	76	1.33	56.8%	0.5%		1.0%	0.5%	58.9%
Home Depot Clay #6153	N	Y	ES5	6/21/2018	9/5/2018	76	1.33	56.4%	0.5%		1.0%	0.5%	58.4%
Home Depot Greenbush #1263	N	Y	ES5	9/28/2018	12/11/2018	74	1.06	57.7%	0.4%		1.0%	0.5%	59.6%
Home Depot Amsterdam #1289	N	Y	ES5	6/29/2018	9/6/2018	69	1.31	56.8%	0.4%		1.0%	0.5%	58.7%
Home Depot Cropsey #1256	Y	N	ES5	12/30/2016	2/15/2017	47	2.80	54.2%	0.4%	2.0%		0.5%	57.0%
Home Depot Camillus #1257	N	Y	ES5	8/16/2018	9/6/2018	21	1.18	57.8%	0.2%		1.0%	0.5%	59.5%
Home Depot Albany #1241	N	Y	ES5	11/6/2018	11/21/2018	15	0.95	58.6%	0.0%		1.0%	0.5%	60.1%
Home Depot Utica/New Hartford #1254	Y	Y	ES5	9/28/2018	10/3/2018	5	1.06	57.3%	0.0%	2.0%	1.0%	0.5%	60.8%
Home Depot Dewitt/East Syracuse #1236	N	Y	ES5	12/18/2018	12/20/2018	2	0.84	57.8%	0.0%		1.0%	0.5%	59.3%
Marcus Garvey Apartments	Y	N	ES5	3/30/2017	4/1/2017	2	2.56	54.1%	0.0%	2.0%		0.5%	56.6%
Home Depot #1215	Y	N	ES5	3/31/2017	4/1/2017	1	2.55	54.5%	0.0%	2.0%		0.5%	57.0%

By plotting the adjusted NYSERDA cumulative efficiency, and comparing those data points for 2016 through 2018 sites to Bloom fleet data for the 2015 and 2018 Vintages, we show that the efficiency data generally show improvements over the 2015 vintage Bloom fleet that has *already demonstrated a MTTR of 4.7 years.*[6]

Figure 5: **NYSERDA Efficiency Data**



Summary and Conclusions

Bloom has been installing and operating our Energy Servers for close to a decade. In addition to the advances in our SOFC technology through our research and development efforts, we have collected significant amounts of operating data through our RMCC, which we use herein to demonstrate the actual MTTRs of our Global Fleet. This has also allowed us to continually improve the operating performance of our PMs. We have observed the operating performance for our 2015 Vintage to achieve an MTTR of 4.7 years before being returned to our Repair and Overhaul Center for refurbishment.

Today, our ability to predict the performance of our PMs and Energy Servers is based not only on our technology leadership and research and development capability, but is also based on models built with extensive field data we have collected over the past decade. This unique capability is at the core of our ability to project our MTTR today, as well as the MTTRe tomorrow. These models show that our MTTRe on our recent vintages is more than 5 years.

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[6] Note the NYSERDA data point at approximately 2.0 years age and 54% cumulative efficiency appears to be a low outlier. The Bloom system meter at this site shows a cumulative efficiency 1.8% higher than the NYSERDA meter indicating a potential calibration issue here.