Master Thesis

Actors, Coalitions, and Drivers in the Ramp-Up of the Hydrogen Economy in the United States

Submitted by

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ACF	Advocacy Coalitions Framework
AFPM	American Fuel & Petroleum Manufacturers
BEV	Battery-Powered Electric Vehicle
BIL	Bipartisan Infrastructure Law
CARB	California Air Resource Board
CATF	Clean Air Task Force
CCS	Carbon Capture and Storage
CHFC	Clean Hydrogen Future Coalition
DOE	Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EU	European Union
FCEV	Fuel Cell Electric Vehicle
FCHEA	Fuel Cell & Hydrogen Energy Association
FCVT	FreedomCAR and Vehicle Technologies Program
FE	Office of Fossil Energy
FECM	Office of Fossil Energy and Carbon Management (former FE)
GHG	Greenhouse Gas(es)
HFCIT	Hydrogen, Fuel Cells, and Infrastructure Technologies Program
HFI	Hydrogen Fuel Initiative
ICE	Internal Combustion Engine Vehicle
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act
IPCC	Intergovernmental Panel on Climate Change
IPP	Intermountain Power Project
ISO	Independent System Operator
NE	Office of Nuclear Energy
NGO	Non-Governmental Organization
NRC	National Research Council
NRDC	Natural Resource Defense Council
NREL	National Renewable Energy Laboratory
MIT	Massachusetts Institute of Technology
OCED	Office of Clean Energy Demonstrations
PNGV	Public-Private Partnership for a New Generation of Vehicles
PPA	Power Purchasing Agreement
R&D	Research and Development
RMI	Rocky Mountain Institute
RTO	Regional Transmission Organization
SC	Office of Sciences
SMR	Steam Methane Reforming
UNFCCC	United Nations Framework Convention on Climate Change
U.S.	United States
VPPA	Virtual Power Purchasing Agreement
ZEV	Zero Emission Vehicle

1 Introduction and Research Question

Perhaps Jules Verne was right when he wrote in 1874 that "*water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable*" (The Conversation, 2019). In contrast to Verne's vision, most of the hydrogen use cases today employ hydrogen as a resource rather than as an energy carrier: hydrogen serves as a feedstock and reactant in various industrial sectors including refineries for petroleum production, e. g. to lower sulfur content of diesel fuel (Fuel Cell and Hydrogen Energy Association [FCHEA], 2020, p. 38; EIA, 2016; International Energy Agency [IEA], 2019, pp. 91–92), in the chemical sector, especially in methanol, ammonia and fertilizer manufacturing (IEA, 2019, pp. 99–101) as well as in metal treatment (see FCHEA, 2020, pp. 38–39; IEA, 2019, pp. 108–109). Hydrogen production for these applications primarily relies on fossil fuels, leading to significant global carbon emissions (IEA, 2019, pp. 37–38).

However, recently, low-carbon hydrogen[1] as a clean energy carrier has received growing attention as a promising solution to substantially reduce greenhouse gas (GHG) emissions in industrial processes, transportation, the electricity system, and the heating sector, where alternative solutions for decarbonization have been lacking (FCHEA, 2020; Lebrouhi et al., 2022).

The March 2023 *Intergovernmental Panel on Climate Change* (IPCC) report emphasizes the critical need for swift decarbonization, stressing that 3.3 – 3.6 billion people live in context *"highly vulnerable to climate change"* (Lee et al., 2023, p. 5). Climate change induced problems, brought by unsustainable socio-technical systems, such as electricity, food, buildings, industrial manufacturing, and heat, impose big societal challenges necessitating the transition to low-carbon socio-technical systems (Köhler et al., 2019; Lee et al., 2023). With climate change as a main driver, low-carbon hydrogen has gained momentum in recent years all around the globe to slow down climate change and improve air quality (IEA, 2019; Lebrouhi et al., 2022). Among others, the United States (U.S.), China, Germany, South Africa, Chile, and Australia, have adopted hydrogen strategies outlining strategic use cases for domestic hydrogen applications to limit GHG emissions (Department of Energy [DOE], 2023c; Lebrouhi et al., 2022). Furthermore, researchers conclude that the deployment of low-carbon hydrogen has the

[1] here understood as hydrogen with a smaller carbon footprint than its conventional production processes (see e. g. International Energy Agency (IEA) (2019, p. 34))

potential of creating a high number of jobs - one million in the EU alone (Cuevas et al., 2021) -, earning billions of dollars of revenue, reducing dependency of imported fossil fuels, and strengthening overall energy resilience (Lebrouhi et al., 2022). The geopolitical implications of hydrogen as a future energy carrier have been addressed by the International Renewable Energy Agency in a special report (International Renewable Energy Agency, 2022).

Ensuring the successful reduction of emissions by major polluting nations, such as the U.S., the largest economy of the world and responsible for 12.5% of global CO_2 emissions in 2021 (European Commission, 2022), is crucial for the continued flourishing of humanity on earth. Throughout history, climate policy in the U.S. has typically taken a back seat until recently (Mildner et al., 2020; Müller, 2020). Before Joe Biden assumed office in the White House in 2021, the Obama administration (2009-2017) stood out as the only exception to announce extensive and binding GHG emission targets. However, these targets were later overthrown by President Trump (2017-2021), who strongly supported domestic fossil fuel production and showed limited enthusiasm for climate policy (Mildner et al., 2020). A substantial challenge to the efficacy of climate policy in the U.S. stems from the pervasive institutionalization of lobbying by the business sector, especially from fossil fuel industries (Hebenstreit, 2020; Rosenbaum, 2017, pp. 80–82). This sector's close linkage to political actors complicates the adoption of low-carbon technologies in the U.S. (Goldberg et al., 2020; Rosenbaum, 2017, pp. 80–82).

However, the current U.S. government under President Biden has passed legislations massively subsiding low-carbon hydrogen (DOE, 2023c, pp. 6–9) potentially fueling the hope that the U.S. is on a pathway to deep decarbonization of hard-to-abate sectors (including industrial processes, the electricity sector, and transportation). Therefore, a critical question to ask is what the catalysts of this new development are and whether incumbent fossil fuel-based socio-technical systems have lost their political support in the U.S. No prior research has examined the political forces driving the recent hydrogen boom in the U.S., including actors and coalitions influencing or opposing this development. Hence, to address this research gap, the decision to study the example of low-carbon hydrogen in the U.S. has been made. The guiding research question to be answered is "*Who are the political actors and coalitions that drive or oppose low-carbon hydrogen and what is their impact on the ramp-up of the hydrogen economy in the United States?*". By answering the research question, this study complements the literature on sustainability transitions by widening the field to low-carbon hydrogen.

The Advocacy Coalition Framework (ACF) will serve as the theoretical lens to examine the political actors and coalitions influencing hydrogen policy in the U.S. Given the diverse stakeholders involved in U.S. hydrogen policy, including government entities like the U.S. Congress, the Department of Energy (DOE) as well as its suboffices, private companies, non-governmental organizations (NGOs), and research institutions, the ACF can provide valuable insights into deep-seated beliefs of key actors involved in low-carbon hydrogen. This framework helps to clarify relationships among engaged actors and reveals conflicting interests and disputes in hydrogen policymaking. The ACF is well-suited for this purpose as it examines developments over an extended time-period and considers changing framework conditions such as peaks in oil prices or growing concerns about climate change.

This study starts with presenting an overview of climate targets, energy use, and hydrogen deployment in the U.S. today. The analysis then unfolds in two stages: Firstly, a comprehensive overview of the historical progression of low-carbon hydrogen technologies in the U.S. is provided to pinpoint key actors and coalitions involved in past hydrogen technology initiatives with a focus on the period between 1993 and 2023. Secondly, to gain insights on actors and coalitions engaged in current hydrogen policymaking, lobbying for different implementation styles of the hydrogen production tax credit passed by the Biden administration in the *Inflation Reduction Act* (IRA) of 2022 is studied. This is done to observe key stakeholders and their preferred policy positions in a recent political battle. The acquired findings can help to identify deep core beliefs of actors engaged in hydrogen today and therefore crucially complement this study.

By answering the research question, this study concludes with a comprehensive overview of actors and advocacy coalitions in the U.S. hydrogen policy subsystem. The analysis specifically identifies entities fostering and resisting the development of low-carbon hydrogen. This research offers an external perspective on low-carbon development in the U.S. enabling the reassessment of existing government initiatives. The results obtained can assist policymakers in refining their strategic approaches for future policymaking by identifying potential allies and enabling well-informed decisions.

1.1 Literature Review

Previous studies in the U.S. have focused on Republican and Democratic governing influence in the realm environmental and climate policy, such as a study conducted by Parks et al. which revealed that climate change hearings are more frequent under Democrat-controlled Congresses (Park et al., 2010). In these sessions, pro-environment voices and mainstream scientists dominate. In contrast, Republican-controlled sessions often challenge climate science and emphasize the drawbacks of regulating carbon dioxide (ibid.). Furthermore, Democratic governance on the State level is associated with improved air quality, likely attributable to stricter pollution standards, enhanced monitoring, and stronger rule enforcement, as well as increased environmental expenditures, according to studies by Beland & Boucher, 2015, and Pacca et al., 2021. However, in fossil-fuel dependent states, Democratic governors tend to support less stringent environmental measures, explained by the influence of interest groups opposing strong regulations (Pacca et al., 2021). Furthermore, it was found that within the studied sample, Republican governors received twice as many contributions from polluting industries compared to their Democratic counterparts (ibid.). In a 2020 study using data from 28 years, Goldberg et al. found a significant link between political donations from oil and gas industries and officials' voting patterns against environmental policies, highlighting the efficacy of anti-environmentalist lobbying (Goldberg et al., 2020). Ultimately, a study conducted by Colhane et al. investigated how polluting industries hinder ambitious environmental and climate policy to be passed in the State of Massachusetts (Culhane et al., 2021).

Hence, the current body of literature underlines the expectation that polluting industries exert a substantial influence on U.S. environmental and climate policy, alongside with the two major political parties. Consequently, the analysis will closely scrutinize the behavior of these key actors, encompassing the Democratic party, the Republican party, and private corporations including major oil and gas companies.

The following section sums up studies employing the ACF relevant to this analysis. While the ACF is a prominent framework to analyze environmental and energy policy (see e. g. Markard et al., 2016, Gronow & Ylä-Anttila, 2019, Milhorance et al., 2021, and Nevzorova & Kutcherov, 2021), it should be noted that, research on policy coalitions regarding hydrogen is limited due to its relatively recent emergence and has focused on Europe so far (Belova et al., 2023; Malmborg, 2023).

In the context of political coalitions in the U.S., using the ACF, Heikkila et al. did a comparative study of advocacy coalitions in relation to shale oil and gas development in the U.S., China, and Argentina finding that coalitions engaged in the U.S. consist of more diverse stakeholders than in China and Argentina (Heikkila et al., 2019). Furthermore, Weible and Elgin did a study on advocacy coalitions featured by the energy policy subsystem in Colorado (Elgin & Weible, 2013). The authors found two coalitions mainly engaged in this policy subsystem, a large pro climate coalition and a small anti climate coalition (ibid.).

On the national level, core beliefs of national and international actors shaping environmental and climate policy have been investigated e. g. through discourse network analysis by Kukkonen and colleagues using 1410 statements of stakeholders engaged in environment and climate policy finding that mainly three coalitions sharing similar beliefs engage: The *Environment Coalition*, *Economy Coalition*, and *Science Coalition* (Kukkonen et al., 2017). Concerning U.S. national stakeholders, the *Environment Coalition* predominantly consists of the Democratic Party, NGOs, and government entities, such as the Obama administration. The *Environment Coalition* prioritizes environmental preservation even in the face of potential economic costs or expresses the belief that climate protection does not have to limit economic growth (ibid.). The *Economy Coalition*, conversely, is composed of the Republican Party, major oil and gas corporations, governmental bodies like the Bush administration, and conservative think tanks (ibid.). This coalition shares a common ideology of prioritizing economic considerations over environmental concerns while emphasizing the uncertainties of climate science (ibid.). Lastly, the *Science Coalition* comprises national and international research institutions, such as the MIT, and approaches climate change as a scientific question without adopting specific value-based positions (ibid.).

Ultimately, a quantitative study conducted at the University of Michigan found that private companies *"that directly emit more carbon are more likely to join coalitions that oppose climate action"* (Cory et al., 2020, p. 82). A coalition in this study was understood as joining a trade association that opposes climate action (ibid.).

2 Theoretical Framework

The ACF was originally developed by Paul A. Sabatier (Sabatier, 1986, 1988, 1998) and Hank C. Jenkins-Smith (Sabatier & Jenkins-Smith, 1993) and has been considered one of the most influential and successful theories to understand policy processes and outcomes (Weible et al., 2020).

The complex nature of modern challenges has compelled policymaking to occur within specialized policy subsystems, involving political actors who possess expertise in specific policy domains (Sabatier & Weible, 2007). A policy subsystem comprises diverse public and private actors from various institutions focused on a specific policy area, like agriculture (Sabatier, 1998). Within these subsystem, actors constantly engage in efforts to influence policy outcomes of the subsystem (ibid.). Political actors are understood as any person "*directly or indirectly influencing subsystem affairs*" spanning from government officials, representatives of the private sector, journalists, scientists, representatives of NGOs, think tanks, members of the court, private consultants etc. (Jenkins-Smith et al., 2018, p. 139). In the case of low-carbon hydrogen policy in the U.S., the main actors include officials from the government, the DOE, which is responsible for administering the nation's energy policy, Congressional committees, the Environmental Protection Agency (EPA), private companies, trade associations, NGOs, and research institutions.

Typically, a policy subsystem intersects with other related subsystems (Jenkins-Smith et al., 2018). For instance, the energy policy subsystem in Colorado intersects with the local food policy subsystem and is embedded within the broader national energy policy subsystem (ibid.). In the context of this study, the hydrogen policy subsystem is deeply intertwined with the national energy policy subsystem and also intersects with both the national climate policy subsystem and the environmental policy subsystem.

It is argued that each political actor has certain beliefs that can be further divided in three types: (i) deep core beliefs, (ii) policy core beliefs, (iii) secondary beliefs (Jenkins-Smith et al., 2018; Sabatier, 1988). Deep core beliefs include fundamental normative values and interests (freedom, security, love, health, money etc.) and perceptions like the nature of man (inherently evil vs socially redeemable) which are not policy specific but concern several policy subsystems (Jenkins-Smith et al., 2018; Sabatier, 1988). Deep core beliefs are notably difficult to change (ibid.). Policy core beliefs are regarded as a translation of deep core beliefs and are subsystem specific. They include how serious a problem is perceived, causes of a problem, priorization of values, and suggested solutions (ibid.). Policy core beliefs are difficult to change but can do so when "*experience reveals serious anomalies*" (Sabatier, 1988, p. 145). Secondary beliefs are easiest to change and concern the actors preferred policy design, policy instrument, and budget allocation to achieve the desired outcome (Sabatier, 1988).

According to the ACF, actors within policy subsystems align themselves with allies who share their policy core beliefs (Sabatier, 1988). Non-trivial coordination among these actors can lead to the formation of advocacy coalitions based on shared core beliefs (ibid.). Typically, a policy subsystem consists of 2-4 advocacy coalitions, however, exceptional cases exist where subsystems may feature only one coalition or more than four (ibid.). Sabatier posits that these coalitions tend to remain relatively stable over extended periods, often enduring a decade (Sabatier, 1998). Consequently, researchers are encouraged to center their analyses on long timeframes, typically spanning 10 years or more (ibid.).

Following the theory, every policy subsystem is impacted by two types of external factors: Firstly, stable factors, such as the distribution of natural resources, cultural values, societal organization, and the nation's legal system. These factors change gradually, often taking a span of 10 years or longer, and consequently, they rarely serve as justifications for policy change (Jenkins-Smith et al., 2018; Sabatier, 1988). Secondly, dynamic factors such as shifts in socio-economic conditions (fluctuations in oil prices, inflation, and public opinion), changes in governing coalitions, advancements in technology, and policy influences from other subsystems are prone to change (Jenkins-Smith et al., 2018; Sabatier, 1988). These dynamic factors, by constraining or influencing the resources available to actors within a policy subsystem, can significantly contribute to drastic policy changes occurring within a relatively narrow period (ibid.).

Comprehending policy change and stability constitutes a fundamental area of focus within the ACF (Jenkins-Smith et al., 2018). A central premise to the ACF is that political programs and policies are translations of policy-oriented beliefs. *"Major policy changes"* indicate significant shift of directions and goals in the policy subsystem while *"minor policy changes"* are evidence for changing secondary aspects of the subsystem, such as changes in policy instruments used (Jenkins-Smith et al., 2018, p. 145). Furthermore, the ACF outlines four paths to policy change: (i) external shocks, such as a change in the dynamic factors influencing the policy subsystem (ii) internal shocks and other events in the policy subsystem, like policy fiascos and scandals

(iii) policy-oriented learning, and (iv) negotiated agreements (Jenkins-Smith et al., 2018; Pierce et al., 2020).

3 Methodology and Data Sources

The unit of analysis in this study is the national hydrogen policy subsystem of the U.S. Notably, the U.S. operates within a multi-level governance system comprising national, state, and local levels. While acknowledging interactions of these governance layers, this analysis focuses on actors at the national level with a few exceptions. This research aims to identify key actors and advocacy coalitions sharing similar core beliefs within the studied subsystem.

Sabatier and Jenkins-Smith suggest extending the analysis to span a minimum of a decade (Jenkins-Smith et al., 2018; Sabatier, 1988). The studied timeframe spans over the last 30 years (1993-2023) with the main emphasis on recent developments from 2021 and onwards. The first focal point of this study is examining political actors that pushed clean hydrogen technologies in the past. The study's second focal point, extending from 2021 onward, involves examining actors and coalitions striving to influence the implementation of the hydrogen production tax credit outlined in the IRA.

Sabatier proposes that employing qualitative content analysis of publications of actors engaged in a policy subsystem offers a highly suitable method to empirically explore policy core beliefs (Sabatier, 1988). Consequently, studying government documents and publications from interest groups presents a systematic opportunity to identify core beliefs and shifts within the belief system of key actors (ibid.).

As scientific work in this area has been lacking, primary data sources had to be used to a large extent to conduct the analysis. This study employs qualitative content analysis of government documents and published literature of key stakeholders (strategies, drafts, bills, hearings, reports, websites of government institutions and other stakeholders, press releases, open letters etc.) as primary sources to identify actors and their core beliefs. Moreover, this analysis integrates secondary sources, including scholarly research and third-party analyses to supplement the findings.

Furthermore, actor beliefs regarding the implementation of the hydrogen production tax credit were categorized in six categories that were inductively derived. These categories cover the stances of actors, both in favor and against, regarding a strict implementation of additionality, temporal matching, and deliverability to qualify for the hydrogen production tax credit. The operationalization of these categories is described in detail in Chapter 6.

The question of which actors are assessed as being ‘central’ in the U.S. hydrogen policy subsystem arose several times during the research process. Since the number of actors that are engaged in the U.S. hydrogen policy subsystem is notably high, not all of the engaged actors are considered. This research exclusively examines the most influential actors who consistently emerged as prominent throughout the research process, including private companies, trade associations, research institutions, NGOs, party representatives, and national and local government entities. Consequently, the list of identified actors obtained at the end of this study is not exhaustive. However, the outlined coalitions will give a good overview of the U.S. hydrogen policy subsystem.

To validate the acquired results and gain insights not attainable solely through document analysis, two semi-structured expert interviews were carried out with Max Grünig, who holds the position of a Senior Policy Advisor at the think tank E3G. E3G has specialized in the political economy of climate change.

4 A Snapshot of Current Energy and Hydrogen Use in the U.S.

This chapter will provide a first overview of the status quo regarding U.S. climate targets, energy consumption, CO_2 emissions, and hydrogen deployment. This is done to familiarize the reader with the studied country before the actual analysis begins.

4.1 National Climate Targets

The U.S. government exhibited a dithering course regarding the nation's announced climate targets. Barack Obama (2009-2017) became the first U.S. President to announce far-reaching climate goals which were then overturned by President Trump (2017-2021) who exited the U.S. from the *Paris Climate Agreement* (Mildner et al., 2020). With Biden assuming office in 2021, climate policy has been back on the table. Under Biden, the U.S. re-entered the *Paris Climate Agreement* and the government submitted a long-term strategy to the *United Nations Framework on Climate Change Convention* (UNFCCC) committing itself to climate neutrality by 2050 and cutting GHG emissions about 50-52% by 2030 compared to 2005 levels (U.S. Department of State, 2021a, 2021b). Furthermore, 100% carbon-free electricity is targeted by the year 2035 (ibid.).

In order to realize this ambitious goal, the U.S. would be required to add a capacity of roughly 60-70 GW of renewable energy systems and carbon-free electricity sources on average annually until 2050 (U.S. Department of State, 2021b, p. 29). This magnitude of capacity expansion notbaly surpasses the current growth rate of renewables which amounted to ~28 GW in 2021 (S&P Global Market Intelligence [S&P Global], 2022). It is therefore doubtful whether the U.S. will be able to achieve their self-imposed climate goals. Especially, complete decarbonization of the electricity sector by 2035 presents a substantial challenge, particularly for states like West Virginia, where the majority of electricity, such as 91% in 2021, is still generated from coal (Nuclear Energy Institute, 2022).

