PROSPECTING THE FUTURE FOR HYDROGEN FUEL CELL VEHICLE MARKETS

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Introduction

As there are currently no retail markets for either hydrogen as a transportation fuel or fuel cell vehicles, any discussion of such markets necessarily prospects the future. To do so, we must evoke an image of the future. Such a task is inherently uncertain—many forecasts have been wrong even for mature markets, much less markets as tenuously incipient as those for hydrogen and fuel cell vehicles (FCVs).[1] We undertake this risky enterprise by framing the discussion of future markets for hydrogen and FCVs around these two questions.

1. What is the history and future of mobility?
2. Within this future, why would anyone buy a hydrogen fuel cell vehicle?

We address the uncertainty of predicting the future by grounding our answers in a theory of the development of modern societies and the related long-term development of the infrastructures modern societies build to support themselves. The infrastructures we address are automobility, energy, and information.[2] This theory and history describe a trajectory from which we argue modern societies are unlikely to deviate, except in the case of catastrophic events or fundamental shifts in values. Given this, it seems plausible to us that the further into the future we go, the more likely it is that the future we describe will come to pass.

Based on this theory and history of infrastructure development, and particularly on the nascent integration of these infrastructures, we propose that the next supporting infrastructure built by modern societies will be a system that fully integrates automobility, electricity, and information. This will be accomplished, in part, by the transformation of automobiles from their current design and role as primarily mobility tools. In a technological sense, automobiles will become integrated information-mobility-electricity platforms; in a behavioral sense, they will become mobile activity locales. One of the behavioral and technological integrations is *mobile electricity*, the integration of electric-drive, energy storage and delivery, and mobility technologies such that it is possible for the vehicle to deliver electricity for non-propulsion uses wherever it is, whether it is stationary or mobile.

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[1] For purposes of this discussion, we will adopt the convention that all fuel cell vehicles will be direct-hydrogen designs. Thus we will shorten "hydrogen fuel cell vehicle" to the simple acronym FCV. Should future FCV designs be something other than direct-hydrogen, we currently believe that only the details of our discussion will need to be revised, not the overall direction.

[2] These are not the only supporting infrastructures of modern societies, but they are three of what are arguably the four most important for this discussion. The other, which regrettably cannot be given full attention here, is democratic governance. On another topic, by "information" we mean an interrelated suite of socio-technological systems that include information, communication, and computation technologies. Thus we will use "information" and "communication" interchangeably.

Based on all this, we argue that in the future, FCVs will gain competitive advantage in the market if hydrogen and fuel cells are the best energy carriers and converters to power integrated information-mobility-electricity platforms. FCVs may also be afforded further competitive advantage by policies that are both sensitive to automobiles new role as mobile activity locales and create socially sanctioned rewards for progress toward the collective benefits which are the real goals of a transition to hydrogen.

A History and Future of Mobility

We are looking into the future in this paper, exploring in some detail how FCVs might fit into a picture much larger than just the automobile market. That larger picture is the future of personal mobility, and in particularly automobility. We take *automobility* to be personal (and though we will not focus on it in this paper, commercial) mobility afforded by the democratization of access to systems that allow individuals to move in a self-directed fashion through the space and time of their daily lives.[3] Over the past century, we have built three interconnected socio-technological systems to support and provide automobility. They are automobiles, roads, and fuels.

We are motivated primarily by the potential changes that fuel cells bring to automobiles, by trends in consumer use of electricity during travel and in their vehicles, and overall trends in consumer lifestyles. We explore trends in consumer demand for mobility, particularly mobile electricity and information technologies, and the development of the infrastructure for that extended mobility. We argue that in the future all automobiles will be transformed from simple mobility tools into mobile activity locales. To achieve this, the technology of future automobiles will be fully integrated information-mobility-electricity platforms. We will discuss how such transformation and integration is consistent with the long-term development of modern societies and evidence that both are already starting.

Before the self-proclaimed "realists" dismiss this exercise as futuristic optimism, we note that not everything we explore paints a happily-ever-after story for hydrogen, FCVs, and the future of automobility. We are not talking about progress *per se*, but rather we are situating FCVs within long-term trends and feedbacks between culture and technology. Competing automotive technologies will offer mobile electricity; FCVs will not have this market to themselves. The lifestyle trends we examine run counter to the hopes of many hydrogen and FCV proponents for less energy use. These trends also challenge the hopes of "new urbanists" for a future of reduced personal vehicle use.

[3] We can have personal mobility without automobility, but we can't have automobility without personal mobility.

The future we describe is also not pre-determined; it is a history we have not yet written. The forces behind these trends are central to the definition of modern societies, but they are not immutable or "natural." They are the product of human decision-making and social forces. We think that the future we evoke in this paper will help researchers, policy-makers, and even ordinary citizens to calibrate ideas about future energy use and lifestyle as well as illuminate potential market pathways for hydrogen and FCVs.

Despite the potential attractions of a hydrogen-based economy and hydrogen-based transport, there are many barriers for hydrogen and FCVs to overcome before they compete with current technologies. When reviewing these barriers, it is easy to predict the failure of FCVs. It is more difficult to identify potential pathways by which hydrogen and FCVs might become successful. Taking the latter approach, we explore the following question: in ten to twenty years, what could motivate car buyers to choose FCVs? And by extension, under what conditions would they pick FCVs over other vehicles in the market? Our overall approach is to evoke an image of the future based on several inter-related, long-term trends in the development of modern societies. Such a future context then becomes one in which hypothesis regarding future markets for hydrogen FCVs may be stated and evaluated.

How to Represent the Future?

A methodological framework to prospect the future

Often the main assumption in studies of technology adoption is technological determinism, that technologies such as automobiles, telephones, and electricity have steered history. We do not follow this view. We argue that successful technologies are those that are in synchrony with the major trends of history. This is our hypothesis about FCVs and mobile electricity; we believe these technologies might succeed because they follow the main trends of history.

The encounter between transportation innovations and both the lifestyle goals of individuals and households and the profit motives of business provides a rich field of research and clues to methodologies. Our approach is to ground research in the lifestyles and goals of respondents, while employing multiple, staged research methods. These methods include public drive tests and demonstrations, interactive gaming-interviews, and detailed surveys that simulate future scenarios. This approach (as applied to the case of battery electric vehicles) is described elsewhere (Turrentine and Kurani, 1998, Kurani and Turrentine, 2002b). Two elements of this approach pertinent to prospecting the future are the characterization of the recent social epoch that social scientists refer to as *modernity* and the concept of *lifestyle*.

Social theorist Anthony Giddens (1991) defines *lifestyles* as "…routinized practices…habits of dress, eating, modes of acting, and favored milieu for encountering others; but the routines followed are reflexively open to change in light of the mobile nature of self identify." *Modernity* is distinguished from prior traditional social epochs by the difference between change and stasis. Traditional societies attempt to replicate themselves from one generation to the next. Modern societies are inherently dynamic, changing from generation to generation. Transitions in our lives were typically ritualized in traditional society in rites of passage, or signposts. Under modernity, the transitional self has to be explored and constructed as part of a reflexive process of connecting personal and social change. Under conditions of modernity, institutions require individuals to account for their behavior as choices; institutions do not define behavior as traditions. Modernity is characterized by the emptying of space and time, that is the future is seen as resulting from personal choices. Under conditions of traditional society, the space and time of a life are largely determined. In modern society, we are expected to choose spouses, leaders, religions, vocations, where we live, and even whether we become parents. We are not free to choose; we have to choose in the absence of traditions.

Giddens (1990) attributes the dynamism of modernity to "…the separation of time and space and their recombination in forms which permit the precise time-space 'zoning' of social life." What facilitates this zoning? How is it that identity itself has become mobile? Two basic processes are mobilization and (following from it) globalization. Globalization includes the destruction of local measures of time and space, and their replacement with universal measures. Mobilization is understood to be the spread of mobility throughout a population; in some sense, it is the democratization of mobility. In this sense, the approach toward universal automobile ownership in modern societies is understood not merely as a profound technical and economic transformation; automobility is itself one tool for achieving the time and space zoning of social life. Under modernity, identity has become auto-mobile.

In this paper we argue that hydrogen and fuel cells will effectively compete in a future market for automobility if they are integrated with mobility and information systems. Mobile electricity and communication extends the choice framework, especially in terms of time-space zones, personal and social investments in those zones, and emphasizes choice mechanisms over localized practices. All locations become globalized and vehicles become addresses. Mobility is the process behind lifestyle choice.

Context to evaluate FCVs: Evoking a future

We have now described all the elements we will use to evoke an image of the future. We have described how FCVs may be a new product, most importantly as integrated information-mobility-electricity- platforms. While other energy technologies can also provide mobile electricity, FCVs combine mobile electricity with other advantages. Compared to batteries to provide mobile electricity, fuel cell systems can provide more power and more energy; compared to combustion engines, fuel cell systems produce zero local emissions and less noise.

