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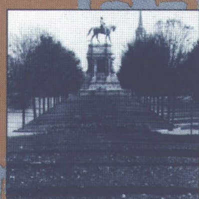

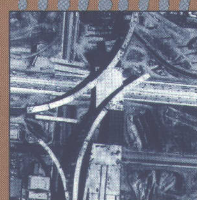

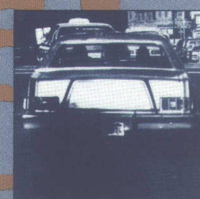

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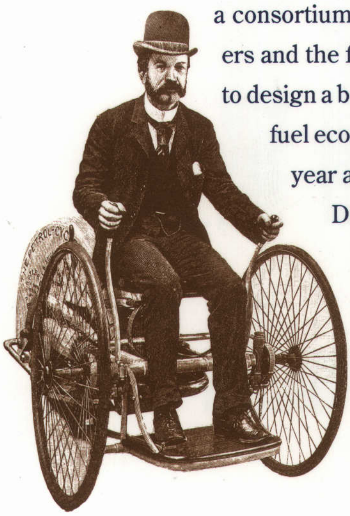
Despite huge reductions of noxious emissions from factories and cars, Southern California's air is still terrible. It's so bad that the state is requiring that two percent of new cars sold in 1998 be zero polluters and ten percent by 2003. Many researchers here have become preoccupied with the foul air, and so are searching for ways of making cars less obnoxious and hence better servants.

A lot has been happening in this field in recent days. At the request of the State Legislature, the UC Transportation Center helped by creating a panel to explore the options. Its inquiry was aimed at finding the 10 to 15 percent of cars that cause 50 percent of pollution from vehicles. In his article here, Charles Lave describes both the problem of testing automobile emissions and the panel's proposals for taming the most-noxious tailpipes. The study examined the effectiveness of alternative testing technologies and of associated simulation models. Perhaps even more important, it exposed serious differences between federal and state emission-control methods, differences that have yet to be resolved.

In a remarkable shift toward a national industrialization policy, the White House recently proposed deferring anti-trust regulations to permit a consortium among the big-three automakers and the federal government. The aim is to design a better car — safer, with improved fuel economy and reduced emissions. A year ago in the first edition of ACCESS, Dan Sperling and colleagues discussed the array of alternative fuels now available. As they predicted, it seems many of us will soon be driving electric cars. Soon GM will be testing the market for its Impact. A research team at UC Irvine is currently conducting market surveys to test motorists' receptivity to electric cars. Here, Allen Scott reports on his UCLA team's explorations into the prospects for building an electric-car industry in Southern California. It seems the betting odds are coming to favor electrics. And yet, it's still not clear where the electricity will come from.



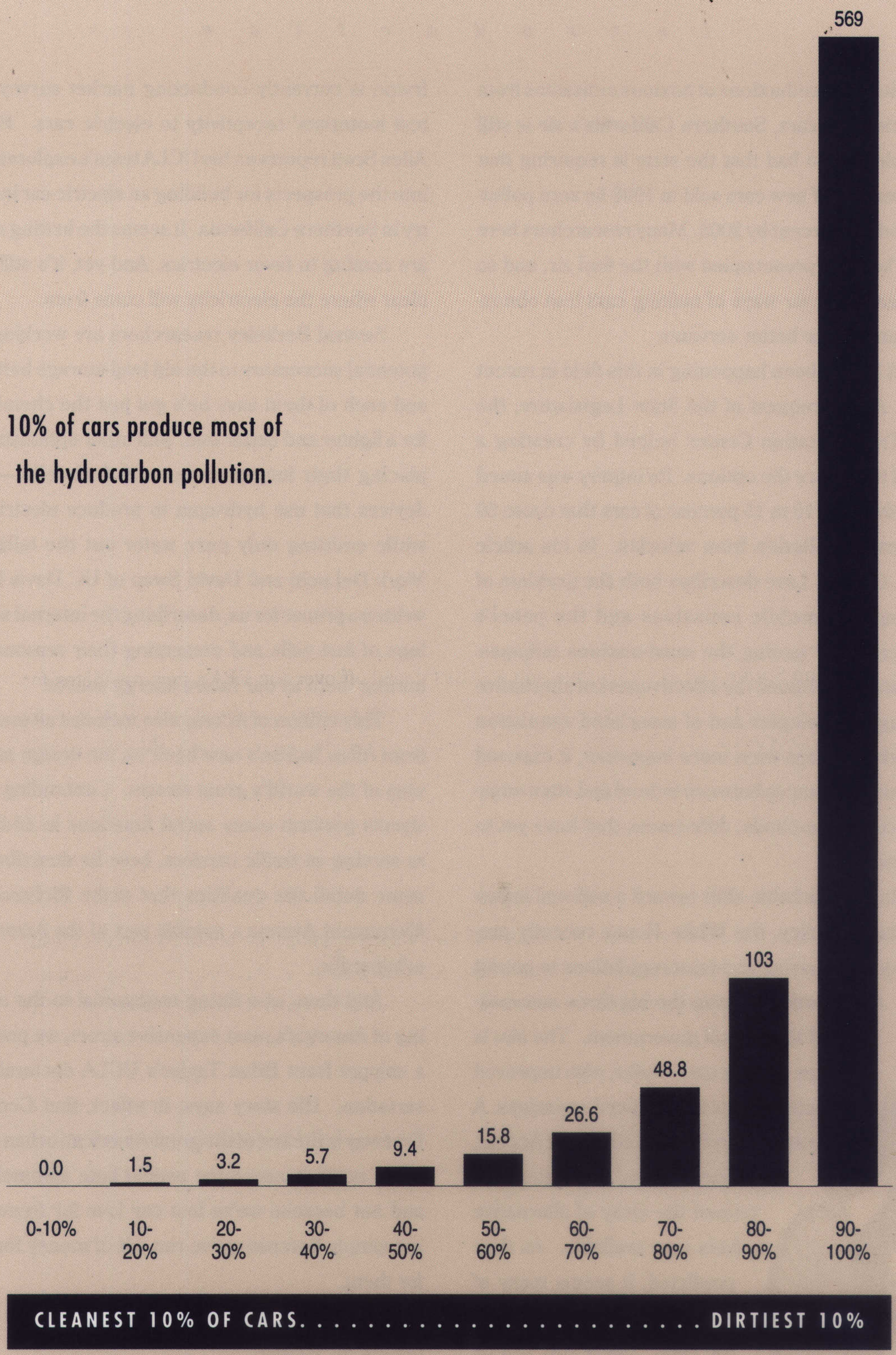
Several Berkeley researchers are working on potential successors to the old lead-storage battery, and each of them says he's got just the chemistry for a lighter and better one. Still other optimists are placing their long-term bets on fuel cells — on devices that use hydrogen to produce electricity, while emitting only pure water out the tailpipe. Mark DeLuchi and David Swan of UC Davis have written a primer for us, describing the internal workings of fuel cells and presenting their reasons for touting them as our future energy source.

This edition of ACCESS also includes an excerpt from Allan Jacobs's new book on the design attributes of the world's great streets. Contending that streets perform many social functions in addition to serving as traffic carriers, here he describes in some detail the qualities that make Richmond's Monument Avenue a notable part of the American urbanscape.

And then, as a fitting testimonial to the opening of America's most expensive street, we present a snippet from Brian Taylor's UCLA doctoral dissertation. His story says, in effect, that Century Freeway is the last of the great American urban freeways, not because some people hate automobiles and not because we've lost our love for freeways, but simply because we've run out of money for pay for them.

Melvin M. Webber
Director

10% of cars produce most of the hydrocarbon pollution.



Average Idle Tailpipe Hydrocarbon Emissions in Parts per Million

Source: Buzz Breedlove, *Motor Vehicle Inspection and Maintenance in California* (Sacramento: California Research Bureau, 1993), p. 19. Based on 1991 random-roadside-survey data obtained from Bureau of Automotive Repair.

Clean for a Day

California Versus the EPA's Smog Check Mandates

BY CHARLES LAVE

In the Spring of 1993 California and the EPA faced-off over the EPA's new mandates for checking auto emissions. The California Senate asked the University of California Transportation Center to provide a "blue ribbon" evaluation of the issues. This article tells what we discovered. The final picture is not clear enough to distinguish good guys from bad guys, but we can see well enough to know that the EPA's new national rules for smog checks are deeply flawed.

Background

When today's cars leave the assembly line, their emissions are about 95 percent cleaner than those of the cars of thirty years ago. Alas, they don't remain that way. The complex emission control systems can deteriorate or break unless they are carefully maintained, and these cars can become very dirty indeed. How dirty? Taking the auto fleet as a whole, most of the total emissions are produced by only 10 to 15 percent of all autos.

Realizing the importance of maintenance, more than a decade ago California required all cars to have their emission control systems periodically tested and certified. Testing procedures have become more elaborate and more extensive over time, and there are currently about 9,000 certified smog check stations.

Now EPA wants to require an even more elaborate testing procedure: it devised a testing machine that is far more expensive; and, to assure that the machine is used properly, it wants to have all the testing done at a network of about 100 centralized, state-controlled testing stations. ➢

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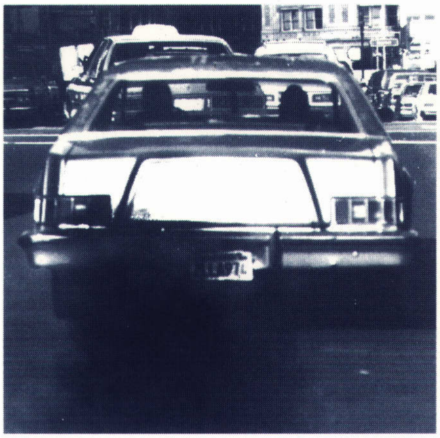


Most of the California debate has concentrated on the issue of centralized versus decentralized testing and on the attendant loss of smog check jobs. The underlying conceptual issues are actually a good deal more interesting than that.

Clean for a Day

California's current inspection program is designed to assure that cars are clean one day every two years — the inspection day. Successive programs have improved that test and reduced fraud. We worked hard at making that one day cleaner and cleaner, while ignoring the car's performance on the other 729 days. The new testing program mandated by EPA continues this clean-for-a-day focus. Consider the history.

Following a number of partial inspection schemes, California instituted the BAR84 program (Bureau of Automotive Repair 1984) and began biennial inspection of all cars. An official panel later evaluated the program and concluded that the BAR84 was a failure — it did not clean the vehicle fleet as much as had been promised. Why? Some thought the problem was an inadequate testing device. Others thought the problem was fraudulent testers, or cheating motorists who tampered with their emission systems to make their cars run better. So a new testing program, the BAR90, was started. The designers promised it would be more accurate and would deter fraudulent testing and tampering by motorists. But evaluation, after a few years, showed that the new test was also a failure.

Now EPA wants to impose a third version of the test, one with even more expensive testing machines and even better control over the testers. One is reminded of the old cartoon where a repairman is hammering on a complex machine he does not understand. In frustration he says: "Get me the bigger hammer, kid."

Stuck in the Same Old Rut

All these testing programs share two main characteristics: they are universal and periodic. Universal, in that they test all cars even though we know that only 10 to 15 percent of them are very dirty; thus we are largely wasting the money and time of 85 to 90 percent of the motorists. Periodic, in that the inspections occur at fixed times with long intervals between tests. Such periodic testing is akin to a program that "controls" drunken driving by scheduling drivers for a breathalyzer test every two years. Obviously, it is performance between tests that matters.

We have some data on that. California does a few thousand roadside emission checks each year: a random sample of cars is pulled over and tested. One researcher, Douglas Lawson[1], got the clever idea of classifying the test data according to the date of each car's mandated biennial smog check. He plotted emission levels of cars that were due for smog check within the next 90 days, and he plotted the emission levels of cars that had passed their biennial test within the past 90 days. If the smog check program works, there ought to be large differences between the pre- and post-test samples. In fact, it's impossible to discern any difference between the two plots: the average car looks no cleaner after it has been checked and certified than it did almost two years after its last test. Clearly, our program of universal, periodic testing works poorly.

New research has another important result: a properly performed BAR90 test (the current California test) will reliably detect gross emitters. Consider the implication. Given that the BAR90 can detect gross emitters, but yet they are still on the road, it seems obvious that the critical problem is weak enforcement rather than weak testing. Some kind of monitoring between inspections is needed to deal with tampering, breakage, and deterioration, and to improve BAR90 inspectors' performance.

Instead of shifting focus to detection and enforcement, EPA doggedly pursues the "bigger hammer" approach. It has concentrated on improving the accuracy of the biennial inspection — the car *will* be clean by the end of inspection day! The new EPA test, the IM240, may be somewhat more accurate than the BAR90. (It uses a dynamometer to measure emissions under acceleration instead of only during idle.) But in any event, the difference from BAR90 is not large compared to the effects of tampering and deterioration between inspections.

EPA also insists that testing be centralized at a few state supervised sites because, it believes, centralized inspectors will be better inspectors — they may know cars better, they may be more careful, and hence they may do better inspections. We think this is unlikely, given the low wage rates assumed by EPA in its cost/benefit studies.

