Bloomenergy

TECHNICAL NOTE

How Bloom Reduces Emissions

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Executive Summary

Bloom Energy's mission is to make clean, reliable, and affordable energy for everyone in the world. Our solid oxide fuel cell product, the Bloom Energy Server, delivers highly reliable and resilient, 'Always On' clean electric power. Our Energy Servers generate electricity without combustion, utilizing natural gas, biogas, or hydrogen as fuel. At Bloom Energy, we work to contribute to the creation of sustainable communities by reducing carbon emissions and criteria air pollutants.

Our Energy Servers that run on hydrogen or biogas can produce carbon neutral power, and those fueled by natural gas produce carbon emissions. Our Energy Servers are however, among the most effective ways to displace less efficient centralized power plants with more efficient distributed generation, thereby achieving the combination of near-term emission reductions and increased resiliency. Power generation from our Energy Servers reduce carbon emissions and other air pollutants in the same manner as wind and solar generation — by displacing dirtier power plants. However, unlike wind and solar, our Energy Servers can do so around the clock.

To validate the net emissions reduction impact of our Energy Servers, Bloom commissioned a leading independent engineering firm, DNV-GL, to review the methodology used to determine our Energy Server's emissions performance. DNV-GL found that our analysis relies upon valid reference data and computational approaches aligned with industry practice.

The results show that since Bloom began commercial deployments in 2011 our systems have achieved:

- Approximately **2.33 million metric tonnes of CO_2 reduction globally through 2019**, equivalent to 18,900 acres of forest preservation or taking nearly one half of one million cars off the road for a year[1]
- Associated criteria pollutant reductions, including **5.05 million pounds of sulfur oxides (SOx), and 8.9 million lbs. of nitrogen oxides (NOx), equivalent to** preventing approximately 5,200 lost work days and more than 30,000 days of restricted activity due to illness.[2]

In this paper, we review Bloom's emissions profile to illustrate how our technology reduces emissions and delivers local air quality benefits. We'll review our historical performance and how Bloom is positioned to continue leading the way toward a low carbon future.

Marginal Emissions: Comparing Absolute Emissions with Emissions from Displaced Alternatives

Establishing Bloom's climate impact requires a comparison between its absolute emissions and the emissions from displaced alternatives. When a new, efficient distributed energy resource, such as a solar project or Bloom Energy Server, is brought online, it reduces the amount of power required from energy sources that generate "on the margin" – meaning those units that are operating to meet the last unit of energy demand.

The PJM regional transmission organization[3] explains how this works, describing wholesale energy markets that function to dispatch generators as follows:[4]

> The price for wholesale electricity [is]...... set by organized wholesale markets. The clearing price for electricity in these wholesale markets is determined by an auction in which generation resources offer in a price at which they can supply a specific number of megawatt-hours of power.
>
> If a resource submits a successful bid and will therefore be contributing its generation to meet demand, it is said to "clear" the market. The cheapest resource will "clear" the market first, followed by the next cheapest option and so forth until demand is met. When supply matches demand, the market is "cleared," and the price of the last resource to offer in (plus other market operation charges) becomes the wholesale price of power.

1 https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

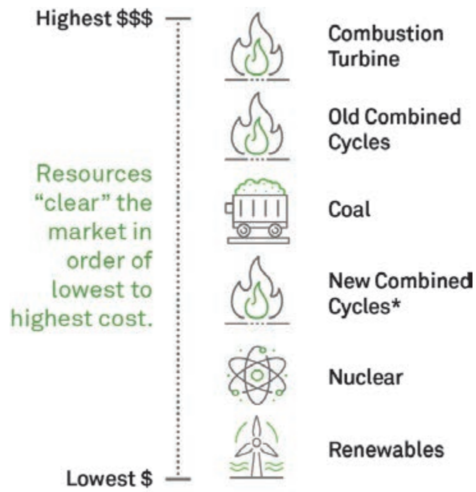
2 Based on California default values from the Clean Power Plan https://www3.epa.gov/ttnecas1/docs/ria/utilities_ria_final-clean-power-plan-existing-units_2015-08.pdf

3 PJM coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia

4 https://learn.pjm.com/electricity-basics/market-for-electricity.aspx

As a result of the wholesale energy market structure and the operating costs of power plants (see *Figure 1* below), the "marginal generator" that is displaced from the power market when its power is no longer needed is typically a CO_2 emitter and is generally the highest CO_2 emitter operating at any given time.

Figure 1: **Prioritization of Dispatch**[5]



* New combined cycles are more fuel efficient.

Energy providers on the margin are typically the most flexible but least efficient energy generation sources, which operate at the lowest electrical efficiency. This necessarily brings the highest levels of associated emissions, as more fuel is required to generate power per unit of electricity delivered. When more efficient or cost effective solutions displace marginal power sources, the highest cost resources are the first resources requested to be shut off.

