Air Quality and GHG Emission Impacts of Stationary Fuel Cell Systems

An assessment produced by the Advanced Power and Energy Program at UC Irvine

Introduction. The increasing percentage of intermittent renewable solar and wind generation on the grid requires a support strategy to maintain and improve reliability and resiliency, and provide ancillary services. While electric batteries provide one cornerstone in the strategy, a firm (24/7, load-following) and clean (low or zero carbon emission, and virtually zero emission of criteria pollutants) power generation technology is required as the primary cornerstone.

Combustion technologies (e.g., gas turbines) currently serve this role. The environmental challenges (climate change, degraded air quality) attributed to combustion, however, call for a viable, non-combustion alternative. Fuel cell systems, with high-efficiency and negligible emission of criteria pollutants, operate with electrochemistry (rather than combustion chemistry) and represent the sole commercially viable, non-combustion, firm power generation resource.

Several studies have examined the potential of fuel cells in supporting a future grid with high renewable penetrations.[1-4] This document summarizes benefits to air quality (AQ) from the deployment of megawatt-class stationary fuel cell systems, hereinafter referred to as Transmission Integrated Grid Energy Resource (TIGER) stations, on the utility side of the meter.[5] A three-dimensional AQ model (CMAQ[6]) is utilized over a portfolio of scenarios to evaluate how the use of TIGER installations, both with and without combined heat and power (CHP) strategies, can support high levels of renewable resources in place of natural gas power plants, reduce emissions of both criteria pollutants and greenhouse gasses (GHG), and how resulting emission reductions affect AQ throughout California. Finally, a health impact assessment is conducted using a model developed by the U.S. EPA (BenMAP[7]) to quantify and value the benefits to human health resulting from AQ improvements.

Methods. Modeling of the interactions of the electrical grid, renewable resources, and TIGER stations is described in Shaffer et al. 2015.[8] Briefly, the Holistic Grid Resource Integration and Deployment (HiGRID) model is used to analyze a 5 gigawatt (GW) deployment of TIGER Stations at distribution substations for three renewable penetrations of the California electrical grid: 33%, 43% and 50%. Relative to a Base Case without TIGER stations, the study demonstrated that 5 GW of multiple 10-50 megawatt (MW) TIGER stations can (1) provide the clean 24/7 load-following complement required to manage and maintain grid stability in the presence of a high-penetration of renewable grid power generation and, in tandem, reduce the emissions of NO_x (Figure 1) and GHG (Figure 2). Additionally, the inclusion of CHP strategies to capture and utilize waste heat was shown to further enhance the emission reductions.

For this work, the estimated emission reductions in Shaffer et al. are applied to study the impact on regional and urban AQ (i.e., resulting changes in the concentrations of criteria pollutants in the atmosphere). An understanding of emission changes, both in location and time, followed by simulations of atmospheric chemistry and transport, is required to understand how technologies impact ambient pollutant levels. TIGER stations reduce emissions by (1) offsetting emissions from