However, the zigzag course (GHG emission targets announced by Obama, Trump's withdrawal from the *Paris Climate Agreement*, and Biden's efforts to recommit to GHG emissions reduction) has undermined political credibility of the announced climate targets (Max Grünig, personal interview, October 9th, 2023). The Biden administration is now attempting to counteract this by offering various incentives for renewable energy technologies, low-carbon hydrogen, and low-carbon transportation options, including tax credits, loans, grants, and funding for research, development, and demonstration (McKinsey & Company, 2022; The White House, 2021). Finally, the impact of these incentives remains to be seen, and it exists an ongoing uncertainty whether a future Republican-led government will once again abandon U.S. climate goals.

4.2 National Energy Mix

Total energy consumption in the U.S. has been more or less constant since 2005, see Figure 1 (EIA, 2023g). The primary energy mix of the U.S. has been dominated by fossil fuels, with petroleum accounting for 36%, and natural gas accounting for 33% in 2022 (EIA, 2023g). The share of energy produced from coal decreased in the last decade and amounted to 10% in 2022. Renewable energy sources, such as hydropower, wind, solar, geothermal, and biomass, have been growing in the energy mix and comprised 12% of the total primary energy consumed in 2022 while nuclear power represented 8% (ibid.).

U.S. Primary Energy Consumption between 1950-2022 (left) and in 2022 (right)

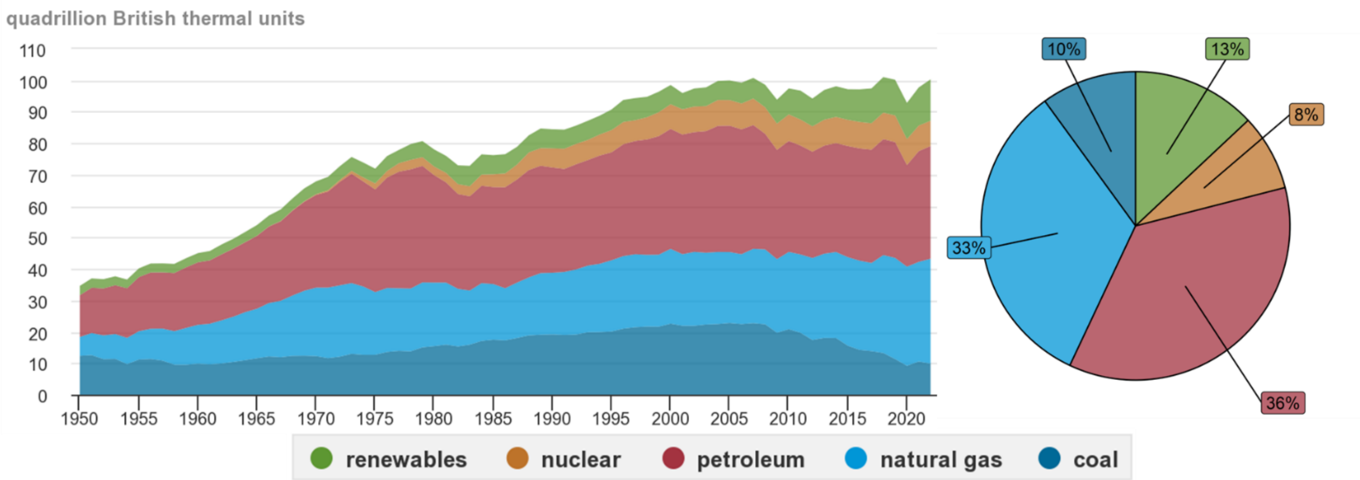

Figure 1: U.S. primary energy consumption of each energy feedstock between 1950-2022. Figure on the left illustrates the historical development. Source: Energy Information Administration [EIA], 2023g. Figure on the right illustrates the primary energy consumption of the U.S. in 2022. Own Illustration based on EIA, 2023g.

Figure 2 illustrates electricity generation in the U.S. by energy source. It is striking that the amount of electricity produced by coal power in the U.S. was more than halved between 2001 and 2022 amounting to ~800 TWh today (EIA, 2023c). This is mainly due to the replacement of coal with natural gas for electricity generation. Natural gas consumption was more than doubled in the same period amounting to 1700 TWh in 2022 (ibid.). Furthermore, the share of renewable energy has been growing consistently reaching a maximum of 21.5% in 2022 (ibid.).

Notably, the share of renewable energy in the U.S. energy mix varies significantly from State to State, with some States relying heavily on fossil fuels, while others have made significant investments in renewable energy sources (Nuclear Energy Institute, 2022). The State of Vermont leads the nation in the share of electricity generation from renewable energy sources, with already 100% of the in-state produced electricity coming from renewables in 2021 (EIA, 2022b). Conversely, numerous States heavily rely on fossil fuels, such as coal and gas, for a substantial portion of their electricity (Nuclear Energy Institute, 2022). For instance, in 2021, West Virginia generated 90% of its electricity from coal (ibid.).

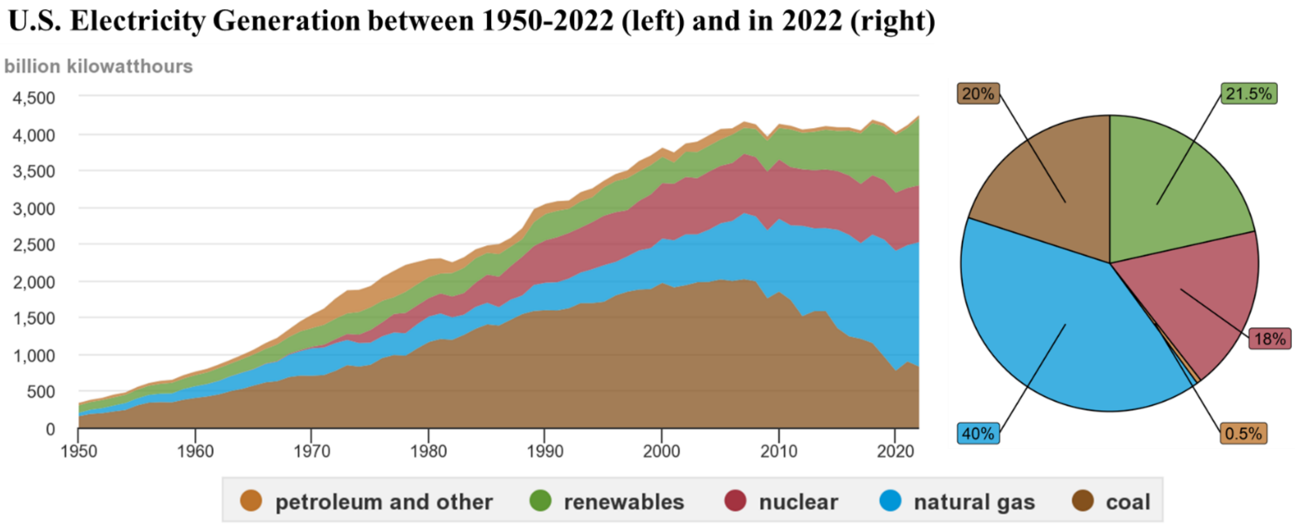

Figure 2: U.S. electricity generation of each energy feedstock between 1950-2022. Figure on the left displays the historical development. Source: EIA, 2023c. Figure on the right displays the U.S. electricity mix in 2022. Own illustration based on EIA, 2023c.

4.3 National Carbon Emissions

In 2021, the U.S. was responsible for 12.5% of global CO_2 emissions making it the second largest polluting country in the world after China (European Commission, 2022). The transportation sector stands out as the leading economic sector responsible for U.S. GHG emissions, comprising approximately 28% of total emissions in 2021 (Environmental Protection Agency [EPA], 2023d). Close second comes the electric power sector at about 25% followed by the industry sector responsible for about 23% of the nation's GHG emissions (ibid.). Carbon emissions by economic sector are illustrated in Figure 3. Hence, there exists a considerable potential to decarbonize with low-carbon hydrogen technologies, especially within these three sectors (see e. g. FCHEA, 2020).

The EPA, which is in charge of regulating air quality and GHG emissions, has repeatedly tightened emission standards for the transportation sector since 1970 (EPA, 2023c). Furthermore, the EPA is authorized to regulate GHG emissions from the power sector since 2015 (Outka, 2016). Nevertheless, the U.S. has no implemented carbon taxation or carbon trading system, limiting the incentive to transition to clean technologies in sectors beside the power and transportation sector (Max Grünig, personal interview, October 9th, 2023). Carbon taxation and emission trading is only done on the local level, as for example through the *Regional Greenhouse Gas Initiative*, joined by the States of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia (RGGI, 2023).

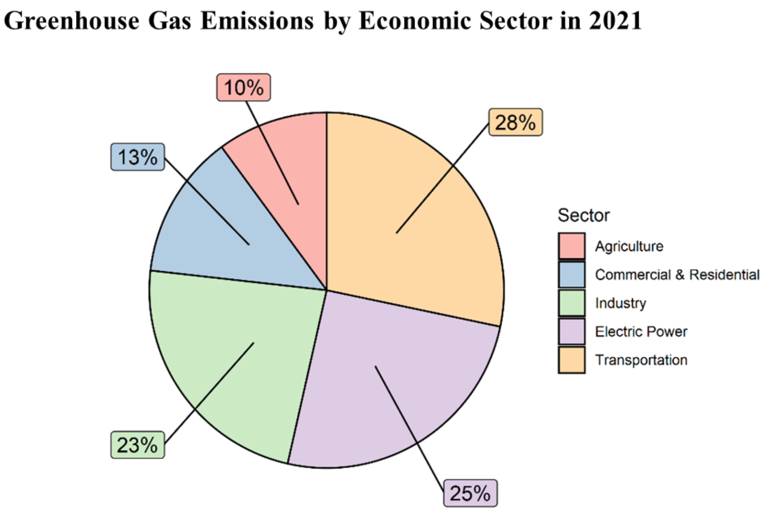

Figure 3: U.S. GHG emissions by economic sector in 2021. Transportation, Electricity Generation, and Industrial Processes are responsible for the largest part of the emissions. Own illustration based on EPA, 2023d.

4.4 Hydrogen Use Today

The U.S. consumes over 11 million tons of hydrogen per year (FCHEA, 2020, p. 38). In 2020, 57% of hydrogen consumed in the U.S. served for refining, 38% for ammonia and methanol production, and 2% for metal treatment (FCHEA, 2020, p. 20). The last 4% account for different hydrogen use cases, including its use as fuel for fuel cell power systems (FCHEA, 2020, p. 20). In 2021, over 95% of hydrogen produced in the U.S. was classified as grey hydrogen[2]

[2] Grey Hydrogen: hydrogen produced from natural gas or methane using steam methane reforming is termed grey hydrogen. The CO_2 emissions generated in this process are not captured and released into the atmosphere (see National Grid (2023) and IEA (2019, p. 34)).

produced from steam methane reforming[3] (SMR) while less than 1% of hydrogen was categorized as green hydrogen[4] produced from electrolysis and renewables (DOE, 2023c, p. 38). As a consequence, the hydrogen industry today significantly contributes to national GHG emissions (Shearman & Sterling, 2021).

Despite the U.S. government's significant efforts in the 2000s to make hydrogen-powered cars market-compatible (see e. g. Trinkle, 2009), fuel cell electric vehicles (FCEVs) represent a minority of the current car stock in the U.S (IEA, 2022, p. 30). At the end of 2021, the IEA quantified the number of FCEVs in the U.S. with 12,400 in addition to 66 hydrogen refueling stations, almost all of them located in California (California Energy Commission, 2023, p. 11; IEA, 2022, p. 30).

4.5 Hydrogen Fuel Cells as Backup Power Systems

In the past, hydrogen fuel cells were deemed as too expensive for backup power, given the availability of more cost-effective conventional alternatives such as diesel generators (Romm, 2006, pp. 27–42). However, in recent years, hydrogen fuel cells for backup power systems have been experiencing increasing popularity due to their high reliability (DOE, 2013a; National Renewable Energy Laboratory [NREL], 2015). Presently, the U.S. hosts over 500 MW of operational fuel cell backup power systems. These systems have been mainly embraced by governmental bodies and big corporations like Microsoft (DOE, 2013a; pv magazine, 2022). Nevertheless, as outlined in the previous paragraph, this use case of hydrogen is still a rather peripheral phenomenon.

4.6 Hydrogen Strategy of the U.S.

In 2023, the U.S. administration endorsed its inaugural official hydrogen strategy, highlighting technology-neutral *“clean hydrogen”* (DOE, 2023c). Clean hydrogen refers to hydrogen produced from various energy feedstocks including fossil fuels with carbon capture and storage[5]

[3] For more information, see IEA (2019, pp. 37–42)

[4] Green hydrogen: hydrogen produced from electrolysis and renewable electricity is referred to as green hydrogen. Zero GHG emissions are generated in this production process (see National Grid (2023) and IEA (2019, p. 34)).

[5] With carbon capture and storage technology, most of the carbon emissions generated in a technical process are captured and prevented from leaking into the atmosphere. For more information see Umweltbundesamt (2022).

(CCS) (blue hydrogen[6]), renewable, and nuclear energy (pink or purple hydrogen[7]) (DOE, 2023c). Consequently, the government does not favor a particular 'color' of hydrogen, leading to the utilization of the term clean hydrogen in various government documents (ibid.). The term clean hydrogen is used in the following to describe hydrogen produced with a smaller carbon footprint than grey hydrogen, such as hydrogen produced from fossil fuels with subsequent CCS, nuclear energy, or renewable energy.

The hydrogen strategy furthermore revolves around three core principles: (i) identifying key applications where clean hydrogen can substantially mitigate GHG emissions, (ii) minimizing the costs associated with clean hydrogen production, and (iii) concentrating efforts on establishing local hydrogen hubs (ibid.).

The first principle refers to the idea that hydrogen should be deployed for GHG reduction in sectors where alternative solutions, such as electrification, are lacking (DOE, 2023c). These sectors should include heavy industry, long-haul transportation, long-term storage of energy to stabilize the grid, and the prospect of exporting clean hydrogen to U.S. allies (ibid.). The DOE concludes that clean hydrogen should not compete against other efficient decarbonization technologies, such as electrification (DOE, 2023c).

Reducing the cost of clean hydrogen is the second pillar of the U.S. hydrogen strategy (ibid.). The DOE launched the *Hydrogen Energy Earthshot Initiative* (Hydrogen Shot), inspired by the *Moonshot Initiative* that put the first man on the moon in 1969, with the stated goal to reduce the price of 1 kg clean hydrogen to $1 in 1 decade until 2031 ("1 1 1") (DOE, 2023c). Loan guarantees, creation of regional hydrogen hubs, tax credits for hydrogen production, and research and development (R&D) of clean hydrogen technologies are various instruments being used by the current administration to achieve this goal. The *1 1 1 Initiative* has been complimented by additional funding from the *Infrastructure Investment and Jobs Act* (IIJA) allocating $1 billion to R&D to drive down costs of hydrogen produced by electrolysis (ibid.). Technology neutral hydrogen production is a crucial element of the strategy (DOE, 2023c). As of now, fossil fuel based hydrogen production has been cheaper than using electrolysis (ibid.). Figure 4

[6] Blue Hydrogen: hydrogen produced from natural gas or methane using SMR with CCS is termed blue hydrogen. Most of the CO_2 emissions generated in the production process are captured and not released into the atmosphere (see National Grid (2023) and IEA (2019, p. 34)).

[7] Pink / Purple Hydrogen: hydrogen produced with nuclear energy is termed pink or purple hydrogen (see National Grid (2023) and IEA (2019, p. 34)).

illustrates current costs per kilogram hydrogen produced from electrolysis (left) and methane (right) as well as the cost reduction needed to achieve the aspired costs of $1 per 1 kg of hydrogen. However, Figure 4 does not consider subsidies outlined in the IRA which could be a game changer for production costs of clean hydrogen.

The third pillar of the national hydrogen strategy is the policy focus on the development of local hydrogen hubs, an area of mass hydrogen production allocated next to high demand use cases, which are going to be outlined in the following paragraph.

Figure 4: Current and targeted cost reduction for clean hydrogen production from electrolysis (left) and methane (right). Currently, hydrogen production from methane amounts to ~$1.60 / kg and is therefore much cheaper as its counterpart of from electrolysis which costs ~$5 / kg produced. O&M stands for operation and maintenance and T&S stands for transport and storage. Source: DOE, 2023c, 41 & 44.

4.7 Hydrogen Hubs

The IIJA enacted in 2021 established the legislative framework for $8 billion of funding for the creation of multiple hydrogen hubs across the U.S. (IEA, 2023). The IIJA mandated hubs demonstrating clean hydrogen from nuclear, renewable, and fossil fuel sources, with two hubs located in regions rich in natural gas resources (Infrastructure Investment and Jobs Act, 2021, Sec. 813). Thus, the importance of technology neutrality for clean hydrogen production was once again emphasized in the IIJA. The DEO was tasked to assess future hydrogen hubs for IIJA funding under these outlined criteria.

In October 2023, DOE's Office for Clean Energy Demonstration (OCED) completed its assessment of hydrogen hub proposals and formally declared the establishment of seven *Clean*

Hydrogen Hubs across the States of West Virginia, Ohio, Pennsylvania, California, Texas, Minnesota, North Dakota, South Dakota, Delaware, New Jersey, Illinois, Indiana, Michigan, Washington, Oregon, and Montana. (Office of Clean Energy Demonstrations [OCED], 2023). As required by law, these hydrogen hubs will leverage diverse energy sources including nuclear energy, renewable energy, biomass, and natural gas for clean hydrogen production (ibid.). Figure 5 illustrates geographic location of the announced *Clean Hydrogen Hubs*.

Figure 5: Geographic location of selected Clean Hydrogen Hubs in the U.S. that will receive funding from the BIL. Source: Green Stocks Research, 2023.

- The *Appalachian Hydrogen Hub*, located in States with abundant natural gas resources - West Virginia, Pennsylvania, and Ohio - focuses on producing cost-effective clean hydrogen from natural gas with CCS (OCED, 2023).
- In contrast, the *Pacific Northwest Hydrogen Hub* aims to demonstrate hydrogen production solely through electrolysis, utilizing various energy sources, with the goal of significantly reducing electrolysis-produced hydrogen costs in the coming years (OCED, 2023).
- The *Mid-Atlantic Hydrogen Hub*, spanning Pennsylvania, Delaware, and New Jersey, aims to showcase clean hydrogen production through electrolysis, utilizing electricity from renewable energy and nuclear power sources (OCED, 2023).

- The *Gulf Coast Hydrogen Hub*, centered around Houston, Texas, capitalizes on hydrogen production from renewable energy sources as well as fossil fuels with CCS, making use of Texas' wind power potential and abundant natural gas resources. Texas furthermore benefits from an extensive natural gas pipeline network and existing hydrogen infrastructure as hydrogen is already used today at a large scale in oil refining and the chemical sector (OCED, 2023).
- The *California Hydrogen Hub* stands out as the only hub demonstrating hydrogen production exclusively from renewable energy and biomass (OCED, 2023).

4.8 Lighthouse Clean Hydrogen Projects

The recent surge in interests in clean hydrogen in the U.S. began when the Biden administration passed the IIJA in 2021, allocating $9.5 billion to hydrogen research and demonstration projects (IEA, 2023). Additionally, the momentum continued with the IRA in 2022, introducing substantial tax credits and other incentives for hydrogen production (for more information, see DOE, 2023c, pp. 7–8) leading to many private companies investing into clean hydrogen production on U.S. territory (Air Products, 2023; ExxonMobil, 2023, p. 63; Green Hydrogen International, 2023; Los Angeles Department of Water & Power, 2020). This section provides a concise overview of some of the most significant clean hydrogen projects, though it is not an exhaustive compilation.

- The *Intermountain Power Agency* aims to transform the *Intermountain Power Project* (IPP), presently one of the largest coal power plants in the U.S., into a hydrogen power plant. IPP will transition into a combined cycle gas turbine, utilizing a mixture of natural gas and up to 30% green hydrogen to generate an output of 840 MW of electricity from 2025 on (Los Angeles Department of Water & Power, 2020). Over the years, the share of fired hydrogen should increase with the ultimate goal to power the gas turbine entirely with hydrogen by 2045 (ibid.). The IPP initiative stands out for several reasons: the hydrogen employed in the project will be generated on site through renewable sources and electrolysis and subsequently stored in an underground salt cavern. The IPP uses hydrogen as a seasonal energy storage, enabling the gas power plant to play a pivotal role in stabilizing the electricity grid during times of low renewable energy generation and high electricity demand (Los Angeles Department of Water & Power, 2020).