Based on these current market dynamics, oil is the highest cost of these options, then coal where applicable, then natural gas. The average coal power plant has an emission rate of 2,065 lbs. of CO_2/MWh while natural gas plants emit at 895 - 1,307 lbs.[6] In comparison, Bloom Energy fuel cells have an emission rate of 679 - 833 lbs. CO_2/MWh.[7]

Every unit of electricity that Bloom Energy Servers produce offsets a unit of electricity from a marginal source with corresponding benefits for emissions. Since Bloom's carbon intensity is lower than the displaced alternatives, the net impact is measurable emissions reductions. Carbon impact measurement based on the displacement of marginal emissions is the standard for emissions accounting for distributed energy generation assets such as Bloom's Energy Servers.

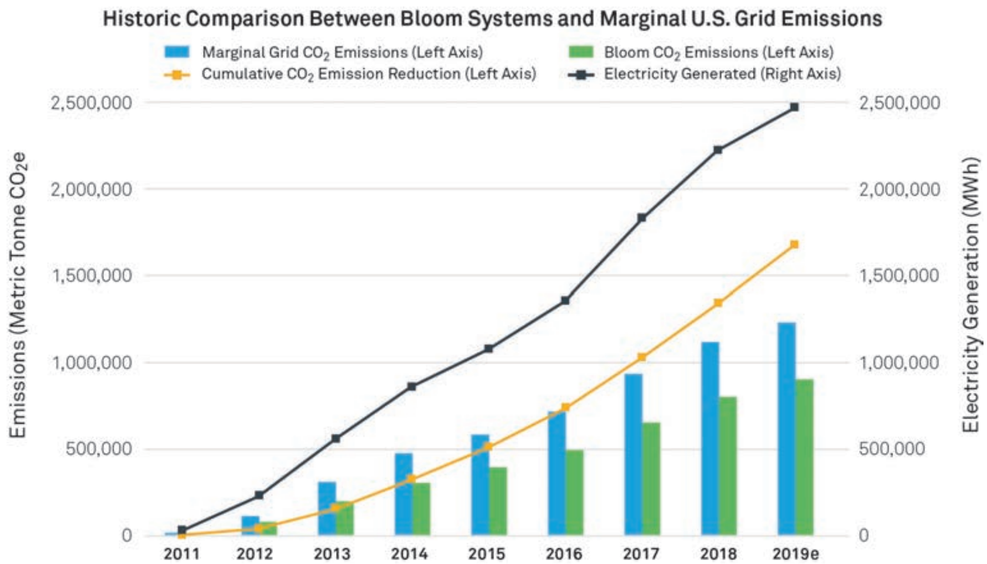
Bloom Energy Servers Compared to US Marginal Emissions – Carbon Impact & Air Quality

Figure 2 shows Bloom's historical domestic absolute carbon emissions modelled against those that would have been produced by the generation of an equivalent amount of electricity from the marginal generators in the regions in which the units operate[8]. The analysis represents Bloom's combined historical average fleet emissions performance of both its first generation ES5700/10 systems and current ES-5 systems.

Bloom's CO_2 emissions reductions — the yellow line in *Figure 2* — are based on comparison to historical EPA eGRID non-baseload data, which is issued every two years (not yet released for 2018). It serves as a transparent proxy for marginal emissions values across the relevant time period and regional footprint. Regional performance comparisons (see Figure 9: Regional Breakout below) illustrate that Bloom has reduced emissions compared to the power plants we have displaced (the marginal emitter) in every region in all years.

5 PJM Learning Center Website https://learn.pjm.com/electricity-basics/market-for-electricity.aspx
6 2017 EIA data from 'Electric Power Annual' Dataset
7 Bloom E5 Datasheet
8 https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