We have stated that FCVs will enter a future context, but a future context that is shaped by historical conditions. That context and those conditions are subject to examination, in particular by methods sensitive to the fundamental processes that define modern societies. Modern societies both support and are supported by several infrastructure systems. While automobility systems are central to our thesis, these systems are augmented by communication systems that give "mobility" to information and thus can allow a person to create action at a distance. Further, the capabilities of mobility and communication systems are leveraged by energy systems acting as multipliers that allow mobility and communication systems to move more people, more goods, and more information faster and more broadly. All three of these socio-technological systems are means to overcome what Hägerstrand (1970) characterized as a system of three types of constraints: capability, authority, and coupling. In particular, capability constraints "…arise from biological requirements and *the tools available to an individual to mediate time and space*." [Emphasis added.]

Next, we present data regarding the development of these multiple infrastructures. We note that they are all roughly contemporaneous. This simultaneity in time is not coincidental, but evidence of a modernizing society invoking capabilities that in turn define modernity. In a sense, these evidences are the infrastructure of our image of the future and our thesis that mobile electricity, and more fully, integrated mobility-energy-information platforms are potentially the next such supporting infrastructure.

Infrastructures of Modern Societies

Mobility Infrastructure

We examine trends in the development of mobility systems, primarily automobility. The three main supporting physical infrastructures for autombility are roads, vehicles, and fuels.[4] We focus on the roads and vehicles first; fuels will be treated in the subsequent section on energy.

Roads

Until well into the 20th century, the majority of roads in the US were little more than dirt tracks. Following a boom in railroad building in the late 19th century, the number of miles of railroads in

[4] We may not be accustomed to thinking of vehicles as *infrastructure*, but if we keep in mind that what we are really interested in is the behavior of autombility and the social conditions of modernity, then motor vehicles are one of the underlying technical systems that support this behavior and these conditions. In this sense, other socio-political infrastructures also underlie autombility. Approval of legislation to build the National Interstate System came as result of a number of innovations in federal funding and the relationship between federal and state governments, and the extension of federal labor laws to the state contracted highway construction projects. Governance then is another supporting infrastructure.

the year 1900 (260,000) exceeded the number of miles of roads that had any type of improved surface (125,000) (FHWA, 1976). "Improved surface" should not be confused with "paved surface." Only two percent of those 125,000 miles were paved with asphalt or concrete—and the majority of these were in urban areas (American Association of State Highway Officials, 1953, p. 162-163). In short, the only national transportation network capable of comparatively high speed and volume transportation services at the turn of the 19th to 20th centuries was the railroads. The railroads were an important step forward in mobility, in fact steam locomotives were among the early mobile power plants, but the ability of the railroads to facilitate automobility is limited *in a world where automobiles, roads, and refueling networks are built specifically to facilitate automobility*.

The need for an improved national highway system was highlighted during the first and second World Wars. Not only did the wars divert material, fuel, and finances away from the construction, maintenance, and operation of roads, but also the movement of war materials in heavily laden trucks further degraded the generally poor quality roads. While urban and rural residents had complained for years about the shortcomings of poor roads, the disruption of non-war related mobility during the war years created a collective (though by no means unanimous) will to solve the problem of poor roads.

The specific system of interstate highways we recognize today was authorized by legislation signed by President Eisenhower in June of 1956. That system is known as the National System of Interstate and Defense Highways. The idea of such a national system was first incorporated in federal legislation in the Federal-Aid Highway Act of 1944. This system, treated as a single large project, resulted in the construction of over 42,000 center-line miles of highway "…so located as to connect by routes, as direct as practicable, the principal metropolitan areas, cities, and industrial centers, to serve the national defense, and to connect at suitable border points with routes of continental importance…." (FHWA, 1976 p. 468). As of today, this entire system is essentially complete. No new centerline miles of the National Highway System are planned; any additions of lane-miles (road widening) will be approved locally.

While the construction of the national interstate highway system was one great story of road building in the US in the 20th century, the improvement and paving of millions of miles of other roads is the other great advance that further facilitated the mass marketing of automobiles and thus the spread of automobility. Data from the USDOT (2001, Table HM-12) indicate that between 1941 and 1995, total centerline miles of public roads increased from 3.3 million to 3.9 million—an 18 percent increase over 54 years. On the other hand, the centerline miles of *paved* public roads show a more dramatic increase—from roughly 600,000 to 2.4 million, or a 120 percent increase over the same period. This was the result of efforts to pave roads in urban areas, roads connecting metropolitan areas, and roads connecting rural areas to urban markets.

Vehicles

Long-term, consistent data series on the population of automobiles do not exist. Vehicle definitions have changed over time, registration requirements continue to vary across states, and requirements to register various types of motor vehicles were implemented over time. However, any inaccuracies due to inconsistency do not invalidate the general point—in approximately 100 years, the population of automobiles in this country has grown from zero to a level where there are more automobiles than licensed drivers in the US. According to Stilgoe (2001), about 300 automobiles were operating in the US in 1895. Data for the period from 1990 to 2001 are plotted in Figure 1.[5]

Early in the 20th century, automobile ownership was concentrated in urban areas—partly as a function of wealth and partly as a function of the availability of paved roads. The highest per capita concentrations of automobiles were to be found in the cities of Washington, D.C. and New York (McShane, 1994). His and others' accounts provide a fuller history of the automobile, but as the absolute growth rate of the population of automobiles and the relative growth in the population of automobiles compared to the resident population indicate, throughout the 20th century, automobiles—and thus automobility—have been spreading across the US population.[6]

Data from the later part of the 20th century indicate that by 1960, only 21.5 percent of US households owned no motor vehicles; by the year 2000 this had dropped to 9.5 percent (Davis and Diegel, 2001. Table 11.4). In fact by the year 2000, most US households (56.8 percent) owned two or more vehicles. Even very high rates of household vehicle ownership are not limited to a very few households According to analysis by Patricia Hu (2003), the percentage of US households that own more motor vehicles than there are drivers in the household increased from 16.5 percent in 1995 to 22.4 percent in 2001.

One long-term trend that transportation analysts from the 1960s and 1970s believed would end was the increase in the population of vehicles in proportion to the population of licensed drivers. At that time, the fact that not all drivers (on average) owned a vehicle was one explanation for why the population of vehicles was growing faster than the population of people. The thinking

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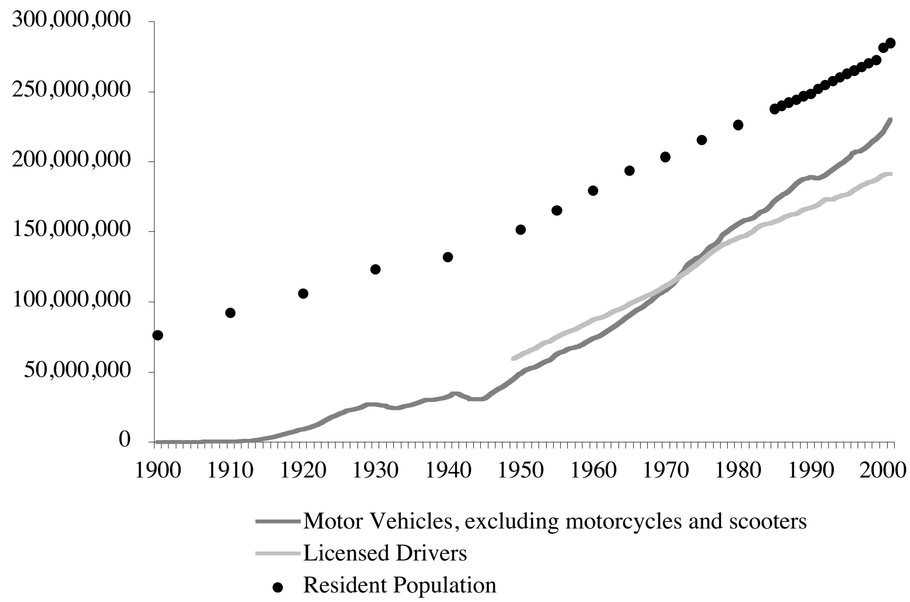
[5] The vehicle data are for all highway-licensed motor vehicles except for motorcycles and motor-scooters. Thus it includes buses, heavy-duty trucks, and truck-tractors.

[6] Automobility is not universal in the US. According to data from the 2001 National Household Transportation Survey, 7.9 percent of US households own no motor vehicles (USDOT, 2003). We infer that in many cases this is not voluntary, but rather caused by poverty. Households with incomes less than 25,000 $US2001 account for 20.3 percent of households that own no vehicles (ibid.). As we continue to build a modern society that sustains and is sustained by infrastructures of automobility, we argue that our society obligates itself to insure that all its citizens have means to participate in social and civic life.

among analysts was that since cars and trucks are expensive to own and operate, households would not invest in more vehicles than they had drivers. The data in Figure 1 suggest that in the early 1970s we exceeded the ratio of one vehicle per driver. However the data in Figure 1 include buses and heavy trucks. Still, we did pass this threshold for light-duty vehicles only in 1985. By then, there were over 171 million light-duty cars and trucks in use in the US—one for every licensed driver—according to data from the Federal Highway Administration (cited in Davis and Diegel, 2002, p. 6-5 and p. 11-3). For the year 2000, FHWA reports the number of light-duty automobiles and trucks increased to over 220 million, and the ratio of light-duty vehicles to licensed drivers increased to 1.1. Despite prior expectations, the number of vehicles continues to grow faster than the number of drivers.

