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The dimensions of the policy debate over transportation energy: The case of hydrogen in the United States

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Abstract

Environmental and politico-strategic concerns have driven the increase in policy activity related to energy that the United States witnessed in the last few years. The nature of the issues at stake and the level of stakeholder involvement result in a highly complex policy debate. The broad concern of this paper is the study of this energy-policy process and the identification of the main policy issues. Specifically, multivariate analysis is applied to data on a wide variety of stakeholders' policy beliefs and policy preferences to identify the policy dimensions that characterize the debate over energy policy in the United States. The focus is on the policy debate over hydrogen as a transportation fuel, although many results are applicable to the debate over transportation energy at large. The analysis uses a dataset of 502 individuals from 323 different stakeholder organizations obtained via a web-based survey specifically designed for this study.

Keywords: Policy process; Hydrogen; Transportation energy policy

1. Introduction

These are exciting times for everyone interested in energy policy. Fundamental questions related to the societal and strategic implications of the way we provide for our energy needs have installed themselves in the policy debate in a way reminiscent of the late 1980s. Thirty years ago, policy activity on transportation energy rose driven predominantly by concerns over urban ambient air quality, and resulted in such landmark statutory pieces as the 1990 Clean Air Act Amendments, California's Sher Act of 1988, and the California Low-Emission Vehicle and Clean Fuels program. The dominant issue then was essentially domestic in nature. In the 21st century, and after dramatic improvements on ambient air quality, stronger awareness about the finiteness of recoverable oil reserves, and the rise of a virtual consensus about the causal link from carbon emissions to global climate disruption, the nature of the dominant policy issues became international.

Also reminiscent of the late 1980s, much of the policy discussion on transportation energy that we witness today is directed to finding paths away from the status quo. Because most of the oil consumed in the majority of the industrialized countries (with few exceptions like Canada and Norway) comes from foreign sources—leading to a sense of energy insecurity—and because every bit of carbon in petroleum fuels eventually ends up in the atmosphere, the bottom-line question has become "What is the best trajectory toward lower reliance on oil?" Every stakeholder in the transportation-energy arena—including oil companies—is mulling over this question.

My choice of the word "trajectory" is not fortuitous. Dosi (1982) defined "*technological* trajectory" as the direction of progress within a given technological paradigm.[1] Indeed, key to finding answers to the question just posed is technological progress and innovation. However,

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[1] Dosi (1982) introduced the notion of "technological paradigm", defined as "an 'outlook', a set of procedures, a definition of the 'relevant' problems and of the specific knowledge related to their solution" (p. 148)

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whenever policy elites believe that progress within the dominant technological paradigm may be insufficient to solve the policy problem, much of the policy debate starts focusing on paradigm shifts. In the 1990s, for instance, a new paradigm was proposed in the form of battery electric vehicles (BEVs).[2] In the 2000s, the proposed new paradigm took the form of hydrogen fuel-cell vehicles (FCVs).

While important lessons were learned during the policy process over BEV and FCV (Collantes, 2006), our understanding of how radical innovations and paradigm transitions take place and the role of public policy in inducing these processes is far from complete. Kemp (1997) argued that "what is missing in the policy debate [over a transition away fossil fuels] is a framework for understanding change in complex technology systems, especially how the dynamics of technology interact with the socio-economic system from which it emerges" (p. 290). Indeed, with debates over paradigm shifts, not only technology learning takes place—policy learning occurs as well through the complex interaction of stakeholders, each of who has her/his particular set of policy preferences. This paper is concerned with identifying the issues that define such policy debates—I refer to these issues as policy dimensions. As a case study, I use the recent policy debate over hydrogen in the US, which, as I will show, yields many results that may be generalized to the broader debate of transportation energy.

Typically, scholarly studies that identify the policy dimensions of a particular policy process are also concerned with the positions that affected stakeholders take along each of the policy dimensions (e.g. Jenkins-Smith and St. Clair, 1993; Zafonte and Sabatier, 2004; Weible and Sabatier, 2005; Collantes, 2006). The study herein presented covers a wider set of specific policy aspects than typical studies. The consequent abundance of data and results justifies focusing this paper only on the policy dimensions. I expect to discuss stakeholders' policy preferences in a separate paper.

I structure this paper as follows. In Section 2, I describe the methodology, including a conceptual model of the policy process concerned with technological innovation, the data-gathering process, and methods for data analysis. In Section 3, I present and discuss my findings on the policy dimensions that characterize the policy debate. In Section 4, I discuss my results and draw general conclusions.

2. Methodology

The analysis presented in this paper is part of a larger project aimed at understanding the dynamics of the policy process when significant technology progress is involved or pursued. The project focuses on the adoption of hydrogen as a transportation fuel. To guide the study and the associated data collection, the conceptual framework outlined in Section 2.1 was developed. The data-gathering process is described in Section 2.2, while the methods of analysis are detailed in Section 2.3.

2.1. Conceptual framework

Building upon existing theories of the policy process such as the Advocacy Coalition Framework (Sabatier, 1987, 1988; Jenkins-Smith, 1988) and Multiple Streams (Kingdon, 1984; Zahariadis, 1999), theories of organization decision making such as the Garbage Can (Cohen et al., 1972; Padgett, 1980; Bendor et al., 2001; Olsen, 2001), social psychology theories such as the theory of Planned Behavior (Fishbein and Ajzen, 1975; Ajzen and Fishbein, 1980), and my own studies of the policy process (e.g. Collantes, 2006; Collantes and Sperling, 2007), I developed a conceptual framework for the study of policy processes that involve technology innovation. The basic structure of the framework is shown in Fig. 1.

For the purpose of this paper, we need not dwell on the specifics of the theoretical foundations of the building blocks of the model or on how they integrate into an explanatory framework of the policy process. It suffices to explain the meaning of each of the concepts comprising the conceptual model shown in Fig. 1.

2.1.1. Policy beliefs

Policy beliefs are here understood as empirical perceptions and normative opinions about relevant policy questions and/or policy behavior. Essentially, empirical perceptions are subjective assessments of cause–effect relationships. One example would be a stakeholder's assessment of the level of abatement of anthropogenic emissions of carbon dioxide necessary to prevent severe disruptions of the global climate. Normative opinions are subjective value assessments of policy questions and/or

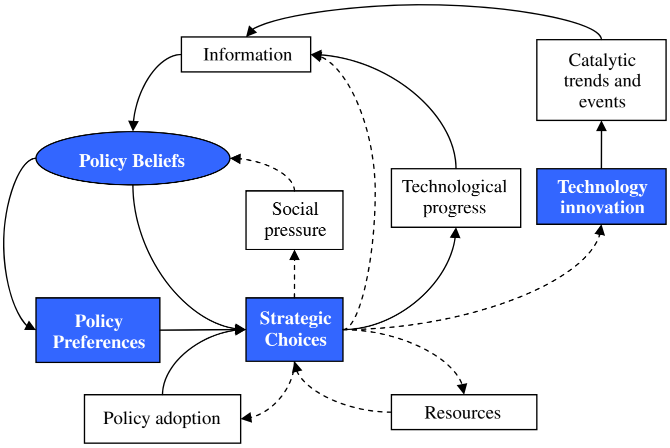

Fig. 1. Conceptual model of policy processes involving technological innovation.

