Self-Regulation and Innovation

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**Abstract**: Self-regulation—governance of firm behavior by private entities—has a long history both in the United States and globally, and there is an extensive literature on the topic. But there has been far less attention paid to the role self-regulation can play in spurring and enabling innovation and growth within emerging industries. These industries—both currently emerging ones such as hydrogen and artificial intelligence, as well as formerly new (but now well established) activities in hydraulic fracturing and Internet communications—plausibly benefit from self-regulation’s ability to coordinate economic actors and reassure often skeptical publics. Examining the ways that self-regulation impacts this special type of industry is important both to expand the self-regulation literature to account for an explosion of innovative industries in recent years and to strengthen the innovation literature, which explores how other factors, such as intellectual property rights and public incentives, spur or stifle innovation.

Relying on a comprehensive analysis of existing literature and our own case studies, we identify the attributes of a self-regulatory regimes that seem to support innovation and the scaling up of operations. Our case studies show that innovative, emerging industries rely on self-regulation to provide an important balance of certainty and flexibility; fill substantive and jurisdictional regulatory gaps as industries emerge; provide healthy competition among standards to produce effective and efficient standards; and simultaneously produce standards within multiple components of a networked. We also show that the best self-regulatory regimes are complemented by public governance, since pure self-regulation can leave substantive gaps and pose risks of capture and anti-competitive behavior that can lead to more heavy-handed public regulation or reputational crises. Overall, our research draws attention to the need for careful coordination of a public-private standards strategy for the many industries we will need to solve many of the world’s problems.

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# Introduction

The concept of industry self-regulation is nearly as old as industry itself. We know, for instance, that early guilds of merchants and craftsmen set and enforced quality and trading standards to maintain the reputation and integrity of their goods.[[3]](#footnote-3) And despite the more recent expansion of governmental regulation, self-regulation remains a core legal and regulatory mechanism in our society.[[4]](#footnote-4) Most importantly for our purposes here, it has also proven critical in emerging industries, particularly those involving innovative and complex technologies that rely on network effects and create coordination challenges,[[5]](#footnote-5) though this function of self-regulation has been underexplored.

In this Article, we study several of these emerging industries—the nascent hydrogen industry, the historical development of the Internet, the early days of hydraulic fracturing for oil and gas, and the burgeoning artificial intelligence field—in order to shed light on the theory of self-regulation and how it applies in the context of especially technical, networked, and urgently needed emergent industries. We examine how self-regulation, in concert with some degree of public regulation, can contribute to the growth and success of these industries while ensuring that the public is protected from potential harms. Through this analysis, we expand the self-regulation literature to explicitly address innovation; connect the innovation literature with self-regulation theory; and more fully examine the interaction between public and private standards, particularly within emerging industries.

In focusing on self-regulation and innovation, we bring together two literatures—the self-regulation and innovation literatures—that are usually siloed from each other.[[6]](#footnote-6) There is a robust literature exploring the conditions under which effective self-regulation is likely to emerge and be effective,[[7]](#footnote-7) and the relationship between self-regulatory standards and public (“meta”) regulation.[[8]](#footnote-8) There is also a growing literature on the value of self-regulation in the environmental and energy contexts.[[9]](#footnote-9) These literatures pose the question of the suitability and effectiveness of self-regulation often in the context of well-established industries such as the chemical manufacturing industry, and there has been inadequate discussion of the extent to which self-regulation enables innovation and coordination (as well as risk mitigation) within *nascent* industries. Another literature explores the possible value of regulatory uncertainty within nascent technological areas, but primarily with a focus on public regulation and private law, not on self-regulation.[[10]](#footnote-10) And a large innovation literature explores the drivers of nascent industry but tends to give short shrift—if any attention—to how regulation (whether public or private) can complement these drivers.[[11]](#footnote-11)

Building on self-regulation and innovation theory and drawing lessons from case studies, we argue that a combination of private and public regulation seems to be a critical driver of such emerging industries, with self-regulation sometimes playing the leading role. This is likely to be particularly true for networked industries with multiple components that require coordination—in other words, the dominant type of firm in today’s economy.[[12]](#footnote-12) Our case studies suggest that public regulatory institutions can spur the development of industry standards, help to address conflicts among competing industry standards, and fill in gaps in standards in order to support emerging industries. The layering of public governance atop private standards is also important for the more traditional reasons explored in the literature on “meta-regulation” of SSOs and SROs, as self-regulation can raise concerns about capture and anti-competitive behavior.[[13]](#footnote-13) In some cases the need for government intervention to overcome coordination problems and to address externalities may become so acute that self-regulation needs to give way to exclusive public governance. But our examination of emerging industries convinces us that self-regulation often must play a meaningful role, with careful attention paid to the level of public standards needed to further support innovation and to address long-known challenges of self-regulation.

Through case studies of the trajectory of self-regulation in nascent and once-nascent industries, we aim to provide new insights into the role that self-regulation, complemented by public governance, can and ought to play in enabling innovation and coordinated scaling in emerging industries. We also emphasize potential challenges of relying on self-regulation in these domains and the need for careful design to construct a glide path for both industry and more traditional, public governance to take the reins.

This Article unfolds as follows. Part I of the Article explores the history of U.S. self-regulatory regimes. Part II analyzes at the level of theory the conditions that likely tend to support self-regulation, the contexts in which self-regulation may be the most effective, the extent to which self-regulation can enhance or impede firm performance (including firms in emerging, networked industrial sectors), and the optimal balance of public and private standards. Part III is the core of the Article: an empirical investigation of how private standard setting and self-regulation is developing (in the case of hydrogen and learning language models (LLMs)) or has developed (in the case of other areas, such as the Internet and hydraulic fracturing). We ask and answer questions about how well the theory outlined in Part II matches the reality: that is, how the various standard-setting efforts have been coordinated (or not), how effective the standards seem to have been at resolving the primary risks and technical issues presented by emerging industries, and what can be done to spur a dynamic relationship between industry self-regulation and innovation through public and private standards. Part IV then offers a synthesis and insights for those thinking about the role of self-regulation in all emerging industries and how self-regulation, alongside public governance, might best spur and support innovation.

## The Role of Self-Regulation in the United States

Much regulation in the United States involves a government entity issuing commands and imposing consequences on private firms or individuals. Regulation is in fact a much larger concept, however, and “encompasses a much broader array of pressures and policies deployed by a variety of actors, both governmental and nongovernmental, to shape the behavior of firms and thereby address market failures and other public problems.”[[14]](#footnote-14) One deviation from the paradigmatic case of command-and-control regulation is self-regulation, which “refers to any system of regulation in which the regulatory target—either at the individual-firm level or sometimes through an industry association that represents targets—imposes commands and consequences upon itself.”[[15]](#footnote-15) Self-regulation is, in practice, extremely diverse, but it is commonly conducted through industry-wide trade associations and SSOs, such as the American National Standards Institute (ANSI), the American Society for Testing and Materials (ASTM), and the American Society for Mechanical Engineers (ASME).[[16]](#footnote-16) Increasingly, SSOs like the International Organization for Standardization (ISO) play an important role in harmonizing business practices across international boundaries.[[17]](#footnote-17) SROs, too—organizations formed by associations firms to both write and enforce standards for those firms—are similarly common, as explored here, with prominent examples from the financial, energy, and computing sectors.[[18]](#footnote-18) Indeed, self-regulation by SSOs and SROs is pervasive, providing critical guidance in sectors ranging from aerospace to consumer products, cannabis, and construction and manufacturing.[[19]](#footnote-19)

Self-regulation has a long and storied history in the United States, and it is poised to become even more important in the coming decades as the need for regulation, particularly in critical, highly technical areas with coordination challenges, outpaces government’s ability to provide it. One of the more storied (and studied) loci for self-regulation is the financial sector.[[20]](#footnote-20) Historically, much of the securities industry has been regulated by two familiar private organizations—the New York Stock Exchange (NYSE) and the (private) Financial Industry Regulatory Authority (FINRA)—that are loosely overseen by the U.S. Securities and Exchange Commission.[[21]](#footnote-21) FinTech—the practice of using technology in the financial sector—is borrowing this model and applying it to new financial services to “increase investor protection and enhance the reputation of the industry.”[[22]](#footnote-22) The cannabis industry, too, relies extensively on self-regulation, in part due to federal jurisdictional limits—even hostility—as we discuss below.[[23]](#footnote-23) Highly technical industries, such as those involving construction, writing, and fire protection for commercial, industrial, and residential buildings, are replete with private standards, many of which are adopted within and sometimes modified by state and municipal codes.[[24]](#footnote-24)

Also worth noting is the substantial amount of self-regulation in the environmental space as a complement to relatively comprehensive public governance.[[25]](#footnote-25) For instance, chemical manufacturers, under the leadership of the Chemical Manufacturers Association, helped institute a program called “Responsible Care” that created “practice codes” to help firms set voluntary performance standards for hazardous chemicals management.[[26]](#footnote-26) A variety of non-governmental organizations have also helped to spearhead industry self-regulation in sustainable forestry and fishing practices.[[27]](#footnote-27) And much of what Vandenbergh and Gilligan refer to as “private environmental governance,” such as eco-labeling, is an example of self-regulation in response to the threat of climate change and other environmental threats.[[28]](#footnote-28)

The energy sector, too, has long relied on industry self-regulation, perhaps in large part due to the technical complexity of many issues that arise in the industry. The argument in favor of self-regulation in highly technical contexts is that the self-regulator possesses “superior knowledge of the subject compared to the government agency.”[[29]](#footnote-29) Most famously, nuclear power producers turned to self-regulation in the wake of the Three Mile Island near-disaster in 1979, creating the Institute of Nuclear Power Operations (INPO) to manage a performance regulation regime for nuclear safety.[[30]](#footnote-30) Less well known are the private “grid regulators” that ensure that electric power is reliable and affordable. The North American Electricity Reliability Corporation (NERC) helps set standards for reliability and resilience of grid infrastructure, along with reliability standards from the private North American Energy Standards Board.[[31]](#footnote-31) A meta-regulator, the Federal Energy Regulatory Commission, oversees NERC’s standard-setting and enforcement, with a health dose of deference to NERC and private sub-entities of NERC called Regional Entities that do much of the organization’s work.[[32]](#footnote-32) Additionally, private Regional Transmission Organizations (RTOs) govern electric transmission systems and manage markets for wholesale energy on a regional basis, also with (deferential) FERC oversight.[[33]](#footnote-33)

Beyond electricity, in the oil and gas production and transportation context, American Petroleum Institute (API) standards—more than 700 of them—govern well construction, drilling, and hydraulic fracturing (now applied to nearly all U.S. gas wells); pipeline and distribution line design and operation; and technologies and practices for waste handling and disposal, covering most components of the oil and gas supply chain.[[34]](#footnote-34) Federal and state regulators have incorporated many of these standards directly into public governance.[[35]](#footnote-35)

The emerging hydrogen sector—a critical sector to address climate change, and one that we also investigate in this Article—will likely be no exception to this history of self-regulation in the energy sector. Hydrogen is a fuel produced from natural gas or water that can be stored in tanks or underground and transported by truck, barge, or pipeline for industrial, commercial, and residential uses. With proper modifications and safety precautions, hydrogen can be burned or used in lieu of natural gas and other fuels in a residential stove or furnace, industrial boiler or process, or power plant. Already, major gaps are apparent in existing government regulatory programs designed to address problems in other energy subsectors. For instance, while the Pipeline and Hazardous Materials Safety Administration (PHMSA) has promulgated a trove of safety standards for the construction of pipelines for many hazardous substances, such as natural gas, it has yet to classify hydrogen as a hazardous substance and would, in any event, need to substantially change existing standards to respond to the unique challenges created by hydrogen pipelines with respect to flammability. For the same reasons, the emerging hydrogen industry cannot simply repurpose the many private standards that exist for other subsectors of the energy industry. Additionally, there are no federal provisions indicating whether the federal government or states will permit interstate hydrogen pipelines or import and export terminals, making it difficult to coordinate the infrastructure buildout necessary to scale the industry.[[36]](#footnote-36)

Another somewhat nascent but rapidly-evolving industry investigated here—artificial intelligence, and particularly open large language model artificial intelligence such as ChatGPT—is primarily self-regulated through an SRO called the Frontier Model Forum, formally launched in July 2023 by the major OpenAI firms.[[37]](#footnote-37) This Forum researches AI safety, identifies “best practices and standards,” and is designed to support “information sharing among policymakers and industry.”[[38]](#footnote-38)

We could go on, but the basic point is clear by now: self-regulation plays a major role in the U.S. economy, and indeed in the world economy. As part of a core suite of “flexible” regulatory tools,[[39]](#footnote-39) self-regulation has been a key part of a broader societal turn away from state-centered regulation and towards what some have called “responsive regulation”[[40]](#footnote-40) and “collaborative regulatory governance,”[[41]](#footnote-41) which includes regulatory action, norm-building, and collaboration by a variety of non-state actors. Much of the impetus for self-regulation undoubtedly came from an impulse to deregulate, or at least to dilute the state’s control over regulation. While this legacy is important to appreciate as a historical matter of how we got here, it is also important to realize that self-regulation is now how much regulation is done, and that the original motivation for self-regulation need not correspond neatly with self-regulation’s actual effects. In the next Part, we suggest that a major function of self-regulation, whether intended or not, is the fostering of the conditions that enable innovation in emerging industries.