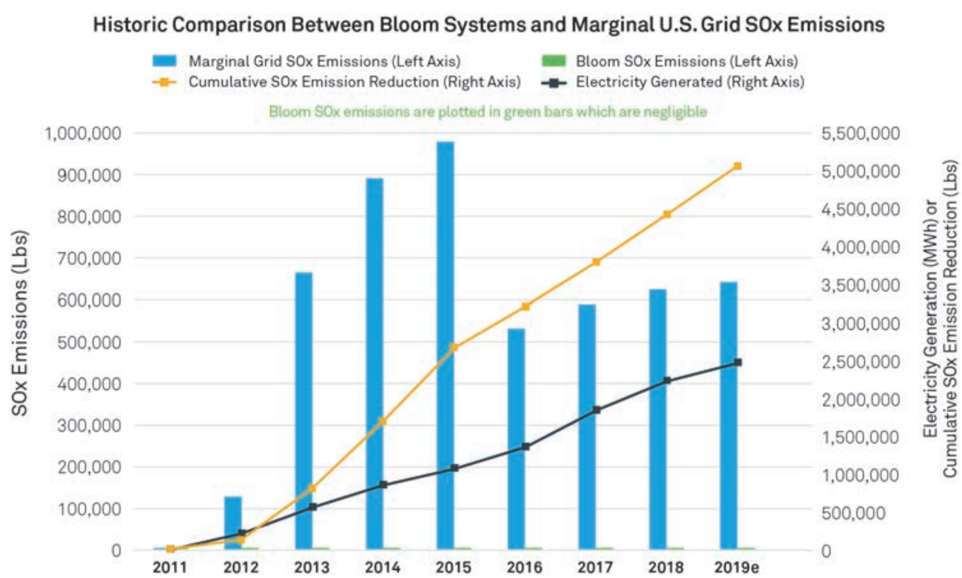
Figure 2: **Carbon Impact**

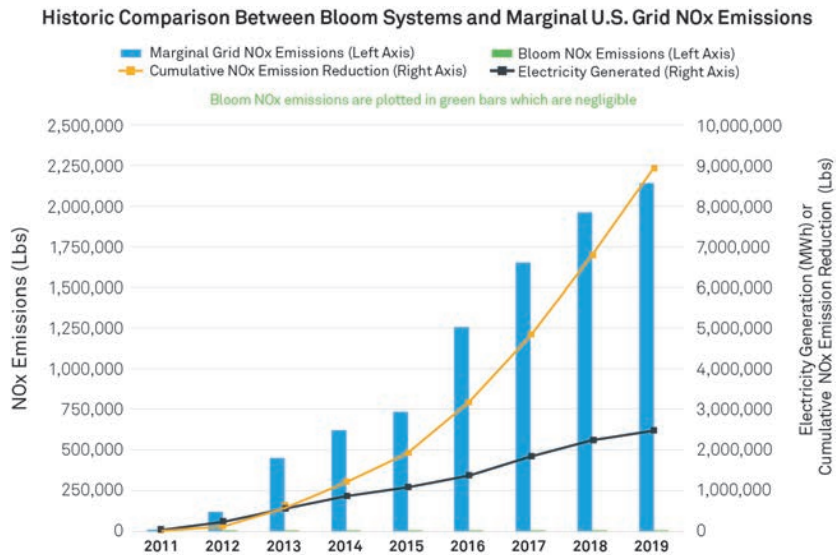


**2019e is pro-rated for the entire year based on Jan-Sep rate.*

We've taken the same approach for evaluating air quality impact for SOx and NOx, two primary criteria pollutants also benchmarked in EPA's eGRID non-baseload data. As demonstrated in *Figure 3* below, Bloom's output does not even register in the chart in relation to displaced marginal emissions.

Figure 3: **Air Quality Impact**





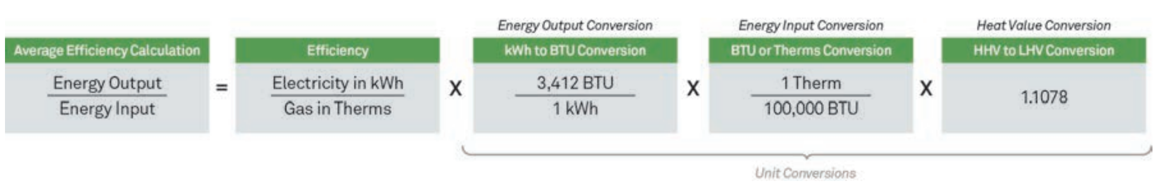
Carbon Impact Methodology

To begin determining our carbon emissions, we use the standard chemical conversions in the equation below to derive pounds of CO_2 emitted per kWh from our natural gas-fueled Energy Servers, the volumes of which can be directly calculated based on an Energy Server's net electrical efficiency (the fraction of the input chemical energy in the fuel converted into electrical energy).

$$\frac{\text{lbs } CO_2}{\text{kWh}} = \frac{\text{1 mmBtu}}{\text{1,000,000 Btu}} \times \frac{\text{116.89 lbs } CO_2}{\text{mmBtu}} \times \frac{\text{3,412 Btu}}{\text{kWh}} \times \frac{1}{\text{Eff (\%)}} \times 1.1078$$

Note: lower heating value (LHV) is converted to higher heating value (HHV) by a factor of 1.1078. It is also worth noting is that this analysis captures the overall MWh produced by Bloom's fleet outlined in Figure 2 to ensure any variations in system output are accurately and fully reflected in the calculations.

Bloom monitors and aggregates daily system efficiency levels down to the level of each Energy Server through use of the conversion below.



Using these conversions, Bloom can calculate the carbon emissions profile from its equipment, but that isn't the same thing as Bloom's climate impact. To measure emissions reductions, Bloom's absolute emissions are then compared to the emissions from the generators we displace — the marginal emission.

Methodology Validated by Expert Organizations and Academia

Researchers at the Rochester Institute of Technology, Carnegie Mellon[9,10], UCSD, Yale, Dartmouth, the National Bureau of Economic Research[11], UC Berkeley[12], and UC Davis[13] have published on the appropriateness of the marginal

9 *Environ. Sci. Technol.* 2017512112988-12997

10 *Environ. Sci. Technol.* 2012, 46, 4742–4748

11 Graff Zivin, J.S.,et al. Spatial and temporal heterogeneity of marginal emissions: Implications for electric cars and other electricity-shifting policies. J. Econ. Behav. Organ. (2014),

12 JAERE, volume 5, number 1. © 2018 by The Association of Environmental and Resource Economists

13 American Economic Journal: Economic Policy 2015, 7(3): 291–326

emissions based impact calculation methodology. Additionally, the following sample of organizations use this approach in program administration:

- World Resources Institute
  - o In guidance for voluntary carbon reporting under its GHG Protocol[14]
- California Public Utilities Commission
  - o In measuring performance under the Self Generation Incentive Program (SGIP)[15]
- The UNFCC's Clean Development Mechanism
  - o In generating Certified Emissions Reductions from grid connected distributed energy projects under the Kyoto Protocol[16]
- Business Renewables Center (BRC)
  - o In guiding its 200 member brands to account for the impacts of power purchase agreements. NGO partners in the BRC include the Rocky Mountain Institute, World Wildlife Fund, World Resources Institute, Business for Social Responsibility, and CDP's RE 100 Program and We Mean Business Coalition[17]

Marginal emissions proxies are tracked by the US Environmental Protection Agency (EPA), in its eGRID non-baseload reference data. The EPA suggests that this data is "recommended to estimate emission reductions from… projects that reduce consumption of grid supplied electricity[18]."

Bloom follows this recommendation and utilizes this data to calculate our historical domestic emissions reductions by comparing our systems' localized annual emissions to the marginal emissions displaced (see *Figure 4* below for the geographical regions reported). For clarity, we also incorporate the EPA's default values for line losses from transmission avoided by our distributed deployments.

Other sources of marginal emissions data and methodology exist, but eGRID data provides a consistent, transparent methodology covering all US regions over all of the years needed to produce an historical analysis for Bloom's entire fleet. To confirm results of our analysis using hourly marginal emissions data, Bloom commissioned the non-profit organization WattTime to reconstruct the analysis using its 2018 proprietary model for California and found comparable results.

Figure 4: Grid Subregions[19]

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14 http://pdf.wri.org/GHGProtocol-Electricity.pdf

15 https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Demand_Side_Management/Customer_Gen_and_Storage/2017_SGIP_AES_Impact_Evaluation.pdf

16 https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v4.0.pdf]

17 https://businessrenewables.org/what-we-do/

18 https://www.epa.gov/sites/production/files/2018-02/documents/egrid2016_technicalsupportdocument_0.pdf

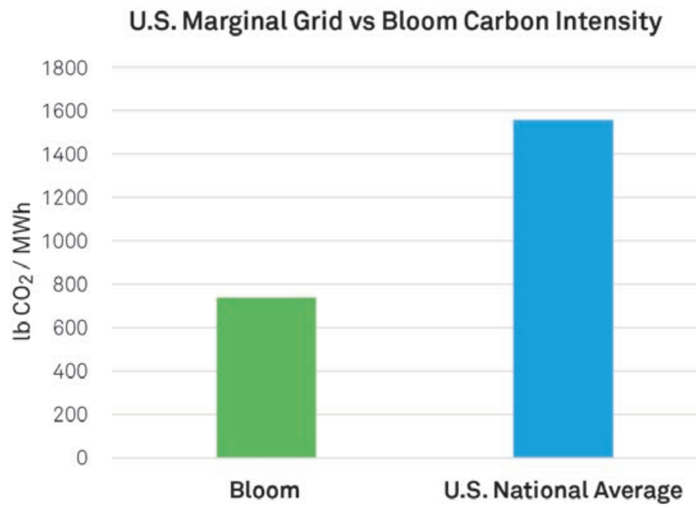
19 https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

Carbon Impact Breakdown

Utilizing the methodology described above, our analysis below shows that Bloom's fleet has generated emissions reductions in every year and every region we operate since beginning scalable commercial deployments in 2011.

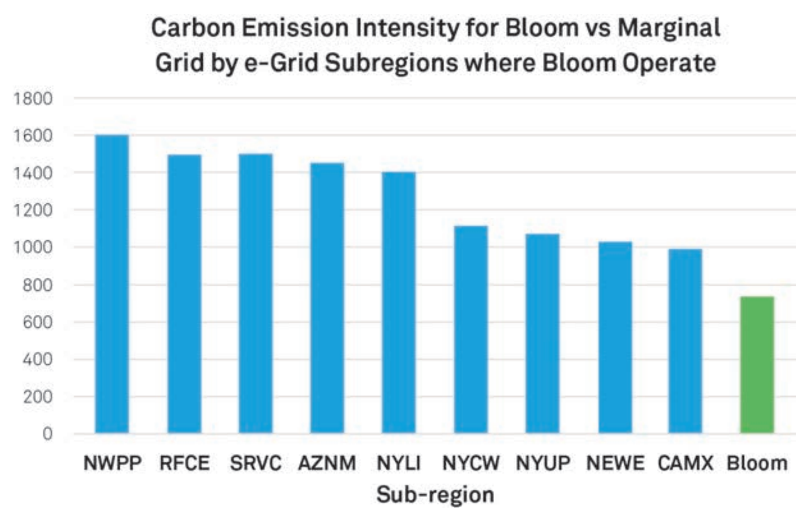
Figure 5 below demonstrates how power produced by a Bloom ES-5 system is more than 50% less carbon intensive than the national average of displaced alternatives based on 2016 eGRID data.