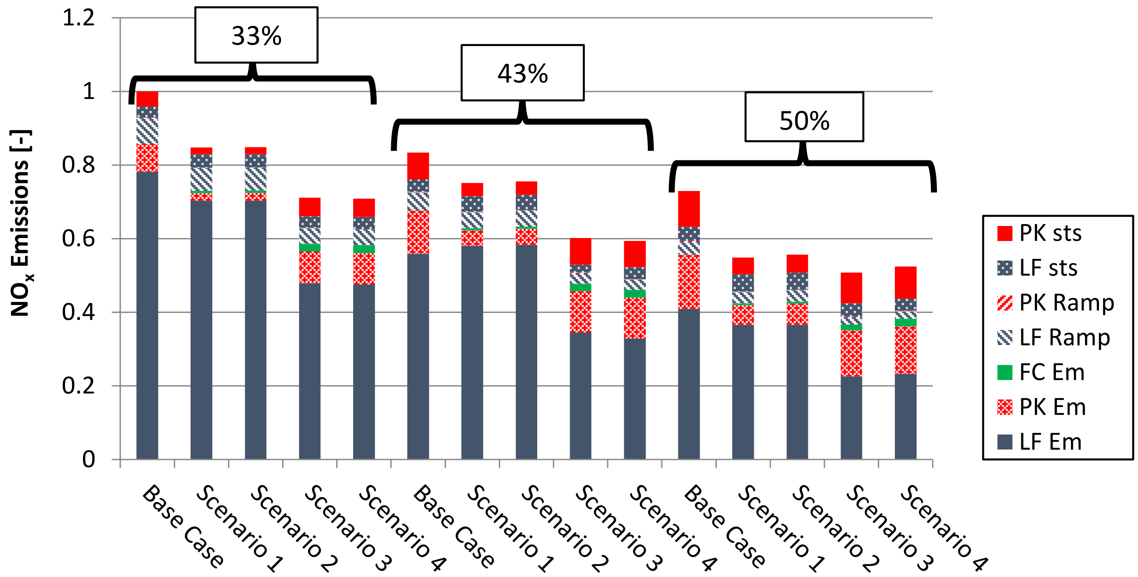


Figure 1. Normalized NO_x emissions for TIGER Station deployment scenarios relative to a Base Case without Tiger Stations[8]