(*footnote continued*)
One such technological paradigm is the petroleum-fueled internal combustion engine.

[2] The adoption of methanol as a transportation fuel also took center stage in the debates in Washington, DC, and California.

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behavior—they relate to the question of how policy-related behavior should or ought to be. Normative opinions are affected by empirical perceptions and by the expectations of relevant sectors of society (social pressure) weighted by the stakeholder's motivation to comply with social pressure.

2.1.2. *Policy preferences*

A policy preference is a behavioral intention and it can be defined as the level of support that a stakeholder is ready to give to a specific policy course of action. Reliable measures of true policy preferences are often difficult to obtain. Public statements on policy preferences can be more reliably considered a mix of true policy preferences and strategic behavior. In general, what a stakeholder expresses in a public setting (public hearing, media, conference, etc.). will be the result of her true policy preferences, the coordination with policy allies, and the expectations of the audience (e.g. peers, policy-makers, the general public, etc.) Such dissonance between true and stated may, to some extent, apply to policy beliefs as well.

2.1.3. *Social pressure*

Although indicated by a single block in the schematic in Fig. 1, social pressure encompasses a wide variety of mechanisms, internal and external to the stakeholder organization. One important form of internal social pressure is the organization's goals and/or interests. To some extent, organizations' goals may be affected by the expectations of their constituencies (e.g. members of environmental NGOs, corporate shareholders, elected-officials' constituents, the executive-branch office to which a regulatory agency responds, etc.) Examples of forms of social pressure external to the organization are market demand for consumer-good attributes and expectations of the public opinion regarding, say, pro-environmental behavior.

2.1.4. *Strategic choices*

Stakeholders' strategic choices are broadly defined as all stakeholders' activities directed toward the achievement of their strategic goals in the policy process. These activities can take myriad forms, including coalition formation, lobbying, partnership building, legislation drafting, education and outreach, budget allocations, public relations, policy implementation, policy enforcement, suit filing, research and development, publishing in scientific journals, testifying at congressional hearings, deploying a new technology, colluding, etc.

Specific concepts like coalition choices (ACF) and policy entrepreneurship (Multiple Streams) are encompassed by the broader concept of strategic choices. The inclusion of this concept in the model recognizes the behavioral complexity of the policy process, whereby multiple strategies are often pursued, either collectively or individually. Some of such activities are difficult to operationalize and measure, so it is often left to the researcher to decide which ones are amenable to treatment in each particular case.

2.1.5. *Catalytic trends and events*

The notion of catalytic trends/events captures the evolution of the policy problem—it denotes conditions, sometimes exogenous, that trigger, motivate, and/or provide a rationale for policy activity. Examples include the trend in ambient air quality, a natural disaster, a change in administration, and a disruption in energy supply. Such factors do not affect the policy process directly—as shown in Fig. 1, they are filtered through information to then affect stakeholders' set of beliefs. Strictly, it is not the problem per se that motivates the policy process, but rather the information available about it and the accepted information (scientific or otherwise) about the cause–effect relationship between the problem and how it affects society. Catalytic events/trends provide a subset of the stakeholders with robust storylines to "sell" their policy preferences to other players in the policy subsystem (predominantly the media and policy-makers).

2.1.6. *Technological progress and technological innovation*

The ultimate variable that I am interested in modeling is technological innovation, which is here understood as the commercial deployment of a technology sought after—explicitly or implicitly—by the policy process. Technological innovation is the result of a number of factors, some of which the policy process has no control over. For example, whether and when technologies may reach commercial maturity is, as a general rule, uncertain, often *highly* uncertain, and virtually always asymmetrically uncertain.

The policy process has more direct control over technological progress, a concept here defined as the measurable evolution of a technology toward a state of commercial maturity. Technological progress is fundamentally a function of research and development, which in turn is a function of resources—human and capital. Provided that meaningful resources are allocated for R&D in a given technology, the question is not whether that technology will undergo progress or not, but rather whether it will undergo *sufficient*—and sufficiently rapid—progress. This uncertainty is a central feature of technology-driven policy processes.

2.2. *Data*

In the context of a study of the policy process related to hydrogen as a fuel, I designed a web-based survey to collect information from a wide range of stakeholders. In May 2005, an email was sent to a sample of about 4000 individuals, from about 1450 different organizations in the US and many other countries, inviting them to take the survey. The target population is the set of stakeholder

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organizations that are active in the hydrogen policy process, most of which, it should be noted, are also active in other policy processes related to transportation energy. Details on the survey sampling scheme, respondents' characteristics, and general descriptive statistics, can be found in Collantes (2005).

The survey was designed to obtain information on the building blocks of the conceptual model in Fig. 1, in addition to respondents' characteristics. The policy questions ranged from general policy issues to technology-specific. The latter were mostly centered on hydrogen, since the main purpose of the study is to understand the policy debate over *hydrogen*—no assumption was made regarding the pros and cons of hydrogen vis-à-vis other alternatives. The survey elicits responses in support of as well as in opposition to hydrogen.

A total of 502 responses from 323 organizations were obtained, for an approximate 12% individuals' response rate and a 22% organizations' response rate. While I believe these response rates are encouraging taking into account that the survey targeted people with significant time constraints, I prefer not to assess the quality of the response based on response rates. I rather assess response quality by looking at two factors: (a) the distribution of responses across organization categories and (b) whether responses were obtained from key stakeholders.

Table 1
Respondents' organization categories

Organization category	Frequency	Comments
Automobile company	30	Most major companies represented
Oil energy company	13	Most major companies represented
Electricity energy company	20	
Natural gas provider	9	
Hydrogen production/supply	24	Five of these also represent an oil company
Hydrogen production/ dispensing equipment	14	
Fuel-cell developer	24	
Electric battery developer	11	
Government, federal	21	
Government, state	31	Majority in this group, from California
Government, local	16	Most in this group, from California
Regulatory agency	15	Most in this group, from California
Permitting official/office	2	Lower response than expected
University	63	
National laboratory	27	
NGO, environment	26	
NGO, health	4	
NGO, business	6	
Media	10	
Consulting	59	
Other	79	

I provided respondents with a list of categories of organizations and asked them to indicate all the categories that fitted their organizations. Table 1 shows the organization categories and the number of respondents with offices in the US falling within each of them. My analysis focuses on respondents based in the US. This choice follows two rationales. First, the sample is clearly dominated by such respondents (see Table 1). Second, administrative and political boundaries suggest that, for the stakeholder analysis of interest to this paper, it would be incorrect to mix the US subsample with those from other countries.