Even ignoring the fact that IM240 is just another clean-for-a-day program, it has serious drawbacks. First, it will take a long time to implement because it will be difficult to gain permits to site these large, noisy stations. (Imagine the delay that a few home owners, or smog check stations, might cause by using the legal remedies available under California's labyrinthine environmental permit process.) Second, a centralized IM240 program is likely to seriously inconvenience motorists because of the added time to locate, drive to, and then wait for an inspection. EPA says the average queue is only five minutes in those states that have centralized inspections. But they measure the delay during a typical hour, not the delay experienced by a typical motorist. It is analogous to saying that "Los Angeles freeways are uncongested during a typical hour" because there are 18 non-rush hours, though this statement hardly describes the congestion experienced by most commuters.

How can we implement a better inspection and maintenance program, one that assures performance between inspections?

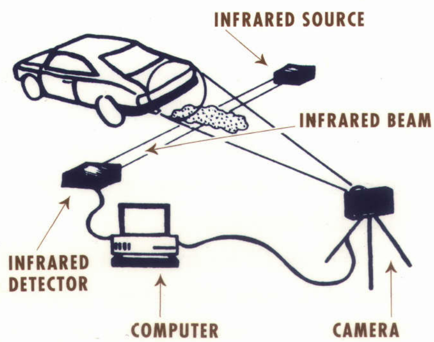
Remote Sensing to the Rescue

While all this feuding has been going on, a chemist at the University of Denver, Donald Stedman[2], developed a new way to measure auto emissions. He shines an infrared light beam across the roadway and measures the characteristics of the light that passes through the exhaust plume. The device can measure carbon monoxide and hydrocarbon content, and it is currently being improved to measure nitrogen oxides as well. The advantage of Stedman's sensor is that it is fast, cheap, and unobtrusive. No special pull-overs are needed. It measures the cars as they drive by and can tell immediately whether emission levels violate the law.

EPA examined the remote sensor and concluded it was not good enough: they say the sensor gives only a one-second snapshot of the car's emissions, not a measure of its performance over an entire driving cycle.

These one-second snapshot readings may be unusually high or low, compared to a long sample, and hence the remote sensor will miss some polluters while harassing drivers of some clean cars. Since the remote sensor is not as accurate as the IM240, EPA sees little use for it. ➢

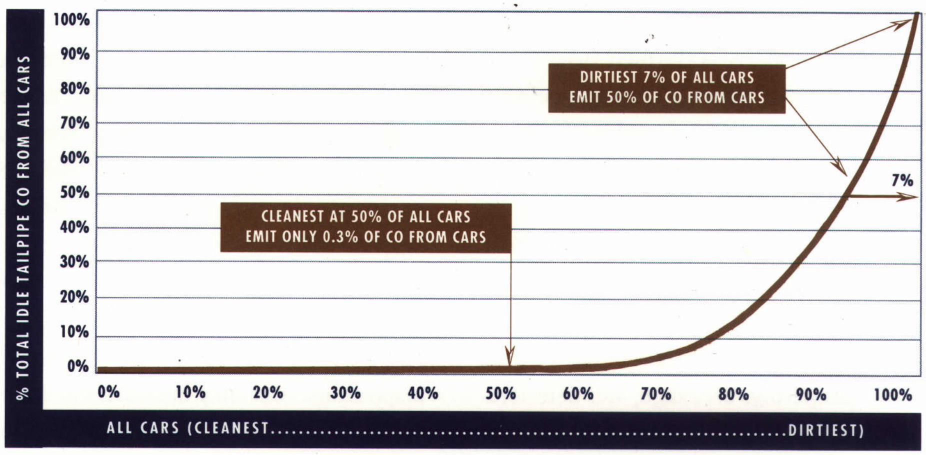
REMOTE SENSING SCHEMATIC



[1] Lawson, 1993. Lawson's analysis questions the need for EPA'S IM 240 test—it does not outperform the idle test. The phrase "Clean for a Day" is his.
[2] Bishop, et al., 1993.

Carbon Monoxide Emissions from All Cars

Source: Buzz Breedlove, *Motor Vehicle Inspection and Maintenance in California* (Sacramento: California Research Bureau, 1993), p. 18. Based on 1989 random-roadside-survey data obtained from Bureau of Automotive Repair.



Stedman says: the way around the accuracy problem is to flag only those cars with very high emission readings on the remote sensor. This guards against "false fails." EPA replies: Yes, but a high cutpoint will allow some gross emitters to escape detection.

We say, EPA's argument misses the point of the new technology: it is not to be used for a biennial inspection but rather to constantly monitor the entire auto fleet. Yes, a gross polluter might escape detection during any given sensing-event. But if cars are monitored many times per year (easily possible because the remote sensor is cheap and unobtrusive), then the probability of detection can be made as high as we wish. We substitute a large number of cheap, continuing tests for one expensive test every two years. We gain the ability to monitor performance continuously.

Recommendations

Neither remote sensing nor IM240 is a mature inspection and maintenance program — we know little about effectiveness under actual large scale implementation. Fresh, important information about their uses and limitations emerges every month.

We do not ***know*** which of these alternatives is best. Neither can EPA. The evidence is not sufficient to make a considered judgment.

These uncertainties make it irrational to build a costly, extensive network of IM240 test stations. True, some analysts strongly believe it will work, but California has already implemented two other highly recommended inspection and maintenance programs that did not turn out as expected.

It makes sense to delay major commitments to these programs, while further exploring their potential. Thus, we recommended the following ***Interim Program:***

- Continue biennial inspections with the existing decentralized BAR90 stations. Supplement these with remote sensors to randomly test cars between inspections. Build a few centralized IM240 stations to see how well they perform.
- Cars flagged by the remote sensor receive a citation requiring them to be inspected at a special referee facility that only does smog checks. If they fail the test there, they must be repaired elsewhere and then retested.

This interim inspection and maintenance (I/M) program has many desirable features:

- It can be implemented quickly. The initial referee facilities will be specially certified BAR90 stations, with a few IM240s too. Performance of the IM240 can be compared against the BAR90 under real world conditions; if it actually is better, we build more of them and phase out the BAR90 Referee stations.
- The average daily reading of the remote sensors directly measures the auto fleet's on-the-road emissions. For the first time we will have a broad measure of effectiveness — the gauge needed to evaluate alternative I/M programs.
- It field-tests and corrects any operational problems with the IM240 and the remote sensors, and it produces realistic data on waiting times and other problems.
- Implementation is incremental: untried new technology is phased-in

gradually, with careful evaluation at each stage. In contrast, EPA's centralized IM240 program is an expensive, giant leap into the unknown.

Our recommended Interim Program might be implemented on either a statewide basis or in a single geographic area. We might even consider a "shoot out" between the alternative programs: implement each alternative on a small scale in a geographically distinct area of the state, then monitor the results to see which is most effective.

Summing Up

I/M policy is following a well-worn rut, a rut so deep that the practitioners can no longer see out to view the alternatives. This rut is called periodic inspection. And the perspective from inside the rut makes people believe they should concentrate on producing more and more accurate tests.

But the I/M question turns on human issues, not engineering ones. How much fraud and tampering exist and how can we deter it? How can we encourage motorists to maintain their cars? How will inspection stations function in terms of waiting time, detection and repair of problems, and cost effectiveness? Experience-based data are required if we are to resolve these questions. Theoretical arguments are not enough.

Our interim program is designed to provide immediate I/M improvement while collecting the needed data. By the end of the proposed testing period, we will know where we ought to go next, and how to get there. Before trying yet one more expensive universal inspection program, it is worth implementing this modest supplement to the existing I/M program. It is an excellent transition strategy, no matter where we want to end up.

Adopting EPA's program would be a mistake. It is expensive. It will entail years of delay before there is any effect. It is likely to seriously inconvenience drivers. And most of all, there is little reason to believe that EPA's program will reduce vehicular emissions.

Epilogue

In September 1993, the California Assembly and the Senate Transportation Committee passed bills containing many of the provisions in our report, and the Governor indicated he would sign such legislation. Before final reconciliation and passage of the legislation, though, EPA suggested a cooling-off period during which all parties would try to negotiate a mutually satisfactory plan. The deadline is January 1994.

Acknowlegments

The tone and implications of this summary are my own. The research was done in conjunction with professors Amihai Glazer and Daniel Klein of the University of California, Irvine economics department: they get credit for most of the insights and analysis. Richard Crepeau and Maria Koskenoja provided research assistance: they get credit for most of the work. The full report is cited below.

I have written on public policy issues for almost thirty years and never had a report taken so seriously before. Why was this one apparently influential? Probably because we were lucky enough to write about a topic with employment implications — the jobs at the 9,000 decentralized smog check stations — at a time when unemployment was a serious concern in California. That is, to the extent we influenced anything, it was probably for the wrong reasons. Still, it's nice to have an effect every few decades. ◆

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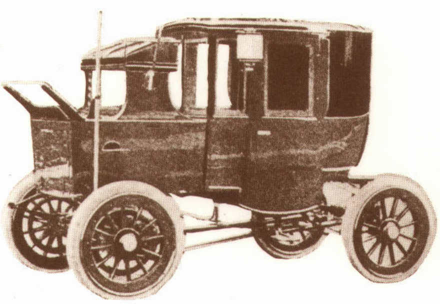
SOUTHERN CALIFORNIA: THE DETROIT OF ELECTRIC CARS?

BY ALLEN J. SCOTT

The California economy is in the doldrums, especially in the Los Angeles region, owing in large part to the decline of aerospace-defense industries. The region also suffers from the nation's worst pollution problem, owing largely to its dependence on automobiles. So, we're led to ask whether these linked perils might be converted into a combined opportunity. We ask whether we might blunt both the environmental and the employment problems by building a new electric-vehicle industry in Southern California that exploits its skilled but underemployed labor and managerial resources and creates a transportation system that doesn't pollute.

In a study we conducted two years ago[1], researchers projected a new electric-vehicle industry in the United States, focused on both final assembly and components manufacturing. The study predicted that the industry will at first be small in scale, serving rapidly shifting niche markets instead of achieving large-scale mass production. Therefore, the pioneer companies will need to adopt highly flexible production technologies and adaptive organizational forms. The industry will comprise many different subcontractors and specialized suppliers in a dense network with little vertical integration. That is, one company will not manufacture an entire vehicle on its own. Instead, many specialized companies will contribute to the finished product, and significant parts of the industry will concentrate in the same geographical area.



But where will the main concentrations of production be located and within what institutional frameworks? The industry could very well develop in either Japan or Europe under the aggressive industrial policies that prevail in those two places, or in the Northeast of the United States where domestic car producers are now planning manufacturing systems to beat the Japanese and European competition. General Motors has plans to man-

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ufacture an electric passenger car, the Impact, at its Reatta plant in East Lansing, Michigan; however, the Impact project is now reported to be considerably delayed. Given the headstart Japan, Europe, and the U.S. Northeast have on automobile manufacturing, why would Southern California be a likely world center for producing electric cars?

It's a mistake to assume that manufacturing electric cars will require similar processes and equipment as for manufacturing conventional cars. On the contrary: by one estimate, 40 percent of the components and subsystems in an electric vehicle *must* be different from those of a gasoline vehicle, and another 30 percent *should* be different.[2] So, it might be easier to develop an electric-car industry from scratch than to reshape the gasoline-car industry. If so, then Southern California is a likely place to start.

CALIFORNIA'S LEAD

The economic and human resources for an electric-car industry are already in place in Southern California. Los Angeles has an enormous aerospace industrial complex that could be used to produce electric-car parts. Particularly important are the numerous plastics molding firms, foundries, machine shops, tool and die manufacturers, and electronic-components producers. (See Table 1.) Engineering, technical, and skilled craft labor abounds.

On the political front, local groups have been advocating development of an electric-vehicle industry. A powerful coalition has formed joining those committed to reducing air pollution in the Los Angeles Basin with those concerned about the region's faltering economy. The movement is propelled by politicians at all levels of government, powerful local agencies, lobbying groups, large corporations, labor unions, and academic institutions.

Already the new industry is taking root. In 1989 the Los Angeles City Council adopted an initiative to sponsor production of at least 5,000 electric passenger cars and 5,000 electric vans by 1995. Eighteen companies responded to the initiative. The city selected a Swedish-British venture named Clean Air Transport to produce a hybrid gasoline-electric car (the LA 301) with $7 million in financing from the city's Department of Water and Power. However, the company has been unable to raise matching funds from private sources.

Another electric-car manufacturing venture in the region is Amerigon. The company's CEO has been a prime mover in the formation of CALSTART, a local not-for-profit consortium which has successfully raised public funds through the federal Advanced Transportation Systems and Electric Vehicle Consortia Act of 1991. With these and other funds, CALSTART has produced a demonstration electric car using components made by Southern Californian firms. The purpose of producing the demo car was to develop CALSTART's systems engineering capacities and to organize an effective subcontractor base in the region.

Another firm, Solar Electric, recently opened a plant in south-central Los Angeles where it will manufacture purpose-built electric vehicles—cars originally designed as electrics—as well as converting conventional vehicles. ➢

[1] Morales, et al., 1991.
[2] Bell, 1992.

