

## Article

# Navigating the Implementation of Tax Credits for Natural-Gas-Based Low-Carbon-Intensity Hydrogen Projects

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**Abstract:** This paper delves into the critical role of tax credits, specifically Sections 45Q and 45V, in the financing and economic feasibility of low-carbon-intensity hydrogen projects, with a focus on natural-gas-based hydrogen production plants integrated with carbon capture and storage (CCS). This study covers the current clean energy landscape, underscoring the importance of low-carbon hydrogen as a key component in the transition to a sustainable energy future, and then explicates the mechanics of the 45Q and 45V tax credits, illustrating their direct impact on enhancing the economic attractiveness of such projects through a detailed net present value (NPV) model analysis. Our analysis reveals that the application of 45Q and 45V tax credits significantly reduces the levelized cost of hydrogen production, with scenarios indicating a reduction in cost ranging from USD 0.41/kg to USD 0.81/kg of hydrogen. Specifically, the 45Q tax credit demonstrates a slightly more advantageous impact on reducing costs compared to the 45V tax credit, underpinning the critical role of these fiscal measures in enhancing project returns and feasibility. Furthermore, this paper addresses the inherent limitations of utilizing tax credits, primarily the challenge posed by the mismatch between the scale of tax credits and the tax liability of the project developers. The concept and role of tax equity investments are discussed in response to this challenge. These findings contribute to the broader dialogue on the financing of sustainable energy projects, providing valuable insights for policymakers, investors, and developers in the hydrogen energy sector. By quantifying the economic benefits of tax credits and elucidating the role of tax equity investments, our research supports informed decision-making and strategic planning in the pursuit of a sustainable energy future.

**Keywords:** low-carbon intensity; hydrogen; tax credit; project finance

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## 1. Introduction

The global energy landscape is undergoing a significant transformation, driven by the urgent need to address climate change and the collective shift towards a clean energy economy. Hydrogen, especially low-carbon-intensity hydrogen, stands at the forefront of this transition, promising to bridge the gap where direct electrification is challenging, such as in the heavy industry and transport sectors [1–4]. Unlike conventional hydrogen production, low-carbon-intensity hydrogen can be produced through various processes, from fossil fuels to renewables, significantly reducing greenhouse gas emissions and aligning with global sustainability goals [5–8]. This contextual shift underscores the critical need for our research, pinpointing the vital role of policy mechanisms, such as tax credits, in facilitating this transition.

Incentivizing this shift, the US government introduced specific tax credits under the Inflation Reduction Act—Sections 45Q and 45V. Section 45Q is designed to encourage carbon capture and sequestration (CCS) technologies, while Section 45V specifically targets clean hydrogen production [9,10]. These policy measures are instrumental in reducing the financial burden of adopting emerging—often expensive—clean technologies, making

low-carbon hydrogen projects more economically viable and attractive to investors and developers [11,12].

The economic feasibility of a hydrogen project hinges significantly on the ability to maximize financial incentives and minimize costs. While the potential of tax credits like 45Q and 45V to transform the project economics, potentially shifting a project from marginal to financially attractive, is recognized, their practical application and impact is not straightforward, and there is a significant gap in understanding their practical applications and project impacts. This gap hinders stakeholders' ability to leverage these financial incentives fully, thereby impeding progress toward a low-carbon energy future.

Therefore, our study aims to address this critical gap by elucidating the mechanics of the 45Q and 45V tax credits and assessing their direct impact on the economic attractiveness of low-carbon-intensity hydrogen projects. Additionally, we will explore the inherent limitations of utilizing these tax credits, focusing on the challenges posed by the scale of tax credits in relation to the tax liability of project developers. A secondary objective involves examining the role and concept of tax equity investments to navigate these challenges, thus enabling the effective monetization of the tax credits.

Central to our investigation are several research questions that guide the scope of our analysis: How do the 45Q and 45V tax credits influence the economic feasibility of natural-gas-based low-carbon-intensity hydrogen production projects? What are the main barriers to fully utilizing these tax credits, and how do they impact project development and investment decisions? Lastly, how can tax equity investments overcome the limitations of direct tax credit utilization, and what implications does this have for scaling low-carbon hydrogen projects?

In a landscape where economic viability is closely tied to policy incentives, a comprehensive grasp of tax credit implementation is not just beneficial; it is essential for the successful deployment and scaling of low-carbon hydrogen projects. By addressing these pivotal questions, our study seeks to provide valuable insights for policymakers, project developers, and investors on optimizing the benefits of tax credits to advance low-carbon hydrogen production.

## 2. Literature Review

The development of low-carbon hydrogen, particularly through pathways that minimize environmental impact, is crucial for addressing climate change challenges. Equally important is the policy landscape that shapes the economic and technological environment within which hydrogen projects are conceptualized and implemented via incentivizing investment decisions by firms [13]. Yang et al. provide an in-depth analysis of how renewable energy sources, coupled with effective policy support, are key to unlocking the potential of low-carbon hydrogen production, emphasizing the urgency of integrating these elements for a successful energy transition [14]. This chapter delves into the dual avenues of technological innovation and policy support, highlighting their pivotal roles in the hydrogen sector's evolution. This current study focuses on how to apply policy support to lower the cost of the production pathway. Hence, it is critical to form a solid understanding through the current research body of relevant background knowledge on the hydrogen production pathway, life-cycle emission, and the current mechanism of tax credits available for natural-gas-based hydrogen production.

### 2.1. Natural-Gas-Based Hydrogen Production Pathways and Life-Cycle Emissions

Natural-gas-based production, integrated with carbon capture and sequestration (CCS), remains one of the most cost-competitive options [15]. Integrating carbon capture and storage (CCS) with these technologies further enhances their appeal by mitigating CO<sub>2</sub> emissions associated with hydrogen production. Steam methane reforming (SMR) is the most mature method for hydrogen production, reacting methane with steam to produce hydrogen and carbon monoxide (CO), followed by a water shift reaction (WGS) that further generates hydrogen by reacting CO with water to produce H<sub>2</sub> and CO<sub>2</sub> [5,6,16]. SMR is

an established technology, making it cost-effective, especially for large-scale operations. The carbon footprint, substantial without CCS, can be mitigated by integrating CCS. In a typical modern SMR plant, about 60% of the total CO<sub>2</sub> produced is contained in the tail gas; after, it is contained in the WGS unit and then in the pressure swing absorption unit (PSA), as indicated in Figure 1, with the remaining 40% of CO<sub>2</sub> being the product of fuel combustion that provides heat input to the steam reformer, combined with some recycled vent gas. For brownfield projects, where existing infrastructure is leveraged, or for smaller-scale projects, SMR is often a better choice due to lower retrofitting costs and process familiarity. SMR with a CCS capture rate above 90% is widely accepted as feasible [17–21]. However, as of now, there has been no actual demonstration to date, and existing setups allow for around 40–45% carbon capture rates [18], as these facilities are integrated into refineries and ammonia plants where the plant design was not specifically designed for low-carbon-intensity hydrogen.

