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"Demonstrated" Technology: Three Examples from History and an Analysis of Nuclear Waste Management

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Summary

This is an analysis of three major technological innovations -- the steam engine, the moving assembly line, and the modern transport airplane -- in order to determine what has been established from previous experience regarding the stage at which a technology is considered to be "demonstrated." I have selected these three because each is a well-recognized technological advance and each has been studied in detail, so that complete information is available on the steps in their development. They have certain features in common which offer some guide as to the point at which a technology can be said to have been demonstrated. Each was an application or extension of existing knowledge or capability. The demonstration of the technology is the point at which it can be determined that the extension or application of the technology will perform the desired function.

In this report I will: first, define how one may determine that a technology has been demonstrated; second, give examples of classic demonstrations; and lastly, review the status of Nuclear Waste Management.

With respect to High-Level Nuclear Waste Management: The methods have been thoroughly studied, both in the United States and elsewhere, and substantial experience has been

acquired through disposal procedures for existing facilities and by experimentation. Based on this evidence I conclude that a demonstrated technology exists in High-Level Nuclear Waste Management, in the sense that I understand the terms as a historian of technology.

I. DEMONSTRATED TECHNOLOGY

1. The Historical Evidence

New technologies ordinarily derive in incremental steps from existing bodies of knowledge and technical capabilities. The advance occurs because of an insight into methods of using a given body of knowledge and technical capability to achieve a novel but calculable result. The quantum leap into the unknown is so rare that it can be disregarded for our purpose.

A new technology is demonstrated when it is established that it will perform its designed function. This can be done by various kinds of experimentation and testing, and most effectively by developing a prototype or by pilot operation and/or field testing. The major technological innovations described later in this report illustrate these methods of demonstration:

i) Demonstration of prototype: This is illustrated in James Watt's first steam engine, built in 1769. This engine never went into commercial use, but it showed Watt's major innovative ideas (condensing the steam in a separate chamber rather than in the cylinder, and using steam instead of atmospheric pressure to power the engine) would work as he had calculated.

The other prototype example is the DC-1 airplane (1933). This was a synthesizing of known aeronautical technologies so as to achieve optimal utilization of these technologies. When the DC-1 was test-flown, it demonstrated that the results calculated for the design had been achieved. While only one DC-1 was ever built, it led to the enormously successful DC-3.

ii) Demonstration by pilot operation: The Ford Motor Company's magneto assembly line, installed early in 1913, is used as the example of this method. It combined known technologies (conveyor belt, standardization of parts, interchangeability, synchronization of materials flow) in a novel way. The success of this experiment was sufficient evidence for the Ford Company to adopt full-scale assembly-line production for the entire auto within the same year.

iii) Demonstrated by field testing: A classic example is Marconi's experimentation with wireless telegraphy. In 1884, he made the critical decision to experiment with a grounded antenna. This involved building a transmitter and receiver, and gradually increasing the distance between them from 2 to 18 miles over two years. These were strictly test transmissions but they convinced Marconi that his system worked and that transmission over any distance was now feasible. He patented his discovery in 1896, and proceeded to raise capital successfully for the Marconi Wireless Telegraph Co. Ltd. At the end of 1901, the first transatlantic radio signal was successfully transmitted, but the demonstration of technology had occurred with the 18 mile transmission five years before.

Each of these demonstrations occurred before the technology in question was in full-scale operation or had become profitable. This is the standard pattern; the demonstration of the technology is what justifies putting it into use and developing it further. This aspect of technological innovation is explained[1] by Dr. Nathan Rosenberg, Professor of Economics at Stanford, in the following statement:

> "In making new products and processes practicable, there is a long adjustment process during which the invention is improved, bugs ironed out, the technique modified to fit the specific needs of our users. The idea that the invention reaches a stage of commercial profitability first and is then "introduced" is, as a matter of fact, simple-minded. It is during a (frequently protracted) shakedown period in early introduction that it becomes obviously worthwhile to bother making the improvement."

The same thing is said in more compressed form in Industry's

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[1] Nathan Rosenberg, Perspectives on Technology, Cambridge University Press, London, 1976, p. 167.

"Approvals of Technology" submission[2] to the State Energy Commission:

> "Economics essentially affects whether the technology will in fact be implemented, not whether it exists and is capable of implementation."

