Technical Notes

How Bloom Reduces Emissions

Executive Summary

Bloom Energy's mission is to make clean, reliable energy affordable for everyone in the world. The company's Energy Server is an advanced distributed energy generation platform that provides cost effective, clean, reliable power. Using solid oxide fuel cell technology, our Energy Servers convert natural gas, biogas, hydrogen or blends thereof into electricity at high efficiency and without combustion, significantly reducing environmental impacts in both terrestrial and marine environments. The company also manufactures solid oxide electrolyzers that can generate carbon-free hydrogen from renewable or nuclear electricity. At Bloom, we work to contribute to the creation of sustainable communities by reducing carbon emissions, criteria air pollutants, and water usage with every megawatt hour we produce.

As of 2022, we have over 900 customer installations globally totalling over 950 MW of fuel cells in North America, India, Japan, and Korea. Our customers often operate critical infrastructure with significant energy resilience requirements. Bloom provides solutions that allow our customers to confidently take charge of their energy future.

Our Energy Servers that run on hydrogen or biogas produce carbon neutral or zero carbon power, while those fueled by natural gas produce carbon emissions. However, our Energy Servers are among the world's most efficient power generation devices and displace electricity produced by less efficient centralized power plants. This means we can deliver a powerful combination of near-term emission and water reductions with increased resiliency. Our Energy Servers reduce environmental and human health impacts in the same manner as wind and solar generation — by displacing dirtier power plants. Although, unlike wind and solar, our Energy Servers can operate and produce electricity around the clock and require a fraction of the land used.

Bloom produces annual verified greenhouse gas inventories as a part of our sustainability reporting, but also takes the extra step to quantify avoided emissions from our projects. Our GHG inventories and avoided emissions methodologies are third-party verified by Ramboll, a leading independent engineering firm. Since 2011, when Bloom began commercial deployments, and through the end of 2022, our systems have achieved:

- **3.66 million metric tonnes of CO_2e reduction,** equivalent to **over 4.3 million acres of forest preservation** or taking **over 814,825 cars off the road for a year.**[1]
- Associated criteria pollutant reductions, including **6.8 million pounds of sulfur oxides (SOx), and 16.2 million pounds of nitrogen oxides (NOx), equivalent to** preventing approximately 1,566 lost workdays and more than 9,260 days of restricted activity due to illness.[2]

In this paper, we review Bloom's environmental profile in detail 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 net-zero 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 distributed energy resource, such as a solar project or Bloom Energy Server, is

[1] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
[2] Air quality equivalencies from EPA's COBRA tool (https://cobra.epa.go)

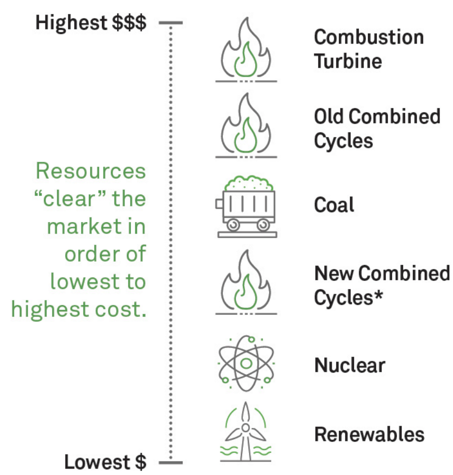
brought online, it reduces the amount of power required from energy sources on the grid that generate "on the margin" — meaning those units that are operating to meet the last unit of energy demand.

The PJM regional transmission organization[3] articulates the concept well in its learning center, 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 the market at 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.

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 necessity 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.

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[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
[5] PJM Learning Center Website https://learn.pjm.com/electricity-basics/market-for-electricity.aspx

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 2,260 lbs. of CO2/MWh while natural gas plants emit at 970 lbs. of CO2/MWh[6]. In comparison, Bloom Energy fuel cells have an emission rate of 679 - 833 lbs. CO2/MWh[7].