TABLE 1

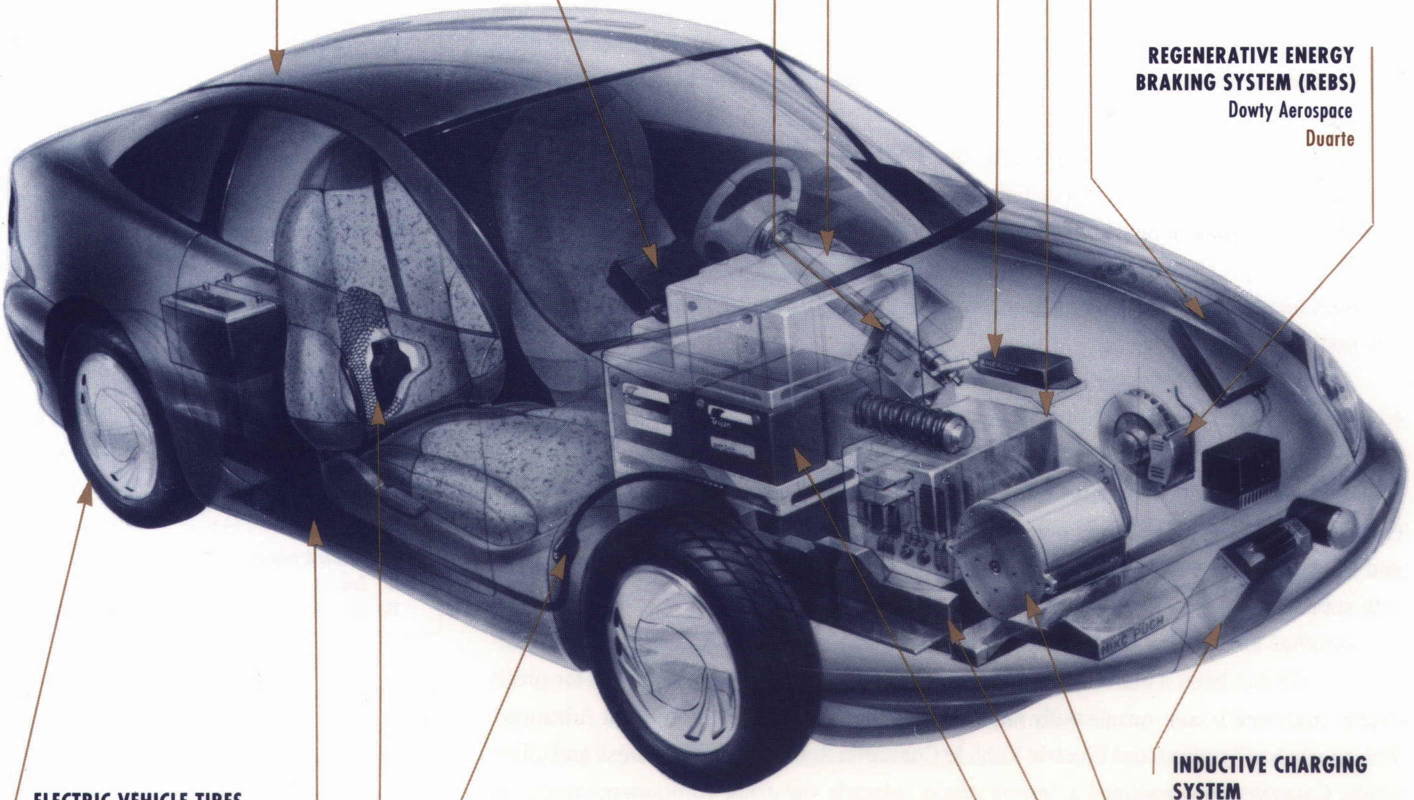
Employment in selected manufacturing sectors, Los Angeles County, 1990

STANDARD INDUSTRIAL CATEGORY	EMPLOYMENT (000)
30 Rubber & miscellaneous plastic products	**34.6**
306 Fabricated rubber products	4.5
308 Miscellaneous plastics products	28.2
33 Primary metal industries	**21.0**
332 Iron & steel foundries	3.0
335 Nonferrous rolling	4.4
336 Nonferrous foundries (castings)	7.2
34 Fabricated metal products	**64.7**
344 Fabricated structural metal products	15.7
345 Screw machine products	8.2
346 Forgings & stampings	6.4
35 Industrial machinery	**58.6**
354 Metal working machinery	9.4
356 General industrial machinery	7.4
357 Computer & office equipment	12.1
36 Electronic equipment	**64.8**
362 Electrical industrial apparatus	4.0
364 Lighting & wiring equipment	13.4
366 Communications equipment	5.2
367 Electronic components	25.1
37 Transportation equipment	**156.6**
371 Motor vehicles & equipment	12.9
372 Aircraft & parts	124.9
376 Guided missles, space vehicles, parts	15.4
38 Instruments & related products	**91.2**
381 Search & navigation equipment	63.4
382 Measuring & control devices	13.5

The 491,000 workers currently employed in these sectors, along with the technology, can undoubtedly be reoriented to the needs of electric-vehicle production. One major problem, of course, is that some of these sectors are dominated by defense contractors, who will have to change their cost-plus, quality-at-any-price habits. They will have to convert to forms of manufacturing more suited to the competitive pressures of civilian markets.

Source: State of California , Employment Development Department, *Annual Planning Information, Los Angeles-Long Beach Metropolitan Statistical Area (Los Angeles County).*

Of manufacturers involved in the CALSTART project, most are in Southern California (cities marked in brown)



Although these pioneer firms may ultimately fail (the risks they face are enormous), the organizational patterns, know-how, and political support they generate in Southern California will surely pave the way for future local efforts in electric-vehicle development and production. Further legislation is expected to make gasoline-powered cars more expensive to operate, increasing the attractiveness of electric vehicles. Thus, if collective efforts can be intensified, a new and growing industrial complex can be expected to take shape over the next several years. And with an early start, Southern California stands a good chance of beating the competition.

THE COMPETITION

Southern California's leadership in electric-vehicle production is far from assured. In fact, the region faces extremely serious competition from the existing automobile industry. General Motors, Ford, Chrysler, Toyota, Nissan, Mitsubishi, Suzuki, Daihatsu, Peugeot, Fiat, Volkswagen, Mercedes Benz, and BMW all plan to bring a variety of electric vehicles to market in the near future. They are working on both conversions of gasoline-powered models and purpose-built vehicles. Ironically, one major stimulus to the auto giants' interest in electric-vehicle technologies has been California's strong statutory attack on air pollution: many have even targeted California as their primary market.

The major car producers have several established advantages over potential Southern California rivals. They have had long experience in building and managing large-scale production systems for vehicle manufacture. They have marketing expertise and distribution networks. They have both the legal and technical ability to deal with the maze of costly regulations governing vehicle safety in the United States. They have the engineering and financial resources to meet onerous front-end research and development costs. But one obstacle prevents them from making use of those advantages: very few people want to buy an electric vehicle—yet.

BATTERIES AND THE MARKET

Right now, few consumers would buy an electric car because of the expense and inconvenience of running one. With current technologies, battery-powered cars can drive only 80 to 120 miles before dying, and a recharge takes up to 8 hours. Even with new technologies for a hybrid vehicle driven by both electricity and gasoline, the drawbacks imposed on the individual buyer are still great. Research being conducted on batteries in a wide variety of agencies and firms, such as US Advanced Battery Consortium, will certainly improve battery technology in the future. However, for the present, battery technology remains primitive. (See DeLuchi and Swan, p. 14, for an alternative to batteries.)

Without advanced battery technology, the private costs in terms of money and effort will continue to be higher for electric cars than for gasoline cars. But public interest in electric cars grows because gasoline cars are so polluting. The effects of air pollution on citizens' health, quality of life, and even business viability have long concerned people in Los Angeles, the automobile capital of the nation. There is now great interest in the region, and in California at large, in aggressively attacking pollution by getting rid of its main cause: the gasoline engine. However, because people are not likely to switch to public transportation in huge numbers, policy-makers are looking at electric cars as a potential solution.

The California Air Resources Board now mandates that 2 percent of car-makers' fleets in the state shall be composed of zero-emission vehicles (ZEVs) by 1998, 5 percent by 2001, and 10 percent by 2003. Other states have set similar targets. Thus, political leaders are forcing a market for electric vehicles. Eventually, as manufacturers improve their technologies, making electric cars perform better and cost less, a natural market will replace the politically created one. The stage at which every family wants an electric car, however, is still in the far future.

While electric-vehicle markets remain small, the massive scale advantages of the principal car producers cannot be brought fully into play. For the time being, the electric vehicle industry will consist of large numbers of small manufacturing operations producing limited batches of vehicles in designs liable to frequent alteration.

The fragmented nature of the industry provides California with its best opportunity. Even if Southern California could not in the long run compete in final vehicle assembly, it should nonetheless be able to build a very significant capacity in components and parts production. Indeed, CALSTART's main goal is to concentrate on creating a components industry in the region that will supply major electric-vehicle assemblers in other parts of the world.

AN INFANT INDUSTRY

We are now observing in Southern California a classic instance of what product-cycle theorists call "the period of infancy," when we typically find: (a) a small number of pioneer entrepreneurial firms; (b) industrial product and process configurations that are highly unstable and susceptible to rapid change; (c) considerable subcontracting activity in ➢

order to reduce in-house costs, as well as to enhance flexibility; (d) high levels of risk and a high probability of bankruptcy for many participants. Out of this initial period of ferment, the firms that find superior combinations of technology, management, and marketing strategies survive.

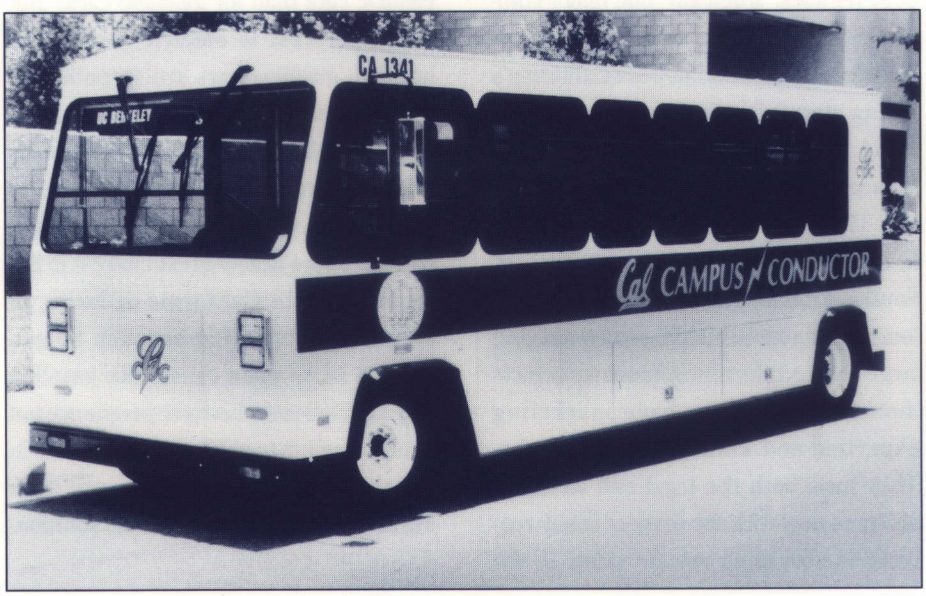
Intense inter-firm network relations that tend to occur in this early phase lead participants to locate in the same geographical region. This agglomeration produces a local labor market of trained specialists for the industry. It also offers possibilities for setting up institutional infrastructures that help to maintain advantages in technological improvement and innovation, labor training, information services, and just-in-time processing networks.

One of the major assets for electric-vehicle manufacturing in Southern California is significant public support for the industry. This support reduces the industry's initial risks and hence improves its chances for shifting out of infancy and into a phase of substantial growth. However, the form that public policy should take poses some extraordinarily difficult questions.

RECOMMENDATIONS

Without attempting to specify the precise terms of actual policy actions and their institutional expressions, I would argue that public policy needs to encourage the following features in the industry and its milieu:

- *Flexible production systems* so that adaptations to rapidly changing technological and market conditions can be swiftly introduced.
- *Collaborative inter-firm relations* and joint-venture activities so that problems can be creatively resolved by pooling resources.
- *Active transference of skills and technologies* from the aerospace-defense industry into the electric-vehicle industry.
- *Inclusion of many different firms and technologies* in the policy-making process in order to allow for the possibility of unforeseen and unpredictable advances.
- *Investment in basic infrastructural services and skills* required by the industry



➢ A fleet of electric buses is now operating in full-scale transit service between the Berkeley campus and downtown. Built in California by Electricar Industrial Vehicles, the buses are battery powered, supported by solar roof panels and regenerative braking.

(e.g., crash-testing facilities, training of electric-car technicians and repair personnel).

- *Continued public investment in research and development* for the industry, perhaps by making increased sums of money available to CALSTART or similar consortia.
- *Intensified efforts* to extend the market for electric vehicles (e.g., through tax rebates, parking privileges, reduced electricity prices, HOV lane privileges, recharging facilities away from home, increased taxes on gasoline).

There is a considerable role for governmental and other public agencies, private-public consortia, industry associations, labor unions, citizens' groups, and others in helping to accomplish tasks such as these. At the same time, a key piece of the puzzle is still missing from the emerging electric-vehicle industry in Southern California.

MAJOR MANUFACTURERS

What's missing is direct participation by major vehicle manufacturers. Except for General Motors' subcontracting of design and controller development tasks to AeroVironment and Hughes, respectively, no major automaker yet has contributed to the electric-vehicle industry in Southern California. However, as we have already seen, the major car manufacturers already have enormous acquired advantages in the development, production, and marketing of road vehicles.