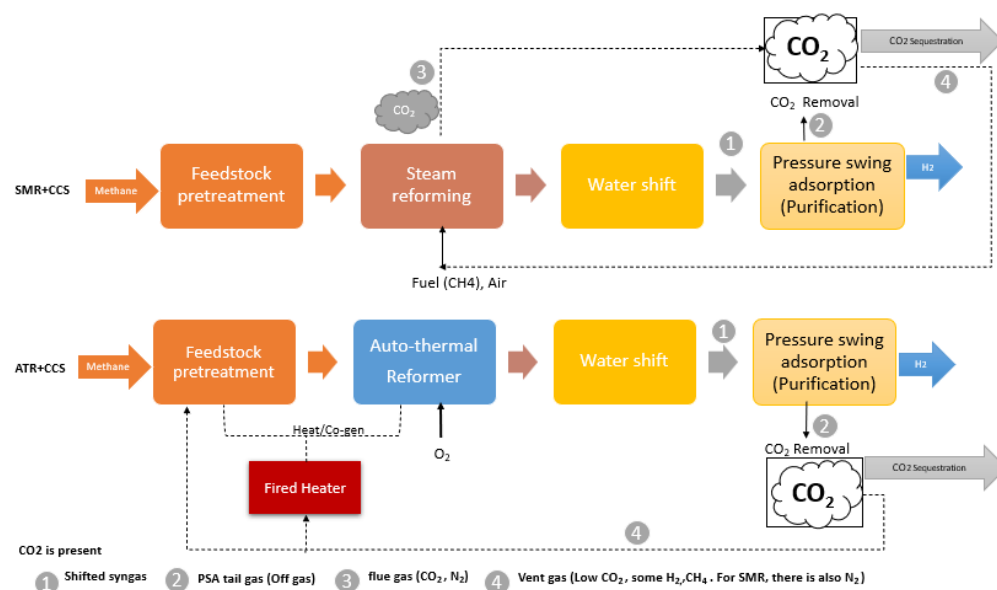


**Figure 1.** Hydrogen production via steam methane reforming (SMR) and autothermal reforming (ATR) with carbon capture (In traditional SMR processes, 60% CO<sub>2</sub> is captured from steam/shifted syngas, while the rest of flue gas with low purity is not captured. The ATR process has one single stream of CO<sub>2</sub> from steam that is simpler for higher capture efficiency).

With the emphasis on low-carbon-intensity hydrogen, autothermal reforming (ATR) as a hydrogen production technology has gained more momentum. ATR uses oxygen and steam, allowing for a more thermally efficient process. While complex and with higher capital costs due to the integration of air separation units, ATR systems benefit from reduced flue gas volumes, enhancing the efficiency of CO<sub>2</sub> capture [22]. This makes ATR an attractive option for greenfield projects where new facilities are being constructed. Its lower carbon footprint, particularly with high CCS efficiency, is a key advantage and can capture up to 95% of emissions [5,17–19,23].

When evaluating the on-site CO<sub>2</sub> footprint of a hydrogen production facility, whether utilizing SMR or ATR, key determinants include the specific design of the plant and operational parameters. Although ATR may generally offer a lower carbon footprint, especially when coupled with efficient CCS, the final CO<sub>2</sub> emissions are heavily influenced by the plant's specific design, feedstock, energy sources, and actual integration level of CCS technologies. For example, advancements in post-combustion capture designs could improve the efficiency of SMR's CCS process [5,6,17–19,24].

Aligning hydrogen production with decarbonization goals requires a broader concept of life-cycle emissions, encompassing existing infrastructure, the pathway of upstream

feedstock, the carbon intensity of regional electricity grids, and the design specifics of CO<sub>2</sub> capture systems. Such a holistic approach ensures that the decarbonization potential of hydrogen technology is fully realized, acknowledging a more comprehensive picture of a technology's environmental impact. An accurate estimate of the carbon footprint associated with hydrogen production from natural gas requires accounting for the various sources of emissions from well to the point of use, as shown in Figure 2. Hence, it becomes clear that the choice between SMR and ATR is not straightforward and is contingent upon a multitude of factors beyond just the immediate CO<sub>2</sub> emissions. The full life-cycle emissions include all the emissions from all energy expended from the extraction and transportation of natural gas (upstream emissions), emissions associated with imported electricity used in production, the hydrogen production process (e.g., SMR or ATR), and the carbon capture process including capture, transport, and storage [24–26]. For instance, in regions where the electricity grid has high emissions or lacks renewable sources, ATR's life-cycle emissions could exceed those of SMR [16–18].

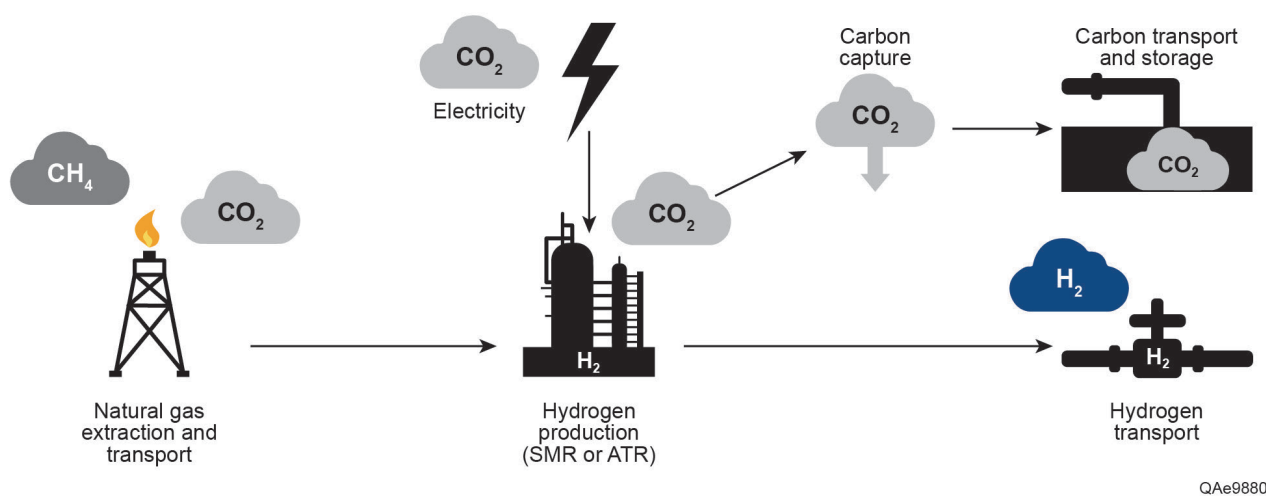


**Figure 2.** Life-Cycle Emission of Natural-Gas-Based Hydrogen.

Figure 3 demonstrates a wide range of carbon intensities for natural-gas-based hydrogen production due to different production technologies and capture rates. Furthermore, it is important to recognize that these intensities shown are only the median and the BAT (best available technology) figures from selected sources; the life-cycle emission of each production path could range widely because of factors such as transportation leakage rate, electricity grid carbon intensity, specific conditions, and regulations of the production location [18,22,27,28]. With multitudes of factors and emission impacts, policies aimed at subsidizing clean hydrogen production, particularly those that account for the full spectrum of life-cycle emissions, can play a critical role in shaping the adoption of technologies like ATR and SMR with CCS and will be discussed further in the following section.