Figure 5



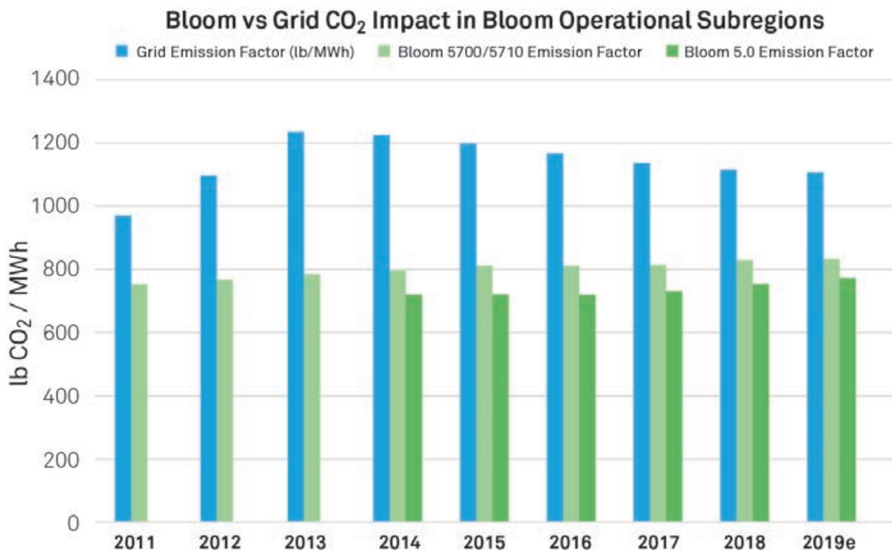
Moving beyond a national average, in *Figure 6* below, we also see that Bloom's ES-5 systems are more carbon efficient than marginal emitters in every region we operate based on 2016 eGRID data.

Figure 6



For transparency, it is also important to understand how Bloom's less efficient first generation ES5700/10 systems perform. The graphic below demonstrates how each fleet has performed year-over-year versus the marginal emissions average of the regions in which they operate. Although it is a characteristic of solid oxide fuel cells that the absolute emissions from the fleet increase each year as efficiency degrades over time, *Figure 7* shows that such efficiency degradation does not materially affect the emissions reductions.

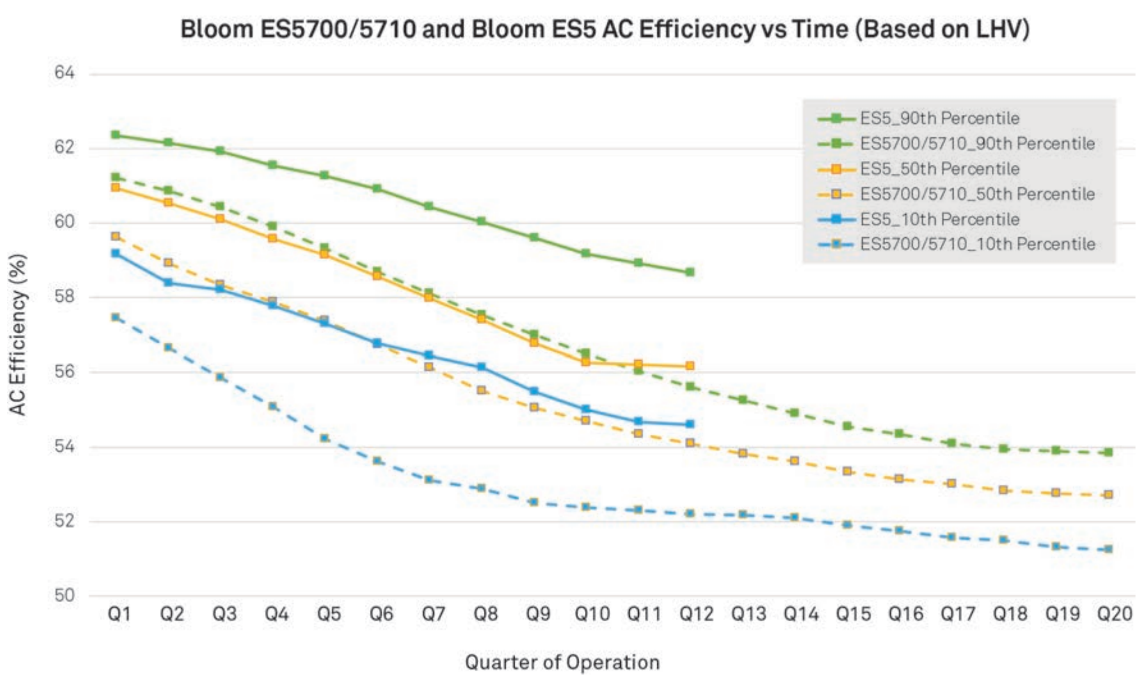
Figure 7



As with any thermal power plant, Bloom's efficiency performance is the primary driver of absolute emissions in deployments where natural gas is used as fuel. Bloom provides our customers with warranties and guaranties regarding our Energy Servers' efficiency, and we repair any Energy Server that fails to perform in accordance with these commitments.