To recapitulate, a technology is demonstrated when it is established that it will perform the function for which it was designed. This point is normally reached before the technology has become fully operational or economically successful; demonstration is in fact a necessary prelude to adoption. A demonstrated technology may subsequently be refined and improved. It almost certainly will be because this is characteristic of all technology, and the subsequent improvements in no way affect the validity of the original demonstration.

The history of technology offers ample evidence to support these conclusions. The examples cited in this report are among the great epochal innovations. They are also representative of the course that a technological innovation ordinarily takes.

2. When Will It Be Used?

Certain conditions other than economic or social benefit are necessary for technological innovation. Manifestly there has to be an incentive. This has usually been the prospect of economic benefit, but other motives may operate

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[2] Federal 'Approvals' of Technology Under AB2820 and AB2822"; Testimony by the Nuclear Industry and California Electric Utilities, at Hearings May 26, 1977, on Dockets 76-NL-1

also. Watt began his search as a routine assignment from the University, and then was carried on by the curiosity of a highly skilled craftsman with a good background of current scientific knowledge.

Timing is also important in terms both of the demand for the technology and the ability to do it. Leonardo da Vinci could conceive of a flying machine, but Renissance Italy had not attained the level of technical skill needed to make it. Watt, on the other hand, lived in a society already in the Industrial Revolution, with the technical capacity to build his engine and the economic incentive to use it. With Ford and Douglas the methods and devices that they combined had all been used separately in one form or another; the incentive to undertake the combining was the prospect of expanding their market.

The term "prospect" is important, because economic risk-taking is always present in technological innovation. A technical innovation may be, and usually is, undertaken in the hope of profit; but while technical feasibility can be calculated accurately, economic projections always have an element of risk. Ford's mass market could have been overestimated. In the same industry, the steam automobile was definitely a successful technology, but it proved to be an economic failure. In the cases cited, even when the technical achievement had been brilliantly demonstrated, it was still necessary for Boulton and Watt, the Ford Motor Company, and Douglas Aircraft to go out and sell their products agressively.

To sum up, while technological change is normally undertaken in expectation of profit, the technology has to be developed first, before there can be conclusive assurance of profit-ability. A technology is successfully developed when it is established that it will perform its designed function, and this can be demonstrated in various ways: a pilot operation, a prototype, and in some situations by laboratory or field testing.

3. Analysis of Definitions

Historians of technology have not previously had occasion to need an exact definition of "demonstrated" or "existing" technology. There apparently has been little call to provide such a label, as a business or governmental unit decides this in the context of its needs. This issue has not yet come before the Society for the History of Technology.

The definition of Demonstrated Technology in the report[3] on "High-Level Waste Management" (the Lieberman definition), is obviously designed to be comprehensive, and is.

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3 "High-Level Waste Management" Testimony by J. A. Lieberman, W. A. Rodger and F. P. Baranowski for the Nuclear Industry and the California Electric Utilities, March 21, 1977 on Dockets 76-NL-1 and -3; p. 7.

> Demonstrated Technology: The level of technology when enough engineering information has been developed at laboratory, bench and/or pilot plant-prototype scale so that competent governmental or commercial groups would be able, if they so desired, to design and build a full-scale plant or facility or perform the process to accomplish the defined mission. Demonstrated technology does not require prior operations under actual working conditions, or at expected scale of activities, or for expected periods of operation, so long as sufficient information has been developed to provide confidence that successful operations can be accomplished.

This includes all the fundamental points. My major criticism is that it is somewhat over-elaborate, mainly because it is attempting to cover all possibilities. The statement in the "Approvals of Technology" document[4] is clearer and more concise.

> There should not be much doubt as to the meaning of the words "technology" or "technology or means." These terms commonly refer to the existence of a body of knowledge with respect to a technical method of achieving an objective rather than to the existence of equipment or facilities for performing a task.

While it defines "technology" satisfactorily, it essentially returns to the Lieberman statement to explain "demonstrated."

Both statements are certainly valid. They agree with each other on the essentials of what constitutes "demonstrated technology," and I agree also on these essentials. My differences and criticisms are perhaps semantic.

