CHAPTER THREE

INTERNATIONAL AND COMPARATIVE LAW PERSPECTIVES OF HYDROGEN ECONOMY

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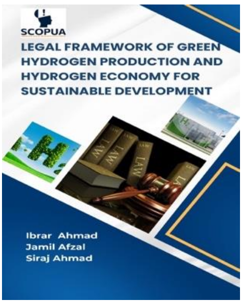

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Abstract

This chapter delivers a detailed analysis of the legal frameworks underpinning the global hydrogen economy, focusing in particular on international legal systems and comparative national strategies. This chapter commences by considering the functions of primary international legislative instruments, i.e., multilateral treaties and conventions, for the regulation of international hydrogen trade (cross-border movement of hydrogen) and the role they play in promoting international cooperation. Key agreements such as the United Nations Convention on Contracts for the International Sale of Goods (CISG) and WTO frameworks set the baseline rules for cross-border hydrogen deals, common rules on certification, trade, and compliance. These international legal frameworks are an essential way of facilitating the frictionless flow of hydrogen-related technologies and resources internationally, given the inherently cross-border aspects of hydrogen production and trade. The chapter then shifts to examining how different jurisdictions, including the EU, the US, and India, have formulated regulatory approaches to regulate hydrogen technologies. Through the analysis of the way national legal systems have transposed international standards to the domestic level, the chapter points out the varied regulatory solutions and the range of legal instruments that foster the development of hydrogen.

Keywords: *Perspectives of Hydrogen Economy; International and Comparative Law; Comparative Law of Hydrogen Economy; International Law of Hydrogen Economy*

3.1. International Law and the Hydrogen Economy

The Paris Agreement (2015), the United Nations Framework Convention on Climate Change (UNFCCC), and the Kyoto Protocol are important in the context of hydrogen at the global level [1]. These deals have paved the way for sector coupling and decarbonization, seeing hydrogen increasingly tipped as a key component in the global clean energy shift. The Paris Agreement, which serves as the bedrock of international climate architecture, seeks to cap global warming to well below 2°C but is pursuing efforts to limit the temperature rise to 1.5°C and calls for innovation in clean technology in areas like hydrogen [2],[3].

Although voluntary "Nationally Determined Contributions" (NDCs) underpin national pledges in the accord, there's no way to ensure compliance [4]. This non-obligatory approach entails that although countries are invited to include hydrogen in their climate strategies, they are not obliged to achieve any target related to hydrogen deployment. The consequence is that hydrogen policy often stands or falls based on (soft) law, not so much due to robust legal obligations.

The Kyoto Protocol set binding targets for the reduction of greenhouse gas emissions for developed countries and developed mechanisms for its implementation, including emissions trading (ET), joint implementation (JI), and the Clean Development Mechanism (CDM) [5],[6]. These measures created an incentive for low-carbon investments, including hydrogen technologies, especially in the developing world. However, the Kyoto Protocol was flawed, as it did not include emerging economies, which did not share similar binding targets. This void is even more striking now that emerging economies are gaining importance in the hydrogen transition. The lack of punitive or coercive tools has delivered serious challenges for holding to account those who do not fulfil commitments relating to hydrogen. This is particularly significant in developing countries, in which resources for hydrogen projects are scarce and national institutions are not able to adequately fulfil international obligations. When it comes to the future, it is evident that the treaties provide a globally broad framework for hydrogen implementation, while their success will rely on how countries implement these global commitments into tangible strategies at home.

The hydrogen economy and multilateral environmental agreements (MEAs), including the Convention on Biological Diversity (CBD) MEAs establish norms for environmental conservation that guide how new technologies, like hydrogen, may be introduced and deployed sustainably and in a way that does not undermine biodiversity [7],[8]. The CBD stresses the importance of a precautionary approach in large projects (like hydrogen production) to prevent possible damage to ecosystems and local populations. It is consistent with the main Sustainable Development Goals (SDGs), such as SDG 13 (climate action) and SDG 7 (affordable and clean energy). As a result, MEAs help bring the technological side of the development of hydrogen technologies together with respect for the environment while contributing to both climate mitigation and sustainability goals in general. Take the CBD, which encourages countries to undertake a thorough analysis of the ecological implications of hydrogen projects before advancing large-scale infrastructure. In the rapidly growing hydrogen economy, MEAs can be one of the institutions to ensure social and environmental considerations in national hydrogen policy. This is relevant for countries wanting to achieve climate goals, but be aware that their energy approaches are unintentionally deleterious to biodiversity or people.

3.2. International Trade Law and the Hydrogen Economy

International trade law, governed by agreements like those under the World Trade Organisation (WTO), plays a pivotal role in the development of the global hydrogen economy [9],[10]. The General Agreement on Tariffs and Trade (GATT), the Agreement on Subsidies and Countervailing Measures (ASCM), and the Technical Barriers to Trade (TBT) Agreement are essential in shaping the rules for hydrogen trade across borders. They support non-discrimination and transparency in trade, both of which are essential to allowing hydrogen to flow freely across the world. One of the mega-issues in the hydrogen trade is the influence of tariffs and non-tariff barriers, which can make the cost of hydrogen and its infrastructure rise, explaining why trade in hydrogen has remained relatively small compared to that of natural gas. The WTO's non-discrimination principle would mean that countries cannot take discriminatory measures against imported hydrogen technologies (including green hydrogen) unless they can justify them by invoking exceptions, such as to meet national security considerations. However, the WTO has yet to formulate rules specifically for hydrogen, and so a great deal will hinge on the interpretation and enforcement of these agreements about this new sector. Taking into account the hydrogen economy, international trade law will be even more important. Making it possible to access the market and ensure the security of investment will require aligning regulatory requirements to establish a common certification scheme and to deal with the legal issues involved in the cross-border transportation of hydrogen. The trade law will also have to respond to specific issues related to the hydrogen market to reconcile fair competition with security and environmental protection. As the hydrogen economy grows, so will policy frameworks have to respond to new needs, especially in developing countries. Two factors hamper the quick rollout of hydrogen technologies in these regions: legal uncertainty, policy fragmentation, and a lack of infrastructure. Supportive, non-discriminatory regulation and administration of standards could also be supplemented with improved enforcement mechanisms, more explicit provisions ensuring that investments in the area are protected, and internationally aligned action to promote the deployment of hydrogen technology at scale, productively, and sustainably.