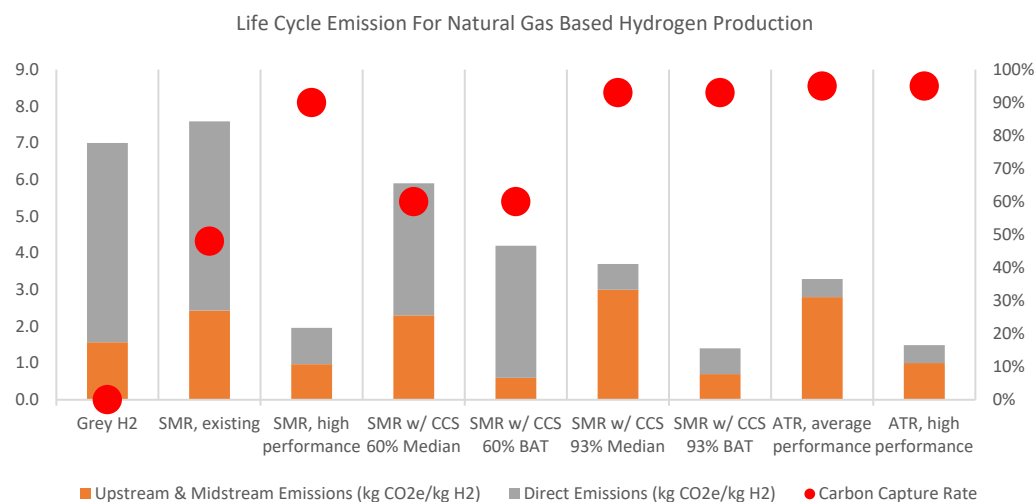


**Figure 3.** Life-cycle emission for natural-gas-based hydrogen production [8,18].

## 2.2. Policy Support for Hydrogen Development

At the core of the hydrogen economy's potential is the transition towards cleaner hydrogen production methods, as illuminated by the International Energy Agency (IEA) [3], not only aiming to diminish the direct emissions from hydrogen production but also aligning with broader decarbonization efforts.

While electrolysis presents a path towards clean hydrogen, natural-gas-based production, especially when integrated with efficient carbon capture and sequestration (CCS) methods, remains one of the most cost-competitive and effective pathways for hydrogen production currently [5,6,16,27]. The economic and technical viability of these methods, at least in the short-to-medium term, underscores the need for robust policy support to bridge the gap and align with decarbonization objectives [4,29,30]. Máté et al. confirms the environmental Kuznets curve theorem and underscores the crucial moderating role of taxation in amplifying the positive effects of renewable energy supply on reducing carbon intensity [31]. Governmental actions at international and national levels are crucial for creating conducive environments for developing additional low-carbon hydrogen capacity, thereby encouraging natural-gas-based production methods alongside efficient CCS measures [3,4,8,32,33]. Gao et al. also confirmed the effective role of tax policy in promoting emission reduction strategies by firms [13].

The impact of fiscal incentives such as tax credits and subsidies in reducing emissions and costs associated with hydrogen production is evident [15,30,34,35], and there could be further energy efficiency gain from tax incentives for investments illustrated in quasi-natural experiments [36]. As technological pathways to hydrogen production evolve, so does the policy framework supporting these advancements. The case of Anhui Province, China, emphasizes the importance of substantial funding and fiscal policies in achieving sustainable development towards carbon neutrality [14].

Financial mechanisms, particularly tax credits such as Sections 45Q and 45V under the Inflation Reduction Act [10,37], stand out as significant incentives that directly influence the economic viability of hydrogen projects. These policies aim to reduce the carbon footprint of hydrogen production and catalyze investments in hydrogen infrastructure and market creation.

The unique contribution of this current work lies in its focused analysis of the economic implications of the 45Q and 45V tax credits under the Inflation Reduction Act on CCS-integrated hydrogen production projects. This research adds value by providing actionable insights for policymakers, energy sector developers, and investors, highlighting the effectiveness of specific fiscal measures in promoting clean hydrogen production. By bridging the gap between policy intentions and practical implementation, this work

contributes to the broader dialogue on energy policy and hydrogen economy, aiming to accelerate the transition towards a low-carbon energy future.

In conclusion, the strategic implementation of policy measures, particularly those focused on financial incentives and regulatory frameworks, plays a critical role in enabling the development of a hydrogen economy aligned with global sustainability goals [2,34].

In light of the current landscape, where natural-gas-based production with CCS emerges as one of the most cost-competitive and effective pathways—at least for the foreseeable future—it is crucial to articulate the value proposition of policy support, which is the objective of this current study. Such support is instrumental in developing additional capacity for low-carbon hydrogen, encouraging the adoption of efficient CCS measures, and effectively managing carbon through appropriate incentives.

### 3. Methodology

The effectiveness of policy support is not uniform; it is shaped by the specificities of each incentive mechanism and its alignment with broader decarbonization objectives. Tax credits 45Q and 45V offer distinct benefits focused on specific aspects of hydrogen project development. Tax credit 45Q is intended for projects that capture and sequester carbon dioxide. The amount of credit available per metric ton of CO<sub>2</sub> depends on the utilization or sequestration approach. This not only incentivizes the reduction in carbon emissions but also encourages innovation in carbon capture and storage (CCS) technologies. Tax credit 45V, on the other hand, targets the production of clean hydrogen, providing a tax credit per kilogram of hydrogen produced. The credit amount varies based on the carbon intensity of the hydrogen production process, promoting technologies that result in lower greenhouse gas emissions.

The essence of tax credits, particularly Sections 45Q and 45V, lies in their ability to directly reduce the tax liability of entities engaged in low-carbon-intensity hydrogen projects. This mechanism is crucial for stakeholders in the hydrogen energy sector, affecting the decision-making criteria of projects, including NPV and capital budgeting conclusions, which impact overall project feasibility. Tax credits are fundamentally different from tax deductions. While deductions reduce taxable income, tax credits provide a dollar-for-dollar reduction in the actual tax liability, making them especially valuable for incentivizing investments in sustainable hydrogen production technologies.

Examining how these policy mechanisms influence the technological choices and designs of hydrogen production projects is imperative. The subsequent sections detail the methodological approach, including articulating the implementation assumptions of 45Q and 45V tax credits, the analysis of life-cycle emissions, and the financial modeling techniques employed to assess the impact on the viability of hydrogen production projects.

#### 3.1. The 45Q Tax Credit

The 45Q tax credit provides incentives for carbon capture and sequestration activities. The credit amount varies based on factors such as the in-service year of the equipment and whether the carbon oxide is geologically stored or used in enhanced oil recovery (EOR) projects. Here is a timeline of the information regarding the 45Q tax credit and how the range of the credit is determined [10,38,39].

##### 2008: Introduction of the 45Q Tax Credit

The 45Q tax credit was initially introduced in 2008 as part of the Energy Improvement and Extension Act of 2008. Initially, it only offered credit for capturing and storing carbon dioxide (CO<sub>2</sub>) from power plants and industrial facilities. There was a cap on the original credit; after 75 million metric tons of CO<sub>2</sub> was claimed cumulatively by all qualified facilities, the credit would no longer be available. Additionally, the credit was only available to facilities that captured at least 500,000 metric tons of CO<sub>2</sub> during a taxable year and was only available to facilities engaged in geologic carbon sequestration. The initial credit was USD 20 per metric ton for CO<sub>2</sub> sequestered in secure geological storage and USD 10 per

metric ton for CO<sub>2</sub> used as a tertiary injectant in enhanced oil recovery (EOR) before being sequestered. The amount of the credit was scaled every year to account for inflation.

