An Actor-Network Theory Analysis of the Failure to Develop California's Proposed "Hydrogen Highway Network"

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Brenna Bartholomew

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor
Benjamin Laugelli, Department of Engineering and Society

Introduction

On April 20th, 2004, Governor Arnold Schwarzeneggar of California signed Executive Order S-7-04, calling for the rapid commercialization of hydrogen fuel cell technologies with the intent to transform California's interstate system into a vast network of hydrogen fueling stations, dubbed the "California Hydrogen Highway Network" (Exec. Order No. S-7-04, 2004). The state legislature drafted a plan soon thereafter which outlined the development of 50-100 hydrogen fueling stations along California's highways by 2010 (Romm, 2006). Yet by 2012 only six fueling stations were operational and open to the public, and today the number has barely reached 60 (California Fuel Cell Partnership, 2012**;** California Energy Commission, 2022).

The failure of this proposed system is often attributed to the technical shortcomings of hydrogen fuel cell technology, including difficulties with hydrogen storage and transportation, as well as the considerable economic hurdles for both hydrogen powered vehicles and fueling stations (Ellison, 2004). However, these outlooks fail to consider social and conceptual factors that contributed to the system's lack of success, including political actors, environmental organizations, and consumers themselves. If we continue to focus solely on the technical challenges facing new hydrogen infrastructure projects, we will fail to fully understand how non-technical actors influence the timeline and trajectory of these projects, and similar proposals for green vehicle technology may face failures in the future unrelated to their technical feasibility.

Drawing on Actor-Network Theory, I argue that hydrogen storage difficulties, in conjunction with the inhibitive costs of hydrogen vehicles and fueling stations, misalignment of consumers' perceptions, environmentalist skepticism, and diminished support from the federal government, led to the failure and continuing struggles of California's "Hydrogen Highway

Network." Actor-Network Theory seeks to understand how different actors, both technical and non-technical, interact to accomplish a specific goal and are recruited by a network builder to form a technological network (Cressman, 2009). Utilizing this concept, I analyze how the California Hydrogen Highway Network struggled to develop in order to understand both the human and non-human actors involved in hydrogen infrastructure projects. To support my argument, I analyze studies examining California vehicle consumers' perceptions of hydrogen technology, articles published by The Sierra Club, and budget data from the federal government.

Literature Review

While a small amount of research exists on the causes behind the failure of California's hydrogen highway, these analyses usually focus on the limitations of the underdeveloped technology involved in the proposed infrastructure. Other works that have looked at obstacles the project faced at the time of its proposal cited similar technological concerns, as well economic hurdles such as the high cost of hydrogen vehicles and fueling stations. While these are both certainly contributing factors to the project's failure, these analyses only hint at the socio-technical forces at play in this project's development and do not fully analyze additional social actors.

In "California's Hydrogen Highway Reconsidered," Joseph Romm explains the project's poor performance at the time of the article by discussing the various technological challenges that hydrogen vehicles face, including "on-board storage issues," limited range, and a need for new, innovative materials to solve these problems (Romm, 2006). He also describes " high fueling costs," including the immense costs to produce and transport hydrogen, stating that "We are many decades away from a time when hydrogen cars could be a cost-effective greenhouse

gas mitigation strategy" (Romm, 2006). While the article touches on the need for government investment and support, Romm stops short of analyzing the political factors present in the highway's struggles.

In a similar vein, Katherine Ellison outlines the technological uncertainties that the project faced at the time of its conception in 2004. Once again, hydrogen storage was noted as an outstanding problem that needed to be addressed, as well as how to decide on the specific technology that would be implemented to power hydrogen vehicles (Ellison, 2004). The article also addresses the economic barriers to the project, arguing that "the cost of hydrogen power… is bound to be more expensive than oil for some time" and raising concerns over the expensive nature of personal hydrogen vehicles (Ellison, 2004). By discussing the immense cost of hydrogen vehicles, Ellison alludes to the consumer as a social actor at play in this network, but does not directly consider the consumers' role in the highway's success or failure.

Although there is certainly a need to learn from the technological deficiencies of the hydrogen highway in its early stages, there is also value in examining the other actors that failed to coalesce to form a cohesive network. The current understanding frames the introduction of hydrogen vehicles and fueling stations as a purely technological and economic issue without considering how additional social and conceptual actors may contribute to or exacerbate these obstacles. In this paper, I elaborate on the failings of California's hydrogen highway by examining several social actors, including vehicle consumers, environmental organizations, and the federal government, and their role in preventing the hydrogen highway network from achieving the success its architects originally envisioned.

