A 100 Percent Renewable Electric Grid

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

100% Renewable Grid. To achieve a 100% renewable electric grid, the entire portfolio of power must be generated from sources with zero emission of both greenhouse gases (GHG) and criteria pollutants. The principal examples of such generation sources are solar and wind.

Challenge. A major challenge to reach a 100% renewable grid is the management of load balancing, reliability, and the dynamics associated with the diurnal and seasonal variation, intermittency, and limited capacity factor that accompany a high penetration of solar and wind power generation. In addition to accurate forecasting of intermittent solar and wind resources,[1,2] meeting this challenge requires a systems analysis tool to identify the generation technologies required to enable and manage the solar and wind resources associated with a 100% renewable grid.[3]

Under the auspices of the California Energy Commission, a significant systems analysis tool, the "Holistic Grid Resource Integration and Deployment (HiGRID)" code, was developed by the UC Irvine Advanced Power and Energy Program to guide planning a modern electric grid.[4] Over the past four years, HiGRID has been used to evaluate a myriad of scenarios to determine the resources needed to manage the intermittency, diurnal variation, and constrained capacity factor associated with solar and wind. Without exception, the following two key resources emerge as required to manage the intermittent and diurnal/seasonal variability and limited capacity factor of solar and wind:

(1) Energy storage resources comprised of batteries, hydro, and hydrogen; and
(2) Clean, 24/7, load-following, renewable power generating resources.

Energy Storage Resources. While electric battery and hydro storage will provide a cornerstone to storing energy available from otherwise curtailed wind and solar resources, the generation of renewable hydrogen through electrolysis is emerging as the crucial storage technology to (1) absorb the levels of projected curtailed energy, (2) store the energy, and (3) convey the energy to the points of use. The natural gas distribution system is immediately available as a resource to store and distribute the "Power-to-Gas (P2G)" supply of renewable hydrogen. At some point, dedicated hydrogen pipelines can serve as the storage and distribution resource. P2G supports the ubiquitous utilization of stationary and mobile fuel cell-electric power generation across a spectrum of applications associated with a zero-carbon grid.

Clean 24/7 Load-Following Renewable Power Generation Resources. Stationary fuel cell systems are emerging as uniquely suited to generate the required clean, 24/7, load-following, renewable power with the added attribute of virtually zero emission of criteria pollutants. Already meeting initial market demand for base load power generation, more than 30% of the fuel cells operating today in California are generating renewable power by operating on locally-derived and directed biogas.[5] To meet the challenge of the next-generation 100% renewable grid, stationary fuel cells systems are being deployed today with (1) the requisite load-following attributes, and (2) operation on hydrogen, as well as natural gas and biogas. Simply stated, stationary fuel cell systems are:

- A required resource, along with energy storage, to enable and manage a 100% renewable grid.
- A perfect match for the utilization of the renewable hydrogen generated from otherwise curtailed wind and solar resources.

Stationary Fuel Cells are a Clean Electric Generation Resource. Fuel cells are a non-combustion technology that convert the chemical energy of a fuel directly into electricity via an electrochemical reaction. Fuel cells operate on external fuels, such as natural gas, biogas, and/or hydrogen, and continuously provide electricity as long as fuel is provided. In contrast to combustion engines, fuel cells operate at high efficiency, an attribute that scales from kilowatts (for supporting individual buildings) to scores of megawatts (for supporting the grid) with a concomitant reduction in the emission of carbon when operating on natural gas.[6] When operating on biogas, fuel cells emit net zero carbon and, when operating on renewable hydrogen, fuel cells emit zero carbon. These important attributes allow fuel cells to provide different industries and applications with a wide range of energy, environmental, and economic benefits.

In particular, on the customer side of the meter, fuel cells provide continuous clean, reliable, and load-following power and can be configured to provide seamless transition to meet critical loads in the case of a utility grid outage, eliminating thereby the need for backup diesel generators. Fuel cells can also support combined cooling, heat, and power (CCHP) operations for further reductions in carbon emission.[6,7] Additionally, tri-generation fuel cell systems produce electricity, heat, and hydrogen, providing not only the expected high-quality electricity and heat, but also hydrogen for fueling fuel cell electric vehicles (e.g., light-, medium-, and heavy-duty vehicles, and cargo and materials handling equipment). On the utility side of the meter, fuel cells today provide clean generation and grid support at the distribution level. Through hybrid fuel cell-gas turbine technology (Figure 1), fuel cells can provide 24/7 renewable power generation to complement a high-penetration of intermittent, diurnal and seasonal varying wind and solar.