Figure 1: US Vehicle, Licensed Driver, and Resident Populations during the 20th Century



Sources:
Vehicles and licensed drivers: USDOT 1996a and annual (1996b to 2001)
Residents: USDOC (2001)

Energy Infrastructure

We address two energy infrastructures: the retail gasoline network to power automobility during the 20th century and the national network for distributing electricity. The latter has powered some new automobiles introduced in response to air quality requirements and serves as one alternative model of fuel distribution for FCVs. As with mobility infrastructure, the larger point of this section is that we have spread the benefits and costs of increased consumption of a greater variety of energy sources throughout the population. We started the 20th century consuming limited quantities of locally produced energy. Throughout the century we built systems to provide us with increasing energy from increasing varieties of fuels, and we built long-distance energy distribution systems.

Gasoline

It may be inferred that the widespread adoption of automobiles and the construction of a nationwide system of paved roads was accompanied by a concurrent availability of fuel. The earliest history of competition between internal combustion, external combustion, and electric vehicles aside, the growth of a gasoline retail network specifically for automobiles began in or about the first decade of the 20th century. There are several competing claims to the "first gasoline station" spanning from the year 1905 to 1912.[7] Prior to these (or any other) claims to the first gasoline station, gasoline was sold in cans which could be bought at grocery stores, lumberyards, coal merchants, and perhaps ironically, a number of establishments providing services to horse and carriage owners—carriage shops, blacksmith shops, and liveries.

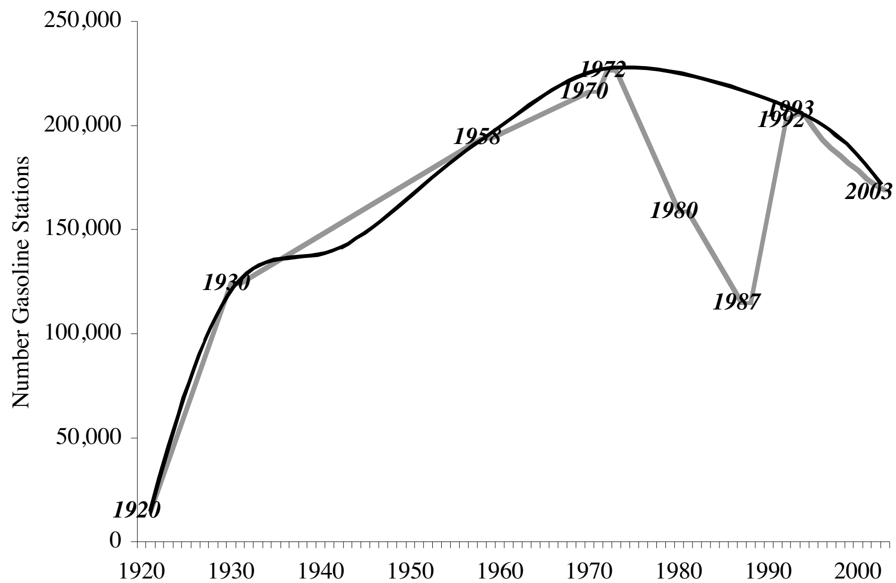
Regardless of when the first gasoline station opened, several of the accounts cited in footnote 7 concur that by 1920 gasoline pumps were evident throughout North America. One history of the chemical industry states there were 12,000 gasoline stations in the US in 1920, and that this had increased to 143,000 by 1929 (http://www.concentric.net/~Rnk0228/petrolhist.html). In 1972, the US Bureau of the Census' Economic Census estimated there were 226,459 retail gasoline outlets in the US. By the year 2003, the National Petroleum News (NPN) estimated this number had dropped to 167, 571.[8] (The NPN data can be seen on the US DOE's Office of Transportation

[7] According to information posted on the Missouri State Department of Transportation web site the world's first gasoline station opened in 1905 in St. Louis, MO (http://www.modot.state.mo.us/about/history.htm). Chevron, then Standard Oil of California, claims a plant manager in Seattle, WA opened the first "service station" in 1907 (http://www.chevron.com/learning_center/history/topic/service_stations/). Charles Rolston is reported to have opened a gasoline station in the name of Imperial Oil in Vancouver, British Columbia in 1908, the first in Canada and "allegedly" the world (http://www.shriners.bc.ca/shriners/rolston.shtml). This claim is amended to "Canada's first gasoline station" and to the year 1907 by Imperial Oil's own accounts (http://www.imperialoil.com/Canada-English/Investors/Operating/Petroleum_Products/I_O_PetroleumHistorical.asp). Still another claim states the first gasoline station in the US opened in Columbus, OH in the year 1910 (http://www.porterwright.com/history/history-09.htm). The Antique Automobile Club of America credits Standard Oil with opening the first gasoline station in the US. The station they cite opened in Cincinnati, OH in 1912 (http://www.aaca.org/junior/mileposts/1912.htm).

[8] National Petroleum News conducts an annual survey in the first quarter of the year. This data series starts in 1992.

Technology web site: http://www.ott.doe.gov/facts/archives/fotw279supp.shtml).[9] We provide a composite view of the changes in gasoline retailing during the period from 1920 to 2003 in Figure 2. Data points are shown by a label indicating their year. If we treat the data as all coming from the same series—that is, as measuring the same thing—we get the somewhat implausible trajectory shown by the grey line. A more plausible trajectory is shown by the black line. This trajectory is based the assumptions that Census data prior to the early 1970s and NPN data in the 1990s are accurate counts of the locations at which retail customers could buy gasoline and that growth in the gasoline retail network stalled during the 1930s and 1940s, as did sales of vehicles.

Figure 2: Composite estimates of trends in the US gasoline retail network, 1920 to 2003



Note: See text for explanation of trend lines.
Sources:
1920 to 1987: Jakle, John A. and Sculle, Keith A., p. 58.
1992 to 2003: National Petroleum News survey data, available at
http://www.ott.doe.gov/facts/archives/fotw279supp.shtml

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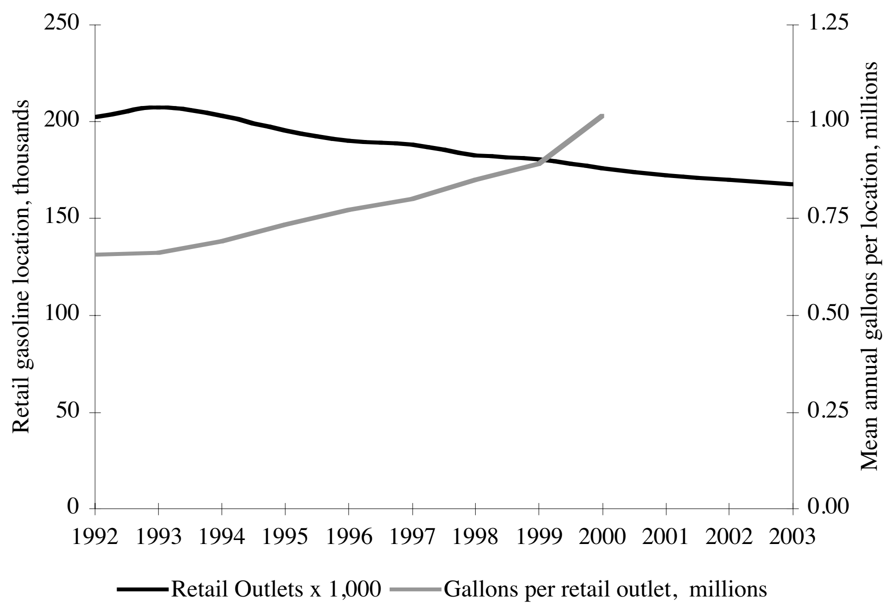
[9] Long-term counts of the number of gasoline stations are subject to some uncertainty as the reality of gasoline retailing has shifted from stations dedicated to the sale of fuels and services intended primarily for automobiles toward more generalized stores selling a variety of food, beverages, and other goods and services intended primarily for the occupants of automobiles. Lately, this has included the sales (and branding) of gasoline by large general retailers and grocery stores. The National Petroleum News now undertakes an annual survey intended to count all locations that retail gasoline. In their latest report, they opine that the Census counts from prior to the early 1970s are accurate since the transformations in gasoline retailing that render later counts less accurate started then.

Through the 1990s the trend in gasoline retailing was toward fewer retail locations, each one selling on average more gasoline. Because many people have proposed that the gasoline retail network serve as the basis for a retail hydrogen network, we highlight this trend in Figure 3. According to the NPN data plotted there, the number of gasoline retail locations declined from 207,416 in 1993 to 167,571 in 2003. By the end of the 1990s the mean sales of gasoline per location exceeded one million gallons; in 1972 the average retail gasoline location sold less than half this amount—approximately 445,000 gallons. Despite, the reduction in the number of retail gasoline outlets in the US during the 1990s, gasoline stations remain ubiquitous.

