# The Path to Zero Carbon for Data Centers - Hydrogen

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## Overview

This white paper presents a comprehensive analysis of the carbon footprint implications associated with the use of diverse hydrogen supplies globally for powering data centers. It highlights Hydrogen's potential as an alternative primary power source for data centers, especially in relation to the national power grid. The document conducts a thorough comparative evaluation of microgrid-based solutions versus conventional grid-connected approaches, concentrating on critical factors like carbon intensity and emissions.

The industry identifies three tiers of carbon footprint sources:
1. Scope 1 Emissions: Scope 1 includes emissions from sources that an organization owns or controls directly.
2. Scope 2 Emissions: Scope 2 encompasses indirect emissions resulting from the generation of purchased and consumed energy. For instance, emissions from electricity generation used in our buildings fall under this category.
3. Scope 3 Emissions: Scope 3 covers emissions that a company does not directly produce or result from assets it owns or controls. Instead, these emissions arise indirectly from the company's value chain activities; Scope 3 includes all emission sources outside the Scope 1 and 2 boundaries.

The paper also outlines the essential steps to achieve zero emissions in data center operations, particularly focusing on micro-grid and off-grid applications. A substantial part of the paper is devoted to the discussion of the ECL solution, a hydrogen-based power system designed to operate continuously for data centers, ensuring zero emissions and maintaining a zero Scope 1 and 2 carbon footprint.

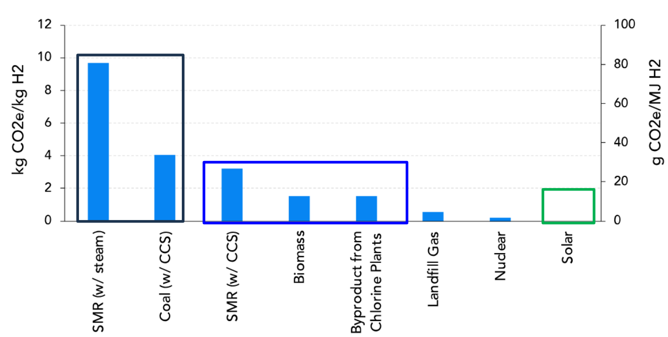
To validate the effectiveness of the ECL solution, the analysis contrasts the carbon footprint of conventional grid power, encompassing Scope 1, Scope 2, and potentially Scope 3 emissions, with that of on-site Hydrogen micro-grid power generation, as exemplified by ECL's model. This comparison is intended to underscore the environmental benefits and the substantial potential for carbon footprint reduction when adopting hydrogen-based power solutions in data center contexts.

## Hydrogen Color Code and Carbon

Common to the industry, Hydrogen is categorized by virtual color categories to represent its carbon intensity and the energy source used in its production. We will specifically concentrate on three types of Hydrogen: Grey, Blue, and Green. Please refer to the appendix for a comprehensive understanding of the hydrogen color scheme.

Initiating our discussion on Hydrogen, we have included a detailed graph in the appendix. This graph presents the average carbon intensity associated with various hydrogen production methods, correlated with their respective colors in the hydrogen spectrum. This visual representation aids in elucidating the environmental impact and sustainability of each hydrogen type, providing a clearer understanding of the implications of choosing one type over another for various applications.

**Figure 2. Well-to-Gate (WTG) Carbon Intensity (kg CO2e/kg H2) of Hydrogen Production by Pathway from GREET 2021**



## GREY HYDROGEN

The production of grey Hydrogen primarily uses natural gas, Methanol, and Ethanol as feedstock. The process involves steam methane reforming (SMR), where methane ($CH_4$) from natural gas reacts with steam ($H_2O$), resulting in the production of Hydrogen, carbon monoxide, and a small amount of carbon dioxide. It's noteworthy that SMR is the predominant method for hydrogen production globally, accounting for approximately 95% of current output.