Figure 1. Hybrid Fuel Cell Gas Turbine System under Development by LG Fuel Cell Systems for the California Market

An additional benefit of fuel cell systems is the provision of 24/7, clean, load-following power with capacity factors at virtually 100%. This corresponds to the production of clean, renewable electric energy (MWh) per unit of capacity (MW) that is on the order of six (6) times that of solar power systems (assuming a 15% capacity factor for solar) and on the order of three (3) times that of wind power systems (assuming a capacity factor of 30% for wind). Thus, investments in fuel cell capacity produce vastly more renewable energy than wind or solar power systems per unit of capacity installed. Unlike investments in solar and wind power systems, installations of fuel cell systems can be used by the utility to (1) support capacity and reserve requirements that are used for grid reliability, and (2) serve as an alternative to increasing utility system transmission and distribution upgrades.

Criteria Pollutant Emissions. In addition to mitigating carbon emissions on natural and bio gas, and eliminating carbon emissions when operating on renewable hydrogen, fuel cells generate and emit zero emission of criteria pollutants. This is in sharp contrast to traditional combustion-based power generation options. For example, Figure 2 compares NOx emissions for various electricity generation sources. Natural gas combustion generator emissions are shown without post exhaust treatment (SCR), a strategy added to combustion generators to reduce the NOx emissions to meet permit levels. Fuel cell exhaust is virtually void of criteria pollutant emissions (i.e. no requirement of exhaust clean-up) and substantially below both the traditional combustion power plant best available control technology (BACT) bar and distributed generation (DG) certification levels. In the South Coast Air Quality Management District and other districts, fuel cells do not require permitting for deployment.

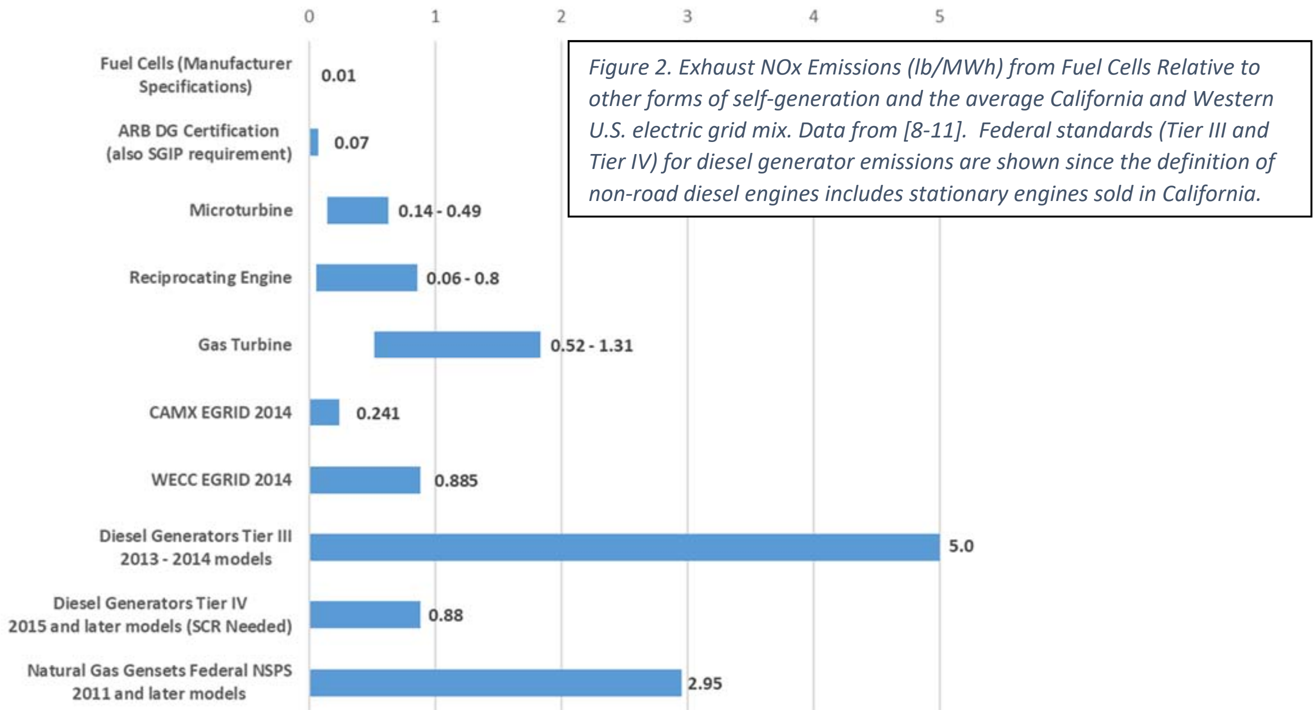

Figure 2. Exhaust NOx Emissions (lb/MWh) from Fuel Cells Relative to other forms of self-generation and the average California and Western U.S. electric grid mix. Data from [8-11]. Federal standards (Tier III and Tier IV) for diesel generator emissions are shown since the definition of non-road diesel engines includes stationary engines sold in California.

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