The US-based subsample is distributed across all the main organization categories targeted by the sampling scheme, with the exception of permitting officials from whom fewer responses than desired were obtained. I take this distribution as a measure of success in terms of response. Honoring the confidentiality agreement signed with the respondents, I cannot disclose the name of participant organizations. I can say, however, that responses were obtained from virtually all the key organizations in the policy debate. Based on these two parameters, I believe the quality of the response can be considered very high.

2.3. Methods

It would be difficult to draw useful conclusions by analyzing separately the responses to every single question in the survey. It is instead preferable to reduce the complexity of the information collected by means of appropriate statistical techniques. One such technique is factor analysis. Factor analysis identifies patterns of responses to sets of items (questions or statements). Groups of items with responses that tend to correlate with each other are often representative of an underlying concept or construct. Many concepts—for instance attitudes (toward the environment, etc.)—cannot be directly measured by means of a single item. Factor analysis can thus help to identify groups of items that can potentially represent underlying concepts and define measures (or factors) of such concepts.

Applying factor analysis to items in the survey, I obtain a number of policy constructs—measures of the policy dimensions that characterize the debate over hydrogen. To test whether the identified factors constitute reliable measures of an underlying construct, I use Cronbach's α. Typically, values of Cronbach's α bigger than 0.7 are considered to be indicative of a reliable construct (see, for example, Bollen, 1989, pp. 215–218, for a discussion of Cronbach's α reliability measure). The measures obtained in Section 3 constitute estimates of the constructs in the conceptual model (for example, policy beliefs and policy preferences) and could be used to test the model integration suggested in Fig. 1. For further details on factor analysis, the reader is referred to, for instance, Bollen (1989), Nunnaly and Bernstein (1994), and Rencher (2002).

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Table 2
Response frequency for influence questions

Influence question	1 = "Strongly disagree"	2 = "Disagree"	3 = "Neutral"	4 = "Agree"	5 = "Strongly agree"
A	16	48	78	142	63
B	10	24	69	144	106

3. Results

I now proceed to the analysis, to identify the various dimensions of the policy debate over hydrogen, as revealed by the data.

3.1. *Efficacy*

The notion of efficacy comes out of the political science literature and essentially denotes how influential a political actor perceives herself to be. Prewitt (1968) defines political efficacy as "the person's belief that political and social change can be effected or retarded and his efforts, alone or in concert with others, can produce desired behavior on the part of political authorities" (p. 225). The influence that a policy actor may have on the policy behavior of their respective organizations and on the policy process at large is determined by a variety of factors, such as level of expertise in a relevant field, organization size, rank or authority, and others. In the study of a policy process, understanding the landscape of ideas does not suffice—it is also necessary to establish a connection between the ideas and the influence of those who hold them.

I conceptualize efficacy as having two components: the individual's influence within her own organization and her organization's influence within the policy process. I operationalize this concept in the survey by means of the following two statements:

A. Policy-makers seriously consider the opinions of your organization on hydrogen technology/policy.
B. Your organization seriously considers your opinions on hydrogen technology/policy.

Table 2 shows the frequencies of responses for each of these questions, excluding missing values, for the US-based subsample.

Influence within organizations may materialize directly or indirectly, as decision-makers are likely influenced by organization members whom they consult with. About 71% of the US-based responses indicated either agreement or strong agreement with the statement that their opinions on hydrogen technology/policy are seriously considered by their organizations.

In any one-policy process, not all opinions count equally. The more influential a stakeholder, the greater her ability to steer the debate. I believe that this influence heterogeneity needs to be reflected in the analysis. There is, however, no established methodology to do this. I hereby propose a measure of influence defined by the product of the responses to statements A and B. Efficacy is a policy actor's belief and does not necessarily correspond exactly with the actual influence that she may have. The evidence suggests, however, that efficacy and actual influence do correlate closely (e.g. Weissberg, 1975). Under the proposed operationalization, efficacy may take values ranging from 1 to 25. The opinion of a respondent with efficacy 25 is thus expected to be extremely important in formulating the positions related to hydrogen policy of an organization that has direct influence over policy-making. Fig. 2 shows the distribution of this measure of influence across the US-based subsample.

Ways to operationalize influence other than the one used here are also possible. For lack of an established methodology, I feel comfortable with the operationalization used, because it avoids sample-wide homogeneity and because it reflects the non-constant marginal increase of influence that, I believe, exists in real-world policy processes.[3] I will incorporate this measure of influence into the rest of my analysis.

3.2. *Policy drivers*

Policy activity necessarily responds to one or more drivers.[4] In the broadest, simplest, categorization, stakeholders invest resources in a policy process either to protect economic interests or to pursue societal benefits. The conceptual model represents policy drivers as objective measures (catalytic trends/events). However, it is stakeholders' *perceptions of and beliefs about* the policy problems that influence their decision to participate.[5]

To understand what policy issues motivate stakeholder participation in the policy process related to hydrogen, the survey included the following question: In your opinion, how much of a problem is each of the following issues PRESENTLY? The question was followed by five options: dependence on foreign oil, global warming, air pollution, the need to find alternatives to oil, and economic development. Beliefs on the seriousness of each of these policy issues were collected on a seven-point semantic scale

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[3] The marginal increase in influence is not constant. A one-unit increment in the response to statement A or B will have a larger impact on the overall measure of influence as the response moves toward the higher end of the response scale.

[4] By policy drivers, I refer to public policy issues that may motivate stakeholder participation in a policy process.

[5] This notion is borrowed from Ajzen and Fishbein's theory of planned behavior.

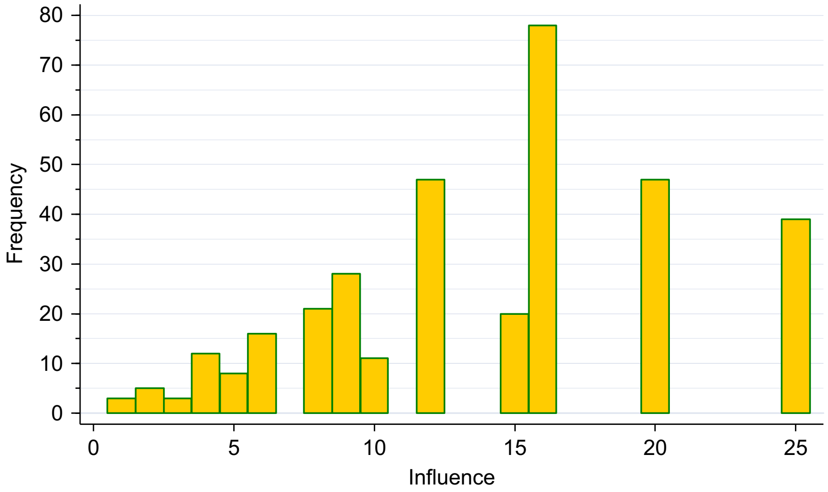

Fig. 2. Distribution of influence in the US-based subsample.