3.3. Energy Role of International Organisations

3.3.1. International Energy Agency (IEA)

The International Energy Agency (IEA) has historically played a vital role in influencing global energy strategy, and the energy group's activities in the hydrogen space are no different [11]. The IEA is an advisory body with a brief to provide policy guidance, thorough analysis, and facilitate collaboration among member countries. Its major publications, like the Global Hydrogen Review or the future of Hydrogen, offer crucial analysis of how to scale up the production of hydrogen, lower costs, and then roll out the product across global energy systems. IEA's Hydrogen Roadmap Providing recommendations, in detail, for governments and industries, the IEA's Hydrogen Roadmap acts as a vital reference for any country working on or looking to develop a hydrogen strategy [12],[13]. The IEA's greatest strength is being able to offer solid analytical frameworks for the deployment of hydrogen. The agency also notes the need for upscaling low-emissions hydrogen production, notably electrolysis from renewable power and investment in electrolyser manufacturing capacity. The IEA has also championed the establishment of international certification schemes to guarantee the environmental soundness of hydrogen supply chains. For example, the IEA's work on ISO technical standards on greenhouse gas emissions accounting in hydrogen production is central to the development of emerging certification systems, including in the European Union, the United Kingdom, and Australia. However, the IEA's sway is limited by the fact that it does not have enforcement power. Although it can offer advice and promote collaboration, it is powerless to force sovereign states to follow its recommendations. As a neutral agency that relies on voluntary compliance, whether the OIE will succeed is largely in the hands of individual countries willing or not willing to adopt their policies to global best practices. Secondly, there are still strong economic hurdles to hydrogen deployment. The IEA calculates that hundreds of billions of dollars of investment are needed to expand the production of low-emission hydrogen to the levels required to meet global climate goals. The IEA's lack of mandate to promote investments in hydrogen infrastructure reflects the importance of complementary financial mechanisms, perhaps led by multilateral development banks or climate finance institutions [14],[15].

3.3.2. International Renewable Energy Agency (IRENA)

The International Renewable Energy Agency (IRENA) has become a leading champion of global hydrogen arrangements, which aim for policy harmonisation, capability development, and the establishment of a legal and regulatory framework supportive of the global hydrogen economy [16],[17]. IRENA's work that is particularly relevant in the context of accelerating cross-border trade in hydrogen is one that involves advocating harmonised certification schemes and sustainability criteria that can facilitate trade in hydrogen and its derivatives. The joint IRENA Collaborative Framework on Green Hydrogen has been critical in facilitating international collaboration [18]. Several countries, including Germany, Japan, Morocco, and the United Arab Emirates, have worked with IRENA to help ensure their domestic hydrogen strategies are benchmarked against global best practices. The National Hydrogen Roadmap of Morocco and Japan's strategy for importing green hydrogen, for example, mirrors IRENA's influence and its certification, emissions accounting, and infrastructure frameworks. This collaboration has led to case study agreements, pilot initiatives, and common technical standards, which provide a real indication of convergence in law. However, there are still challenges in the face of regulatory diversity. The European Union has established strict emission standards for green hydrogen, but the United States, among other countries, has looser benchmarks. Such inconsistencies hinder cross-border trade, forcing exporters to jump through legal hoops to access various markets. IRENA's advocacy for investments in public-private partnerships and attraction continues to support these initiatives to enable developing countries to engage with hydrogen economies.

3.3.3. World Trade Organisation (WTO)

The World Trade Organisation (WTO) assumes an important role in the development of the legal environment for international hydrogen trade, especially for market access, dispute settlement, and trade policy coordination between its member states [10],[19]. Key WTO agreements, such as the General Agreement on Tariffs and Trade (GATT) and the Agreement on Subsidies and Countervailing Measures (ASCM), are central mechanisms for the governance of hydrogen trade about export duties, the capacity to manage subsidies directly to hydrogen, and the intellectual property status of hydrogen production technologies. Since hydrogen is now becoming an independent product traded on the market, the importance of the WTO in bringing it into the market is growing. Some targeted trade barriers are already emerging, including plans to limit the export of hydrogen from domestically produced renewables. While these measures provided ambiguity as to whether export of hydrogen would be treated differently, they raised the risk of issues relating to supply security and market distortion and could place restrictions on hydrogen exporters. The WTO's dispute system could be a crucial tool for addressing disputes over these issues and helping ensure that national rules do not represent hidden trade barriers.

The WTO struggles to make its trade rules compatible with the particularities of hydrogen as it also crosses with environmental regimes. The multiplication of bilateral and regional agreements, with their own sets of norms, hampers the striving for coherence in hydrogen trade at a global level. Therefore, the WTO needs to cooperate closely with organisations like IRENA and IEA to ensure the complementarity of trade policies, mutual recognition of standards, and avoidance of regulatory fragmentation [20],[21].

While there may be agreement on the objective of creating open markets, regulatory coherence, and international cooperation, challenges persist between different legal systems and institutional preferences. Nonetheless, instances of successful cooperation, such as that of IRENA and WTO, do exist and indicate the possibility of synergies and a way forward. Such collaborations are the key to surmounting regulatory and legal obstacles that are standing in the way of bringing hydrogen technologies to scale.