#### 2018: Bipartisan Budget Act

The Bipartisan Budget Act of 2018 significantly expanded the 45Q tax credit from primarily geologic carbon sequestration to encompass a few methods of biologic sequestration methods. Initially, the credit was USD 22.66 per metric ton of CO<sub>2</sub> in 2017, with a planned linear increase to USD 50 per metric ton by 2026 for permanent geological storage, and USD 12.23 per metric ton of CO<sub>2</sub> in 2017, with linear increases to USD 35 per metric ton by 2026 for tertiary injectant, adjusted for inflation thereafter [38,40,41]. It also removed the previously existing cap of 75 million metric tons of qualified carbon oxide captured by all taxpayers and extended the commencement of construction deadline for qualifying facilities. The expansion also broadened the scope of eligible carbon capture, utilization, and storage (CCUS) activities, including direct air capture (DAC), and a wider range of industrial facilities, such as steel mills, cement plants, and chemical plants. The expanded credit also covered the utilization of captured CO<sub>2</sub> in the production of various products. This includes converting CO<sub>2</sub> into fuels, chemicals, and building materials, thereby using CO<sub>2</sub> as a resource rather than emitting it as a waste product.

#### 2021: New Legislation

New legislation introduced in 2021 proposed further improvements to the 45Q tax credit. This included increases in the credit value from USD 50 to USD 85 per metric ton for CO<sub>2</sub> captured and stored in saline geologic formations and from USD 35 to USD 60 per ton for CO<sub>2</sub> stored via EOR [42,43]. A crucial element of the proposal was to extend the deadline for starting construction on qualifying CCUS projects. This extension allowed for more time for the development and planning of CCUS initiatives. Furthermore, the proposed changes included requirements for labor standards. Projects seeking to qualify for the enhanced tax credits needed to adhere to certain labor conditions, such as paying prevailing wages and complying with registered apprenticeship programs [38].

The 2021 proposals, therefore, intended to build upon earlier expansions, focusing on increasing the financial incentives and making CCUS technologies more accessible, as well as appealing to a broader spectrum of industries.

#### 3.2. The 45V PTC Credit

The Inflation Reduction Act of 2022 (IRA), passed by the Senate on 7 August 2022, included several provisions for significant domestic energy investments to reduce carbon emissions by roughly 40% by 2030 [9,10,44]. Section 45V under IRA defines the Clean Hydrogen Production Tax Credit (PTC) as a ten-year tax credit covering various production methods based on life-cycle carbon intensity. Table 1 summarizes the value of the PTC for hydrogen depending on life-cycle emissions.

**Table 1.** PTC credits depending on life-cycle emissions (kg CO<sub>2</sub>e/kgH<sub>2</sub>) [9,45].

| Life-Cycle Emissions (kg CO <sub>2</sub> e/kgH <sub>2</sub> ) | PTC Value (2022 USD/kgH <sub>2</sub> ) |
|---------------------------------------------------------------|----------------------------------------|
| 4–2.5                                                         | 0.60                                   |
| 2.5–1.5                                                       | 0.75                                   |
| 1.5–0.45                                                      | 1.00                                   |
| 0.45–0                                                        | 3.00                                   |

There are two aspects of the definition and scope: first, the 45V tax credit specified that the life-cycle greenhouse gas emissions aligned with the Clean Air Act [37] as the aggregated quantity of greenhouse gas emissions (including direct and significant indirect emissions) from feedstock generation or extraction to the delivery and use of the finished fuel to the ultimate consumer. Second, the 45V tax credit also required using the GREET

model to determine the scope of life-cycle emission calculations. In the case of natural-gas-based hydrogen production, we followed the directives and calculated the life-cycle emissions of shale gas production transported via pipeline to a centralized hydrogen plant using the GREET model [9,45].

Hence, the subsidy range received for PTC may vary from USD 0.6/kg to USD 1.0/kg H<sub>2</sub>. However, through various scenarios, we, as the researchers, find it is rare to reach USD 1.0/kg H<sub>2</sub> with average-sourced natural gas from regular infrastructure setup. Here is a list, which is not exclusive, of remaining technical requirements for the 45V tax credit that need to be addressed and examined:

- Production efficiency for hydrogen production processes is technically feasible and economically viable.
- Large-scale demonstrations of reliability and consistent performance of hydrogen production technologies needs to meet commercial benchmarks.

The literature review reveals a dynamic field where technological innovation intersects with policy incentives to shape the future of low-carbon hydrogen production. While significant progress has been made in developing and deploying SMR and ATR technologies integrated with CCS, ongoing research is essential to optimize their efficiency and environmental benefits. Similarly, tax credits under Sections 45Q and 45V have emerged as critical tools for reducing the financial barriers to clean hydrogen projects, yet their full potential is contingent on a deep understanding of the fiscal landscape and the strategic use of tax equity financing mechanisms. This review underscores the need for continued exploration into both the technological advancements and economic strategies that will drive the adoption of low-carbon hydrogen as a key component of a sustainable energy future.

There are two different methods to estimate the tax credit on the production of hydrogen.

### 3.3. Tax Credit Converted to Per Unit Produced

The 45V tax credit is calculated as the amount of tax credit received for each unit of hydrogen produced, while the 45Q tax credit is calculated based on the carbon captured. One simple way to compare these two is to calculate the conversion factor, which estimates an equivalent credit per kg of hydrogen produced, based on the capture rate of carbon, as in the following equation:

$$\left( \frac{\$ \text{ Credit/metric ton CO}_2}{1000} \right) \times (\text{CO}_2 \text{ capture rate, kg CO}_2/\text{kgH}_2).$$

For example, if a hydrogen production plant has a CO<sub>2</sub> capture rate of 8.9 kg CO<sub>2</sub> per kg of hydrogen produced with permanent geological storage, it qualifies for the USD 85 per metric ton of tax credit under the latest tax credit 45Q guideline. Then, the credit can be converted into per kg of hydrogen produced as follows:

$$\text{Credit per kg of H}_2 = (\$85/1000) \times (1 \text{ kg H}_2/8.9 \text{ kg CO}_2) = \$0.757.$$

The method of converting tax credits to a per-unit cost basis serves as an essential initial step in comparing the effects of the 45Q and 45V tax credits on hydrogen production. This approach offers a straightforward calculation, transforming complex tax incentives into more digestible per-kilogram metrics. However, this simplicity comes with its limitations when used in isolation. Without integrating these per-unit costs into a comprehensive net present value (NPV) model, the analysis fails to capture the full spectrum of economic impacts these tax credits have on a project.

### 3.4. Integrating Tax Credit Calculations in Net Present Value (NPV) Analysis

Net present value (NPV) is a financial metric to evaluate the profitability of an investment. It represents the difference between the present value of cash inflows and the present value of cash outflows over a project's lifetime. A positive NPV indicates that the

projected earnings (in present dollars) exceed the anticipated costs, making the project potentially profitable.