Every unit of electricity that Bloom Energy Servers produce avoids a unit of energy being produced through other means and typically offsets a unit of electricity from a marginal generator on the grid 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[8].

Marginal emissions implications also drive voluntary corporate energy procurement, with standards organizations like World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), universities and national laboratories, consultancies like E3 and Watt Time, industry associations like the Clean Energy Buyer Alliance and leading corporates including Google all contributing to an increasingly large body of work that details how the consequential impacts of energy-related decision making are reflected in marginal emissions comparisons.

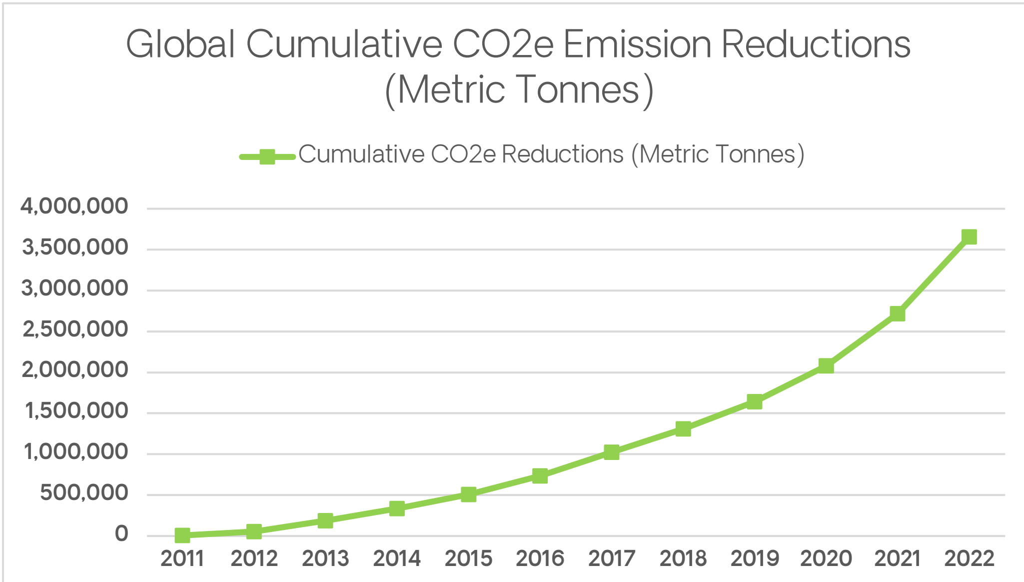
Additionally, marginal emissions profiles form the basis of crediting mechanisms in numerous regulatory programs including in carbon intensity scores in the California Low Carbon Fuel Standard (LCFS) Program and in carbon offset generation in the European Emissions Trading Scheme (EUETS).

Bloom Energy Servers Compared to Global Marginal Emissions

Figure 2 shows Bloom's historical global 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[9]. The analysis represents Bloom's combined historical average fleet emissions performance. Reference data for the chart below are derived from historical EPA eGRID non-baseload dataset for our domestic installations, and global country-wide grid emission sources such as the United Nations Framework Convention on Climate Change International Financial Institutions Default Grid Factors (UNFCC IFI Factors)[10], the Carbon Footprint Grid Electricity Emission Factors[11], the Institute for Global Environmental Strategies (IGES) List of Grid Emission Factors[12], and the Central Electricity Authority CO_2 Baseline Database[13] for our international installations. Taken together, they provide average annual marginal emissions values across the relevant timeframe and regional footprint.