## Self-Regulation in Emerging Industries

The long history of self-regulation, both in the United States and globally, has produced many lessons on the conditions that have tended to produce successful self-regulatory regimes and why self-regulation worked well in these contexts. Alongside a hefty literature on these topics, this history has also produced important information about the proper degree and type of meta-regulation—the layering of public governance atop private standards, But there is a substantial gap in knowledge around innovation, self-regulation, and new industries. This Part analyzes existing knowledge on both successful and failed self-regulatory approaches, fleshes out a theory of complementary public and self-regulation within nascent economies, and identifies theoretical and empirical gaps that remain to be filled.

### A. General Factors that Support Successful Self-Regulatory Regimes

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Self-regulation emerges for a variety of reasons, and its effectiveness depends on an equally varied array of factors, as the literature has explored in depth (typically for established industries). The literature links drivers of self-regulation to pressures such as “non-legal interventions like social movement activism,”[[42]](#footnote-42) a desire to boost the reputation of an industry,[[43]](#footnote-43) attempted avoidance of potential legal liabilities or the threat of more heavy-handed government regulation,[[44]](#footnote-44) or a combination of these forces.[[45]](#footnote-45) In addition, self-regulation might be a desirable arrangement for government regulators, who may lack the necessary expertise or resources to run a successful regulatory program themselves,[[46]](#footnote-46) or who may see self-regulation as a pragmatic style of iterative, flexible regulatory governance.[[47]](#footnote-47) If self-regulation works—i.e., if the standards address risks and externalities efficiently and effectively and are enforced—they can offer many benefits. Proponents of self-regulation often tout the “responsiveness” and “reflexivity” of self-regulation as an alternative to traditional models of regulation.[[48]](#footnote-48) Finally, particularly when it is paired with standardization, self-regulation can provide a stable platform for innovation, although, as we will discuss, this rationale for self-regulation is perhaps the most undertheorized.[[49]](#footnote-49)

Despite its potential benefits, self-regulation does not always succeed. Studies of the chemical industry’s Responsible Care program suggest that it “largely failed, at least in its early years and at least when measured in terms of reducing members’ toxic emissions.”[[50]](#footnote-50) Indeed, a more recent study of Responsible Care found that plants that participated in the program emitted 15.9 percent more toxic pollution than similar non-participating plants.[[51]](#footnote-51) Naturally, the question arises: Why does self-regulation sometimes work and sometimes not work? On one account, firms develop and join self-regulatory frameworks for their symbolic value and often lack economic incentives to actually change behavior or “raise the bar” above a perfect convergence between self-regulation and managerial objectives.[[52]](#footnote-52) Against this conclusion, some research finds that “the institutional structure that accompanies self-regulation can control behavior through more informal coercive, normative, and mimetic means.”[[53]](#footnote-53) These more informal pressures can, in theory, motivate firms to engage in meaningful self-regulation. However, “[r]esearch has shown that organizations will not reliably self-regulate without the pressure of deterrence.”[[54]](#footnote-54)

While these firm-level studies focus largely on incentives and institutions, it is also the case that characteristics of the regulated industry can greatly impact self-regulatory governance independent of these other variables. One strand of the literature examines the firm attributes that must be present to incentivize self-enforcement by firms, observing that self-regulation is likely to be more effective with smaller, more tightly-knit industries that can easily police bad apple firms who might wish to free-ride on the reputational benefits of private standards without actually complying with them.[[55]](#footnote-55) Again, the Responsible Care program is instructive. Several studies conclude that one reason Responsible Care was less successful than other comparable programs, such as INPO, is that it attempted to coordinate self-regulation across a highly heterogeneous group of firms, some of which had incentives to free ride on the program’s reputational benefits while not actually making meaningful changes to practices.[[56]](#footnote-56) By contrast, INPO involved a “much smaller and more homogeneous” set of firms, which gave “individual firms more of a common interest” and gave industry leaders more power to “rein in potential outlier firms.”[[57]](#footnote-57) As with any collective action problem, the degree to which individual actors have divergent preferences, the more difficult the achievement of a coordinated self-regulatory strategy is likely to be.[[58]](#footnote-58) It is still possible for intra-firm self-regulation to take its place, but these programs are more apt to be scattershot and to fail to drive meaningful behavioral change due to the lack of group pressure.

The deficiencies of self-regulation cannot always be solved internally—say, by tightening lines of communication or connection in an association of firms to address collective action and free-riding. In these cases, the addition of public governance through meta-regulation is often needed. A large literature explores the art of balancing private and public involvement in standard-setting. Saule Omarova categorizes a variety of forms of public involvement in the self-regulatory project, such as “sanctioned” self-regulation, in which government actors must approve private rules; “mandated” self-regulation in which government requires self-regulation; and “co-regulation,” in which “public agencies and private market actors cooperate in the creation, implementation, and enforcement of rules.”[[59]](#footnote-59) In the financial context, James Fanto observes that some types of meta-regulation—such as a proposed public Financial Service Oversight Council assigned to project and prevent risks in the financial industry—might simply reinforce a particular form of top-heavy institution that is unable to accurately predict and respond to risks, whether it is private or public.[[60]](#footnote-60)

### B. The Distinctive Opportunities and Challenges of Self-Regulation in Emerging Industries

Much of the existing literature on self-regulation reviewed in Part II.A. is cast at a general level. The question typically addressed within this literature is when self-regulation will occur and when it will be successful across a wide range of firms. Due to this focus on generalizable theories, the literature so far has missed some of the distinct questions that arise around self-regulation in emerging industries, where there is a premium on innovation and flexibility, as well as potential network and coordination benefits of self-regulation for scaling up operations. There is a push for self-regulation in specific emerging industries such as the peer-to-peer sharing economy[[61]](#footnote-61) and in FinTech “regulatory sandboxes”[[62]](#footnote-62) where space for innovation is highly prized. Yet these movements are only beginning to generate theory and evidence in support of a broadly applicable theory of self-regulation in emerging industries. There is a need for more careful thinking about the specific opportunities and challenges of self-regulation in emerging industries,. Simply put, self-regulation is likely to play a very different role in industries that are poised to grow substantially than in industries that resort to self-regulation to solve a reputational or legal risk problem. This moves us beyond questions of the effectiveness of self-regulation (such as whether it serves as mere window dressing or a more genuine deterrent to risky industry behavior) to fundamental issues involving the circumstances under which self-regulation is likely to play a fundamental role in supporting industrial development while effectively addressing risks and public concerns associated with such development.

For an emerging industry, it can be difficult if not impossible to spur government institutions to be proactive about supplying needed regulation. The hydrogen industry is a case in point: despite consensus-based calls for more federal regulatory action to fill gaps in existing regulations created by new hydrogen technologies and practices,[[63]](#footnote-63) the federal government has shown limited initiative in taking on even relatively uncontroversial regulatory updates. The combination of scarce resources for regulatory housekeeping and the fact that the hydrogen industry is still in the cradle make it highly unlikely that the federal government will prioritize regulation in this area. Innovation-focused entities such as the National Renewable Energy Laboratory, Argonne National Laboratory, and Sandia National Laboratories have highlighted regulatory progress and gaps, summarized existing standards and regulations, and directly supported efforts to write gap-filling regulations.[[64]](#footnote-64) Yet agencies, such as the Federal Energy Regulatory Commission (FERC) and PHMSA— which control the fundamental regulations in other, more established subsectors of the energy economy—have made few, if any, meaningful changes to adapt existing frameworks to hydrogen.

And even if the federal government were to provide regulatory gap-fillers for the hydrogen industry, it is not necessarily clear that these gap-fillers would be preferable to a more organic convergence on coordinated industry standards. Self-regulation, with its built-in focus on efficient, responsive, flexible, comprehensive, and coordinated regulation, may be better suited for industries that are in rapid stages of evolution and learning. Self-regulatory standards can, in other words, strike a delicate balance between regulatory certainty and flexibility–a particularly important feature for emerging industries in which regulatory learning and updating are key. Likewise, self-regulation might present greater opportunities for more bottom-up competition over standards than a more top-down public governance approach would allow. Furthermore, for industries such as hydrogen that produce complex coordination challenges, private actors—particularly SSOs that take a birds-eye view on all facets of an industry, from production through distribution—tend to produce the type of coordinated standards that help to guide all components of an industry forward at the same time. For example, ASTM International, in promoting its comprehensive private cannabis standards, boasts a “360-degree approach” to regulating and supporting the expanding industry.[[65]](#footnote-65)

This is not to say that public standards should play no role in emerging industries, however. Just as meta-regulation is sometimes needed to address the collective action or free-riding problems associated with industry self-governance, government involvement can address these problems and even spur innovation in the context of emerging industries. But it is to say that self-regulation may be uniquely well suited to emerging industries, and that the advantages it creates in this domain are worthy of greater attention. In what follows, we highlight and categorize structural advantages like these that can make self-regulation particularly attractive at the early stages of a needed industry’s development, and we explore the complementary role of public governance.

1. Competition in Standard Setting

 One question that is decidedly present in the context of emerging industries is competition for self-regulatory primacy. This trend stands in stark contrast with many established industries, which often already have trade associations or other networks that can supply top-down standards that cover the entire industry.[[66]](#footnote-66) With emerging industries, it will often be the case that there are many potential private standards. In some cases there are too many standards, and this drives the formation of an SSO or SRO, or public intervention. Take the example of standards for fitting fire hoses to fire hydrants—of which there were more than 600 in 1914, leading to collaboration between the National Fire Protection Association and U.S. National Institute of Standards and Technology to form a national standard.[[67]](#footnote-67) Even when too many standards generate problems—such as the Great Baltimore Fire of 1904, in which hoses did not fit to fire hydrants—the top down organization that addresses these problems and creates a uniform standard has a diverse range of examples to draw from in this case, potentially generating a more effective and efficient standard.

Standards-based competition—as with public regulatory competition in federalist or decentralized governance systems[[68]](#footnote-68)—could generate more effective, efficient controls that best address the diverse needs of regulated entities, and perhaps even more so than in the public context. Indeed, for better or worse, competitive self-regulation sometimes fills a space that would otherwise be occupied by states competing to attract industry or residents through beneficial regulatory diversity.[[69]](#footnote-69) The literature on inter-jurisdictional regulatory competition (public or private) suggests that although there may sometimes be a “race to the bottom” in terms of regulatory stringency and efficacy, this is highly context dependent.[[70]](#footnote-70) In some cases, interjurisdictional regulatory competition, by creating a market for “locational rights,” leads to a “race to the top.”[[71]](#footnote-71) That is, if people demand quality regulation and are able to vote with their feet by relocating to a different jurisdiction that better matches their preferences, theory suggests we should end up with regulation that is welfare enhancing.[[72]](#footnote-72)

There are good reasons to think that the benefits of regulatory competition are more likely to accrue in the context of competition for self-regulatory primacy than in the classic case of interjurisdictional governmental competition. To the extent that incentives for self-regulation exist at all, choice among potential SSOs and SROs presents a far more realistic version of “foot-voting” for rules than does Tiebout’s public governance example, in which residents shop by moving to packages of local government goods, services, and taxes that best meet their needs.[[73]](#footnote-73) One of Tiebout’s core assumptions was that voters are mobile and can express preferences through exit and entry. But voters are often tied to jobs, family, mortgages, or other localized obligations that make moving quite difficult. Self-regulatory standards, unlike public rules promulgated by municipalities, remain unburdened by artificial jurisdictional lines. Private standard-setting bodies and SROs can and often do offer their standards to any relevant subscriber or qualifying member—namely, any industrial actor on the globe that fits within the technical confines of the industry subject to the standards. This makes locational mobility of the regulated actor a non-issue.[[74]](#footnote-74)

Beyond mobility, Tiebout’s assumption that foot voters are knowledgeable about the different governance options may be truer in the self-regulatory setting, where actors are relatively sophisticated and might actively research and shop for private standards in an effort to appease potential investors and consumers, or, perhaps, avoid threats of overly stringent public governance. In fact, the limited empirical evidence that does exist about competition over self-regulatory governance, drawn from the self-regulation of the Internet of Things field, suggests that potential subscribers to competing SSOs are savvy shoppers. Potential subscribers, the data show, choose SSOs that provide a “broad membership base” and “low costs and fast development” of standards.[[75]](#footnote-75)

Finally, while those building from Tiebout’s work tend to assume (often incorrectly) that public governments meaningfully and methodically experiment with different policies,[[76]](#footnote-76) private standard setting organizations often *do* engage in more purposeful experimentation with standards and assessment of their efficacy, in part to advertise results to firms that might subscribe to the standards. Indeed, as we explore in Part III, many members of the hydrogen industry are developing their own standards and associated technical experiments designed to test and demonstrate the efficacy of various standards.