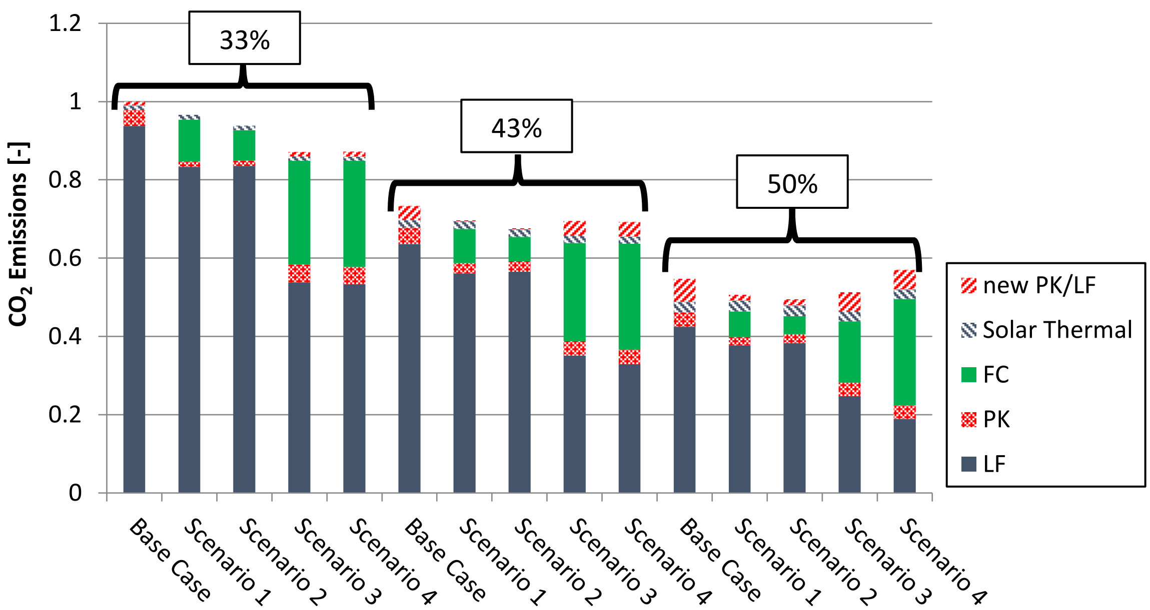


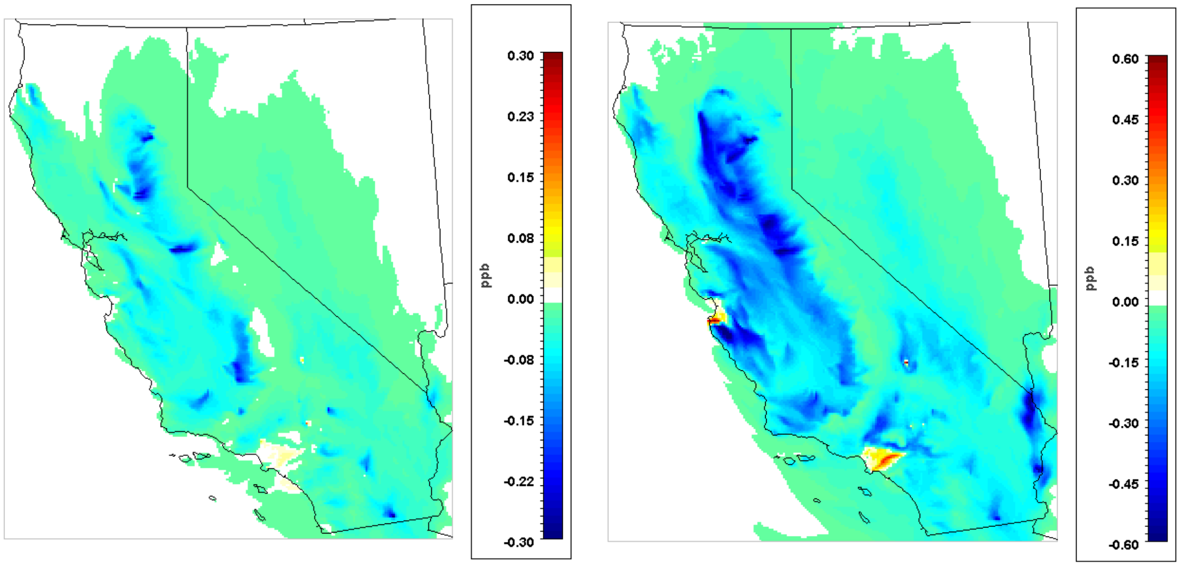
Figure 2. Normalized CO_2 emissions for several TIGER Station deployment scenarios relative to a Base Case without Tiger Stations[7]

natural gas power plants that would otherwise be required to balance renewable resource integration, and (2) displacing emissions from industrial boilers through the use of waste heat captured via CHP. The emissions reductions are spatially and temporally allocated to the locations of natural gas power plants and industry within California. CMAQ is then utilized to predict the impact of emission reductions on AQ throughout California. Specifically, quantification of changes in ground-level concentrations of ozone (a key component of photochemical smog) and fine particulate matter ($PM_{2.5}$) are considered, due to the well-understood detrimental impacts on human health[9-11] and the difficulties many regions of California currently experience in meeting health-based standards. Impacts are predicted for both summer and winter episodes as the dynamics of pollutant formation have a strong seasonal dependence. Furthermore, the improvements in regional air pollutant concentrations achieve benefits to human health that have monetary value to society. These benefits can be estimated by using concentration-response functions that quantify morbidity and mortality health effects and valuation functions from health economic studies to monetize quantified public health effects. The environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP) from the U.S. EPA is used to estimate the number and value of health impacts resulting from changes in air pollution concentrations.

Results. The following presents results from the prediction of changes in ground-level ozone and $PM_{2.5}$ for scenarios of TIGER station deployment relative to a baseline of natural gas power plants. Additionally, the use of CHP to provide heat in place of industrial boilers is compared to electricity-only utilization. As shown in Figure 3a, by avoiding emissions from natural gas plants, TIGER stations improve ground-level concentrations of ozone in many areas of California in summer months (when baseline ozone levels are highest and regularly exceed regulatory standards[12]). Improvements increase when CHP is included in the scenario, as emissions of NO_x from industrial boilers are further reduced (Figure 3b). The location of large point sources, both for power generation and industry, are visible in the results and contribute to the largest impacts.

