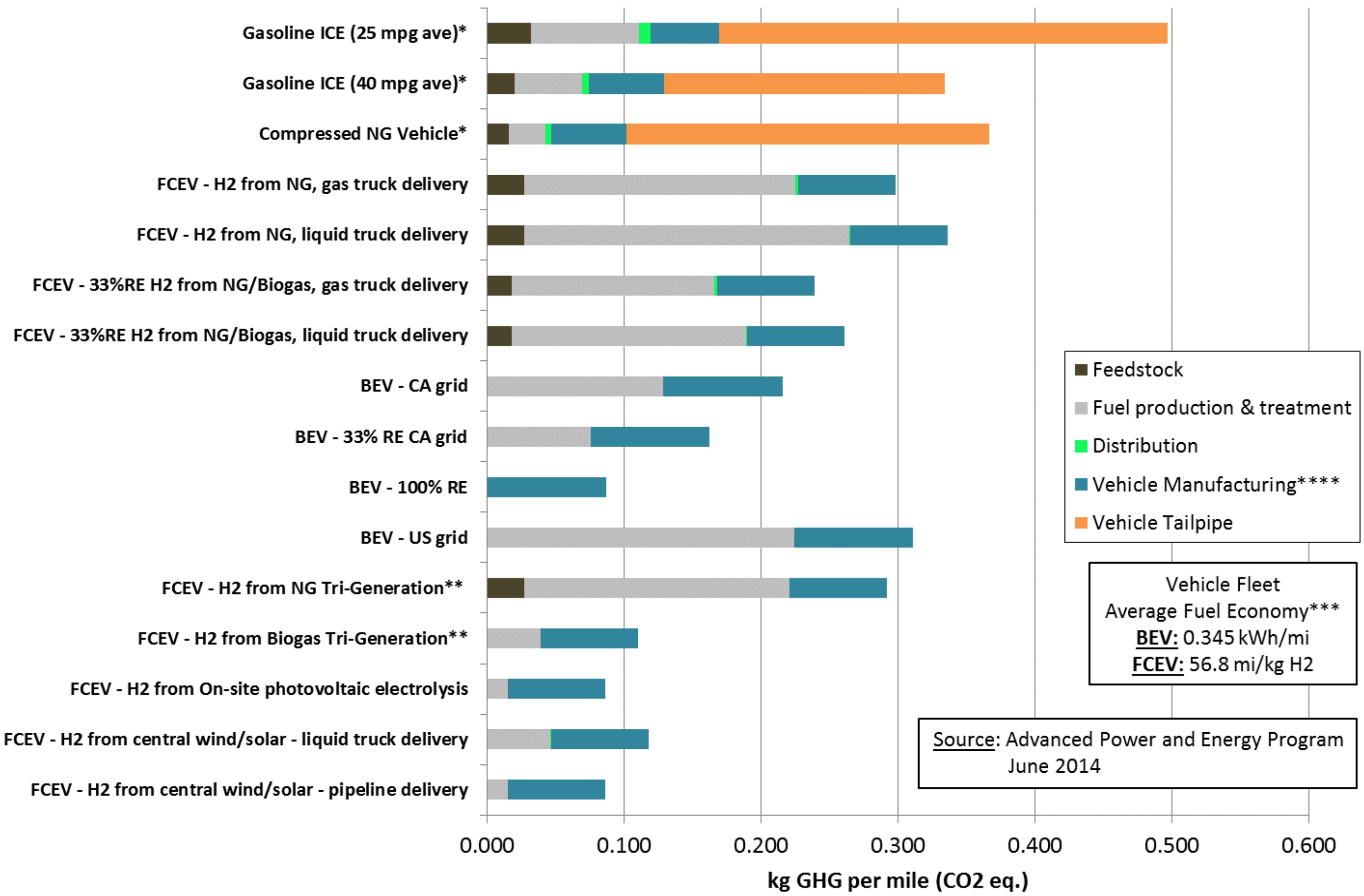
Well-to-Wheels Greenhouse Gas Emissions of Advanced and Conventional Vehicle Drive Trains and Fuel Production Strategies

Assessment and results produced by the Advanced Power and Energy Program at UC Irvine

A variety of advanced light-duty vehicle technology options are either on the road commercially today or expected to be retailed within the next few years. It is important to understand how these various transportation strategies will impact our greenhouse gas footprint based on their fuel production strategy, technology characteristics, and performance. While some advanced vehicle technologies emit zero emissions from the tailpipe (e.g., battery electric vehicles and fuel cell electric vehicles), there are still emissions associated with the upstream processes responsible for fuel production, treatment and delivery. The approach of assessing vehicle performance and impacts starting with the supply chain of the fuel all the way to the operation of the vehicle is called a well-to-wheels analysis.