Incorporating tax credit calculations into the NPV study of a hydrogen project, like a hydrogen production plant with carbon capture and storage (CCS), is crucial to accurately assess the financial viability of such projects. This section will outline a methodology for integrating tax credits into a cash flow calculation. To compare the difference of the economic impacts from the two tax credits, that is, Sections 45Q and 45V, one must consider both the cash inflows and outflows over the project's lifespan. Key components include the following:

- Initial investment: the total upfront capital required to develop the project, including costs for technology, construction, and setup;
- Operational costs: ongoing expenses such as labor, maintenance, utilities, and materials;
- Revenue streams: income from the sale of hydrogen and possibly from selling captured CO<sub>2</sub>, if applicable;
- Tax credits: annual credits received.

$$NPV = \sum_{t=0}^N \frac{FCF_t}{(1 + WACC)^t},$$

$$FCF = EBIT - \text{Tax} + \text{Depreciation} - \text{Change in Gross Fixed Asset} - \text{Change in Net Working Capital},$$

and

$$EBIT = \text{Revenue} - \text{Expenses} - \text{Depreciation}.$$

WACC is the project's weighted average cost of capital. In the case when there is no tax credit, Tax can be calculated as

$$\text{Tax} = EBIT \times \text{Tax Rate}.$$

With tax credit, the project's tax liability can then be calculated as

$$\text{Tax} = EBIT \times \text{Tax Rate} - \text{Tax Credit}.$$

The free cash flow equation can then be re-written as

$$FCF = EBIT \times (1 - \text{Tax Rate}) + \text{Tax Credit} + \text{Depreciation} - \text{Change in Gross Fixed Asset} - \text{Change in Net Working Capital}.$$

Since the purpose of this study is to compare how the two types of tax credits (45Q and 45V) will affect NPV, the following additional assumptions are made:

- Sections 45Q and 45V will apply to the same project in the same company.
- The tax credit will not affect the project's revenue and expenses.
- The tax credit will not affect the project's capital structure and risk.

The only difference in the FCF equation, and thus the NPV equation, when applying Sections 45Q and 45V, will be the difference from the different tax credits. That is, the difference in the NPV of the project can be calculated directly by the difference of the present value (PV) of the tax credit. For the 10-year production tax credit for hydrogen,

$$\left[ PV_{45V} = \sum_{t=1}^{10} \frac{\text{Credit /kg of H}_2 \text{ (45V)} \times \text{Hydrogen production per year}}{(1 + r)^t} \right].$$

The equivalent PV of the 45Q sequestration tax credit for each kg of hydrogen produced over the 12-year period is

$$\left[ PV_{45Q} = \sum_{t=1}^{12} \frac{\text{Credit / metric ton of CO}_2(45Q) / 1000 \times \text{CO}_2 \text{ capture rate} \times \text{Hydrogen Production per year}}{(1+r)^t} \right].$$

here, the CO<sub>2</sub> capture rate is the amount of CO<sub>2</sub> captured per kg of hydrogen produced, which helps to estimate the equivalent credit on an H<sub>2</sub> basis. By comparing (PV<sub>45Q</sub>) and (PV<sub>45V</sub>), one can obtain an understanding as to which tax credit scenario provides a higher NPV for the project, while another alternative, which is likely easier to understand, would be to convert the impact on the project value on a levelized cost basis. It would arrive at a dollar amount per kg of hydrogen produced under each tax credit scheme for the same facility.

The NPV model, which considers the time value of money and encompasses all future cash flows, provides a more accurate representation of a project's financial viability over its entire lifespan. It accounts for variable production rates, operational efficiencies, and the specific duration during which the tax credits apply—crucial aspects that the per-unit cost method oversimplifies. Therefore, while the per-unit cost offers an essential comparative foundation, it must be utilized within the broader context of an NPV analysis to truly understand the economic implications of tax credits on hydrogen production projects. This integrated approach ensures that decision-makers can accurately assess the value of tax credits, considering the complexities of production levels, time-bound incentives, and overall project economics.

#### 4. Results and Limitations

##### 4.1. Tax Credit Impact Sensitivity

The scenario assumes an ATR plant with 90% CCS and 660,000 kg/d of production capacity located in the US. The base scenario results in a USD 1.41/kg of levelized cost for hydrogen production without any tax incentive, with an average natural gas price delivered to the plant at USD 4.11/MMBtu, an electricity price at USD 0.075/kWh, and a discount rate of 8%. With the base scenario as the benchmark, the analysis calculates different levels of tax credit received by the project, either from 45Q or 45V. Figure 4 indicates the real levelized cost of hydrogen in real 2020 dollars as a function of 45Q versus 45V incentive structure; below, the base scenario cost is indicated by the black line at USD 1.41/kg.

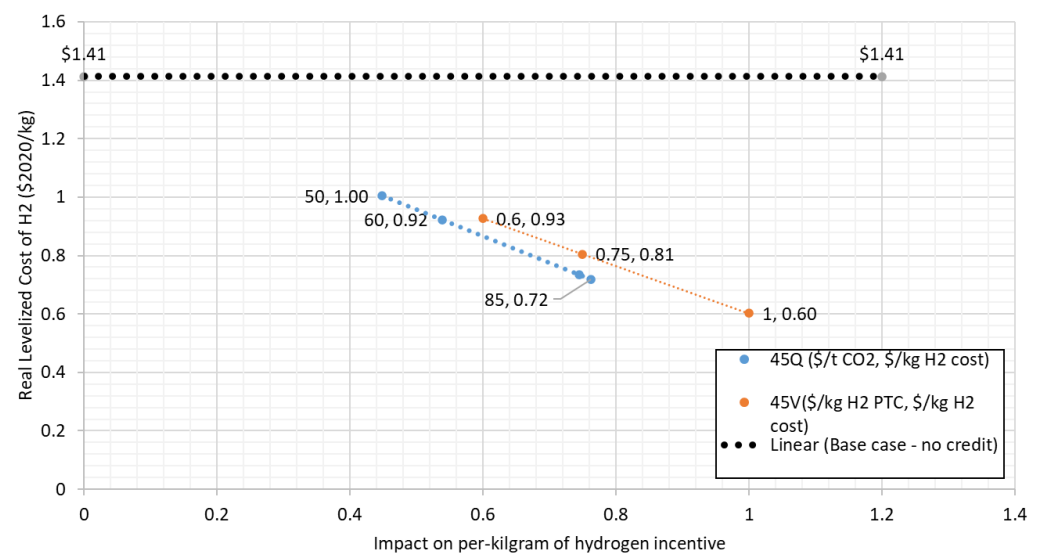


**Figure 4.** Impact on hydrogen's levelized cost from 45Q (blue color) versus 45V (orange color).

Given the latest 45Q tax credit, the likely tax impact would be in a range of USD 65–85/ton for CO<sub>2</sub> if 90% of CO<sub>2</sub> is captured from the total of 8.9 kg CO<sub>2</sub> emitted per kg of hydrogen produced. For the 45V tax credit, the likely impact is determined based on the

life-cycle footprint of CO<sub>2</sub>. For example, if we assume 3.8 kg of CO<sub>2</sub> to remain after 90% CCS, it leads to a USD 0.60/kg of the 45V tax credit. Based on the GREET model [46], an ATR plant with 90% CCS has a likely 45Q tax credit between USD 0.60 and 0.75/kg.