A major boost to development of a Southern California industry could be achieved by combining in one local production complex (a) some representation from major car manufacturers with (b) continued initiatives for components development and systems engineering. I believe that *state and local policy-makers should now be concentrating attention on attracting one or two major manufacturers (whether American, Japanese, or European) to Southern California* to participate in and to enhance current developments.

At the outset they should aim to establish not major assembly facilities but small craft centers making vehicles in relatively small batches for limited markets. This might be accomplished by persuading companies already having design centers in the region to upgrade and broaden their local facilities. It would, of course, require material incentives of various sorts to attract major manufacturers to the region, but the time to act is now. Otherwise, electric-vehicle manufacturing industries may begin developing in other regions, and California could lose its early-mover advantage.

The big manufacturers, however, may be deterred by the bad press about California's faltering economy. There is thus a need for careful documentation of the real advantages of a California location for the major producers. Among these are the possibilities of

- Tapping into significant local public support
- Local access to the first major market for electric vehicles
- Participation in a multi-faceted industrial and technological effort involving creative interactions within the developing local supplier base.

If the ideal scenario of joining with the big auto manufacturers can be achieved, Southern California may well become a major growth pole for the electric-vehicle industry, producing a diversity of components and other inputs as well as assembled vehicles. With this capacity, the region might eventually be capable of serving not only local markets, but also markets in the rest of the country, if not the world. At the very least, the region will be a major center of innovative components and subsystems production for the industry worldwide. ◆

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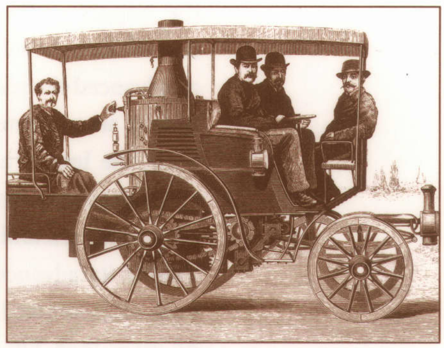

An early alternative to an electric car.

The Promise of Fuel-Cell Vehicles

BY MARK DELUCHI AND DAVID SWAN

In 1990 General Motors unveiled a new battery-powered electric vehicle, called the Impact — the flashiest, best-engineered electric vehicle ever. Thanks to an advanced electric drivetrain and a lightweight aerodynamic, energy-conserving body, the Impact accelerates faster than comparable gasoline-powered cars. However, even under the best conditions, despite its advanced technology and its state-of-the-art lead-acid battery, it will go no more than 120 miles and, as with all battery-powered vehicles, it requires hours to recharge.

The great attraction of electric cars is the absence of tailpipe emissions. In the parlance of the California Air Resources Board, they are zero-emission vehicles (ZEVs). The Board rekindled interest among major automakers in ZEVs a couple years ago when it announced that 10 percent of all cars sold in California by 2003 must be zero-emitters. Many analysts believe it will be difficult to sell enough battery-powered cars to meet that requirement. Virtually no one believes ZEVs will dominate the motor-vehicle market unless they can accelerate as fast, drive as far, and be refueled as quickly as today's gasoline cars.

The only ZEV that potentially can satisfy these requirements is a fuel-cell vehicle (FCV). An FCV combines the best features of a battery-powered car — zero emissions, high efficiency, quiet operation, and long life — with the long range and fast refueling of a gasoline car. This combination makes FCVs one of the most attractive and important transportation technologies for the 21st century.

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Fuel-Cell Electric Cars

An FCV is an *electric-drive* vehicle that uses a fuel cell and fuel-storage system in place of, or perhaps in parallel with, a rechargeable storage battery. The fuel-cell and fuel-storage system, like the battery, provides electricity to an electric drivetrain, which consists of a motor, an electronics control package, and a transmission. A complete fuel-cell and fuel-storage system consists of several components:

- *the fuel-cell stack* (an assembly of individual fuel cells) which produces the electricity
- *a storage container* for the fuel (hydrogen or a hydrogen-containing compound such as methanol)
- *auxiliary subsystems*, which, depending on the type of fuel cell, compress and supply air, cool the stack, keep the membranes saturated with moisture and dispose of excess water.

If the boarded fuel is something other than hydrogen, a *reformer* will also be needed to convert the fuel into hydrogen and CO_2. (The CO_2 is emitted to the atmosphere.) In some designs a *peak-power device*, such as a high-power battery, "boosts" the power when needed.

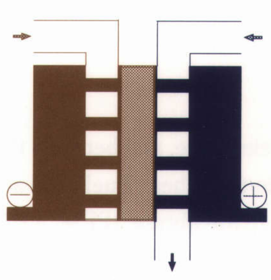
The Fuel Cell

The fuel cell, like a rechargeable battery, is an electrochemical reactor: within it chemical reactants (oxidizing and reducing agents) react and produce the electricity that runs the electric motor. However, there are important differences between a fuel cell and a battery.

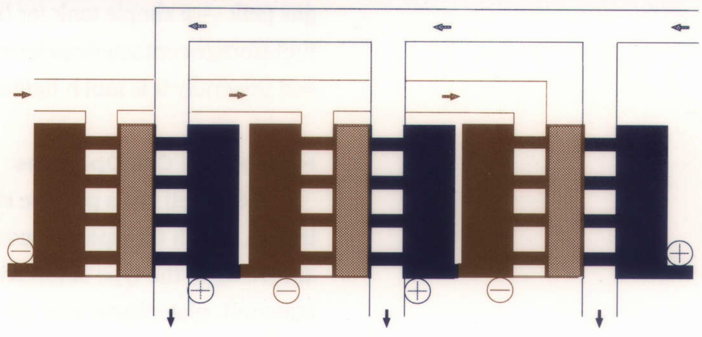
A battery is an energy-storage, electricity-production, and "waste"-storage package all in one: not only does it produce electricity, it contains the reacting compounds and the products of the reaction. The fuel cell, on the other hand, is an electricity-production device only. It does not store energy or waste products.

The fuel cell uses oxygen from the air as the oxidizing agent; a battery uses an oxidant chemically stored within itself. The fuel cell uses a reducing agent (fuel) stored in a separate storage tank; a battery uses a reducing agent chemically stored within itself. The fuel cell ejects the product of the electricity-generating reaction — pure water — to the atmosphere; a battery stores the reaction products within itself. ➢

FUEL-CELL- voltage 0.7 volts



FUEL-CELL STACK- voltage 2.1 volts



Individual fuel-cells generate power. However, this power is generated at low voltages (approximately 0.7 volts). To get more power and higher voltages, many cells are linked together (much as D cells are placed end to end inside a flashlight). The many cells placed end to end are called a fuel-cell stack.

NEGATIVE SIDE (ANODE)

1. Hydrogen gas enters the fuel cell at the negative electrode (anode).

2. The Hydrogen molecules dock on the anode catalyst, which causes it to split into its proton and electron parts.

3. Only protons can move toward the positive electrode (cathode) through the acid electrolyte.

4. By an external circuit, the electrons move to the positive electrode (cathode). Through this external circuit useful work (powering an electric vehicle) is done.

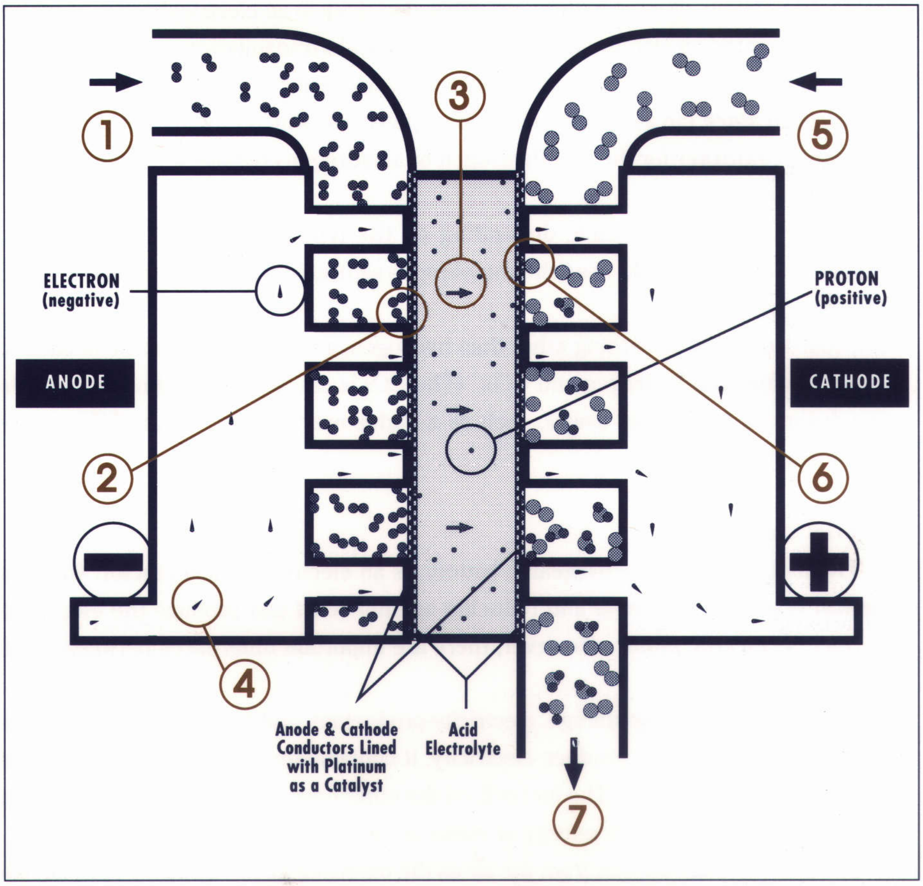
POSITIVE SIDE (CATHODE)

5. Clean air (containing oxygen) enters the fuel cell at the positive electrode (cathode).

6. The oxygen molecules dock on the cathode catalyst. In this position the oxygen attracts the protons and the electrons (powering the electric vehicle). This reaction forms water.

7. Product water and oxygen-depleted air leaves the fuel cell.

ACID ELECTROLYTE FUEL-CELL



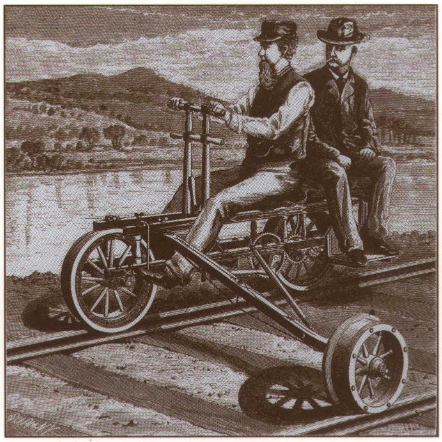
Graphics by Manohar Prabhu

With these differences come major advantages for the fuel-cell system. When a rechargeable battery runs out of energy, the chemical reactants that produce the electricity must be regenerated from the reaction products, within the battery, by the recharging process. By contrast, when a fuel-cell system runs out of fuel, the separate fuel-storage container simply can be refilled from an outside source, in minutes, just as a gasoline tank is filled at a service station. Indeed, an FCV will have a fuel tank similar to a gas tank — a simple tank for liquid fuel or a high-pressure vessel for gaseous fuel. The fuel-storage container can be refilled much more quickly than a battery can be recharged, and generally it is much lighter and may be more compact per unit of energy stored.

How a Fuel Cell Operates

A fuel cell has a positive electrode, a negative electrode, and between them an electrolyte, which transports ions from one electrode to the other. Fuel cells are classified according to the type of electrolyte: proton-exchange membrane (PEM; a solid polymer material), phosphoric acid (liquid), alkaline (liquid), molten carbonate (molten salt), or solid oxide (a ceramic). Today, many researchers believe that PEM fuel cells, which will be commercially available within a few years, are best suited for use in highway vehicles in the near term.

In a fuel-cell system, hydrogen is either stored as such on board the vehicle or produced by reforming methanol into hydrogen and carbon dioxide. Hydrogen is delivered to the negative electrode (the anode), and air (comprising mainly oxygen and nitrogen) is delivered to the positive electrode (the cathode). At this point the electrochemistry begins: in effect, hydrogen reacts with oxygen and the reaction releases energy. The anode, where the hydrogen "docks," is a conductive material (typically carbon) coated with a catalyst (typically platinum) and connected to a current-collecting wire and to the electrolyte. The cathode, where the oxygen from the air docks, is constructed much like the anode. (The nitrogen in the air is not involved in the electrochemistry; it passes inertly through the system.)



In a sense, the oxygen "wants" to react with the hydrogen. Imagine that oxygen gas has a "magnetic" attraction for the electrons of hydrogen. This is the driving force behind the electrochemistry. However, because the hydrogen and the oxygen are physically separated, they cannot come together and transfer electrons directly.

Instead, in the fuel-cell system — and this is the first distinguishing feature of an electrochemical as opposed to a combustion reaction — the oxygen gas "pulls" on the hydrogen electrons via the current-collecting wire that runs from the anode to the cathode. The platinum catalyst holds the hydrogen atoms in such a way as to make it easier to withdraw the electrons.