3.4. Global Standards for Hydrogen Technologies and Safety

The development and use of international standards play a key role in the advancement of hydrogen technology and applications around the world [22]. The necessity of these standards, and especially of those established by the International Organisation for Standardisation (ISO) and the International Electrotechnical Commission (IEC), is, from a technical point of view, the basis for guaranteeing that hydrogen technologies are safe and can also be applied in different regions. Standards produced under the auspices of the ISO and IEC are essential to the development of international trade, investment, and operational interoperability by providing a core set of technical specifications and safety benchmarks for the production, storage, transport, and use of hydrogen. These harmonised standards fill these regulatory voids and ensure that hydrogen technologies can be deployed safely and in a uniform manner, irrespective of where the technology is introduced. They lower trade barriers, facilitate cross-border investment, bring clarity to manufacturers, operators, and regulatory authorities, and can help scale hydrogen technologies.

Central to the safe introduction of hydrogen as a fuel are formal international standards, including the ISO 14687 requirement for the quality of hydrogen fuel for fuel cell vehicles and the ISO

16110 for hydrogen generation system safety and performance [23],[24]. ISO 19880 also specifies design and functional requirements for hydrogen fuelling stations that are in place to ensure that the refuelling infrastructure operates safely and optimally [25],[26]. For fuel cell technologies, both for stationary and mobile applications, safety and performance are covered by the IEC 62282 standard, whereas the IEC 60079 series deals with the use of electrical apparatus in explosive atmospheres, which is crucial for hydrogen production and refuelling stations [27],[28]. More recently, ISO/TS 19870 was published as a technical specification to assess greenhouse gas emissions in the hydrogen value chain, which helps to foster transparency and test sustainability claims [29]. These standards are crucial to verifying the reliability, safety, and quality of hydrogen technologies, to stimulating worldwide acceptance of hydrogen technology, and to the infiltration of hydrogen into the international supply chain.

To promote safety through a transparent framework, the standards of ISO and IEC also facilitate the integration of hydrogen technologies into different markets by guaranteeing interoperability and equality. Standardisation facilitates the transfer of technology, saves costs, and de-risks investment by providing a predictable regulatory regime. It also promotes the trust of the public in hydrogen technologies by assuring that they comply with safety and quality criteria that are universally accepted. However, there are many complications to accomplish a reconciled safety rule across jurisdictions. National and regional variations still inhibit regulatory consolidation as differences in public safety priorities, environmental rules, and technological preparedness amongst member states persist. For example, Europe's strict safety standards for hydrogen refuelling stations and production stations stand in stark contrast with relatively weak safety frameworks in some parts of Asia and Africa [30]. In addition to this, the use of more advanced safety solutions can be taken on quicker by the early movers of hydrogen technology, while poorer regions may slow down in terms of implementing best practices. These heterogeneous regulations, combined with differences in technology readiness, make it difficult for hydrogen technology to be scaled globally.

Work towards harmonising safety standards is ongoing, with substantial coordination at the international level, e.g., between ISO and IEC and organisations like the IRENA (International Renewable Energy Agency) and the IEA [31]. These companies, alongside local regulators and industry bodies, are collaborating to harmonise safety protocols and produce common guidelines. Some advances are being achieved at the European Union (EU) and Organisation for Economic Cooperation and Development (OECD) level, such as the development of common safety regimes to fill regulatory gaps [32]. Such partnerships are essential for the development of stable regulatory frameworks, the lowering of compliance costs, and facilitating an enhanced global deployment of hydrogen technologies. Despite the obstacles, this GLIH work is crucial to maintaining the safety, security, and accessibility of hydrogen, wherever it is used. Overall, the importance of following ISO and IEC along the pathway to global safety and interoperability in hydrogen technologies and systems is essential to ensure that hydrogen is adopted as a worldwide clean energy solution. They form the necessary base for technical requirements to ensure the safe use of hydrogen technologies and to facilitate international trade and investments. International collaboration and also proactive safety standard updates are necessary to respond to new challenges: new technologies, safety issues, and regional regulatory differences, due to the fact that hydrogen technologies are now evolving.

3.5. Comparative Law Analysis: Hydrogen Economy Regulations in Key Jurisdictions

3.5.1. European Union (EU) Hydrogen Legal Framework

The European Union (EU) Green Deal and EU Hydrogen Strategy, both published in 2020, are complements to the EU legal and policy structure for hydrogen within an energy policy framework [33],[34]. The Green Deal is an EU initiative under which the EU pledges to become climate-neutral by 2050, with hydrogen considered to be a key enabler to decarbonise hard-to-electrify sectors such as heavy industry, long-distance transport, and heating [35]. The EU Hydrogen Strategy is a logical next step following the EU's previous work on renewable hydrogen, which supplemented previous policies on conventional, synthetic, and low-carbon fuels, as well as the overarching objective of reducing emissions across every sector.

It focuses largely on legal measures, such as support for hydrogen infrastructure, standardisation of hydrogen technologies, and the establishment of clear regulatory frameworks that would allow cross-border trade and market integration, among other things. Its main features include ambitious objectives, such as the production of 10 million tonnes of renewable hydrogen by 2030 and the development of hydrogen valleys and hydrogen road transport in Europe [36],[37]. Policy measures such as the H_2 and Decarbonised Gases Market Package and delegated acts under the RED add layers to the definition of renewable hydrogen with strong criteria around life-cycle emissions and additionality - clear signals and a system of traceability for investors and the market. The EU approach is phased, with a first phase centred on the deployment of green hydrogen in existing industrial uses and pilot projects and latter phases targeting increased production, infrastructure development, and integration of hydrogen across energy systems. This staggered approach allows the legal and regulatory framework to develop alongside technological and market developments, and it is flexible as the hydrogen economy matures. It focuses largely on legal measures, such as support for hydrogen infrastructure, standardisation of hydrogen technologies, and the establishment of clear regulatory frameworks that would allow cross-border trade and market integration, among other things. Policy measures such as the H_2 and Decarbonised Gases Market Package and delegated acts under the RED add layers to the definition of renewable hydrogen with strong criteria around life-cycle emissions and additionality - clear signals and a system of traceability for investors and the market. The EU approach is phased, with a first phase centred on the deployment of green hydrogen in existing industrial uses and pilot projects and latter phases targeting increased production, infrastructure development, and integration of hydrogen across energy systems. This staggered approach allows the legal and regulatory framework to develop alongside technological and market developments, and it is flexible as the hydrogen economy matures.