[6] https://www.eia.gov/tools/faqs/faq.php?id=74&t=11
[7] Bloom E5.5 Datasheet (https://www.bloomenergy.com/wp-content/uploads/bloom-energy-server-2023.pdf)
[8] https://files.wri.org/d8/s3fs-public/pdf/ghgprotocol-electricity.pdf
[9] https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid
[10] https://unfccc.int/documents/437880
[11] https://www.carbonfootprint.com/docs/2023_02_emissions_factors_sources_for_2022_electricity_v10.pdf
[12] https://www.iges.or.jp/en/publication_documents/pub/data/en/1215/IGES_GRID_EF_v11.1_20230318.xlsx
[13] https://cea.nic.in/cdm-co2-baseline-database/?lang=en

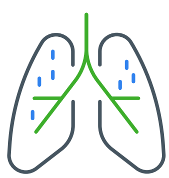
Figure 2: Carbon Impact



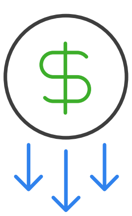
We've taken the same approach for evaluating domestic air quality impact for SOx and NOx, two primary criteria pollutants also benchmarked in EPA's eGRID non-baseload data[14]. Since our first Energy Servers began operation in 2011 through the end of 2022, we quantified the following impacts to local air quality in the regions that we operate:

99.9+%

Reduction in NOx and SOx Emissions



NOx Reductions: **8,107 tons**
SOx Reductions: **3,398 tons**



- Equivalent savings to the healthcare systems: **$150,667,000 - $339,810,000**
- Avoided work loss days: **1,566**
- Avoided cases of respiratory symptoms: **533**

[14] Air quality equivalencies are modelled using EPA's COBRA tool (https://cobra.epa.gov)

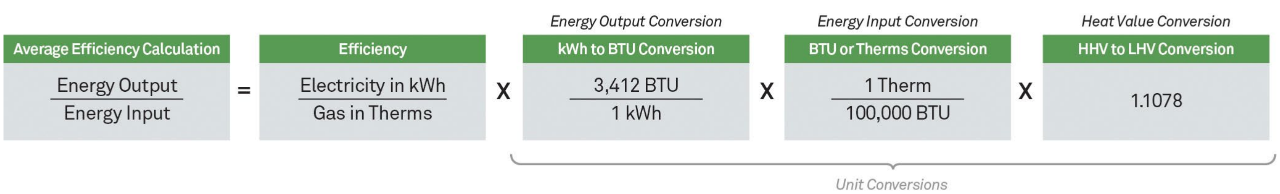
Carbon Impact Methodology

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 and is dependent on the net electrical efficiency of the system (the fraction of the input chemical energy in the fuel converted into electrical energy).[15]

$$\textbf{Energy Server}\ \frac{lbs\ CO_2}{kWh} = \frac{1\ mmBtu}{1,000,000\ Btu} \times \frac{116.98\ lbs\ CO_2}{mmBtu} \times \frac{3,412\ Btu}{kWh} \times \frac{1}{Eff\ (\%)} \times 1.1078$$

Note: lower heating value (LHV) is converted to higher heating value (HHV) by a factor of 1.1078. It is also worth noting 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 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 unit of power.

Methodology Validated by Expert Organizations and Academia

Researchers at the Rochester Institute of Technology[16], Carnegie Mellon[17], UCSD, Yale, Dartmouth, the National Bureau of Economic Research[18], UC Berkeley[19], UC Davis[20], Princeton University[21], and the Proceedings of the National Academy of Sciences (PNAS)[22] have published on the appropriateness of marginal emissions-based impact methodologies. Additionally, the following sample of organizations use this approach in program administration:

- **WRI**
  - In guidance for voluntary carbon reporting under its GHG Protocol[23]

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[15] The amount of carbon in natural gas for our U.S. customers comes from the EPA's Emission Factors for Greenhouse Gas Inventories Table 1.
[16] Environmental Science & Technology 2017 51 (21), 12988-12997
[17] Environ. Sci. Technol. 2012, 46, 4742–4748
[18] 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),
[19] JAERE, volume 5, number 1. © 2018 by The Association of Environmental and Resource Economists
[20] American Economic Journal: Economic Policy 2015, 7(3): 291–326
[21] https://dataspace.princeton.edu/handle/88435/dsp011j92gb736
[22] https://www.pnas.org/doi/abs/10.1073/pnas.2116632119
[23] http://pdf.wri.org/GHGProtocol-Electricity.pdf