The first observation of the tax credit scenarios compared to the base scenario is that all scenarios with tax credit have lower levelized costs of hydrogen, significantly ranging from USD 0.41/kg to USD 0.81/kg of hydrogen. Secondly, with the likely range of the 45Q tax credit that can be claimed for an ATR with CCS, the 45Q tax credit has a more beneficial impact on the overall levelized cost, although the benefit is quite small, about 3–5 cents per kg of hydrogen.

The direct impact of these tax credits on project economics cannot be overstated. By effectively lowering the project cost, they improve the return on investment and can be the determining factor in a project's financial viability. For instance, a hydrogen production facility that may be marginally profitable or even unprofitable in the absence of tax credits could become economically viable once the value of these credits is factored into the financial model.

With the estimated impact on the produced hydrogen, it is important to recognize that the actual execution of the 45Q tax credit also assumes a list of technical requirements, listed below, which need to be addressed and examined.

- Capture rate: the required carbon capture rate and how this can be validated through commercial operation;
- Measurement and verification: the methodologies for measuring and verifying the amount of CO<sub>2</sub> captured, sequestered, or utilized and the need for robust monitoring, reporting, and verification (MRV) systems;
- Sequestration integrity: the requirements for ensuring permanent CO<sub>2</sub> sequestration and the need for long-term monitoring protocols to prevent leaks;
- Environmental compliance: the need for adherence to environmental regulations, particularly concerning the impact on air, water, and soil during the capture and sequestration process.

#### 4.2. Limitations of Tax Credits and the Role of Tax Equity Investments

While tax credits under Sections 45Q and 45V significantly enhance the economic appeal of low-carbon-intensity hydrogen projects, they are accompanied by certain limitations and considerations, particularly in their direct application. This section outlines these limitations and introduces the concept of tax equity investments as a pivotal mechanism in project financing to overcome these constraints.

The effectiveness of tax credits is inherently tied to the tax liability of the entity undertaking the hydrogen project. The key limitation here is straightforward: if an entity's tax liability is less than the value of the tax credits it earns, it cannot fully utilize these credits immediately. For example, if a company is eligible for USD 5 million in tax credits but only has a tax liability of USD 2 million, the remaining USD 3 million in credits cannot be applied within that tax year. This situation can often arise with start-ups or companies investing heavily in new technologies, where profits (and hence tax liabilities) may not be immediately realized.

Another consideration is the time-bound nature of tax credits. Often, tax credits have expiration dates or are subject to phase-out schedules, which can affect long-term project planning. Moreover, the complexity of tax laws and the potential for legislative changes add an element of uncertainty, necessitating careful, forward-looking planning and a thorough understanding of current tax legislation. To address the limitation of insufficient tax liability and fully harness the value of tax credits, many projects turn to tax equity financing. This involves a partnership between the project developer (who earns the tax credits) and a tax equity investor (typically a financial institution or a corporation with a significant tax appetite). In a tax equity deal, the investor provides upfront capital to the project in exchange for the right to claim its tax credits. This arrangement benefits both

parties; the project developer receives the necessary funding, while the investor leverages the tax credits to reduce their own tax liabilities.

Tax equity investments play a crucial role in bridging the gap between the availability of tax credits and the ability of project developers to utilize them. These investments can be structured in various ways, with common models including partnership flips, sale-leasebacks, and inverted leases. Each structure has its nuances regarding how the tax credits are allocated and when the investor can claim them. For project developers, engaging in tax equity financing can significantly enhance project viability. It allows them to monetize the tax credits efficiently and apply the proceeds towards project development costs. For investors, these deals offer a financially attractive opportunity, especially in a low-interest-rate environment, as tax credits provide a guaranteed return on investment in the form of tax savings.

Here is a hypothetical example of an autothermal reforming (ATR) project with carbon capture and storage (CCS) to demonstrate the decision-making process for how tax equity plays a role in project financing. Imagine the EcoSynthetics company plans to develop an ATR facility with integrated CCS for hydrogen production. This facility is designed to produce hydrogen while capturing and storing the CO<sub>2</sub> emissions generated. The total cost of the project is estimated at USD 1.2 billion. The facility is projected to produce 1 million kilograms of hydrogen daily with 95% CO<sub>2</sub> capture, equivalent to 3.09 million metric tons of CO<sub>2</sub> per year. The facility has two tax credit options of 45Q versus 45V and selects 45V for the tax credit at an expected tax credit of USD 85/ton for permanent geological storage, equivalent to a tax credit reaching up to USD 262 million to be utilized annually. However, the project's annual tax liability is USD 26 million, which is insufficient to utilize the full amount of tax credit. Hence, the ATR project decides to pursue the 45Q option due to the higher credit value and enters into a tax equity deal with a large financial institution, FutureFund. FutureFund agrees to provide USD 500 million in capital for EcoSynthetics's project. FutureFund will receive 90% of the 45Q tax credits generated, equating to USD 236 million annually. Additionally, a revenue-sharing agreement is made for the sale of hydrogen produced. EcoSynthetics completes the ATR+CCS facility and begins operation, producing hydrogen and capturing CO<sub>2</sub>. FutureFund utilizes the USD 236 million in tax credits to offset its tax liabilities, potentially spreading over several years, and a share of hydrogen sales. EcoSynthetics benefits from the capital investment, making the project feasible. The advantage of this tax equity deal is that it allows both parties to undertake a high-cost project with significant environmental benefits. They effectively monetize the tax credits, offsetting project costs and improving financial viability. This partnership fosters the growth of sustainable energy projects while offering financial benefits to the investors.

The limitations of direct tax credit utilization underline the importance of tax equity investments in low-carbon hydrogen project financing. Understanding and effectively navigating the landscape of tax equity is essential for project developers to fully capitalize on the opportunities presented by tax credits like 45Q and 45V. The company is not avoiding taxes; it is using tax credits as the law allows, for incentivizing certain investments. These tax credits are not intended to enable companies to avoid taxes indefinitely but to accelerate the transition to cleaner energy sources. As the clean energy sector continues to evolve, tax equity financing will likely play an increasingly prominent role in facilitating the growth and success of environmentally sustainable projects.

## 5. Conclusions

This paper has traversed the landscape of the 45Q and 45V tax credits, dissecting their roles in fostering the financial viability of hydrogen projects equipped with carbon capture and storage (CCS). From the outset, we acknowledged hydrogen's pivotal place in the transition to clean energy, especially for sectors where direct electrification is less feasible. The introduction of Sections 45Q and 45V by the US government under the Inflation Reduction Act has been a game-changer, underscoring the government's commitment to decarbonization. Section 45Q bolsters CCS technologies by providing a per-ton credit for

carbon sequestration, while 45V directly promotes clean hydrogen production, with credits scaled according to carbon intensity.