***Funding Tools and EU Policies Supporting Hydrogen Development*:** The EU has developed a variety of funding options and policy tools to support research, innovation, and infrastructure in a bid to achieve its hydrogen aspirations [38]. At the top of the list is Horizon Europe, where a €1 billion budget is earmarked for the Clean Hydrogen Partnership in support of joint research activities and the establishment of hydrogen valleys across Europe [38]. One of the world's largest funding programs for low-carbon technologies, the Innovation Fund has already awarded billions of euros to hydrogen-related projects. The Connecting Europe Facility (CEF) equally stimulates EU hydrogen development by facilitating cross-border hydrogen infrastructure [39]. The most recent calls for proposals have earmarked €600 million for Projects of Common Interest (PCIs) or Projects of Mutual Interest (PMIs) to streamline permitting and regulatory processes for certain important hydrogen interconnections [39],[40]. Furthermore, member states are permitted to support hydrogen projects under the EU's State Aid Guidelines, so national hydrogen efforts can continue with respect to the EU legislation. Initiatives such as the Clean Hydrogen Partnership and other calls for proposals all support the continuous deployment of funds towards research, demonstration, and market uptake, further heralding the EU's commitment towards enabling a strong hydrogen economy.

The EU Emissions Trading Scheme (ETS) is a core pillar of the EU's climate policy and a key driver for the uptake of green hydrogen [41]. The ETS places a price on carbon emissions, creating economic penalties for carbon-intensive energy production and a corresponding advantage for switching to low-carbon and renewable hydrogen. The scheme has just been reformed to cover all hydrogen production pathways as well, which entails that renewable and low-carbon hydrogen plants have access to free allowances and market signals. The package known as Fit for 55, which lifts the level of ambition of the ETS and broadens the ETS, will pave the way for hydrogen uptake to go faster by making green hydrogen more economically competitive against fossil-based solutions. Introducing the Carbon Border Adjustment Mechanism (CBAM) will guarantee that hydrogen products imported into the single market are subject to the same environmental requirements, preventing carbon and environmental leakage and guaranteeing a level playing field for EU hydrogen producers [42],[43]. Combined, these steps support the EU's climate and energy leadership and boost investment in green hydrogen while keeping EU-produced hydrogen competitive internationally.

Regulatory Authorities and Legal Background**:** Hydrogen energy policies in the EU. The regulation of hydrogen power exists in various institutions and actors in the EU, of which the European

Commission and its DG Energy are among the most significant actors [34],[44]. The Commission, in particular its Directorate-General for Energy, has the task of establishing and stimulating hydrogen-related legislative frameworks, to follow up on the progress, and to guarantee that it would be compliant with the EU-level energy and climate objectives. The European Court of Justice (ECJ) is also instrumental in interpreting and enforcing EU legislation, making sure that national hydrogen policies are in line with this legal framework, and settling issues on cross-border commercial hydrogen and market entry [45],[46].

The EU's hydrogen legal framework is a tangled labyrinth of rules, regulations, and decisions on everything from safety to the environment and market integration. The Hydrogen and Decarbonised Gas Market Package, which is in force from August 2024, foresees a Union-level certification system for low-carbon hydrogen, includes a requirement to unbundle hydrogen network operators, and lays down provisions on infrastructure planning, network tariffs, and third-party access [47]. These actions are in addition to implementing acts under the Renewable Energy Directive, which sets out criteria for renewable hydrogen and presents detailed life-cycle emissions calculation schemes. Other regulatory matters, such as the blending of hydrogen into natural gas infrastructure, the repurposing of existing infrastructure, as well as the setting up of hydrogen refuelling stations, are also covered by the EU legal framework, ensuring the safe and optimal integration of hydrogen in the energy system of the EU. The coherence and coordination between member states will be monitored by ACER and national regulatory authorities to foster the development of a homogeneous and competitive hydrogen market [40].

3.5.2. United States: Federal and State-Level Hydrogen Regulations

The regulation of hydrogen in the US is complex, involving many dimensions of interaction between federal states that play different but complementary roles in promoting the development of the hydrogen economy. Key federal agencies, such as the Department of Energy (DOE), the Environmental Protection Agency (EPA), and the Department of Transportation (DOT), are addressed, as well as the path-breaking actions of the states [48]. This analysis will also discuss the challenges of legal jurisdictional overlaps and regulatory fragmentation and the necessity of further harmonisation in the regulation of hydrogen. The federal role in hydrogen technology research, development, and demonstration (RD&D) is diverse and expanding and is a significant component of the RD&D investments that the federal government makes in advancements to energy technology. Among the most notable federal initiatives for the regulation and commercialisation of hydrogen technologies in the country are the Inflation Reduction Act (IRA), the Bipartisan Infrastructure Law (BIL), and the Energy Act of 2020 [49],[50].

***The Energy Act of 2020*:** The Energy Act 2020 was a game-changing piece of legislation offering a big, clear signal to accelerate the development of clean energy technologies, including hydrogen [51]. It provided nearly $2.5 billion in funding for Department of Energy (DOE) sustainable transportation activities, including designated funding for hydrogen and fuel cell R&D [52]. One of the Act's main goals was to promote innovation in hydrogen production, distribution, and storage, specifically, to help hydrogen develop into a commercially competitive alternative to the traditional fossil fuels. The Energy Act's funding applies in the context of a broader federal approach to make hydrogen a cornerstone of the U.S. clean energy future [53]. The fund does not just help to drive R&D in hydrogen technologies but also to create the infrastructure needed to enable widespread hydrogen adoption. The Act can deliver the latter, enabling the inclusion of hydrogen as an integral component of the overall energy scope in the country.

Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA): In subsequent years after the Energy Act, the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA) also ramped up the federal government's support of hydrogen [54],[55]. The BIL reserved $8 billion in funding for the establishment of Regional Clean Hydrogen Hubs (H_2Hubs), which seek to establish coordinated clusters of hydrogen producers, users, and infrastructure developers [56]. These hubs aim to help scale up the use of clean hydrogen by ensuring infrastructure for production and consumption is available in large enough quantities. The BIL also allocated $1 billion for clean hydrogen electrolysis technologies and $500 million for research, development, demonstration, and deployment (RDD&D) programs [49]. The IRA created a Hydrogen Production Tax Credit (PTC) that would incentivise the production of clean hydrogen [57]. These incentives, combined with funding to further develop clean vehicle manufacturing and to spur carbon capture, are spurring broad private sector interest in developing hydrogen production.

Department of Energy (DOE)**:** The DOE's Hydrogen and Fuel Cell Technologies Office (HFTO) is critical to the advancement of the hydrogen economy in the US [58]. The HFTO runs a number of funding programs for hydrogen R&D and deployment, including infrastructure grants, safety improvements, and permitting roadblocks [58]. While the 2023 Department of Energy $62 million grant was given to 20 projects in 15 states, it re-emphasises that the feds are deferring to states when it comes to unique hurdles relating to hydrogen [59]. One of the examples of that investment is the

Department of Energy's $1.66 billion loan guarantee for Plug Power, an innovative clean hydrogen production company. The loan will back hydrogen production plant construction, evidence of the level of federal investment in hydrogen infrastructure. The EPA is heavily involved in this aspect of the production of hydrogen to ensure that emissions standards are met by hydrogen production on a national level. Under the Clean Air Act, the EPA establishes emission standards for hydrogen production facilities that limit the greenhouse gases emitted by these operations to the greatest degree achievable. The agency's Clean Hydrogen Production Standard sets out the requirements for what qualifies as "clean" hydrogen, an important step to making sure hydrogen production can support the U.S.'s climate goals. In 2023, the EPA proposed a power plant rule that initially included substantial hydrogen blending in new natural gas-fired power plants. The rule was, however, significantly trimmed on concerns over cost and availability of hydrogen and infrastructure issues. Nonetheless, the continued regulatory work by the EPA signals an increasing awareness that hydrogen can help decarbonise hard-to-electrify sectors, like heavy industry and power generation. Another important subset of the regulatory portfolio of the EPA is that of safety regulations. The design, storage, and handling of hydrogen systems are covered by standards like NFPA 2 and NFPA 55, assuring that hydrogen infrastructure complies with the most stringent safeguards. The EPA's emissions and safety standards also help provide a stable regulatory environment for investment in hydrogen technologies.

The transportation of hydrogen, including through pipelines, is under the regulatory purview of the Department of Transportation (DOT) [60]. The U.S. Department of Transportation (DOT), through the Pipeline and Hazardous Materials Safety Administration (PHMSA), regulates the safety of hydrogen pipelines under 49 CFR Part 192 [60],[61]. Today, there are roughly 700 miles of hydrogen pipeline under federal jurisdiction, with more planned to go in the ground as hydrogen infrastructure grows. The PHMSA's efforts will focus on hydrogen pipeline integrity, material standards, and emergency response plans for accidents [62]. Recent research is primarily devoted to investigating the impact of hydrogen on pipeline materials and the development of standards for the safe transportation of hydrogen on a large scale. With increasing penetration of hydrogen, DOT's role in assuring safety and reliability for hydrogen transportation infrastructure will play a substantial role in the success of the hydrogen economy.

Although federal policies lay the groundwork for hydrogen commercialisation, the states are central to the promotion of hydrogen through state regulations and incentives. Several states, including California, New York, and Colorado, have also launched their own hydrogen regulatory initiatives, often with more aggressive plans to deploy hydrogen above what the federal government requires [53]. California has traditionally been an early adopter of clean energy policies, and in the case of hydrogen, its regulatory regime is reflective of its commitment to driving down greenhouse gas (GHG) emissions. The California Hydrogen Roadmap and Low Carbon Fuel Standard (LCFS) are key components of California's approach to encouraging renewable hydrogen production and infrastructure [63]. The LCFS offers attractive economics for hydrogen producers and developers and supports the growth of clean hydrogen by providing credits for lowering the carbon intensity of transportation fuels. California. As of 2023, there are 65 hydrogen refuelling stations in California with a goal of 129 by 2029 [64]. Although not without obstacles, such as station reliability, California continues to lead the way on hydrogen infrastructure. California's lawmakers have also made it easier for hydrogen projects to get permits. New laws like SB 1420 have included carbon capture mandates for blue hydrogen projects, continuing to bring hydrogen policies in line with state decarbonisation goals [53]. These initiatives have helped solidify

California as a template for other states hoping to build hydrogen systems. Other states have also outlined unique hydrogen road maps. For instance, New York is prioritising code adoption, safety, and community outreach for developing hydrogen infrastructure and using federal investment to deploy stations. Washington and Colorado are including hydrogen in their larger decarbonisation plans. Colorado's Low-Carbon Hydrogen Roadmap notes hydrogen's potential to help meet Colorado's aggressive greenhouse gas reduction goals by focusing on end-uses where electrification is not feasible. Texas and Louisiana have taken a more industry-centric path, forming hydrogen production task forces and regulatory commissions to evaluate permitting and infrastructure requirements for the hydrogen industry [65]; and these state-level actions mirror the heterogeneous energy economies and priorities among states.