Figure 3: Trends in Gasoline Retailing in the US at the end of the 20th Century

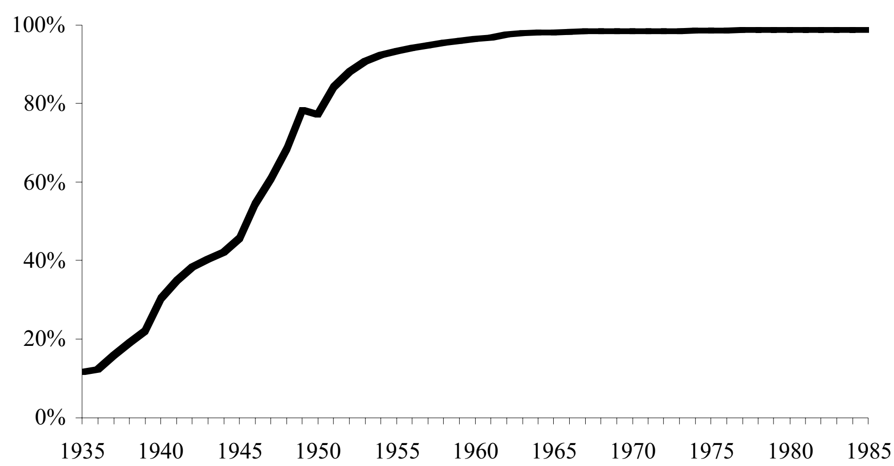


Sources:
Retail outlets: National Petroleum News survey data, available at
http://www.ott.doe.gov/facts/archives/fotw279supp.shtml
Gasoline sales: Transportation Energy Data Book, 22nd edition. Table 2.9.

Electricity

Contemporaneous with automobiles, roads, and gasoline, over the past century another social and technical transformation occurred through electrification. Electrification facilitated increases in the variety of fuels we consumed, increases in the amount of energy consumed—directly and indirectly—by citizens of a rapidly modernizing America, and allowed for the distribution of energy at both a dense, local scale and across long distances. Thomas Edison built his first electric power plant in 1882. It supplied DC electricity, and because of transmission losses the first users of electricity were limited to businesses and residents near this power station; electricity from it was used primarily for incandescent lighting. Today nearly 100 percent of American residential and business locations are served by electricity. Our time series data on the spread of electricity to American homes is limited to rural electrification. According to a history of the Tennessee Valley Authority, by the year 1930 approximately 90 percent of urban residents in the US were served by electricity while only 10 percent of rural residents were so served (http://newdeal.feri.org/tva/tva10.htm).[10] Through the efforts of the federal Rural Electrification Administration, the percentage of rural residents who had electricity had increased to 25 percent by 1939. The data for rural residents are corroborated by the data for farms in Figure 4. Only 11.6 percent of US farms were electrified in 1935. By 1953, nine out of ten farms were served by electricity and by 1963 farm electrification was nearly universal (97.9 percent). Data from the 2001 American Housing Survey indicates that greater than 99 percent of occupied American residences have electrical service of some kind (US Department of Commerce, 2001. Table 2-5).

Figure 4: US Farms with Electricity Service, 1935 to 1985



Source: US Department of Agriculture, Rural Electrification Administration. (1985) pp. 6-7.

[10] We are as yet unable to determine if the 90 percent figure for urban residents means that 90 percent of urban residents lived in cities served by electricity, or whether it means 90 percent of all urban residents actually had electricity in their homes.

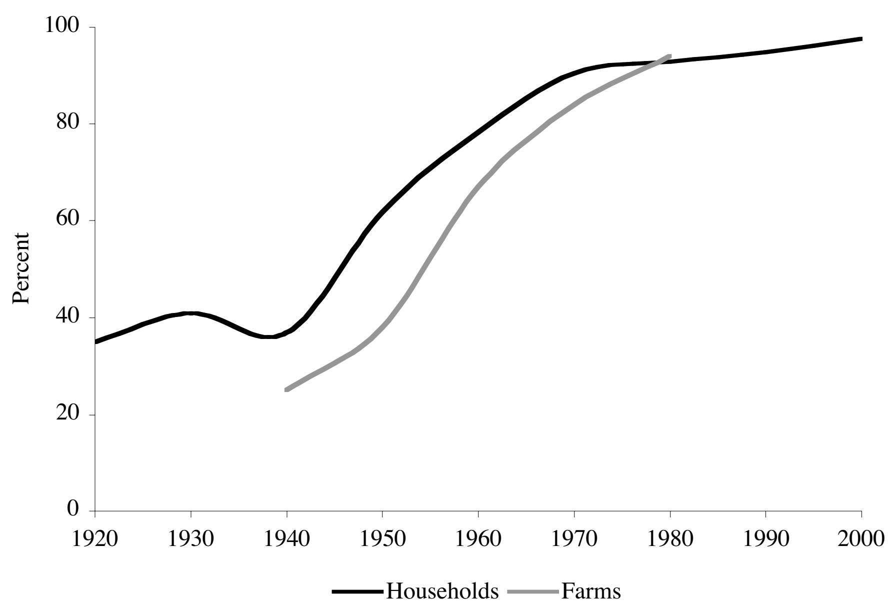
Information Infrastructure

In this section we discuss how we first hardwired the country for telephony; then we built wireless telephony. Building first on the telephone network we hardwired the Internet; now we are building a wireless network. These trends point to a future in which we continue to untether information from location.

Telephony

With automobility and new energy supply and distribution systems, the advent of the telephone was another great leap forward in overcoming Hägerstrand's capability constraints. Alexander Graham Bell's first phone call to his assistant in the next room was made on March 10, 1876. By 1920, 35 percent of US households had telephones. Data from the US Federal Communications Commission on household access to landline telephones are plotted below in Figure 5. The drop in the proportion of US households with telephones during the Depression of the 1930s indicates that phones were still not quite necessities at that time. However, the market for home phone service rebounded following the Second World War. Access is now nearly universal as the FCC reports 97.6 percent of US households had a landline telephone in the year 2000.

Figure 5: Percent of US households and farms with landline telephones, 1920 to 2000



Source:

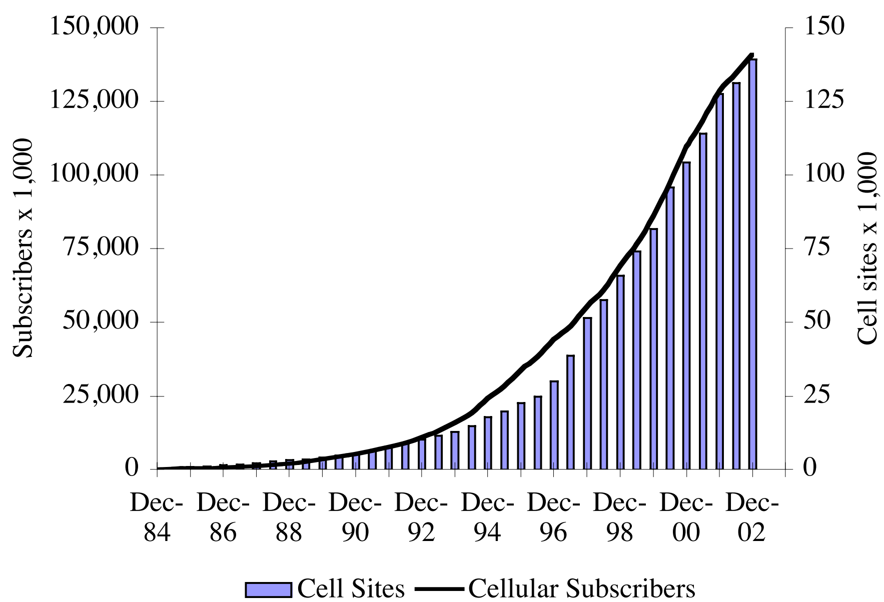
Households: Federal Communications Commission (2003), Table 16-4.

Farms: US Department of Agriculture, Rural Electrification Administration. 1985. pp. 6-7.

Significant differences in residential landline telephone service did exist between urban and rural populations, and continues to exist across the population by income. In 1940 only about two-thirds as many farms had landline telephones as did all US households. This gap appears to have closed by 1980. While residential access to a telephone is now nearly universal, discrepancies by income persist. As late as March 2000, only 87.5 percent of households with incomes less than 10,000 $US1984 had residential telephone service (FCC, 2001) There is considerable variation by state. In March 2001 only 70 percent of households in Indiana below this income threshold had telephones; 98 percent of such households in Maine did (ibid).