To be sure, there are some assumptions that may remain unmet in standards-based competition. For example, Tiebout assumed that no economies or diseconomies were shared among communities, whereas local governments’ regulations regularly have positive and negative spillover effects. The same is true for private standard setting. Although standards can be proprietary and more easily limited to subscribers, their benefits—such as creating overall investor confidence in a subset of actors within an emerging economy—cannot be easily cabined. Furthermore, some broader assumptions of regulatory experimentation remain unrealistic in both the private and public contexts, including, for example, the questionable assumption that those designing and enforcing a governing regime will honestly measure and share negative results in addition to positive ones.[[77]](#footnote-77) Nevertheless, there are reasons to believe that competition for self-regulation in emerging industries is a feature, not a bug, and one that would necessarily be forfeited if public regulation were to intervene too quickly.

1. Striking a Critical Balance Between Regulatory Flexibility and Certainty: Substance and Jurisdiction

Industry actors and investors frequently cite the importance of regulatory certainty or predictability, arguing that without clear, relatively durable guiding standards it is difficult to attract adequate investment or make large capital outlays. Industry actors do not want to invest in capital and procedures for compliance only to find these investments obsolete within several months or years. For emerging industries in which jurisdictional authority is often unclear (federal versus state control, for example), clarity as to *who* will regulate also plays an important role.

 Some degree of regulatory certainty is therefore particularly critical for emerging industries, which need large initial investments to undertake the expensive and risky endeavor of building a network of infrastructure from scratch. Yet as scholars in the energy sphere have observed, there are many types of regulatory certainty, and in fact some degree of uncertaintyor vagueness can create flexibility, which is also essential for emerging industries, particularly those at an early technological development stage, to allow them to experiment.[[78]](#footnote-78) As such, the special situation of emerging industries like hydrogen or AI creates a need for a “Goldilocks” approach to the balance between certainty and uncertainty. Here again, self-regulation can be better suited to find this balance.

a. Substantive Clarity and Risk Mitigation

Regulatory uncertainty often means that there simply are not many (or any) regulations on the books guiding a particular industry—thus making it unclear whether the industry will be permitted or banned or how and whether it will be regulated. This poses problems for the public—in the form of potentially unmitigated risks—and for industry, in the form of uncertainty and concerns about a high-profile negative event that will stifle further development of the industry.

Regulatory uncertainty arises in several different ways—sometimes through a lack of any regulation—posing a question of when and to what extent an emerging industry will be regulated, if at all—and most commonly through the limited application of existing regulations to a new industry. For hydraulic fracturing, for example, one environmental group persuaded the federal Eleventh Circuit to hold that the Safe Drinking Water Act—which requires regulatory approval prior to the injection of substances underground—applied to hydraulic fracturing. (Congress later exempted hydraulic fracturing from the Act.[[79]](#footnote-79)) For AI, there are large grey areas of regulation, with some existing public standards applying in only a limited way (such as Federal Trade Commission rules).[[80]](#footnote-80)

Regulatory uncertainty of all types involves a climate in which new rules might emerge once an industry is developed—presenting a potentially drawn-out legislative or regulatory process and the risk (to industry) of stringent, costly regulation in the future. For the public, there are concerns that the regulation will be inadequate to address risk, or, if there is high demand for the emerging product, that it will stifle innovation.

For this type of substantive uncertainty—the question of whether the industry will be regulated at all, or banned, and *how* it will be regulated—self-regulatory standards can play an important role. These standards can fill in gaps and produce a somewhat predictable path forward for the industry. For the many types of regulations in which omissions are not a ban, the lack of any public regulation threatens to produce a regulatory “wild west” scenario, in which industry proceeds with no regulation. This, in turn, can produce negative effects and understandably alarm residents near or those affected by the emerging industry (not to mention risk-conscious investors) and can trigger moratoria and bans. A clear set of self-regulatory standards that are consistently enforced can alleviate a regulatory void, address emerging risks, and potentially avoid the drastic public remedy of a ban. Indeed, particularly in the early stages of an industry, the industry actors themselves likely have superior knowledge of risks as compared to officials.[[81]](#footnote-81) And if public regulation eventually emerges, it often incorporates some of the self-regulatory standards already in place, thereby avoiding dramatic substantive changes.[[82]](#footnote-82)

This very progression occurred within the oil and gas industry, for which there were few state-specific environmental regulations of the oil and gas industry before a new type of hydraulic fracturing dramatically expanded in the mid-2000s, causing production to boom.[[83]](#footnote-83) A number of local governments with non-existent or sparse oil and gas ordinances, and certainly no comprehensive regulations specific to hydraulic fracturing, reacted with moratoria and bans.[[84]](#footnote-84) Others allowed the development to proceed and eventually incorporated a substantial number of the API standards that industry already followed, such as regulation of the safe construction of wells to prevent leakage of pollution underground; standards for property design and operation of waste impoundments; and preferred technologies that prevent dangerous well explosions during drilling and hydraulic fracturing.[[85]](#footnote-85) With many of the outright bans and moratoria facing trouble in court, the private API standards approach quickly became the standard. But without the standards in place, the regulatory vacuum that might have existed would likely have changed the dynamics of how courts and other policymakers viewed heavy-handed, precautionary regulation.

As we will discuss in more detail in Part III, a great deal of substantive regulatory gap-filling of this sort already appears to be occurring in the hydrogen context. The industry recognized the lack of a clear standard for the safety of hydrogen pipelines as an impediment to growth as early as 2007, when the American Society of Mechanical Engineers was in the process of developing consensus standards for such pipelines. As the president of ASME’s technical branch noted in 2009, although the “traditional approach to standardization has included writing prescriptive standards only after technology is fully established and after commercialization has been completed,” a “lack of standards in a particular area can actually create a barrier to commercialization.”[[86]](#footnote-86)

Similar concerns abound for the artificial intelligence industry, which is very aware of the risks posed by its technology and the harm that could ensue (in addition to, potentially, more heavy-handed regulation than the industry would prefer). In addition to launching an SRO in July 2023 to address these risks, the chief executive of OpenAI testified before Congress in May 2023, acknowledging that the technology could do “significant harm to the world” and supporting government oversight.[[87]](#footnote-87)

1. Stable Jurisdictional Control

Beyond substantive omissions or a lack of clarity, another type of regulatory uncertainty is jurisdictional, involving the serious issue of which level or levels of government will regulate and whether an industry will be subject to conflicting regulatory regimes at different levels.[[88]](#footnote-88) This type of uncertainty can in some cases be beneficial—e.g., by allowing the emerging industry to experiment in a variety of locations without a national standard that has incorrectly predicted the risks. This jurisdictional openness can support the same type of experimentation with standards discussed in Part B.1.A., which can again produce effective, responsive, and efficient rules.[[89]](#footnote-89) But jurisdictional uncertainty, in particular, as opposed to a mere substantive diversity of standards as an industry emerges, can also pose a formidable obstacle. The emerging cannabis industry is a case in point. As Professor Jonathan Adler observes, this policy area is a key example of competitive federalism, in which states compete to offer packages of policies preferred by voters. Yet federal law, which impedes everything from bank lending to tax credits in the area of legalized marijuana, often gets in the way of what could be productive competition.[[90]](#footnote-90) Indeed, ASTM International plays a key role in providing a comprehensive set of private cannabis standards to support quality assurance, marketing, testing, and other aspects of the industry within a complex federal jurisdictional climate.[[91]](#footnote-91)

The Internet represented—and AI now represents—an even more uncertain jurisdictional extreme, presenting a form of industry that transcended sovereign boundaries and defied traditional jurisdictional control.[[92]](#footnote-92) It is hard to imagine any industry that has not been touched by Internet technologies, or that will be touched by AI in the future, yet there are no sovereign actors with comprehensive authority over all economic activities that might rely on these technologies. Here, self-regulation of a broad suite of practices and technologies, complemented by public standards, was and is essential because it can respond to issues in the use of these technologies wherever and whenever they occur, as we discuss in Part III.

1. Flexibility

Although emerging industries need reasonably predictable rules and knowledge of the jurisdictional level at which these rules will be promulgated and implemented, *flexible* rules that allow for learning and updating are also critical. Here, there is a delicate balance between certainty and durability, on the one hand, and the need to be able to modify rules when there is a good reason to do so, such as when new risks become apparent or when new technologies come on the scene and take the industry in an unpredicted direction. Substantive flexibility is built into self-regulatory regimes, with most standard-setting organizations having regular schedules for reviewing and updating standards. As shown in Part III below, the SSOs with hydrogen standards have in some cases already amended or updated these standards several times, or even canceled them in light of new data on superior self-regulatory approaches.

In the oil and gas context, the American Petroleum Institute has three models for updating standards: 1) “periodic maintenance,” in which standards must be reviewed “when technological changes affect their currency or at least once every 5 years”; 2) “continuous maintenance,” for which revisions may be proposed at any time,”; and 3) “stabilized maintenance,” under which standards for mature technologies and practices must be reviewed every ten years.[[93]](#footnote-93)

Periodic amending and updating of standards produces calculated flexibility—a form of regular, scheduled modification and updating of standards that does not unduly compromise certainty. Public regulation can and sometimes does achieve a similar result through requirements for the periodic sunsetting and review of rules,[[94]](#footnote-94) but empirically speaking, such rules appear far less prevalent than built-in review in the self-regulatory context.

Self-regulation also offers important jurisdictional certainty and flexibility–giving a national or international SSO or SRO primary control while providing room for state, federal, or international government actors to enter the regulatory sphere, either by displacing some standards or, as often occurs, incorporating many of them by reference.

### C. Simultaneous Production of Standards to Address Coordination Challenges

Beyond facing regulatory uncertainty, emerging industries often present distinct coordination challenges. These challenges arise even if the industry is not exceedingly complex from a supply chain perspective. Take the example of a widget that has one ingredient and one end use. Producers and transporters of the ingredient; the widget manufacturer; and transporters, distributors, and end users of the widget still must emerge, somewhat simultaneously. The simultaneous development of these distinct industry components is itself a challenging proposition calling for some coordinating feature, be it an organized group of industry actors, a vertically-integrated firm, or government-led coordination through an economic development organization or similar entity.[[95]](#footnote-95) But spurring separate and disparate governmental agencies with control over different parts of the supply chain to regulate at the same time—either independently or in a coordinated fashion—is similarly challenging.

Bottom-up self-regulation is the more likely approach to the development of coordinating standards in various components of an emerging industry. Larry Lessig describes a “coordinating standard” as “a rule that facilitates an activity that otherwise would not exist” and limits liberty simply to ensure that the activity can exist.[[96]](#footnote-96)  Lessig’s simple example of a coordinating standard is one that requires driving on the right-hand side of the road.[[97]](#footnote-97) Without an agreed-upon approach to driving, the many disparate vehicle drivers would have no reasonable way of sharing a road. Nascent or once-nascent industries such as hydrogen and the Internet create more complex examples, in which numerous standards must converge to allow vehicle users to locate hydrogen fueling stations with compatible fueling technologies, for example, or Internet users to connect to a network and understand the letters that identify a webpage. Lessig observes that coordinating standards can be top-down or bottom-up.[[98]](#footnote-98) With the Internet and, so far with hydrogen, the standards have been very much a bottom-up effort, with industry leading the way toward coordination, albeit with government actors sometimes spurring or at least aiding such efforts.[[99]](#footnote-99)

This is not to say that governments always fail in coordinating regulation for emerging industries or economic trends. But comprehensive sets of rules that cover multiple components of an industry and enable the industry simply to exist in its essential networked form, from manufacturing to transportation and distribution, appear to be far more common in the private context. This is likely because industry associations that cover multiple facets of the supply chain—or even disparate associations—have strong incentives to coordinate to write a comprehensive set of standards, as occurred in the context of oil and gas and its extensive set of API standards.[[100]](#footnote-100) Alternatively, industry may work with an independent SSO to gain a bird’s eye view, as has occurred for cannabis and ASTM International[[101]](#footnote-101) and appears to be the case for hydrogen so far.