- The gas supplier *Air Products* invests $4.5 billion to build one of the largest CCS projects of the world in Louisiana to produce clean hydrogen, called the *Louisiana Clean Energy Complex* (Air Products, 2023). The project will rely on natural gas for hydrogen production and store up to 95% the CO_2 emitted during the production process in porous rocks underground (ibid.). The hydrogen produced will either be injected into the Gulf Coast pipeline network or used to produce clean ammonia in a neighboring plant (ibid.).
- The oil and gas giant *ExxonMobil* is in the process of constructing a blue hydrogen facility in Baytown, Texas, geared towards an annual production goal of 1 million tons of clean hydrogen (ExxonMobil, 2023). This endeavor complements their existing global hydrogen production of 1.3 million metric tons (ibid.). If successful, this initiative will augment *ExxonMobil*'s current hydrogen production by an impressive 65%. (ExxonMobil, 2023, p. 63). Texas' well-established gas and storage infrastructure coupled with a high hydrogen demand for oil and petroleum refining and other products provide a conducive environment for the implementation of clean hydrogen projects (Center for Houston's Future et al., 2022).
- Texas is furthermore set to host one of the world's largest green hydrogen initiatives: *Green Hydrogen International* has unveiled plans for a 2.2 GW electrolyzer project, supported by 3.75 GW of behind-the-meter solar and wind power facilities, enabling an annual hydrogen production of 280,000 tons with the perspective to further increase green hydrogen production later (Green Hydrogen International, 2023). The chosen site also features voluminous salt caverns, offering the possibility of storing hydrogen underground (ibid.). The generated hydrogen will be utilized in nearby ammonia production facilities, in the production of more sustainable aviation fuels, and supplied to other local customers (ibid.).

5 Historical Development of the Hydrogen Economy in the U.S.

Now that an overview of the status quo of hydrogen technologies in the U.S. today was presented, it is interesting to ask which factors shaped hydrogen development in the past. This chapter explores the historical progression of a hydrogen economy in the U.S. A major question to be answered in this chapter is which actors accelerated and legitimated clean hydrogen technologies in the past.

The term *"hydrogen economy"* was originally defined as an economy in which "*hydrogen would be used to transport energy from renewables (at nuclear or solar sources) over large distances; and to store it (for supply to cities) in large amounts"* (J. O. Bockris, 2002, p. 732). However, here it is argued that this definition falls short of many hydrogen use cases that have been discussed today. For instance, worth adding to the definition is that hydrogen, as it is discussed today, would not only be used to supply cities but also to supply infrastructure, such as refueling systems for transportation, backup power systems, and industrial processes. Furthermore, hydrogen as discussed above does not solely rely on renewables and nuclear power, but also on natural gas and SMR with subsequent CCS as well as potentially other technologies (e. g. thermochemical water splitting, for more information see Office of Energy Efficiency & Renewable Energy [EERE], 2023b). Despite these additions, the quintessence of the original definition, namely hydrogen being moved as an energy carrier on a large scale in a hydrogen economy, is certainly still applicable in today's development.

5.1 Pioneering Phase (1970-1993)

The South African chemist John O'Mara Bockris initially pursued the idea that from a certain distance on, it might be cheaper to transport energy in the form of hydrogen instead of electricity; this distance was estimated to be around 200 miles in 1972 (Bockris, 2002). From 1971 on, Bockris concluded that hydrogen has many more use cases and could eventually be used as a universal energy carrier to limit environmental pollution (ibid.). The first paper with *"hydrogen economy"* in the title published in 1972 by Bockris and Appleby explored possible hydrogen use cases, such as for long-haul energy transportation and environmental pollution mitigation (Bockris & Appleby, 1972). Then, during the inaugural *World Hydrogen Energy Conference* in 1976 hosted in Miami, hydrogen was recognized as a promising clean energy carrier of the future (Lattin & Utgikar, 2007; Veziroglu, 2008). However, when investigating hydrogen use cases further, such as for long-haul energy transportation, researchers run into trouble: due to its physical properties, hydrogen leaks significantly easier than conventionally natural gas, and, hydrogen leaks are much harder to find (Bockris, 2002). Furthermore, concerns regarding embrittlement emerged (ibid.). The promises of hydrogen success predicted in the 1970s for 1985 and 2000 (see, e. g. Valette et al., 1978) did not materialize, and the role of hydrogen in energy systems was grossly overestimated in retrospect (Lattin & Utgikar, 2007).

5.2 Clinton (1993-2001): Paving the Road for Hydrogen

In the early 1990s, the DOE didn’t establish the hydrogen sector its own budget, yet (Romm, 2006, p. 9). Instead, funding for hydrogen was included in the renewable energy budget and consisted of only one to two million dollars (ibid.). This situation changed when Democrat Bill Clinton won the presidential election in 1992, driven by the momentum fueled by the first global Earth Day in 1990 and the influential UN Conference on Environment and Development in Rio in 1992. With Al Gore becoming vice president who already published a book addressing the looming ecological crisis in 1992, called *Earth in Balance* (Gore, 1992), environmental policy was central to the Clinton administration after a period of relative standstill (Müller, 2020). While Clinton’s predecessor, George H. W. Bush (41st President of the U.S. 1989-1993), had signed the UNFCCC in 1992, the Clinton administration explored further steps of U.S. climate policy by signing the *Kyoto Protocol* in 1997. However, the *Kyoto Protocol* was not ratified by the Republican-controlled Senate, which also repeatedly blocked increased spending on environmental programs and alternative energy during the Clinton administration (Müller, 2020).

Alongside environmental concerns, the Clinton administration directed attention to reducing U.S. dependency on imported petroleum, prompting an exploration of alternative fuel and propulsion technologies in the passenger vehicle sector (Trinkle, 2009, p. 32). The Clinton administration then initiated a *Public-Private Partnership for a New Generation of Vehicles* (PNGV) upon Bill Clinton's inauguration in 1993 (Trinkle, 2009). The PNGV initiative sought to enhance the competitiveness of the U.S. automotive industry and decrease national reliance on oil (ibid.). The primary emphasis was on enhancing the energy efficiency of conventional petroleum-powered vehicles, while also exploring hydrogen and fuel cells as potential alternative propulsion technologies (ibid.).

In the years after 1993, DOE's budget for hydrogen and fuel cell research was incrementally increased to several million dollars in 1998 resulting in reduced costs and a significant increase in energy efficiency of fuel cells for vehicles (DOE, 2000; Romm, 2006, p. 11). The DOE's efforts in hydrogen research bore fruit and in January 2000 when vice president of *General Motors*, Harry Pearce, publicly stated that the DOE successfully had *"brought fuel cells from aerospace to automotive"* (Romm, 2006, p. 11). Since the early 2000s, major U.S. car manufacturers initiated hydrogen projects, which were paralleled by significant endeavors of prominent oil corporations to produce hydrogen from fossil fuels (Romm, 2006, p. 9).

5.3 Bush (2001-2009): Sparking the First Hydrogen Boom in the U.S.

In contrast to Clinton, President George W. Bush adopted a confrontational stance towards the environmental movement from the outset and upon assuming office in 2001, he ultimately announced the U.S. withdrawal from the *Kyoto Protocol* (Rosenbaum, 2014, p. 12). Furthermore, the Bush administration was contending that science on human-induced climate change was disputed (Müller, 2020). Bush's chief of staff for the White House's *Council on Environmental Quality*, Philip A. Cooney, doctored climate reports to cast doubt on robust climate science findings (Müller, 2020; New York Times, 2005). However, Bush had other motivations for pursuing clean hydrogen technologies than environmental and climate concerns: the U.S. faced a substantial challenge regarding its dependency on imported oil (Congressional Research Service, 2011; Romm, 2006, p. 12).

During the period from the early 1990s until 2005, the country's reliance on foreign oil imports, particularly from the Middle East, notably increased (ibid.). The 9/11 terror attacks in 2001 further escalated public and governmental concerns of the nation's oil dependency and DOE officials emphasized the unavoidable connection between procuring foreign oil and inadvertently contributing financial backing to terrorist activities (Romm, 2006, p. 12). To emphasize the U.S. reliance on foreign oil, it should be noted that since 2000, the country had been importing over 50% of its oil demand (Congressional Research Service, 2011). This trend reached its zenith in 2005, with U.S. net oil imports surging to over 60% followed by a fall in imports due to a politically steered increase of domestic energy production (ibid.). Figure 6 illustrates the share of net-imported oil and oil prices between 1990 and 2020. It is evident how oil prices saw a significant increase since the year 2003 and following.

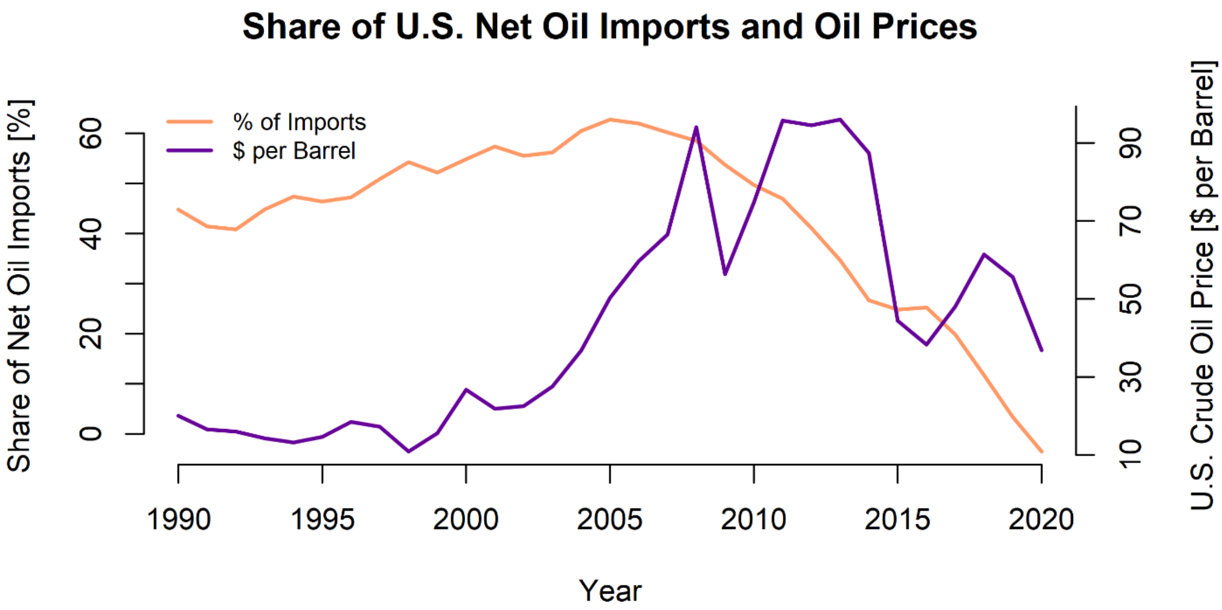

Figure 6: Oil prices and share of net oil imports between 1990 and 2020. Own illustration. Data extracted from Energy Information Administration [EIA], 2023d and EIA, 2023g.

The transportation sector, making up for two thirds of total U.S. oil demand, demonstrated a high degree of petroleum dependency in the early 2000s (EIA, 2023f; Romm, 2006, p. 13). 97% of transportation operations relied on oil as the primary energy source between 2000 to 2005 (ibid.). Viable technical alternatives for transportation were scarce during this period which left the sector little options to reduce its oil consumption. Therefore, the transportation sector became the central focus of efforts to limit U.S. oil dependency and increase energy security during this time, bringing hydrogen and fuel cell technologies as clean, oil-independent options to the forefront (Romm, 2006, p. 13). In 2002, the Bush administration transformed PNGV into the *FreedomCAR* initiative, redirecting its focus towards FCEVs as a long-term technological solution for cars (Trinkle, 2009, p. 292). This marked a departure from the Clinton's PNGV, which prioritized immediate gains in energy efficiency for combustion vehicles (Trinkle, 2009, p. 292).

The overarching aim of *FreedomCAR* was for light-duty vehicles to be capable of operating "*completely free of petroleum and free of harmful emissions*" (National Research Council [NRC], 2008, p. 18). Reducing reliance on foreign oil imports held a *"central"* position within the partnership's objectives (ibid.). Research under the *FreedomCAR* focused among others on fuel cell technologies, hydrogen storage systems, and hydrogen production and delivery systems (ibid.). However, the Bush administration faced criticism for neglecting the current impact of cars with Ashok Gupta, lead energy economist of the prominent environmental NGO *Natural Resources Defense Council* in 2003, stating that "*FreedomCAR is really about Bush's freedom to do nothing about cars today*" (Grist, 2003).

Completion of the *FreedomCar* program was aimed by 2017 which should result in offering a *"large"* number of Americans FCEVs by 2020 (NRC, 2008, p. 83). The initiative was funded with several hundred million USD annually (NRC, 2008, p. 17).

Governmental oversight of *FreedomCAR* resided within the DOE, specifically through the Office of Energy Efficiency and Renewable Energy (EERE). At that time, two programs were administered by EERE to facilitate *FreedomCAR*: the *FreedomCAR and Vehicle Technologies Program* (FCVT), and the *Hydrogen, Fuel Cells, and Infrastructure Technologies Program* (HFCIT) (NRC, 2008, p. 2). As Figure 7 illustrates, some HFCIT components were assigned to other DOE offices than the EERE: hydrogen production from coal with CCS under the Office of Fossil Energy (FE), hydrogen production from high-temperature nuclear reactor research under the Office of Nuclear Energy (NE), and fundamental research, under the Office of Sciences (SC) (NRC, 2008, pp. 20–21).

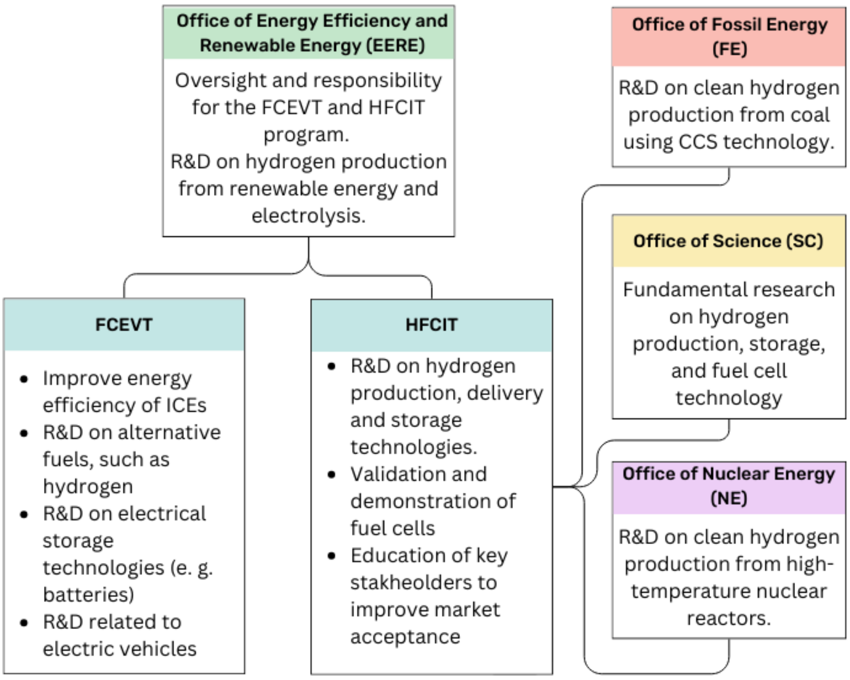

Figure 7:Government supervision of the FreedomCar initative. The EERE was responsible for administering two programs under FreedomCar: FCEVT and HFCIT. Own illustration based on NRC, 2008.

FreedomCar became the first extensive governmental program to investigate clean hydrogen production. It focused on hydrogen production from diverse energy feedstocks including coal, renewables, and nuclear energy to improve energy security (NRC, 2008, p. 84). However, funding disparities for R&D on hydrogen production were notable between the FE and the EERE in 2006, with FE receiving $95 million for hydrogen production compared to EERE's $8 million (NRC, 2008, p. 82). Thus, during that period, the budget allocation for hydrogen production research indicated a preference for hydrogen produced with coal and CCS over renewables.

In 2003 *FreedomCAR* expanded from including only the three biggest car manufacturers *DaimlerChrylser, Ford*, and *General Motors* to five large fossil fuel companies *BP, Chevron, ConocoPhillips, ExxonMobil* and *Shell Hydrogen* and was from now on called the *FreedomCAR and Fuel Partnership* (*FreedomCar Partnership* in the following) (NRC, 2008, p. 17). The involvement of major oil and gas corporations in the partnership is unsurprising, considering hydrogen production has predominantly been done using natural gas. However, it underscores the long-standing and intertwined relationship between major oil and gas companies and hydrogen production in the U.S., with big fossil fuel companies already positioning themselves early for a potential clean hydrogen production.

In January 2003, the administration's hydrogen endeavors were further expanded when in his state of the union speech, Bush announced the *Hydrogen Fuel Initiative* (HFI) to complement the *FreedomCAR Partnership*. HFI should be supported by $1.2 billion for hydrogen and fuel cell research over five years so that *"America can lead the world in developing clean hydrogen-powered automobiles"* (The White House, 2003).

In 2005, Congress passed the *Energy Policy Act* of 2005 which was motivated by competing concerns about energy security, the environment and climate, as well as concerns about economic growth (Congressional Research Service, 2006). The *Energy Policy Act* of 2005 mandated grant programs, testing initiatives, and tax incentives to promote alternative fuels and advanced vehicles (ibid.). Specific goals outlined in the act included deploying 100,000 hydrogen-fueled vehicles by 2010 and aiming for 2,500,000 hydrogen-fueled vehicles in the U.S. by 2020 (Energy Policy Act, 2005, Sec. 811). Additionally, the legislation mandated the DOE to actively encourage the development of a *"sufficient"* hydrogen fueling infrastructure to be completed by the year 2020 (Lattin & Utgikar, 2007, p. 3234). Nonetheless, the allocated funding of $1.2 billion in 2003 fell significantly short of the necessary amount to achieve the established goals, particularly as the infrastructure alone was estimated to cost $500 billion to meet 40% of the vehicle demand (ibid.).

5.4 Obama's Greening the Economy (2009-2017)

Starting with the Obama administration, U.S. energy policy has been oriented towards the golden triangle of energy policy consisting out of sustainability, economic efficiency, and energy security, while prior administrations gave sustainability a secondary role in their energy policy (Mildner et al., 2020; Müller, 2020).

Upon assuming office in 2009, President Obama was presented with promising indicators for a more progressive environmental and climate policy, given that the Democratic Party maintained control of both chambers of Congress, in addition to the Presidency. *"Greening the Economy"* was a prominent term during Obama's first term, referring to nation's shift towards renewable energy and climate friendly economic restructuring (Mildner et al., 2020). However, the 2007-2008 financial crisis had significantly impacted the U.S. economy for the following years. Obama inherited its lingering effects during his first Presidency limiting his flexibility on passing environmental and climate policy, resulting in blocked or unrealized programs due to congressional constraints (Rosenbaum, 2014, pp. 13–14).

In 2009, the *American Recovery and Reinvestment Act* was passed (Rosenbaum, 2017, p. 36). It encompassed a massive economy recovery program amounting to $100 billion of spendings, tax incentives, and loans to promote energy efficiency, renewable energy, and R&D of fuel-efficient cars. While hydrogen received some attention and funding in the *American Recovery and Reinvestment Act*, government funding for clean hydrogen technologies saw a significant decrease from 2011 on under the Obama administration, as evident in Figure 8 (IEA, 2019). In contrast to Bush's hydrogen initiatives, the funding provided through the *American Recovery and Reinvestment Act* primarily targeted fuel cell power systems, leading to a significant rise in the deployment of fuel cells as backup power systems after 2010 (DOE, 2010; NREL, 2015, p. 4). Additionally, the funding facilitated the widespread adoption of fuel cell-powered forklifts in warehouses across the U.S. (DOE, 2018a).

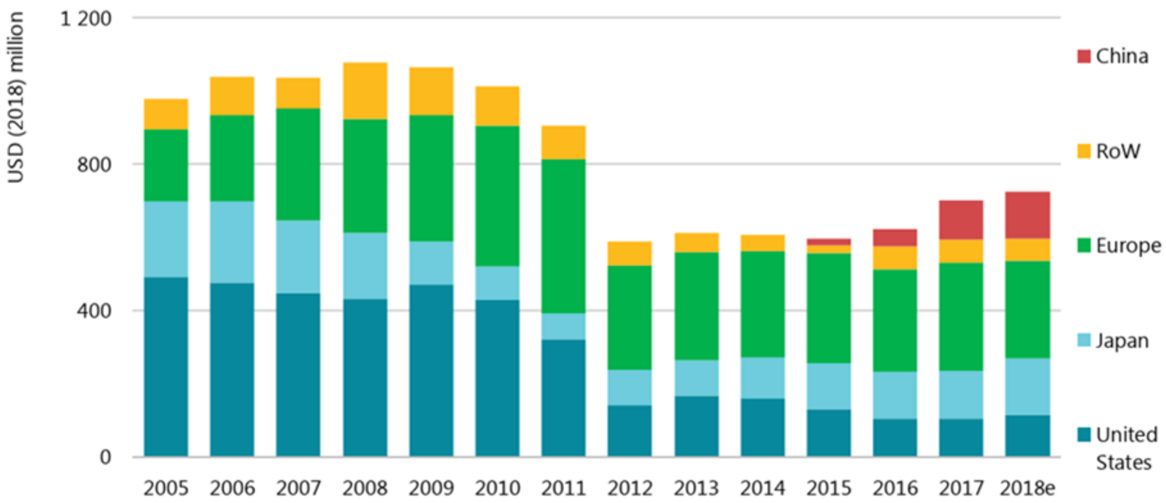

Figure 8: Global Funding for hydrogen and fuel cell technologies between 2005 and 2018. U.S. funding for hydrogen dropped significantly after 2012. Source: IEA, 2019, p. 20.