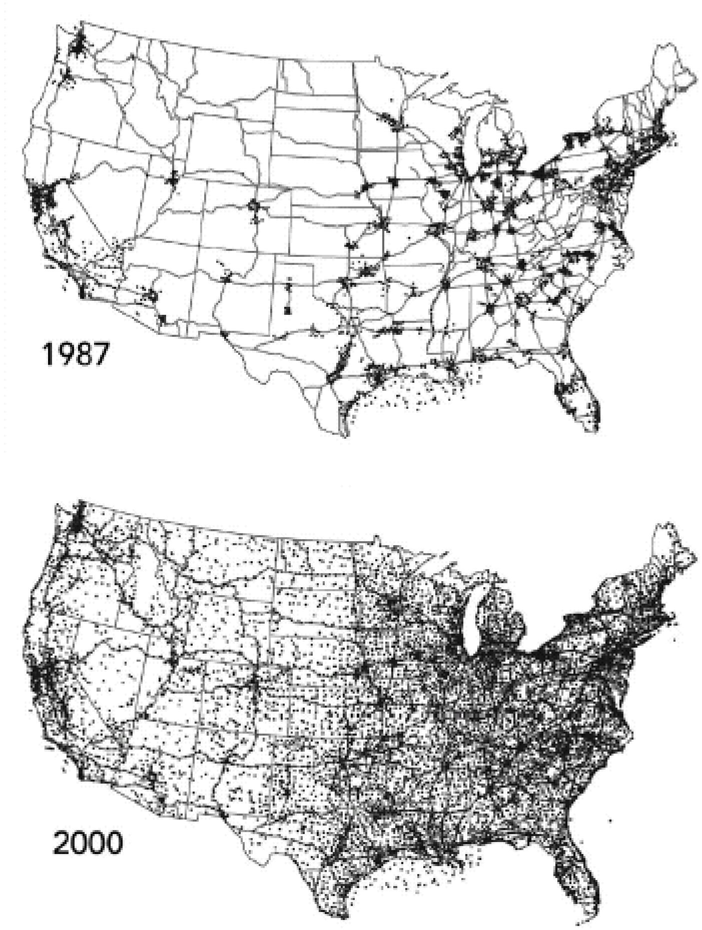
The wireless phone network—cellular—got its commercial start in the early 1980s. Data showing the growth of the physical network and the number of cellular subscribers are shown in Figure 6. In 1984 there were 346 cellular transmission sites in the US and 91,600 subscribers. It has taken only 20 years for the cellular phone network to become available to most Americans. By December 2002, there were nearly 140,000 cellular transmission sites and over 140 million US subscribers. The change in geographic distribution, and in particular the increase in density, of the cellular transmitter sites is shown in Figure 7.

Figure 6: Number of cellular transmission sites and cellular phone subscribers in the US



Sources: Cellular Telephone Industry Association’s Semi-annual Wireless Industry Survey, June 1985 to December 2002.

Figure 7: Change in geographic distribution of cellular transmitter sites in the US, 1987 to 2000



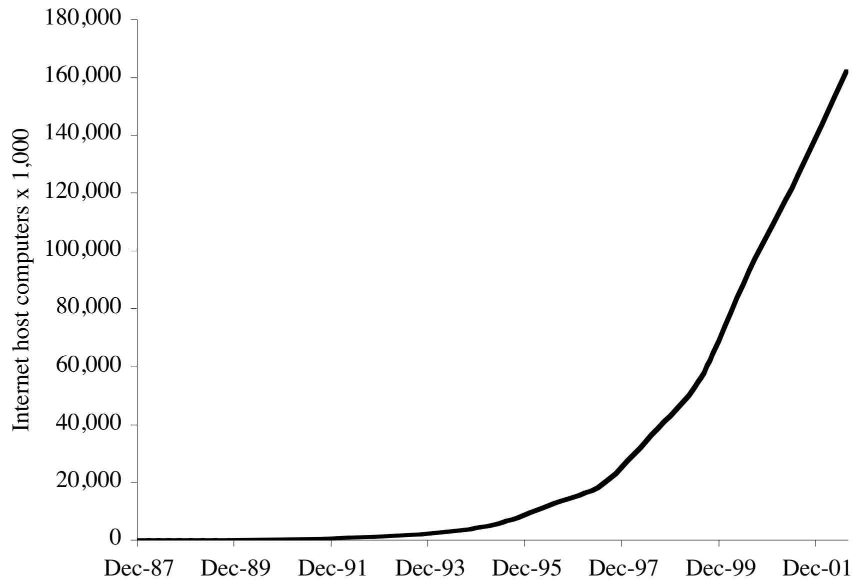
Source: Winkle (2002)

The cellular phone system has not supplanted the landline network; "cell phone-only" residences are still rare, the availability of cell phone service varies by urban and rural locations, and connection quality can be variable which can limit the effectiveness of cellular phones for both voice and data transmission. The cellular phone system has not replaced the landline phone system, but supplemented it. As demonstrated during the blackout of much of the northeast US and southeast Canada in September 2003, the cellular system is less robust in the face of electricity outages (New York Times, 2003a, b). Still, for many people cellular telephony has transformed personal and work-related communications. The nearest phone is now attached to their belt or in their purse. New social protocols are still being developed. How do we respond the person on the phone at the table next to us in the restaurant, or the driver in the next lane? For many, a telephone is no longer a location to be sought out, but a personal accessory.

Internet

The Internet operates on a backbone of dedicated, high-speed, hardwire communications "pipelines" and specialized computers—routers—to direct the flow of information. In 1981 the pre-cursor to the Internet consisted of 213 interconnected computers. This hardware system grew slowly through the 1980s, tripling in size over ten years. Only in the early 1990s did the system begin expanding rapidly, creating a network of global reach. There were an estimated 162 million host computers by the end of 2002. This trajectory is plotted in Figure 8.

Figure 8: Internet host computers, international

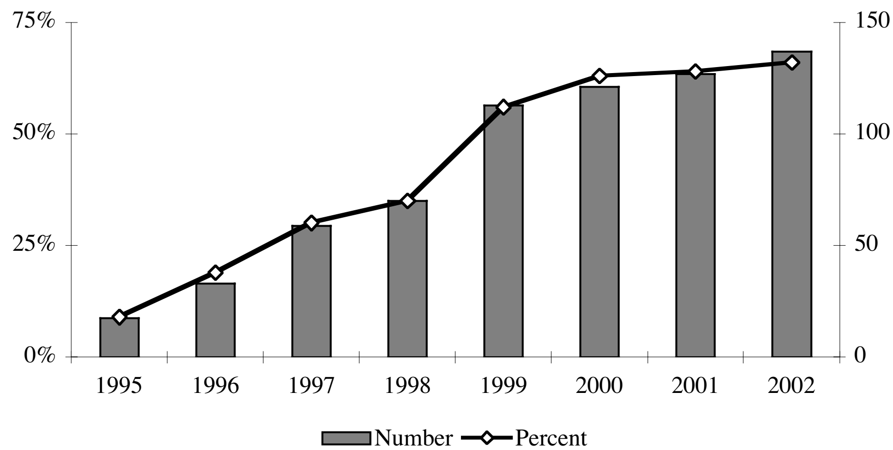


Source: Internet Software Consortium (http://www.isc.org/)

Estimates of the growth in the number and proportion of the adult US population who are Internet users are presented in the Figure 9. On a percentage basis, the growth in the adult US population who use the Internet is remarkable. In only seven years, the percentage of the adult US population who use the Internet grew from nine to sixty-six percent.

Another way to measure the growth of the Internet is the increase in the number of Internet protocol (IP) addresses. Devices connected to the Internet are assigned an IP address. The current common form of an IP address is a version 4 address. There are 4 billion possible IPv4 addresses. Because of growth in the number host computers, routers, and users as well as inefficiencies in how IP addresses were first allocated, it is estimated we will run out of the IPv4 addresses in 2005. IPv6 addresses are already being implemented. The number of IPv6 addresses is estimated to be greater than 35 trillion. The practical implication of the vast number of IPv6 addresses is that virtually every electronic device can have its own IPv6 address. IPv6 addressing is one change that opens the possibility for automobiles and their occupants to communicate with a wide variety of vendors, information sources, and other vehicles and people.

Figure 9: US Adult Internet users



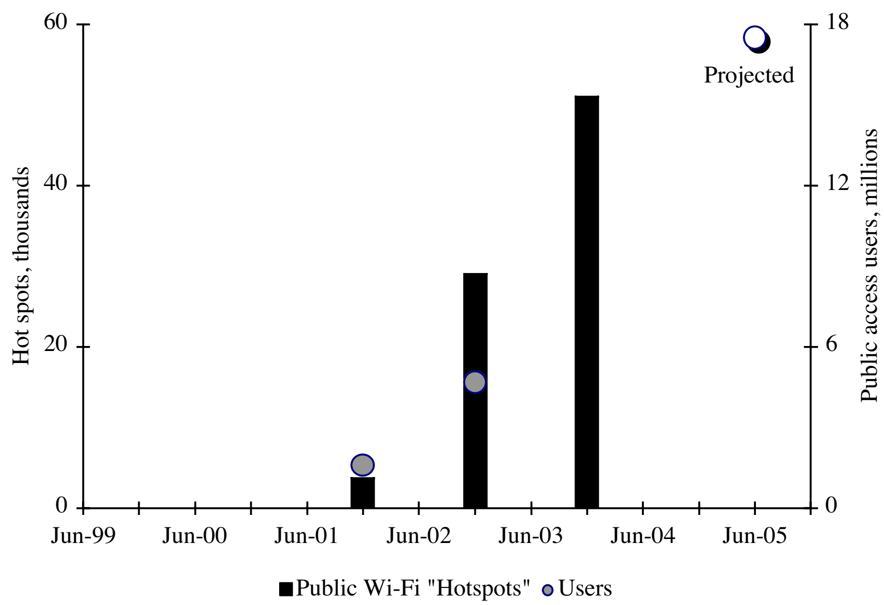
Source: Harris Interactive (2003)

Wireless Networking

Another recent development that is essential to increased communications is wireless networking. The initial entry of the Internet into most of our homes was through the phone lines. But whether through phone lines or not, users' connections to the Internet were initially hardwired. This is rapidly changing with the advent and spread of wireless networking technology. Currently, there are a few different wireless networking standards. Two of the more popular are known commonly as "Bluetooth" and "Wi-Fi." Bluetooth is a low power, relatively low speed protocol; typical transmission distances are 10 m, and typical data throughput is 1mbps. Wi-Fi, short for "wireless fidelity," has a transmission range of 100 m and a data throughput of up to 11 mbps under ideal conditions. A "wi-max" wireless protocol (802.16) is under development. Experimental results indicate a data transmission range on the order of 50 km and a data throughput of 70 mbps.