Industries with interconnected or networked *risks* seem particularly motivated to coordinate in the standard-setting context, as evidenced by the electricity industry. The North American Electric Reliability Council (NERC—now the North American Electric Reliability Corporation) is composed of electric utility members, and these members formed NERC in the 1960s to address the cascading risks that permeate the electrical system.[[102]](#footnote-102) The electric grid—generation, transmission, and distribution—is tightly interconnected, and electricity supply depends on a delicately-balanced flow of electricity through wires at all times; any instability at any physical point in this vast interconnected network can accordingly cause large regions to lose power for days at a time, leading to billions of dollars in economic loss. NERC subsequently developed a relatively comprehensive set of standards for the reliability of all grid-connected infrastructure, from transmission lines and substations to power plants and distribution wires, which endured for decades without public oversight.[[103]](#footnote-103)

Self-regulation alone, however, might not achieve the degree of standards coordination necessary for a complex supply chain in need of innovation within all links that form the chain. Here, governments, play an important, top-down complementary role in producing or encouraging the formation of comprehensive, more coordinated standards (public or private or both) that address the many facets of an emerging industry–particularly when they view this industry as critical to public goals. As we discuss in Part III, the Department of Energy (DOE) is following this path in the hydrogen context, with an explicit mission of “coordinating and accelerating the efforts of major standards and model code development organizations and regulatory agencies so the required standards, codes, and regulations for hydrogen technologies can be prepared and adopted to facilitate commercial applications of these technologies in a timely manner.”[[104]](#footnote-104)

Beyond spurring the development of coordinated standards (public or private or both), governments often work to clarify and educate new industrial players on the existing and emerging standards that apply to them, thus attempting to ease regulatory burden and hasten the development of the industry.  In the context of the U.S. hydraulic fracturing boom, some states took both of these approaches, promulgating relatively comprehensive regulatory changes and regulatory menus that clarified the suite of regulations that applied to drilling and hydraulic fracturing.[[105]](#footnote-105) This was due to a combination of citizen concerns about adequate compliance with regulation, the fact that many industrial actors were rushing in from other states and were unfamiliar with state-specific rules, and the desire of some states to encourage economically beneficial oil and gas development by clarifying the rules. In the hydrogen context, as discussed in Part III, the federal government has created permitting checklists and guidance for industry participants while supporting efforts to fill in standards-based gaps.

Finally, some governments are so motivated to spur industrial transition that they also take measures to implement and ensure *compliance* with the private or public regulations, or both, on behalf of industry—bringing governmental assistance with coordination of standards to the highest level. This is one form of what Coglianese & Mendelson call “meta-regulation.”[[106]](#footnote-106)

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In summary, self-regulation seems particularly well poised to address some of the critical challenges faced by emerging industries that are technically complex and face steep coordination challenges. Self-regulation, perhaps even more so than public standards, can produce effective, responsive standards through regulatory competition. Self-regulation can provide certainty in the face of regulatory gaps yet needed flexibility through periodic updating as an emerging industry learns of new or different risks.  And although governments can continue to play an important role in coordinating public and private standards as they emerge, industry is even more motivated to play this part and is perhaps more likely to be centrally engaged in organizing and integrating the standards that address numerous components of a complicated supply chain. Self-regulation, in other words, can be a key enabling component of a nascent industry’s efforts to grapple with coordination problems.

Despite these benefits, there are important limitations to self-regulation that are important to note in the context of emerging industries. Extensive reliance on self-regulation without adequate attention to self-regulatory decisionmaking structures can give individual firms too much power in the process—thus risking problems of capture and regulation that insufficiently protects public welfare, and perhaps that delivers inefficient rents to the most powerful players.[[107]](#footnote-107) This could be particularly problematic during the early stages of an industry, when even those most familiar with the risks still have much to learn about safe design and deployment of technologies. A classic example of inefficient technological lock-in is the QWERTY configuration of most keyboards, which, according to some accounts, was adopted because of the preferences of a now obsolete profession of telegraph operators–we are still beholden to their preferences to this day.[[108]](#footnote-108) Furthermore, even well-intentioned, highly-informed industry actors can have blind spots to important regulatory areas—areas that might be better detected by more neutral government actors with a bird’s-eye view. Yet self-regulation, complemented by public governance and well-designed SSO standards development processes, seems to hold great promise for emerging industries such as hydrogen.

This discussion gives short shrift to the many other factors supporting innovation, in part due to space limitations yet also in part purposefully. The innovation literature extensively explores the role of intellectual property, traditional property rights, regulatory exemptions, and, more recently, the role of commons and peer production in the emergence of an industry.[[109]](#footnote-109) But it says too little about self-regulation as a potential driver of innovation.

## Self-Regulation of Nascent Networked Industries and Services

The theory that self-regulation can help to spur and support the growth of an emerging industry, as suggested in Part II, is best tested by examining how self-regulation plays out on the ground in emerging industries.

This Part takes up that task, assessing the role of self-regulatory standards in emerging economies—particularly networked ones—and the degree to which this case study accords with the theory in Part II. It begins by analyzing how self-regulation in the hydrogen context largely parallels the historic emergence of industries and associated standards. This Part then examines the first, failed attempt to jump start a hydrogen economy in California—a story that suggests the importance of standards in the successful development of a nascent industry. Additionally, it examines the experience with self-regulation so far in the more recent, global effort to spur a hydrogen economy, highlighting some important successes and some challenges.

Following the in-depth hydrogen case study, this Part draws examples from another highly-networked, technical, critical industry–the Internet economy–that emerged from a thread of activity to a status of global dominance. The comparison between the Internet economy and the hydrogen economy, the latter of which is essentially at the dial-up equivalent stage of development, allows us to further examine the promise and perils of self-regulation in supporting growth in emerging industries writ large.

Finally, this part briefly explores the beginnings of complementary self-regulation and public governance in the artificial intelligence sector, exploring some of the early lessons from this field.

This Part chooses these case studies to further highlight the theoretical principles (and some practical examples from a broad range of sectors) highlighted in Part II. It focuses on hydrogen and the Internet because these sectors were, or once were, critical emerging industries that were highly networked—involving multiple sub-sectors that required coordination for the industries to be successful. This Part also briefly explores artificial intelligence (a non-network industry[[110]](#footnote-110)) because it is particularly representative of two of the features that we focus on in this Article. It is emergent and critical, in that AI could offer extensive societal benefits yet also poses grave threats.[[111]](#footnote-111)

### A. Hydrogen as a Textbook Case of Growth Through Self-Regulatory Support

The development of industry standards in the hydrogen space largely reflects a pattern of standards within similar emerging industries over the past two centuries: an individual or company pioneers a new technology or practice, a nascent but growing industry endeavors to persuade the public of the need for this innovation and of its safety and/or utility; and somewhat coordinated industry standards, alongside or prior to governmental regulations, emerge. Industry writes these standards (or relies on an SSO to write these standards) for several purposes: to persuade the public of the safety of the innovation; to avoid the potential for an industry-wide collapse if a high-profile safety incident were to occur; and to produce somewhat coordinated standards to make implementation of the innovation feasible.

* 1. Why A Focus on Hydrogen?

The hydrogen economy—one that has faltered in the past and is now receiving billions of dollars in global support—serves as an ideal case study of the role of self-regulation in complex emerging economies. It is a nascent, critical, highly-networked industry. In 2023, hydrogen is an industry that barely exists at present but that must become much more central in a short amount of time to meet public climate governance goals. Despite playing an extremely minor role in today’s economy, hydrogen is at a critical growth stage because it is integral to most strategies for decarbonization of the economy. Studies suggest that using hydrogen as a liquid or gaseous fuel to replace existing fossil-fuel products could be essential to decarbonizing heavy industry, air travel, shipping, and other “hard to decarbonize” activities.[[112]](#footnote-112) In every scenario identified by the Deep Decarbonization Pathways Project, so-called “green” hydrogen (hydrogen manufactured through electrolysis using renewable energy power) use will have to expand massively, providing low-carbon liquid fuel for transportation and gas fuel for building heating and industrial activities.[[113]](#footnote-113) Increasingly, proponents are touting the potential clean energy storage benefits of using excess renewable energy to generate hydrogen fuel, which, unlike intermittent renewable energy, can be easily stored for later use.[[114]](#footnote-114)

Due to the central role of hydrogen in the energy transition to a lower-carbon future, governments are racing to enlarge the hydrogen sector, investing more than $200 billion in concrete global government funding for the industry, including $8 billion in the U.S. Bipartisan Infrastructure Bill dedicated to supporting “clean hydrogen hubs” and funding research and development of hydrogen production techniques.[[115]](#footnote-115) The U.S. Inflation Reduction Act includes a new tax credit for hydrogen production, provides property tax credits for hydrogen fuel stations, includes hydrogen-fueled vehicles within a new Clean Vehicle Credit ($7,500 for new vehicles), and contains numerous other provisions supporting a hydrogen economy.[[116]](#footnote-116) Despite the current enthusiasm and government support for hydrogen, a mountain of hurdles stands between these ambitions and the realization of a hydrogen economy, including the challenge of getting multiple components of a networked economy up and running simultaneously and producing standards to guide all of these components while avoiding duplicative efforts at standard-setting.

At present, the hydrogen industry is essentially undeveloped. While in the United States hydrogen is currently shipped through about 1,600 miles of pipeline and used in certain refinery and chemical manufacturing processes,[[117]](#footnote-117) many of the expected applications of hydrogen are entirely hypothetical at this point, and generation, storage, transportation, and distribution would all have to be scaled up drastically, and simultaneously. The Department of Energy’s comprehensive “Hydrogen Program Plan” estimates that there is likely to be a $2.5 trillion global market for hydrogen by 2050, with the U.S. share of the market amounting to $750 billion per year.[[118]](#footnote-118)

Adding to the challenge, the hydrogen economy will have to be a networked, infrastructure-heavy industry, and it therefore poses classic coordination problems.[[119]](#footnote-119) Production is unlikely to emerge without committed end-use outlets and pipelines and distribution infrastructure to access those outlets; end users, in turn, will not commit to purchase hydrogen without an assurance of steady availability and transport options for the product. The hydrogen economy is in some sense a “lumpy social good” that may not be supplied without careful coordination of the various complementary (and, in some cases, nonexistent) components of the industry.[[120]](#footnote-120) Furthermore, hydrogen has classic network effects; hydrogen-fueled vehicles and factories will be more economical the more the network of pipelines, distribution lines, and (for vehicles) fueling stations expands, and the more end uses emerge. Developing all of these physical system components simultaneously to achieve the needed coordination of the hydrogen economy and realize network effects poses an enormous challenge–particularly the need for the simultaneous development of standards in many different facets of the industry. Beyond coordination challenges, the hydrogen industry is somewhat path dependent: once a specific design for metals for hydrogen tanks and pipelines is selected, it will be difficult to turn back. Such path dependency is often cited as a factor militating in favor of self-regulation,[[121]](#footnote-121) and it will be exceedingly important to get the substantive standards right in the hydrogen space–creating certainty for industry yet also allowing some flexibility as more is learned. And finally, jurisdiction over the many components of the hydrogen economy is far from clear, leading to regulatory gaps and also calling for cross-jurisdictional consistency—which self-regulation can provide—while public entities iron out *who* will ultimately regulate particular aspects of the hydrogen economy.

Compounding coordination challenges and the need for relatively rapid expansion of a network of hydrogen infrastructure are environmental and human health risks. Many components of the hydrogen economy will require attention to safety concerns. Although hydrogen is safer than other common fuels with respect to toxicity, it is a highly flammable and more easily ignitable substance, both in liquid form and in gas form.[[122]](#footnote-122) Transporting hydrogen through pipelines is challenging because hydrogen embrittles the metals typically used for pipelines..[[123]](#footnote-123) For workers handling and storing hydrogen, suffocation is a very real risk.[[124]](#footnote-124) For many of these challenges, the unique characteristics of hydrogen will prevent simple adoption of existing regulatory approaches. Rather, rules and standards will have to be developed from scratch at the same time that researchers are continuing to update learning about hazards and industry is experimenting with solutions. Federal and state regulations, moreover, have lagged well behind innovation in this space. Even relatively simple questions, such as whether and how to repurpose natural gas pipelines to facilitate transportation of hydrogen, are currently in flux and are unlikely to be addressed in government regulations any time soon. Instead, much of the regulatory governance of the nascent hydrogen economy will have to be provided through self-regulation, and as we will discuss in this Part much of that self-regulation is already taking place.

2.The Evolution of Hydrogen Self-Regulation

One of the most coordinated standards for hydrogen—and one that covers many aspects of the hydrogen supply chain—is housed within one of the oldest and most-used standards setting organizations in the United States, the National Fire Protection Association (NFPA). Numerous states and local governments directly incorporate NFPA standards into their building, fire, and electrical codes. And the history of NFPA standards largely parallels the story of standards in a number of emerging industries, including hydrogen.