The Obama administration then changed direction and objective of Bush's *FreedomCar Partnership*. As Obama's Secretary of Energy, Steven Chu, took charge of the DOE he pushed for the discontinuation of EERE's $168 million funding for hydrogen technologies in transportation (Biello, 2009; Tollefson, 2009). Chu held the personal belief that the realization of a *"hydrogen car economy"* within the next 15-20 years was unlikely to happen (ibid.). However, the National Research Council (NRC) criticized the planned funding cuts for hydrogen urging the administration to keep a focus on long-term solutions for oil independency and emission reduction in the transportation sector (NRC, 2009). Ultimately, the House of Representatives prevented complete funding removal by agreeing to a compromise, reducing EERE's fuel cell program budget to $68 million for 2010, marking a $100 million decrease from the previous year (DOE, 2009; Tollefson, 2009). The *FreedomCAR Partnership* was then transformed into the *U.S. Drive Partnership* from May 2011 on (NRC, 2013, pp. 18–20). The Obama administration shifted its focus towards near-term solutions, such as improved energy efficiency of conventional internal combustion engine vehicles (ICEs), and R&D on battery-powered electric vehicles (BEVs) as well as hybrids (ibid.). In the years before, the *FreedomCAR Partnership* had significant troubles developing a commercial fuel cell for vehicles; and interest from car manufactures in fuel cell technologies remained limited as U.S. car manufacturers were more committed to conventional combustion engines (Behling, 2013). Despite no longer being the primary focus, research on FCEVs and clean hydrogen technologies continued and were recognized as a long-term solution for vehicles under Obama's *U.S. Drive* initiative (NRC, 2013, p. 19). However, within the transportation sector, historically a significant driver for clean hydrogen technologies, hydrogen lost its central importance. The hydrogen boom that began in the early 2000s in the U.S. had ended.

The key instrument used by President Obama to issue executive orders for environmental and climate protection was the *Clean Air Act* of 1970 which serves as the principal legislation in the U.S. for regulating emissions and air pollution (Outka, 2016). Its implementation and enforcement are overseen by the EPA, tasked to ensure public health and environmental protection across land, water, and air (ibid.). The EPA, not holding the status of a ministry, is under direct supervision of the President who can select the leader of the agency and, thus, significantly shape its agenda (Müller, 2020). Initially, under the Bush administration, the EPA had refused requests to regulate carbon dioxide emissions (Outka, 2016). However, in a landmark Supreme Court decision in the case *Massachusetts vs EPA* in 2007, the Supreme Court deemed this refusal arbitrary and attested the agency authority and responsibility to regulate GHG, such as CO_2, when they are assessed as harmful for human health (Mildner et al., 2020; Outka, 2016). Two years later, under Obama in 2009, the EPA officially recognized CO_2 and five other GHG as threats to the public health, enabling the enforcement of more stringent measures for these emissions (EPA, 2022). Leveraging the *Clean Air Act*, the EPA tightened emission standards for trucks and heavy-duty vehicles during Obama's first Presidency, and revised regulations on various environmental issues, including mercury pollution from industrial facilities and toxic air pollutants (Rosenbaum, 2014, p. 15, 2017, p. 36).

In the 2010 midterm elections, the House of Representatives shifted to a Republican majority, which opposed Obama's environmental initiatives (Rosenbaum, 2017, p. 36). Faced with a divided Congress, Obama's first administration encountered a legislative deadlock following the midterm elections (ibid.).

When President Obama began his second term in the White House in 2013, from the outset, his administration shifted its focus towards the fight against climate change, a matter repeatedly emphasized by President Obama in public speeches (Rosenbaum, 2014, p. 15). Obama primarily relied on his executive powers to enforce his environmental agenda, as the Republican majority in Congress posed impenetrable obstacles to the enactment of extensive climate legislation (ibid.). He exploited the *Clean Air Act* further and tasked the EPA to draft the *Clean Power Plan*, passed in 2015, which included the first binding national GHG reduction target for the power sector (EPA, 2015; Rosenbaum, 2017, p. 37): Carbon pollution from fossil fuel-fired power plants should be reduced by 32% in 2030 compared to 2005 levels (ibid.).

While the Obama administration made significant progress in deploying renewable energy systems including solar and wind (see e. g. The White House, 2015), clean hydrogen remained a marginal topic in political discussions during that time (Piria et al., 2021). The funding allocated to DOE's hydrogen and fuel cell technology program during Obama's second term totaled $130-$190 million annually, representing a reduction of nearly half compared to pre-2011 levels (DOE, 2023a). Also, within the transportation sector, the strong focus on FCEVs had diminished (NRC, 2013, pp. 18–20). Instead, the success for BEVs materialized when costs of BEVs were halved within four years and BEV sales tripled in 2013 compared to 2012 due to extensive support from the EERE (DOE, 2013b).

At the conclusion of Obama's tenure, the U.S. joined the *Paris Climate Agreement* in 2015, committing to a comprehensive decarbonization agenda. The administration then laid out its *Mid-Century Strategy for Deep Decarbonization*, which was published in November 2016, right before Trump took over (The White House, 2016). Within this strategy, hydrogen received little attention. However, some applications for hydrogen were mentioned f. e. in long-distance transportation and the decarbonization of hard-to-electrify industrial sectors (The White House, 2016). Moreover, in 2016, the DOE started its *H2@Scale* initiative, overseen by the EERE, with the goal of extending clean hydrogen and fuel cell technologies beyond transportation (DOE, 2021b, p. 12; EERE, 2020). This initiative aimed to explore the uses of clean hydrogen derived from renewables, fossil fuels with CCS, and nuclear energy across different sectors, including synthetic fuel production, industrial processes, chemical processes, metal production, heat, and the power sector. It achieved this by allocating funding for demonstration projects in these domains (ibid.). *H2@Scale's* vision is illustrated in Figure 9.

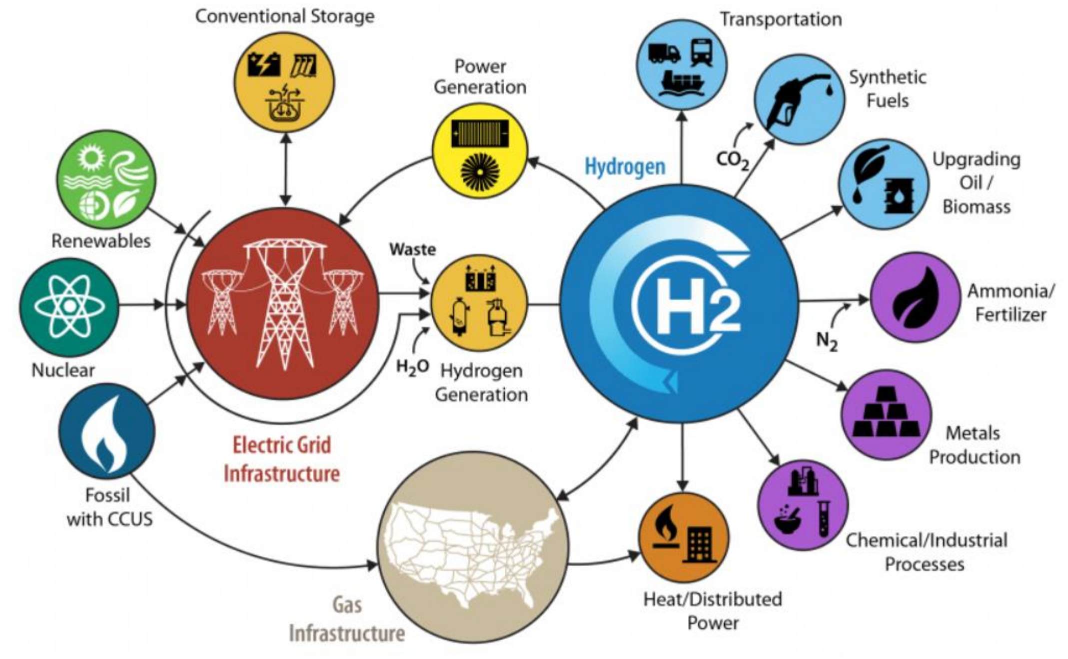

Figure 9: H2@Scale's vision: bringing clean hydrogen produced from diverse energy feedstocks (nuclear, fossil fuels, renewables) to various use cases including stabilization of the power sector, transportation, chemical and industrial processes. Source: NREL, 2021, p. 4.

5.5 Trump's Turbulence (2017-2021): Resurgence of Fossil Fuels

While the Obama administration focused primarily on economic efficiency and sustainability, the administration of Donald Trump pursued a different agenda, which was primarily concerned with energy security and economic efficiency, showing little enthusiasm for sustainability (Mildner et al., 2020).

Trump himself, along with several of his Secretaries and numerous members of the Republican Party, openly expressed skepticism about human-induced climate change, resulting in minimal emphasis on climate policy of his administration (Mildner et al., 2020; Politico, 2018). On the first of June in 2017, Trump fulfilled a significant campaign promise by declaring that the U.S. would withdraw from the *Paris Climate Agreement*, characterizing it as "*very unfair at the highest level to the United States"* (Fox News, 2017).

Trump presented his *America First Energy Plan* in 2017, which outlined how a domestic increase in fossil fuel production would reduce U.S.' dependency on foreign oil (Mildner et al., 2020). Throughout his Presidency, fossil fuels regained political prominence, viewed as sources of energy security, job opportunities, and affordable energy (ibid.).

Like Obama, Trump strategically used his executive authority over the EPA and appointed fossil fuel industry lobbyists Scott Pruitt and later Andrew Wheeler as agency heads. Trump aimed to boost domestic oil and gas production by extensively rolling back environmental regulations through presidential decrees (Atlantic Council, 2017; Müller, 2020). Authors concluded that during Trump’s administration, the EPA was prevented from fulfilling its mission of adequately protecting the health of people, land, air, and water due to substantial financial cutbacks and active ‘misdirection’ by its leaders (Biebricher, 2020; Mildner et al., 2020; Schnapp, 2020). Unlike his predecessors, Trump did not regard the significant energy consumption of the transportation sector as a matter of national security (Mildner et al., 2020) and he instructed the EPA to relax the standards on emissions and energy consumption of vehicles in 2018 (EPA, 2018).

President Trump's administration sought to increase U.S. foreign policy influence through what Trump called *“Energy Dominance”* (Mildner et al., 2020). The term referred to a boost in domestic fossil energy production, reduced energy imports, and increased energy export (The Fuse, 2021). Within the year Trump took office, the U.S. overtook Saudi Arabia and Russia in oil production and has been the largest oil producer of the world ever since (Enerdata, 2023a). During the Trump years, the U.S. furthermore significantly increased its natural gas production (Enerdata, 2023b). Notably, this growth has centered around the contentious extraction of shale oil and shale gas through hydraulic fracturing (fracking) (Mildner et al., 2020). With its emergence as one of the world's leading fossil fuel producers (oil, gas, coal), the U.S. has considerably minimized its reliance on energy imports (EIA, 2022a).

While the Obama administration and later the Biden administration (from 2021 on) requested higher budgets for the EERE, the key governmental institution responsible for renewable energy and clean hydrogen funding, than Congress was willing to approve, the Trump administration consistently proposed substantial budget reductions for the EERE in 2018, 2019, 2020, and 2021 (DOE, 2017, 2018b, 2019, 2020; Foehringer Merchant, 2019). The suggested cuts would also have eliminated crucial funding for clean hydrogen technologies. For instance, in 2020, the Trump administration attempted to cut EERE's budget from $2.38 billion in 2019 to only $0.34 billion, indicating an 85% budget reduction which would have reduced hydrogen technology funding of the EERE from $120 million in 2019 to only $44 million in 2020 (DOE, 2020). Requested and approved budget for the EERE between 2014 and 2023 are illustrated in Figure 10.

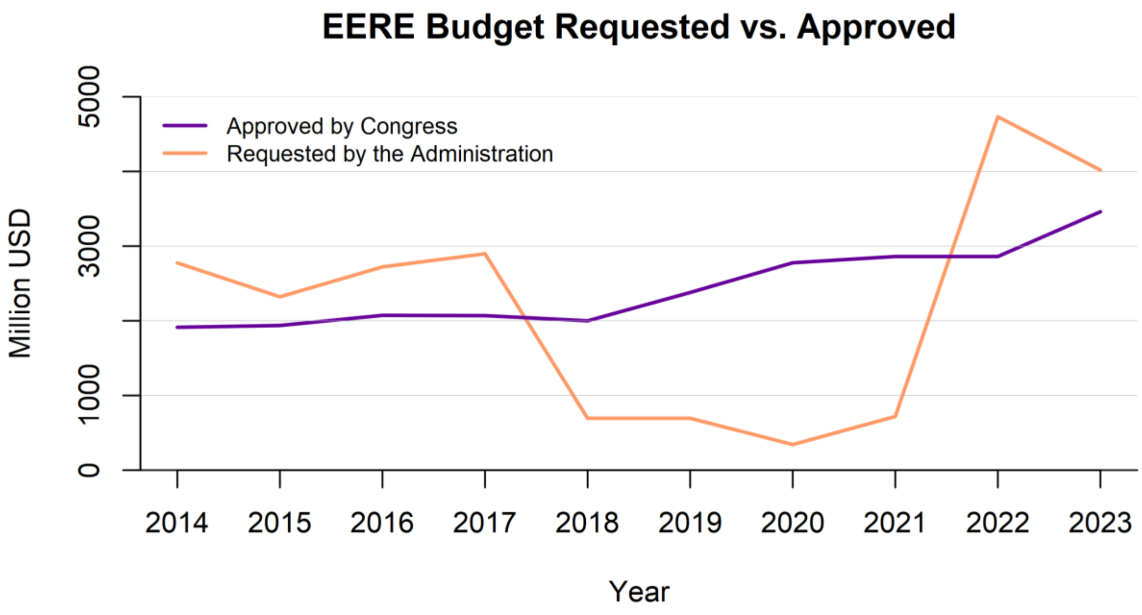

Figure 10: EERE's budget requests which were submitted by the administration versus the budget that was actually approved by Congress between 2014 and 2023. It is noticeable that during the Trump years, significantly less money was requested than approved. The administrations under Obama and Biden consistently sought higher budget for the EERE than Congress was willing to grant. Own illustration based on DOE's annual budget justifications.

One motivation for proposing the significant budget cuts was the strong austerity course that the Trump administration had employed (Max Grünig, personal interview, September 29th, 2023). Another role was likely played by Trump's skepticism towards renewable energy.

However, these budget proposals were met with disapproval in Congress, where legislators not only opposed the cuts but sometimes allocated even more money to the EERE than in the previous year, see Figure 10 (ibid.). This behavior demonstrates a strong bipartisan support in Congress for EERE's programs (see as well U.S. Government Publishing Office, 2018). Thanks to Congress, funding for renewable energy and clean hydrogen technology remained consistently high, totaling one to two hundred million U.S. dollar annually throughout the Trump era (DOE, 2023a). In 2020, a noteworthy sum of $64 million, constituting a significant portion of the annual funding for clean hydrogen technology, was committed to supporting 18 clean hydrogen demonstration projects under *H2@Scale* (DOE, 2021a). This indicates a further transition away from clean hydrogen applications in the transportation sector to a broader set of applications.

Moreover, resistance to Trump's anti climate agenda came also from within the DOE and its suboffices, such from within the EERE (Piria et al., 2021). To safeguard funding for R&D of renewable energy systems including clean hydrogen technology, the term *"climate change"* or the goal of GHG regulation disappeared from various DOE and EERE reports during the Trump era (ibid.). Instead, mentioned benefits of DOE and EERE programs became fostering innovations, enhancing the resilience of the electricity sector, supporting economic policy, and bolstering national security (DOE, 2019, p. 79; Piria et al., 2021).

5.6 Biden (2021 - today): Reviving U.S. Climate Policy

The Presidency of Joe Biden was very welcomed by environmental protection organizations and environmental NGOs, such as *Greenpeace*, the *Environmental Defense Fund*, and the *National Wildlife Federation* after four years of Trump's anti-climate agenda (Environmental Defense Fund [EDF], 2021, p. 3; Greenpeace, 2021; The National Wildlife Federation, 2021). With landmark legislations, such as the IIJA and the IRA, the Biden administration recalibrated U.S. energy policy with an emphasis on economic competitiveness and sustainability as it is outlined in this chapter. Furthermore, Biden found himself in a situation in which the country has sufficient domestic oil and gas production to meet its own demand and even export fossil fuels, especially liquified natural gas, at a large scale (EIA, 2023b, 2023d). Nevertheless, oil prices skyrocketed after Russia's war on Ukraine had started (EIA, 2023e), putting doubt on the premise that a surplus in domestic fossil energy production automatically leads to lower oil prices and questioning the U.S. comfortable position regarding energy security.

However, an interviewed expert noted that concerns about national security have become less significant in the current U.S. clean hydrogen development compared to the early 2000s (Max Grünig, personal interview, September 29th, 2023). This development is attributed to the reduced dependency of the U.S. on foreign oil today, making saving oil through advancing clean hydrogen less critical (ibid.).

On his first day in the Oval Office, 20th of January 2021, President Biden demonstrated his commitment to climate protection by signing an executive order which would return the U.S. to the *Paris Climate Agreement* (U.S. Department of State, 2021a). Later in November 2021, the Biden administration submitted the U.S. long-term climate strategy to the UNFCCC, pledging to achieve climate neutrality by 2050, reduce GHG emissions by approximately 50-52% by 2030 compared to 2005 levels, and generate 100% carbon-free electricity by 2035 (U.S.

Department of State, 2021b). With this ambitious climate agenda, clean hydrogen technologies, along with other renewables, have once again become central to U.S. energy policy. Furthermore, President Biden managed to substantiate his climate agenda with legislations, as detailed below.

5.6.1 Infrastructure Investments and Jobs Act of 2021

A significant policy bill approved by Congress and signed into law by President Biden in 2021 is the IIJA. The IIJA often is referred to as *Bipartisan Infrastructure Law* (BIL), as the law was adapted with bipartisan support from Republican and Democratic representatives with 19 Republican Senators voting for the BIL in addition to their Democratic counterparts (npr, 2021). The IIJA directed $1 trillion into infrastructure, including roads, bridges, ports, and clean energy (Metropolitan Transportation Commission, 2021). In particular, $9.5 billion were dedicated for clean hydrogen research and demonstration (IEA, 2023). $8 billion were provided to establish at least four regional *Clean Hydrogen Hubs*, an additional $1 billion designated for research and development in clean hydrogen production through electrolysis, aiming to significantly reduce the costs associated with hydrogen derived from electricity (ibid.). And $500 million should fund domestic clean hydrogen supply chains (ibid.). This investment in clean hydrogen technologies considerably surpasses the budget the U.S. government was willing to allocate for hydrogen in all previous years. To oversee these financial allocations, the DOE established a new Office in 2022: the OCED (DOE, 2021c, p. 1). Among its responsibilities, this office is tasked with supervising hydrogen demonstration projects and administering the $8 billion intended hydrogen hubs (American Energy Innovation Council, 2023). In 2023, the OCED finalized its evaluation of hydrogen hubs, revealing funding of seven designated *Clean Hydrogen Hubs* (OCED, 2023). Furthermore, The IIJA represents the first legislation that established a formal definition for the term *clean hydrogen* which was defined as hydrogen produced with less than 2 kg of CO_2 equivalents emitted per kilogram of hydrogen produced (Infrastructure Investment and Jobs Act, 2021, Sec. 822).

Under the IIJA, the DOE was mandated to establish hydrogen hubs showcasing clean hydrogen production from fossil fuels with CCS, renewable energy, and nuclear energy with two hydrogen hubs preferably being placed in regions with the most abundant natural gas reserves (Infrastructure Investment and Jobs Act, 2021, Sec. 813). With the passage of the IIJA, Congress has emphasized the importance of technology neutrality for clean hydrogen production and demonstrated a lack of consensus regarding a specific 'color' of hydrogen, such as green hydrogen.

5.6.2 Inflation Reduction Act of 2022

At the forefront of U.S. legislation driving clean hydrogen production alongside the IIJA today is the IRA, signed into law by President Biden in August 2022. Contrary to what the name suggests, the goal of the IRA is rather about stimulating the U.S. economy and investing in green technologies than combating inflation (Hüther & Matthes, 2023). While the IIJA secured bipartisan support, including some Republican votes, the IRA was passed solely with the backing of the Democratic Party, as not a single Republican vote in Congress supported it (United States Senate, 2022). Thus, President Biden was dependent on gathering all Democratic and independent Senators behind the IRA, a difficult endeavor.