Conceptual Framework

Actor-Network Theory (ANT) provides an effective socio-technical framework through which to analyze the complex network of California's proposed hydrogen highway. ANT studies technological artifacts not as isolated agencies, but as pieces of larger technological networks made up of diverse actors that come together to achieve a common purpose. Actors in these networks are heterogeneous, meaning they can be human or non-human, and they can often be broken into several different categories, including social, technical, conceptual, natural, and economic (Cressman, 2009). Additionally, any technology can be seen as either a discrete actor or as a network of many diverse actors, depending on the perspective and boundaries of the analysis.

ANT seeks to understand the relationships between different actors that make up a technological network, such as governments, people, concepts, and machines, and how they interact to either develop a strong network or work against each other, leading to a network's collapse (Cressman, 2009). Identifying and analyzing these associations can be used to understand power dynamics in a network and how some networks become more influential and durable than others. At the heart of each technological network is a network builder who identifies the problem or cause that the network seeks to address, as well as the actors needed to accomplish this goal (Cressman, 2009). The network builder then recruits these actors and attempts to realign their interests to match those of the network. The process through which these actors are recruited and connected to form the network is known as translation (Cressman, 2009).

Drawing on Actor-Network Theory, in the analysis that follows I begin by identifying three different human, social actors that played a role in the hydrogen highway: vehicle consumers, environmental organizations, and the federal government. Through analysis of each

of these actors' beliefs, perceptions, and support of hydrogen power at the time of this project's conception, I examine how they were interconnected and influenced not only the network as a whole, but also each other. Based on this analysis, I argue that these three actors were never fully recruited and incorporated into the hydrogen highway network, stopping the process of translation short and inhibiting the system from successfully developing into a stable, flourishing network.

Analysis

In Governor Arnold Schwarzenegger's 2004 State of the State address, he confidently declared, "I'm going to encourage the building of a hydrogen highway to take us to the environmental future… I intend to show the world that economic growth and the environment can coexist." (Schwarzenegger, 2004). Several months later in April of 2004, Governor Schwarzenegger signed Executive Order S-7-04, setting in motion his plans for the development of the California Hydrogen Highway Network. Responsibility for building this network was quickly passed to several agencies within the California government, including the California state legislature, which drafted a blueprint plan for the project's development, as well as the California Air Resources Board and California Energy Commission (California Air Resources Board, n.d.). Since responsibility for this project was shared by many different groups within the government, the California government as a whole can be viewed as the network builder for this system.

Many different actors have contributed to the progress and struggles of this network. Often cited primary technical actors include the hydrogen fuel cell technology in vehicles and hydrogen storage and transportation technology, while economic actors include the costs of

building hydrogen fueling stations and hydrogen fuel cell vehicles (HFCVs) (Romm, 2006; Ellison 2004). Less considered actors, which are equally as important in building and maintaining this network, are social and conceptual actors, such as consumers, car manufacturers, environmental organizations, governments and their policies, perceptions of hydrogen and its safety, and oil and gas companies (Martin et al., 2009; Birdsong, 2005; Slater, 2004; Service, 2009). Many of these groups are interconnected, influencing each other with their decisions and preventing or encouraging others to align with the network. In the following paragraphs, I highlight three important social actors — vehicle consumers, environmental organizations, and the federal government — and analyze how the actions and beliefs of each group contributed to the failure of the California Hydrogen Highway Network.

Vehicle Consumers

Vehicle consumers are a key actor necessary for creating demand for a hydrogen fueling system. Yet it seems that consumers were never adequately educated on the technology and performance of hydrogen vehicles and were not actively recruited into the network. In the 2009 study "Behavioral response to hydrogen fuel cell vehicles in refueling: Results of California drive clinics," University of California, Berkeley researchers sought to examine California consumers' reactions to HFCVs by recording their perceptions before and after taking a test-drive (Martin et al., 2009). Researchers first surveyed participants' prior experience with alternative fuel vehicles and found that "Roughly 86 percent of respondents considered themselves to have no experience with hydrogen," further concluding that "Although California has led the nation in hydrogen deployment, opportunities for respondents to see hydrogen vehicles outside the clinic are limited," and "obtaining exposure to a hydrogen vehicle would have been difficult for people in the region" (Martin et al., 2009).