Our discussions revealed that while the 45Q tax credit has a more established presence in the financial strategies of hydrogen projects, the newly introduced 45V tax credit carries the potential to further accelerate the adoption of low-carbon hydrogen production. However, it is important to recognize that 45V is still in its regulatory infancy, without finalized guidelines. The most recent development is the proposed guidance on 45V by the US Department of Treasury and International Revenue Service (IRS) released on 22 December 2023, along with a newly released model (45VH2-GREET 2023) by the DOE to support the life-cycle emissions of hydrogen production, followed by a 60-day commenting period with public hearings scheduled in March 2024 (U.S. Department of the Treasury, IRS Release Guidance on Hydrogen Production Credit to Drive American Innovation and Strengthen Energy Security | U.S. Department of the Treasury (<https://home.treasury.gov/news/press-releases/jy2010>, accessed on 24 December 2023)). The proposed regulations reflect the Biden Administration's policy choices in response to intense lobbying and public debate. They generally adhere to stricter rules on time matching, additionality, and regionality for the purchase of energy attribute certificates to be eligible for tax credits. We decided not to wait for the finalized ruling of the 45V guidance before publishing this paper, given that it is sufficient to conclude that this uncertainty casts a shadow of ambiguity over projects that rely on the clarity of the tax credits for economic success. Despite these challenges, the optimism surrounding 45V is palpable, particularly among ATR projects vying for a place in hydrogen hubs. Many of these projects are poised to utilize renewable gas and electricity, pushing the envelope on reducing life-cycle carbon intensity. This forward-thinking approach is indicative of the sector's agility and responsiveness to policy-driven market signals.

In synthesizing the key takeaways, we find that, first, the NPV model offers a more accurate representation of a project's profitability, factoring in operational efficiencies, variable production rates, and the specific duration of tax credits. This methodology underscores that while converting tax credits to a per-unit cost provides a useful comparative basis, it must be integrated into an NPV analysis to fully capture the economic implications of tax credits on hydrogen production projects, ensuring that decision-makers can make informed assessments of project viability considering the complexities of production levels and financial incentives. Second, incorporating tax credits 45Q and 45V significantly reduces the levelized cost of hydrogen production from an ATR plant with 90% CCS, enhancing the project's economic viability. The analysis demonstrates that 45Q tax credits generally provide a slightly more favorable impact on reducing levelized costs compared to 45V, with potential reductions in hydrogen costs ranging from USD 0.41/kg to USD 0.81/kg. Last, the direct application of tax credits faces limitations due to entities' tax liability constraints, potentially hindering the immediate full utilization of the credits. Tax credits are time-bound, introducing additional complexities in long-term project planning and financial modeling. Tax equity investments emerge as a critical solution to the direct utilization limitations of tax credits, enabling projects to monetize these incentives effectively and secure the necessary funding.

Before wrapping up, we must acknowledge additional caveats. The actual impact of these tax credits on a project's bottom line will vary widely and will be influenced by a host of factors, including (but not limited to) regional regulatory frameworks, the carbon intensity of local energy grids, and the scale of the projects in question. Moreover, as technology and policy evolve, so will the strategies for harnessing these fiscal incentives. In conclusion, this paper presents a clear narrative; the strategic implementation of tax credits like 45Q and 45V is beneficial and essential for the success of low-carbon hydrogen projects. While uncertainties regarding the final form of 45V remain, the industry's enthusiasm for its potential suggests a readiness to embrace and adapt to new policy environments.

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## References

- James, N.; Menzies, M. Distributional Trends in the Generation and End-Use Sector of Low-Carbon Hydrogen Plants. *Hydrogen* **2023**, *4*, 174–189. [CrossRef]
- Griffiths, S.; Sovacool, B.K.; Kim, J.; Bazilian, M.; Uratani, J.M. Industrial Decarbonization via Hydrogen: A Critical and Systematic Review of Developments, Socio-Technical Systems and Policy Options. *Energy Res. Soc. Sci.* **2021**, *80*, 102208. [CrossRef]
- International Energy Agency. *The Future of Hydrogen*; International Energy Agency: Paris, France, 2019.
- Staffell, I.; Scamman, D.; Abad, A.V.; Balcombe, P.; Dodds, P.E.; Ekins, P.; Shah, N.; Ward, K.R. The Role of Hydrogen and Fuel Cells in the Global Energy System. *Energy Environ. Sci.* **2019**, *12*, 463–491. [CrossRef]
- Khan, M.A.; Daiyan, R.; Neal, P.; Haque, N.; MacGill, I.; Amal, R. A Framework for Assessing Economics of Blue Hydrogen Production from Steam Methane Reforming Using Carbon Capture Storage & Utilisation. *Int. J. Hydrogen Energy* **2021**, *46*, 22685–22706.
- Oni, A.O.; Anaya, K.; Giwa, T.; Lullo, G.D.; Kumar, A. Comparative Assessment of Blue Hydrogen from Steam Methane Reforming, Autothermal Reforming, and Natural Gas Decomposition Technologies for Natural Gas-Producing Regions. *Energy Convers. Manag.* **2022**, *254*, 115245. [CrossRef]
- Lee, K.; Liu, X.; Vyawahare, P.; Sun, P.; Elgowainy, A.; Wang, M. Techno-Economic Performances and Life Cycle Greenhouse Gas Emissions of Various Ammonia Production Pathways Including Conventional, Carbon-Capturing, Nuclear-Powered, and Renewable Production. *Green Chem.* **2022**, *24*, 4830–4844. [CrossRef]
- IEA. *Comparison of the Emissions Intensity of Different Hydrogen Production Routes*; IEA: Paris, France, 2023.
- Department of Energy. *Guidelines to Determine Well-to-Gate Greenhouse Gas (GHG) Emissions of Hydrogen Production Pathways Using 45VH2-GREET 2023*; Department of Energy: Washington, DC, USA, 2023.
- Shearman and Sterling. Inflation Reduction Act: Key Green and Blue Hydrogen and CCUS Provisions. Available online: <https://www.shearman.com/en/perspectives/2022/08/inflation-reduction-act-key-green-and-blue-hydrogen-and-ccus-provisions> (accessed on 20 January 2023).
- U.S. Department of Energy. *DOE National Clean Hydrogen Strategy and Roadmap*; U.S. Department of Energy: Washington, DC, USA, 2022.
- IEA. *Global Hydrogen Review 2023*; IEA: Paris, France, 2023; pp. 1–176.
- Gao, X.; Zheng, H.; Zhang, Y.; Golsanami, N. Tax Policy, Environmental Concern and Level of Emission Reduction. *Sustainability* **2019**, *11*, 1047. [CrossRef]
- Yang, L.; Wang, S.; Zhang, Z.; Lin, K.; Zheng, M. Current Development Status, Policy Support and Promotion Path of China's Green Hydrogen Industries under the Target of Carbon Emission Peaking and Carbon Neutrality. *Sustainability* **2023**, *15*, 10118. [CrossRef]
- Kolahchian Tabrizi, M.; Famiglietti, J.; Bonalumi, D.; Campanari, S. The Carbon Footprint of Hydrogen Produced with State-of-the-Art Photovoltaic Electricity Using Life-Cycle Assessment Methodology. *Energies* **2023**, *16*, 5190. [CrossRef]
- Katebah, M.; Al-Rawashdeh, M.; Linke, P. Analysis of Hydrogen Production Costs in Steam-Methane Reforming Considering Integration with Electrolysis and CO<sub>2</sub> Capture. *Clean. Eng. Technol.* **2022**, *10*, 100552. [CrossRef]
- Air Liquide Engineering & Construction Low-Carbon Hydrogen | Air Liquide Engineering & Construction. Available online: <https://engineering.airliquide.com/technologies/low-carbon-hydrogen> (accessed on 19 December 2023).
- Gorski, J.; Jutt, T.; Wu, K.T. *Carbon Intensity of Blue Hydrogen Production*; Pembina Institute: Calgary, AB, Canada, 2021.
- Liu, N. *The Shell Blue Hydrogen Process*; Shell Catalysts & Technologies: Houston, TX, USA, 2020.
- NRG Energy. Petra Nova Status Update. Available online: <https://www.nrg.com/about/newsroom/2020/petra-nova-status-update.html> (accessed on 19 December 2023).
- Shell. Shell Proposes Large-Scale CCS Facility in Alberta. Available online: [https://www.shell.ca/en\\_ca/media/news-and-media-releases/news-releases-2021/shell-proposes-large-scale-ccs-facility-in-alberta.html](https://www.shell.ca/en_ca/media/news-and-media-releases/news-releases-2021/shell-proposes-large-scale-ccs-facility-in-alberta.html) (accessed on 19 December 2023).
- Antonini, C.; Treyer, K.; Streb, A.; van der Spek, M.; Bauer, C.; Mazzotti, M. Hydrogen Production from Natural Gas and Biomethane with Carbon Capture and Storage—A Techno-Environmental Analysis. *Sustain. Energy Fuels* **2020**, *4*, 2967–2986. [CrossRef]

