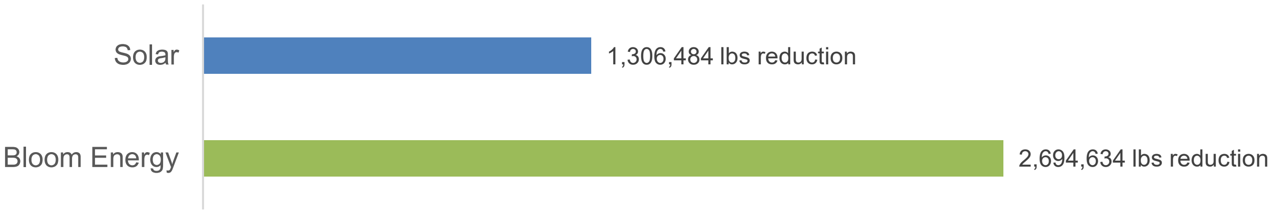
WHITE PAPER | April 2019

How Fuel Cells Reduce Carbon Emissions As Effectively As Renewables

Executive Summary

Sustainability is a key factor in the long term viability of the energy infrastructure in the United States. Today there are more electricity generation technologies with both affordable and clean characteristics including solar photovoltaic (PV), wind turbines, and fuel cells. Understanding how these technologies impact the carbon emissions of the regional grid requires an understanding of carbon accounting methodology, marginal emissions, and the capacity factor of various technologies. An example calculation is provided for a New York installation where a 1 megawatt (MW) baseload fuel cell solution is shown to be more than twice as effective in displacing carbon emissions as a 1 MW solar PV solution.

Figure 1: Carbon Emissions Displacement Summary



1 Energy Use Is On The Rise

The United States is at a crossroads in determining an energy generation strategy to address both rising demand on the grid and environmental concerns. Greenhouse gas (GHG) emissions have continued to rise with an escalating energy demand, further exacerbating the risks associated with climate change. Despite pressure to reduce GHG emissions from the electricity sector, studies have demonstrated that carbon dioxide levels, a leading GHG contributor to climate change, are projected to increase by 2.5% in the United States in 2018[1]. Global leaders are faced with the challenge of determining how to provide energy security in the face of increasing demand while simultaneously reducing their environmental footprint.