These findings indicate a failure on the part of the California government in their outreach efforts towards consumers to educate and encourage the use of HFCVs. By neglecting to create opportunities for consumers to engage with hydrogen vehicles, whether through test-drive events or public information sessions, for example, the California government left a key actor ignorant to the performance and potential of the technology. With limited knowledge of the new vehicles, there was no personal connection and limited incentive for consumers to join the hydrogen network by switching from their prevailing vehicles of choice. The government of California could not realign consumers' interests to match those of the network because consumers had no reason to change their vehicle interests with limited knowledge about the alternatives.

Martin et al. (2009) further observed that inexperience with HFCVs correlated to lower perceptions of the technology and especially its safety. The percentage of respondents who reported positive overall impressions of HFCVs and vehicle and refueling safety increased after test-driving and interacting with an HFCV at the clinic (Martin et al., 2009). These results highlight that consumers were not inherently resistant to HFCVs or new vehicle technology. With proper engagement and increased education, consumers felt more comfortable with the technology, possibly indicating an increased likelihood to purchase or use HFCVs. However, with limited means to engage with the new technology, as Martin et al. (2009) stated before, a widespread rise in public knowledge and comfort never occurred. Without consumer awareness or ease with the vehicles, demand for HFCVs and their refueling stations struggled to rise, in turn inhibiting the recruitment of other actors, including car manufacturers and oil and gas companies.

Vehicle consumers in California were a key social actor necessary for building the foundation of the hydrogen highway network, yet they were left uneducated and unaware of the new technology, leaving them unable or unwilling to join the network. One could argue that the hydrogen highway did not necessarily need consumers in the beginning of its formation in order for the network to succeed. Constructing these fueling stations could be seen simply as a matter of supplying the building materials, developing the fueling technology, and obtaining investments from oil and gas companies, with consumer support following later once these stations were in place. However, this approach does not consider the fact that companies are usually unwilling to invest in projects when there is uncertainty about the return on their investment. As Annie Birdsong notes in an article for World Watch magazine, there exists a "chicken or egg problem" with hydrogen in which companies are reluctant to invest in fueling infrastructure if few vehicles will use it, and auto manufacturers have tended to suppress large-scale production of HFCVs due to a lack of infrastructure (Birdsong, 2005). To avoid this problem, both the fueling stations and the widespread use of HFCVs need to grow in parallel, which requires the support and participation of vehicle consumers. California consumers should have been recruited at the beginning of this project to ensure the construction of a durable and stable foundation on which the network could succeed.

Environmental Organizations

Another seemingly distant, though highly influential, social actor that contributed to the struggles of the California Hydrogen Highway Network were environmental organizations like the Sierra Club. The hydrogen highway plan was devised as a way to reduce carbon emissions in California and promote green, climate-friendly technology. However, the project's promotion as an infallible green solution to traditional vehicles faltered without the full support of climate

organizations. In a 2004 *Sierra* magazine article titled "Elemental Dreaming," Dashka Slater argues that hydrogen is not the miracle solution it is touted to be because the gas is largely produced from fossil fuels. Quoting the director of the Sierra Club's Global Warming and Energy Program, Slater compares the approach to "a nicotine patch that causes cancer" (Slater, 2004).

Not only does Slater denounce hydrogen as the next greatest solution to the world's energy problem, but she depicts it as almost repulsive, portraying it as a toxic solution to an already toxic habit. Lending hydrogen such a negative connotation persuades readers and followers of the Sierra Club to grow wary of the use and promotion of hydrogen as an alternative fuel. The Sierra Club dismantled the image Governor Schwarzeneggar and his administration had built of the project as an impressive step towards California's green future, a harsh critique that contributed to reducing the credibility and the validity of the goal of the hydrogen network, likely detracting support. As a prominent voice in California, and the United States, the Sierra Club's views had influence over those of other actors involved in the network, including consumers, investors, and politicians.

This influence can be seen in the directions and information they gave to their readers as well. The following year, in a 2005 *Sierra* magazine article titled "The Perfect Fix," two authors outline steps everyday consumers can take to reduce their carbon footprint in their homes, offices, and through their means of transportation. In discussing options when buying new cars, the authors direct readers away from HFCVs, writing "Fuel-cell-powered cars are a decade or more away, but HYBRID VEHICLES are already on the streets" (McCourt & McManus, 2005). Here, the authors denounce HFCVs not because of the carbon-intensive means of hydrogen production, but because they were not the fastest means to reduce vehicle emissions. In this

sentence alone, the authors cast doubt on the viability and readiness of the technology and give readers a call to action in direct opposition to the hydrogen highway network.