A key characteristic distinguishing grey Hydrogen from other forms produced via SMR is the absence of carbon capture and sequestration (CCS). In the case of grey Hydrogen, the $CO_2$ and CO generated during the reforming process are emitted directly into the atmosphere without any capture or storage. Despite this, grey Hydrogen is typically regarded as having a moderate impact on greenhouse gas (GHG) emissions, producing slightly less than black and brown hydrogen variants.

When quantifying its environmental impact, grey hydrogen production results in an emission range of approximately 4 to 9.5 kilograms of $CO_2$ for every kilogram of Hydrogen produced. For the purposes of our analysis, we will adopt an average emission figure, assuming an offset of around **7 kilograms** of $CO_2$ per kilogram of Hydrogen (**Grey**). This assumption allows for a more standardized and realistic assessment of the environmental footprint associated with grey hydrogen production.

## BLUE HYDROGEN

Blue Hydrogen represents an advancement over grey, black, and brown Hydrogen in terms of reducing carbon emissions. This variant not only uses natural gas (or occasionally coal) in steam methane reforming (SMR) to produce Hydrogen, but it also integrates carbon capture and sequestration (CCS) into the process. Essentially, CCS captures the carbon dioxide and carbon monoxide generated during SMR, preventing their release into the atmosphere and instead storing them underground. This method offers a low-carbon alternative to traditional hydrogen production methods. Interestingly, it's possible to achieve carbon-negative blue Hydrogen.

This more sustainable version of blue Hydrogen utilizes Renewable Natural Gas (RNG) instead of conventional fossil-based natural gas. RNG is derived from capturing methane emissions from agricultural sites, landfills, and wastewater treatment plants, which would otherwise contribute to greenhouse gas emissions. Depending on the source, RNG can have a Carbon Intensity (CI) score ranging from -530 to 80, with lower scores indicating better environmental performance. The most environmentally beneficial type of RNG comes from dairy farms, with CI scores between -530 and -150.

When traditional grey Hydrogen is converted to blue Hydrogen using CCS, the carbon intensity of blue Hydrogen is estimated to be between 2.75 and 3.5 kilograms of $CO_2$ per kilogram of Hydrogen. For our calculations, we will use an average emission figure of **3 kilograms** of $CO_2$ per kilogram of Hydrogen (**Blue**), providing a standardized measure for evaluating its carbon footprint. This approach helps assess the environmental benefits of blue Hydrogen, particularly in comparison to other Hydrogen types.

## GREEN HYDROGEN

Green Hydrogen is renowned for its exceptionally low carbon impact, making it a highly sustainable energy source. It is produced through water electrolysis using electricity exclusively from renewable sources such as wind, solar, hydropower, or tidal power. In regions like California, for instance, green Hydrogen generated using solar or wind power can have a Carbon Intensity (CI) score of 10.51, per the California Air Resources Board's (CARB) hydrogen Lookup Table.

However, there are significant considerations regarding green Hydrogen, notably its production cost. As of 2020, producing green Hydrogen was two to three times more expensive than producing blue Hydrogen. The International Energy Agency (IEA) reported in 2021 that the cost for Hydrogen produced using an electrolyzer ranged from $3 to $8 per kilogram, despite accounting for only about 0.03% of all hydrogen production. Recognizing green Hydrogen's potential in decarbonizing various operations, especially those reliant on or transitioning to Hydrogen, there is a concerted effort to reduce the costs associated with electrolyzers. This effort is bolstered by the incentives provided by the 2022 Inflation Reduction Act (IRA).

For the purpose of our analysis, green Hydrogen is considered to have a zero-carbon footprint. Therefore, our calculations will assume a carbon emission of **0 kilograms** of CO2 per kilogram of Hydrogen (**Green**). This assumption highlights green Hydrogen's role as a clean and renewable energy source with significant potential for contributing to global decarbonization efforts.