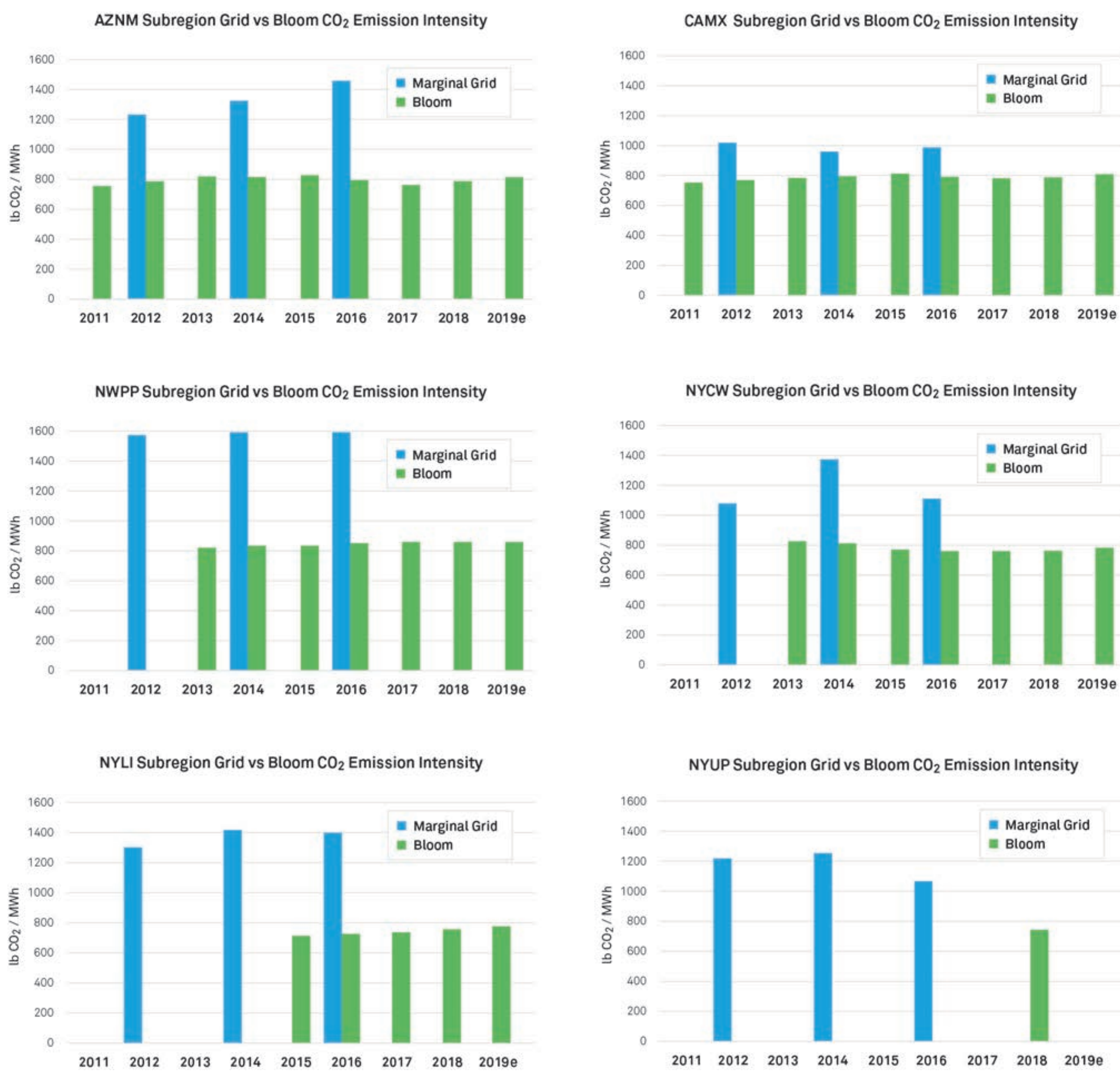
Figure 8 below shows another view of Bloom's efficiency performance, with the plot showing five-year average fleet efficiencies for both ES 5700/10 and ES5 equipment generations. As fleets age, we see average efficiency declines, but the degradation stabilizes, which ensures continued emissions reductions over the system's life.