Table 3
Beliefs about seriousness of policy problems

Weighted statistic	Policy problem			
	Oil dependency	Global warming	Air pollution	Oil scarcity
Mean	5.98	5.49	4.99	5.38
Std. deviation	1.23	1.59	1.43	1.55

anchored by 1 = "Not at all a problem" to 7 = "Extremely serious problem". The main reason for using a seven-point scale with verbal ratings only to the end points was to safely assume a linear progression in the value of the variable between the lower and upper ends.[6] The idea was to use these questions as "thermometers" of the policy drivers that would enable temporal comparisons, in the case of subsequent administrations of the survey.

Table 3 shows the weighted mean of the responses to each of the policy issues, for the entire US-based subsample.[7] I present means instead of medians because I understand these perceptions as continuous constructs, even though responses are collected on a discrete scale.

On average, respondents perceive oil dependency as the more serious problem. The difference between this variable's mean and those of the other three variables is statistically significant (p-value = 0.000).

Perceptions on the seriousness of policy problems may be an indicator of motivation for policy activity, but not necessarily of motivation for activity on *hydrogen* policy. To complement the measure of motivation above described, the survey included the following question: In your opinion, how important is to develop a HYDROGEN-based transportation system in the country where you are based to (a) reduce the dependency on foreign oil of the country where you are based? (b) reduce greenhouse gas emissions in the long term? (c) comply with ambient air quality standards in the country where you are based? (d) develop alternatives to oil? (e) comply with existing legislation or regulations in the country where you are based? Answers were collected on seven-point semantic scales anchored by 1 = "Absolutely unimportant" to 7 = "Extremely important". A summary of the responses is presented in Table 4.

On average, respondents think that the problem that hydrogen is most fit to address is the need to find alternatives to oil. The difference between the sample mean for this variable and the other four is statistically significant (p-value = 0.000).

3.3. Policy beliefs and general policy preferences

The survey contained 14 policy-belief statements, responses to which were collected on a five-point Likert scale anchored by "strongly disagree" (coded as 1) and "strongly agree" (coded as 5). Table 5 shows the weighted and non-weighted means and standard deviations of the responses to each of the policy-belief items. Even though the response scale is discrete, I show means and standard deviations instead of medians and quartiles because beliefs are actually continuous constructs.

Factor analysis of the statements in Table 5 on the US-based subsample uncovered two reliable underlying policy-belief dimensions, shown in Table 6.[8] Shaded cells in each column indicate the statements that were used to estimate Cronbach's α and to interpret the meaning of the latent construct (policy dimension) measured by the factor.

The first factor, *Pro Government Support*, is composed of the first three statements in Table 6. This factor captures the underlying policy belief that governments should take

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[6] Such assumption is less robust for Likert-type response scales.

[7] For weighting throughout the paper I use the efficacy variable.

[8] The specifics of the type of factor analysis used are shown at the foot of the tables.

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Table 4
Beliefs about fitness of hydrogen as a solution to issues

Weighted statistic	Issue				
	Oil dependency	Global warming	Air pollution	Oil scarcity	Comply regulations
Mean	4.73	4.91	4.31	5.37	3.52
Std. deviation	1.92	1.93	1.94	1.77	1.89

Table 5
Means and standard deviations for responses to policy-belief statements

Statement	Non-weighted		Weighted	
	Mean	Std. deviation	Mean	Std. deviation
Governments should be first adopters of hydrogen vehicles	3.72	1.18	3.81	1.15
Governments should provide funds or the development of hydrogen fueling infrastructure	3.84	1.26	3.95	1.24
Governments should provide funds for demonstration programs on hydrogen technologies/systems	4.15	1.03	4.20	1.00
Environmental regulations should be standard based, not technology based	4.13	1.08	4.20	1.03
Government regulations can accelerate technological innovation	4.18	0.85	4.21	0.84
All policy benefits and costs can be reflected reasonably well in a cost–benefit analysis	2.90	1.14	2.89	1.14
Sequestration is a promising way to deal with CO_2 emissions from hydrogen production	3.20	1.16	3.25	1.17
The external costs of energy PRODUCTION should be internalized	4.06	0.90	4.06	0.92
The external costs of energy USE should be internalized	4.10	0.88	4.12	0.89
Anthropogenic CO_2 emissions are a significant cause of global warming	4.03	1.05	4.08	1.02
Governmental policies should be more concerned with helping lower-income groups than helping higher-income groups	3.52	1.12	3.49	1.13
In general, market-based policies are more effective than command-and-control policies	3.95	1.03	3.96	1.03
In general, protecting the economy is more important than protecting the environment	2.39	0.94	2.38	0.89
More international collaboration is desirable on policies related to hydrogen	3.94	0.90	3.97	0.89

Table 6
Factor loadings on policy-belief statements

Policy-belief statement	Factor loadings	
	Government should lead	Internalizing externalities
Governments should be first adopters of hydrogen vehicles	0.87	−0.05
Governments should provide funds for the development of hydrogen fueling infrastructure	0.93	0.00
Governments should provide funds for demonstration programs on hydrogen technologies/systems	0.90	0.04
The external costs of energy PRODUCTION should be internalized	−0.02	0.96
The external costs of energy USE should be internalized	0.02	0.96
Eigenvalues	2.44	1.84
Cronbach's α	0.89	0.85
Pairwise correlations		
Government should lead	1.00	0.00
Internalizing Externalities	0.00	1.00

Principal-components factor analysis, oblique 5th-power promax rotation with Horst modification.
Variance explained: 84%.
*Statistically significant at the 0.05 level.

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Table 7
Means and standard deviations for responses to policy-preference statements

Statement	Non-weighted		Weighted	
	Mean	Std. deviation	Mean	Std. deviation
A tax on gasoline to account for its air pollution costs	3.95	1.17	3.94	1.19
A tax on gasoline to encourage less driving	3.51	1.34	3.55	1.31
Incentives for buyers of vehicles that bring societal benefits relative to standard gasoline vehicles	4.23	0.99	4.28	0.97
A carbon tax	3.85	1.19	3.88	1.21
Increasing fuel-efficiency requirements on new light-duty vehicles	4.46	0.90	4.47	0.91
A tax on gasoline as a source of revenue for the development of a hydrogen infrastructure	3.20	1.38	3.26	1.39
Promote basic research on hydrogen technologies at universities	4.31	0.84	4.31	0.86
Economic incentives (“carrots”) for firms to accelerate the market introduction of fuel-cell vehicles	3.95	1.11	3.99	1.15
Regulation that ensures liability insurance of hydrogen infrastructure at reasonable prices	3.66	1.13	3.66	1.16
A mandate on the quantity/percentage of hydrogen-fueled vehicles produced	2.30	1.21	2.33	1.25
A mandate on the quantity/percentage of zero-emission vehicles produced	2.97	1.38	3.01	1.40
A mandate on the quantity/percentage of fueling stations that offer hydrogen	2.65	1.25	2.63	1.27
Regulating the minimum percentage of hydrogen to be produced from renewable sources of energy	3.32	1.32	3.32	1.32

an active role, particularly financial, to help moving forward toward a potential adoption of hydrogen as a transportation fuel. As characterized by the operational statements, government investments may take the form of early purchases of hydrogen vehicles, financing the deployment of a hydrogen delivery infrastructure, and funding demonstration programs. I expect this policy dimension to be found in policy process related to any alternative fuel, not just to hydrogen.