While the U.S. President initially planned to pass the *Build Back Better Act*, comprising of approximately $3.5 trillion of investment into healthcare, infrastructure, and climate policy, crucial resistance came from within Democratics's own ranks, especially from Senator Joe Manchin (Roll Call, 2022). Senator Manchin, member of the Democratic Party and representing West Virginia, a fossil fuel dependent State, repeatedly vetoed the *Build Back Better Act* bill mainly citing inflation concerns and stating that he could not support such a large financial package (ibid.). Critics within the Democratic Party raised concerns about Senator Manchin's close ties to fossil fuel industries, accusing him of undermining President Biden's climate agenda (The independent, 2021). Notably, in 2022, Manchin became the top recipient of contributions from the U.S. oil and gas industry, receiving over $768,000 (Open Secrets, 2023b), underscoring the sector's significant lobbying efforts. Manchin's opposition to Biden's climate agenda supports evidence from earlier research that found that Democratic policymakers in States reliant on fossil fuels tend to place less emphasis on environmental policies (Pacca et al., 2021). However, Senator Manchin publicly acknowledges the benefits of clean hydrogen derived from various energy sources, emphasizing enhanced energy resilience of the U.S through hydrogen (Atlantic Council, 2023).

Finally, the IRA, born out of a compromise with Senator Manchin, culminated in a bill of roughly $500 billion instead of the $3.5 trillion originally envisioned by Biden (McKinsey & Company, 2022). ~$369 billion in the IRA were earmarked for clean energy initiatives, marking it as the most substantial investment in clean energy in U.S. history (Hüther & Matthes, 2023;

McKinsey & Company, 2022). To put this in perspective, the entire federal budget of the German government for the year 2023 amounted to approximately $490 billion[8] (Bundesministerium der Finanzen, 2023).

The IRA supports hydrogen development in the U.S. through multiple policy instruments (DOE, 2023c). These include providing loans and grants for clean hydrogen demonstration projects including demonstrations in the industrial sector as well as for auto manufacturing facilities producing low-emission vehicles like FCEVs, and grants for clean heavy-duty vehicles powered by hydrogen (DOE, 2023c). Furthermore, the act includes loans to repurpose energy infrastructure, incentives to deploy CCS systems, and crucially, a tax credit for clean hydrogen production (ibid.). The hydrogen production tax credit operates based on the carbon emissions associated with hydrogen production and will be examined in detail in Chapter 6. It varies, with the lowest tax credit being awarded for emissions of up to 4 kg CO_2 per kilogram of hydrogen produced and the highest for emissions ranging from 0 to 0.45 kg CO_2 per kilogram of hydrogen produced, as it is outlined in Table 1 (EERE, 2023a). To put the production tax credit into perspective, Figure 11 illustrates +carbon emissions per kilogram hydrogen produced by dif-

Carbon Intensity (kg CO_2 per kg H_2)	Max Hydrogen Production Tax Credit
4-2.5	$0.60
2.5-1.5	$0.75
1.5-0-45	$1.00
0.45 - 0	$3.00

Table 1: Hydrogen production tax credit in U.S. The tax credit is depending on the emitted CO_2 in the hydrogen production process. Source: EERE, 2023a.

ferent energy feedstocks.

The hydrogen production tax credit is commonly known as the 45V tax credit, as it has been outlined in the IRA under section 45V (Inflation Reduction Act of 2022, 2022, Sec. 45V). An important feature of the 45V tax credit is its ability to serve as a direct payment to hydrogen producers under specific circumstances (Cooper et al., 2022). Additionally, clean hydrogen producers have other ways to monetize it (ibid.). It was highlighted that investors in clean

[8] Corresponds approximately to €470 billion (as of September 2023).

hydrogen production believe that, thanks to the production tax credit, clean hydrogen production can now be achieved at more or less zero costs (Max Grünig, personal interview, October 9th, 2023). Furthermore, the production tax credits will be crucial for a rapid clean hydrogen roll-out, as most stakeholders have identified the high costs for end users as the main barrier for a broader application of hydrogen (DOE, 2023c, p. 24).

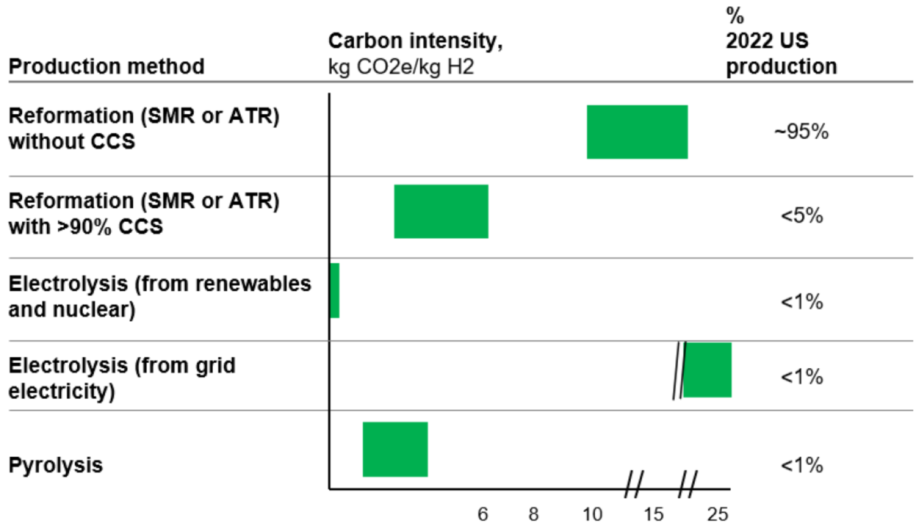

Figure 11: CO_2 intensity of clean hydrogen production in the U.S. depending on energy feedstock and technology. Using grid electricity, clean hydrogen produced would emit over 15 kg CO_2 / kg H_2. Thus, only SMR with subsequent CCS, autothermal reforming (ATR) with CCS or clean hydrogen produced from renewables with electrolysis would currently qualify for a hydrogen production tax credit. Source: DOE, 2023c, p. 38.

Moreover, the IRA introduces another tax credit for clean hydrogen production with CCS technologies, known as the 45Q tax credit. This tax credit is especially interesting for fossil fuel companies producing clean hydrogen (Max Grünig, personal interview, October 9th, 2023). The DOE is convinced that with the new introduced tax credits, breakeven points for clean hydrogen compared to the conventional have already been reached in some cases, like in ammonia refining, or will be reached in the next 10 years in many other sectors, such as in heavy-duty trucking (DOE, 2023c, p. 23).

It is crucial to understand that the new boom in hydrogen technologies goes beyond the realm of transportation. Clean hydrogen is now being incorporated into various sectors, including heavy industry (such as steel and chemicals), long-haul transportation, and long-term energy storage (DOE, 2023c).

The paramount importance of the economy in U.S. politics was emphasized by an interviewed expert, stating that climate legislation alone cannot secure electoral victories (Max Grünig, personal interview, September 29th, 2023). Consequently, the Biden administration's legislative initiatives, including the IRA and the IIJA, are primarily geared towards stimulating economic growth, promoting job creation, and advancing green innovation research, in addition to reducing nationwide GHG emissions (Center for American Progress, 2023). It is estimated that the IRA has already created an amount of 170,000 jobs in the first year after its passage (ibid.). President Biden's strategy involves capitalizing on untapped future markets, such as clean energy and clean hydrogen, that the previous administration under Trump has ignored (Max Grünig, personal interview, October 9th, 2023). Investing in a renewable energy and clean hydrogen also offers additional political advantages, such as fostering the support from the environmental movement for Biden's administration (ibid.), enhancing national security through improved energy and grid resilience, and promoting better air quality (DOE, 2023b, p. 75).

In 2023, the government did pass its first official hydrogen *U.S. Clean Hydrogen Strategy and Roadmap* which was already outlined in Chapter 4.6.

Similar to Obama, the EPA emerges as an important ally for Biden’s climate agenda: under the Biden administration, the EPA proposed updated regulations for coal and natural gas-fired power plants, aiming to avoid 617 million tons of CO_2 through 2042 (EPA, 2023b; Jenks et al., 2023). Interestingly, the new standards proposed by the EPA offer diverse pathways for achieving GHG reduction, emphasizing the adoption of CCS technology and clean hydrogen co-firing[9] to mitigate emissions (ibid.). By emphasizing the importance of hydrogen for fossil fuel power plants, the EPA legitimizes the future adoption of clean hydrogen technologies, making the EPA a key actor in the U.S. hydrogen policy subsystem.

Nevertheless, the U.S. Congress - which has already been skeptical of clean energy policies in the past (see Mildner et al., 2020) - represents a political bottleneck during the Biden administration in which originally planned climate policies are many times severely weakened. When analyzing the unfortunate trajectory of *the Build Back Better Act* initially introduced by President Biden in March 2021 and signed into law as the IRA in August 2022, it can be observed how the Congress watered down President Biden's originally envisioned $3.5 trillion heavy social, climate and infrastructure bill to a $400 billion law (Roll Call, 2022). In order to pass a law, the administration needs a majority in both chambers of Congress, the House of

[9] Hydrogen co-firing refers to the process of mixing the fuel, natural gas, with a certain share of hydrogen to minimize air pollution and GHG. See for more information: The Breakthrough Institute (2023).

Representatives and the Senate (Oldopp, 2013, p. 29). In both chambers, a majority for Biden's endeavors in the 117th Congress was questionable, especially in the Senate. The 117th Congress (01.2021 – 01.2023) included 139 *"climate skeptics"* (Drennen & Hardin, 2021). 52% of House Republicans and 60% of Republican Senators are challenging robust climate science which makes more than every second Republican representative (ibid.). Thus, it is unsurprising that Republican representatives keep criticizing Biden's energy policy and climate agenda as harmful to U.S. citizens (see e. g. Senate Committee on Energy & Natural Resources, 2023a). Ultimately, only a fraction from what was envisioned by the Biden administration could be written into law due to Congressional restraints.

After the 2022 midterm elections for the 118th Congress (03.01.2023 – 03.01.2025), the Democratic Party lost majority of the House of Representatives but retained the Senate with a slim majority. Effectively, however, this means that no more far-reaching climate legislation is likely to be passed by Congress during Biden's first Presidency, as the Republicans always have the option to block it.

5.7 Summary of U.S. Hydrogen and Fuel Cell Policy Between 1993-2023

To understand the political resurgence and debates around hydrogen technologies in the U.S., one must view hydrogen in the context of overarching U.S. energy and environmental policy.

In its early stages, clean hydrogen was primarily viewed as a solution to reduce U.S. heavy oil dependency and mitigate environmental pollution (Romm, 2006, pp. 10–15). Consequently, the initial focus of clean hydrogen technology development revolved predominantly around the transportation sector which exhibited a heavy reliance on petroleum during that time (ibid.). Bush replaced Clinton's PNGV with the *FreedcomCar Partnership* shifiting its main emphasis on FCEVs. Under Bush, extensive research efforts were dedicated to clean hydrogen technologies and hydrogen-powered vehicles, motivated crucially by the U.S. aim to decrease dependency on foreign oil (ibid.).

However, upon assuming office, Obama's administration suggested a significant reduction in hydrogen subsidies, as Obama's Energy Secretary was skeptical about FCEVs. However, Congress prevented this proposal from being implemented. The Obama administration transformed Bush's *FreedomCAR* initiative into *U.S. Drive* shifting the focus from FCEVs to BEVs and incremental improvements of combustion engines (NRC, 2013, pp. 18–20).

To sum up, U.S. funding for hydrogen and fuel cell technology has been very unstable and inconsistent, as there has been no national consensus to commit to the clean hydrogen vehicles in the 2000s. After the transportation sector lost interest in hydrogen technologies, clean hydrogen moved to the background of the political discourse under Obama. This might have led to heightened risk aversion among car manufacturers and diminished interest in clean hydrogen and fuel cell R&D. It is noticeable how each President sought visibility with his own initiatives related to the car sector between 1993 and 2017.

Under President Trump, fossil fuels regained political prominence and the high oil consumption of the transportation sector was no longer seen as a matter of national security (Mildner et al., 2020). Trump attempted to slash funding for EERE's renewable energy and energy efficiency programs including for clean hydrogen. However, Congress refused to cut the budget of the EERE again.

With Biden becoming President, clean hydrogen development gained traction through an elaborate climate agenda by the current administration. Clean hydrogen was elevated to a prominent position in U.S. energy policy through the enactment of lighthouse legislations including the IRA and the IIJA, providing substantial support for the deployment of clean hydrogen technologies (DOE, 2023c; IEA, 2023). This revival of clean hydrogen under President Biden's leadership, expands the role of hydrogen beyond transportation. It is now recognized as a tool to reduce GHG emissions in industrial processes, the electricity sector, and long-haul transportation (DOE, 2023c). Additionally, clean hydrogen is regarded as a catalyst for economic growth and job creation. Numerous companies, including major players in the oil and gas sector, such as *ExxonMobil*, *Air Products*, and *BP*, have recently revealed plans for clean hydrogen production, capitalizing on the tax credits implemented by the Biden administration (Air Products, 2023; BP, 2022a; ExxonMobil, 2023, p. 63).

The most important milestones in U.S. hydrogen policy between 1993 and 2023 are summarized in Figure 12.

The direction climate targets and funding for clean hydrogen under a possible future Republican-led U.S. government is yet to be determined. However, with the IRA and IIJA, important mechanisms have been deployed to fund clean hydrogen which are challenging to reverse for a future government (Max Grünig, personal interview, September 29th, and October 9th, 2023). Furthermore, it's improbable that funding for clean hydrogen and fuel cell R&D will be entirely eliminated, even if an opponent of these programs, such as Trump, will be elected President in 2025. Historically, clean hydrogen R&D programs have endured under every administration since 1993, including hydrogen skeptic administrations like the Obama or Trump administration, consistently receiving $100-$300 million funding annually (DOE, 2023a). This is mainly due to the U.S. Congress which has shown persistent bipartisan support from Democrat and some Republican representatives for funding of EERE's program and is anticipated to maintain this support in the future.

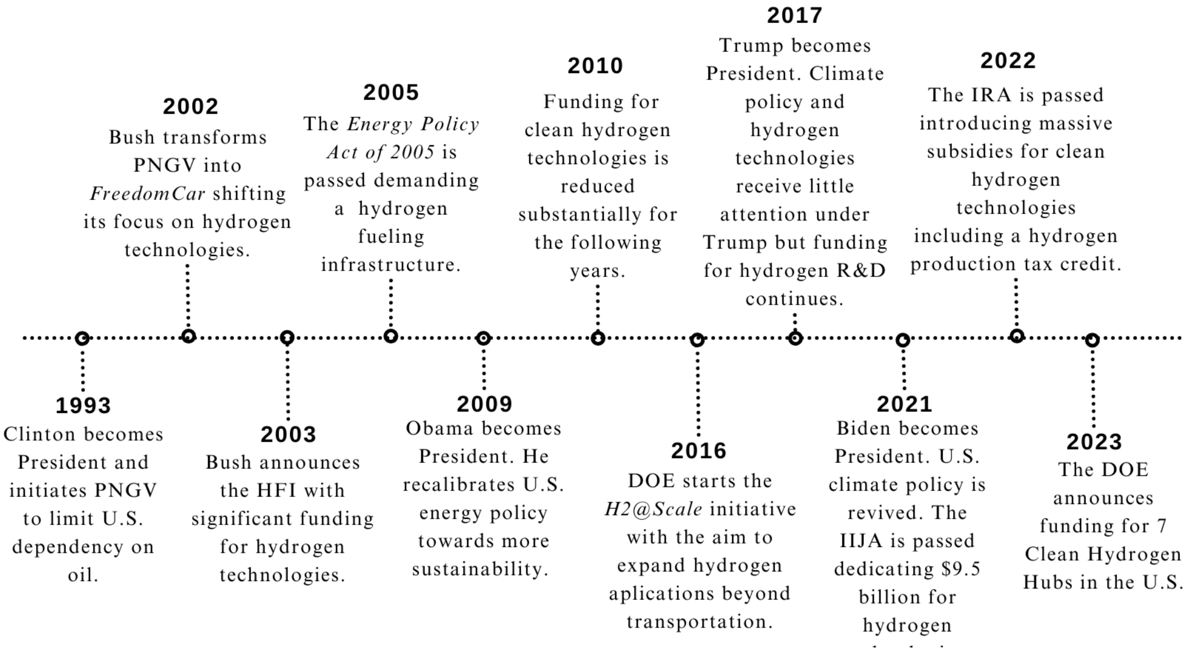

Figure 12: Historical milestones of U.S. hydrogen policy between 1993 and 2023. Own illustration.

6 Advocacy Coalitions Shaping Clean Hydrogen Policy in 2023

Following the assessment of actors pushing and opposing clean hydrogen in the past, it becomes pertinent to scrutinize actors and advocacy coalitions influencing clean hydrogen policy in the U.S. today. Fortunately, the 45V tax credit, detailed in Chapter 5.6.2, presents a valuable opportunity to investigate stakeholders involved in clean hydrogen policymaking in 2023. Therefore, this chapter provides a comprehensive analysis of the politics surrounding the implementation of the 45V hydrogen production tax credit. The aim is to complement historic evidence with data from 2023 resulting in a better understanding of past and present advocacy coalitions, including their core beliefs, engaged in the hydrogen policy subsystem.

The specific implementation details of the 45V hydrogen production tax credit have not been finalized, yet. Consequently, a diverse set of stakeholders including NGOs, think tanks, universities, trade associations, companies, and government entities, try to influence the implementation of the production tax credit. This provides a distinctive opportunity to observe the engagement of key stakeholders and their advocacy positions within the hydrogen policy subsystem, contributing to a deeper understanding of their belief system.

6.1 Lobbying for Different Implementations of the Hydrogen Tax Credit

The U.S. has the reputation of being the *"motherland of lobbyism"* (Leif & Speth, 2003, p. 30) and it can be argued that this term is nowadays more true than ever, as spending on lobbying has constantly increased from $1.5 billion in 1998 to over $4 billion in 2022 (Open Secrets, 2023a). Lobbying is highly institutionalized in the U.S. with interest groups, including fossil fuel industries, environmental NGOs, think tanks, and trade associations, wielding substantial influence on policymaking across sectors (Hebenstreit, 2020; Lammert et al., 2020). In the case of lobbying for different implementation styles of the 45V hydrogen production tax credit, writing letters, and providing technical information on the subject to government representatives has been one of the main lobbying efforts.

The political battle discussed in this chapter is centered on the uncertainty within the IRA regarding the quantification of lifecycle emissions from clean hydrogen production using grid-connected electrolyzers. Different approaches to lifecycle analysis result in varying emissions on paper, leading to differences in eligibility for a hydrogen production tax credit. Precise measurement of emissions from electrolysis-based hydrogen production is crucial, as it determines the amount of tax credit granted or denied. Therefore, the exact implementation of the 45V production tax credit is highly political as a lot of money for the government and business owners is at stake (Max Grünig, personal interview, September 29th, 2023). Additionally, many institutions expressed concerns about an implementation style that might support polluting hydrogen production methods (see e. g. Center for Biological Diversity et al., 2022).

The IRA states that "*Not later than 1 year after the date of enactment […] the Secretary shall issue regulations […] for determining lifecycle greenhouse gas emissions''* mandating Bidens's Secretary of Treasury, Janet Yellen, to formulate detailed guidance for accurate carbon emissions of clean hydrogen production (Inflation Reduction Act of 2022, 2022, Section 45V). To do so, the Treasury Secretary will receive technical assistance of the Energy Secretary and the DOE (Max Grünig, personal interview, September 29th, 2023).

The Department of Treasury has failed to meet an important deadline outlined in the IRA, which required guidance on quantifying CO_2 emissions for hydrogen production from electrolyzers by August 2023, and are still pending as of October 2023. The Department of Treasury likely didn't miss the deadline accidentally, indicating internal disagreement over the specific design features of the 45V tax credit, including criteria on additionality, temporal matching, and deliverability, which will be further explained in this chapter. This is not surprising, given the subject's complexity as well as the considerable influence exerted by interest groups in shaping the policy process (see e. g. AGRU America Inc. et al., 2023, FCHEA, 2023, and 350 New Mexico et al., 2022).

As demonstrated in Chapter 5.6.2, the 45V tax credit is granted based on emissions from clean hydrogen production, with the highest credit awarded for 0-0.45 kg CO_2 and the lowest for 2.5-4 kg CO_2 generated per kilogram of hydrogen produced (EERE, 2023a). But measuring the generated GHG emissions exactly is especially hard for grid-connected electrolyzers. The average carbon intensity of the U.S. electricity grid would be too high to qualify for a clean hydrogen production tax in the case of grid-connected electrolyzers (DOE, 2023c, p. 38): one kilogram of hydrogen produced with average grid electricity in 2022 would emit over 15 kg CO_2 in the process (ibid.).

However, big trade associations, e. g. the *Fuel Cell & Hydrogen Energy Association* (FCEHA) representing interests of companies engaged in clean hydrogen production like the gas corporation *Air Liquide* and the fuel cell manufacturer *Plug Power*, seek to claim the tax credit by providing Renewable Energy Credits[10] (RECs) and Power Purchasing Agreements (PPAs) (FCHEA, 2022). This way, 'clean' hydrogen production could take place using grid electricity while still harnessing the production tax credit. Other organizations, such as the NGOs *Center for Biological Diversity* and *Friends of the Earth*, criticize this practice as harmful to the environment (Center for Biological Diversity et al., 2022).