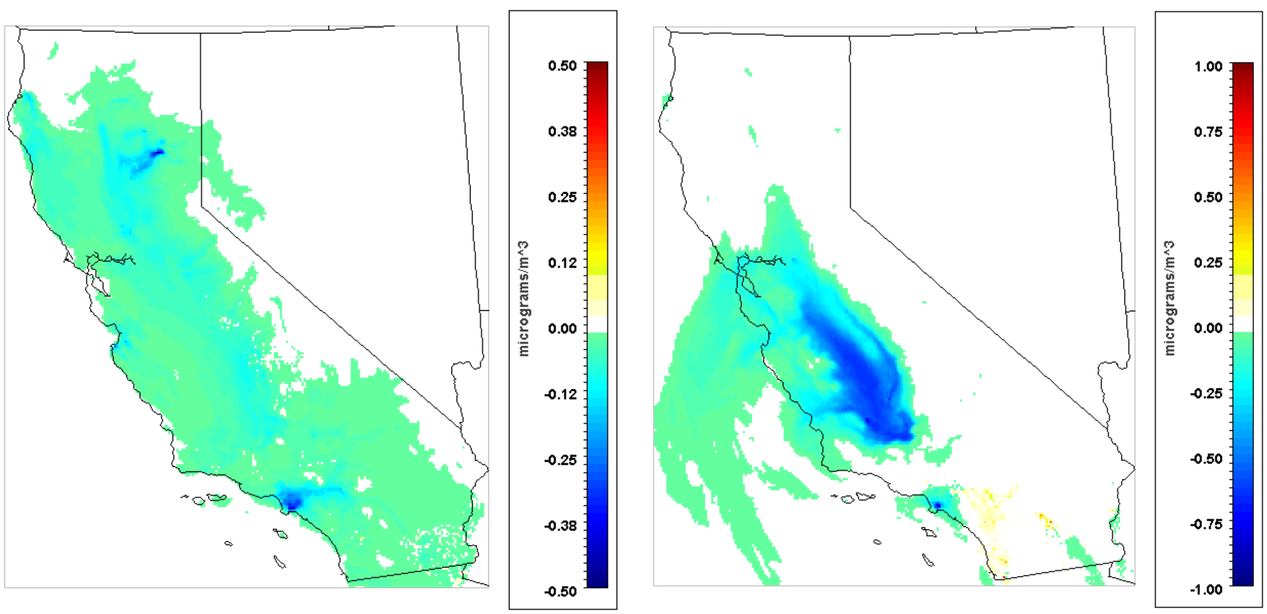
Summer levels of $PM_{2.5}$ often exceed health-based standards in parts of the Central Valley and other urban areas including southern California and the S.F. Bay Area.[13] Similarly, in winter, many regions of California experience ambient levels of $PM_{2.5}$ that are harmful to human health – notably the Central Valley.[14] Figure 4 demonstrates the ability of TIGER stations with CHP to improve $PM_{2.5}$ levels in both summer (Figure 4a) and winter (Figure 4b) in California. Peak improvements occur in locations associated with the highest background levels and high populations. For example, impacts in Southern California and the Central Valley in both summer and winter are particularly valuable to the State due to the current AQ challenges in these areas during those seasons.

These results clearly demonstrate the ability of TIGER stations to capture and utilize waste heat when deployed in CHP applications as an important factor in increasing AQ benefits. The inclusion of emission reductions from industrial boilers significantly enhances improvements in both ozone and $PM_{2.5}$. In particular, $PM_{2.5}$ reductions in winter are desirable due to implications for human health in the regions impacted. In addition to attaining emission reductions, benefits of CHP strategies include reduced energy costs, increased energy efficiencies, and increased reliability and support for the electric grid.[15] The ability of TIGER stations to provide CHP services is then an important opportunity to support renewable integration while maximizing emission, efficiency and AQ benefits.



(a) (b)

Figure 3. Improvements in ozone in Summer for TIGER Station deployments utilized for (a) electric-only and (b) electric and CHP strategies to reduce emissions from power plants and large industry.



(a) (b)

Figure 4. Improvements in $PM_{2.5}$ in (a) Summer and (b) Winter for TIGER Station deployments with CHP to reduce emissions from power plants and industry.

Figure 5 displays the estimated value of positive health impacts from AQ improvements for the scenario assuming fuel cell systems with CHP are utilized. Improvements result in health benefits through reduced exposure to ozone and $PM_{2.5}$, including avoided incidence of premature deaths and reduced incidence of many other damaging health effects that are not fatal (i.e., morbidity) including emergency room and hospital admissions, school and work loss days, asthma, and myocardial infarction. Using functions derived from health economic research, the value of these avoided health impacts can be estimated. In total, these impacts are sizeable and estimated at approximately $1,572,330 per day in winter and $2,145,950 per day in summer.