The oxygen's "magnetism" pulls the electron off the hydrogen and draws it through the wire toward the cathode, in the way that gravity pulls a ball down a tube toward the ground. The electrons traveling through the wire have energy, or the potential to dowork, just as a ball falling in a tube has energy. Along the way, the electrons pass through an electric motor, where they give up some of their energy electrically by turning the motor — just as balls in a tube would give up some of their energy if they struck and turned a paddle wheel connected to the tube. The energy-depleted electrons join the oxygen gas at the cathode.

Meanwhile, back at the anode, hydrogen-minus-electron has become a proton, which has a positive charge. Over at the cathode, oxygen-plus-electrons has a negative charge. These opposite charges attract. Now we come to the second distinguishing feature of the electrochemical system: a second pathway, but one that transports only ions (protons, in this case). This pathway is the electrolyte, for example the proton-exchange membrane in a PEM fuel cell. The electrolyte is in effect "impervious" to electrons and oxygen and hydrogen molecules. Thus, the positively charged ions from the anode travel through the electrolyte toward the negatively charged oxygen ions at the cathode. When the reaction between these positive and negative ions is catalyzed at the cathode, the result, elegantly, is pure water.

In a sense, the electrochemical reaction just described is a carefully controlled combustion reaction. The hydrogen and oxygen reactants can just as well be burned in an internal combustion engine. There, hydrogen and oxygen are not kept separate, as they are in a fuel cell, but instead are mixed together. A localized blast of energy (a "spark") slams oxygen into hydrogen and "loosens" or breaks off the hydrogen electrons, so that electron transfer from hydrogen to oxygen is immediate and direct. That transfer releases energy (due to the formation of the new bonds with oxygen), just as it does in the fuel cell. ➢

But in an internal combustion engine this release of energy is rather more chaotic than in a fuel cell. In the internal combustion engine, the oxygen "pulls" the electrons and the rest of the hydrogen to itself so violently that the electrons and the rest of the hydrogen "slam" into the oxygen. The energy of "collision" from the formation of the new compound (hydrogen-plus-oxygen, which is water) causes the new compound to kick about tremendously. The kicking assembly knocks other oxygen and hydrogen molecules together hard enough for them to react, form new compounds, release more energy, trigger other collisions, and so on. The result is the furious kinetic energy of combustion.

In fact most of the energy of combustion is wasted when excited molecules bounce against the sides and top of the engine, rather than against the moving piston, heating up the engine and the environment. Moreover, the excited hydrogen and oxygen molecules contain so much energy that they cause other molecules, such as nitrogen, to react and produce undesirable compounds, such as nitrogen oxides. The combustion reaction, then, is relatively inefficient and inevitably polluting.

By contrast, the electrochemical reaction, as we have seen, is more controlled. The platinum catalyst "loosens" the electron without an external source of energy, and the special "electron tube" (the electric wire) connects the hydrogen and oxygen and channels the electron to the working device, the electric motor. Less energy is wasted and there are no undesirable side reactions. Moreover, the electric drive itself is considerably more efficient than the piston drive and transmission system. That's in part because electric motors do not consume energy when the vehicle is not moving, and they can actually recapture energy when the vehicle is decelerating. The result is an inherently cleaner and more efficient energy-conversion system.

A fuel-cell-powered ZEV bus by Ballard Power Systems, Canada.

The first fuel-cell vehicle, 1958.

Environmental Effects

In a hydrogen-powered PEM fuel cell, water is virtually the only effluent. A hydrogen-fueled PEM fuel cell cannot produce carbon monoxide, hydrocarbons, sulfur oxides, or toxic air pollutants, because there is no carbon, sulfur, or metal in pure hydrogen fuel. A PEM fuel cell can't even produce nitrogen oxides from atmospheric nitrogen, because it operates far cooler than the temperature required to produce them. Assuming that pure water-vapor is not considered a pollutant, then a hydrogen-powered FCV is a zero-emission vehicle.

Methanol FCVs produce tiny amounts of NO_x and CO from the methanol reformer, and a small amount of evaporated methanol from the fuel-supply and fuel-storage system. These emissions are very small, although they may disqualify methanol FCVs as pure zero-emission vehicles.

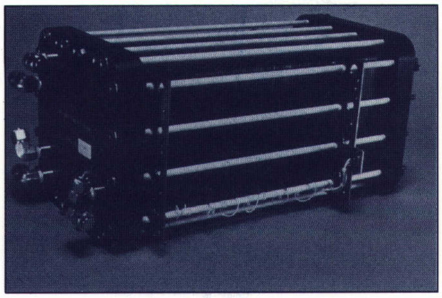
The Fuel-Storage System

Hydrogen fuel needed by fuel cells can be provided by reforming methanol into hydrogen and carbon dioxide, or by storing hydrogen on board the vehicle. Hydrogen can be stored as a compressed gas, a metal hydride, a cryogenic liquid, a liquid hydride, a cryoadsorbed gas, or a cooled and compressed gas. The choice between methanol and hydrogen is one of the most contentious issues facing engineers, systems analysts, and policy analysts interested in FCVs.

Methanol has one key advantage over hydrogen. Because it's a liquid at normal temperature and pressure, it's much simpler and less costly to store than is hydrogen. In fact, the huge difference between the cost of a methanol tank and the cost of

THE POWER GENERATOR SYSTEM (PGS)

To operate efficiently a fuel-cell stack must be kept at an appropriate temperature (approximately 70 degrees Celsius).
100% relative humidity must be maintained internally to facilitate the electrochemical process.
Hydrogen and oxygen (in air) must be delivered in controlled quantities at specific pressures. These requirements are implemented via a support system for the fuel-cell stack. The fuel-cell stack along with this external system is called a power generator system.



A fuel-cell stack loaned to UC Davis by Ballard Power Systems, Inc.

hydrogen storage might be sufficient to give methanol-fueled FCVs lower lifecycle costs than hydrogen-fueled FCVs. On the other hand, hydrogen has two advantages over methanol.

First, methanol requires a reformer to convert it into hydrogen and carbon dioxide. This reformer, which a hydrogen FCV does not need, reduces the efficiency of fuel use and in other ways can adversely affect the design of the fuel cell. Second, even the most environmentally benign way of making methanol — by gasifying biomass (plant materials and animal wastes), such as wood, and synthesizing the gaseous products into liquid methanol — is considerably less benign than producing hydrogen by splitting water with solar electricity (e.g., photovoltaic or wind power). For example, large-scale farming of biomass for energy can cause problems like erosion, contamination from herbicides and fertilizer, and loss of biological diversity .

Current FCV Development Efforts

The fuel cell is not new technology. William Grove built the first fuel cell in England in 1839. In the 1960s, NASA used PEM fuel cells to power Gemini spacecraft, and today alkaline fuel cells are used on board the Space Shuttle. However, until a few years ago, fuel cells simply were too bulky and heavy and far too costly to be considered seriously for use in motor vehicles. But within the last seven years, the performance of fuel cells, particularly of the PEM type, has improved substantially. Even more recently, researchers and developers have begun to consider low-cost materials and manufacturing techniques.

There are several FCV demonstration projects in North America and Europe. Energy Partners of Florida is designing and building a hydrogen-powered FCV with a 20-Kw PEM fuel cell, a 20-Kw peaking battery, and compressed-hydrogen storage. Ballard Power Systems of Canada is operating a 30-foot transit bus powered by compressed hydrogen and a PEM fuel cell. The U. S. Department of Energy is supporting two fuel-cell-vehicle projects: the Georgetown Bus Project (using reformed methanol, a phosphoric acid fuel cell, and a peak-power battery) and a project with General Motors (slated to deliver a methanol-fueled, PEM-powered, battery-supplemented FCV by 1996). There also are fuel-cell-vehicle projects in Japan and Europe.

Safety and Economics

To be marketed successfully, FCVs must prove to be safe and economical, as well as technically sound. In particular, hydrogen will not be accepted as a transportation fuel until policy makers and the public are convinced it's no more dangerous than gasoline. Officials at the U.S. National Bureau of Standards, Stanford Research International, and the German "Alternative Fuels for Road Transport" program independently conclude that the hazards of hydrogen are different from, but not necessarily greater than, those presented by current petroleum fuels. Limited experience with and analyses of hydrogen storage systems indicate that they are relatively safe, and it seems likely that the public will come to accept that conclusion.

Over 100 years ago quite similar objections were voiced against gasoline. After a few years of experience, the apparently tolerable safety record of gasoline dispelled the most serious concerns.

Unless FCVs are mandated on environmental grounds (which seems unlikely), they will have to compete in the marketplace with vehicles using batteries, petroleum, and nonpetroleum fuels. It is, of course, impossible to make definitive statements about FCV economics, because fuel cells and electric-drive technology are still evolving. However, it will be possible and instructive to conduct comparative economic analyses and to consider a range of cost scenarios.

A recent exploratory analysis of the lifecycle costs of alternatively fueled vehicles found five noteworthy results:

- Hydrogen FCVs probably will have a lower lifecycle cost per mile than internal combustion vehicles burning hydrogen, primarily because electric drives are more efficient and less costly.
- Hydrogen FCVs probably will have a lower lifecycle cost than battery-powered vehicles, except perhaps for those with a short range. That will surely be so if batteries prove to be more expensive than fuel cells.
- FCVs will be competitive with gasoline vehicles at gasoline prices of less than $1.50/gallon (including taxes), if optimistic but not implausible cost goals are met.
- Methanol-fueled FCVs probably will have a lower lifecycle cost than hydrogen-fueled FCVs, due primarily to the high cost of hydrogen storage.
- Lifecycle competitiveness with gasoline-powered vehicles does not depend entirely on large reductions in the cost of the fuel cell itself; other economic factors, such as vehicle life and maintenance costs, can be just as important.

Prospects

If FCVs continue to develop as we expect, they will be cleaner and more efficient than internal-combustion vehicles and perform better at lower cost than battery-powered vehicles.

Fuel-cell technology must progress steadily over the next decade if fuel cells are to achieve high specific power and high efficiency at relatively low cost. The peak-power device and the hydrogen-storage system in the FCV also must be developed further.

Although the impending research and development tasks are not trivial, there are many technology and design routes for each task. There are at least three different kinds of potentially suitable fuel cells (PEM, alkaline, and solid oxide), at least four different ways to supply peak power (several types of batteries, ultracapacitors, flywheels, or the fuel cell itself), and many ways to store hydrogen. We are therefore optimistic that eventually all components of FCVs will be developed successfully. We emphasize, though, that commercial success certainly is not guaranteed, and at best is many years off.

Ultimately, marketability will be the yardstick of success. To begin to understand how consumers will use and react to FCVs, a variety of experimental vehicles should be built and tested. The purpose of these projects should not be to display a purportedly finished technology, but rather to experiment — to feed responses from users back to basic research and development. FCV technology already is far enough along that this experiment and feed-back strategy could begin today. Within a decade this strategy could provide a reasonably clear picture of the ultimate technical and economic potential of the fuel cell in transportation. With success, FCVs could become an important component of a strategy for reducing dependence on imported oil, mitigating global warming, and improving urban air quality, and all at an acceptable cost. ◆

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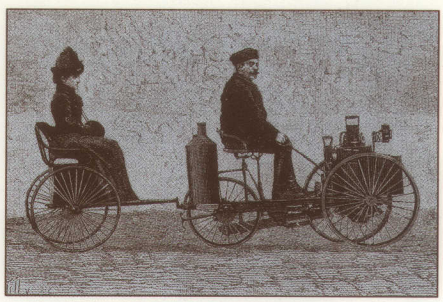

GREAT STREETS:

MONUMENT AVENUE, RICHMOND, VIRGINIA

BY ALLAN B. JACOBS

Streets are more than public utilities, more than mere traffic conduits, more than the equivalent of water lines and sewers and electric cables, more than linear physical spaces that permit people and goods to get from here to there. To be sure, communication remains a major purpose, along with unfettered public access to property. These roles have received abundant attention, particularly in the latter half of the twentieth century. Other roles have not.

Streets shape the form and comfort of urban communities. Their sizes and arrangements give or deny light and shade. They may focus attention and activities on one or many centers, at the edges, along a line, or they may simply direct one's attention to nothing in particular. The three streets that lead from the Piazza del Popolo in Rome, Via del Corso in the center, give focus to that city as does nothing else. So does Market Street in San Francisco, and a hundred Main Streets in small cities across the United States.

Streets allow people to be outdoors. Except for private gardens, which many urban people do not have or want, or immediate access to countryside or parks, streets constitute the out-of-doors for many urbanites. Streets are also places of social and commercial encounter and exchange. They are where people meet — which is a basic reason we have cities in any case. People who really do not like other people, not even to see them in any numbers, have good reason not to live in cities or to live isolated from city streets. ➢

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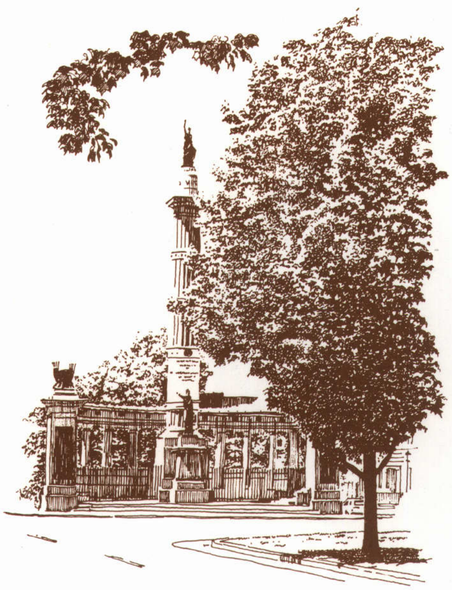
This article is adapted, with permission, from his recently published book, Great Streets *(Cambridge: MIT Press, 1993).*



The street is movement — to watch, to pass — especially movement of people: of fleeting faces and forms, changing postures and dress. You see people ahead of you or over your shoulder or not at all, absorbed in whatever has taken hold of you for the moment, but aware and comforted by the presence of others all the same. You can stand in one place or sit and watch the show. The show is not always pleasant, not always smiles or greetings or lovers hand-in-hand. There are cripples and beggars and people with abnormalities, and, like the lovers, they can give pause: they are cause for reflection and thought. Everyone can use the street. Being on the street and seeing people, it is possible to meet them, ones you know or new ones. Knowing the rhythm of a street is to know who may be on it, or at a certain place along it during a given period; knowing who can be seen there or avoided.