As explained by NFPA’s former Executive Director, a group of pioneering individuals formed the NFPA as individuals were first inventing and attempting to prove technologies for spraying water on fire–the predecessors to modern sprinkler systems—and the safety of electricity and electricity hook-ups. As new sprinkler systems took root in the 1870s, a number of different designs and standards emerged, as exemplified by nine different standards for the size of water pipes and spacing of sprinklers within buildings in the vicinity of Boston in 1895. This created a “plumber’s nightmare” and endangered the success of the fast-growing industry.[[125]](#footnote-125)

At the same time, five different U.S. standards “addressed the safe use of electrical equipment,” creating five different sets of rules for electricians installing such equipment, and generating “confusion and controversy.”[[126]](#footnote-126)  And the safety of electrical hook-ups was by no means proven or widely accepted by the public at this point; indeed, the 1893 World’s Fair included a “Palace of Electricity” that insurers were reluctant to cover prompting the organizers to hire an expert (William Henry Merrill) to prove the safety of the electrical equipment and hookups.[[127]](#footnote-127) Electrical manufacturers subsequently wrote to Merrill for certifications of their products as safe, spurring him to create a safety testing laboratory (ultimately to be named “Underwriters Laboratories”) supported by fire insurers and electrical manufacturers.[[128]](#footnote-128) But other private electrical codes were emerging at the same time, primarily written and administered by fire insurance underwriters and associations of electrical equipment manufacturers, thus contributing to the confusion noted above.[[129]](#footnote-129)

The late 1890s was therefore a scene of conflicting industry standards creating a confusing array of rules for electricians installing wiring and outlets and for plumbers installing sprinkler systems–all relatively new and innovative technologies at the time. Yet the confusion did not only arise on the installation side. Manufacturers were centrally concerned about easing installation so as to prove and sell their products, and fire insurance companies wanted more guidance and input on the preferable standards. Insurance underwriters and manufacturers accordingly gathered in two separate important convenings in 1896—one in which a National Electric Code was formed, and another in which members developed the NFPA. By 1897, the NFPA was established as the centralized private body for all standards relating to fire protection–electrical, sprinkler-related, and otherwise.[[130]](#footnote-130) Fast forward to the twenty-first century, and NFPA now has one of the most comprehensive hydrogen codes–a code “structured to be the national code for hydrogen safety in the US.”[[131]](#footnote-131)

The trajectory of the hydrogen industry and associated private standards is similar to that of then-nascent technologies addressed by the NFPA, from electricity to sprinkler systems in the late 1800s. Indeed, Underwriters Laboratories, originally formed to help standardize and buttress private electrical safety standards, even has its own standards for hydrogen fuel cells.[[132]](#footnote-132) As in the electricity and fire safety contexts, an emerging industry (in this case hydrogen) is endeavoring to persuade the public to adopt a new technology—including in the end-use residential context—and is reliant on plumbers and similar installers to ensure the widespread adoption of the technology. Competing or confusing standards for installation will cause delay and potential failure. And here, too, the emerging industry is, above all, attempting to persuade the public and insurers of the safety of its products, particularly given historic high-profile incidents such as the Hindenburg explosion. Although further study has revealed that the explosion was primarily caused by the flammable chemical coating on the zeppelin, the public often focuses on the hydrogen that fueled the flying machine.[[133]](#footnote-133)

Beyond airships, some of the earliest U.S. uses of hydrogen were in the 1950s, when NASA began using hydrogen as a rocket fuel.[[134]](#footnote-134) It appears, however, that the American Institute of Aeronautics and Astronautics did not develop formal standards until 2004.[[135]](#footnote-135) Indeed, most U.S. hydrogen standards have only emerged in the past two decades, and many remain to be developed, as we discuss in this Part. Table 1 provides a summary and timeline of some of the key private standards in the hydrogen industry.

Table 1. Examples of Major Hydrogen Industry Standards and Their Timelines

(All table data from Fuel Cell Standards 2022.)

|  |  |  |
| --- | --- | --- |
| **Industry Area** | **Standard-Writing Organization** | **Timing of Initial Publication and Revision, If Any** |
| Hydrogen transportation tanks and storage vessels | American Society of Mechanical Engineers | 2004 (transportation tanks); 2010 (plastic pressure vessels). New rules being developed by Project Team on Hydrogen Tanks. |
| Sampling for pollutants in hydrogen fuel; screening hydrogen fuel cell quality | Society of Automotive Engineers (fuel cells)  ASTM International (fuel) | 2005; revised 2008 and 2011, reaffirmed 2015, published 2020  Some standards as early as 2010; subsequent updates and withdrawals through 2022. Some standards withdrawn because better sampling methods were identified; others withdrawn due to lack of activity. |
| Hydrogen pipelines: design | American Society of Mechanical Engineers  Compressed Gas Association (international standards) | 2007  2005; 2013 reaffirmation |
| Hydrogen pipelines: materials, testing, operation, maintenance, etc. | American Society of Mechanical Engineers  Compressed Gas Association (international standards) | 2009; later editions in 2011, 2014, 2019  2005; 2013 reaffirmation |
| Hydrogen vehicle fueling protocols | Society of Automotive Engineers | 2010 Technical Information Report; 2014 standard, revisions 2016 and 2020 |
| Hydrogen road vehicles and fueling equipment | International Organization for Standardization    ANSI/CSA America | 2014; various reconfirmations and amendments for different components, other new publications 2016, 2017, and currently under development  2015; re-affirmed 2019 |
| Hydrogen vehicle fuel containers | ANSI/CSA America | 2014; re-affirmed 2019, second edition 2021 |
| Hydrogen producers (“generators” of hydrogen)--electrolysis | CSA Group | Under development starting in 2021–joint U.S.-Canadian effort |

Prior to this recent push for standards, one pioneering U.S. state attempted to jumpstart one component of the hydrogen economy—vehicles powered by hydrogen fuel cells, which in turn required hydrogen fueling stations. This effort, which occurred without the support of many public or private regulations, was largely a failure, producing lessons about why the more recent, second generation of more comprehensive hydrogen standards is likely critical to the attempted resurgence of a previously failed industry. Indeed, the current push for a hydrogen economy is far more ambitious than California’s 2005 initiative, demanding a suite of factors to support innovation—including better standards. We now turn to what might be learned from this cautionary tale about the risks to emerging industry from the lack of self-regulatory standard setting.

1. California’s “Hydrogen Highway”: A Cautionary Tale?

In 2005, Governor Arnold Schwarzenegger released a plan to scale up the use of hydrogen fuel cell vehicles in the state under California’s Zero Emission Vehicles regulation.[[136]](#footnote-136) While this Hydrogen Highway plan focused on just one of the many potential uses of hydrogen, it is still possible to glean broader lessons from this experiment regarding the importance of self-regulation in the emerging hydrogen economy. Indeed, this case may well be a cautionary tale about trying to scale an innovative technology without well-developed self-regulatory governance frameworks in place.

The California Hydrogen Highway Blueprint was intended to proceed in several stages, combining public and private initiatives to build a network of hydrogen fueling stations and assist automobile manufacturers in developing models of cars with fuel cells. The first phase set a relatively meager target of 50-100 fueling stations and 1,200 fuel cell vehicles by 2010. The second phase greatly scaled up the ambition, calling for 250 hydrogen fueling stations and 10,000 predominantly fuel cell vehicles (it is possible, though less desirable, to burn hydrogen in modified internal combustion engines); phase three called for a doubling of the vehicle count to 20,000.[[137]](#footnote-137) Years later, it is clear that almost none of this came about: Hydrogen fuel cell vehicles are now a “legacy zombie technology” linked in the popular imagination to a “bad bet by the state.”[[138]](#footnote-138) The state has already spent $125 million on the program and fallen short of expectations, with just about 50 fueling stations and about 9,000 hydrogen-powered vehicles.[[139]](#footnote-139)

While some of the failures of the Hydrogen Highway can be attributed to the economics of the technology and the chicken-egg problem of building fueling infrastructure before there was consumer demand, at least some of the failure is likely also attributable to the infancy of the movement to develop standards at the time of the program’s rollout. Although the Blueprint document emphasized the need to jumpstart the process of developing codes and standards, this work was slow to catch on. It was not until 2014 that California adopted NFPA 2, which provides comprehensive standards for generating, handling, and storing liquid and gaseous hydrogen, in the California Fire Code and California Building Code (although, to be fair, NFPA 2 itself was not finalized until 2011).[[140]](#footnote-140) Several of the most important standards for fuel cell vehicles, such as Society of Automotive Engineers J2719, on hydrogen fuel quality for fuel cell vehicles, and J2760, on pressure terminology used in fuel cells, did not come out until after 2011 as well. What this means, practically, is that the few fueling stations that did exist in the early stages of the Hydrogen Highway project had to pass through permitting processes by reinventing the wheel for each project rather than simply following standard industry practices that would guarantee success–a process that surely added cost and uncertainty to efforts to build stations. Moreover, because of this diversity of standards, it was possible for different stations to operate using different technologies and specifications–surely a challenge for workers constructing these stations and a headache for would-be hydrogen fuel cell vehicle owners who reportedly run into many problems with out-of-service stations.[[141]](#footnote-141) This lack of standardization is analogous to the challenges faced early in the electricity and fire protection/prevention industries, when competing standards caused confusion for plumbers and electricians and failed to assure consumers of the efficacy and safety of what were then relatively new products.

Whether the more developed codes and standards that exist today could reverse the fortunes of the California Hydrogen Highway program is an open question. Just last year, the California Energy Commission authorized $169 million in new funds to open up 111 public hydrogen fueling stations. Now, developers have a wealth of materials to assist them in streamlining projects, including NREL-funded YouTube videos, providing essential information on relevant codes and standards and the permitting process.[[142]](#footnote-142) Still, it might be too late for the hydrogen automobile industry. Automakers have scaled back production of fuel cell vehicles in favor of battery-electric models, which seems to be taking hold as the dominant technology for light-duty vehicles.[[143]](#footnote-143) Perhaps this trajectory would have been different had the standards been developed at the outset. Indeed, it is possible that with more standards in place now and the Clean Vehicle Credit in the Inflation Reduction Act incentivizing new purchases, hydrogen vehicles may still have a future in the United States.[[144]](#footnote-144) That is especially the case because, as we demonstrate in the next subsection, the movement to produce standards is no longer in its infancy.

1. The Second Generation of Hydrogen Standards: Competition, Coordination, and Certainty in the Midst of Regulatory Gaps

The current global push for hydrogen is far more ambitious than California’s hydrogen vehicle efforts. Countries around the world are investing billions of dollars in an entire hydrogen economy, envisioning the production, transport, and distribution of hydrogen to support a variety of end uses in the residential, commercial, industrial, and energy storage sectors. Happily, an impressive suite of industry standards has emerged in the past decade (compare a compilation from 2011[[145]](#footnote-145) to one contemplated just 7 years later in 2018,[[146]](#footnote-146) suggesting potentially more hope for this round of attempted innovation. But much progress remains to be made, as explored here.

In the United States, the effort to develop industry standards is increasingly a coordinated effort amongst SSOs. Members of the hydrogen industry from all portions of the supply chain have joined the Fuel Cell & Hydrogen Energy Association, with a mission of “[p]roviding the industry a voice in shaping regulations, codes, and standards to enable commercial growth, while ensuring the highest levels of consumer safety and satisfaction,” among other purposes.[[147]](#footnote-147) FCHEA works to draft some standards–particularly in the hydrogen sector–but is primarily concerned with educating private- and public-standard setting bodies about hydrogen developments and providing a centralized portal of all of the global hydrogen standards currently in place. One organization has begun to create a singular set of comprehensive guidelines and information–a document rising to “platinum” status in an industry that involves so many coordination challenges.[[148]](#footnote-148) This coordination of standards may in part arise from the physical interconnectedness of the emergent hydrogen economy, requiring production facilities to be connected to storage, pipelines, distribution lines, and end users.

In the UK, an effort to convert the UK’s residential cooking and heating system from natural gas to hydrogen also has cooperative elements. All of the country’s gas distribution companies have joined in an effort to test and prove the safety of gas distribution and use in homes—a program somewhat similar to Merrill’s Underwriters Laboratories in the early U.S. electricity industry.[[149]](#footnote-149) They are also testing public perceptions of hydrogen, engaging residents in interviews and deliberative workshops in order to better understand people’s understanding of hydrogen and its benefits and risks.[[150]](#footnote-150) This consortium is now working to demonstrate the safety of hydrogen distribution and use in actual neighborhoods in London.

Interestingly, government entities also assist these coordinated standards development processes while still leaving the matter to SSOs. These efforts endeavor to “[i]dentify regulators and agencies that need to be engaged by stakeholders for future systems” and “[i]dentify limits of federal oversight (i.e., state/local jurisdiction rather than federal”).[[151]](#footnote-151) We discuss these efforts below in the context of the theoretical factors connecting standards and innovation that we introduced in Part II.

1. The Benefits and Limitations of Self-Regulation in the Growth of Hydrogen

The evolution of industry standards for hydrogen alongside the slow and sometimes halting growth of the industry itself provides important insights into the role of self-regulation in supporting or limiting an industry’s trajectory, as explored here.

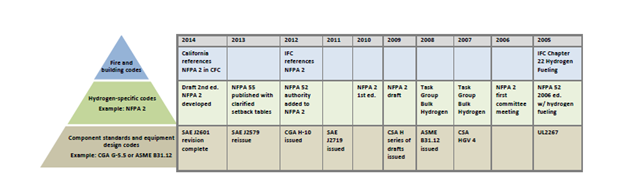
* 1. Competition and Coordination in Hydrogen Standard Setting

A well-populated set of standards has already emerged for an almost wholly theoretical hydrogen economy and is impressively varied–applying to most segments of the supply chain, ranging from production and storage to the safety of hydrogen in a variety of end uses, such as vehicles.[[152]](#footnote-152)  There are 393 standards published globally, and 15 under development in 2022, suggesting a relatively robust competition in standard setting.[[153]](#footnote-153) This is further supported by the variety of organizations offering such standards, including competing substantive standards within the same regulatory space. Organizations that have published ten or more hydrogen standards include the American Society for Testing and Materials, American Society of Mechanical Engineers, Compressed Gas Association (CGA), CSA Group, International Electrotechnical Commission, and International Organization for Standardization, and many other organizations have produced smaller sets of standards within this space.