The following graph has been produced based on a well-to-wheels analysis of vehicle types performed by the Advanced Power and Energy Program at UC Irvine gathering data from various sources in addition to using data obtained from industrial partners. The results, assumptions, and data associated with the results are regularly reviewed and updated annually or as the need arises to reflect the latest available information.



* Gasoline ICE and Compressed NG vehicle WTW information obtained from the Low Carbon Fuel Standard, except vehicle manufacturing.
**Tri-Generation is a novel technology that was conceived by the National Fuel Cell Research Center in 2001 to simultaneously generate electricity, hydrogen, and heat. It was developed into the first prototype in collaboration with FuelCell Energy, Inc., and Air Products and Chemicals, Inc. The first demonstration of this technology in the world is currently being demonstrated at the Orange County Sanitation District while operated on renewable biogas derived from the wastewater treatment process. For more information on Tri-Generation please visit: http://www.apep.uci.edu/3/research/partnership_TRI-GEN.aspx
***Fleet-wide average fuel economy is the representative fuel economy of the average vehicle in the light-duty vehicle fleet. This is a weighted average of the fuel economy of different size vehicles. Each vehicle class is weighted by their contribution to the total light-duty vehicle fleet according to the CARB EMFAC model.
****Vehicle manufacturing emissions obtained from automaker data input.

Electric Energy Input Requirements for Electricity-Based Vehicle Fueling Pathways

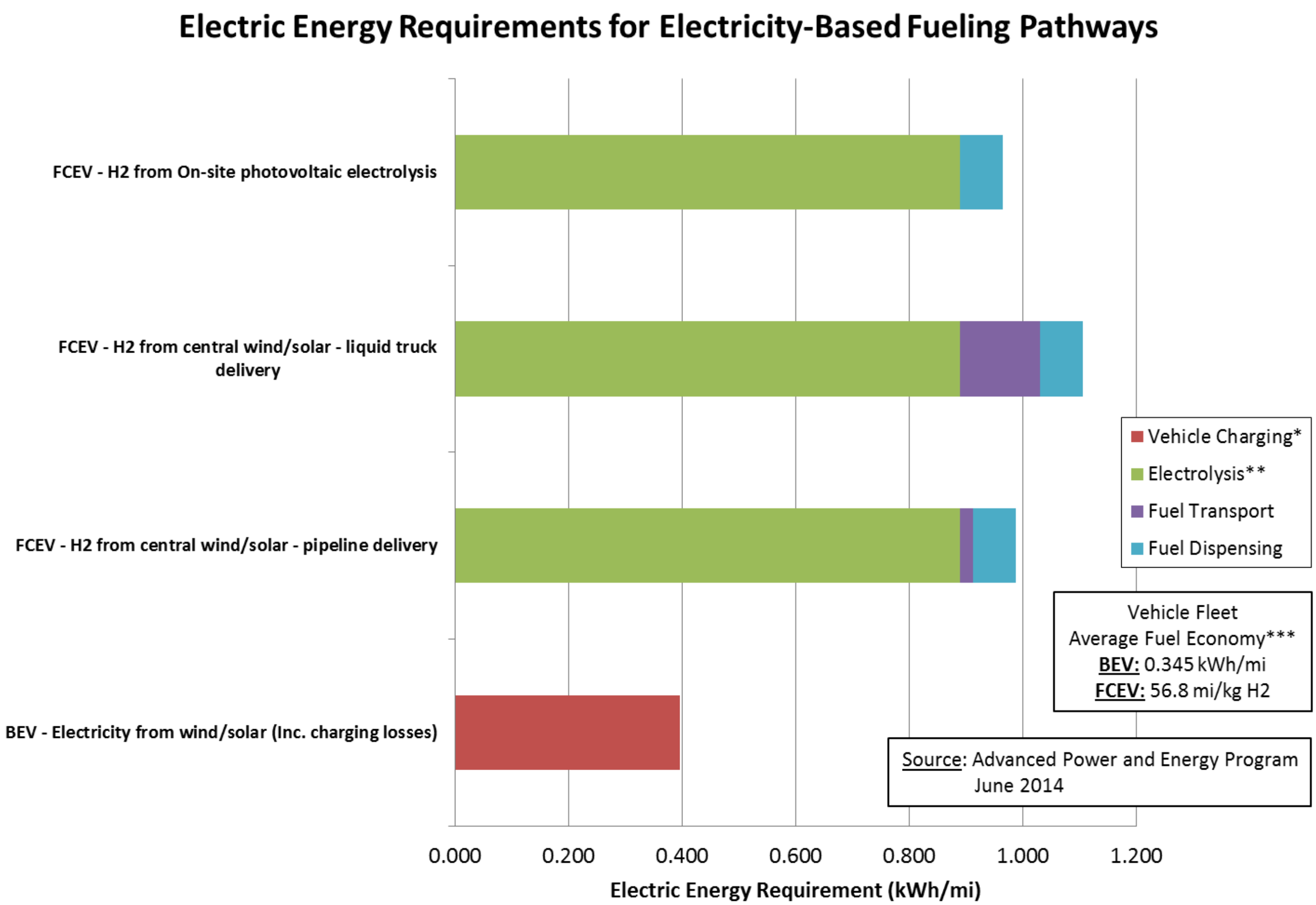
Many potential vehicle fueling pathways utilize electric energy either directly as vehicle fuel or as primary drivers for fuel production, transport, and dispensing processes. When using renewable energy, the carbon footprint of these pathways may be similar, but the amount of energy required to provide vehicle fuel varies between different pathways and infrastructure configurations.