As well as to see, the street is a place to be seen. Sociability is a large reason cities exist, and streets are a major if not the only public place for that sociability to develop. At the same time, the street is a place to be alone, to be private. It's a place where the mind can wander, triggered by something there on the street, or by something internal, more personal. It's a place to walk while whatever is inside unfolds.

Some streets are for exchange of services or goods: places to do business. They are public showcases, meant to exhibit what a society has to offer, and to entice. The merchant offers the goods, displays them, on the street if allowed, with wares to be seen. The looker sees, compares, fingers, discusses with a companion, and ultimately decides whether to enter the selling environment or not, whether to leave the anonymity and protection of the public realm and enter into private exchange.

The street is a political space. It's on Elm Street that neighbors discuss zoning or impending national initiatives and on Main Street, at the Fourth of July parade as well as the anti-nuclear march, that political celebrations take place. It's not easy to distribute non-mainstream ideas in a shopping mall, much less to have a demonstration in one. Those are private places. Lest we discount the importance of the public street as a political place in favor of modern electronic media of communication, recall where the demonstrations and actions and marches of the late 1980s took place in eastern Europe: in public places and most especially in streets.

It is not surprising that, given their multiple roles in urban life, streets require and use vast amounts of land. In the United States, from 25 to 35 percent of a city's developed land is likely to be in public rights-of-way, mostly in streets. When we speak of the public realm, we are speaking in large measure of streets. What is more, streets change. They are tinkered with constantly. Every change opens an opportunity for improvement. If we can develop and design streets so that they are wonderful, fulfilling places to be — community-building places, attractive public places for all people — then we will have successfully designed about one-third of the city directly and will have had an immense impact on the rest.

So, in our pursuit of good and fulfilling urban places, it is important to study the physical, designable, buildable qualities of the best streets — the great streets.

AMERICA'S RESIDENTIAL BOULEVARDS

The residential boulevard may be a unique North American contribution to the world's streets. Generally wide, residential boulevards are invariably tree-lined, they often have graceful curves, they are shaded and cool in the summer, and they are quiet. They come with or without a planted median (through which a trolley may once have run) and they are long. Lined with large homes, spaced at some distance from each other and well set back from the street on cared-for lawns, these streets bespeak well-being. They were supposed to. Often they were the centerpiece of land development promotions and were finely built in advance of the homes that were to line them, to give a sense of what was to come, to tell the prospective well-to-do owner-builder that this would be just the place for him and his family. Roots of these streets may be in French boulevards, or English villages, or the residential sections of earlier American small towns with their elm-shaded main streets. They are often associated with suburban development, not as often with central urban environments.

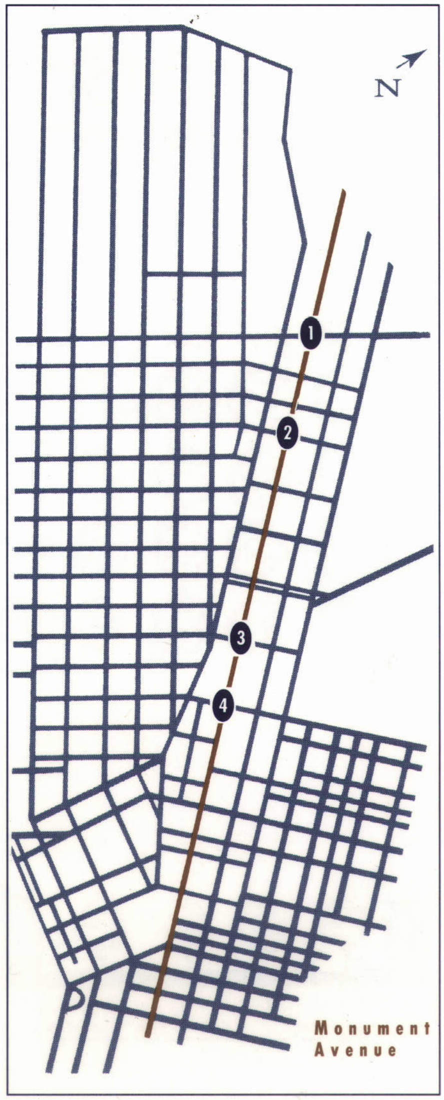
The various parkways connecting the lakes and that are part of the Minneapolis park system are such streets, and so is Massachusetts Avenue in Washington, D.C., Shaker Boulevard in Shaker Heights, Ohio, and Fairmount Boulevard or Euclid Heights Boulevard in Cleveland Heights, immediately east of Cleveland. Still others are Saint Charles Avenue in New Orleans (an urban example) and Orange Grove Boulevard in Pasadena, California. Monument Avenue is urban and not far from the city center. Nor is it necessary to be well-to-do to live along it. Its physical design is compelling.

MONUMENT AVENUE

Monument Avenue starts with a different name, Franklin Street, at Capitol Square in the downtown area, one and one-half miles away, and becomes Monument Avenue at Stuart Circle, marked by a statue of "Jeb" Stuart. It then proceeds straight in a northwesterly direction for many miles to the end of the city. At its officially named beginning, Monument Avenue is part of the Fan District, two blocks in from this area's northern edge.

The Fan District is made of tight urban streets lined with mostly brick townhouses that share common walls, and with one-, two-, and four- family dwelling structures and apartment buildings set close to each other and narrowly setback from the sidewalks. Along some streets there is a sense of elegance and of early wealth. Just to the east of the Fan District lies Virginia Commonwealth University — many new buildings mixed with old ones, students, growth, activity, some spilling over into the Fan. It is the kind of area that, during the 1950s and 1960s, was classified as "inner city blight." Still, people who saw the potential of the location, the urban streets, and the housing, devoted great care to the Fan District. There has been much restoration, often, it seems, by young people. Not all of the Fan District is in the best condition; if there was wealth earlier, some of it seems gone now, but the elegance and the urbanity remain.

We are interested in the stretch of Monument Avenue running from Stuart Circle to North Boulevard, a distance of eight blocks covering close to one mile. This section is a great street: an urban residential boulevard close to the city center; a grand remembrance to a lost cause, the Civil War. It is a positive achievement of physical design that is a social achievement as well. ➢



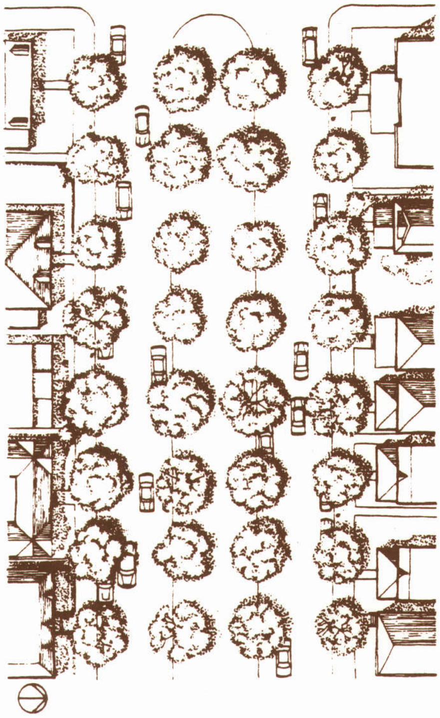
A The Fan District

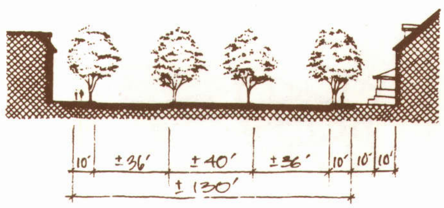
1 Stonewall Jackson Monument

2 Jefferson Davis Monument

3 Robert E. Lee Monument

4 J.E.B. Stuart Monument





Plan and section drawing—
Monument Avenue

The special character of the buildings along Monument Avenue lies more in their variations than in their individual designs. Some are outstanding and all are pleasant. They all have doors that face the street. They all have many windows, usually with fine panes, and many have porches that permit people to inhabit the street without actually being on it. Bricks are in a wide variety of earth tones. The 10 or 20 feet of front yard, a transition between public and private realms, permit a variety of landscape designs, including trees and flowering plants. Mounument Avenue is not a street for one class of people: the elderly, young, and middle-aged live there, and the well-to-do and the less well-to-do, if not the indigent. There are not too many well-designed residential boulevards that can respond to the housing needs of a diverse population.

Monument Avenue's street section is deceptively simple. A 40-foot central median is flanked by two 36-foot roadways which in turn are bounded by 10-foot sidewalks. Houses and small apartment blocks are set back 20 feet from the walks, except that porches, where they exist, are only 10 feet back. Buildings are two and one-half to three and one-half stories high. Just inside the curbs, along the two walks and in the median, are pin oaks and sugar maples, mostly the latter. Varying in height from 30 to 50 feet, they form four straight lines.

The linearity of extremely well-executed parts — the trees, the median, the streetlights, details of the curbs and street paving itself, and the houses — punctuated by four monuments along the way, accounts for the special physical character of the street. The tree spacing is uniform, 36 to 40 feet apart, and the trees line up across the street, coming as close as possible to intersections. Their crowns often join together, reinforcing the four lines. Streetlights spaced 80 to 115 feet apart also create lines along the sidewalks. The streetlights have two designs, with the most elegant being an acorn globe on a dark green, fluted pole. The two 36-foot-wide automobile roadways are paved with a gray asphalt brick bordered on each side by 3-foot wide concrete strips. Each roadway permits two parking lanes and two moving lanes, more (by one parking lane) than is permitted on a street of that width designed in the early 1990s. Since there are no breaks in the curbs, linearity is again emphasized. Finally, there are the buildings. Although they are different one from another in design and in materials (though many are brick), they are of similar height so that they, too, form lines along the street. They are close enough to each other that, walking or driving along the street, one does not normally see rear yards.

The linearity is punctuated on Monument Avenue. In addition to the focal points at the start and end of the street, monuments of Stuart at the start and of Stonewall Jackson at North Boulevard, there is the grandly scaled Lee Monument and the one of Jefferson Davis as well. Each is a focal point, each a reason to pause if not to stop. In the length of a mile, these special moments are important as reminders that we are on a marked, special path and we know when we have passed it. Traffic on this section of Monument Avenue moves purposefully but not with great speed. For reasons not altogether understood — perhaps it's the monuments that compel some attention, perhaps it's just the pleasantness of the drive and the not overly wide roadway — drivers seem to proceed reasonably, not speeding.

On a Sunday morning in spring, the trees have already bloomed. It is quiet, but there are people using Monument

Avenue: churchgoers, joggers, cyclists, walkers. People who look like university students enter and leave apartment units. Older women, at windows, watch the passersby. At various corners there are some small notices, and maybe a balloon or two. It seems that this is a route of a charity walk of some kind today. In small groups of ten to twenty, people are walking on this part of Monument Avenue, having come off one or two of the intersecting streets. In time one notices that groups are walking in both directions. There are people of all ages, blacks as well as whites in the same group. They pass along for several hours. There must have been good reasons for choosing Monument Avenue for their stroll. Without knowing for sure, one would like to think that it represents to the larger community a special place, a most pleasant street on which to be.

Interestingly enough, many of the best streets can and do handle a lot of auto traffic. But, the auto isn't given priority over the other objectives and purposes. Often, these streets are not wide by today's standards. Where they are, and certainly the right-of-way (but not the auto cartways) of Monument Avenue is wide, there are many non-traffic things in them — sidewalks, trees that continue to the corners, medians, details — that reduce the sense of largeness. In the end, it may be easier to design a great street, one that fits into a community, if multiple objectives are served than if we try to serve only one or two, especially if the one or two are traffic. ◆

Grove Avenue in the Fan District, early in the century.