The following figure from the National Renewable Energy Laboratory shows the time-based trajectory of the key hydrogen standards for automobile fueling stations and how standards for the components of these stations (shown in the bottom row) developed as broader station-based standards simultaneously emerged. All-in-all, the many standards that have emerged to address what may ultimately be a U.S. hydrogen economy appear to be relatively complete, at least in terms of covering most aspects of the hydrogen economy. The National Renewable Energy Laboratory concluded as early as 2015 that private standards and government regulations “address all key aspects of system design, construction, operation, and maintenance” in the context of hydrogen fueling stations for vehicles.[[154]](#footnote-154)

Experts at Sandia National Laboratories, reviewing private standards and public regulations that apply the hydrogen economy, identify only seven areas—out of dozens—that are not “hydrogen ready” due to a lack of standards, although some of these areas are quite consequential. For example, experts surveying the standards and regulations note that there are no regulations authorizing hydrogen import or export terminals; no regulations addressing the sale or distribution of hydrogen to residences; and no testing requirements for furnaces, boilers, and similar residential heating systems that could run on hydrogen.[[155]](#footnote-155) Similarly, there is a need for more technical data as remaining gaps are filled. This appears to be happening organically. For instance, ASME formed a separate non-profit LLC to test the technical aspects of hydrogen and specifically inform the consensus process, noting that “[a] series of technical reports addressing hydrogen infrastructure applications directly resulted in new ASME code rules for pressure vessels, piping, and pipelines specific to hydrogen.”[[156]](#footnote-156) These rules are particularly important as industry players contemplate how to retrofit existing natural gas pipelines so that they are appropriate for the transportation of hydrogen.

**Timeline of codes and standards development and the codes and standards hierarchy (Rivkin et al. 2015).**



As the remaining gaps become smaller, we are seeing a turn to intra-standard competition. That is, private standards-setting organizations are even addressing flaws that they see in other standards. For example, the CGA officially expressed concerns that some NFPA rules for the setback of hydrogen storage tanks from nearby infrastructure were “unclear.”[[157]](#footnote-157) CGA accordingly published a Position Statement that it asked hydrogen storage tank installers to follow and asked the NFPA to clarify “unclear separation distances” between hydrogen storage tanks and other infrastructure.[[158]](#footnote-158) NFPA did amend its separation distance requirements in 2016, although it is not clear whether this was in direct response to CGA’s request. Rather, as early as 2010 NFPA has begun to reconsider the required distances between hydrogen storage tanks and other infrastructure and humans to base its standards more clearly on risk factors, such as the type and probability of hydrogen exposure rather than solely the total volume of hydrogen stored in the tank. NFPA built upon government (Sandia Lab)-developed hydrogen models and updated the standards in 2010 and again in 2016.[[159]](#footnote-159)

In short, while there are still holes to be filled, the self-regulatory framework for hydrogen is quite robust, and certainly much more so than in the 2000s with California’s failed “Hydrogen Highway” experiment. Most major issues now have at least some degree of standardization from at least some SSO, resulting in a veritable quilt of self-regulation. While this state of affairs is preferable to ten years ago, it also points the way to new challenges of coordination and competition, and the balance between the two. Self-regulation in the hydrogen economy appears to be poised to turn to a period of refinement, competition, and experimentation to improve the existing suite of standards.

1. Simultaneous Production and Coordination of Standards Within a Vast Hydrogen Supply Chain: The Case for Active Coordination

Although letting one thousand flowers bloom in the standard setting context has produced relatively complete standards, new challenges are now emerging. A patchwork of competing standards can be confusing and expensive to comply with, among many other challenges. The “black start” of a highly-networked economy from ground zero—requiring the simultaneous development of production, transportation infrastructure, and end uses—is a situation that desperately calls for the development of a comprehensive set of standards at multiple points of the supply chain. In the context of hydrogen, producers, storage companies, pipeline and distribution line builders, owners, and operators, and end users all need minimum safety standards to begin operating, and few parts of the industry will function very effectively if the other parts are not up and running.

In short, there does seem to be a pressing need for more top-down coordination of hydrogen’s well-populated self-regulatory ecosystem. Interestingly, some of the law firms most active in the hydrogen space assume that *government* will have to produce a relatively comprehensive set of standards, arguing that “[t]he federal government will need to incorporate hydrogen into its broader regulatory scheme for hydrogen to truly become part of the energy infrastructure in the U.S.”[[160]](#footnote-160) And indeed, government is playing a critical, albeit merely facilitative, role in the development of a coordinated U.S. hydrogen economy by working hand-in-hand with SSOs.  An abundance of relatively uncoordinated standards, paired with some standards-based gaps, is a particular threat for hydrogen, given its potentially expansive use in the residential setting for cooking, heating, and backup generation.  As the DOE notes, there are 44,000 local jurisdictions in the United States, all of which have their own building codes.[[161]](#footnote-161) Many states provide a uniform building code (comprising primarily private standards incorporated by reference) that local governments adopt, but local governments are not always required to follow this standardized approach. The DOE is working with private standards-development organizations to attempt to coordinate the plethora of disparate building code standards that could potentially apply to residential hydrogen uses.[[162]](#footnote-162)

As part of its effort to speed up and help coordinate the development of comprehensive, navigable standards for hydrogen, the DOE is also working to identify “gaps in the standards development process and provide methods to close the gaps,” “[p]roviding support for key international standards meetings,” supporting research and development efforts that provide the data needed to develop effective standards, and “[s]upporting the codes and standards adoption process,” among other coordinating activities.[[163]](#footnote-163) The DOE and its subunits are also endeavoring to ease industry compliance with a complex set of regulations that apply to numerous aspects of the supply chain, producing videos and literature on how to permit a hydrogen fueling station; charts that map out public and private hydrogen standards; checklists and permitting guides; trainings of code officials who review compliance with hydrogen requirements; and regular trainings on emerging hydrogen technologies and hub opportunities, the content of hydrogen standards, and status of newly developed standards.[[164]](#footnote-164)

Despite concerted governmental efforts in coordinating hydrogen standards, the bulk of the efforts appear to be emerging from industry associations, as we predict would occur in Part II. For example, the DOE refers viewers to an association-created database of hydrogen standards, which characterizes standards by the organizations that created them and the sectors to which they apply.[[165]](#footnote-165)  This organization—the Fuel Cell & Hydrogen Energy Association—also supports industry standard development efforts. And as explored above, organizations such as NFPA and the Compressed Gas Association are actively working to develop more comprehensive standards and to address gaps in standards. Additionally, ASME formed a separate organization to specifically test the technical aspects of the industries for which it develops standards; it has used ASME Standards Technology LLC to test hydrogen risks and produce technical papers to directly inform the ASME hydrogen standards process.[[166]](#footnote-166) The precise balance between SSO or SRO-led coordination and government-led coordination is being determined in real time, but the overall need for some degree of coordination is clear and is being met.

1. Evidence of Balanced Certainty and Flexibility Within Hydrogen Standards

A critical feature of regulations guiding all industries—but particularly those in the development phases—is the creation of regulatory guidance that is relatively stable yet also offers flexibility through periodic updating or standards. Stable standards provide some degree of certainty and predictability as industry invests in the capital and services needed to comply with regulation. Periodic updating of standards not so frequent as to upset or overturn substantial investments in compliance, yet frequent enough to address new information about risks and regulatory needs— in turn allows for changes that may enhance consumer confidence and address industry concerns about overly costly or inadequately effective regulations.

 The relatively comprehensive set of U.S. industry standards for hydrogen appears to be playing a critical role in filling some large regulatory gaps that produce uncertainties for a nascent hydrogen economy—particularly PHMSA’s failure to write regulations for the safety of pipelines that carry hydrogen and FERC’s lack of hydrogen pipeline construction standards. And industry associations are actively updating these standards as they learn of new risks, as demonstrated by NFPA’s updating of its hydrogen storage tank regulations in 2010 and 2016 based on new government risk models.

### B. Self-Regulation and Public Governance in the Growth of the Internet

A variety of industrial sectors beyond the energy sector offer similarly important insights into the potential for self-regulation to support emerging industries–particularly technologically complex industries with network effects. The Internet is perhaps the most apt example. Here, too, was a largely undeveloped public good–-a small yet critical information network pioneered by the military and, at first, offering extremely limited access by private individuals. As the Internet grew, it represented even stronger network effects than hydrogen; it increased in value with every new connection of an individual to the literal information network, and it required a physical, interconnected infrastructural web of wires and hardware. Even more so than hydrogen, the Internet was also a good with an extreme lack of jurisdictional clarity—indeed, a good that defied all traditional political boundaries. And as with hydrogen, the Internet involved detailed technical questions that those closest to its formation were most familiar with.

The Internet began as a U.S. military endeavor, led by the government, or, more specifically, private government contractors.[[167]](#footnote-167) But as private individuals pushed for and obtained access to it, government involvement in the design and control of the Internet substantially changed, while self-regulation expanded. The predominant, early assumption of experts was that this technologically complex, sprawling network *required* self-regulation. Commentators noted the need for flexibility of standards as technologies rapidly evolved and emphasized the highly technical nature of the Internet, which called for private expertise in standards development.[[168]](#footnote-168) To a large degree, governments agreed with arguments for a light public regulatory touch. The Clinton Administration formally declared a self-regulatory approach to the Internet,[[169]](#footnote-169) and subsequent administrations tended to follow suit. But as with hydrogen, government regulation played an important complementary role, and, many argue, should be even more active within the Internet regulatory sphere today.[[170]](#footnote-170)

1. A Brief History of Internet Self-Regulation

To many experts, as the seemingly impossible alien being called the “Internet” began to emerge from its military roots, there was no question that this strange and endlessly sprawling beast of an industry required self-regulation. For example, David Johnson and David Post argued that “[g]lobal computer-based communications cut across territorial borders, creating a new realm of human activity and undermining the feasibility--and legitimacy--of laws based on geographic boundaries”[[171]](#footnote-171) Indeed, the Internet emerged primarily with the support of self-regulation, but courts and legislation also played an important role throughout the development of this critical and ultimately sprawling good.

The standards that allowed the Internet to flourish fall decidedly within the realm of self-regulation, although they originated within a quasi-governmental body. Specifically, in 1968, the university-based computer science contractors comprising the Advanced Research Projects Agency (ARPA, called the Defense Advanced Research Projects Agency, or DARPA, as of 1972) began a “nomadic, collegial, open and consensus-based process” for developing standards that would define an information network that would eventually come to be known as the Internet.[[172]](#footnote-172) Most members of this “Network Working Group” were graduate students. This group eventually morphed into the IAB–still primarily composed of “self-selected” private individuals–and in 1986 designated an organization called the Internet Engineering Task Force (IETF) to do much of its work; the IAB reserved for itself a review and appellate role.[[173]](#footnote-173) Specifically, the IAB tasked the IETF with “the general responsibility for making the Internet work and for the resolution of all short- and mid-range protocol and architectural issues required to make the Internet function effectively.”[[174]](#footnote-174) In 1992, the IETF opened up its standards process in response to criticism of relatively closed decisionmaking by its tight group of engineer members, and by this time it was recognized as the “primary venue for internet standards development.”[[175]](#footnote-175)

The IETF continues to serve as the primary Internet standards-setting organization, although it is not formally characterized as a “voluntary consensus standards body” by the Office of Management and Budget and the Standards Development Organization Advancement Act of 2004.[[176]](#footnote-176) The IETF fails to meet this definition because it does not have formal stakeholder or interest group balance requirements, instead relying on a fully open process in which “all interested parties have an opportunity to participate.”[[177]](#footnote-177)

1. The Internet’s Foreshadowing of the Benefits and Challenges of Self-Regulation in Emerging Industries

As would be shown for hydrogen more than twenty years later, the growth of the Internet and associated self-regulatory standards demonstrated the importance–and limitations–of self-regulation in several distinct areas, including the benefits of regulatory competition among industry actors and SSOs, the coordination of standards by SSOs, and substantive and jurisdictional certainty and flexibility.

* 1. Competing Standards

As noted above in the hydrogen context, self-regulation can benefit emerging industries in its allowance of competition among numerous competing standards developed by industry actors and associations hoping to enable a successful new industry.  Under the right circumstances–adequate coordination and information sharing, among others–the “best” standards (e.g., those that allow for growth of the new industry while also adequately addressing public concerns) may rise to the top.