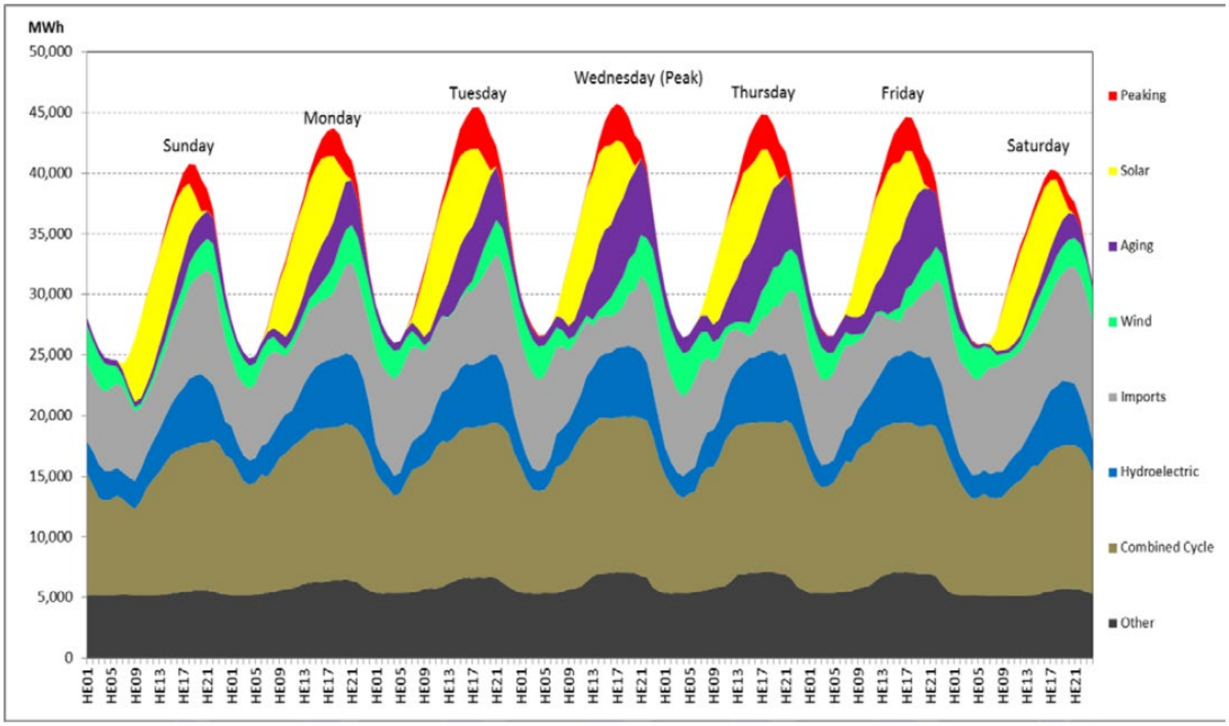
---

[1] Global Energy Growth is Outpacing Decarbonization; Global Carbon Project 2018

2 How Distributed Generation Displaces Grid CO_2 Emissions

When a new, efficient distributed energy source is brought online, it reduces the amount of power required from energy sources that generate “on the margin” – referencing those units that are operating to meet the last unit of energy demand. In order to displace CO_2, these marginal power sources must be CO_2 emitters, which is the case for a majority of the United States energy environment. Energy providers on the margin are typically the most flexible but least efficient energy generation sources, expressing the highest heat rate and associated emissions. 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 CO_2/MWh[2]. Comparatively, leading technologies such as fuel cells have an emission rate of 679 - 833 lbs CO_2/MWh[3]. Hydroelectric, nuclear and coal are traditionally baseload resources as these cannot be easily start up or shut down. When marginal power sources are displaced by more efficient or cost effective solutions, it is done so in a reverse merit-order basis (oil, natural gas and coal are the first resources requested to be shut off). Figure 2 provides a sample generation profile for California[4].

Figure 2: California Generation Mix – 2016 ISO Select Data



New energy generation technologies influence grid sources on the margin at different times and capacities due to variation in output. Figure 3 shows profiles of three technologies. Wind is more

---

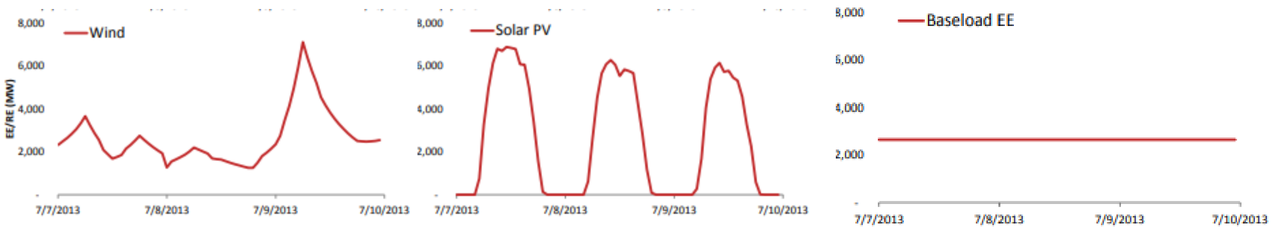
[2] *2017 EIA Data from ‘Electric Power Annual’ dataset*

[3] *Bloom Energy ES5 Data Sheet*

[4] *Mccarthy, Ryan & Yang, Christopher. (2010). Determining marginal electricity for near-term plug-in and fuel cell vehicle demands in California: Impacts on vehicle greenhouse gas emissions. Journal of Power Sources. 195. 2099-2109. 10.1016/j.jpowsour.2009.10.024.*

variable and displaces centralized energy sources when it peaks during the evening and nighttime hours. Solar PV reaches peak output mid-day, exporting energy to the grid during a lower demand period. This behavior can be complementary between technologies albeit unpredictable. Always on technologies, like fuel cells provide constant power at all times.

Figure 3: Power Profile By Distributed Generation Technology[5]



It will be critical to understand the time-dependent energy profiles for distributed generation technologies to evaluate displaced emissions. This will be captured as the Capacity Factor and will be discussed in more detail later in this analysis.

3 Factors In Emissions Calculations

There are a number of factors to be considered in order to calculate emissions displacement from distributed energy projects including accounting protocol, marginal emissions, and capacity factor. These are each outlined below in further detail.

Emissions Accounting Protocol: Organizations looking to calculate potential emissions reductions and displacement of marginal emitters can use recommended guidelines from the World Resource Institute (WRI) Greenhouse Gas protocol, which is the most widely used GHG accounting methodology and the foundation for nearly every GHG standard and program. The GHG Protocol utilizes project level emissions accounting and also includes sector-specific guidance for on-site electric generation projects. “The guidelines are applicable to… project activities that reduce consumption of grid electricity: These types of project activities reduce the need for grid-based electricity by… generating electricity onsite so that supply from the grid is unnecessary”.