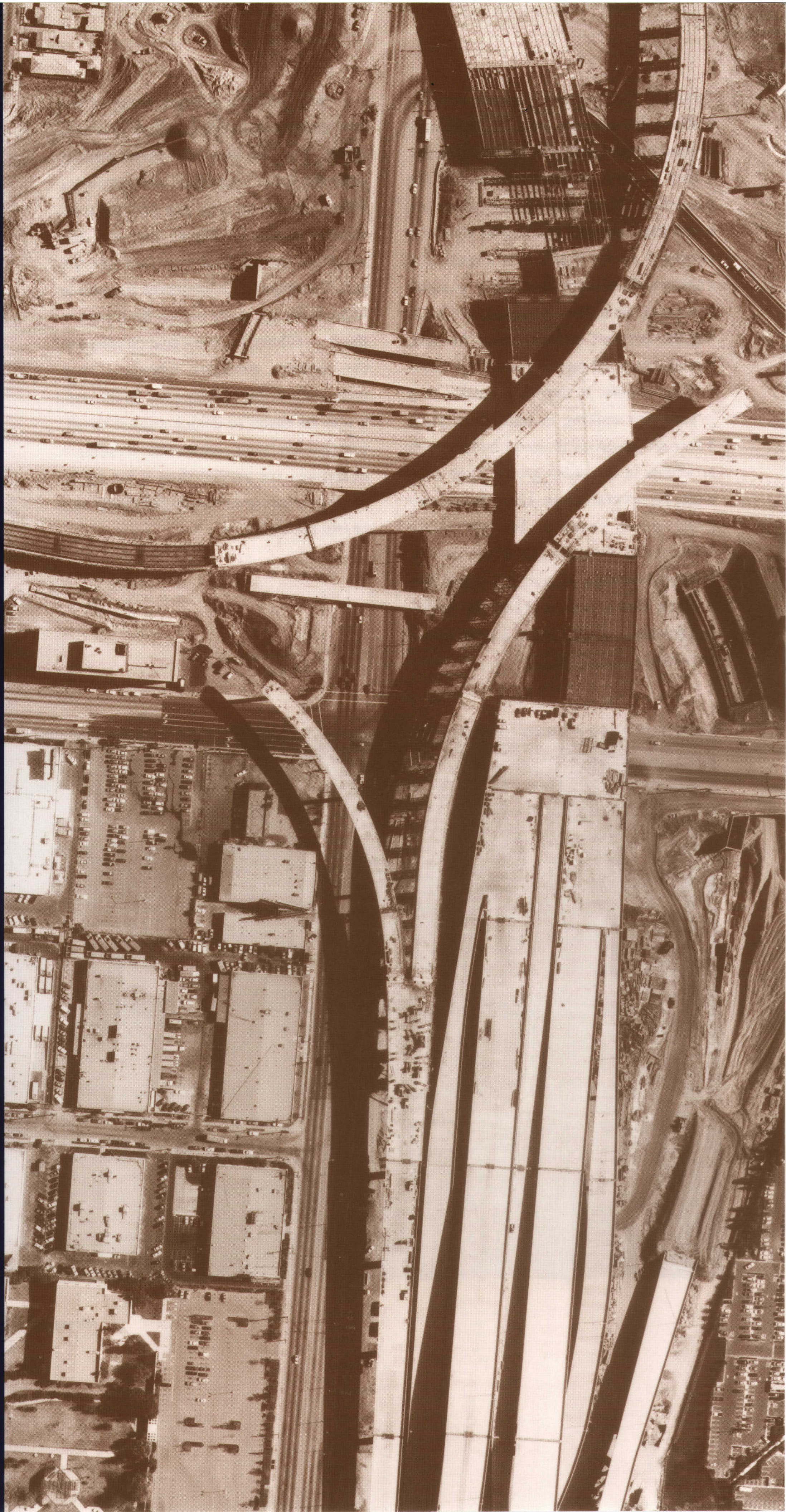
"I am...firmly convinced that the demand for good roads will not end. In fact, I expect a resurgence of freeway building in the years ahead....our freeway program will have to be expanded — and soon."

—James A. Moe
Director of the Department of Transportation, State of California, 1973.

"This Administration has no intention of participating in the construction of any more Cadillac-commuter systems that have very little chance of providing adequate benefits.... As for starting new freeways, I just do not see that happening."

—Donald E. Burns
Secretary of Business and Transportation, State of California, 1975.

Century Freeway nearing completion in November 1992. ➛



Why California Stopped Building Freeways

BY BRIAN D. TAYLOR

Planning and construction of metropolitan freeway systems in the 1950s and 1960s are frequently cited examples of planning gone awry. Critics point to insulated and indifferent highway builders, who concern themselves more with traffic flow than communities and carve up cities with little regard for the negative social, psychological, and aesthetic effects of freeways. Many freeway projects in cities around the country provoked "freeway revolts" — intense community opposition to specific freeways projects which led officials to delete controversial routes from state freeway plans. ➢

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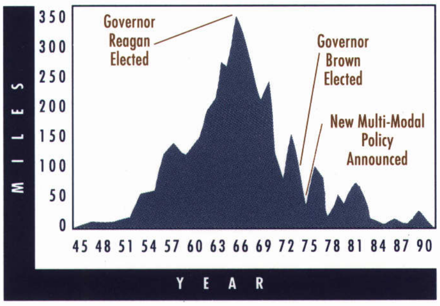
This article is drawn from his doctoral dissertation in urban planning, University of California, Los Angeles.

FIGURE 1

Centerline Miles of Freeway Constructed in California



Source: Caltrans Annual Reports

The freeway revolts dovetailed with broader environmental activism in the 1970s to cause many states to shift their focus from freeways and automobiles to other modes of transportation. The new attention given to public transit, carpooling, bicycling, and walking is often credited (or blamed) for dramatically curtailing freeway development in cities around the country. Such is the case in California, where in 1975 the state formally renounced its 1959 California Freeway System plan and adopted a new "multi-modal" stance.

There remains a widespread belief that worsening air pollution, fuel shortages, and community opposition to particular freeway projects combined in the 1970s to stop freeway development. While it is true that state freeway plans were scaled back in 1975, the idea that this planning change alone stopped freeway development in California is erroneous.

The principal reason California and most other states stopped building freeways was that the freeway program began running out of money in the 1960s. Highway finance programs, established during the 1950s to fund ambitious plans for freeways, could keep pace with neither the rapid escalation of freeway costs nor the growth in vehicle travel. By choosing to ignore the incipient fiscal woes of the freeway programs in the 1960s, the states and the federal government predetermined that metropolitan freeway development would be a losing cause in the 1970s.

The Promise of the 50s

The creation of the federal Highway Trust Fund in 1956 was the most significant piece of the freeway funding puzzle. But the entire freeway funding package was assembled gradually, both in state houses and later in Washington, between the late 1940s and the early 1960s. When the last of the freeway-related tax increases was adopted as part of the Federal Highway Act of 1961, freeway funding appeared set.

Enthusiasm for freeway development in California was at near fever pitch in 1959 when the state adopted a 12,241-mile freeway plan. Proposing to build a system nearly one-third the length of the entire Interstate program, the California plan called for the extensive development of both urban and rural freeways. In cities, the freeways were platted on roughly four-mile grids and, given the rapid growth in highway revenues, such an ambitious system appeared quite feasible.

Inflation-adjusted revenues for state highways increased over 400 percent between 1947 and 1961— the 1990 equivalent was over $3.5 billion per year. In the late 1950s, the freeway system in California was growing by over 150 miles per year (and by over 2,500 miles per year nationwide), and the state believed the federal/state financial program was sufficient to complete the planned system by 1980.

California Repudiates its Freeways

When freeway development declined in the late 1960s and early 1970s, people naturally attributed it to a change in public policy. In California, critics held Democratic Governor Jerry Brown and Department of Transportation Director Adriana Gianturco responsible. Indeed, blaming Brown and Gianturco for the state's traffic congestion problems has become California lore.

In 1986, the San Francisco Chronicle blamed Brown and Gianturco for "crippling" the state's freeway program, saying, "Californians today are paying the price for these politician's arrogant — and naive — view that drivers could be forced out of their cars by simply not building any more freeways."[1]

However, when relevant political and planning events are juxtaposed with annual freeway miles constructed, we see that such interpretations of history are more histrionic than historical. (See Figure 1.) In March 1975 the Brown Administration did formally announce a shift in state transportation priorities from constructing new freeways to improving operations on existing freeways and expanding urban public transit. But Figure 1 clearly shows that freeway development in California began a precipitous decline in 1967. In other words, California had stopped building freeways years before the state announced its intent to stop building freeways.

The causes of declining freeway construction in the 1960s were primarily financial. Funding simply did not exist to build many new freeways, and the 1975 pronouncement by the Brown Administration brought freeway policy and planning in line with this financial reality.

Even if the Brown Administration had announced in 1975 that the state remained committed to implementing the 1959 freeway plan, it is unlikely that any additional miles of freeway would have been built. As we will see, to reverse the decline of freeway construction substantially in 1975 would have required an extraordinary new financial commitment to freeways. The cost/revenue squeeze on freeway development was so severe by 1975 that even a doubling of highway revenues in the mid-1970s would not have restored freeway construction to the levels of the early 1960s.

When George Deukmejian replaced Brown as Governor in 1983, he promised the state a pro-freeway policy. Despite the renewed commitment to the California Freeway System plan, however, the cost/revenue squeeze in freeway finance continued, and freeway construction did not rebound. In fact, more than twice as many new miles of freeway were built during the eight years of the "anti-freeway" Brown Administration (291 miles) than during the eight years of the "pro-freeway" Deukmejian Administration (103 miles). Lacking increased funding, Deukmejian's new pro-freeway policies were all but irrelevant.

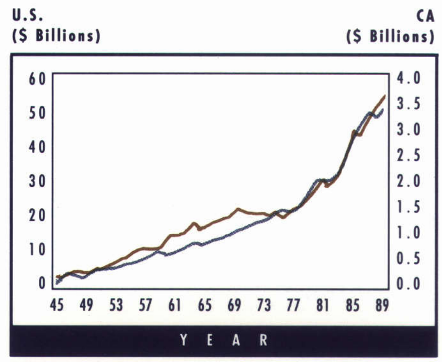
Collapse of Freeway Finance

Early on, belief in the solvency of the freeway program appear well-founded. While the construction of new freeways fell off in the late 1960s and 1970s, highway revenues and highway expenditures continued to rise. (See Figure 2.) Expenditures on highways in California and nationwide have risen steadily since World War Two and grown at a consistently high rate since the mid-1970s. In the 1980s, highway expenditures doubled, increasing more in absolute terms than in any previous decade. ➢

[1] San Francisco Chronicle, "The Traffic Mess," *San Francisco Chronicle,* August 31, 1986: p.1

FIGURE 2

Total Highway Expenditures in Unadjusted Dollars

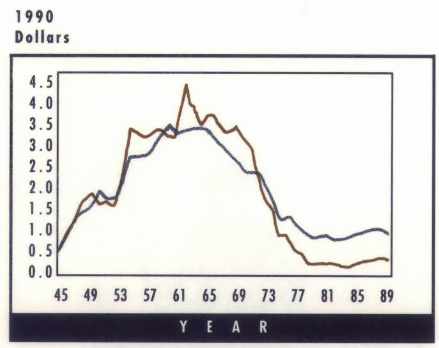


California
United States

Source: U.S. Federal Highway Administration Annual Reports

FIGURE 3

Highway Construction Expenditures in 1990 Dollars per 100 VMT



California
United States

Source: U.S. Federal Highway Administration Annual Reports

Note: Construction expenditures adjusted for inflation using the California State Highway Construction Cost Index and the U.S. Highway Construction Cost Index.

Looking at highway expenditures alone, however, presents a misleading picture of highway finance since 1965. It does not account for freeway expenditures vis-à-vis other streets and roads; it does not account for the rising costs of highway construction and maintenance; and it does not account for the explosive growth in vehicle travel. When each of these factors is controlled for, a far different picture of highway finance emerges.

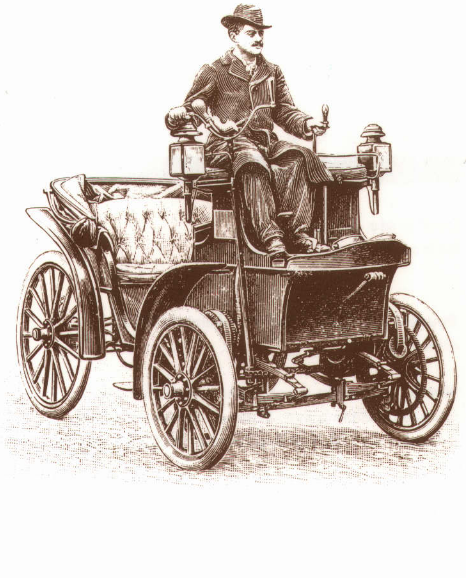
If we look at state highway construction expenditures in 1990 dollars per 100 vehicle-miles of travel, then highway construction expenditures peaked nationally in 1959 and in California in 1961. (See Figure 3.) Adjusted nationwide highway construction expenditures began a steady fifteen-year decline beginning in 1964. Since 1979 expenditures have remained fairly stable at about $1.00 per 100 VMT — about one-third of the 1959 peak.