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[4] Ref. 2, p. I-4.

Both statements emphasize that a technology does not have to be fully operational to be considered demonstrated. I understand the importance of the point, and I agree with it.

To emphasize that the point of demonstration is beyond theoretical calculation, I propose the following definition:

A technology is demonstrated when:

i) A sufficient body of knowledge has been developed with regard to technical methods of achieving the desired objective to give assurance that this objective will in fact be attained, and

ii) This knowledge has been sufficiently tested by experiment, prototype design, pilot operation, or other acceptable method, to show that it can be applied to the desired purpose through the existing technical capability or straight-forward extensions.

These conditions definitely are satisfied by the present technologies for reprocessing nuclear fuels and for nuclear waste disposal, just as they are satisfied by the historical analogies I have used.

II. REVIEWS OF THREE EXAMPLES OF TECHNOLOGY

1. The Steam Engine

The steam engine is one of the few great inventions which does not have conflicting claimants; credit goes unquestioningly to James Watt. Basically, what he did was to put together existing knowledge and techniques, with an infusion of brilliant insight. This does not in any way diminish the achievement; it is the process by which virtually all technological advance is accomplished.

The elements that Watt brought together were:

i) Knowledge of atmospheric presssures. This was developed about a century earlier and by Watt's time was well understood by educated people.

ii) Research on the properties of heat. Watt knew of this because much of it was done at Glasgow University, where Watt worked as instrument maker. The principal figures in this research, James Black and John Robinson, belonged with Watt to a society which met periodically for discussion of the members' intellectual interest.

iii) Existing technology. Watt became interested in steam power through the Newcomen engine, which had been in use for about fifty years when Watt started his work - initially through being asked to find out why a demonstration model of a Newcomen engine would not work. This engine used atmospheric pressure. It consisted basically of a cylinder open at one end and a piston. Steam was admitted while the piston was at the open end and then condensed, whereupon atmospheric pressure on the piston provided the power stroke. The engine was used widely to pump mines.

Thus there was available the basic components of the steam engine -- piston, cylinder, boiler, firebox, and automatic valve gear -- in operating form, plus the capability of making them. Watt's great contribution was to eliminate the waste of heat in the cylinder by adding a separate condensing chamber. Then he recognized that the cylinder should be closed at both ends and steam pressure used instead of air pressure, removing another source of heat loss.

An engine incorporating these principles was built and demonstrated in 1769. Improved techniques for boring cylinders permitted a more successful engine in 1774. Either engine may be considered to have demonstrated the technology. Both preceded commercial use; the first sales of Boulton and Watt engines were made in 1776. I would rank the 1769 engine as the successful demonstration of the technology; it established that a steam engine built on Watt's principles would definitely work as it was expected to. What came after was improvement and refinement. In fact, Watt's initial decision to add the condensing chamber can be taken as the point of demonstration. It marks the transition from the atmospheric to the steam engine, yet it was a step well within the capacity of contemporary British technical skill to execute. Watt could be sure of the result even before he built his first engine.

Watt's incentive was initially to solve a problem that had been referred to him. Then, as he studied the mechanism, his curiosity led him to look for methods of improving it, on the basis of knowledge he already possessed. He was obviously aware quite early in his work that a more efficient prime mover than the Newcomen engine would be a promising prospect in Britain's expanding industrial economy, and he found financial support on this ground. But the technology was demonstrated first, and undoubtedly had to be, before it was put into industrial use or began to earn a return.

2. The Moving Assembly Line

Mass production is perhaps the greatest distinctively American contribution to modern technology. Its fundamentals are precision, standardization, interchangeability, synchronization, and continuity, and it first appeared in complete form with the introduction of the moving assembly line by the Ford Motor Company in 1913. This process was fundamentally a synthesizing of known technologies to achieve a desired goal: increased production at lower cost.

An account of the evolution of mass production techniques is given in Appendix A. It is worth noting that several European efforts in this direction all proved to be false starts, whereas in the United States there was an uninterrupted progression from the early experiments in standardization, interchangeability, and continuous flow. As early as 1850 these techniques were referred to in Europe as "The American system of manufacture."