Wireless networks are appearing in homes and businesses as substitutes for hardwire networks. They are also appearing in a variety of other places, offered as an amenity to an increasing number of business travelers, mobile workers, students, and others who wish to have access to the Internet and their e-mail. Restaurants, airports, movie theaters, and other locations offer public access to wireless networks—some charge for access, others provide it for free. Early figures on the proliferation of public Wi-Fi networks and users are shown in Figure 10. Apple Computer first commercialized Wi-Fi networks in 1999. Public access points, known as "hotspots," are estimated to now number approximately 50,000. This is likely to continue to increase rapidly. The telecommunications company SBC announced in August 2003 plans to install 20,000 access areas in 6,000 hotels, airports, convention centers, restaurants, and other locations throughout its 13-state service area. The telecommunications company Verizon announced in May 2003 it would provide Wi-Fi access from phone booths in Manhattan.

Figure 10: US Public Wi-fi networks and users



Source: New York Times (2003c)

Combining Infrastructures

Our central thesis is that three supporting infrastructures of modern societies—automobility, electricity, and information—will be integrated into the next such supporting infrastructure. This process has already started in a number of ways. Already there are systems that integrate pairs of these infrastructures. We have discussed the combining of mobility and communications in the example of cellular telephony; wireless Internet networks are another example. Also, mobility and electricity are already being combined. With these two pairs of infrastructures already combining, the complete integration of all three appears to offer no significant technical barriers.

Mobility and Communications: Wireless Networking

According to a report from Allied Business Intelligence, by 2007 as many as 19 percent of new vehicles will have embedded Bluetooth, and 12 percent embedded Wi-Fi, wireless networks. Bluetooth networks may handle on-board communications, for example, replacing hardwiring between sensors and computers. This could reduce production and maintenance costs. Bluetooth or Wi-Fi networks could handle communications between vehicles and a variety of stationary or mobile devices, depending on distances and data quantities. Such communications could facilitate payment of road and bridge tolls, fuel transactions, and other purchases. Vehicle safety systems could be built around vehicle-to-vehicle communication networks, improving on existing (though still limited in numbers) adaptive braking systems. Improved wireless networking can also make full screen, high-speed Internet access available in automobiles, improving on the few lines of text available from existing cellular phones.[11]

Mobile Electricity

Mobile electricity is already happening in a number of ways. Some of these represent important markets for auxiliary electric power devices such as portable generators; some are extensions and expansions of long available, but heretofore minor capabilities, such as the 12-volt "cigarette lighter" outlet in vehicles.

The number of 12-volt electrical outlets in automobiles has increased in recent years, particularly in light trucks. Automakers are not only offering multiple outlets in each vehicle, they are also providing outlets in several areas of the interior. Generally, the larger the vehicle, the more "zones" of the vehicle have 12-volt outlets. Most small and midsized SUVs have outlets in the front and rear. Larger SUVs have three zones of 12-volt outlets—front, rear, and cargo area. The Hummer H2 comes with a total of five such outlets. However, newly redesigned smaller SUVs and minivans are including multiple 12-volt outlets in three zones of the vehicle. For example, the Honda Pilot, Volvo XC90, Cadillac SRX, and Lexus RX330 are all midsize SUVs that were launched (or relaunched) recently and all have front, rear, and cargo area electrical outlets. This proliferation of electrical outlets is relatively new in smaller vehicles and may indicate that consumers are demanding greater on-board electrical power.

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[11] Not only is the information that can be displayed on currently available "internet phones" limited, such devices can only communicate with Internet sites programmed specifically to do so.

Portable generators are another way that people have been making electricity mobile. The construction trades, recreational vehicle owners, festival promoters, and many others have used these ICE-powered devices to provide electricity off the grid. But these mobile electricity applications are marginalized by noise, localized exhaust emissions, and weak or absent integration with vehicles. The converse of taking electricity off the grid is supplying electricity to the grid. Building owners have used standby (though not necessarily portable) generators, fuel cells (though typically not hydrogen-fueled PEM fuel cells), and battery banks to provide back-up electrical power to applications especially sensitive to electric power disruptions. These include hospitals, attended care facilities, and health clinics, banks and credit data processing centers, and even homeowners concerned with electrical power outages.

Combining mobility and electricity raises the question of which of these types of applications might an FCV fulfill. Further, mobile electricity raises the question of what ways might lifestyle activities and business operations change if on the one hand the 12-volt barrier is broken, and on the other, high power mobile electricity doesn't require a separate portable generator, but is fully integrated into every vehicle sold.

Evoking the Future

We have presented ideas about what it means for a society to be on a trajectory of modernity and we have presented historical data on the socio-technological infrastructures that the evolving modern society in the US has built to sustain the processes of becoming and being modern. Such histories and trajectories could be constructed for Canada, most of Europe, and more recently parts of Asia and Latin America. These infrastructures are part of modern societies efforts to overcome constraints to the fundamental processes of mobility and globalization. That capabilities such as mobility should reshape even personal identity is central to our approach to studying markets for mobility and communication technologies.

The automobile and the attendant systems of roads, fuels, taxation, federal and state relations are central to automobility. Mobility is given further reach in time and space by communications technology. Each of these is levered by increased energy use. We have built systems of access, energy, and communications, of roads, fuel pipelines, and electrical distribution systems across this country. Over much the same time, we built a hardwired network of telephony for real-time communication. Next we began to spread that communications capability more finely across space and time by untethering telephony from location. We are now pushing further to spread access to electronic data everywhere through wireless networking and satellite communication. The capability to take relatively large amounts of clean, quiet electricity and spread it across the landscape in the form of FCVs fits this historical pattern—even if this wasn't the reason we started to contemplate FCVs in the first place.

This then is our image of the future. The intersection of the processes of modernity and the socio-technological systems modern societies build to sustain those processes lead to a world in which each of us, increasingly, must ask ourselves this question:

What will we do—when we can do anything, anywhere, anytime?

This is the future context FCVs will enter. It is a context in which the processes and meaning of "modern" will advance further as FCVs continue to develop, mature, and ultimately enter the daily life of modern citizen/consumers.

WHY WOULD ANYONE BUY AN FCV?

In defining what we believe an FCV to be, we discover clues as to why people would buy them. The integration of systems of mobility, electricity, and information technologies transforms the automobile from a mobility tool into a mobile activity *locale* and a mobile electricity source. Giddens (1984) conceptualizes *locales* not primarily in terms of the physical place, but in terms of the use of the place as a setting for social interaction. The automobile is a mobile activity locale whether it is stationary or in motion. A mobile activity locale is mobile both in the sense that some activities may be undertaken while it is in motion and in the sense that it facilitates the convening of activities in novel geographic locations. If your car is fully equipped to be your workplace, then your workplace isn't permanently defined by a street address or by longitude and latitude. Your business addresses may consist of a URL and a GPS transponder. The only practical reason for a street address or post office box may be legal requirements that a business be incorporated some "where." For parents busy chauffeuring children, the automobile becomes a mobile study hall, video arcade, changing room, dining room, or bedroom. The automobile becomes a locale for activities formerly reserved for home, restaurants, and other stationary locales, and makes those activities mobile. Automobiles may become destinations themselves.

In short, the reasons to buy an automobile shift from primarily transport purposes to new lifestyle and work structures—patterns that we see are already developing. Many workers already extend their workday into their commuting time, using cell phones, laptop computers, and other mobile tools to connect with their offices while on the road. Perhaps the single most compelling argument we can give for the future of automobiles as mobile activity locales is that automakers are already designing their vehicles to be such. While mobile office features are not yet standard offerings in current vehicle models, heightened mobile electricity and mobile technology are showcased in select concept cars. For example, Daimler-Chrysler's Dodge MAXXcab concept vehicle introduced at the 2000 North American Auto Show included a built-in laptop computer, Internet access, a DVD-entertainment center, and voice recognition controls, all powered by a next-generation 42-volt electrical system (Daimler-Chrysler, 2000). More mundane, and therefore more important, automakers now routinely offer a number of standard or optional features that are aimed at the multiple activities already being carried out in vehicles and hint at future capabilities. These include rear seat DVD entertainment systems (often supplementing multi-speaker, multi-zone audio systems), multi-zone HVAC, and pet-friendly restraints.

A New Product

If we sell FCVs as merely a replacement for ICEVs the market will develop slowly, if at all. In particular, the driving range of hydrogen FCVs will likely be limited compared to ICEVs for some time. Thus FCVs would seem to suffer some of the same limits as do battery electric vehicles—limited range and high cost. In fact we saddle FCVs with a constraint EVs did not suffer—the lack of home refueling. The more we portray FCVs as similar to ICEVs, the more FCVs must compete in arenas were ICEVs dominate. One clear lesson from the last two decades of experimentation and small-scale market launches of a variety of AFVs and EVs is that gasoline and diesel are hard to beat—on their terms. The nature of our approach is to change the terms by proposing a new product category (integrated information-mobility-electrical platforms) and a marketing approach (social marketing) in which gasoline and diesel vehicles are not necessarily supreme.