23. sbh4 Consulting. SMR, ATR and POX Processes for Syngas Production. Available online: <https://sbh4.de/assets/smr-atr-and-pox-processes.pdf> (accessed on 19 December 2023).
24. AlHumaidan, F.S.; Absi Halabi, M.; Rana, M.S.; Vinoba, M. Blue Hydrogen: Current Status and Future Technologies. *Energy Convers. Manag.* **2023**, *283*, 116840. [\[CrossRef\]](#)
25. Shamsi, H.; Tran, M.-K.; Akbarpour, S.; Maroufmashat, A.; Fowler, M. Macro-Level Optimization of Hydrogen Infrastructure and Supply Chain for Zero-Emission Vehicles on a Canadian Corridor. *J. Clean. Prod.* **2021**, *289*, 125163. [\[CrossRef\]](#)
26. Frank, E.D.; Elgowainy, A.; Reddi, K.; Bafana, A. Life-Cycle Analysis of Greenhouse Gas Emissions from Hydrogen Delivery: A Cost-Guided Analysis. *Int. J. Hydrogen Energy* **2021**, *46*, 22670–22683. [\[CrossRef\]](#)
27. Spath, P.L.; Mann, K.M. *Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming*; National Renewable Energy Laboratory: Golden, CO, USA, 2001.
28. Al-Breiki, M.; Bicer, Y. Comparative Life Cycle Assessment of Sustainable Energy Carriers Including Production, Storage, Overseas Transport and Utilization. *J. Clean. Prod.* **2021**, *279*, 123481. [\[CrossRef\]](#)
29. Yap, J.; McLellan, B. A Historical Analysis of Hydrogen Economy Research, Development, and Expectations, 1972 to 2020. *Environments* **2023**, *10*, 11. [\[CrossRef\]](#)
30. Al Shammre, A.S.; Benhamed, A.; Ben-Salha, O.; Jaidi, Z. Do Environmental Taxes Affect Carbon Dioxide Emissions in OECD Countries? Evidence from the Dynamic Panel Threshold Model. *Systems* **2023**, *11*, 307. [\[CrossRef\]](#)
31. Máté, D.; Török, L.; Kiss, J.T. The Impacts of Energy Supply and Environmental Taxation on Carbon Intensity. *Technol. Econ. Dev. Econ.* **2023**, *29*, 1195–1215. [\[CrossRef\]](#)
32. Gas Infrastructure Europe. *Picturing the Value of Gas Storage to the European Hydrogen System*; Gas Infrastructure Europe: Brussels, Belgium, 2021.
33. Gowdy, J. *Building the Hydrogen Value Chain*; Regen: Exeter, UK, 2021.
34. Talebian, H.; Herrera, O.E.; Mérida, W. Policy Effectiveness on Emissions and Cost Reduction for Hydrogen Supply Chains: The Case for British Columbia. *Int. J. Hydrogen Energy* **2021**, *46*, 998–1011. [\[CrossRef\]](#)
35. Zhang, Y.; Gautam, R.; Pandey, S.; Omara, M.; Maasackers, J.D.; Sadavarte, P.; Lyon, D.; Nesser, H.; Sulprizio, M.P.; Varon, D.J.; et al. Quantifying Methane Emissions from the Largest Oil-Producing Basin in the United States from Space. *Sci. Adv.* **2020**, *6*, eaaz5120. [\[CrossRef\]](#)
36. Song, Y.; Song, R.; Liu, J. Hydrogen Tightness Evaluation in Bedded Salt Rock Cavern: A Case Study of Jintan, China. *Int. J. Hydrogen Energy* **2023**, *48*, 30489–30506. [\[CrossRef\]](#)
37. Clean Air Task Force. Carbon Capture Provisions in the Inflation Reduction Act of 2022. Available online: <https://cdn.catf.us/wp-content/uploads/2022/08/19102026/carbon-capture-provisions-ira.pdf> (accessed on 20 January 2023).
38. Congression Research Service. *The Section 45Q Tax Credit for Carbon Sequestration*; Congression Research Service: Washington, DC, USA, 2023.
39. Ren, B.; Male, F.; Duncan, I.J. Economic Analysis of CCUS: Accelerated Development for CO<sub>2</sub> EOR and Storage in Residual Oil Zones under the Context of 45Q Tax Credit. *Appl. Energy* **2022**, *321*, 119393. [\[CrossRef\]](#)
40. 45Q Carbon Sequestration Tax Credit: What It Is & How to Get It. Available online: <https://www.brownwinick.com/insights/45-q-carbon-sequestration-tax-credit-what-it-is-how-to-get-it> (accessed on 13 March 2024).
41. Notice 2023-46: Carbon Oxide Sequestration Credit under Section 45Q, Inflation Adjustment Factor for 2023—KPMG United States. Available online: <https://kpmg.com/us/en/home/insights/2023/06/tmf-notice-2023-46-carbon-oxide-sequestration-credit-inflation-adjustment-factor.html> (accessed on 13 March 2024).
42. Internal Revenue Service. *Instructions for Form 8933: Carbon Oxide Sequestration Credit*; Internal Revenue Service: Hong Kong, China, 2023.
43. Internal Revenue Service. Inflation Reduction Act of 2022. Available online: <https://www.irs.gov/inflation-reduction-act-of-2022> (accessed on 10 March 2023).
44. Krupnick, A.; Bergman, A. *Incentives for Clean Hydrogen Production in the Inflation Reduction Act*; Resources for the Future: Washington, DC, USA, 2022.
45. Lin, N.; Chen, Y.; Madariaga, M.P. Route-to-Market Strategy for Low-Carbon Hydrogen from Natural Gas in the Permian Basin. *Fuel* **2024**, *355*, 129420. [\[CrossRef\]](#)
46. Argonne. GREET Model. Available online: <https://greet.es.anl.gov/> (accessed on 6 February 2023).

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