By the time Henry Ford came on the scene these techniques had reached a high degree of refinement and American industry had acquired a substantial backlog of know-how and skill in using them. In the automobile industry itself, Henry M. Leland of Cadillac gave a demonstration of interchangeability in 1908 that profoundly impressed the British automotive world. Thus Ford and his associates had no need to "invent" anything. The solution to their problem lay in finding the way to combine and apply known and used techniques in a way to achieve their objective of large-scale production at low unit cost.

In this case, the point at which the assembly-line technique was demonstrated can be accurately fixed. The first stage in its development was the installation of a moving assembly line for flywheel magnetos about May 1, 1913. Previously magnetos were assembled by having one workman do the entire job, with a maximum output per man of one magneto every 18 minutes. Skilled labor was required, and even so uniformity was difficult to maintain. The first trial of the assembly line method raised output to a magneto per worker every 13 minutes, and this figure was later reduced to five, all at substantially less cost.

The technology was here clearly "demonstrated." A magneto is not a simple device to construct, and in this case it was not only necessary that these assembly-lire products should work satisfactorily, it was equally essential that any magneto coming off the line should fit and function on the flywheel of any Ford engine. This one experiment fully justified extending the moving assembly line technique to the production of the entire vehicle, which was in fact done at the Ford Motor Company by the end of that same year (1913).

3. The Modern Transport Airplane

In the ten years between 1930 and 1940 the American aircraft industry became the world's leading producer of commercial transport aircraft and it has maintained this position ever since. This was a more substantial achievement than appears on the surface; as late as 1935 there were five British airframe builders larger than the biggest American firm, and the British aircraft industry was smaller than the German. They all, including the American companies, were primarily builders of military aircraft; yet the American breakthrough in the transport field represented an achievement in design that was adopted by everyone in military planes as well.

This breakthrough is fully described in Appendix B. As with the two examples previously cited, it was achieved by synthesizing existing knowledge and techniques in such a way as to achieve a novel but planned result. The new type of airplane that was created was a monoplane, usually low-wing; of all-metal, stressed-skin, monocoque construction, with controllable pitch propellers, retractable landing gear, and wing flaps. Every one of these features had been separately introduced earlier and tried, but with unsatisfactory results until they were properly combined with each other in an integrated design.

Competitive pressures among airlines and aircraft manufacturers were the incentive behind this technological feat.

After some preliminary experimentation, the first definite approach to this integrated design was the Boeing 247 of 1932. It had all the features described above except wing flaps, an omission that pushed it into oblivion surprisingly fast. Nevertheless, when the Boeing 247 was introduced it so clearly made existing transports obsolete that TWA turned to Douglas Aircraft for an effective competitor (Boeing was then part of a combine that included United Airlines.) The result was the DC-1, precursor of a long series of transports. There was only one DC-1 because the DC-2 was already in production by the time the DC-1 was testflown, and in fact the famous DC-3 was on the way by the time the DC-2 went into service.

The DC-1 was the demonstration of the technology. The adoption of wing flaps allowed it to have more powerful engines and to be bigger and faster than the 247. The technology was convincingly demonstrated on September 20, 1933, when the plane comfortably outdid its performance specification on a cross-country trial flight. But a strong case can be made that the point of demonstration came earlier.

Credit might be claimed for the 247, on the ground that the addition of wing flaps was basically just a refinement of the original design. However, the flaps were integral to the completed design of the DC series, since they made possible safe take-off and landing of bigger and heavier aircraft, capable of carrying a payload that would make commercial operation profitable without subsidy. It was said of the DC-3 that it was the first transport that could support itself economically as well as aerodynamically, and these were the planes that established American domination of the world's airways.

The feasibility of the design for its planned purpose was fully demonstrated in the DC-1, and this was done even before the cross-country flight of September, 1933, or even the initial test flight on July 1 of that year. Paradoxically, one of the proofs of success was that only one of the type was built. Both the maker and the purchaser were so certain of their performance expectations that, as stated before, a larger version of the design was already in production by the time the DC-1 was finished.