By printing "HYBRID VEHICLES" in capital letters, the authors emphasized the importance of hybrid alternatives, even lending their use a sense of urgency. The phrase stands out to readers and is more likely to remain in their minds than the term "fuel-cell powered cars" which was quickly glossed over and dismissed. The article is persuasive in its promotion of hybrid vehicles over HFCVs, in both its content and style, and directly calls on readers to oppose the hydrogen highway network by buying hybrid vehicles instead. Readers of *Sierra* magazine are presumably environmentally conscious consumers who are likely to consider their climate impact in their purchases. Through this article, the Sierra Club directed an entire group of consumers, who would otherwise be interested in new, green vehicle technology, away from HFCVs and towards alternative, hybrid vehicles. In this way, environmental organizations like the Sierra Club influenced the decisions of consumers, contributing to their inability or unwillingness to join the hydrogen highway network.

The Federal Government

Finally, although the California Hydrogen Highway Network was a state-level initiative, support from the federal government, or lack thereof, was a crucial actor that worked against the formation of the network. Federal funding is often critical to support the research and development of advanced technologies, but with frequent administration turnover, funding can be intermittent or uncertain. In 2003, President Bush announced a federal hydrogen fuel initiative, investing "$1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles," paving the way for Governor Schwarzenegger's creation of the hydrogen highway project (U.S. Department of Energy, n.d.).

However, six years later the Obama administration reversed the federal government's support of hydrogen fuel cell research, drastically reducing its funding. Figure 1 provides excerpts from the Department of Energy's (DOE) itemized congressional budget request for the 2010 fiscal year, with the relevant hydrogen technology lines outlined in red (U.S. Department of Energy, 2009).

Figure 1

Excerpts from the Department of Energy's Congressional Budget Request for 2010

Department of Energy
FY 2010 Control Table by Organization
(dollars in thousands - OMB Scoring)

	FY 2008 Current Approp.	FY 2009 Current Approp.	FY 2009 Current Recovery	FY 2010 Congressional Request	FY 2010 vs. FY 2009 $	FY 2010 vs. FY 2009 %
Assistant Secretary For Energy Efficiency And Renewable Energy						
Energy Efficiency and Renewable Energy						
Energy Efficiency and Renewable Energy RDD&D						
Hydrogen technology	206,241	168,960	43,400	——	-168,960	-100.0%
Fuel cell technologies	——	——	——	68,213	+68,213	N/A
Biomass and biorefinery systems R&D	195,633	217,000	786,500	235,000	+18,000	+8.3%
Solar energy	166,320	175,000	——	320,000	+145,000	+82.9%
Wind energy	49,034	55,000	118,000	75,000	+20,000	+36.4%
Geothermal technology	19,307	44,000	400,000	50,000	+6,000	+13.6%
Water power	9,654	40,000	——	30,000	-10,000	-25.0%
Vehicle technologies	208,359	273,238	——	333,302	+60,064	+22.0%
Building technologies	107,382	140,000	——	237,698	+97,698	+69.8%
Industrial technologies	63,192	90,000	50,000	100,000	+10,000	+11.1%
Federal energy management program	19,818	22,000	——	32,272	+10,272	+46.7%
Advanced Technology Vehicles Manufacturing Loan Program						
Direct loan subsidy costs	——	7,500,000	——	——	-7,500,000	-100.0%
Administrative expenses	——	10,000	10,000	20,000	+10,000	+100.0%
Total, Advanced Technology Vehicles Manufacturing Loan Program	**——**	**7,510,000**	**10,000**	**20,000**	**-7,490,000**	**-99.7%**

Under President Obama, the DOE cut all funding for hydrogen technology research between 2009 and 2010, in favor of other advanced vehicle technologies, such as electric vehicles (EVs). Some funding for fuel cell technologies was retained, but largely for stationary systems, not vehicles (U.S. Department of Energy, 2009). Ending federal funding meant that outstanding technological issues the hydrogen highway faced, including difficulties with hydrogen storage and transportation, were no longer a priority or concern of energy research and could not be solved as rapidly. Following the budget cuts, California had to rely on state-level research initiatives or the innovation of private vehicle and fuel companies, and struggled to

solve all of the technological issues it needed to overcome by itself. Without the federal government's sustained support, the technical actors necessary in the hydrogen network could not be fully developed and implemented.