Skyrocketing Freeway Costs

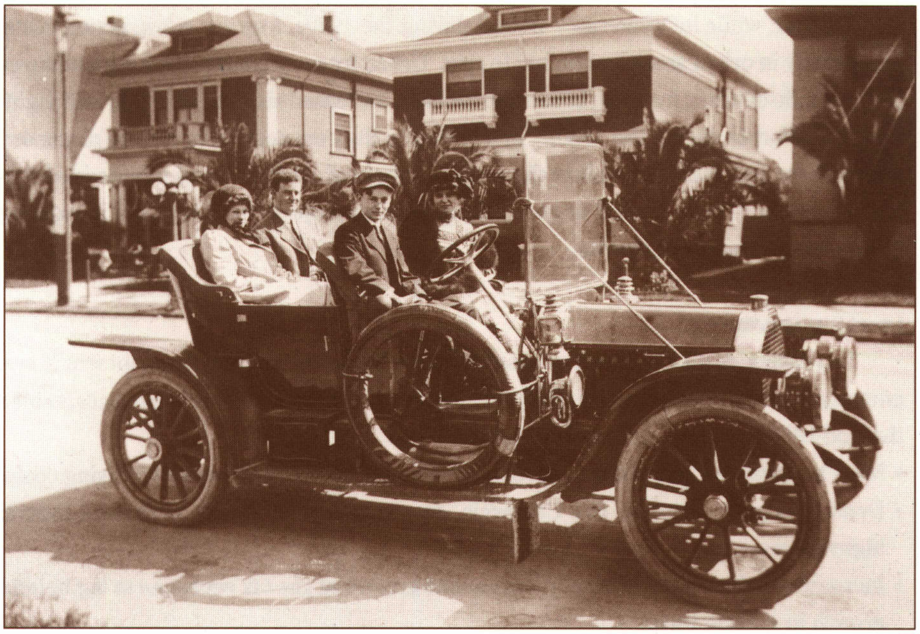
The principal cause of declining freeway development was the dramatic rise in construction and maintenance costs during the 1960s, 1970s, and 1980s. Freeway development costs nationwide grew much faster than the general rate of inflation during those three decades. Freeway costs rose faster in California than in the nation as a whole, and faster in cities than in rural areas. There were four forces behind the rapid escalation.

Inflation of all construction and maintenance unit costs. During the 1950s, highway construction unit costs were essentially flat, which led analysts to assume in their calculations that there would be little or no escalation in construction costs between 1959 and 1980. Beginning in the early 1960s, however, highway construction unit costs began to rise significantly, for the same reasons that all construction costs rose: high levels of demand for construction services, strong demand for construction materials and equipment, and high levels of unionization resulting in rapidly climbing wage rates. Furthermore, highway maintenance and operating costs also escalated, especially in the 1980s. In recent years, freeway maintenance has come to mean much more than landscaping and lane striping: as freeways built in the 1950s reach the end of their thirty-year design lives, they require major repaving and reconstruction.

Significant growth in the scope and scale of freeway projects. The earliest freeways in Los Angeles and San Francisco were built for 55-miles-per-hour design speeds, but nearly all freeways on the Interstate system and eventually all new freeways in the California Freeway System were built for 70-miles-per-hour design speeds. The higher design speeds required more right-of-way to accommodate high-speed curves, making it more difficult to shoehorn urban freeways into built-up areas. Many design changes were intended to improve safety, but other design changes were made under community pressure. Cities regularly pressured the California Division of Highways to increase the number of interchanges in urban areas or to add more street over- and under-crossings. Finally, the slowing pace of new freeway development also encouraged upscaling of surviving plans. State highway departments tried to design more and more capacity into the few remaining new routes — more lanes, more eleborate interchanges, separated weaving sections — all of which drove costs up further.



Rising urban land values dramatically raised right-of-way costs. The need to purchase right-of-way in advance of development poses the freeway planner's dilemma: metropolitan land values appreciate in anticipation of future freeway development, which drives up freeway right-of-way costs. At first, California devoted a very high proportion



Californians taking a spin before freeways came along.

of the state highway budget to right-of-way acquisition. In 1955, nearly 28 percent of total state highway expenditures were for rights-of-way; by 1976 it was less than 2 percent. What happened was, as funding began to run short in the early 1960s, the state chose to use dwindling resources to construct freeways on rights-of-way already in hand, while cutting down on advance right-of-way acquisition. In less than ten years, beginning in 1964, California's right-of-way expenditures dropped from twice the national average per vehicle-mile of travel to slightly less than the national average. Meanwhile, right-of-way costs continued to increase steadily. Thus, future metropolitan freeway development was all but foreclosed.

Environmental and community concerns increased administrative and planning costs while also raising design standards. Construction of the seventeen-mile Century Freeway that runs from the Los Angeles International Airport in the west to the City of Norwalk in the east is a textbook lesson in cost escalation. The process of acquiring the right-of-way for the Century Freeway was nearly complete in 1972 when a coalition of area residents, environmentalists, and civil rights organizations filed suit against the state for failing to comply with environmental and relocation laws and regulations. After nearly ten years of litigation, the California Department of Transportation (Caltrans) agreed, among many other concessions, to implement a $300 million program to rebuild, relocate, and rehabilitate over half of the residential dwellings cleared for the freeway. The delays, legal costs, additional relocation expenses, and added design requirements are estimated to have increased the project's total cost from $502 million in 1977 to $2.5 billion in 1993. Even with the effects of inflation controlled for, the cost of the Century Freeway increased 131 percent to nearly $150 million per mile in 1990 dollars. On most earlier projects, however, the added environmental costs were a far smaller proportion of increased costs. Most cost increases attributable to new environmental requirements during the 1970s were actually due to construction delays; the environmental documentation and approval process lengthened the time required to plan a new freeway which proved costly during periods of inflation.

In concert, these four factors combined to make freeway costs skyrocket between 1960 and 1990. During the 1960s, freeway development costs in California increased at an average 8.2 percent per year, which was 3.5 times the average annual inflation rate of 2.4 percent. In the 1970s, owing in part to much higher rates of inflation, costs rose even faster. State highway construction expenditures in California rose from $4.1 million per mile in 1970 to $16.7 million per mile in 1980, an average annual increase of 12.1 percent, well ahead of the average 1970s inflation rate of 8.7 percent. ➢

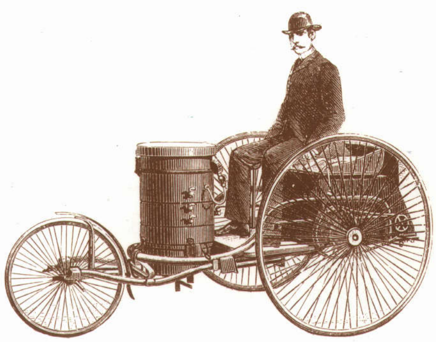
Further, while inflation rates slowed during the 1980s, freeway construction costs, particularly in urban areas, continued to rise. Urban freeway construction expenditures per new mile of urban freeway, in constant dollars, increased six-fold nationally and eight-fold in California during the 1980s. In addition to the cost escalation factors discussed above, these cost increases reflect the small numbers of urban freeway miles added during the 1980s. These tended to be small, expensive projects to close gaps in existing metropolitan freeway networks.

Lagging Revenues

Increasing costs would not necessarily have hindered freeway development if revenues had grown proportionally. But revenues have lagged behind increasing costs since the mid-1960s for three principal reasons:

- Most highway tax instruments, particularly the gas tax, are not indexed to rising costs.
- Densely populated states, like California, do not receive all locally generated federal highway revenues.
- Increasing vehicle fuel efficiency has caused growth of gas tax revenues to lag behind growth in vehicle travel.

Just as freeway costs were skyrocketing during the 1970s, highway revenues began to falter. Inflating construction unit costs, upscaling freeway designs, rapidly increasing right-of-way costs, increased maintenance load, and expanded environmental costs have been squeezed by revenue sources not indexed to either vehicle travel or inflation.



Conclusion

Individual freeway revolts and debates over the California Freeway System plan attracted substantial public attention in the 1970s, but they were not principally responsible for curtailing freeway construction in California. Annulment of the California Freeway System plan occurred several years earlier when the Governor and State Legislature chose to ignore the collapse of the freeway finance program.

A financial crisis among the state's largest public transit systems, however, did prompt California to adopt a large new subsidy program for public transit. In 1971, California created the largest state transit subsidy program in the country when 1/4 cent of the six-cents-per-dollar state sales tax was dedicated to public transportation.

This dramatic shift in fiscal priorities in 1971 — from freeways to public transit — was not accompanied, at the time, by a shift in state freeway plans. But, by neglecting the fiscal woes of the freeway program beginning in the mid-1960s, the Governor and State Legislature effectively killed the 1959 California Freeway System plan and rendered moot subsequent debates over freeway planning and policy. In other words, financial politics lead the freeway planning process.

While the scale of the public transit subsidy program adopted in 1971 was far smaller than what would have been needed appreciably to revive freeway construction in California, it did divert legislative attention (and largesse) from restructuring highway finance. Freeways were left to make do on a finance package that appeared generous in the 1950s, but proved to be inadequate just a few years later.

Out of Cash—
I-280, San Francisco.

In June 1990, however, the voters of California agreed to raise the state gas tax nine cents per gallon by 1994 to support new freeway construction and improved road maintenance. The day after the election, the Los Angeles Times declared:

> California voters, often trend-setters for the nation, have sent a new message with their decision to double the state gasoline taxes — they now are willing to raise certain taxes to remedy a critical problem.[2]

While voter intent might be clear, it is unlikely, given the magnitude of the cost/revenue squeeze in freeway finance, that a nine-cent-per-gallon increase will "remedy" the problem of urban traffic congestion in California. The additional funds will be used to close some gaps in the existing freeway system and to expand the capacity of some aging freeways, but no major new freeway projects are on the horizon in California.

The persistence of the fiscal crisis that preempted freeway policy and planning debates in the 1970s holds an important lesson for planners and policymakers today: freeways, as they are currently financed, have been priced into obsolescence. If large-scale metropolitan freeway development in California had simply been shelved by the Brown Administration in the 1970s, then it might be restored by a renewed commitment to freeway building in the 1990s. But this is not the case. Despite recent gas tax increases, the cost/revenue squeeze in freeway finance endures. And while the cost/revenue squeeze is perhaps tightest in California, the trends outlined here can be seen nationwide. Short of road pricing, toll financing, or some other radical restructuring of highway finance, a new wave of metropolitan freeway development is simply not possible. ◆

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TRAVEL AND DEMOGRAPHIC CHANGE IN THE U.S.						
					1969-90 % CHANGE	
	1969	1977	1983	1990	ANNUAL RATE	OVERALL CHANGE
DEMOGRAPHICS (000)						
Population	197,213	213,141	229,453	239,416	0.9	21
All Households	62,504	75,412	85,371	93,347	1.9	49
One Person Households	10,980	16,214	19,354	22,999	3.6	109
Male Licensed Drivers	57,981	66,199	75,639	80,289	1.6	38
Female Licensed Drivers	45,005	61,353	71,376	82,707	2.9	84
Male Workers	48,487	55,625	58,849	63,996	1.3	32
Female Workers	27,271	37,394	44,395	54,334	3.3	99
Household Vehicles (000)	72,500	120,098	143,714	165,221	4.0	128
Household VMT (000,000)	775,940	907,603	1,002,039	1,409,600	2.9	82
Vehicles per Licensed Driver	0.70	0.94	0.98	1.01	1.8	44
ANNUAL PERSON TRIPS BY MODE						
Auto & Van (000)	123,519	149,597	167,736	189,526	2.1	53
Light Trucks (000)	8,128	17,589	23,874	27,006	5.9	232
JOURNEY TO WORK (MODAL SPLIT)						
By Auto/Truck (Percent)	90.8	93.0	92.4	91.4	0.0	1
By Public Transit (Percent)	8.4	4.7	5.8	5.5	-2.0	-35
By Other Mode (Percent)	0.8	2.3	1.8	3.1	6.7	288
Average Commute By Car (Miles)	9.9	9.2	9.9	10.6	0.3	7
Average Commute By Car (Minutes)	22	20.4	20.4	19.7	-0.5	-10
HOUSEHOLD VEHICLE OWNERSHIP (PERCENT)						
One-Adult Households (30% of 1990 HHs)						
Zero vehicles available	56.2	39.2	34.0	21.4	-4.5	-62
One or more vehicles available	43.8	60.8	66.0	78.6	2.8	79
Two-Adult Households (58% of 1990 HHs)						
Zero vehicles available	12.4	7.5	5.8	3.6	-5.7	-71
One vehicle available	57.3	33.1	29.2	20.4	-4.8	-64
Two or more vehicles available	30.3	59.4	65.0	76.0	4.5	151
Three (or more)-Adult Households (12% of 1990 HHs)						
Zero vehicles available	8.2	5.9	5.6	4.7	-2.6	-43
One or more vehicles available	32.2	15.9	13.4	14.3	-3.8	-56
Two vehicles available	42.6	34.4	27.1	28.5	-1.9	-33
Three or more vehicles available	17.0	43.8	53.9	52.5	5.5	209
Zero-Driver Households (10% Of 1990 HHs)						
One-Driver Households (40% of 1990 HHs)						
Zero vehicles available	15.6	9.6	11.2	6.3	-4.2	-60
One or more vehicles available	84.4	90.4	88.8	9.4	0.5	11
Two-Driver Households (41% of 1990 HHs)						
Zero vehicles available	2.3	1.1	1.2	0.9	-4.4	-61
One vehicle available	52.5	24.1	22.0	16.5	-5.4	-69
Two or more vehicles available	45.5	74.8	76.8	82.6	2.9	83
Three (or more)-Driver Households (9% of 1990 HHs)						
Zero vehicles available	0.8	0.4	0.1	1.1	1.5	38
One vehicle available	17.2	5.7	4.6	5.0	-5.7	-71
Two vehicles available	51.7	30.7	24.4	24.2	-3.6	-53
Three or more vehicles available	30.3	63.2	7.9	69.7	4.0	130

Source: Preliminary figures from the 1990 Nationwide Personal Transportation Survey.

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