## Hydrogen Power Carbon Footprint

When it comes to operating a microgrid for hydrogen-based power generation, the prevalent approach involves using hydrogen fuel cells. Although alternative methods exist, this paper will specifically focus on fuel cell-based power generation systems. We'll explore three primary models for hydrogen sourcing for on-site generation and their impact on the carbon footprint.

1. Pipeline Delivery ("Over the Fence"): This method involves Hydrogen being delivered directly via a pipeline. A key advantage of pipeline delivery is its negligible carbon footprint, meaning the overall carbon footprint of the Hydrogen is solely from its production, as detailed previously.

2. Delivery by Truck: This method involves transporting Hydrogen by truck, which adds a transportation-related carbon footprint. The carbon emissions for truck delivery depend on the distance from the production site to the delivery location as well as the type of vehicle. We will consider two scenarios:

- Hydrogen Truck Delivery: This method involves using trucks powered by hydrogen fuel cell engines. It is characterized by a zero-carbon footprint, aligning with the sustainability goals of hydrogen energy.

- Diesel Truck Delivery: In this scenario, we consider the carbon emissions from a typical diesel truck. The emissions are calculated based on:
  - The average CO2 emission is 75 grams per ton per kilometer.
  - The capacity of a hydrogen delivery truck to carry 8 tons of liquid Hydrogen, resulting in an emission of approximately 0.6 kg of CO2 per kilometer.
  - Assuming a typical delivery distance of 800 kilometers (approximately 500 miles), this equates to a total of 480 kg of CO2 for a delivery of 8000 kg of Hydrogen.

These two delivery methods will be evaluated for our analysis to determine their impact on the overall carbon footprint of hydrogen-based power generation systems. This approach allows for a comprehensive understanding of the environmental implications of different hydrogen delivery methods.

3. The on-site hydrogen generation method will be addressed separately in another document.

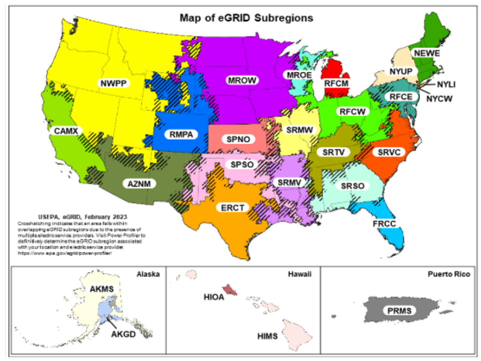
## Grid Carbon Footprint

In conventional power planning, there's a common perception that the electrical grid is relatively clean, often described with terms like "50% renewable energy grid" or "green grid." However, the actual carbon footprint of grid-delivered power often diverges significantly from these idealized descriptions. This discrepancy becomes particularly evident when examining the carbon intensity of grid electricity in various states across the United States.

To provide a more accurate and realistic perspective, the following table presents the typical carbon footprint associated with grid-delivered power in different U.S. states, alongside the national average. These values are crucial for our analysis as they offer a baseline for comparing the carbon efficiency of traditional grid power against alternative power sources like Hydrogen.

This data serves as a key reference point for our calculations, enabling us to assess the environmental impact of relying on the grid for power and to contrast it with the potential benefits of transitioning to cleaner energy solutions. By presenting state-specific data alongside the U.S. average, the table helps to highlight regional variations in grid cleanliness, which is an essential factor in evaluating the overall effectiveness and sustainability of power planning strategies.

| Region/State | Kg CO2/MWh |
|---|---|
| California -CAMX | 242 |
| Mid-West – SRMW | 705 |
| Virginia/Carolina -SRVC | 291 |
| Michigan - RFCM | 554 |
| Oahu - HIOH | 746 |
| RFC – East – RFCE | 306 |
| RFC – West – RFCE | 477 |
| MRO East - MROE | 722 |
| | |
| US Average | 453 |




Source: "Power Profiler ZIP Code Tool with eGRID2021 Data" - https://www.epa.gov/egrid/power-profiler#/

In many grid-based data centers, diesel generators are commonly used as backup systems to provide power during grid outages. Typically, these diesel generators are run for about 100 hours per year for testing and maintenance purposes.