- **WBCSD**
  - o In its framework for accounting and assessing the decarbonizing impact of companies' low and zero emissions solutions in collaboration with the Net Zero Initiative (NZI)[24]
- **California Public Utilities Commission**
  - o In measuring performance under the Self Generation Incentive Program (SGIP)[25]
- **The UNFCC's Clean Development Mechanism**
  - o In generating Certified Emissions Reductions from grid connected distributed energy projects under the Kyoto Protocol[26]
- **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[27]

Marginal emissions proxies are tracked by the US Environmental Protection Agency (EPA) in the 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[28]."

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).

Other sources of marginal emissions data and methodology exist, but eGRID and the international marginal grid emission sources listed above provide a consistent, transparent methodology covering all domestic and international regions required to cover all the years needed to produce an historical analysis for Bloom's entire fleet.

Transportation and Distribution Losses

Transmitting electricity over transmission and distribution lines results in some of the electricity being lost, a concept known as line losses. This reduces the total amount of electricity that is delivered to a customer. This means that more electricity must be generated to meet the same level of demand. Bloom's Energy Servers generate electricity onsite and, therefore, have a line loss of zero. The eGRID dataset includes regional line losses and these values are added to the marginal emission rates to calculate a net carbon impact from our domestic Energy Servers.

The GHG Protocol includes guidelines for including line losses to quantify greenhouse gas reductions from distributed energy projects and to include emissions related to line losses from purposed electricity in the Scope 3 category 3 covering upstream fuel and energy-related activities.

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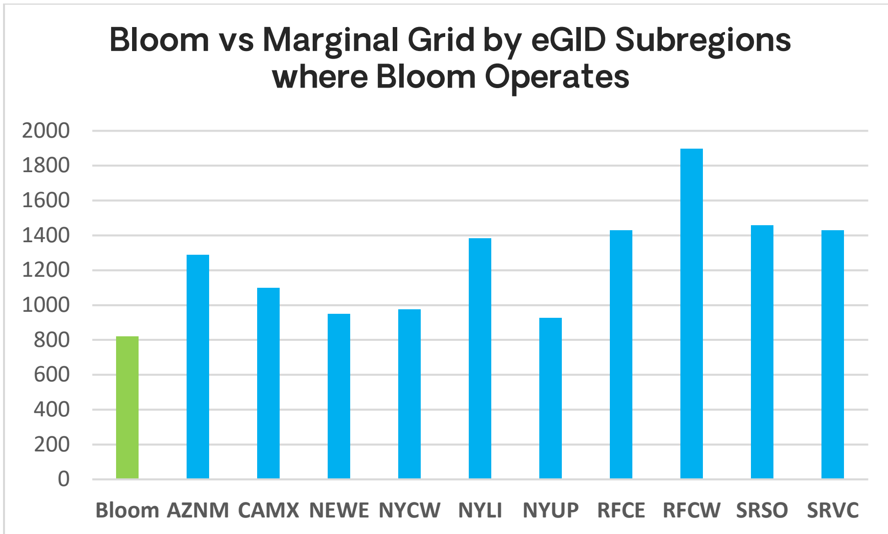
[24] https://www.wbcsd.org/Imperatives/Climate-Action/Resources/Guidance-on-Avoided-Emissions
[25] https://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/Utilities_and_Industries/Energy/Energy_Programs/Demand_Side_Management/
Customer_Gen_and_Storage/2017_SGIP_AES_Impact_Evaluation.pdf
[26] https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v4.0.pdf]
[27] https://businessrenewables.org/what-we-do/
[28] https://www.epa.gov/sites/production/files/2018-02/documents/egrid2016_technicalsupportdocument_0.pdf