The 45V tax credit can be designed in a way to either support low-carbon clean hydrogen or 'dirty' clean hydrogen production depending on implemented criteria on additionality, temporal matching, and deliverability (Center for Biological Diversity et al., 2022; Princeton Zero Lab, 2022). Crucial unresolved matters and the political battle surrounding the utilization of RECs and PPAs revolve around these three fundamental criteria (additionality, temporal matching, and deliverability) which must be addressed by the Secretary of Treasury when issuing guidance on clean hydrogen production**.**

Thus, the U.S. has arrived at a critical juncture concerning the future of clean hydrogen. This chapter aims to elucidate possible criteria on additionality, temporal matching, and deliverability by offering a summary of the perspectives of key stakeholders within the hydrogen policy subsystem regarding these three criteria.

The Department of Treasury issued a formal request for feedback from stakeholders involved in clean hydrogen in the end of 2022, seeking input on the specific implementation details of the 45V tax credit (Department of Treasury, 2022). As of November 2023, the Department of Treasury received a total of 243 stakeholder comments (Regulations.gov, 2023). The analysis presented herein is based on these comments which outline opportunities and concerns of the preferred implementation style of the 45V tax credit. The annex offers a comprehensive summary of the institutions whose comments were examined in the analysis[11].

[10] Renewable Energy Credits (RECs) represent tradable certificates certifying the generation of a specific amount of electricity from renewable sources, providing a means for organizations to claim the environmental benefits of renewable energy production. RECs can be compared to Guarantees of Origin (GOs) in Europe.

[11] Note that entities that did not express a specific opinion on any of the three criteria (additionality, temporal alignment, deliverability) are not considered in this analysis and not included Table 2-4.

6.2 Coalitions on Additionality

"*Additionality, in the context of grid-connected hydrogen electrolyzers, is defined as the adding of a new zero-carbon energy source to a grid to meet the new load associated with an electrolyzer and to reduce the electrolyzers effective greenhouse gas emissions*" (Rocky Mountains Institute [RMI], 2023, p. 5). In other words, it has been discussed in the U.S. whether the load an electrolyzer puts on the grid has to be compensated with additional renewable energy sources corresponding to the electrolyzers load or not. The Secretaries of Treasury and Energy are tasked with addressing several critical questions, including whether an electrolyzer must be supplemented by additional renewables to generate clean hydrogen or if existing renewables can qualify as 'additional' for clean hydrogen production. Furthermore, if lenient criteria on additionality are deemed acceptable, the potential financial implications for the government must be assessed (Max Grünig, personal interview, September 29th, 2023). The 'no-additionality scenario' would allow entities to claim the highest tax credit by demonstrating reduced CO_2 emissions solely through providing PPAs or RECs which can lead to a high level of tax losses, as the tax credit would then be granted without major hurdles (ibid.). This implementation style might furthermore result in no GHG emissions being prevented by hydrogen deployment or even result in additional emissions from new electrolyzers (Natural Resources Defense Council [NRDC] & Clean Air Task Force [CATF], 2023). On the other hand, the Secretaries must anticipate the impact on the future clean hydrogen economy if stringent additionality requirements are imposed, which could potentially deter investors in clean hydrogen initiatives.

The political landscape is divided on the issue of additionality. Various trade associations like the *Clean Hydrogen Future Coalition* (representing major players involved in clean hydrogen production such as oil and gas giants like *Chevron*, *Shell*, *Bp*, and *Linde*) as well as the *Nuclear Energy Institution* (representing interests from nuclear energy suppliers and companies involved in nuclear energy) have stated their displeasure about a stringent additionality criterion (Clean Hydrogen Future Coalition [CHFC], 2023; Nuclear Energy Institute, 2022). Furthermore, the *Clean Hydrogen Future Coalition* concludes that "*if Congress wanted additionality, they would have been included in the statutory language"* referring to the fact that additionality is not explicitly mentioned in the IRA (CHFC, 2023, p. 3). Other trade associations representing companies involved in clean hydrogen, such as the FCHEA, have argued that additionality for clean hydrogen production would be arbitrary and undermine the decarbonization of the economy *"by delaying the hydrogen roll-out"* (FCHEA, 2023, p. 1).

On the other hand, prominent environmental organizations, such as the *Natural Resources Defense Council*, the *Clean Air Task Force*, and *Earthjustice* strongly advocate for a stringent additionality criterion. According these institutions, without additionality, hydrogen production might divert renewable electricity from the grid that is needed to decarbonize other sectors (350 New Mexico et al., 2022; NRDC & CATF, 2023). The *Clain Air Tasks Force* and the *Natural Resources Defense Council* state in a letter that a strict additionality criterion is *"legally necessary"* to ensure emission reduction through clean hydrogen production and that an *"additionality-free [...] regulation"* would undermine the purpose of the IRA which is "*the reduction of planet-warming emissions"* and would thus be *"inherently arbitrary"* (CATF & NRDC, 2023, p. 3).

The disagreement about additionality delves into the core purpose outlined in the IRA. Business-related interest groups like the FCEHA contend that the IRA aimed to foster the hydrogen industry, negating the legitimacy of additionality (FCHEA, 2023). Conversely, environmental NGOs, such as the *Clean Air Task Force* and the *Natural Defense Council*, argue that the IRA's purpose was to reduce GHG emissions, making additionality a logical necessity (NRDC & CATF, 2023). This case highlights how identical legislative language can be interpreted differently based on individual interests.

Actors' stances on the additionality criteria are summarized in Table 2. A strict approach to additionality is interpreted as mandating the construction of new additional renewable energy systems to offset the electrolyzers power consumption. This includes providing PPAs with the renewable energy operator of the newly added systems or RECs to prove renewable energy consumption. Furthermore, increasing renewable portfolio standards of an U.S. State to offset the load of an additional electrolyzer is also considered to be a strict additionality implementation.

In a lenient approach, there would be no need to install additional renewable energy systems to prove tax credit eligibility. Renewable electricity consumption would solely be demonstrated through RECs and PPAs without expanding renewable capacities. However, this approach risks to divert renewable electricity necessary for decarbonizing other sectors to power electrolyzers, resulting in potentially increased overall electricity consumption. In the worst-case scenario, the additional load the electrolyzers put on the grid would be compensated by increased fossil fuel electricity production leading to higher overall net emissions (see e. g. 350 New Mexico et al., 2022).

Strict Implementation: RECs and PPAs from additional supply necessary to prove eligibility for the production tax credit.	**Soft Implementation:** No additionality required. RECs and PPAs can be used to prove tax credit eligibility without adding new renewable energy systems.
Clean Air Task Force, Earthjustice, Sierra Club, Energy Innovation, Environmental Defense Fund, Friends of the Earth, Institute for Policy Integrity, Natural Resources Defense Council, Rocky Mountain Institute, Princeton Zero Lab, Representative of the State of New York and 4 other States	American Council on Renewable Energy, American Chemistry Council, FCHEA, Advanced Biofuels Business Council, Clean Hydrogen Future Coalition, Nuclear Energy Institute, Renewable Hydrogen Alliance, State of Colorado, Business Council for Sustainable Energy

NGO Association Government Entity Research Institution (Think Tank, Uni)

Table 2: Advocacy coalitions on the additionality criterion.

6.3 Coalitions on Temporal Matching

"*Temporal matching, in the context of grid-connected hydrogen electrolyzers, refers to the required time alignment of clean electricity production and consumption to calculate the project emissions and determine credit eligibility*" (RMI, 2023, p. 6). Temporal matching is about aligning clean hydrogen and renewable energy production in order to reduce CO_2 emissions. It's complex due to renewables' intermittent nature, causing grid carbon intensity to fluctuate significantly within a day. Temporal matching entails averaging CO_2 intensity over various time granularities, spanning from no time matching to calculating annual, hourly, or sub-hourly average CO_2 emissions for hydrogen production (RMI, 2023). Based on these calculations, decisions are made regarding the eligibility for a tax credit within that specific timeframe.

Researchers discovered that annual time matching, as opposed to hourly or sub-hourly matching, could inaccurately measure carbon intensity of hydrogen production by up to 35% per year (Miller et al., 2022). Furthermore, this inaccuracy is not significantly reduced when applying monthly temporal matching (ibid.). The discrepancy could open the door for greenwashing hydrogen: for instance, assuming annual temporal matching, hydrogen produced solely from coal power could be deemed 'clean' and qualify for a tax credit, as long as the region's annual grid carbon intensity remains below a certain threshold. Thus, hourly, or sub-hourly matching is most precise when it comes to pinpointing low-emission hydrogen production times (Miller et al., 2022).

The Biden administration faces several challenges in regulating temporal-matching. Implementing hourly or sub-hourly matching can pose technical difficulties for existing infrastructure and power systems as it was outlined for example in a letter signed by 45 companies (including the oil and gas giant *BP*, the clean power company *Invenergy* and fuel cell manufacturer *Plug Power*) as well as in a letter from the prominent oil and gas corporation *Valero* (AGRU America Inc. et al., 2023; Valero, 2022). Additionally, adopting a strict temporal matching criterion, such as hourly matching, according to these companies, would limit hydrogen production to just a few hours a day. This could potentially reduce clean hydrogen output and scare off investors (ibid.). Overall, various entities, spanning from renewable energy companies like *Invenergy* to significant fossil fuel corporations such as *BP* and *Valero* as well as trade associations representing companies engaged in clean hydrogen production (like the *Renewable Hydrogen Alliance*) and associations representing companies engaged in fossil fuels (like the *Association for American Fuel & Petroleum Manufacturers*), forwarded letters to the Secretary of the Treasury advocating for annual or monthly temporal matching (AGRU America Inc. et al., 2023; American Fuel and Petroleum Manufacturers [AFPM], 2022; Renewable Hydrogen Alliance, 2022). These entities highlighted benefits in pricing, technical constraints, and the accelerated growth of the clean hydrogen market through a *"pragmatic"* implementation of the 45V tax credit (ibid.).

Stakeholders with a primary focus on climate change mitigation and substantial reduction of ational GHG emissions, including environmental NGOs like *WWF* and *Earthjustice*, along with think tanks such as the *Institute for Policy Integrity* and Princeton's University initiative *Princeton Zero Lab*, have advocated for a precise hourly time-matching approach (350 New Mexico et al., 2022; Institute for Policy Integrity, 2022; Princeton Zero Lab, 2022; WWF, 2022). Their argument emphasizes the need for calculating tax credits for clean hydrogen production on a granular basis to prevent additional emissions and avoid greenwashing. According to these institutions, a strict granular framework for temporal matching regarding clean hydrogen production is the only way to ensure the climate benefits of clean hydrogen (ibid.).

Table 3 summarizes actors’ stances regarding temporal-matching. In terms of aligning the timing of hydrogen production with renewable energy production, a strict approach is interpreted as sub-hourly or hourly matching. On the other hand, a soft approach considers annual, quarterly, or monthly alignment as the temporal matching criteria to be enough to determine the tax credit for clean hydrogen production.

Strict Implementation: Hourly or sub-hourly temporal-matching to prove tax credit eligibility.	**Soft Implementation:** Monthly / annual / quarterly temporal-matching to prove tax credit eligibility.
Clean Air Task Force, Earthjustice, Sierra Club, Energy Innovation, Environmental Defense Fund, Institute for Policy Integrity, Natural Resources Defense Council, Rocky Mountains Institute, WWF, Princeton Zero Lab, Clean Energy Buyers Association	American Council on Renewable Energy, American Fuel and Petroleum Manufacturers, Clean Hydrogen Future Coalition, FCHEA, Many U.S. Companies (including Valero, Plug Power, Invenergy, BP, Linde), MIT Energy Initiative, Renewable Hydrogen Alliance, State of Colorado, American Clean Power Association, Business Council for Sustainable Energy, Representatives of the State of New York and four other States

NGO Association Government Entity Research Institution (Think Tank, Uni)

Table 3: Advocacy coalitions on the temporal matching criterion.

6.4 Coalitions on Deliverability

"Deliverability, in the context of grid-connected hydrogen electrolyzers, means that any procured clean electricity used to demonstrate low-carbon hydrogen production should be reasonably expected to be "delivered" to the hydrogen electrolyzer, which is consuming grid electricity" (RMI, 2023, p. 4). Simply put, when renewable sources are curtailed, the electrolyzer must also decrease hydrogen production. This underscores the essential need for a physical connection and proximity of the electrolyzer to renewable power sources.

The political debate around deliverability includes whether a physical connection between renewables and the electrolyzer is necessary for claiming the clean hydrogen production tax credit. And if so, how close electrolyzer and renewable energy source must be co-located.

Stakeholders, such as the trade association *American Council on Renewable Energy*, which represent big companies like the oil and gas giant *Chevron* or the hydrogen technology and natural gas company *Bloom Energy*, assert that a Virtual Power Purchase Agreement[12] (VPPA) between renewable energy and hydrogen producers, should suffice as evidence for clean hydrogen production and tax credit eligibility (American Council on Renewable Energy, 2022). Additionally, the debate if *"book and claim"* mechanisms are enough to qualify for a hydrogen production tax credit, allowing consumers to reserve renewable energy (e. g. in the form of RECs) and assert hydrogen cleanliness without requiring physical grid connection to renewable energy systems, has emerged (see e. g. AFPM, 2022 and Green Hydrogen Coalition, 2022).

Hence, the discussions span from the viewpoint that the electrolyzer does not require a direct link to the renewable energy sources providing its power to the suggestion that it should be incorporated within the same grid interconnection, the same regional transmission organization (RTO) / independent system operator (ISO), or the same grid balancing authority as the corresponding renewable energy source. Among these options, the most stringent approach to ensure deliverability is the co-location of electrolyzers and renewable energy sources within the same balancing authority. Grid-interconnections, RTOs/ISOs, and balancing authorities of the U.S. grid are depicted Figure 13. Since 66 balancing authorities exist within the U.S., this approach represents a limited geographic area in contrast to grid interconnections, which divide the U.S. into only three geographic regions, or RTOs/ISOs of which 10 exist in the U.S., most of them spanning across several States (FERC, 2023).

Stakeholders primarily concerned with GHG reduction, such as the environmental organization *Earthjustice* and *Sierra Club* or research-based organizations, such as the *Princeton Zero Lab* are pushing for stringent spatial regulations concerning the positioning of electrolyzers (350 New Mexico et al., 2022; Princeton Zero Lab, 2022). One frequently cited proposal is to mandate the co-location of electrolyzers and renewable electricity sources within the same grid balancing authority by these stakeholders (ibid.). Additionally, to qualify for the tax credit, the electrolyzer operator must demonstrate their use of renewable energy by either entering into a physical PPA or purchasing RECs from the same geographic region.

[12] A Virtual Power Purchase Agreement constitutes a purely financial agreement. It does not necessitate a physical connection between an electrolyzer and the renewable electricity source. Therefore, a VPPA differs from a PPA that requires a physical connection between electricity consumer and supplier. For more information, see Imolauer (2020).

On the other hand, various companies, such as *Valero*, and trade associations including *Clean Hydrogen Future Coalition* or the FCHEA demand that placing the electrolyzers within the same grid interconnection (Eastern, Western and ERCOT Interconnection) or within the same RTO/ISO as the renewable energy sources it draws on should be enough for proving deliverability (CHFC, 2023; FCHEA, 2022; Valero, 2022). This approach would simplify qualifying for the hydrogen production tax credit, giving much more geographic flexibility to the operator of the electrolyzer.

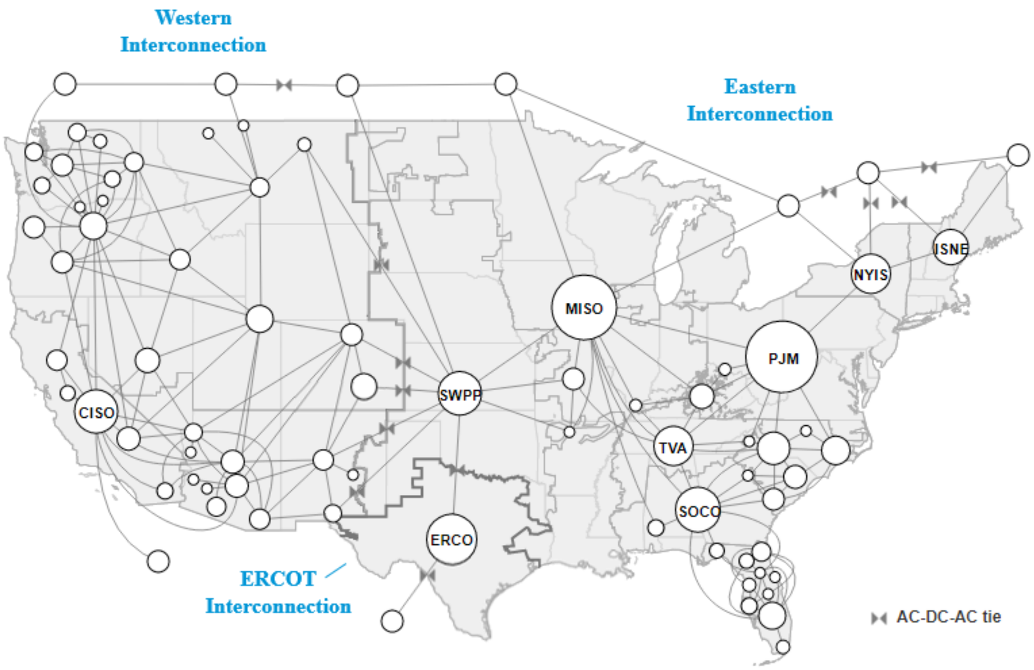

Figure 13: The U.S. electricity grid. The grid has three interconnections: The Western Interconnection, the Eastern Interconnection, and the ERCOT Interconnection. Furthermore, the grid is divided in 10 RTOs/ISOs: Northwest (not indicated on the map), California (CISO), Midcontinent (MISO), New England (ISNE), New York (NYIS), PJM, Southeast (SOCO), Southwest (not indicated on the map), Southwest Power Pool (SWPP), and Texas (ERCO). The smallest units, responsible for matching electricity supply and demand in a specific geographic region, are the balancing authorities of which 66 exist in the U.S. Balancing authorities are represented here with white circles. Source: (EIA, 2023b).

Table 4 summarizes actors' stance on deliverability[13]. Regarding deliverability, a stringent approach is understood as necessitating the electrolyzer to be situated within the same grid balancing authority as the renewable energy source it utilizes. Conversely, a more lenient approach is understood as eliminating specific geographical constraints, allowing the electrolyzer to be located within the same grid interconnection or the same RTO/ISO and still qualify for a hydrogen production tax credit. Regarding the latter, in all three scenarios, the geographical expanse poses a technical challenge in ensuring adequate deliverability.

● NGO ● Association ● Government Entity ● Research Institution (Think Tank, Uni)

Table 4: Advocacy coalitions on the deliverability criterion.

Strict Implementation of deliverability:	**No strict implementation of deliverability:**
Physical connection between renewables and electrolyzer is required to qualify for the tax credit. Electrolyzer and renewable energy source must be co-located within the same balancing authority or a geographical area of a similar size.	Physical connection between renewables and electrolyzer is either not required, or electrolyzer must only be in the same grid interconnection as the renewable energy source, the same RTO / ISO, or a geographical area of a similar size to qualify for the tax credit.

[13] Note that if an entity states information on required deliverability that is imprecise (such as *"relevant spatial guardrails must be incorporated"*) without stating exact geographical boundaries (e. g. within the same grid interconnection, same RTO/ISO, or same balancing authority), this entity is not included in Table 4.

Earthjustice, Sierra Club, Institute for Policy Integrity, Invenergy, Renewable Hydrogen Alliance, State of Colorado, WWF, Princeton Zero Lab	Valero, Fuel Cell & Hydrogen Energy Association, Clean Hydrogen Future Coalition, Business Council for Sustainable Energy, American Council on Renewable Energy, American Fuel and Petroleum Manufacturers American, Clean Power Association

6.5 Summary: the Trade-Offs in Implementing the 45V Tax Credit

By evaluating additionality, temporal matching, and deliverability, the Secretary of Treasury and the Secretary of Energy must balance industry and economic interests, budget constraints, and environmental concerns. Addressing these issues in a way that kickstarts the clean hydrogen economy in the U.S. without discouraging the political support of the climate movement through the adoption of overly lenient criteria is a difficult endeavor. Furthermore, if the U.S. plans to export hydrogen in the future, aligning these criteria with EU standards for renewable hydrogen production would probably facilitate seamless exporting options. However, an interviewed expert involved in talks with clean hydrogen investors, does not currently perceive export considerations as significant in this context (Max Grünig, personal interview, September 29th, 2023).