Brian Soucy, in his analysis (found at https://www.linkedin.com/pulse/carbon-footprint-diesel-generators-brian-soucy/), provides an insightful look into the carbon emissions associated with these generators. According to his research, a 2MW diesel generator produces annual emissions of approximately 159,000 kg. When this figure is broken down based on the generator's operation (assuming 200 hours of operation at 2MW capacity), it translates to an emission rate of 397 kg of CO2 per MWh.

Integrating these figures into the broader picture of data center operations, the use of diesel generators as backup power sources results in an increase of about 2.2% in the carbon footprint for each location. Therefore, when considering the inclusion of diesel generation, the average carbon footprint for power in the United States increases to around 463 kg of CO2 per MWh. This adjustment provides a more comprehensive understanding of the environmental impact of data center operations, highlighting the significance of backup power choices in the overall carbon footprint.

## Data Centers Power Carbon Footprint

According to the Boston Consulting Group (BCG), data centers currently represent 2.5% of U.S. electricity consumption.
By 2030, BCG estimates that data centers could consume 7.5% of all electricity in the U.S.
A fuel cell system to generate 24/7 power will consume 65kg of Hydrogen per MWh.
If we apply the carbon intensity of the different Hydrogen colors, the table below represents the carbon footprint of a Hydrogen data center.

| Hydrogen Type | Carbon per Hydrogen Kg | Kg Per MWh-Pipeline | Kg Per MWh-Delivered | Kg CO2/MWh |
|---|---|---|---|---|
| Grey | 7 | 65 | 69 | 455-483 |
| Blue | 3 | | | 195-207 |
| Green | 0 | | | 0 |
| | | | | |
| US Average Grid | | | | 453 |

The data presented in the above table reveals a compelling insight: even when powering a data center with grey Hydrogen, its carbon footprint is comparable to the average U.S. grid power. This means that using grey Hydrogen for data centers is a more environmentally friendly option than over half of the power sources currently used across the United States.

The environmental benefits are even more pronounced when using blue Hydrogen. In this scenario, the carbon footprint of a data center powered by blue Hydrogen is lower than that of any U.S. grid, underscoring its significant advantage in reducing greenhouse gas emissions.

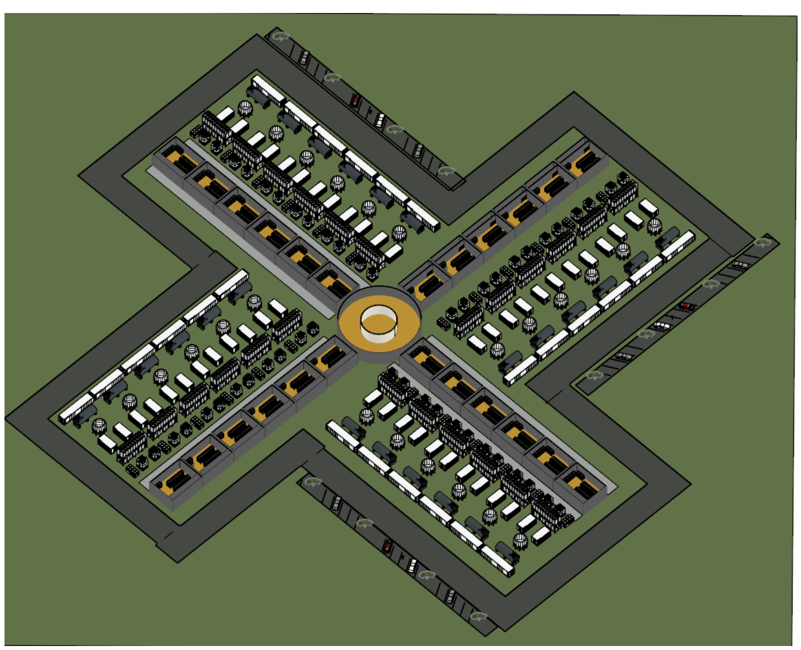
The most environmentally beneficial option is green Hydrogen, which enables data centers to achieve end-to-end zero emissions from production to delivery to the IT. This aligns with the most ambitious sustainability goals, making it an ideal solution for eco-conscious operations.