The private standard that is one of the key layers of the Internet is the TCP/IP created by the quasi-SSO IETF’s predecessor IAB. TCP/IP allows individuals to communicate through “standardized packets'' rather than direct communication that would require specified routes.[[178]](#footnote-178) This standard was itself the subject of early competition between standards-setting bodies. The ISO had created its own, competing protocol for Internet communication when IAB introduced TCP/IP. Indeed, the IAB had considered attempting to join the ISO rather than maintaining its own standard-setting process through the IETF, but the ISO’s rejection of TCP/IP (the standard that ultimately won out) in part caused the IAB to remain independent of other standard-setting bodies.[[179]](#footnote-179) The IAB’s maintenance of independence, and its subsequent development of a standard-setting process that allowed every interested individual to participate, perhaps enabled more healthy competition and discussion within the Internet standards-setting process than would have occurred through a more formal “balanced” or corporatist process, in which different interest groups must have specific representation.

The other unique aspect of Internet standards is that due to the Internet’s defiance of traditional jurisdictional control–i.e., its crossing of boundaries and accessibility to all–literally any group of individuals can create new standards, albeit informal ones. Indeed, in some cases the IETF finds itself competing with the broader user community in its standards development. For example, while the IETF created a “a minimum set of guidelines for Network Etiquette (Netiquette),” individuals and small groups created their own “Netiquette” through FAQs, which are documents on the web that “attempt to distill some Internet wisdom, or Internet norms, for newcomers.”[[180]](#footnote-180) This type of highly competitive, individual volunteer-driven standard setting has likely contributed to the success of the Internet while also exacerbating its challenges, including, for example, the “vigilante” justice to which Internet users sometimes resort.[[181]](#footnote-181) Indeed, more recently, some of the major competing Web users’ approach to false news and harmful posts has elicited a great deal of international attention, with national efforts to address these problems often faltering. Although successful in only limited ways, shared self-regulatory approaches have emerged to somewhat curb the massive expansion of harmful information on the Web.

1. The Critical Nature of Coordinated Standards

Even more so than hydrogen, which required simultaneous development of standards from the production facility to pipelines, distribution lines, and end users, the Internet represented a critical need for an exceedingly complex array of standards, any of which could fail in the absence of sister standards for another component of the network. As Philip Weiser describes the Internet, it consists of four layers, including content (websites), the logical layers that allow Internet communications applications (browser software and media players), layers allowing communication among users, and the physical layer of wires and other technology that carry stored information to the user and allow users to access the internet.[[182]](#footnote-182) All of these layers are themselves quite complex. To name just a few of the complexities, the Internet required the development of standards or guiding norms in all of the following areas:

[W]eb site terms of use; behavioral norms of virtual chat rooms and discussion groups; network administration guidelines; listserv moderator filtering; Internet service provider contracts; Usenet voting procedures;local area network acceptable use policies;newsgroup frequently-asked question files; decisions of virtual magistrates; help manners and programmers manuals for multiuser dimensions; the code embedded in browsers, servers, and digital content; and the technical protocols that enable intra- and internetwork communication.”[[183]](#footnote-183)

Even if several government agencies could have feasibly worked together to simultaneously write these standards, or one umbrella agency could have identified all of these standards-based needs and written them at one time in whole cloth, it was unlikely that such efforts would have fully enabled an effective grid. Indeed, it was the highly technical nature of the grid, its defiance of any traditional political boundaries, and its limitless global reach that led courts, regulatory agencies such as the FCC, and many theorists to argue that self-regulation–or some other form of non-traditional governmental control–would be a key means of governing the Internet. Yet even self-regulation could have been inadequate in terms of supporting Internet innovation, particularly if different, competing standards emerged that prohibited the millions of networks within networks that make up the Internet from connecting to each other or allowing the free flow of information among networks.

For this unwieldy, highly technical agglomeration of hardware, software, codes, wires, and the like–all in need of simultaneous development of standards–the IETF played a key role, providing a centralized, coordinating body from which the bulk of internet standards emerged.[[184]](#footnote-184)

1. Substantive and Jurisdictional Certainty and Flexibility

Beyond coordination challenges, the Internet represented a classic case of a need for both regulatory certainty–particularly given the deep path dependence of Internet standards–and flexibility as the Internet rapidly evolved. Path dependence arises when “past decisions regarding product or standard choice will dictate the choices made in the future,” and self-regulation theorists identify path dependence as one of the features that tends to drive self-regulation.[[185]](#footnote-185) The Internet had strong path-dependence features, as with, for example, the choice of languages to use for web programming.[[186]](#footnote-186) The cementing of a substantive public or private standard that would be broadly accepted and would endure as an accepted practice in the industry was therefore critical.

The need for jurisdictional certainty–in this case a new form of jurisdiction–was also central to the development of the Internet. Hydrogen remains jurisdictionally uncertain, largely because a true hydrogen economy will require interstate pipelines for which Congress has not yet specified   jurisdictional control over siting or construction.[[187]](#footnote-187) But the Internet represented even more uncertainty with respect to who should or even *could* regulate the Internet in the realm of public governance. Information on the Internet can cross hundreds of international boundaries within nanoseconds, leading numerous early cybertheorists and courts to conclude that national control over the Internet was doomed to fail.[[188]](#footnote-188) In 1997, the Southern District of New York observed that “[t]he Internet is a network of networks—a decentralized, self-maintaining series of redundant links among computers and computer network” and concluded that “[n]o organization or entity controls the Internet; in fact, the chaotic, random structure of the Internet precludes any exercise of such control.”[[189]](#footnote-189) The court nonetheless determined that laws such as the Commerce Clause could reasonably apply to the Internet and found that a New York law prohibiting the use of a computer to distribute obscene material impermissibly violated this clause by regulating conduct outside of New York’s borders.[[190]](#footnote-190)

Given the lack of any clear governmental control over the Internet, private standards provided critical jurisdictional certainty in this space, with the IETF essentially initially serving as the international rule-setting body for the Internet.

In summary, the Internet provided early lessons that would foreshadow the importance of self-regulatory standards in numerous emerging, complex industries. At the same time, the development of standards for the Internet demonstrates the challenges of self-regulation–challenges that are familiar to anyone working to develop the hydrogen economy.

### C. Artificial Intelligence at the Cusp of Standards Development and Coordination

The field of AI differs in some respects from the two case studies explored thus far, although it, too, is emergent and “critical” in the sense of offering potentially world-changing benefits yet also substantial harms. AI as defined by NIST is “an engineered or machine-based system that can, for a given set of objectives, generate outputs such as predictions, recommendations, or decisions influencing real or virtual environments.”[[191]](#footnote-191) Large language models such as ChatGPT, in turn, are a common and rapidly changing form of AI and involve “a large-scale probability machine that predicts what word should follow next based on the data it has been trained on.”[[192]](#footnote-192)

AI has been used for important applications in health, such as including “[p]redictors of health deterioration” within platforms that store health records, making health risk predictions at individual medical facilities, and identifying patients that should be transferred to intensive care.[[193]](#footnote-193) AI has also helped to detect fraud or money laundering in financial systems, among other important applications (in addition to trivial ones, such as advanced recommendations for website perusal and shopping destinations).[[194]](#footnote-194) The technology is so game changing that one frequently hears forecasts that it will end work as we know it.[[195]](#footnote-195)

We briefly explore AI as a case study, despite some differences from hydrogen and the internet, because it is one of the most prominent examples of an emerging industry, and its regulatory journey—both private and public—is only just beginning. In terms of its differences from our other two examples, AI as an industry is not particularly networked. It does not involve a group of disparate technologies and practices in different business sectors that require coordination in order for the industry to be effective.[[196]](#footnote-196) Many AI applications draw and connect massive amounts of data from a variety of sources, however, and AI’s use in third-party applications through plugins requires some degree of coordination.[[197]](#footnote-197) Also in contrast with an industry such as hydrogen, the emergence of AI seems inevitable, rather than depending to a meaningful degree on the existence of standards to, for example, address coordination difficulties or allay public fears.[[198]](#footnote-198) Yet, as with our other case studies and additional examples explore here, AI’s trajectory will in large part depend on the effectiveness of some combination of public and private standards. For example, some experts have expressed concerns about emerging regulations that create “significant precedent,” in a negative sense, for the industry, such as deletion of entire machine learning models and algorithms by regulators.[[199]](#footnote-199) And as discussed below, there have already been bans and threatened temporary suspensions of AI products such as ChatGPT.

Despite some differences from the other case studies here, the role of private standards and the emerging application of existing public laws to AI shows just how important a suite of public-private rules can be to address the externalities of an emerging industry and to fill jurisdictional gaps as the industry rapidly expands. It also demonstrates the importance of both government actors and NGO actors in helping to coordinate private and public standards as they emerge, similar to the hydrogen story.

1. Regulatory Gaps and Uncertainty

Few existing U.S. statutes or regulations directly apply to AI, and private standards are only slowly emerging. Some would argue that the relative dearth of public governance is beneficial given the highly complex and technical nature of AI that would lead to “clumsy” and quickly-outdated public regulation.[[200]](#footnote-200) But in the same breath, those acknowledging the benefits of self-regulation for AI also worry that self-regulation in this area lacks adequate enforcement mechanisms and the concern that self-regulatory mechanisms would not be mandatory.[[201]](#footnote-201)

The primary means of public regulation of AI has been through the Federal Trade Commission, which monitors for and enforces issues such as deceptive advertising in AI (unsupported claims that it can perform in a superior way to other products, for example).[[202]](#footnote-202) The FTC has also used its jurisdiction over deceptive and misleading claims to enforce AI’s misleading of web users through practices such as “deepfakes and chatbots.”[[203]](#footnote-203) Further, it is enforcing companies’ use of fraudulently or misleadingly obtained data in algorithms, in some cases requiring algorithmic deletion—“the ordered deletion of computer data models or algorithms that were developed with improperly obtained data.”[[204]](#footnote-204)

Beyond the application of long-running standards for fraudulent and deceptive trade practices to this new technology, few public regulations apply to AI. This allows for potentially large negative externalities as AI grows. It also produces regulatory uncertainty, including bans and threats of bans and moratoria. For example, Italy temporarily effectively banned ChatGPT, alleging violations of EU data protection rules.[[205]](#footnote-205) And prominent industry leaders in the United States have called on the FTC to temporarily suspend ChatGPT releases, alleging unfair and deceptive data practices.[[206]](#footnote-206)

Private standards and best practices are emerging in several different forms, although they are so new that it is not yet clear how they will be enforced or how effective they will be. The Frontier Model Forum—a group of leading AI industries—launched in July 2023 and has not yet issued standards.[[207]](#footnote-207) The private standards already published by the Forum’s major members, however, may foreshadow the likely content of consensus standards. OpenAI—the producer of ChatGPT--has developed policies for usage; content guidelines; and policies for plugins that connect OpenAI to third-party applications, among other standards.[[208]](#footnote-208) Its list of prohibited uses is the most lengthy set of standards. To name just a few examples, OpenAI disallows “the use of our models, tools, and services for illegal activity”; sexual abuse; “hateful, harassing, or violent content”; “generation of malware”; activities with “high risk of physical harm” such as weapons development”; and activities with “high risk of economic harm” such as gambling and payday lending.[[209]](#footnote-209) OpenAI indicates that it will enforce these standards by asking the user of an OpenAI product to “make necessary changes” if a violation is discovered and potentially “suspending or terminating” a user’s account in the event of “[r]epeated or serious violations.”[[210]](#footnote-210)

SSOs are also beginning to take a gap-filling role, with the National Institute of Standards and Technology (NIST) releasing an AI Risk Management Framework in January 2023.[[211]](#footnote-211) This is a voluntary set of standards designed to “to improve the ability to incorporate trustworthiness considerations into the design, development, use, and evaluation of AI products, services, and systems” and, accordingly, “to better manage risks to individuals, organizations, and society.”[[212]](#footnote-212) This consensus-based document, informed by several workshops with public and private stakeholders, a request for information, and public comments, identifies seven central “characteristics of trustworthy AI systems,” such as systems that a “safe,” “secure & resilient,” and “privacy-enhanced.” It then defines these characteristics in detail and provides examples—at a broad level—of how the characteristics can be achieved. For instance, under the characteristic of an “accountable and transparent” AI system, the Framework notes that “[t]ransparency should consider human-AI interaction: for example, how a human operator or user is notified when a potential or actual adverse outcome caused by an AI system is detected.”[[213]](#footnote-213) The document also notes that AI actors should adjust their actions in a manner that is proportionate to potential harm, such as “when life and liberty are at stake” as a result of an AI system.[[214]](#footnote-214)

Public law directed specifically at AI is sparse, although the federal government has defined AI by statute (in the John S. McCain National Defense Authorization Act of 2019), and President Trump issued policy guidance on AI in Executive Order 13859 in February 2019 and an associated Office of Management and Budget memorandum.[[215]](#footnote-215) The memorandum emphasized a hands-off approach to AI regulation, stating:

. . . Federal agencies must avoid regulatory or non-regulatory actions that needlessly hamper AI innovation and growth. Where permitted by law, when deciding whether and how to regulate in an area that may affect AI applications, agencies should assess the effect of the potential regulation on AI innovation and growth. While narrowly tailored and evidence-based regulations that address specific an identifiable risks could provide an enabling environment for U.S. companies to maintain global competitiveness, agencies must avoid a precautionary approach that holds AI systems to such an impossibly high standard that society cannot enjoy their benefits . . . .[[216]](#footnote-216)

The memorandum listed ten high-level principles that federal agencies should follow when considering AI regulatory or non-regulatory actions, including, for example, cost-benefit approaches, public participation in AI rulemaking, performance-based flexible regulation, and fairness and non-discrimination.[[217]](#footnote-217) A statute and executive order also guide the federal government’s use of AI.[[218]](#footnote-218)

Some older statutes directed at specific professions, such as pathology, also provide limits on the acceptable use of AI and requirements for the validation of algorithms.[[219]](#footnote-219) Beyond this, most federal governance of AI is designed to incentivize and further the growth of AI, through the creation of the National Artificial Intelligence Initiative (and a federal office by the same name) in 2020, and a $100-million National Science Foundation Investment in Artificial Intelligence Institutes.[[220]](#footnote-220)

2. Coordination of Emerging Standards

The standards emerging for AI are even more nascent than for hydrogen, and the coordination of standards seen in the hydrogen context has yet to occur. For hydrogen, industry associations have begun to coalesce around consensus standards, and the Department of Energy plays a coordinating role, highlighting gaps in the standards. The AI industry appears to be at an earlier point, with individual AI actors setting their own rules and only just beginning to coordinate themselves. Further, although the OMB has issued a guidance document for how public regulation of AI should proceed, there does not appear to a “coordinating champion” for public and private AI standards. The differences in approaches to private standards in the AI context—and differing opinions about the extent of public governance needed, were highlighted in a May 2023 congressional hearing on ChatGPT.