The fragmented system of regulation of hydrogen in the U.S. also gives rise to a number of legal and practical problems. The overlap between federal and state jurisdiction often confounds project development and delays timelines. For instance, hydrogen production plants and pipelines must be approved by state and federal regulatory bodies, each with its own environmental, safety, and land-use standards. State-level attempts to regulate hydrogen infrastructure can also clash with federal regulation, particularly with respect to emissions standards and the siting of energy generation and distribution systems. Section 401 of the Clean Water Act permits states to stop federal projects that could damage water quality, and that can slow the development of hydrogen infrastructure. The Federal Energy Regulatory Commission (FERC) has at times reversed state efforts to advance clean energy, further highlighting the conflict between uniform federal policy and state-led ingenuity [66]. Economic and political hurdles are complicating the task of devising a unified national hydrogen strategy. States with large FF industries might be unwilling to pursue aggressive hydrogen policies, and spatial heterogeneity in renewable resources affects the potential for hydrogen technologies. In addition, uneven regulatory rules for clean hydrogen production and rules governing safe use have led to a patchwork of rules that can discourage investment in and slow progress toward a vibrant clean hydrogen economy.

3.5.3. Japan's Hydrogen Economy Regulations

Japan's hydrogen regulation has been praised for its ambition and systematic arrangement, which is fitting given the country's energy security and climate action imperatives [67],[68]. As a result, the Japanese government has made hydrogen a key element of its decarbonisation strategy, supported by a strong legal and fiscal framework, high public funding, and an original approach to public-private collaboration. Though this regulatory atmosphere has ushered in a great deal of progress, it is accompanied by significant legal, economic, and technological barriers that make the establishment of a competitive and sustainable hydrogen economy challenging. Japan's hydrogen policy is firmly rooted in the adoption of the Basic Hydrogen Strategy in 2017, an unprecedented document that set a worldwide benchmark [69]. This plan charted a three-stage journey: 1) driving the uptake of hydrogen across mobility and stationary fuel cell applications to build a market in the short term; 2) scaling up the supply chain to reduce costs in a maturing market in the mid-term; and 3) a longer-term ambition of a self-sustaining hydrogen market in the UK by 2050. The government set goals for the cost of hydrogen of 30 yen per normal cubic meter by 2030 and also for a hydrogen supply of three million tonnes per year by 2030 and 20 million tonnes in 2050. These goals are supported by interim targets and periodic policy reviews to ensure committed regulatory flexibility. The Hydrogen Society Promotion Act was passed as a regulation in 2024. Two major subsidy forms were formalised by this Act. The contracting side of the rationale: First, the CfD scheme, designed to bridge the price difference between low-carbon hydrogen and traditional hydrocarbon fuels for up to 15 years, enabling long-term price certainty and investment de-risking. Second, the Act provided for regionalisation, which encouraged the co-location of hydrogen production, storage, and end-use infrastructure. These laws are reinforced by tax credits, R&D grants, and capital subsidies. The government has pledged to spend 15 trillion yen ($138 billion) in public and private investment over 15 years toward achieving cost parity between hydrogen and fossil fuels and ensuring the country's technological dominance at home.

A key feature of Japan's hydrogen policy is its emphasis on public-private partnerships. The government has involved key industrial stakeholders, utilities, and research entities in the development of H_2 projects. To this end, some representative examples of the national program are demonstration projects of the MCH (Chiyoda Corporation) supply chain for hydrogen transportation from Brunei to Japan and a demonstration project of Smart City Kobe, where hydrogen is incorporated into the urban energy system. The Woven City initiative, which is spearheaded by Toyota and Eneos, is a model of how green hydrogen can be incorporated to power urban mobility and residential energy. These have been assisted by government funding and enabling legislation, which has included fast-tracking approval processes for demonstration plants and providing access to public land. Thus, the country has built one of the largest hydrogen-refuelling stations in the world, with the number of stations exceeding 130 in operation as of 2024, and the nation has become a world leader for fuel cell vehicle (FCV) deployment. But even with these accomplishments, the rate of infrastructure build-out has, in parts, fallen short of government aims, with operational issues, like station usage and supply chain reliability, presenting challenges. The description in Japanese highlights significant steps forward in Japan's hydrogen regulations, yet its regulatory landscape is not without significant obstacles. First, the issue of cost competitiveness becomes critical. The CfD system does offer a crucial underpinning to prices, but it also contains the potential for long-term subsistence from subsidy and, counterproductively, an impact on stem progression and cost reduction. The stipulation that projects must pay their own way after 15 years could add more uncertainty, not least with hydrogen markets evolving quickly worldwide and potentially disruptive technological leaps happening elsewhere. Second, technical and safety standards pose continuing legal barriers. The modification of conventional laws, including the High-Pressure Gas Safety Act, to apply it to hydrogen is difficult. Certification of new technologies can be expensive and uncertain, delaying commercialisation and increasing compliance costs. In addition, Japan's threshold for "low-carbon hydrogen" ($\leq$3.4 kg CO_2 per kg H_2) is less ambitious than the minimum European benchmarks, which tend to be less than 2.5 kg CO_2 per kg H_2. This inconsistency begs questions about the environmental integrity of subsidised projects and the potential of "greenwashing" as Japan maintains its focus on subsidising fossil-derived hydrogen with carbon capture and storage (CCS). Third, infrastructure and permitting are still in pieces. Although the Hydrogen Society Promotion Act was billed as a means to simplify that, local governments have a high degree of influence over land use and environmental signoffs, making hydrogen inconsistent in deployment. The lack of a national framework for permitting hydrogen pipelines and storage has been identified as a bottleneck to infrastructure expansion, causing delays and increased costs for developers. Fourth, the values of international cooperation and certification; Japan's hydrogen strategy is naturally international, involving imports from Australia, Brunei, and the Middle East [70]. This raises some difficult legal questions on the certification of vehicles crossing borders, on emissions balancing, and on the convergence of safety and environmental norms. The absence of internationally recognised certification systems for “green” or “blue” hydrogen has made it difficult to assure the environmental integrity of import ports and leaves Japan exposed to possible trade and reputational risks. Japan does participate in certain international standard-setting activities, but it has pursued regulatory policies that are less consistent with those of certain of its major trading partners, thus potentially creating market access and supply chain barriers.