Furthermore, when Hydrogen is produced from Renewable Natural Gas (RNG), it can enhance the environmental performance of both blue and grey hydrogen-based operations. RNG-derived Hydrogen can match or surpass the low carbon footprint of green hydrogen generation. This versatility in hydrogen production underscores its potential as a transformative energy source for data centers, offering a range of solutions to meet diverse environmental and operational needs.

## The Path for Zero-Emission Data Centers – The ECL solution

This document establishes a compelling case for integrating Hydrogen micro-grid power generation as a critical component in the roadmap towards achieving zero-emission data centers. Our analysis demonstrates that utilizing any form of Hydrogen—grey, blue, or green—can significantly impact future data centers' environmental footprint. While the widespread availability and adoption of green Hydrogen across various U.S. locations may take some time, initiating the transition with a blended hydrogen approach can set a solid foundation for achieving zero-emission facilities.

At ECL, we are committed to embracing the potential of green Hydrogen to achieve zero emissions and acknowledging the substantial environmental benefits of using blue or grey Hydrogen in the interim. Our ongoing projects are geared towards this objective, aiming to significantly contribute to a cleaner and more sustainable transition in the data center industry. The image below shows an example of a zero-emission 24MW site.



For more information about our initiatives and progress in this endeavor, we invite you to visit our website at www.ecldc.com. Here, you can stay updated with our latest developments and learn more about how we are actively working towards a future of zero-emission data centers, leveraging the transformative potential of hydrogen-based power solutions.

# Appendix A

## WHITE HYDROGEN

The concept of 'White Hydrogen' might be unfamiliar to many, and understandably so, given its relatively recent emergence in the field of energy research. White Hydrogen refers to Hydrogen that is geologically and naturally occurring, found in underground deposits. This form of Hydrogen presents an intriguing subject for scientific and industrial communities.

As of the current state of research, the practical application of White Hydrogen remains largely unexplored. Scientists and researchers have identified these underground hydrogen deposits, but they are still in the process of developing viable methods for extracting and utilizing this Hydrogen effectively. The potential of White Hydrogen is significant, as it could offer a natural and potentially sustainable source of Hydrogen. However, the journey from discovery to practical application is still in its early stages, and more research and development are needed before White Hydrogen can become a feasible part of our energy landscape.

## BLACK HYDROGEN

Black Hydrogen is produced through the gasification of black coal, also known as bituminous coal. This process involves subjecting the coal to extremely high temperatures, exceeding 700°C (or 1,292°F), to decompose fossil-based or organic carbonic materials without actual combustion. Instead, this transformation is achieved through a controlled introduction of oxygen and/or steam, which breaks down the black coal into a mixture of Hydrogen (H2), carbon dioxide (CO2), and carbon monoxide (CO).

This process is critical to separating Hydrogen from the other chemical compounds produced during gasification. However, a significant environmental concern arises from the fact that the CO2 and CO generated during this process are typically released into the atmosphere. This release contributes to a substantial carbon footprint, making black Hydrogen one of the less environmentally friendly forms of hydrogen production. Due to its high carbon impact, black Hydrogen is often less favored in discussions about sustainable energy solutions and the transition to a low-carbon economy.

## BROWN HYDROGEN

The primary distinction between brown and black Hydrogen lies in the type of coal used for their production. Brown Hydrogen is generated through the gasification of brown coal, commonly referred to as lignite. This process is similar to that used for black Hydrogen, where high temperatures are employed to break down the coal into various chemical compounds.