These results assume that renewable power generation from wind and solar is fully captured and used to either charge electric vehicles or produce hydrogen fuel. For this assumption to be true in the real-world system, the profile of the BEV charging load or the hydrogen electrolysis load must be shaped to follow the generation profile of the wind and solar power installations in time. Because wind and solar power are highly variable, achieving this ideal on a continuing basis requires inherently different solution strategies for BEVs as compared to FCEVs.

By way of explanation, for BEVs the electric load profile is determined by travel demand patterns which limit how well the load profile can be shaped to follow renewable generation even with smart charging. Overcoming this obstacle requires the installation of electric energy storage. For FCEVs, hydrogen production does not have to occur at the same time as vehicle fueling due to inherent hydrogen storage capability in the associated production and distribution infrastructure. Therefore, the electric load profile of hydrogen electrolysis can be more easily shaped to capture variable renewable generation at the expense of requiring more input energy.

BEVs and FCEVs both powered by renewables, represent two different scenarios for greenhouse gas reductions. The BEV scenario has higher energy efficiency and builds off existing infrastructure, but may require large amounts of electric energy storage to realize emissions benefits in the real-world system. The FCEV pathway has lower energy efficiency and requires more infrastructure construction, but may require little to no electric energy storage to realize emissions benefits in the real-world system. Investigation of the relative importance and role of these factors, and the associated economic ramifications, is the subject of ongoing research at UCI. Please visit: Impact of Grid Integration on Greenhouse Gas Emissions.

The graph on the following page captures the required electric energy inputs per mile of travel for different vehicle fueling pathways, gathering data from various sources in addition to data obtained from industry partners. The results, assumptions, and data associated with the results are regularly reviewed and updated annually or as the need arises to reflect the latest available information.



* Includes energy required to overcome losses in electric vehicle charging equipment in addition to the vehicle energy requirement.
**Represents entire electrolyzer system including balance-of-plant for current state-of-the-art systems as tested by NREL.
***Fleet-wide average fuel economy is the representative fuel economy of the average vehicle in the light-duty vehicle fleet. This is a weighted average of the fuel economy of different size vehicles. Each vehicle class is weighted by their contribution to the total light-duty vehicle fleet according to the CARB EMFAC model.