The Department of Treasury has the option to establish a more climate-friendly hydrogen production tax credit, prioritizing stringent additionality, temporal matching, and regional standards to reduce GHG emissions (see e. g. Princeton Zero Lab, 2022, 350 New Mexico et al., 2022, CATF & NRDC, 2023). However, this approach might make the market less appealing, leading to smaller-scale hydrogen production, and scaring-off investors (see e. g. AFPM, 2022, AGRU America Inc. et al., 2023, Renewable Hydrogen Alliance, 2022). Conversely, due to more flexible criteria, lower hurdles to qualify for a hydrogen production tax credit could attract investors and boost the U.S. economy, foster a new industry sector, and increase overall ‘clean’ hydrogen production (ibid.). This approach carries the risk of not effectively minimizing GHG emissions, as it was outlined by many environmental organizations as well as research institutions (see e. g. Princeton Zero Lab, 2022, 350 New Mexico et al., 2022, CATF & NRDC, 2023).

It is likely that a compromise between temporal matching and additionality will arise, as it has been done within the European Union this year[14]. However, an interviewed expert stressed that the U.S. usually is not a country a of compromises (Max Grünig, personal interview, September 29th, 2023).

The examination of advocacy coalitions engaged in the implementation of the 45V tax credit is hereby completed. The next chapter will summarize the findings obtained in Chapter 5 and 6 and integrate them into the broader development.

[14] In two delegated acts, the European Commission e. g. proposed that additionality is not needed if the proportion of renewable electricity exceeds 90% in the bidding zone where the electrolyzer is located. See European Commission (2023).

7 Power Struggle: Actors and Coalitions Driving and Opposing Clean Hydrogen in the U.S.

Now that the advocacy coalitions on the implementation of the 45V clean hydrogen production tax credit as well as the historical development have been summarized, it is time to take a step back and zoom out to the bigger picture. In this chapter, it is aimed to identify the actors and coalitions championing clean hydrogen technologies in the U.S., as well as those expressing skepticism or actively hindering its progress.

7.1 Clean Hydrogen Advocates

Upon closer examination of Table 2-4 and the coalitions formed for and against strict additionality, temporal matching, and deliverability criteria, a discernible pattern emerges. Companies and trade associations that mainly have been engaged in renewable energy production (such as the company *Invenergy* or *Plug Power* and the trade association *Renewable Hydrogen Alliance*) side with major oil and gas companies (like *BP* or *Valero*) and trade association, affiliated with big fossil fuel corporations (such as the *Clean Hydrogen Future Coalitions* or the *Association for American Fuel and Petroleum Manufacturers*) to avoid stringent criteria on temporal matching (AFPM, 2022; CHFC, 2023; FCHEA, 2023; Renewable Hydrogen Alliance, 2022). Thus, the analysis revealed a noteworthy alignment of interests between renewable energy companies and their counterparts in the fossil fuel sector. Regardless of their affiliations with the oil and gas industry or renewable energy sector, trade associations are united in their resistance to oppose stringent regulations concerning additionality, temporal matching, and deliverability as evident from Table 2-4. This pattern is only occasionally disrupted by singular cases, such as the *Renewable Hydrogen Alliance* advocating for strict spatial criteria (Renewable Hydrogen Alliance, 2022).

It was argued by trade associations on the right side of Table 2-4 that flexible criteria related to additionality, temporal alignment, and deliverability would result in significantly larger investments in clean hydrogen and increase clean hydrogen output (AFPM, 2022; CHFC, 2023; FCHEA, 2023; Renewable Hydrogen Alliance, 2022). Thus, lowering the hurdles for securing a tax credit would yield strategic advantages for U.S. companies. Ultimately, flexible criteria would rapidly accelerate the growth of the clean hydrogen economy in the U.S., albeit with reduced emphasis on minimizing GHG emissions (see e. g. Princeton Zero Lab, 2022 and

AGRU America Inc. et al., 2023). Therefore, a first shared belief of this coalition has been refined: for entities advocating for lenient criteria on additionality, temporal matching, and deliverability, such as the FCEHA, the *Renewable Hydrogen Alliance*, the *Clean Hydrogen Future Coalition*, or the Association for *American Fuel & Petroleum Manufacturers*, it is more important to kickstart the clean hydrogen economy than paying attention to the environmental consequences of hydrogen production.

Another crucial belief among entities on the right side of Table 2-4 is that clean hydrogen production must occur technology neutrally (see e. g. FCHEA, 2020). The value of technology neutrality for these entities in clean hydrogen production can be derived solely from the fact that companies represented by trade associations on the right side of Table 2-4 use various energy feedstocks to produce clean hydrogen (including fossil fuels, renewables, and nuclear energy). Furthermore, the FCHEA together with 20 companies (including big players, such as *Air Liquide*, *Air Products*, *Chevron*, *Microsoft*, *Plug Power*, and *Shell*) has presented an industry-oriented hydrogen roadmap advocating for blue hydrogen and CCS technology to be used even beyond 2050 in the U.S. (FCHEA, 2020). With these two exhibited beliefs, prioritizing the economy and technology neutrality, entities on the right side of Table 2-4 are collaboratively called *"Clean Hydrogen Advocates"*

It is striking that the advocacy coalitions opposing stringent additionality, temporal matching, and deliverability criteria are barely joined by other entities than trade associations and companies. An exception offers the university initiative *MIT Energy Initiative* which joined the *Clean Hydrogen Advocates* on the temporal-matching criteria (MIT Energy Initiative, 2022).

Local governments exhibit varying stances regarding additionality, temporal-matching, and deliverability, based on State and specific criteria involved. Representatives of the States of Massachusetts and 11 other States including New York and Maine express concerns about climate change and underline their interest to minimize CO_2 emissions (Attorneys General of Massachusetts et al., 2022). However, government officials of some of these States including New York, Massachusetts, and Maine also advocate for the interests of regional industries resulting in demanding soft temporal matching criteria (Harris et al., 2023).

The *Clean Hydrogen Advocates* are a crucial driver for clean hydrogen in the U.S. Entities of this coalition advocate for technology neutral hydrogen production, rather than exclusively emphasizing green hydrogen produced from renewables with stringent additionality, temporal-matching, and deliverability criteria. Lenient standards for the hydrogen production tax credit are prioritized to rapidly expand clean hydrogen development in the U.S.

7.2 Clean Hydrogen Skeptics

Entities on the left side of Table 2-4 believe clean hydrogen can be beneficial only in specific, rare cases with stringent governmental regulations. Additionally, they express concerns about a potential emission escalation due to clean hydrogen production, emphasizing that lax additionality, temporal-matching, and deliverability criteria could worsen climate issues (see e. g. Center for Biological Diversity et al., 2022). Entities on the left side of Table 2-4 include environmental NGOs (like *Sierra Club, WWF*, *Friends of the Earth*, *Natural Resource Defense Council*, the *Clean Air Task Force,* and *Earthjustice*) think tanks (like the *Institute for Policy Integrity* and *Energy Innovation*), and research institutions (such as the *Princeton Zero Lab).* These entities mostly prioritize the net effect of clean hydrogen production on GHG minimization (350 New Mexico et al., 2022; Center for Biological Diversity et al., 2022; Energy Innovation, 2022). A government tax credit should only be granted if strict criteria regarding additionality, temporal matching, and deliverability are satisfied. This ensures that the incentive is provided exclusively to hydrogen projects that will positively impact net emissions (ibid.).

There are only a few exceptions that contradict the pattern. For example, the *MIT Energy Initiative* stands out as the only research institution advocating for annual matching (a rather lax criteria), which should then later transition into hourly matching as soon as more data on marginal emissions are available, according to this initiative (MIT Energy Initiative, 2022).

The entities on the left side of Table 2-4 are occasionally joined by local governments, such as the State of Colorado on the deliverability criteria or the State of New York on the additionality criteria (Colorado Energy Office, 2022; Harris et al., 2023).

Notably, leading U.S. environmental NGOs, like the *Environmental Defense Fund* and *Sierra Club*, acknowledge hydrogen's emission reduction potential but emphasize risks of increased GHG emissions due to missing regulations and hydrogen leakages[15] (Environmental Defense Fund, 2022; Sierra Club, 2023). *Sierra Club* rejects blue hydrogen outright and expresses skepticism about current clean hydrogen deployment (Sierra Club, 2023). Overall, many

[15] Hydrogen acts like an indirect GHG when emitted into the atmosphere. See Environmental Defense Fund (2022).

environmental NGOs including *Sierra Club,* the *Center for Biological Diversity*, and *Friends of the Earth,* do not support the course of the current government regarding clean hydrogen (Center for Biological Diversity et al., 2022; Sierra Club, 2023).

To sum up, entities on the left side of Table 2-4 mandating strict criteria for clean hydrogen production including additionality, temporal matching, and deliverability, are not in line with the industry's vision for clean hydrogen. Many of these entities express their concerns about clean hydrogen deployment in the U.S. Thus, these entities are termed *"Clean Hydrogen Skeptics"*. The *Clean Hydrogen Skeptics* are the counterpart to the *Clean Hydrogen Advocates* and slow down clean hydrogen development in the U.S.

7.3 "Big Oil" as Driver for Clean Hydrogen

This paragraph provides a detailed analysis of major oil and gas corporations as pivotal actors in the hydrogen policy subsystem due to their substantial economic power, political network, and vested interests. An interviewed expert saw especially big oil and gas corporations promoting clean hydrogen in the U.S. (Max Grünig, personal interview, September 29th, 2023). Many oil and gas giants like *ExxonMobil, Air Products, BP*, and *Linde* have directed investments towards clean hydrogen production and CCS facilities in the Gulf Coast Region (Air Products, 2023; BP, 2022a; ExxonMobil, 2023, p. 63; Linde, 2023). Furthermore, *Shell* aims to secure a *"double-digit market share"* in the global clean hydrogen market by 2030 (Royal Dutch Shell PLC, 2021, p. 18), while *TotalEnergies* plans to allocate 25% of its production and sales to *"low energy molecules"* like clean hydrogen, biofuels, and e-fuels by 2050 (TotalEnergies, 2023b, p. 11).

Moreover, prominent oil and gas corporations wield considerable influence in the hydrogen policy subsystem through initiatives and interest groups, as demonstrated by their active involvement in organizations such as in the *Fuel Cell and Hydrogen Energy Association, American Chemical Council*, *American Gas Association, Association for American Fuel and Petroleum Manufacturers, Clean Hydrogen Future Coalition, American Clean Power Association, Methanol Institute*, and similar entities.

Industry leaders, such as *ExxonMobil, BP, Shell, TotalEnergies*, and *Chevron* have clearly outlined their advocacy for policies incentivizing clean hydrogen production and CCS technology (BP, 2022b, pp. 30–32; Chevron, 2022, p. 11; ExxonMobil, 2023, pp. 4–6; Shell, 2022, p. 27;

TotalEnergies, 2023a). It is likely that subsidies for clean hydrogen and CCS were passed partially due to extensive lobbying efforts by the oil and gas sector (Max Grünig, personal interview, September 29th, 2023). *Shell* stated publicly that they have engaged in personal communication with the Biden administration and Members of the Congress to pass the IRA and hydrogen subsidies (Shell, 2022, p. 27). As key actors in clean hydrogen production, U.S. policymakers involved in hydrogen policymaking must consistently consider the interests and objectives of major oil and gas corporations. These advocacy efforts make big oil and gas corporations a crucial driver for the development of clean hydrogen in the U.S.

To conclude, despite their ongoing involvement in fossil fuel production, the investments of major oil and gas corporations in clean hydrogen production as well as their advocacy for policy incentives for clean hydrogen production signal a shift in their perception of fossil fuels. The development indicates a growing acknowledgment among these companies of the necessity to diversify their energy portfolios and decrease carbon emissions, while envisioning different applications for fossil fuels in the future.

The engagement of fossil fuel companies in clean hydrogen was criticized by environmental organizations like the *Center for Biological Diversity* which called clean hydrogen *"a Trojan horse for polluting industries"* and a *"political cover for fossil fuel interests eager to continue business as usual"* (Center for Biological Diversity et al., 2022, p. 1).

7.4 The Role of Texas and California in Pioneering Clean Hydrogen

7.4.1 Texas

The progress of hydrogen development in the U.S. is characterized by notable disparities between individual States. Some States, like the State of Texas or California, initiated themselves as drivers for clean hydrogen technologies as it shall be outlined in this chapter. Other States, such as West-Virginia, rely on incumbent fossil fuel energy systems like coal and gas, exhibiting limited enthusiasm for transitioning to renewable energy sources (EIA, 2022c).

Texas, known for its abundant solar, wind, natural gas, and oil resources, stands as a prominent energy hub within the U.S. (Fiscal Notes, 2022). Given its status as a focal point for numerous oil, gas, and chemical industries, especially fuel producers, the State features an exceptionally dense pipeline network, see Figure 14 (Center for Houston's Future et al., 2022). This beneficial infrastructure positions Texas as a promising hub with high potential for clean hydrogen production, as well as storage, and demand (ibid.). The advantages of the Gulf region for clean hydrogen production are furthermore underlined with DOE's recent decision to fund one of the hydrogen hubs in the Gulf region with $1.2 billion (OCED, 2023). The hub should produce clean hydrogen from renewables and natural gas (ibid.).

The lack of statewide GHG reduction targets in Texas underscores that clean hydrogen initiatives in the State are primarily motivated by economic factors rather than GHG reduction. Despite individual cities like Austin, Dallas, and Houston having their local climate goals, statewide legislation limits local entities' capacity to regulate GHG emissions (Public Citizen, 2021; The Texas Tribune, 2023).

Big oil and gas firms like *Air Products* and *ExxonMobil* announced clean hydrogen production

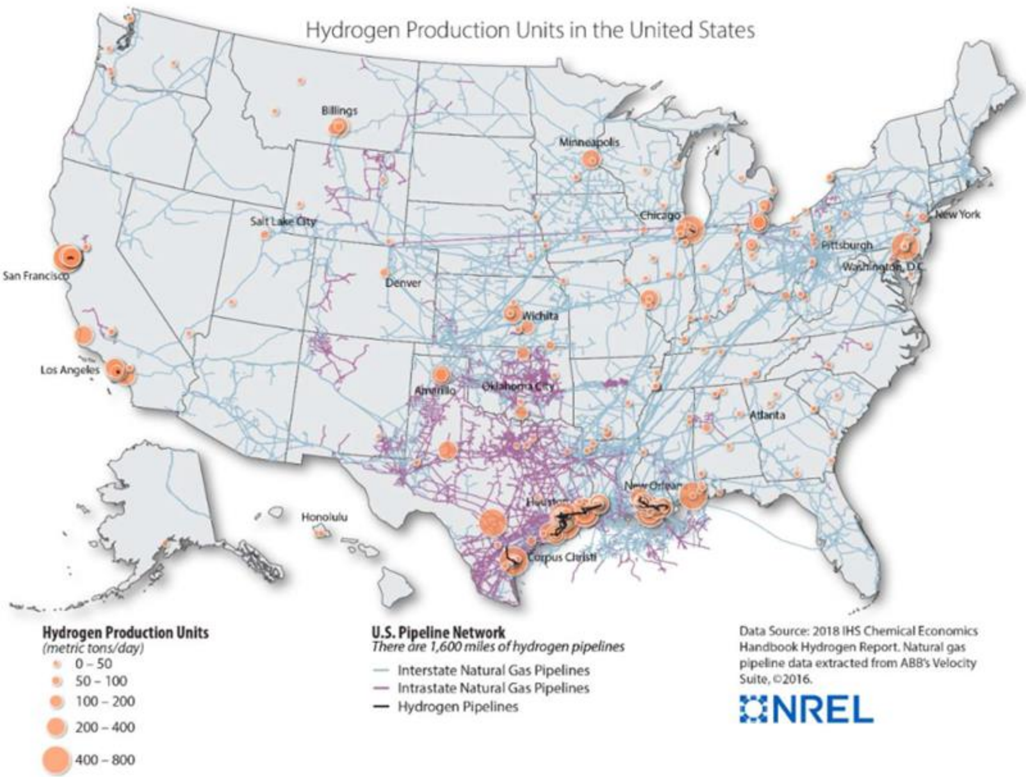

Figure 14: Hydrogen Production units and U.S. pipeline network. Texas emerges as a focal point of the national gas industry, including hydrogen. Source: NREL, 2021b, p. 4.

facilities in Texas, e. g. in Wilbarger County and Bayton (ExxonMobil, 2023, p. 63; Offshore Energy, 2022). Texas Governor, Greg Abott, publicly welcomes clean hydrogen projects in Texas, highlighting economic gains, such as revenue growth and job opportunities, and emphasizing that these initiative would bolster Texas' energy sector leadership (Office of the Texas Governor, 2022).

7.4.2 California

The State of California is another State accelerating clean hydrogen development in the U.S. Historically, California was described as a *"leader in U.S. climate policy"* due to its progressive environmental and climate policies (Bedsworth & Hanak, 2013, p. 664). In 2002, California established strict vehicle emission standards alongside a renewable portfolio requirement for electricity (Bedsworth & Hanak, 2013). Subsequent regulations addressed water, land, and air quality, with ongoing efforts to reduce GHG emissions from motor vehicles (Bedsworth & Hanak, 2013; California Air Resources Board [CARB], 2023).

The *Californian Air Resources Board* (CARB), tasked with supervising the State's air quality, translated Governor's directives from 2018 and 2020 into regulations which demand statewide climate neutrality by 2045 (CARB, 2022). This includes the *Advanced Clean Cars II* rule, requiring that 100% of new vehicles must be zero-emission vehicles (ZEVs) by 2035 (ibid.). Stringent regulations and policies promoting ZEVs have led to California having one of the world's largest hydrogen car fleets (Vijayakumar et al., 2021). As of September 2023, California featured 65 hydrogen fueling retail stations, with Hawaii being the only other U.S. State to have a private-use hydrogen retail station (California Energy Commission, 2023, p. 11).

Furthermore, California, where half of the electricity came from renewables in 2022, possesses substantial potential in renewable sources such as hydropower, solar, and wind (EIA, 2023a). The state's renewable energy standards require 60% carbon-free electricity by 2030 and 100% by 2045 (Public Utilities Commission, 2023).

DOE's recent decision to establish one of the seven hydrogen hubs around California highlights the state's existing hospitable environment for clean hydrogen technologies (OCED, 2023). The California Hydrogen Hub, funded by $1.2 billion, will focus on the production of hydrogen exclusively from renewables and biomass to decarbonize public transportation and port operations (OCED, 2023).

7.5 Government Institutions Driving Clean Hydrogen

7.5.1 Department of Energy

The DOE is one of the 15 departments of the U.S. government and responsible for administering the nation's energy policy. The DOE oversaw nearly all government initiatives promoting clean hydrogen technologies in the past, with the major exception being the clean hydrogen production tax credit enacted in the IRA. Thus, the DOE and its suboffices are one of the most important actors shaping clean hydrogen policy in the U.S.

However, depending on who is ruling in the White House, DOE's efforts to promote clean hydrogen differed significantly. Especially, during George W. Bush's and Joe Biden's administration, the DOE was allocated significant funding for clean hydrogen and fuel cell R&D. Trump's administration, and his Secretaries of Energy, Perry and later Brouillette, aimed to significantly reduce funding for the EERE and clean hydrogen technologies due to the enacted austerity course and Trump's skeptical view on renewables. On the other hand, Steven Chu, Secretary of Energy under Obama remained skeptical about hydrogen as he did not belief it to be the technology needed to reduce GHG emissions in the transportation sector.

Conesequently, the DOE is illustrated with a rectangle in Figure 15 ranging from hydrogen skeptics due to environmental concerns (Chu) and hydrogen skeptics due to austerity policy (Perry and Brouillette).

7.5.2 Office of Energy Efficiency and Renewable Energy

As part of the DOE, the EERE has been in charge of R&D and demonstration of clean hydrogen technologies since the mid-90s (see e. g. Romm, 2006). As stated in the Chapter 5, the EERE was essentially responsible for bringing hydrogen fuel cells to automotive. Furthermore, the EERE and subordinated Offices, such as the NREL, proactively hid the word *"climate change"* and barely mentioned the goal of GHG minimization during the Trump era to prevent renewable energy and clean hydrogen technology funding from being cut (Piria et al., 2021). This illustrated deep-rooting beliefs within the EERE that research and development efforts for renewable energy and clean hydrogen technology hold significant importance for the nation. Consequently, the EERE is considered a central driver for clean hydrogen development in the U.S. and located in the center of Figure 15.

7.5.3 Office of Fossil Energy and Carbon Management

The Office of Fossil Energy and Carbon Management (FECM), formerly known as Office of Fossil Energy (FE), is another Office of the DOE and has been in charge for clean hydrogen production from fossil-fuels, such as coal or natural gas, including R&D of CCS technologies (see e. g. DOE, 2022). These initiatives trace back to the George W. Bush administration, when intensified research on hydrogen and fuel cell technologies were conducted to explore alternative fuels for the transportation sector (see e. g. Trinkle, 2009 and NRC, 2008). FECM and its predecessor FE have consistently received substantial funding, totaling several million dollars annually since the early 2000s, for researching clean hydrogen production with CCS (DOE, 2023a). This funding has positioned FECM as a significant catalyst in bringing CCS technology to the market. Thus, FECM is located at the center in Figure 15.