During the gasification of lignite to produce brown Hydrogen, significant amounts of carbon dioxide (CO2) and carbon monoxide (CO) are released as byproducts. These gases are potent greenhouse gases, contributing to the overall carbon footprint of brown Hydrogen. Consequently, like black Hydrogen, brown Hydrogen is also considered a carbon-intensive alternative due to the substantial greenhouse gas emissions associated with its production process. This aspect of brown hydrogen production highlights its environmental implications and positions it as a less sustainable option in the context of the global shift towards cleaner and greener energy sources.

## TURQUOISE HYDROGEN

Turquoise Hydrogen is generated through a process known as pyrolysis, which involves the decomposition of methane (CH4), typically sourced from natural gas, under extremely high temperatures. This process results in the production of Hydrogen (2H2) and solid carbon (C), a distinct output compared to other hydrogen production methods.

A notable advantage of turquoise Hydrogen is that, unlike the processes used to produce grey, blue, or brown Hydrogen, it does not result in carbon dioxide (CO2) or carbon monoxide (CO) emission. This absence of gaseous carbon emissions qualifies turquoise Hydrogen as a low-carbon alternative, setting it apart from other more carbon-intensive hydrogen production methods.

However, it is important to note that the production of turquoise Hydrogen is currently at an experimental stage. The viability and efficiency of this process on a commercial scale have yet to be fully established and proven. As such, while turquoise Hydrogen presents a promising low-carbon option for hydrogen production, further research, development, and testing are required to determine its practicality and sustainability in larger-scale applications.

## YELLOW HYDROGEN

Yellow Hydrogen is a term used to describe Hydrogen produced using grid electricity, which is typically derived from a mix of various energy sources. This mixture can include renewable sources like solar and wind and conventional fossil fuels such as coal or natural gas. The key process in producing yellow Hydrogen is electrolysis, where an electric current is used to split water molecules into Hydrogen and oxygen.

The carbon footprint of yellow Hydrogen is considered moderate, but it varies significantly depending on the composition of the grid electricity used for electrolysis. If the electricity is predominantly generated from high-carbon sources like coal or natural gas, the resulting Hydrogen's Carbon Intensity (CI) score will be higher, indicating a greater environmental impact. On the other hand, if the electricity is sourced primarily from low-carbon or renewable sources, the CI score will be lower, reflecting a more environmentally friendly production process.

This variability in carbon impact makes yellow Hydrogen a flexible yet complex option. It highlights the importance of the energy mix in the grid and its role in determining the overall sustainability of Hydrogen produced through this method. As the proportion of renewable energy in the grid increases, yellow Hydrogen has the potential to become a more sustainable and lower-carbon energy source.

## PINK/PURPLE/RED HYDROGEN

Hydrogen produced through nuclear energy is commonly referred to by several color designations: pink, purple, or red Hydrogen. Despite the different names, the production method for all these types is identical. This process involves using steam, which is generated in nuclear power plants, and passing it through an electrolyzer. The electrolyzer then performs the task of splitting the steam into two primary components: pure Hydrogen and oxygen.

One of the most significant advantages of this method is the lack of direct carbon emissions associated with the production process. Since nuclear power plants generate steam without combusting fossil fuels, the greenhouse gas (GHG) impact of producing pink, purple, or red Hydrogen is minimal. This positions it as a low-carbon hydrogen production method, offering an environmentally friendly alternative compared to methods that rely on fossil fuels.

This form of hydrogen production leverages the established infrastructure and energy generation capabilities of nuclear power plants, making it an intriguing option in the context of global efforts to reduce carbon emissions and transition to cleaner energy sources. However, it's important to consider nuclear power generation's broader environmental and safety aspects when evaluating the overall sustainability of pink, purple, or red Hydrogen.

Reference: https://www.usgain.com/resources/education-center/the-9-colors-and-carbon-impacts-of-hydrogen/