The second factor, *Pro Internalization*, defined by the last two items in Table 6, captures the underlying policy belief that policies should provide for the internalization of the external costs derived from energy production and consumption.

Some of the policy-belief items in Table 5 were dropped from the factor analysis because they did not form additional reliable measures of policy dimensions.[9] The fact that these items were dropped does not mean that they are not important policy questions though. Some of them might have formed a factor (defining a policy dimension) had the survey included more questions.[10] Others are probably too narrow or specific to be part of a broader policy issue or dimension.

Measures of stakeholders' preferences were obtained on a variety of specific policy tools, using a five-point Likert-type scale anchored by “strongly oppose” (coded as 1) and “strongly support” (coded as 5). Table 7 shows the means and standard deviations of the responses to these statements.

A factor analysis of the items in Table 7 identified the three policy-preference dimensions presented in Table 8. I use parentheses to denote loadings that, though not the highest on a given item, they are helpful in understanding the construct (or policy dimension) that the factor is capturing. Cronbach's reliability measures including such items are shown between parentheses.

The first factor captures the underlying preference for policies that require from industry the supply of technologies and products in levels or quantities determined by regulation. This factor, which I call *Pro Command and Control*, defines the more dominant policy-preference dimension, as suggested by the relative magnitude of the eigenvalues.

The support for fuel-economy regulation, for a tax on gasoline to finance a hydrogen refueling infrastructure, for hydrogen research at universities, and for regulating liability insurance for hydrogen infrastructure have marginally significant loadings on this factor. A Cronbach's α including these three items remains high (0.83), indicating that they can help us in interpreting this first policy-preference dimension. The negative loading on the third of these marginal items suggests that supporters of strong command-and-control policies are in general also disinclined to promote basic research at universities.

The second factor captures the underlying policy preference for reducing externalities associated with the use of road motor vehicles by means of technology-neutral strategies. Such strategies include increasing fuel-economy standards, providing incentives for the purchase of cleaner vehicles, and end-use taxing schemes to internalize externalities like criteria pollutant emissions, fuel consumption, traffic congestion, and greenhouse gas emissions. I call this policy-preference dimension *Pro Tech-Neutral Policy*. Compared with the first factor, this policy dimension is more concerned with addressing the specific policy problem through taxation of the externality source or setting standards, rather than favoring specific technologies.

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[9] In general, the reason to drop items was that the corresponding Cronbach's α's were too low, in which case most of the commonalities in the variances are more the result of random effects than of underlying latent constructs.

[10] The design of a survey generally involves tradeoffs. While increasing the number of questions may improve the quality of the information, it also increases the burden on the respondent, which is likely to result in fewer responses (smaller sample size).

Table 8
Factor loadings on policy-preference questions

Policy preference statement	Factor loadings		
	Pro Command and Control	Pro Tech-Neutral Policy	Pro Facilitating Innovation
A tax on gasoline to account for its air pollution costs	−0.04	0.91	−0.01
A tax on gasoline to encourage less driving	−0.09	0.85	−0.07
Incentives for buyers of vehicles that bring societal benefits relative to standard gasoline vehicles	0.04	0.52	(0.31)
A carbon tax	−0.16	0.89	0.07
Increasing fuel-efficiency requirements on new light-duty vehicles	(0.27)	0.61	(−0.27)
A tax on gasoline as a source of revenue for the development of a hydrogen infrastructure	(0.36)	(0.22)	0.49
Promote basic research on hydrogen technologies at universities	(−0.32)	−0.06	0.87
Economic incentives ("carrots") for firms to accelerate the market introduction of fuel-cell vehicles	0.12	−0.04	0.82
Regulation that ensures liability insurance of hydrogen infrastructure at reasonable prices	(0.34)	−0.02	0.55
A mandate on the quantity/percentage of hydrogen-fueled vehicles produced	0.96	−0.17	0.01
A mandate on the quantity/percentage of zero-emission vehicles produced	0.91	0.16	(−0.28)
A mandate on the quantity/percentage of fueling stations that offer hydrogen	0.93	(−0.20)	0.08
Regulating the minimum percentage of hydrogen to be produced from renewable sources of energy	0.71	0.09	−0.05
Eigenvalues	4.96	2.49	1.33
Cronbach's α	0.86 (0.83)	0.82 (0.80)	0.76 (0.74)
Pairwise correlations			
Pro Command and Control	1.00		
Pro Tech Neutral Policy	0.40*	1.00	
Pro Facilitating Innovation	0.54*	0.23I*	1.00

Principal-components factor analysis, oblique 5th-power promax rotation with Horst modification.
Variance explained: 66%.
*Statistically significant at the 0.05 level.

Note that although the preferences for taxing gasoline to finance a hydrogen infrastructure and for requirements on hydrogen refueling stations have only marginal loadings on the Pro Tech-Neutral Policy factor, they contribute to *increase* Cronbach's α. This means that these two items can be thought of as being conceptually part of the Pro Tech-Neutral Policy dimension too. The second of these items has negative loadings on the Pro Tech-Neutral Policy factor, which is consistent with the philosophy of this policy preference, namely not to favor specific technology winners.

An interesting finding is that the support for fuel taxes and the support for increasing light-duty vehicle fuel-economy standards coexist in the same policy dimension. This suggests that stakeholders tend to view fuel taxes and fuel-economy standards as different facets of the same policy-preference dimension, and, in general, supporters (opponents) of one strategy support (oppose) the other too. The slight decrease of Cronbach's α when the support for fuel-economy standards is excluded shows that this set of items does constitute a reliable measure of a common dimension. Nevertheless, the higher loading of the tax items relative to the other two items in the factor indicates that this policy-preference dimension has a slightly stronger market-based than command-and-control "flavor". The results also reveal the philosophical difference between these two policy approaches. Looking at the Pro Command and Control column, one notices that the loadings of the carbon tax and fuel-economy standard variables—though very marginally significant—are negative and positive, respectively. These signs indicate that stakeholders who are more supportive of command-and-control approaches have, on average, a tendency to favor the setting of fuel-economy standards, over carbon taxes. Taken as a whole however, the first two dimensions are positively, significantly correlated (0.40). This result indicates that supporters of command-and-control approaches are, on average, also somewhat inclined to support technology-neutral policies.