III. CONCLUSIONS ON THE DEMONSTRATED TECHNOLOGY FOR NUCLEAR WASTE MANAGEMENT

The conclusion of a report[5] issued by the American Physical Society states:

> "For all LWR fuel cycle options, safe and reliable management of nuclear waste and control of radioactive effluents can be accomplished with technologies that either exist or involve straight-forward extension of existing capabilities." (emphasis added)

This is precisely the situation analyzed in the previous sections. The normal process of technological change is to extend or apply knowledge and capabilities already in existence in a way that may be novel but is accurately predictable. The demonstration of the technology is the point* at which it can be determined that such extension or application will perform its designed function.

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[5] Draft Report to the American Physical Society by the Study Group on Nuclear Fuel Cycles and Waste Management, released April 25, 1977. This was an executive summary; the full report will be released in the summer of 1977.

*This point, in the examples I used, was:

a) Watt's addition of a separate condensing chamber to the Newcomen engine, effectively creating the steam engine,

b) Ford's adoption of a conveyor assembly system with each worker performing a single operation,

c) Douglas Aircraft's synthesizing of known aeronautical technologies in the design of the DC-1.

This stage has clearly been reached with High-Level Nuclear Waste Management. The methods have been thoroughly studied, both in the United States and elsewhere, and substantial experience has been acquired through disposal procedures for existing nuclear facilities and by experimentation.

There is a thirty-year record, beginning with the initial arrangements for storing liquid wastes at Oak Ridge and Hanford, and later at the Savannah River and Idaho Chemical Processing Plants. These arrangements were carefully enough worked out so that flaws which appeared were readily corrected, such leakage as occurred was safely contained, and the experience gained made it possible to improve and refine the storage techniques.

Solid waste disposal by geologic isolation has a twenty-year developmental record, beginning in 1955 with a conference sponsored by the National Academy of Sciences-National Research Council. The steps in this process have been:

i) Research and laboratory investigation (1955-1965) establishing the suitability of salt formations for the long-term storage of High-Level Nuclear Wastes.

ii) Field testing (Project Salt Vault, 1965-1967) at the Carey salt mine, Lyons, Kansas, with fully satisfactory results.

iii) Various solidification techniques thoroughly tested at Federal facilities and laboratories, with production of solidified high-level wastes begun in 1963 at Idaho Chemical Processing Plant.

iv) Conceptual design for disposal of solidified high level waste by geologic isolation began in 1961, and a system design was subsequently worked out at the Oak Ridge National Laboratories.

Taken together, these steps are the equivalent for Nuclear Waste Disposal of the stage reached in each of the innovations described in the previous sections, when the body of knowledge, techniques, and expertise was sufficient to ensure the technical feasibility of the projected innovation. At this point the technology should be considered demonstrated.

The Oklo phenomena are not definable as technology, since they occurrred through purely natural forces. However, they certainly provide interesting and impressive supporting evidence of the soundness of the technology.

The American Physical Society's study suggests that granite formations may offer greater advantages than salt for the storage of High-Level Nuclear Wastes, but this does not alter the fundamental situation. The study states:

> "Effective long-term isolation for spent fuel, high-level or transuranic waste can be achieved by geologic emplacement. A waste repository can be developed in accord with appropriate selection criteria that would ensure low probability that erosion, volcanism, meteorite impact and other

natural events could breach the repository. The possibility of inadvertent human intrusion can also be made remote and limited in consequences. Hydrogeologic transport is the most important mechanism for potential transport of radionuclides to the biosphere. We conclude that many waste repository sites with satisfactory hydrogeology can be identified in continental U.S. in a variety of geological formations. Bedded salt, proposed for the first repository in current ERDA plans, can be a satisfying medium for a repository, but certain other rock types, notably granite and possibly shale, could offer even greater long-term advantages."

What is proposed about other rock types is simply the process of refinement and modification described by Dr. Rosenberg as as characteristic of technological innovation. The basic technology is the same whether nuclear wastes are isolated in salt, granite, or other rock formations. The APS study confirms that the technology to do this is known and within existing capability.

Paragraph D-3 in part suggests that a "demonstration" has not been carried out, stating:

> "The technology for waste solidification and for constructing and operating a nuclear waste repository has been developed to a point where a demonstration facility can be carried out. A demonstration facility would provide checks on short-term stability of wasteforms and encapsulation, operational experience with waste handling equipment, and initial verification of the predicted effects of the emplaced waste on the immediate geologic environment."