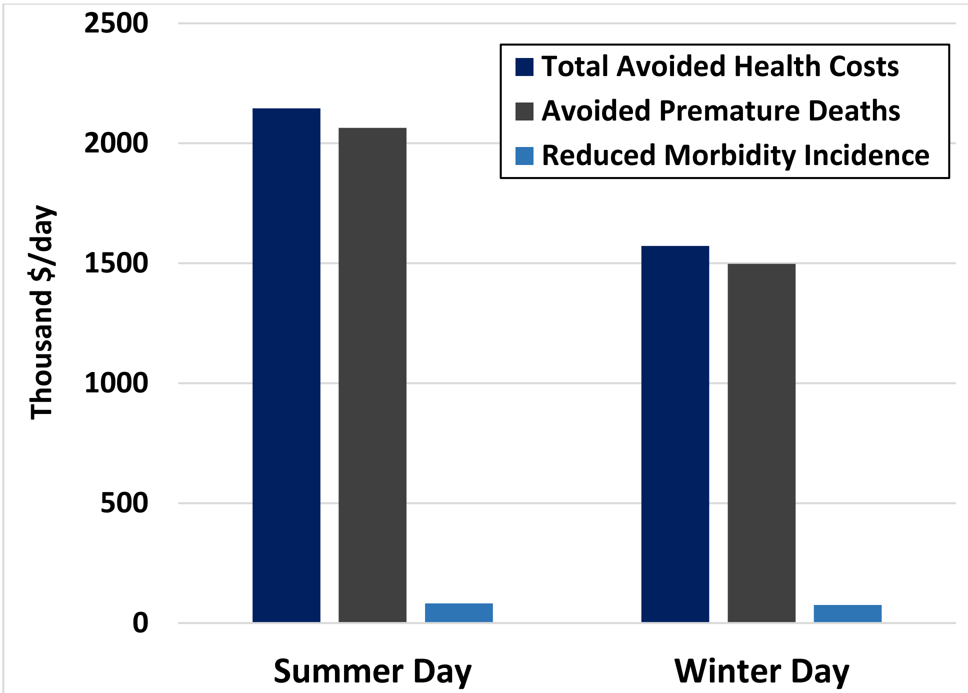


Figure 5. The estimated value of health effects from AQ improvements for fuel cell systems with CHP utilized to provide high quality waste heat in place of stationary boiler operation in industry.

It is also important to note that the use of TIGER stations reduce carbon emissions from the Base Case for all the dispatch scenarios at each renewable penetration. The analysis establishes that (1) TIGER stations reduce GHG emissions even when operated as baseload systems, and (2) TIGER station load-following capability is important for continued GHG emission reductions at higher renewable penetrations. Therefore, stationary fuel cell systems are able to achieve greenhouse gas and AQ co-benefits – an essential capability for technology choice within the pursuit of environmental quality goals.

Conclusions. The following are the salient conclusions from this work:

- By off-setting emissions from combustion technologies, fuel cell systems are ideally suited to balance intermittent wind and solar power on the grid while maximizing the GHG and AQ co-benefits of renewable energy.
- The use of fuel cell systems yields improvements in both ozone and $PM_{2.5}$ in key areas of California associated with high populations and unhealthy levels of pollution including the South Coast Air Basin, S.F. Bay Area, and Central Valley.
- The integration of CHP can enhance the AQ and GHG benefits of fuel cells by providing an effective and efficient mechanism to reduce emissions from traditional thermal generation methods (e.g., industrial boilers and process heat, commercial space and water heating).

- Reductions in pollutant emissions, notably of NO_x, achieves improvements in ground-level ozone and $PM_{2.5}$ in both summer and winter.
- Additional emission reductions from industrial boilers, achievable via CHP strategies, maximize AQ improvements in summer and winter episodes, with particular value to $PM_{2.5}$ in winter.
- The economic value of avoided health impacts from AQ improvements is significant and estimated here to be $2,145,950 for a summer day and $1,572,330 for a winter day

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