3.6. Comparative Analysis of Other Major Jurisdictions

The world's hydrogen transition is a product of an array of legal frameworks and policy regimes, which are proxies for different political economies, stocks of energy, and a philosophy of regulation. This part offers a critical assessment of the hydrogen regulatory landscapes of China, South Korea, and Australia-three jurisdictions that present in stark relief varying legal models that invite further attention as to the promise and peril of hydrogen law and policy. The analysis views best practices, outstanding tensions, and lessons for international harmonisation of hydrogen governance through a comparative, evidence-based lens. China’s posture toward hydrogen is illustrative of the way it handles strategic industries more generally: through top-down planning, heavy investment, and the leveraging of state-owned enterprises (SOEs). The 2022 Plan, a Hydrogen Industry Development Plan (2021–2035) of the central government, was a turning point, as it ultimately incorporates hydrogen into China’s national energy and industrial strategies. The legal regime involves a mix of federal command and provincial innovation. The National Energy Administration and the Ministry of Industry and Information Technology provide broad guidance, but provinces such as Guangdong, Hebei, and Shanghai have unveiled their own roadmaps and pilot regulations that often go beyond national targets. That has led to a fast uptake of infrastructure, with more than 300 hydrogen refuelling stations constructed in China by 2024, the highest in the world. The level of SOE control of hydrogen production and of infrastructure can suppress competition and delay technology innovation, as demonstrated by the slower-than-expected pace of adoption for green hydrogen relative to that of fossil-based production with carbon capture. Also high is the legal uncertainty with hydrogen's classification (as a technical gas or storage) and with safety standards and cross-sectoral integration. In addition, the absence of a single, national low-carbon hydrogen certification system creates the potential for “greenwashing” (the practice of making unfounded or misleading claims about the environmental benefits of products) and complicates trade among countries. Case studies such as Sinopec’s green hydrogen project in the province of Xinjiang and the Zhangjiakou Hydrogen Industrial Park serve as an indication of the sheer magnitude and complexity of China’s strategy. These projects have certainly showcased the ability for rapid state mobilisation, but they also expose regulatory holes in emissions verification and long-term market survival.

South Korea introduced national regulations for hydrogen in 2019 and legislation for the hydrogen economy in 2020 to support the Hydrogen Economy Roadmap (2019), and the hydrogen economy promotion has adopted laws. These laws establish a strong legal foundation for producing, delivering, and using hydrogen and set basic environmental and entry standards. The government’s “Hydrogen Economy Master Plan” has targets of 81,000 fuel cell electric vehicles (FCEVs) and 310 hydrogen refuelling stations by 2025 and 5.26 million tonnes of annual hydrogen production by 2040. South Korea's system has been called a hybrid but is known for its focus on legal certainty and market incentives. The Act also requires hydrogen for public transport fleets and power generation, providing guaranteed demand and de-risking private investment. A key difference is the establishment of a hydrogen certification system that classifies "green," "blue," and "grey" hydrogen according to lifecycle emissions. This brings South Korea in line with international best practice and eases cross-border trade. The law also mandates stringent safety rules led by the Korea Gas Safety Corporation and simplified licensing procedures for hydrogen projects. Notwithstanding these accolades, thornier issues persist. The national hydrogen market is immature, and the high price of green hydrogen production suppresses the competitive power of green hydrogen. Detractors say the government's emphasis on blue hydrogen produced from natural gas with CCS would allow it to further drag its feet on the uptake of genuinely renewable hydrogen. In addition, the speed of change in regulation has, from time to time, been faster than the industry's ability to implement, resulting in implementation clogs. A case study on the introduction of Hyundai's FCV project and the Ulsan Hydrogen City project is also instructive. Both are illustrative of the power of legal clarity and focused incentives in facilitating deployment and of the need for continued adaptation even as underlying technologies and markets change.

Australia's approach to hydrogen is characterised by its market-based process and focus on export. The National Hydrogen Strategy (2019) supplies a malleable framework, with a focus on regulation alignment at federal, state, and territory levels. With its vast renewable resources and proximity to major Asian markets, Australia has set its sights on becoming one of the world's top suppliers of green hydrogen by 2030. The state and federal standards are a patchwork. At the federal level, funding for R&D, demonstration grants, and support for certification and development of standards sits alongside state plans and reforms, as with Western Australia, Queensland, and New South Wales' own hydrogen roadmaps. This fragmented system has allowed innovation to flourish, with more than 90 hydrogen projects announced or underway by 2024, between small pilot plants and large export hubs. Australia's comparative advantages are in regulation and its desire to harmonise with the international community. The government is also working on the creation of hydrogen certification schemes, including the issuance of guarantees of origin that monitor emissions along the hydrogen supply chain, and the certification would be aligned with European and Asian market requirements. That eases cross-border trade and gives credibility to exports of Australian hydrogen. Variations in authorisations, safety regulations, and environmental reviews can create uncertainty and slow the development of new projects from one jurisdiction to another. Industry has complained that there is no national hydrogen act or a single permitting regime to support infrastructure scaling. In addition, the strong export market acceptance in Australia could potentially lead to a failure to develop domestic demand at scale and to lose the chance for hydrogen to integrate into Australian industry and transport. A number of case studies, like the Hydrogen Energy Supply Chain project (HESC) in Victoria and the Asian Renewable Energy Hub in Western Australia, demonstrate the potential of, as well as the challenges associated with, Australia’s approach. These projects illustrate the potential for public-private partnerships and international cooperation, but also underscore the importance of clearer regulatory paths and stronger domestic market signals.