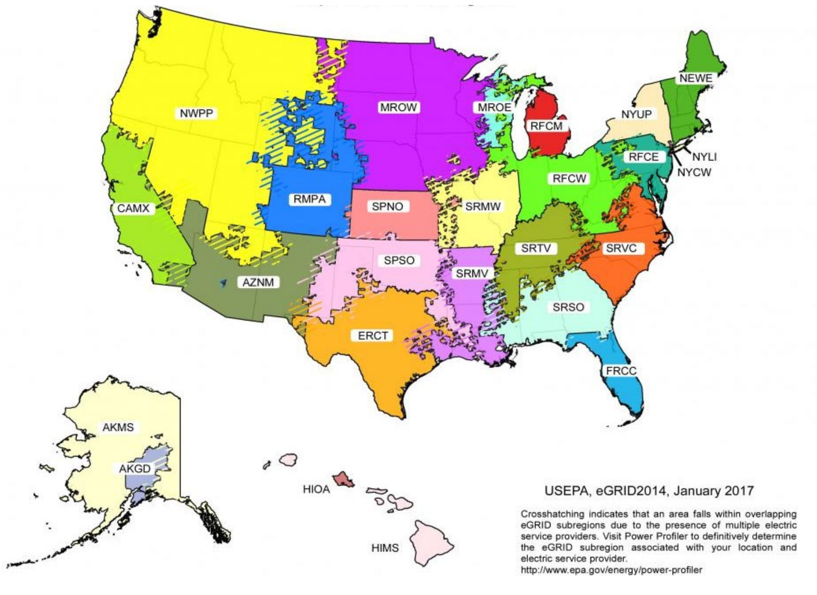
---

[5] *Fisher, J., De Young, R., and Santeen, N.R. (2015) “Assessing the Emission Benefits of Renewable Energy and Energy Efficiency using EPA’s Avoided Emissions and generation Tool (AVERT).” Presented at the 2015 U.S. EPA International Emission Inventory Conference “Air Quality Challenges: Tackling the Changing Face of Emissions.” San Diego, CA*

Project level reporting measures emissions reductions for a specific project in comparison to the marginal power plants on the U.S. electric grid. It is deemed to be the most accurate in capturing the actual change in carbon dioxide emissions. More information can be found in WRI's Guidelines for Grid-Connected Electricity Projects[6].

Marginal Emissions: Marginal emissions reflect what is happening when more distributed generation comes online. Average grid emissions is a calculation but not representative of how a marginal generation unit is displaced by the distributed asset. The US Environmental Protection Agency (EPA) publishes the Emissions & Generation Resource Integrated Database (eGRID). eGRID includes marginal (non-baseload) emission rates which "are recommended to estimate emission reductions from renewable energy or energy efficiency projects that reduce consumption of grid supplied electricity." Furthermore, eGRID publishes both state emissions rates and the recommended subregional emissions rates. As energy supply crosses state lines, states' figures alone are not an accurate determinant when calculating emissions rate. The map below displays the various subregions defined by the EPA.

Figure 4: eGRID Subregions



USEPA, eGRID2014, January 2017

Crosshatching indicates that an area falls within overlapping eGRID subregions due to the presence of multiple electric service providers. Visit Power Profiler to definitively determine the eGRID subregion associated with your location and electric service provider.
http://www.epa.gov/energy/power-profiler

---

[6] *Guidelines for Quantifying GHG Reductions from Grid Connected Electricity Projects, World Resources Institute.*

Capacity Factor: System capacity factor is defined as the ratio of the actual electrical energy output over a period of time to the maximum possible electrical energy output in the same period. The maximum possible output is equivalent to full nameplate capacity if the system is in continuous operation. Intermittent technologies generally have a lower capacity factor. For example, U.S. solar PV capacity factors range from 10% to 25% depending on elevation, latitude, weather patterns, installation configuration, and other physical obstructions. U.S. wind capacity factor can be higher, ranging from 20% to 40%. Clean, primary technologies serve the majority of the load with a capacity factor of 90% or greater. Capacity factor is the key point of difference between always on and intermittent energy sources.

Calculation Methodology: Emissions displacement can be calculated from the inputs:

- Recommended marginal emission rate for comparison
- Project size
- Distributed technology emissions
- Capacity factor

Key equations to use in the calculation are below

CO_2 Reduction per MWh[7] = eGRID Non-baseload CO_2 Emissions For Subregion– Project CO_2 Emissions

Annual CO_2 Reduction = Project Size (MW) x Capacity Factor x Annual Hours x CO_2 Reduction per MWh.