Carbon Impact Breakdown

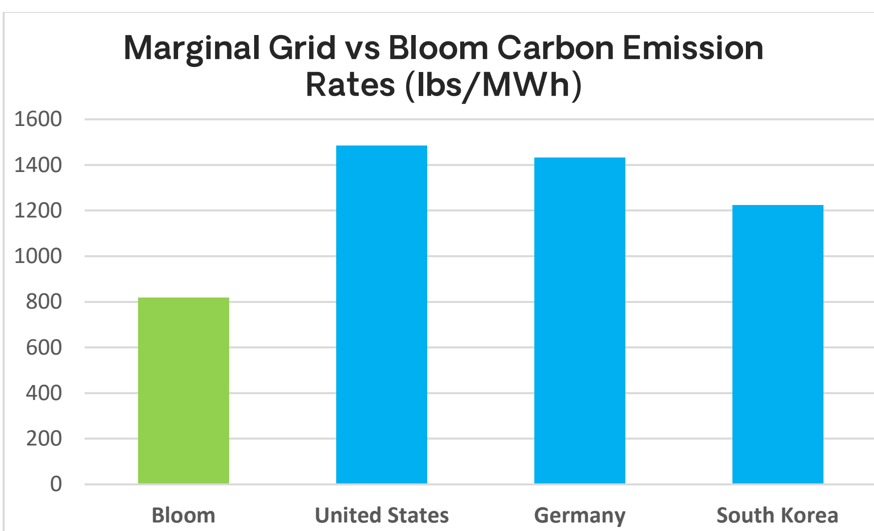
Figure 4



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

Figure 5 below demonstrates how the emissions from power produced by a Bloom Energy Server compares to relevant average marginal emissions rates internationally.

Figure 5



Importance of Air Quality

Criteria pollutants are a class of smog-forming air pollutants regulated by the EPA[29], including NOx and SOx. They are the primary source of air pollution and are produced during fossil fuel combustion. Importantly, Bloom's non-combustion fuel cells emit near-zero smog-forming criteria pollutants.

The health and environmental impacts of combustion related pollutants are both very significant and readily quantifiable. 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**[30]
- **Combustion related air pollution increases pre-term birth risk**[31]
- **Combustion related air pollution causes dementia**[32]

Diesel generator use has exploded in recent years as grid reliability challenges have proliferated. In California for example, there are now 12,000 MWs of generators in place in three of the state's largest air districts[33].

Technology Performance Validation

The California Air Resources Board has certified Bloom Energy Servers as a Distributed Generation[34] 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 completed third party validated testing of its systems by Montrose Environmental to determine that its emissions of nitrogen oxides, carbon monoxide, and VOCs were below the certified limits. Many air districts in California use this certification as the basis for a fuel cell exemption in their regulations. This includes, but is not limited to, the two largest air districts in the state: Bay Area Air Quality Management District and South Coast Air Quality Management District[35]

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 carry critical loads during an outage, the frequency, duration, and severity of which are increasing

[29] https://www.epa.gov/criteria-air-pollutants
[30] 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
[31] 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
[32] 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/
[33] 4 M.Cubed, Back-up Generator Populations in Bay Area, South Coast Continue to Grow; San Diego Home to a Significant Number of Generators, Mostly Diesel Power at 4 (Dec. 2022).
[34] https://ww2.arb.ca.gov/node/1605/about
[35] http://www.aqmd.gov/docs/default-source/rule-book/reg-ii/rule-219.pdf and https://www.baaqmd.gov/~/media/dotgov/files/rules/regulation-2-rule-1/ 32
documents/20171206_fr_0201-pdf.pdf?la=en

every year. We have deployed more than 160 microgrids to date globally and our systems rode through 436 power outages carrying a total of 122,171 MWh of energy demand over 597 outage hours in 2022 alone.