By my understanding of the terms, the above statement says that the technology already has been demonstrated. The proposed "demonstration facility" is recommended on the ground that the technology to do it is now available* -- not to find out if the technology exists. It is apparent that the APS is suggesting only confirmatory information be obtained for specific sites; and that its recommendation does not reflect a view as to need for a "demonstration facility" to show the adequacy of the technology. The purpose of the demonstration facility is clearly to try to establish criteria for choosing** among specific sites; not to test the existing technology for disposal of High-Level Nuclear Wastes. My final judgment on this point would require the complete text of the final report.

This is a good example of the difference between the approach of the scientist and that of the engineer. The scientist likes to seek absolutes, with no pressure of time

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*On June 16, 1977, Dr. L. Charles Hebel (Chairman of the APS Study Group) testified on this point before the California Energy Commission, saying "We are confident that long-term isolation could be effective in geologic repositories for either spent fuel or high-level and transuraino wastes, and in fact, as we assess the technology, there are no technical barriers standing in the way of the development of a repository or the time scales that are bieng sought." Transcript pg. 43; emphasis added.

**On June 16, 1977, Dr. L. Charles Hebel further testified, saying "Well, from our point of view, we wanted to distinguish between demonstration facilities which tell you whether or not you have a viable situation locally and whether the media will work out -- we wanted to distinguish between that scale of facility and a full repository. There is really quite a difference of scales, and it seemed to us important to move rapidly and orderly to, at least, two satisfactory demonstration facilities, and then one would develop, presumable, the most favorable of these into a repository as the needs require." Transcript pg. 55.

to arrive at conclusions and with opportunity to experiment until proof is final and conclusive. This may be too sweeping a generalization, but basically the scientist is not concerned with decision-making. On the other hand, the engineer must be concerned with decision-making: policy decisions by government and industry, and decisions involving the commitment of very large amounts of both public and private funds. Therefore, the engineer has to seek, not the theoretically ideal solution to the problem, but the solution that will work best within a given set of practical conditions. Both approaches have their place, but the issue before us is quite definitely in the engineering category.

Thus it appears that the conclusions specified in AB 2822 have in fact been met:

> "The commission finds that there has been developed and that the United States through its authorized agency has approved and that there exists a demonstrated technology or means for the disposal of high-level nuclear waste."

I conclude that a demonstrated technology exists, in the sense that I understand the term as a historian of technology.

Originally submitted July 8, 1977 to the California Energy Resources Conservation and Developement Commission Nuclear Fuel Cycle Hearings Docket 76-NL-1 and -3.

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Education

1932	B.A., Brown University (history)
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Positions

1936-37	Research Assistant, Brookings Institution, Washington, D.C.
1937-39	Administrative Assistant, Brown University
1939-43	Instructor in History, M.I.T.
1943-47	Assistant Professor of History, M.I.T.
1947-59	Associate Professor of History, M.I.T.
1956-57	Exchange Associate Professor, Case Institute of Technology
1959-76	Professor of the History of Technology, Harvey Mudd College
1965-66	Visiting Professor, Manchester College of Science & Technology, England
Fall, 1973	Visiting Lecturer, Queen's University, Belfast, Northern Ireland
January - June, '74	Senior Resident Scholar, Eleutherian Mills-Hagley Foundation, Wilmington, Delaware
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Major Publications

1949,55,64	The U.S. in World History, McGraw-Hill, N.Y.
1959	American Automobile Manufacturers, Chilton, Philadelphia, Pa.
1965	The American Automobile, University of Chicago Press
1968	Climb to Greatness: The American Aircraft Industry, 1920-1960, M.I.T. Press
1969	Henry Ford, Prentice Hall
1971	The Road and the Car in American Life, M.I.T. Press

Awards

1935-36	Pre-Doctoral Field Fellow, Social Science Research Council
1960	Thomas McKean Memorial Award for Automotive History
1965-66	Senior Postdoctoral Fellow, National Science Foundation
1968	Willard W. Keith, Jr. Fellow in Humanities, Harvey Mudd College

Memberships

Society for the History of Technology, (President, 1973-74).
American Society for Engineering Education (Chairman, Liberal Studies Division, 1962-63, 1968-69).
Economic History Association
NASA Historical Advisory Committee
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