The third factor captures the preference for policies directed to areas key to facilitating the commercialization of hydrogen vehicles: basic research, the deployment of a refueling infrastructure, incentives to production, and liability issues. Stakeholders with higher scores in this dimension are conscious of the processes involved in technological innovation and support policies aimed at fostering them. Reflecting this interpretation, I label this policy-preference dimension *Pro Facilitating Innovation*. Consistent with my interpretation, the incentives for buyers of clean vehicles has a marginally significant positive loading, while the mandate on zero-emission vehicles has a marginally significant negative loading on this factor.

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Indeed, adding these two items, Cronbach's α increases slightly to 0.77, indicating that they contribute to defining, along with the other four items, a reliable policy-preference dimension.

Dimensions should not be interpreted as necessarily mutually exclusive. They define the issues that dominate a certain area of policy debate (in this case, the general policy preferences) but they are not necessarily indicative of how stakeholders split on this debate. For example, the fact that a stakeholder has a high positive score on the Pro Command and Control factor does not necessarily say anything about her score on the other two factors. In this particular case, I find that stakeholders with higher (lower) scores in the Pro Command and Control tend to have higher (lower) scores on the other two dimensions, as indicated by the positive pairwise correlations, shown in Table 8.

3.4. *Preferences on hydrogen production pathways*

The various pathways for the production of hydrogen differ rather significantly in terms of technology maturity, process economics, and societal impacts. Therefore, I expect to find a non-trivial variance in the levels of support for the different pathways across stakeholders. The survey included the question "For the SHORT TERM, would you support policies that promote the following sources of energy for the production of hydrogen?" Responses were collected on five-point scales anchored by "strongly oppose" and "strongly support", for 10 different hydrogen production pathways. The means and standard deviations for the weighted and non-weighted responses are shown in Table 9.

A factor analysis of these items yielded the two reliable underlying policy dimensions presented in Table 10.

The first factor reveals a policy dimension characterized by the preference for hydrogen production pathways with lower environmental impacts. The interpretation of this *Pro Environmental* H_2 dimension is interesting. The items "Natural gas with CO_2 sequestration" and "Coal without CO_2 sequestration" keep marginally significant loadings on this dimension. Cronbach's α of this policy dimension, including these two items, would still be 0.75—high enough to argue that they should be taken into account to interpret the policy dimension. The positive loading on the item "Natural gas with CO_2 sequestration" indicates that supporters of renewable production pathways would in general be supportive of producing hydrogen from natural gas in the short term, if the CO_2 resulting from methane reforming is captured and stored. The negative loading on the item "Coal without CO_2 sequestration" reveals that supporters of renewable production pathways tend to be opponents of producing hydrogen from coal if the resulting CO_2 is not sequestered.

The second factor, *Pro Non-renewable Hydrogen*, captures the preference dimension related to policies that favor hydrogen production from fossil and nuclear sources of energy. The low-carbon non-renewable production pathways—nuclear and coal with CO_2 capture and storage—fall into this factor along with the fossil production pathways. These two pathways have virtually zero loadings on the Pro Environmental H_2 Production factor, indicating that they clearly belong in the Pro Non-renewable policy-preference dimension. The option of natural gas with carbon sequestration, however, shows a non-trivial loading (0.34) on the Pro Environmental H_2 Production factor. How can this pattern of loadings be interpreted? It suggests that the Pro Environmental H_2 Production policy-preference dimension is defined by preferences on the entire spectrum of environmental impacts of hydrogen production, including ambient air pollution, greenhouse gas emissions, and nuclear waste disposal. Stakeholders with higher loading on this factor tend to be unwilling, for example, to accept the risks of nuclear waste to reduce carbon emissions, or to accept the societal costs associated with coal even if most of the CO_2 emitted was captured and sequestered. The moderate acceptability of hydrogen production from natural gas with sequestration reflected in this policy-preference dimension, in my interpretation based on multiple conversations with stakeholders, reflects the fact that this production pathway is perceived as a lower-cost, relatively clean alternative suitable for the short

Table 9
Means and standard deviations for responses to hydrogen production pathway statements

Statement	Non-weighted		Weighted	
	Mean	Std. deviation	Mean	Std. deviation
Coal with CO_2 sequestration	3.21	1.22	3.25	1.25
Coal without CO_2 sequestration	2.00	1.06	1.99	1.08
Natural gas with CO_2 sequestration	3.50	1.08	3.56	1.13
Natural gas without CO_2 sequestration	2.79	1.14	2.87	1.18
Nuclear	3.35	1.32	3.28	1.38
Geothermal	4.10	0.89	4.10	0.91
Petroleum/coke	2.34	1.02	2.29	1.03
Wind	4.22	0.96	4.22	0.99
Solar	4.25	0.97	4.25	1.00
Biomass	4.15	0.99	4.14	1.00

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Table 10
Factor loadings on hydrogen production pathway preferences

Hydrogen production pathway	Factor loadings	
	Pro Environmental H_2 Production	Pro Non-renewable Hydrogen
Coal with CO_2 sequestration	0.09	0.68
Coal without CO_2 sequestration	(−0.24)	0.83
Natural gas with CO_2 sequestration	(0.34)	0.60
Natural gas without CO_2 sequestration	0.03	0.67
Nuclear	−0.07	0.58
Geothermal	0.80	0.01
Petroleum/coke	−0.03	0.75
Wind	0.90	−0.04
Solar	0.92	−0.13
Biomass	0.84	0.07
Eigenvalues	3.59	2.49
Cronbach's α	0.89 (0.75)	0.78
Pairwise correlations		
Pro Environmental	1.00	
Pro Non-renewable	0.19*	1.00

Principal-components factor analysis, oblique 5th-power promax rotation with Horst modification.
Variance explained: 60%.
*Statistically significant at the 0.05 level.

term, until production from renewable sources of energy becomes more economically competitive.

3.5. Social pressure

The notion of social pressure encompasses a wide variety of mechanisms, internal and external to the stakeholder organization. Social pressure has a direct impact on normative policy beliefs. Two important forms of social pressure were measured: market demand and organization's goals and/or interests.

Measures of perceived market demand were obtained through the following questions:

a. In your opinion, CURRENTLY, how many of the following types of light-duty vehicles could potentially be sold/leased annually IN THE MARKET in the country where you are based?
b. What is your best estimate of the EARLIEST and LATEST years when production fuel-cell automobiles could be ready to enter the automotive showrooms in the country where you are based? Assume no new policy incentives.
c. When do you think FCVs will capture 5% of the market of NEW private vehicles in the country where you are based? Assume no new policy incentives.