When Bloom microgrids are in place, they can prevent the need for both marginal generation on the grid and backup diesel generators, which emit both carbon and criteria pollutants into local communities. Diesel generators also need frequent testing to ensure they can and will operate properly when necessary. This causes regularly emitting criteria pollutants even when there is no grid outage. When a diesel generator operates, it emits a higher amount of GHG and criteria pollutants on a per MWh basis. For example, the CO2e emission factor for a Tier 2 diesel generator is 1,243 lb/MWh[36] compared to Bloom's average CO2e emission factor of 818 lb/MWh. In addition, NOx and SOx emission factors for a diesel generator are both 1,000+ times larger than Bloom's near-zero emission factors for NOx and SOx[37].

Impact Moving Forward

While we cannot fully predict the long-term forward evolution of marginal emissions rates, we can anticipate in the near to medium term that marginal emissions profiles are likely to hold relatively constant and continue to reflect emission rates closely tied to natural gas generation. Enormous projected load growth resulting from building and transportation electrification, long interconnection timelines for new renewable projects, transmission constraints, underperforming hydroelectric assets and nuclear retirements will combine to continue to require grid operators to rely on flexible gas generation assets[38].

The marginal emissions in each region are often the last indicator to change when a grid is transitioning to renewable energy. For example, according to EPA's eGRID non-baseload values, the average marginal emissions rate, including line losses, for California is 1,099 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 California average marginal emissions rate is consistent with that of natural gas fired marginal generation, even though the CAMX grid mix is 40% renewable[39]. In new markets, including the Midwest and Southeast, Bloom's systems are more carbon efficient than the marginal generator by more than 50%.

In California, the Public Utilities Commission has created the Avoided Cost Calculator (ACC) to measure the cost and environmental impact created from displaced marginal generation by distributed energy projects. Using the ACC, which includes forward projections by CAISO zone, Figure 6 compares the carbon emissions impact of a new Bloom project to that of grid power supplied by PG&E (i.e., NP15). This model shows that Bloom is carbon reducing in PG&E territory through 2027. Additionally, the EPA provides resources that indicate likely criteria pollutant release from marginal resources in California and the World Resources Institute publishes water use figures for generation assets in the state.

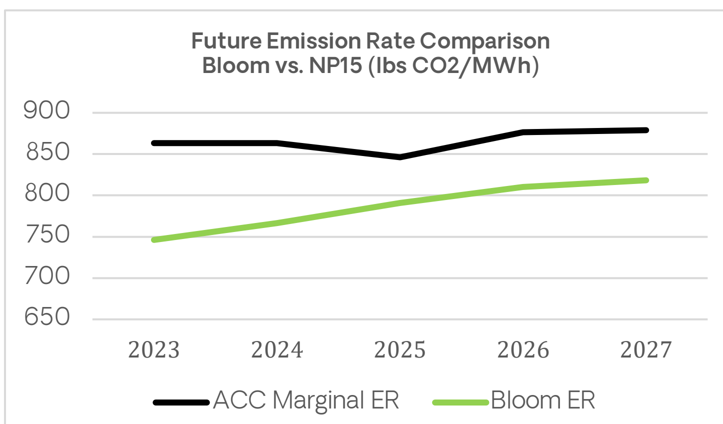


Figure 6. Marginal emission rates for the NP15 region are from the CPUC Avoided Cost Calculator[40]

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[36] https://www3.epa.gov/ttnchie1/ap42/ch03/final/c03s03.pdf
[37] Tier 2 diesel generator NOx and SOx emission factors are 20.28 and 2.2 lb/MWhr, respectively, per https://dieselnet.com/standards/us/nonroad.php#tier4 and AP 42 Table 3.3-1.
[38] https://www.pnas.org/doi/pdf/10.1073/pnas.2116632119
[39] eGRID 2021 BA total renewables generation percent for CAISO
[40] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/energy-efficiency/idsm

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 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 $C0_2$, 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 instrumental to its low carbon future.

Conclusion

Carbon mitigation is 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, AlwaysOn, 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.

Bloom Energy Headquarters
4353 North First Street
San Jose, CA 95134 USA

bloomenergy.com