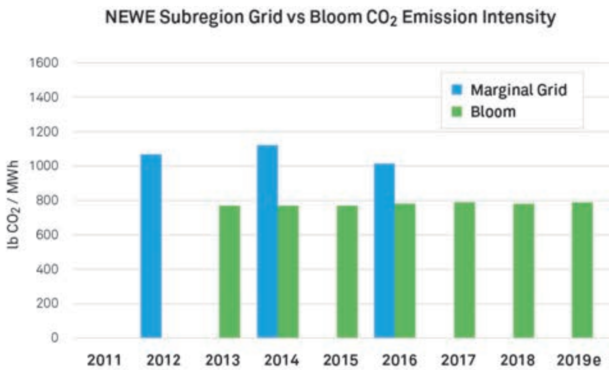
Figure 8

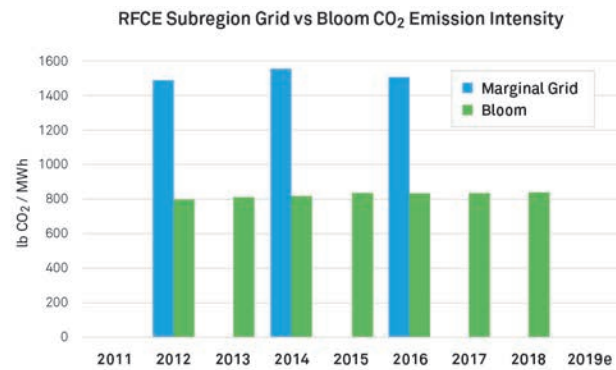


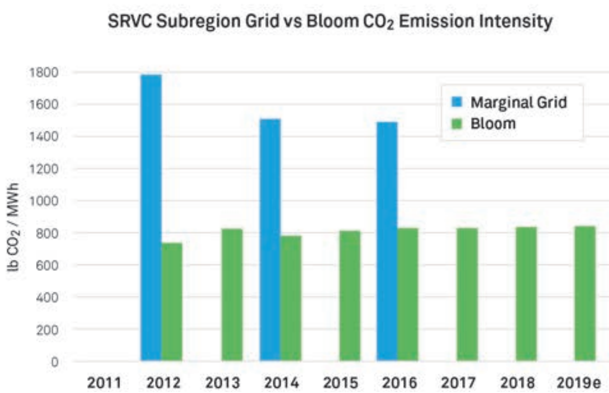
Finally, *Figure 9* below shows emissions reductions quantification from the fleet across all the EPA subregions in which Bloom operates. Our fleet's carbon efficiency ranges from 20-60% depending on the mix of marginal emitters active in a particular region.

***Figure 9*: Regional Breakout**









Additional Emissions Reductions

Importantly, this data reflects the emissions results of Bloom's entire deployed fleet: including systems Bloom owns, customers own, and third-party financiers own. We purposely do not distinguish between those ownership dynamics because we want to transparently demonstrate the nature of Bloom's total equipment performance outside of transactional dynamics that might shift emissions accounting responsibility to one party or another.

The overall reported impact of Bloom's Energy Servers includes additional emissions reductions beyond what is captured by the marginal emissions comparisons depicted in the graphs above, including:

- 18.78 MW of directed biogas transactions, neutralizing the carbon emissions from Bloom units equivalent to 552,250 MtCo2e[20]
- 14.35 MW of international deployments in India, Korea and Japan whose marginal grid emissions are generally higher, resulting in even greater emissions reductions than those cited in domestic comparisons and yield approximately 109,960 MtCo2e[21]
- Displacement of emissions from the use of diesel generators at customer facilities totaling approximately 2 million pounds of known emissions savings to date

Air Quality Breakdown

Criteria pollutants are a class of smog forming air pollutants regulated by the EPA[22], including NOx and SOx. They are the primary source of pollution and are produced during fossil fuel combustion power generation and when backup power generators are in use. Bloom's non-combustion based fuel cells emit virtually no air pollutants.

20 Assumes system owners continued biogas sourcing at initial rates beyond initial contract term

21 Assumes Japanese marginal emissions values recommended by Ministry of Environment, Indian values from the Central Electricity Authority, and Korea based on US marginal emissions average as proxy

22 https://www.epa.gov/criteria-air-pollutants

The health and environmental impacts of combustion related pollutants are both very significant and readily quantifiable. In fact, calculations of the economic and health benefits associated with reducing NOx and particulate matter emissions have been found to exceed the economic and health benefits of reducing carbon emissions on a per ton basis.[23] In light of the overwhelming challenge presented by global climate change, the desire to reduce carbon emissions is appropriately the first and most important emissions reduction objective.

However, there is a steadily growing body of evidence indicating that local combustion related air pollution has far more serious and harmful consequences to human health and the environment than previously understood, including recent findings that:

- Combustion related air pollution may be as harmful to your lungs as smoking cigarettes;[24]
- Combustion related air pollution increases preterm birth risk;[25]
- Combustion related air pollution causes dementia;[26] and
- Particulate matter is the largest environmental health risk factor in the nation, and the resulting health impacts are borne disproportionately by disadvantaged communities;[27]

Technology Performance Validation

The California Air Resources Board has certified Bloom Energy Servers as a Distributed Generation[28] technology due to its air quality emissions profile. This distinction is given to only the cleanest electricity generation technologies in California. As a part of Bloom's certification process with the California Air Resources Board to become a Distributed Generation technology, Bloom went through third party validated testing of its ES5 Systems by the Avagadro Group (now Montrose Environmental) to determine that its emissions of nitrogen oxides, carbon monoxide and VOCs were below the certified limits.

Preventing Pollution and Reducing Emissions During Grid Outages with Microgrids

Bloom's Energy Servers can form the basis of resilient microgrids, which have the capability to separate themselves from the grid and carrying critical load during an outage, the frequency, duration and severity of which are increasing every year. We have deployed more than 85 microgrids to date globally and our systems rode through 550 power outages in 2018 alone.