7.5.4 Office of Clean Energy Demonstration

The OCED is a newly established DOE office that received its first budget in the year 2022 (DOE, 2021c, p. 1). Since then, one of its main tasks has been the administration of $8 billion from the IIJA for clean hydrogen demonstration projects as well as the selection of clean hydrogen hubs (American Energy Innovation Council, 2023; OCED, 2023). By law, the OCED was tasked to fund hydrogen hubs in a technology neutral way, thus hydrogen hubs producing clean hydrogen from natural gas, renewables, grid electricity, as well as nuclear energy were selected (OCED, 2023). Due to the high funding of the hydrogen hubs that are administered by the OCED (note that the EERE ‘only’ received $170 million for hydrogen and fuel cell technology in 2023, see DOE, 2023b, p. 10), the OCED will emerge from now on as a crucial actor in the hydrogen policy subsystem promoting clean hydrogen technologies in the U.S. Therefore, the OCED is located at the center in Figure 15.

7.5.5 Congress

The U.S. Congress prevented clean hydrogen funding from being cut under President Obama and multiple times under President Trump. Thus, Congress showcased the belief that EERE programs including funding for clean hydrogen are substantial for America’s prosperity. Furthermore, Congress demonstrated the importance of technology neutrality for clean hydrogen production by the passage of the IRA and IIJA which is in line with the industry’s vision of clean hydrogen. Congress is therefore illustrated as a central driver of clean hydrogen in Figure 15.

7.5.6 Environmental Protection Agency

The EPA has been subject to substantial presidential influence over the years. Obama utilized the EPA to decrease GHG emissions (see e. g. Rosenbaum, 2017, pp. 36–37), whereas Trump obstructed the EPA's effectiveness in regulating GHG emissions by appointing coal lobbyists as its leaders (Müller, 2020). Nevertheless, as the government entity that is responsible for controlling GHG emissions on the federal level, the EPA has been crucial to accelerate the decarbonization of sectors such as transportation and power plants (EPA, 2015, 2022). In May 2023, under President Biden's leadership, the EPA put forth revised emission standards for coal and gas-fired power plants (EPA, 2023a). These standards emphasize the central roles of CCS and hydrogen co-firing for future compliance (see e. g. Jenks et al., 2023). While EPA's main objectives include reducing air pollution and GHG emissions, the agency also legitimizes the adoption of clean hydrogen through its newly proposed standards. Consequently, the EPA's position in Figure 15 is illustrated as slightly left-of-center.

7.6 Republican Stance on Clean Hydrogen

In its party platform, the Republican Party emphasizes the significance of U.S. resources, especially fossil fuels, for national energy security (Republican National Committee, 2016). Today, a substantial number of Republican representatives emphasize domestically sourced energy from fossil fuels as vital for national security and job opportunities (Senate Committee on Energy & Natural Resources, 2023a). The party maintains a position that downplays climate change concerns and resists government subsidies for renewable energies (Republican National Committee, 2016). Presidents like Trump and George W. Bush appointed advocates of fossil fuels to key positions, leading to a political resurgence of fossil fuels during Trump's administration (Mildner et al., 2020; Müller, 2020). During these administrations, climate policy was either not prioritized or attempted to undo (ibid.). Trump even sought to eliminate government funding for EERE, the key institution funding renewable energy and clean hydrogen technologies, driven by his conviction that government expenditures needed substantial reduction (Max Grünig, personal interview, September 29th, 2023).

Nonetheless, some Republicans also demonstrated support for clean hydrogen, evident in the 2021 passage of the IIJA, which allocated $9.5 billion for U.S. clean hydrogen development, thanks to several Republican votes (npr, 2021). Furthermore, during George W. Bush's administration, clean hydrogen technologies gained prominence due to U.S. oil dependency, leading to the first hydrogen boom and significant R&D progress (Romm, 2006).

Thus, the Republican stance on clean hydrogen is ambiguous and driven by factors other than climate change. There are conflicting views within the party with one wing aiming to cut funding for renewable energies including clean hydrogen and another supporting the development of clean hydrogen deployment. The Republican stance on clean hydrogen is illustrated with a rectangle in Figure 15 ranging from clean hydrogen driving forces, such as the Bush administration, to clean hydrogen impeding forces such as the Trump administration.

7.7 Democratic Stance on Clean Hydrogen

In contrast to the Republican Party, the Democratic Party platform expresses concerns about climate change and its impact on U.S. citizens (Democratic National Committee, 2020). Thus, representatives of the Democratic Party usually support renewables as means to reduce GHG emissions, create jobs, and improve national energy security and resilience of the electricity grid (see e. g. Senate Committee on Energy & Natural Resources, 2023b). However, the Democratic stance on renewables and clean hydrogen varies among party members. Senator Manchin of West Virginia, for instance, expresses doubts about the reliability of renewables and concerns of government subsidies for renewable energies as he beliefs the government should pursue austerity (Atlantic Council, 2023; Senate Committee on Energy & Natural Resources, 2023b).

Under Obama, a Democratic administration put forward the first far-reaching national binding emission reduction target for the power sector (EPA, 2015) demonstrating willingness do decarbonize on large scale. However, during Obama's tenure, clean hydrogen was not deemed essential for curbing national GHG emissions. His Energy Secretary, Steven Chu, viewed clean hydrogen as unsuitable for the transportation sector and aimed to cut its funding (Biello, 2009; Tollefson, 2009). In contrast, under the Biden administration, clean hydrogen became central to U.S. energy policy. The Biden administration has put forward lighthouse legislation supporting clean hydrogen development in the U.S. including the IRA and the IIJA.

The Democratic stance is thus represented as a rectangle in Figure 15 ranging from representatives having climate concerns but doubting hydrogen's benefit (e. g. Obama administration) to representatives with strong ties to fossil fuel industries and challenging subsidies for renewable energies (e. g. Senator Manchin) with many representatives in the middle supporting clean hydrogen development, such as the Biden administration.

7.8 Mapping Advocacy Coalitions Engaged in the Hydrogen Policy Subsystem

This analysis has delineated three primary advocacy coalitions active in the U.S. hydrogen policy subsystem which are illustrated in Figure 15.

The most substantial and influential coalition today is the "*Clean Hydrogen Drivers Coalition"*, comprising members from both the Democratic and Republican party, governmental entities such as the DOE and its suboffices, and the U.S. Congress. This coalition is furthermore reinforced by major corporations, especially from the fossil fuel sector, as well as prominent trade associations. Key shared beliefs encompass the centrality of technology neutrality in clean hydrogen production. Technology neutrality signifies the production of clean hydrogen from diverse energy sources including fossil fuels and CCS, renewables, and nuclear. Additionally, the coalition shares the belief that the hydrogen economy in the U.S. should be kickstarted as fast as possible and that more clean hydrogen production profits the U.S. (and potentially the environment).

The second significant coalition identified is the *"Climate Change Concerns Coalition"* comprising numerous NGOs and research institutions, including university initiatives and think tanks. Shared beliefs within this coalition prioritize environmental protection and climate preservation over the importance of the economy. This advocacy coalition is doubtful whether clean hydrogen can have an actual climate benefit. It advocates for clean hydrogen (mostly green hydrogen) only under stringent regulations including stringent additionality, temporal matching, and deliverability criteria.

The third and smallest coalition identified is the *"Government Austerity Coalition"*. This coalition comprises representatives from both the Republican and Democratic party, albeit it is notably more prevalent among Republicans. Its primary contention against clean hydrogen deployment stems from the conviction that the U.S. government should curtail its spending and subsidies for renewable energy technologies. Moreover, this coalition shares similar beliefs on the benefits offered by fossil fuels to the U.S. (encompassing job opportunities and energy security) and a prevailing skepticism towards renewables in general.

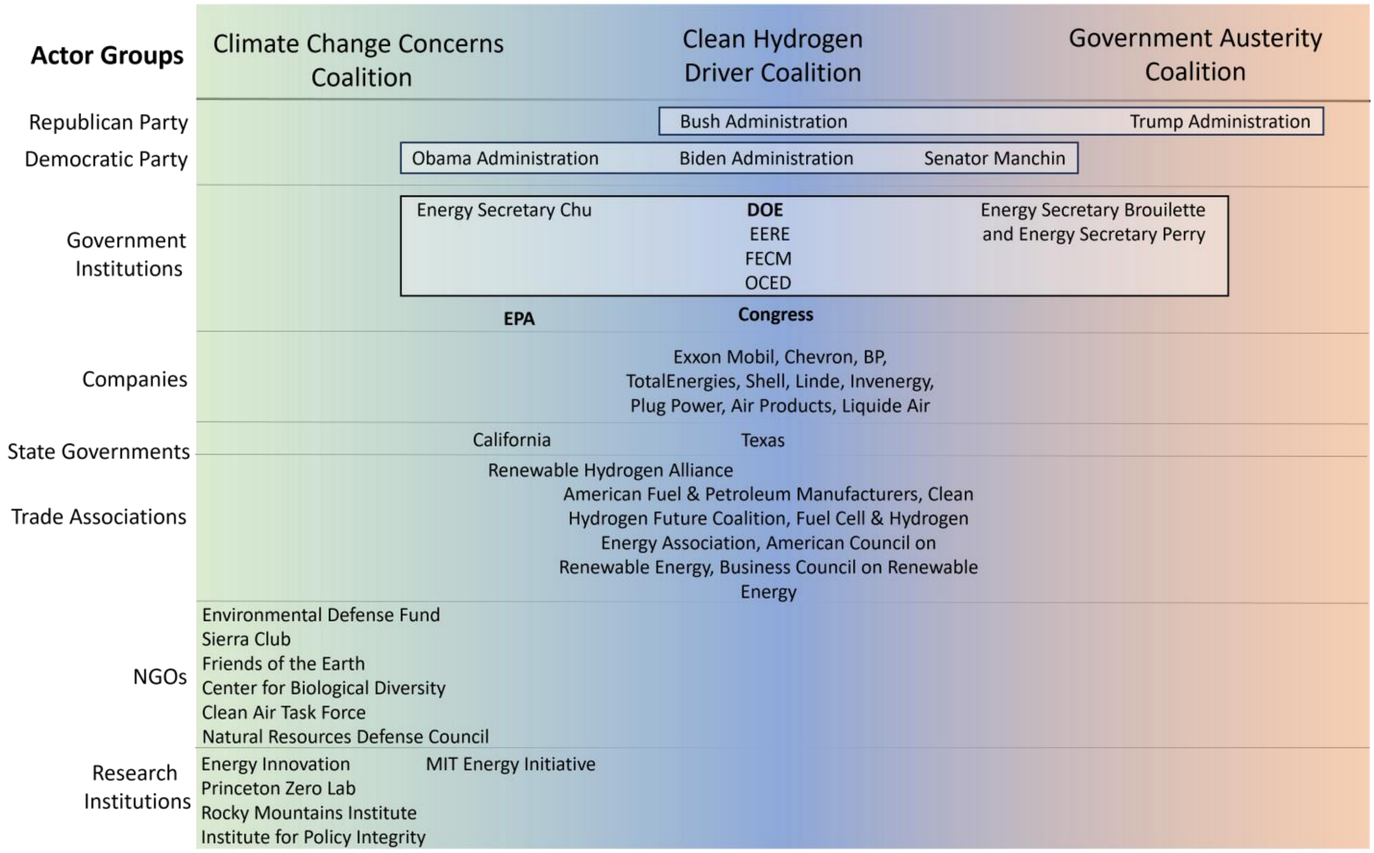

Figure 15: Advocacy coalitions engaged in the hydrogen policy subsystem. This analysis identified three main coalitions competing in the subsystem. The figure displays the most important identified actors in the subsystem but is not exhaustive. Own illustration.

8 Conclusion

This analysis mobilized the Advocacy Coalition Framework to contribute to transition literature by investigating the case of low-carbon hydrogen development in the biggest economy of the world, the United States. The guiding research question to be answered was *"Who are the political actors and coalitions that drive or oppose low-carbon hydrogen and what is their impact on the ramp-up of the hydrogen economy in the United States?* The study unfolded at two stages, first the historical development of hydrogen technologies in the U.S. was analyzed. Then, in a second step, key stakeholders, and their advocacy positions in a current political battle regarding the hydrogen production tax credit were examined. This examination facilitated a better understanding of their belief system.

The trajectory of clean hydrogen initiatives in the U.S. displayed a nuanced evolution between 1993 and 2023. During the tenures of President Bill Clinton (1993-2001) and George W. Bush (2001-2009), the first boom in clean hydrogen primarily revolved around limiting U.S. oil dependency of the transportation sector coupled with environmental concerns. In contrast, President Obama (2009-2017) and President Trump (2017-2021) showed little enthusiasm for clean hydrogen technologies, but due to different reasons. Obama's administration saw hydrogen-powered vehicles as not promising for future transportation and Trump aimed to cut government funding of renewables including clean hydrogen significantly due to his strict government austerity course. The turning point for clean hydrogen occurred in 2021 when President Biden (2021 – today) took office, leading to a resurgence in political interest and support for clean hydrogen technologies. Key legislations put forward by the Biden administration including the *Inflation Reduction Act* and the *Infrastructure Investment and Jobs Act* allocated substantial governmental support for clean hydrogen deployment, making hydrogen central to U.S. energy policy, especially in industrial and chemical manufacturing, transportation, and the electricity sector.

The IRA introduced the 45V hydrogen production tax credit, sparking political debates over its exact implementation regarding criteria on additionality, temporal matching, and deliverability. Two distinct camps have formed, with NGOs and research institutions advocating for stringent criteria to prove tax credit eligibility, while many companies - particularly those involved in fossil fuels - as well as various trade associations oppose a strict implementation of these criteria to qualify for the hydrogen production tax credit.

When summarizing actors and coalitions involved in present and past U.S. hydrogen policy, three distinct advocacy coalitions that share similar beliefs emerge within the hydrogen policy subsystem: the *Clean Hydrogen Drivers Coalition*, the *Climate Change Concerns Coalition*, and the *Government Austerity Coalition*.

The *Clean Hydrogen Drivers Coalition* stands as the largest coalition in terms of identified actors. This coalition comprises big oil and gas corporations, renewable energy companies, trade associations, government entities like the DOE including various DOE suboffices such as the EERE, and the U.S. Congress. Furthermore, members of the Republican Party (e. g. the Bush administration) and the Democratic Party (e. g. the Biden administration) are part of this coalition. Shared beliefs among actors of this coalition include the importance of a quick start of the U.S. clean hydrogen economy, accepting possible environmental and climate disadvantages due to a fast clean hydrogen rollout. Another shared belief concerns the centrality of technology neutrality for clean hydrogen production: clean hydrogen should be produced from fossil fuels with CCS, renewable energy, and nuclear energy. Since this coalition consists of powerful private actors and currently enjoys governmental support, a window of opportunity for clean hydrogen technologies to establish presence in industrial and chemical processing, transportation, and the electricity sector, has opened.

The *Climate Change Concerns Coalitions* is the second largest coalition consisting of prominent NGOs like *Sierra Club* and research organizations such as the *Princeton Zero Lab*. Nonetheless, it is salient that government entities and institutions from the private sectors, such as companies or trade associations, are widely absent in this coalition. The central shared belief within this coalition is the overarching significance of U.S. climate policy to mitigate national GHG emissions. Thus, clean hydrogen should only be deployed when its net impact on GHG emission reduction is evident. According to this coalition, clean hydrogen can only help to mitigate national emissions when strict government regulations (like additionality, temporal matching, and deliverability) are enacted. The EPA and the Obama administration are the sole government bodies that have exhibited some shared beliefs with other actors of this coalition concerning the overall importance of U.S. GHG emission reduction. Due to the lack of support from most government entities as well as the private sector, this coalition can mainly influence policy outcomes through increasing public pressure.

The smallest coalition is the *Government Austerity Coalition.* It consists of representatives of the Republican party (e. g. President Trump) and Democratic party (e. g. Senator Manchin). Shared beliefs include the centrality of limiting government spendings as well as a general degree of skepticism towards renewable energies. This coalition can exert crucial influence through vetoing legislations put forward by U.S. administrations, as it could be seen in the trajectory of the *Build Back Better Act* (see Roll Call, 2022). Furthermore, when members of this coalition form the government, they are likely to propose significant budget cuts for clean hydrogen and renewable energy funding. Notably, the analysis revealed that the *Government Austerity Coalition* lacks support from actors from the private sector.

The results obtained in this study help to facilitate a better understanding of U.S. hydrogen policy in the past and today. In line with the theory, external events, particularly growing climate change concerns, played a pivotal role in shaping hydrogen development in the U.S. Fossil fuel industries, responding to increasing public worries about climate change, acknowledged the need to diversify their energy portfolio by transitioning from sole reliance on fossil fuels to incorporating low-carbon alternatives like hydrogen. Big oil and gas corporations started advocating for policy incentives for clean hydrogen.

During Trump’s Presidency (member of the *Government Austerity Coalition*), no extensive subsidies for clean hydrogen were passed by the government. Lobbying endeavors for clean hydrogen policy incentives did not succeed under Trump’s austerity course. However, with the most recent U.S. Presidential election in 2020, a shift in the power dynamic occurred when the Democratic Biden administration (member of the *Hydrogen Driver Coalition*) replaced the Republican Trump administration. With this change in the political landscape, the *Clean Hydrogen Driver Coalition* gained extensive governmental support. After the change of government, lobbying for clean hydrogen incentives from the oil and gas sector fell on fertile ground resulting in extensive legislations put forward by the Biden administration that supported the adoption of clean hydrogen technologies.

Especially fossil fuel industries such as major oil and gas companies emerged as central drivers for clean hydrogen deployment in the U.S. This study suggests that the recent government initiatives in clean hydrogen did not arise from an increased influence of the *Climate Change Concerns Coalition* but rather stemmed from actor interests of the incumbent fossil fuel socio-technical system. Therefore, political coalitions that have hindered ambitious climate policy in the past (see e. g. Culhane et al., 2021 and Kukkonen et al., 2017) are now the ones responsible for accelerating clean hydrogen deployment in the U.S.

It's intriguing to observe the resistance from environmental NGOs and numerous research organizations against the ongoing development of clean hydrogen in the U.S., a phenomenon that may seem counterintuitive at first. Nonetheless, these entities articulate the fear that the way and extent clean hydrogen is pushed by the current government might exacerbate overall GHG emissions instead of mitigating them (see e. g. Center for Biological Diversity et al., 2022 and Princeton Zero Lab, 2022; Sierra Club, 2023).

This analysis leaves the door open for future research. Examining the relationship between the hydrogen policy subsystem and the renewable energy policy subsystem could be compelling, as many actors may participate in both policy areas. Moreover, the analysis presented in this study focused on the federal level. Therefore, upcoming research endeavors could concentrate on examining the factors influencing clean hydrogen initiatives in particular States, such as States that are suggested to drive clean hydrogen development in the U.S. (e. g. California and Texas) or fossil-fuel dependent States (such as West Virginia).

Ultimately, exploring the political discourse around clean hydrogen in the U.S., with a specific emphasis on Republican representatives who have been skeptical of renewable energy, would be intriguing as many Republican-ruled States benefit from the Biden administration's clean hydrogen subsidies. Therefore, analyzing public statements of Republicans would provide insights into possible differences of how clean hydrogen is framed in contrast to renewable energies.

Declaration of Authorship

I hereby declare that the thesis submitted is my own unaided work. All direct or indirect sources used are acknowledged as references.

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Janek Stockburger, München, 22.11.2023.

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10 Annex

Examined Stakeholder Comments for the 45V Tax Credit Implementation

Stakeholder Name	**Type of Institution**
Advanced Biofuels Business Council	Trade Association
AFL-CIO	Labor Union
American Chemistry Association	Trade Association
American Clean Power Cooperation	Trade Association
American Council on Renewable Energy	Trade Association
American Fuel & Petroleum Manufacturers	Trade Association
American Gas Association	Trade Association
BP	Company
Business Council for Sustainable Energy	Trade Association
Clean Air Task Force	NGO
Clean Energy Buyers Association	Trade Association
Clean Hydrogen Future Coalition	Trade Association
Coalition for Renewable Natural Gas	Trade Association
Earthjustice	NGO
Energy Innovation	Think Tank
Environmental Defense Fund	NGO
Friends of the Earth	NGO
Fuel Cell & Hydrogen Energy Association	Trade Association
Green Hydrogen Coalition	Trade Association
Industrial Innovation Initiative	Trade Association
Institute for Policy Integrity	Think Tank
Invenergy	Company

Letter of representatives of 13 local governments and one government entitiy: Massachusetts, Colorado, Delaware, Illinois, Maine, Maryland, Michigan, New Jersey, New York, Oregon, Rhode Island, Columbia, California, and the Office of the Ramsey County Attorney	Government Entity
Letter of representatives of five local governments and one government entity: New York, Massachusetts, Maine, Connecticut, and Rhode Island	Government Entity
Letter signed by 45 companies	Company
Methanol Institute	Trade Association
MIT Energy Initiative	University Initiative
Natural Resources Defense Council	NGO
Nuclear Energy Institute	Trade Association
Plug Power	Company
Princeton Zero Lab	University Initiative
Renewable Hydrogen Alliance	Trade Association
Renewable Fuel Association	Trade Association
Resources for the Future	NGO
Rocky Mountains Institute	Think Tank
Shell	Company
State of Colorado	Government Entity
State of Massachusetts	Government Entity
Valero	Company
WWF	NGO