Question a included two vehicle types: hydrogen FCVs and hydrogen internal combustion engine vehicles. Answer options were offered in the form of ranges of sales volumes as "0–100", "100–1000", …, "100,000–1 million", plus the options "More than 1 million" and "Don't know". For question b, answer options were provided as year numbers from 2010 to 2030, plus the options "Before 2010", "Later", "Never", and "Don't know". For question c, answer options were provided as year ranges in the form "Before 2020", "Before 2025", …, "Before 2050", plus the options "Later", "Never", and "Don't know". Response frequencies for the two vehicle types in question a are shown cross-tabulated in Table 11, while response frequencies to questions b and c are shown in Tables 12 and 13, respectively. A detailed analysis of the responses to the market-demand questions can be found in Collantes (2007).

Another form of social pressure that affects policy beliefs and motivates participation in the policy process is the organization's market-related interests. Such interests are not necessarily economic; they can be grounded, among other factors, on the societal benefits that the market deployment of a given technology may bring about. This form of social pressure is pre-eminently, though not exclusively, internal to the organization, and may originate, for instance, in shareholders' or constituencies' preferences, and management's strategic decisions. Stakeholders' market-related interests were captured with the following question: "To the interests of your organization, how important is the short-term development of markets for each of these end-use products?" Respondents were then presented with a list of technologies with three response options: "not important", "somewhat important", and "very important".

Shown in Table 14 are the results of the factor analysis performed on these items.

These results show that stakeholders' market-related interests essentially lie along three dimensions. The first

Table 11
Frequencies of beliefs about the sizes of markets for fuel-cell and hydrogen ICE vehicles

Number of fuel-cell vehicles	Number of hydrogen internal combustion vehicles							
	Don't know	$0–10^2$	$10^2–10^3$	$10^3–10^4$	$10^4–10^5$	$10^5–10^6$	$>10^6$	Total
Don't know	64	0	0	0	0	0	0	64
$0–10^2$	0	40	22	13	3	2	0	80
$10^2–10^3$	0	8	39	24	7	1	2	81
$10^3–10^4$	2	0	8	24	13	6	2	55
$10^4–10^5$	4	1	1	5	12	8	1	32
$10^5–10^6$	2	2	1	2	4	14	4	29
$>10^6$	2	0	1	1	1	2	21	28
Total	74	51	72	69	40	33	30	369

Table 12
Frequencies of estimates of earliest market entrance of fuel-cell vehicles

Year	Frequency
2009	46
2010	70
2011	3
2012	33
2013	8
2014	4
2015	106
2016	3
2017	3
2018	6
2020	44
2025	20
2030	9
Later	4
Never	7
Don't know	11

Table 13
Frequencies of estimates of when fuel-cell vehicles capture 5% of new-vehicle market

Year	Frequency
2020	73
2025	71
2030	63
2035	33
2040	23
2045	8
2050	28
Later	11
Never	30
Don't know	24

factor, comprising eight items, represents the underlying interest in the market introduction of hydrogen-fueled technologies in the short term. Naturally, the factor includes the interest in energy stations, where hydrogen-fueled vehicles would refuel. I name this dimension *Hydrogen Tech Interest*.

The second factor—*Grid-Connected Interest*—captures the underlying interest in grid-fed battery electric drivetrains. The interest in gasoline hybrid electric vehicles has a marginally significant loading (0.34) on this factor, indicating that interest in this drivetrain is consistent with interest in vehicles with grid-fed batteries. This effect is explained by the fact that hybrid electric vehicles can be thought of as a stepping stone in the technological evolution toward vehicles with all-electric driving range. The loading on hydrogen plug-in electric vehicles is significant, consistent with the interpretation of this factor. In fact, the loading of this variable is higher than that of alternative fuel vehicles (AFVs), which I included among the main three variables defining this factor. The role of AFV in these results warrants some elaboration. Notice that the loading of AFV on all three factors is relatively low. Even when excluding this variable would have increased the respective Cronbach's α's, I decided to keep this variable in the final solution to show that stakeholders with stronger views (positive or negative) in any of these three factors (issues) would also have relatively strong views on AFV. "Alternative fuel" is, most likely, interpreted differently in each of the factors though. For the first factor, alternative fuel may be interpreted as hydrogen, for the second factor as electricity, and for the third factor as E85 or compressed natural gas.

The third factor—*Mainstream Drivetrains Interest*—captures the interest in internal combustion vehicle drivetrains. The loadings of the two technologies that define this factor—gasoline internal combustion and gasoline hybrid electric vehicles—are high, at 0.89 and 0.76, respectively. The relatively low value of Cronbach's α (0.60) begs the question of whether the interests in these two technologies can reliably be considered to define a market-related interest. I would argue that they can. It is natural for the interest in the development of markets for hybrid electric vehicles to be part of two of the dimensions shown in Table 14. This technology may interest stakeholders either because it constitutes a natural step in a transition toward powertrain electrification or/and because it constitutes the next step in the evolution of the internal combustion powertrain.

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Table 14
Factor loadings on organization interests' items

Organization interests	Factor loadings		
	Hydrogen Tech Interest	Grid-Connected Interest	Mainstream Drivetrain Interest
Gasoline internal combustion engine vehicles	0.04	−0.22	0.89
Gasoline hybrid electric vehicles	−0.05	(0.34)	0.76
Gasoline plug-in hybrid electric vehicles	−0.14	0.91	0.11
Battery electric vehicles	−0.11	0.90	−0.15
Alternative-fuel vehicles	(0.29)	0.32	(0.24)
Hydrogen internal combustion engine vehicles	0.74	−0.03	0.08
Hydrogen hybrid electric vehicles	0.79	0.17	−0.02
Hydrogen plug-in hybrid electric vehicles	0.58	(0.47)	−0.14
Fuel-cell vehicles	0.91	−0.19	0.10
Hydrogen-fueled buses	0.91	−0.13	0.01
Hydrogen energy stations	0.94	−0.20	0.06
Hydrogen stationary applications	0.77	0.02	−0.06
Hydrogen portable applications	0.73	0.09	−0.16
Eigenvalues	5.52	2.12	1.32
Cronbach's α	0.92 (0.91)	0.69 (0.76)	0.60 (0.56)
Pairwise correlations			
Hydrogen Tech	1.00		
Grid-Connected	0.38*	1.00	
Mainstream Drivetrain	0.05	0.26*	1.00

Principal-components factor analysis, oblique 5th-power promax rotation with Horst modification.
Variance explained: 69%.
*Statistically significant at the 0.05 level.

3.6. *Preferences on research policy*

To elicit statements of preferences about hydrogen-related research policies, the survey posed the question "How much would you support government programs for research, development, and/or demonstration in each of the following areas?" Response options were offered on a five-point Likert-type scale anchored by "strongly oppose" and "strongly support". A factor analysis resulted in the two reliable dimensions of research-policy preferences shown in Table 15.

The first factor—*Zero-Emission Research*—captures the latent policy-preference dimension-related research on technologies that would enable the introduction of zero-emission vehicles, including fuel cells, hydrogen storage, hydrogen distribution, and hydrogen production from renewable sources of energy.