When Bloom microgrids are in place, they can prevent the need for both marginal generation and backup diesel generators, which emit both carbon and criteria pollutants into the communities surrounding displaced marginal generators as well as any community facing a prolonged power outage. Diesel generators also need testing, regularly emitting criteria pollutants even when there is no grid outage.

Impact Moving Forward

While we cannot fully predict the forward evolution of marginal emissions profiles, we anticipate that more baseload renewable power will continue to be brought online. With proper integration of renewables into the grid baseload, the marginal emissions rates are likely to stay constant and continue to be driven by inefficient carbon generators in the near to medium term.

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23 Institute for Policy Integrity, New York University School of Law, "How States Can Value Pollution Reductions from Distributed Energy Resources" July 2018, available at: https://policyintegrity.org/files/publications/E_Value_Brief_-_v2.pdf

24 Wang M, Aaron CP, Madrigano J, et al. Association Between Long-term Exposure to Ambient Air Pollution and Change in Quantitatively Assessed Emphysema and Lung Function. JAMA. 2019;322(6):546–556. doi:10.1001/jama.2019.10255 Aubrey, Allison. Air Pollution May Be As Harmful To Your Lungs As Smoking Cigarettes, Study Finds. NPR. 13 August 2019. https://www.npr.org/sections/health-shots/2019/08/13/750581235/air-pollution-may-be-as-harmful-to-your-lungs-as-smoking-cigarettes-study-finds

25 Mendola, P. et al. Air pollution and preterm birth: Do air pollution changes over time influence risk in consecutive pregnancies among low-risk women? International Journal of Environmental Research and Public Health, 2019. https://www.nih.gov/news-events/news-releases/nih-study-suggests-higher-air-pollution-exposure-during-second-pregnancy-may-increase-preterm-birth-risk

26 Jung CR, et. al. Ozone, particulate matter, and newly diagnosed Alzheimer's disease: a population-based cohort study in Taiwan 2015. https://www.ncbi.nlm.nih.gov/pubmed/25310992 https://www.wired.com/story/air-pollution-dementia/

27 Tessum et al. Inequity in consumption of goods and services adds to racial–ethnic disparities in air pollution exposure. PNAS March 26, 2019 116 (13) 6001-6006; first published March 11, 2019 https://doi.org/10.1073/pnas.1818859116

28 https://ww2.arb.ca.gov/node/1605/about

The marginal emissions in a given region are often the last indicator to change when a grid is transitioning to renewable energy. For example, according to the California Independent System Operator ("CAISO"), the average marginal emissions rate for Northern California is listed as 984 lbs. of CO_2/MWh — which is higher than Bloom's Energy Server emission rate of 679 — 833 lbs. CO_2/Mwh discussed above. The Northern California average marginal emissions rate is consistent with that of natural gas fired marginal generation, despite the fact that the CAISO grid mix has 31% renewables[29].

In new markets Bloom is actively exploring, including New Jersey, Maryland and Washington D.C., Bloom's ES5 systems are more carbon efficient than the marginal generator in the eGRID subregion covering the states by more than 50%.

Still, Bloom's commitment to climate action and a clean energy future is moving the company further into new fuels, industries, and technologies that hold the potential for even lower carbon intensity energy production. The journey has already begun, with our current Energy Servers providing carbon reductions in every region in which we operate, as articulated in this paper. But, where do we go from here?

Our Low Carbon Pathway

First, Bloom is actively developing international market opportunities in regions with dirtier grids and higher marginal emissions rates. Additionally, we are working to support new industries like shipping, which is currently powered largely by heavily polluting bunker fuel.

We are also focused on using renewable biogas as the fuel for our Energy Servers. The renewable natural gas market is maturing rapidly, as fuel sources are identified, pipeline capacity is constructed and project development, transactional and policy dynamics mature. Bloom is supporting the growth of this sector in order to help supply customers with the lowest carbon intensive fuel sources possible, but also to support rural communities and municipalities who would benefit from Bloom's flexible, decentralized and resilient energy solution.

For scenarios in which renewable fuels are not available, Bloom is pushing technology and business model boundaries to pioneer carbon capture, utilization & storage (CCUS) potential from its Energy Servers. Because carbon and nitrogen never mix in Bloom's fuel cells, it is both feasible and cost effective to capture CO_2, which can be stored in underground geologic formations or utilized in new products or processes like cement manufacturing and alternative fuel development.

Finally, Bloom sees the widespread deployment of renewable hydrogen fuel emerging as a goal on its low carbon pathway, given that no net greenhouse gases are produced in the process.

Conclusion

Carbon mitigation is hugely important in the long term fight against global climate change. Reducing criteria pollutants has immediate, local and demonstrable impact on human health and wellness. Thanks to its distributed, Always On, non-combustion process of generating clean electricity, Bloom is engaged in both battles, working every day to reduce emissions, build resilience, and promote sustainable communities.

29 http://www.caiso.com/Documents/GreenhouseGasEmissions-TrackingReport-Aug2019.pdf

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