Additionally, this decision signaled a lack of confidence in the potential and likelihood of HFCVs succeeding in the near future. According to Energy Secretary Steven Chu, in making the decision to cut hydrogen funding, "We asked ourselves, "Is it likely in the next 10 or 15, 20 years that we will convert to a hydrogen car economy?' The answer, we felt, was 'No'" (Service, 2009). Cutting funding and portraying hydrogen as a dead-end technology weakened California's hydrogen highway in the view of its other actors. Diminished support from the federal government signaled a reason for consumers, car manufacturers, and oil and gas companies to reduce their support and confidence in the program as well. Just as the Sierra Club dismantled the idea that the hydrogen highway was the next foolproof step to a fossil fuel-free future, the DOE cast aside the belief that widespread use of HFCVs was right around the corner and took actions that not only reflected this conviction, but which also contributed to it coming true. In failing to sustain support for hydrogen technology, the federal government contributed to the hydrogen highway's difficulties in successfully recruiting actors, both technical and social, that it needed to succeed.

Conclusion

Through the sociotechnical framework of Actor-Network Theory, I have argued that the struggles of the California Hydrogen Highway Network were not solely due to technical and economic obstacles, but also due to the wavering support and decisions of various social actors present in the network. Vehicle consumers were a key actor that the California government

needed to recruit from the beginning to build a strong foundation, yet they neglected to do so. Environmental groups, especially the Sierra Club, actively worked against the network, inhibiting the recruitment of other actors through their influence on consumers, while the federal government's failure to sustain funding for hydrogen research resulted in the inability to fully develop technology necessary for the network.

In order to effectively implement new energy technologies in the future, both the technical and social aspects of the issue must be addressed. Analyzing the social relationships, power dynamics, and lines of influence in an emerging technological network such as the hydrogen highway are critical for understanding how a new vehicle technology can either succeed or fail. In the deployment of net-zero emission technologies, engineers should consider the various social actors present in order to ensure their successful introduction and strive towards a cleaner, carbon-neutral world.

References

Birdsong, A. (2005). California drives the future of the automobile. *World Watch*, *18*(2), 26–30.

California Air Resources Board. (n.d.). *Hydrogen fueling infrastructure*. California Air Resources Board. Retrieved February 22, 2023, from https://ww2.arb.ca.gov/our-work/programs/hydrogen-fueling-infrastructure/about

California Energy Commission. (2022, September 30). *Hydrogen refueling stations in California*. Retrieved October 18, 2022, from https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/hydrogen-refueling

California Fuel Cell Partnership. (2012). *A California road map: Bringing hydrogen fuel cell electric vehicles to the Golden State*. https://h2fcp.org/sites/default/files/20120814_Roadmapv(Overview).pdf

Cressman, D., (2009) *A brief overview of actor-network theory: Punctualization, heterogeneous engineering & translation.* ACT Lab/Centre for Policy Research on Science & Technology, School of Communication, Simon Fraser University. https://summit.sfu.ca/item/13593

Ellison, K. (2004, December 1). The road to the hydrogen highway. *Frontiers In Ecology & the Environment*, *2*(10), 560.

Exec. Order No. S-7-04, 4489-4492 (2004). https://www.library.ca.gov/wp-content/uploads/GovernmentPublications/executive-order-proclamation/4489-4492.pdf

Martin, E., Shaheen, S. A., Lipman, T. E., & Lidicker, J. R. (2009). Behavioral response to hydrogen fuel cell vehicles and refueling: Results of California drive clinics. *International Journal of Hydrogen Energy*, *34*(20), 8670–8680. https://doi.org/10.1016/j.ijhydene.2009.07.098

McCourt, S., McManus, R. (2005). The perfect fix. *Sierra Magazine*. https://vault.sierraclub.org/sierra/200507/perfectfix.asp.

Romm, J. (2006, March 15). California's hydrogen highway reconsidered. *Golden Gate University Law Review*, *36*(3), 393 - 412.

Schwarzenegger, A.A. (2004, January 6). *State of the State Address* [Speech transcript]. The Governor's Gallery, California State Library. https://governors.library.ca.gov/addresses/s_38-schwarzenegger1.html

Service, R. F. (2009). Hydrogen cars: Fad or the future? *Science*, *324*(5932), 1257–1259. https://doi.org/10.1126/science.324_1257

Slater, D. (2004). Lay of the land: Elemental dreaming. *Sierra Magazine*. https://vault.sierraclub.org/sierra/200405/lol.asp.

U.S. Department of Energy. (2009, May 6). *Department of Energy FY 2010 Control Table by Organization*. https://grist.org/wp-content/uploads/2009/05/orgcontrol.pdf

U.S. Department of Energy. (n.d.). *Hydrogen Program - Background*. Office of Energy Efficiency and Renewable Energy. Retrieved February 26, 2023, from https://www.hydrogen.energy.gov/background.html