If we focus upon the innovative aspects of FCVs, in particular what we call the *lifestyle attribute*s, we allow FCVs to compete in arenas where they have advantages. Lifestyle attributes of FCVs are those that open new lifestyle activities for households, activities in which they can invest themselves. These activities create new values for vehicles—values which ICEVs may have a difficult time providing.

For example, the FCV attribute of onboard, clean, quiet, high power electricity allows consumers to use household-like appliances in their vehicles, to charge batteries for their electric power tools, to take a microwave oven on their picnic, to bring their television to the beach, to run a business out of their vehicle, or to furnish a campsite with an electric heater. As with many emerging technologies, the complete scope of uses and benefits cannot be fully predicted. Consumers will be the big innovators here, creating whole new uses (activities) for this new attribute. This in turn will affect the design of all vehicles, and possibly pulling different designs of competitors into the market. For example, the advent of mobile electricity may push hybrid electric-ICE vehicles towards larger batteries and more powerful motor/generators.[12]

Additionally, the green market value of FCVs (and competing alternatives) is a lifestyle attribute in that it symbolizes a new way of life to buyers. Many consumers are seeking a way to maintain

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[12] In fact, large-battery, grid-rechargeable HEVs may have one inherent advantage as mobile electricity sources over FCVs—the high energy content of gasoline and the existing, ubiquitous network of gasoline stations.

their automobility while reducing their impact on the planet and the health and well-being of others. As we have seen in initial interviews with hybrid vehicle buyers, much of the value early HEV consumers receive is derived from their sense of being an innovator and from the conversations about their vehicle with others—the sense of being part of a social movement.

One of the difficulties in categorizing FCVs as a new product is that new products create great uncertainty about their marketability and their impacts on policy goals. Also, a new product creates new markets and new market segments, in turn creating great uncertainty about how to market it. Much of the problem is that a new product is discontinuous with the past and the present. Our existing ways of thinking about it—even how, or to whom, to market it—must be rethought. The problem is that most market segmentation schemes are inherently grounded in past and in existing understandings of products and their consumers, or are otherwise based on empirical frameworks that lack the ability to predict new market segments. Segmentation schemes are often based on market histories, or buyer psychographics and demographics. Market research firms strive to market their segmentation schemes. Roper Starch-Worldwide has a proprietary scheme for green consumerism and a recent book purporting to explain how the ten percent of the population identified as "influentials" shapes how the other ninety percent live (Keller and Berry, 2003). The Stanford Research Institute promotes its Values, Attitudes, and Lifestyles (VALS) system. Ray and Anderson (2000) divide the world into "traditionals," "moderns," and "cultural creatives." More so than many other segmentation schemes, they attempt to place the development of each these groups into their historical context. Automakers typically have their own segmentation schemes, often with dozens of segments.

The challenge we face is that if a new product changes how we live and travel, then any one present trend and present understandings are (even more) unreliable indicators of the future The further into the future we prospect, the more we must employ multiple perspectives and examine mutually reinforcing trends of the type we examine in this paper.

What are the competing automotive alternatives?

Even in the present, the alternatives against which FCVs would compete if they were available are changing. The continued tightening of motor vehicle emissions standards has produced continued progress in limiting emissions of criteria pollutants from internal combustion engines. As FCVs continue in their development phase, the stock of ICEVs will continue to get cleaner. It is less clear that ICEVs will get any more efficient or reduce their greenhouse gas emissions. The entry of HEVs into the marketplace may increase the efficiency of the light-duty vehicle fleet. Automobile manufacturers continue to increase the body style and drive train options of HEVs.

How will cleaner ICEVs and new HEV alternatives change consumer expectations about what a car or truck is? It seems plausible to us that over the next several years while FCVs are still in the process of research and development, HEVs in particular will change baseline consumer expectations of automotive performance. Many consumers will come to appreciate the quiet, smooth launch from a stop that can be provided by the electric motor. Many will come to expect a driving range of 500 to 600 miles, rather than the 300 to 400 miles they currently achieve in today's ICEVs. Many will come to appreciate the convenience and lower cost of less frequent refueling. Some will come to expect to be able to choose a vehicle that produces lower greenhouse gas emissions.

How do we insure that FCVs provide us with the benefits we want? Conversely, how do we avoid the situation in which the benefits we get and costs we incur are subject to what may ultimately appear to be arbitrary decisions to solve narrow technical problems? An example of such a situation is recharging for battery electric vehicles. Much of the recharging electronics of an early prototype General Motors Impact were taken off-board the vehicle in order to shave a few pounds and save a bit of space (Shnayerson, 1996). From that decision forward, the availability of recharging infrastructure was reduced because the cost of such infrastructure increased (on a per location basis). Further, any incentive to decrease the weight and size of those recharging components was lost. We see though that subsequent improvements in battery technology render the original weight and space savings trivial, yet the ramifications for EV recharging persist.

One way to avoid this situation is to reposition societal goals and collective benefits through social marketing. Potential collective benefits of hydrogen-based transportation and electrical energy systems include cleaner air and improved public health, as well as reduced risk of global warming, war, and damage to ecological systems from petroleum production and consumption.[13] We require policies to create a market context that values these collective benefits. In the past these policies have included market-based incentives, performance requirements, production mandates, partnerships with industry, and differential access to transportation-related infrastructure. The latter include HOV-lane access for ZEVs and AFVs, provision of public recharging appliances (with their associated parking space) for ZEVs, and car-free zones. These policies span all levels of governance—federal, state, and local. This creates a rich set of possibilities to not only support technology research and development, but to create and evaluate a wide variety of socially created private benefits and conveniences to the drivers of vehicles that contribute to the attainment of collective benefits.

[13] We have elsewhere (Kurani and Turrentine, 2002a) defined *collective benefits* as a subset of public goods that no one gets unless many people act in concert to acquire them. Therefore, we would characterize clean air, reduced risk of global climate change, and peace as collective benefits—no single consumer can buy them.

A unique bundle of attributes

One reason we argue that FCVs are a new product is that they represent a unique combination of attributes and performance capabilities. Other technologies, including HEVs and ICEVs could provide some of these attributes and capabilities, but cannot provide the complete combination of the following benefits:

- Collective benefits such as clean air, reduced risk of global climate change and war, and eased exploitation of wilderness for energy
- Electric drive train benefits such as electric drive feel and new vehicle designs
- Hydrogen from varied fuel stocks and production processes, in particular the potential for carbon-free energy paths
- Automobiles as mobile activity locales facilitating new lifestyles and work structures.

Mobile Electricity affects Vehicle and Fuel Infrastructure Performance and Design

The integration of information, mobility, and electricity into a single platform depends on changes to vehicle and infrastructure design. It also facilitates new design possibilities. Some changes are to basic engineering and design elements of vehicles. If automobiles are going to be transformed so that they support mobile electric applications, they must be capable of physically providing for the application of stored energy to uses other than vehicle propulsion (and related lighting and HVAC services). That is, electrical connections, outlets, and devices must be provided on-board the vehicle.

Rather than simply adding a few outlets, as the information-mobility-electricity platform serves as an increasing variety of mobile locales, the vehicle itself may change too. If we are going to be doing more, varied things in vehicles, we can image that vehicles themselves may get larger (or at least smaller vehicles may get larger) as we need room to store mobile appliances and devices as well as space for ourselves as we do more than simply face forward in our seats. But more than just increased space inside our vehicles, we may desire space that can be configured in multiple ways. The vehicle will need to remain “driver friendly,” while accommodating other uses. This might be accomplished fairly simply with van-like vehicles. More complex solutions include the “plug-n-play” bodies that General Motors has suggested could accompany the development of their HyWire vehicle: whole different bodies may be swapped off and on the same “skateboard” that houses the basic drive-train, suspension, braking, energy storage and conversion systems that power the vehicle.

Relationship between driving range and non-travel use of energy

The idea that some energy stored on-board the vehicle might be used for purposes other than vehicle propulsion and the attendant idea that such non-propulsion uses might promote larger vehicle size have clear implications for driving range (for a given amount of energy stored on-board). Driving range will be reduced by both these things—all else being equal. This creates pressure for all else to not be equal. It speaks to a possible need for a different refueling network morphology than the existing network of gasoline stations. A refueling network to support the uses of an integrated information-mobility-electricity platform may need to be both denser and more extensive. That is, there may not only need to be more hydrogen refueling locations, but they may have to be distributed more widely across the landscape. Hydrogen refueling locations may need to be at different types of places. Notably, the increased energy use in information-mobility-electricity platforms and the ties between vehicle and home developed by the intrusion of "home activities" into the vehicle may create strong incentives to solve the problem of viable home refueling of FCVs. The "energy station" concept, wherein a large natural gas reformer provides energy to both a stationary base load such as a building and hydrogen for refueling the vehicles of the building's occupants, is another way in which the density, distribution, and location of hydrogen refueling may be different than competing fuels such as gasoline. In this sense, the hydrogen refueling network starts to mimic the natural gas reticulation network, rather than the gasoline distribution network. And certainly, the use of on-board energy for non-propulsion uses provides incentives to increase on-board energy storage and the efficiency of onboard appliances and services.