An analysis of China, South Korea, and Australia demonstrates divergence as well as convergence in terms of hydrogen law and policy. China’s top-down model allows for fast deployment but could suffocate competition and innovation; South Korea’s regulatory certainty and national certification help build market confidence but must reconcile the interests of blue and green hydrogen; Australia’s bottom-up approach looks to spark innovation and export readiness but faces regulatory divides and a lack of strong domestic demand. Several policy implications flow from this; legal certainty (from unambiguous and complete regulation to certification schemes) is an investment and an international trade enabler. The second point that needs to be realised is that regulatory agility and harmonisation across government levels are critical to handling technological change and market maturation. Third, adherence to global best practice increases credibility and access to markets, especially those driven by exports. And lastly, a balanced mix of subsidies and market incentives is required to ensure we do not end up with long-term dependence and that we establish a sustainable industry. With the development of the global hydrogen economy, the experiences of these jurisdictions (led by their adaptationism) demonstrate the value of legal frameworks that are flexible and capable of adapting to both domestic needs and international developments. These comparative insights should help inform the next generation of hydrogen regulation so that the law keeps pace with technological and market change.

3.7. Harmonisation of International Hydrogen Legal Frameworks

Challenges to standardising hydrogen regulation worldwide are substantial, including legal, technical, and political issues. One of the first issues is legal fragmentation, the reflection of national interests and energy dependency as a determinate foundation for regulation. For instance, those with large fossil-fuel reserves might prioritise transitional “blue hydrogen”, while others with ample renewables concentrate on “green hydrogen.” This variation makes the search for common definitions, certification schemes, and access to markets difficult, as illustrated by the different strategies taken by the EU, China, and the United States. Advanced economies may have the requirement for highly sustainable hydrogen production criteria, while in the rest of the world, a focus on fast industrialisation and energy access is prevalent. This policy heterogeneity is visible in the patchwork of hydrogen certification: China's hydrogen specifications, the EU's RFNBO specs, California's LCFS, all have various requirements for emissions, verification, reporting, etc [71],[72],[73]. Such inconsistencies hinder international trade, drive up compliance costs, and pose the risk of fragmentation in the market. Another major obstacle is safety and environmental conditions. Inconsistencies in the material of pipelines, the storage procedures, and the accounting of emissions can hamper the inter-regional flow of hydrogen and its derivatives. The launch of ISO/TS 19870 at COP28 in 2023 was one vital step towards the adoption of a commonly agreed-upon methodology for assessing the greenhouse gas (GHG) footprint of hydrogen throughout its life cycle [29],[74]. Lack of anything close to uniform standards also raises the risk of accidents, leakages, damage to the environment, loss of investor confidence, and public trust issues.

Pushing through hydrogen projects in the name of the overriding public interest, as seen in the EU approach in some cases, can lead to the marginalisation of certain groups and to opposition at a local level that can set back, not speed up, project delivery. One-size-fits-all public engagement is inadequate to support all affected communities, making harmonisation commensurately more challenging. Trade law concerns, particularly relating to the World Trade Organisation's (WTO) non-discrimination rules and the TBT Agreement, also make the equation more complicated. Measures incentivising green hydrogen produced domestically relative to imported green hydrogen may contradict WTO obligations, and, given the lack of established practice in this area, a legal foggy cloud remains for both investors and policymakers to navigate. With all these difficulties, much headway is being made through ensuring international and multilateral actions. Leading this trend are the International

Organisation for Standardisation (ISO), International Renewable Energy Agency (IRENA), and International Energy Agency (IEA), which develop common frameworks and modelling. The ISO/TS 19870 standard establishes a universally accepted method for calculating the GHG footprint of hydrogen, enabling transparency and comparison across jurisdictions. Likewise, IRENA's approach to certification governance and cooperative frameworks for certification is seeking to harmonise national schemes and support mutual recognition, a key condition for effective international trade. Bilateral and multilateral pacts have also been important. The EU-China Clean Energy Cooperation Platform and the Clean Energy Ministerial Hydrogen Initiative are good examples of actions to address regulatory barriers and promote technical cooperation. Such agreements typically work towards the harmonisation of definitions, certification criteria, and infrastructure standards, in addition to mechanisms for exchanging best practices in terms of safety and environmental management. The PoS of the EU and the third-party annual certification audits of China, for instance, are oriented to guarantee that hydrogen traded internationally fulfils the agreed environmental and quality standards. At the trade law level, the General Agreement on Tariffs and Trade (GATT)'s TBT Agreement constitutes the core legal infrastructure for non-discrimination under and the use of international standards. But how these principles apply to hydrogen has yet to be tested, and future disputes are sure to centre on the compatibility of national incentives and local content requirements with WTO rules. Not only will the way forward involve technical standardisation, but political consensus is also necessary on fundamentals, including how to define "green hydrogen," the scope of certification, and the trade-off between strictness and flexibility. National regulators are encouraged to harmonise their domestic frameworks with existing international standards, taking into account regional specificities (e.g., regarding resource and socio-economic contexts). The harmonisation of hydrogen law will be indispensable for their development and for the establishment of a transparent, efficient, and durable worldwide hydrogen market.

3.8. Conclusion

This chapter has discussed the developing legal structures related to the global hydrogen economy and identified a great deal of progress as well as ongoing challenges in major jurisdictions. One of the key points revealed is the variety of national approaches to hydrogen: the US, Japan, the EU, China, South Korea, and Australia have each adopted and are pursuing hydrogen regulation set out in separate legal instruments, types of funding, or strategic planning. Those models are represented respectively by the United States, which builds on federal incentives and experimentation at the state level; Japan, characterised by long-term state planning and cooperation between public and private actors; and the European Union, which promotes harmonisation through supranational directives and programmes of certification. China's state-led growth, South Korea's legislative clarity, and Australia's market-led innovation are similarly representative of the range of regulatory approaches. Despite these, some common global legal trends can be identified. Firstly, the momentum for the institutionalisation of hydrogen as a strategic component of national energy and climate policy is palpable, with almost all jurisdictions establishing lofty (if not flyer-friendly) targets for production, infrastructure, and reduction of emissions. Second, governments are also turning to a combination of direct subsidies, tax breaks, and funding for and procurement of R&D to drive both supply and demand. Third, because there is an increasing focus on environmental integrity and on transparency of the marketplace, the number of certification schemes and lifecycle emissions standards has exploded.

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