Sam Altman, the Chief Executive Office of OpenAI, testified extensively about the internal protocols that the company follows to protect privacy, police disinformation, protect children’s safety, ensure cybersecurity, improve accuracy, and deploy ChatGPT products safely. Altman cited to OpenAI’s Usage Policies (discussed above in Part III.C.1.) and noted that OpenAI uses “a combination of automated detection systems and human review to detect potentially violating behavior in order to warn users or take enforcement actions.[[221]](#footnote-221) He also, however, emphasized that “regulation of AI is essential” and noted that Open AI is working to apply the NIST AI principles to its models.[[222]](#footnote-222) Christina Montgomery, Chief Privacy and Trust Officer for IBM, focused more on the company’s self-regulation, emphasizing its creation of an AI Ethics Board, for example, and listing the specific steps taken to minimize risk from posed by OpenAI.[[223]](#footnote-223)

While operating with little coordination of standards on the domestic front, the U.S. AI community is also endeavoring to harmonize its emerging standards with international ones—an effort reminiscent of the early days of the Internet. Brookings, which has led some of the efforts in this space, notes its own forum for AI cooperation formed in collaboration with the Centre for European Policy Studies, as well as A G-7 Leaders Communique on AI and work on AI governance through “the US-EU Trade and Technology Council (TTC), the Global Partnership in AI (GPAI), [and] the Organisation for Economic Co-operation and Development (OECD).”[[224]](#footnote-224)

Overall, AI—one of the most nascent yet potentially transformative industries at the time of this writing—highlights well the role of standards in innovation. The U.S. government is pulling many of the traditional levers that enable and support innovation, such as forming national R&D centers through NSF and creating a federal office to issue incentives and support for AI. At the same time, the government is engaged in the delicate dance of considering its own new standards to mitigate the risks of AI—thus supporting public confidence in this emerging area—while recognizing that too many standards could backfire and hamper innovation. In the meantime, self-regulation is emerging in part due to recognition of the chilling effect that highly-publicized AI risks could have on the industry and the real threat of bans, as seen in Italy. Efforts to coordinate these standards through, for example, the Frontier Model Forum and government- and industry-led coordination efforts are still relatively young. The degree to which a suite of complementary public and private standards will support productive, transformative use of AI and curb potentially large negative harms--and effectively harmonize international standards to support the growth of the industry-- remains to be seen.

## IV. Lessons Learned

The observation in Part II.B.2. that private standards development has tended to *follow* commercialization of technologies—made by the president of the technical branch of the leading U.S. standards organization, ASME Standards Technology LLC—is an intriguing and frankly surprising one. How, after all, could an industry develop so fully—to the point of full commercialization—without standards guiding it and reassuring the public of the industry’s efficacy and safety? Hydrogen is perhaps one of the strongest exceptions to this rule, demonstrating the critical role of standards in an industry that has barely reached the pilot stage in many contexts. Failed efforts by California to produce a viable “Hydrogen Highway” are the result of many factors, but a lack of clear public or private standards for hydrogen fueling station safety may have proven a leading impediment—spurring the private NFPA and federal agencies to develop clear permitting guides and videos for hydrogen fueling stations in the more recent effort to scale up hydrogen.

With hydrogen, standards appear to be one determinant of whether the industry will flourish or once again fall by the wayside as a minor player in the energy sector. In the case of the Internet, standards, too, were critical for issues such as interoperability. For AI, the industry appears to have few impediments to growth; standards are essential not for its emergence, but to temper potentially harmful impacts and to harness this technology to produce meaningful benefits—i.e., medical breakthroughs rather than merely law essays re-formulated in the style of great jurist.

When is self-regulation critical to the emergence of a nascent industry, and what types of standards prove most effective in pushing such an industry toward a commercial, scaled-up, and net-positive state? A great deal of additional empirical analysis is essential to fully answer this question, but we offer initial thoughts here.

  Prior analyses of self-regulation suggest that industries with strong network externalities and path dependence, among other market factors, will gravitate toward self-regulation. With respect to network externalities, in which “the value of a product to consumers is heavily dependent upon its acceptance by other consumers,” the Internet clearly reflects this feature.[[225]](#footnote-225) The more individuals connect to the Internet, the more information is accessible and shared; the more localized networks that connect with others (perhaps most efficiently through shared, commonly understood standards), the more information flow there will be. With hydrogen, too, more consumer demand for hydrogen vehicles and associated fueling stations benefits individual hydrogen vehicle users. Path dependence, in which a choice of web programming language or type of hydrogen fueling station, can also affect the future feasibility of an industry, which tends to call for self-regulation.

Our exploration of the emerging hydrogen industry and associated standards, and the now mature Internet, suggests several other important lessons about industry features–particularly in *emerging* industries–that tend to suggest a need for self-regulation complemented by public governance. First, and perhaps foremost, is the importance of standards in a technical, networked industry that the public perceives to be high risk or highly novel. In the case of hydrogen, industry actors in the UK and US, among many other jurisdictions, have launched efforts totechnically address risk in order to support standards development and assuage public spheres, with UK gas distribution companies funding collective risk laboratories and the ASME producing numerous technical papers to inform hydrogen pipeline standards.[[226]](#footnote-226) In other, simpler industries, with fewer supply chain components and end uses and more familiar technologies, perhaps the industry, the public at large, and regulators are more willing to watch the industry emerge, learning of risks along the way and developing standards ex ante. Not so, it seems, in the hydrogen space.

Another feature of emerging industries that seemingly calls for relatively robust self-regulation is a more complex version of the network externalities story. Beyond involving a product that becomes more valuable the more widespread and adopted it becomes, emerging industries that seem to have benefited from–or even depended upon–industry standards involve a complex physical network with mutually dependent components. For hydrogen, these are the production facilities, pipelines, storage facilities, distribution lines, fueling stations, and vehicles. For the Internet, networked infrastructure is cyberspace–an “interdependent network of information systems infrastructures including . . . telecommunications networks, computer systems, and embedded processors and controllers.”[[227]](#footnote-227)

Beyond the need for standards duringthe commercialization process, hydrogen and the Internet inform questions regarding the *types* of standards that can be most effective in supporting this process. We have already noted the importance of standards buttressed by powerful technical proof. Beyond this need is the critical nature of standards coordination in an industry characterized by a complex network of production, transportation, distribution, and end use infrastructure and operation. For hydrogen, the Fuel Cell & Hydrogen Energy Association is pushing to identify and fill areas currently lacking in standards guidance and to mesh standards development processes toward a more coordinated end goal. Government actors, in turn, such as the National Renewable Energy Laboratory and Sandia National Laboratories, are helping to inform industry actors and the public of the relevant public and private standards—thus easing the permitting of new hydrogen infrastructure—and to support standards development. Additionally, individual standards development organizations are prodding others to improve hydrogen standards and fill gaps, as demonstrated by the CGA asking the NFPA to clarify some of its hydrogen storage standards and creating an advisory document while awaiting this clarification.

As is occurring with the now-mature Internet, as emerging industries such as AI grow and change over time, governance will evolve to represent a more complex mix of private and public regulations–often with public regulations incorporating many private standards by reference but also including new publicly-formed directives. And the debate between the merits of private and public standards will become more intense, as seen by the growing cacophony of voices concerned about self-regulation of Internet content and speech, among many other issues. Ultimately, the standards that seem most likely to expand within the public sphere are those defined by Larry Lessig as “regulating” standards–those that “limit liberty within” an activity to “advance a regulatory end,” such as public safety.[[228]](#footnote-228)  Indeed, Lessig noted that regulatory standards tend to be top-down.

Despite the likelihood of more top-down public regulation of emerging industries as they grow–with the Internet as a prime example–in some cases there are likely to be strong bottom-up additions of regulating standards emanating pioneered by SSOs and SROs, particularly if industry members of these organizations become concerned about unduly strict public regulation or interconnected risks that could cause the whole system to fail. In the case of hydrogen, particularly given stubborn public perceptions of risk in the form of fire and explosion, one or several high-profile incidents could doom the industry, as could the failure of a critical pipeline connected multiple producers to end-users. This could lead industry to continue to play an active role both in curating the coordinating standards (those that allowed the industry to exist in the first place) and the regulating standards, which improve safety, public perception, and other aspects of the now-functioning industry.

# Conclusion

An interesting yet high-stakes experiment in innovation is currently playing out within the United States and globally. It is unclear at this juncture whether extensive global efforts to create a viable hydrogen economy will follow the path of California’s doomed Hydrogen Highway or meet a happier fate. And we cannot now know just how transformative AI will be, and the extent and degree of the risks of this massive technological change.

The role of standards in the future story of these industries is a critical one and provides lessons well beyond the limited spheres explored here, be it the development of advanced medical treatments and vaccinations, self-driving vehicles, and other potentially beneficial technologies currently only on the cusp of commercialization. Indeed, the fate of self-driving vehicles—while not involving the types of coordination challenges seen in the hydrogen context—has many parallels with hydrogen and other portions of the AI industry,[[229]](#footnote-229) including an evolving suite of public and standards, some developed more than others; a great deal of public uncertainty and trepidation with respect to risk, and the lack of complete standards serving as an apparent obstacle to further commercialization. Some states have well-developed rules for self-driven cars, whereas others have no rules. As with hydrogen and other AI fields, the federal government also lacks standards in key areas, with the National Highway Traffic Safety Administration only requiring *reporting* of automated vehicle crashes in 2021 and launching voluntary safety testing measures for automated vehicles in 2020.[[230]](#footnote-230) Some progress on substantive federal rules has been made, however, with the Department of Transportation and NHTSA issuing the Federal Automated Vehicles Policy in 2016—a step not yet taken for hydrogen or areas of AI such as large language models.[[231]](#footnote-231)

Will a global clean hydrogen economy emerge and become part of the solution to climate change? Will AI become a central, productive, and effectively regulated part of most aspects of human life? Much of this depends on the success of the technological development currently supported by a growing suite of industry standards. Ultimately, economics, consumer confidence, and dynamics in other industries are likely to determine the fate of these types of emerging industries. But private standards supported and complemented by public governance will have played a critical role along the winding path of this nascent industry, just as they have and will continue to do for numerous nascent industries.

1. \* Associate Professor of Law, Texas A&M University School of Law. [↑](#footnote-ref-1)
2. \*\* Professor of Law; Professor, College of Earth and Mineral Sciences;  
   Co-funded Faculty – Institutes of Energy and the Environment; Co-Director, Center for Energy Law and Policy, Penn State University—University Park. Thanks to Ibrahim Badawi, Logan Vonada, Daniel Boadi, and Matthew Finnegan for research support through the Penn State Center for Energy Law & Policy, and to the George Mason University Law & Economics Center for its financial support of this project. We are grateful for all the comments we received in presenting this research at the Law & Economics Center’s Workshop on Self-Regulation and at the Texas A&M University School of Law EnviroSchmooze. [↑](#footnote-ref-2)
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4. By self-regulation, we refer to standards written and administered by independent privately-run standards setting organizations (SSOs) or by consortia of firms who form self-regulatory organizations (SROs). Self-regulation has a much broader definition, *see infra* Part I, but we focus on this subset—a particularly large subset—of self-regulation. [↑](#footnote-ref-4)
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