Mobile Electricity affects policy goals and social marketing

Hydrogen and fuel cells are means to other ends. Based on the image of the future we develop here, we foresee two problems in achieving those ends. The first—our ability to capture collective benefits—affects FCVs, but is by no means specific to them. The second, may also not be specific to FCVs, but does point to a need for reanalysis of the likely environmental and geo-political impacts of both FCVs and their likely competitors.

The problem of how (or whether) to market collective benefits of new automotive energy systems remains to be solved. Certainly providing collective benefits cannot be left to the market. We have discussed elsewhere (Kurani and Turrentine, 2002a) how collective benefits suffer from the same market failures as do positive externalities—since people can derive benefits for which they do not have to pay from the actions of others, markets will tend to produce too little of any product or service that produces positive externalities or collective benefits. In that same report (ibid), and previously at 7th Biennial Asilomar conference (Kurani, 1999) we have discussed how social marketing might be used to promote both the policy goals themselves and the sense of participation in creating positive social change. This broad social perspective might be used to promote the use of the greatest net social benefit energy system to produce mobile electricity and power information-mobility-electricity platforms.

The analytical problem created by the transformation of automobiles into mobile activity locales is that it confounds prior evaluations of transportation's social, environmental, and geo-political impacts. The world used to be neatly—if always conceptually—divided into mobile and stationary sources of impacts. Cars and trucks were used primary for mobility; their ancillary energy uses for lighting, HVAC, and entertainment were generally small in comparison. Information-mobility-electricity platforms raise the prospects of significant non-motive energy use in things that may appear to be cars and trucks, but that are used for an expanded variety of activities at many more locales. Whether or not FCVs actual create collective benefits needs to be reanalyzed in view of these possibilities.

A Cautionary, but Motivational, Tale…

We believe the forgoing provides a cautionary but still motivational tale. The fuel cell itself may be a clean and efficient device. However, whether it leads to greater or lesser energy use, greater or lesser emissions of criteria pollutants and greenhouse gases, greater or lesser reliance on petroleum (at least over the short to mid-term) depends our ability to foresee and adapt to changes we believe are all but inevitable in the nature of automobiles and automobility. If modern societies do transform automobiles into integrated information-mobility-electricity platforms, then there are at least three ways energy use and associated emissions will increase:

1. More energy-intensive lifestyles and work structures
2. Larger vehicles
3. More travel

More energy intensive lifestyles and work patterns could evolve in a number of ways. One example would be the potential for increased duplication of HVAC services in vehicles and in buildings. If I cool my car while I use it for my office at the beach, my office in my building may still be cooled. Another example would be the novel introduction of electrically powered services to locales. Campers, who might never imagine they would use a portable generator, may find their integrated electrical generation capability irresistible. Far more prosaic is the possibility of larger numbers of people either pre-heating or pre-cooling their vehicles. Just what people will do with HVAC services is unknown, what we do know is that such services are now almost universally available in automobiles. Adding large amounts of on-board electricity seems a sure way to increase the use of these services.[14]

Larger vehicles seem inevitable if people are going to be using their automobiles for more things other than mobility. They may want to be able to rearrange the space to create different locales; they may simply need more room to carry more appliances, furniture, and other accoutrements. Finally, with the ability to turn any location into a variety of novel locales, it seems plausible that people will travel more travel.

What are the effects on progress toward policy goals?

Faced with these prospects, in order to judge whether or not FCVs can actually create progress toward societal goals while further facilitating mobility we require explicit interaction between market analyses of mobile electricity, FCVs, and their competing alternatives and our analyses of:

- Emissions of GHG and criteria pollutants
- Oil consumption and the geo-politics of oil consumption
- Development patterns and land use
- Wilderness access and road ecology

These in turn can inform vehicle and fuel infrastructure design and policy making to help insure we achieve the desired benefits.

We note that mobile electricity in the form of integrated information-mobility-electricity platforms places similar pressures on all automotive energy pathways. Thus our discussion of a future in which society attempts to invoke a new socio-technical system to support continued democratization of mobility, energy, and communications shifts the frame of reference. FCVs are not to be assessed only relative to today's ICEVs or HEVs. Rather, a comparison to ICEVs and HEVs that are themselves integrated information-mobility-electricity platforms is also required.

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[14] Packard and Cadillac offered air conditioning in luxury models in 1940, but more general market penetration was delayed by World War II. According to Dupont's web site, fewer than 3,000 automotive AC units were installed before the US entry into the war (http://www.dupont.com/suva/na/usa/about/history_timeline.html). Following the war, marketing of automotive air conditioning resumed. Dupont claims that by 1967, 40 percent of new cars and trucks in the US were sold with air conditioning; 72 percent by 1980; and, 90 percent by 1990. The data for the 1990s are corroborated by data from the American Automobile Manufacturers Association (1995, p. 11).

Vehicle and Fuel Infrastructure Design, Mobile Electricity and Driving Range

To provide one practical application of the ideas we discuss throughout this paper, we take a look at the implications of mobile electricity for driving range, or more generally energy storage, goals. The following statement is from the USDOE's *Progress Report for Hydrogen, Fuel Cells, and Infrastructure Technologies Program* (2002):

> "The overarching technical challenge…is how to store the necessary amount of hydrogen needed to fuel the vehicle for its required driving range (>300 miles), within the constraints of weight, volume, efficiency, and cost." [Ellipses added.]

Based on our prospecting the future, there are several reasons to question the characterization of a driving range of greater than 300 miles as both "necessary" and "required." Keeping in mind that the real purpose of the statement is to establish a goal for on-board hydrogen storage, we provide reasons why the stated goal is too low, and possibly too high.

The amount of energy required to drive 300 miles is too low for two possible reasons. First, it's too low if we expect people to both drive 300 miles and make significant use of on-board energy for non-travel services, i.e. mobile electricity. Second, it's too low if, in the interim while FCVs are still being developed, HEVs shift consumer base line consumer expectations of driving range up into the range of 500 to 600 miles.

Conversely, a goal to store energy on-board that is sufficient for a 300 mile driving range could be too high. What if the refueling network morphology for hydrogen is based on the natural gas or electric networks, not the gasoline retail network? In particular, if home refueling of hydrogen is possible, then the relationship between on-board storage and refueling is more like an EV than an ICEV. And if we learned anything from EVs, it is that a 300 mile range driving range is not required if 1) the vehicle can be recharged at home and 2) it is one of a variety of travel tools available to a household (Kurani, Turrentine, and Sperling; 1994, 1996). Further, the benefits of mobile electricity may be such that people will accept more frequent refueling—even in a dispersed retail networks such as the current gasoline network.

Thus it should be understood that our contention is not with the goal of 300 miles *per se*. Our contention is with the characterization of any one goal as necessary and required until integrated analyses of mobile electricity, refueling network morphology, and societal goals are even attempted.

Conclusion: A Future for FCVs?

We have argued that automobiles will be transformed from primarily mobility tools into mobile activity locales. Technologically, this will be facilitated by the integration of three of the supporting infrastructures built by modern societies during the 20th century—automobility, electricity, and information systems. Such integration is in synchrony with the processes of being modern, thus this integrated infrastructure may become the next supporting infrastructure of modern society during the early part of the 21st century. The transformation of automobiles from mobility tools into integrated information-mobility-electricity platforms will take us one step further on a path to the future plotted by the forces of mobilization and globalization. We see mobile electricity is already happening in small but important ways. Mobile communications is further developed, but still expanding into new services and across the population.

The development of these three supporting infrastructures of modernity during the 20th century was driven by mutually supporting relationships—positive feedback—between social forces and technological capabilities. Mobility begat more mobility; energy use begat more energy use; communications begat more communications. Initial evidence suggests that their integration is also driven by positive feedback—mobile communications begets more mobile communications. For those hoping communication might substitute for travel, the scholarship is ambiguous; many studies indicate that more communications leads to more, not less, travel. These relationships point to increased travel, increased energy use, and increased communications, to more mobility of people, commerce, and ideas in the future. If hydrogen and FCVs are to contribute to the collective goals of lowering criteria pollutant emissions, greenhouse gas emissions, and petroleum consumption, it is not obvious that they will do so by breaking these positive feedbacks.

Are FCVs the best power system for integrated information-mobility-electricity platforms? In effect, are FCVs a better way to the future? If they are, they gain competitive advantage as they tap into the long-term social and technological trends we have discussed in this paper. There are existing competitors already providing mobile electricity in some form. However, FCVs add desired attributes—high power and ample energy compared to batteries; quiet and zero local emissions compared to ICEs. Ultimately, there is the promise of a renewable and direct-solar, non-carbon energy path. In that promise lies the potential for hydrogen, FCVs, and fuel cells more generally to capture collective benefits.

Despite the opening questions of the previous paragraph, a future of increased mobility, increased energy use, and increased communications is not inevitable. However, we believe we have shown it is strongly compelled. A hydrogen energy system, made real through fuel cells, holds the potential to create this future while we meet goals to clean the air, protect the functioning of global ecosystems, and limit our dependence on domestic and imported petroleum. But the path toward a future in which we achieve all this is neither certain nor obvious. Recognizing the potential for mobile electricity and mobile communications to confound progress on our collective goals, we believe the research imperatives are these:

- Increase our understanding of the likely new personal and social behaviors, including policy, facilitated by mobile electricity and communications; and,
- Accelerate research and development programs on truly carbon-free energy paths.

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