The items that define the second of the research policy-preference dimensions—*Non-Renewable-Hydrogen Research*—relate to hydrogen production pathways with more negative environmental impacts. Stakeholders with high scores in this policy-preference dimension tend to support research on CO_2 storage, which constitutes a philosophical difference with the Zero-Emission Research dimension, namely to manage carbon emissions instead of reducing them. The relative size of the eigenvalues indicates that the Zero-Emission Research policy-preference dimension is the more important in shaping the debate over hydrogen-related research policy.

4. Discussion

Using an online survey, I collected information on general policy preferences, policy beliefs, social pressure, preferences about hydrogen production pathways, and research policy preferences, from a wide range of stakeholders. Through multivariate analysis of the collected data, I identified, and obtained measures of, the main dimensions of the policy debate related to the adoption of hydrogen as a transportation fuel in the US. Identifying the dimensions of a policy debate is useful in that it reveals the main policy issues that concern stakeholders. Grouping myriad very specific policy issues or questions into a much smaller number of broader policy issues greatly reduces the complexity of the policy picture, helps us better understand what the dominant issues in the policy process are, and may facilitate policy discussions across stakeholders. In this paper, I have not addressed the question of what the positions of different stakeholders are in each of these policy dimensions—this will be the focus of a forthcoming article.

Although some of the policy dimensions identified in this paper are specific to hydrogen policy, many others are applicable to transportation energy policy at large. The data do not allow a comprehensive analysis of all areas of transportation energy policy though. For instance, this paper presents only limited information on climate policy. The results presented herein cannot be generalized to

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broader debates on energy policy because the sample of respondents is representative of stakeholders in the transportation arena only.

Table 15
Factor loadings for technology research policy preferences

Research area	Factor loadings	
	Zero-Emission Research	Non-renewable Hydrogen Research
Fuel-cell membranes	0.95	−0.02
Fuel-cell catalysts	0.93	−0.05
Fuel-cell durability	0.92	−0.02
Fuel-cell efficiency	0.89	−0.03
Fuel-cell sub-freezing operation	0.87	−0.03
Hydrogen storage	0.75	0.14
Hydrogen delivery	0.78	0.07
CO_2 sequestration	0.08	0.63
Hydrogen production from coal	−0.05	0.89
Hydrogen production from natural gas	0.13	0.71
Hydrogen production from renewables	0.69	−0.07
Hydrogen production from nuclear energy	−0.15	0.77
Eigenvalues	6.45	1.69
Cronbach's α	0.95	0.72
Pairwise correlations		
Zero-emission	1.00	
Non-renewable	0.44*	1.00

Principal-components factor analysis, oblique 5th-power promax rotation with Horst modification.
Variance explained: 68%.
*Statistically significant at the 0.05 level.

For reasons explained in Section 2.2, this analysis focused on the subsample of stakeholders based in the US. This focus precludes a generalization of the results to other parts of the world where hydrogen is given consideration as an energy-policy option. Preliminary examination of the data shows that, indeed, the results may be somewhat different for the non-US subsample. For instance, for respondents based in countries other than the US, global warming takes the first place among the policy drivers for hydrogen. Such differences are consonant with expectations and with discussions presented in the literature (see, for example, Hake et al., 2006). In China, interest in alternative fuels has been typically driven by concerns with ambient air quality in urban areas (e.g. Zhao and Melaina, 2006). It is important to recognize, however, that policy processes are not static—they evolve over time according to a complex interplay of exogenous and endogenous determinants. Concerns about energy security and awareness about the importance of reducing greenhouse gases emissions, for example, have been increasing significantly in China, thus creating additional drivers for alternative fuels such as hydrogen (e.g. NDRC, 2007).

In terms of general policy beliefs, the two salient dimensions that I identified are the internalization of energy externalities and the role that the government ought to have on supporting—particularly financially—the adoption to hydrogen as a fuel. The result that stakeholders tend to have similar positions about the internalization of the external costs of both energy generation and energy consumption was not necessarily obvious *a priori*.

I found three salient general policy-preference dimensions: the preference for command-and-control approaches, the preference for addressing externalities with technology-neutral strategies, and the preference for facilitating technological progress and innovation. While the latter is mostly comprised of items related to hydrogen, it can be expected that this dimension will be found in an analysis of transportation energy policy at large. This hypothesis is supported by the fact that the requirements on hydrogen-fueled vehicles and hydrogen refueling stations have insignificant loadings on this factor, suggesting that this policy dimension is representative of a philosophical policy preference rather than a hydrogen-specific one. The taxing of gasoline to support the financing of a hydrogen infrastructure has non-trivial positive loadings on the three policy dimensions. This result suggests that, in general, stakeholders who have a positive stand on any one of the policy dimensions will tend to have a positive stance on this particular policy measure.

The market-related interests of the surveyed stakeholders can be categorized in three areas or technologies: applications of hydrogen, plug-in drivetrains, and gasoline-fueled engine architectures. Observation of the loadings on the last two items shows that organizations mostly interested in plug-in drivetrains have some interest in gasoline hybrid electric vehicles too. The evidence shows that the inverse does not apply: organizations mainly interested in gasoline-powered drivetrains do not show significant interest in grid-fed architectures, although this result may be less robust now, as some car companies start working on the development of plug-in hybrid electric vehicle prototypes. Organizations interested in the success of fuel cells (mobile and/or stationary) tend to be interested in the success of hydrogen (and vice versa). This finding reflects an understanding among stakeholders of the interdependence of the market success of these products.

The debate over how hydrogen should be produced in the short term is, according to my analysis, characterized by two dimensions: the support for production from environmentally friendly sources and the support for production from non-renewable sources of energy. Interestingly, these two dimensions have a significant, though low, positive pairwise correlation. This means that stakeholders who support environmentally- friendly hydrogen production have a slight tendency, on average, to support non-renewable production pathways. Probably the most interesting result in this area of policy is that whether CO_2 emissions are captured and stored or not has little influence on stakeholders' perception about the environmental costs of hydrogen production from fossil fuels.

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There is some indication that stakeholders supportive of hydrogen production from renewable sources are inclined to lend some support to production from natural gas, given that carbon capture and storage is included, but they would not be supportive to production from coal, regardless of whether carbon capture and storage is included or not.

In terms of research policy, the clearer policy issue is whether to support research on areas that would enable an emission-free transportation system. While this result may not seem too surprising, it does provide additional insight into the role of government. The result that support for government funding of research in fuel cells and on renewable production of hydrogen correlates with each other signals a debate over whether government funding should prioritize research toward achieving the maximum societal benefits that a hydrogen-based transportation system can yield.

Having identified the main policy dimensions of the policy debate over hydrogen, future research steps include exploring what the positions of different stakeholders are in each of these dimensions and testing the causal paths proposed in the conceptual model. Research on these areas is currently underway.

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