---

[7] *Here, we follow WRI protocol and calculate reduction compared to marginal emissions. The Appendix contains other accounting methodologies*

4 Comparing Emissions Displacement for Fuel Cell and Solar PV Projects

This section provides an example of CO_2 displacement calculated for a fuel cell solution and a solar PV installation. The fuel cell is a Bloom Energy fuel cell installation utilizing natural gas. The renewable intermittent solution is a solar PV project. A Bloom Energy Server[8] converts standard low-pressure natural gas or biogas into electricity through an electrochemical process without combustion, resulting in significantly higher conversion efficiencies and lower harmful emissions than conventional fossil fuel generation.

The two systems evaluated are a 1000kW (1MW) Bloom Energy fuel cell onsite installation in New York and a 1000kW (1MW) solar PV project in New York. Table 1 provides a comparative summary for these two technologies.

Table 1: Emissions Displacement Summary, New York

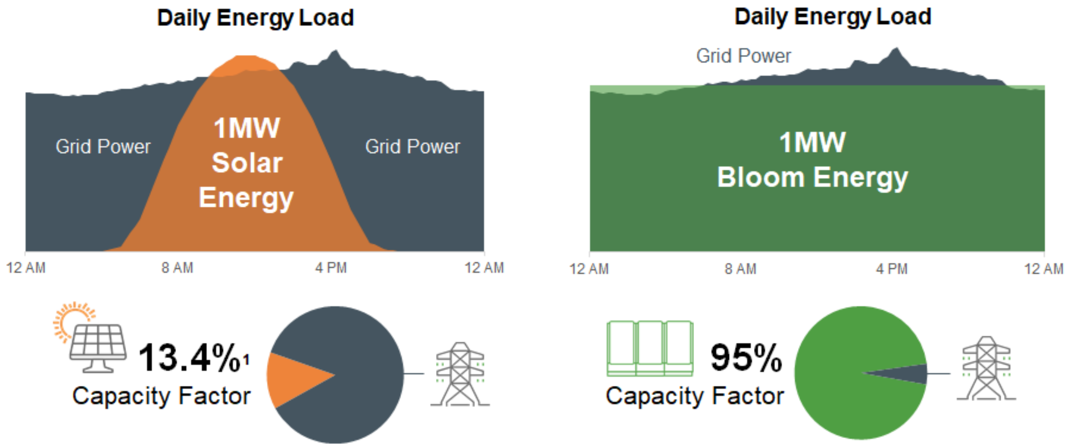
	Bloom Energy	Solar
Project Size (kW)	1000	1000
Capacity Factor (%)	95.0%[9]	13.4%[10]
Annual Energy Production (MWh)	8,322	1,174
Project CO_2 Emissions (lbs/MWh)	789	0
Grid Marginal CO_2 Emissions (lbs/MWh)[11]	1,113	1,113
CO_2 Reduction (lbs/MWh)	324	1,113
Annual CO_2 Reduction in New York (lbs)	**2,694,634**	**1,306,484**

Table 1 demonstrates that a fuel cell solution can displace similar or more CO_2 as compared to a solar PV cell of the same rated size. As a zero emission technology, solar PV has significantly lower CO_2 emissions than a Bloom Energy Server on a per MWh basis. However capacity factor is the driving variable in a holistic analysis. Solar PV is an intermittent energy generation technology with a correspondingly lower capacity factor, resulting in ultimately half of the CO_2 emissions displacement as compared to a Bloom Energy fuel cell over the course of a year. Figure 5 shows a graphical comparison of the two generation profiles overlayed on an example end user load profile.

---

[8] *For more information about Bloom Energy Server, go to www.bloomenergy.com*
[9] *Bloom Energy ES5 Data Sheet*
[10] *NYSERDA RPS-CST Solar PV and On-Site Wind Programs; the Cadmus Group, Inc.*
[11] *EPA eGrid 2016 https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid*

Figure 5: Solar PV vs. Fuel Cell Energy Profile



5 Conclusion

Organizations are being challenged to meet their energy needs sustainably, typically requiring some level of distributed power generation technologies. For organizations evaluating a multitude of distributed energy solutions, an important consideration is the total emissions displacement as part of a long-term energy decision. Among the distributed energy generation options, fuel cell technology stands out as an effective way to immediately address sustainability goals for organizations of all sizes.