J. J. Martin to W. D. McElroy

Dr. W. D. McElroy, Director
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Washington, D. C. 20550

Dear Dr. McElroy:

We appreciate the opportunity to comment on the benefits of basic research for our contemporary society. This is indeed an important question for our time, and many of our AIChE membership have been faced with similar, though perhaps more parochial, fundamental research justification. The remarks that follow represent a consensus of views of members of the AIChE Research Committee. This group of academic, government, and industrial engineers is a standing committee appointed by the AIChE Council to enhance the profession of chemical engineering through activities related to research. Since you are expecting replies from other professional societies, we will largely confine our remarks to those areas of chemical technology representative of our memberships' employment and expertise.

The Impact of Basic Research Is Pervasive

Most of us share the strong opinion that basic knowledge is a catalyst for technical innovation across the board. We feel that NASA and others have tried too hard to find spectacular "spin-offs" to justify fundamental studies. This task is almost self-defeating in that it detracts from the chief role of basic research as a vital input for *all* R&D. Further, *in terms of impact on our society,* the largely unheralded day-to-day improvement research—the cumulative impact of dozens of minor innovations—constitute the real pay-out. For example, in the petroleum industry (*1*) technological progress over the 20-year period ending 1965 is truly impressive:

Well-drilling costs (constant dollars per linear foot)	59% reduction
Crude recovery (% of oil in reservoir)	48% increase
Tanker shipping costs (constant dollars)	55% decrease
Refinery productivity (per man hour)	300% increase

It is hard to point to specific radical breakthroughs in these areas. Yet what research or design engineer could make even the smallest cost reduction without his basic literature data tables, largely derived from the fundamental research of uncounted graduate students. Other studies of mission-oriented research (*2, 3*) also cite the important role of basic research in innovation.

Looking at primary (i.e., radical) innovation, inventions may be classified by the degree to which basic research was involved. Many important inventions did stem directly from fundamental studies—for example, Fleming's chance discovery of penicillin:

Invention	Field of study
Penicillin (Fleming)	Bacteriology; accidental discovery
LP polyethylene (Ziegler, students)	Organometallic-olefin reactions
Molecular sieves (Barrer, chiefly)	Crystalline zeolites
Nylon (Carothers, DuPont group)	Condensation polymerization
HP polyethylene (ICI group)	High pressure chemistry

Much more important and typical, however, are need-oriented inventions based largely on existing knowledge. In all cases, basic data were a necessary input. Often much of it stemmed from fundamental research done many years earlier, for example:

Invention	Information used
Freon	Tables of boiling points, periodic table
Terylene/dacron	Collected works of Carothers
Captan fungicide	Patent on related compound as fly spray
Kodachrome	Fischer-Siegrist patent, publication —1914
Light polarizer	Literature search on polarizing materials

In other examples the required knowledge was contemporary:

Invention	Knowledge required
Buna rubber	Principles of copolymerization
Silicones	Silicone monomer and polymer preparation
Synthetic diamond	High pressure-temperature techniques, equipment
Phillips, Indiana polyethylene	Catalyst research procedures

We also observe that many innovations had to wait for new techniques of measurement before they could be reduced to practice. Every time there is a basic advance in analysis, such as gas chromatography, neutron activation, or electron diffraction, a wave of socially useful innovation follows which is a direct result of this enhanced capacity to measure and interpret our physical world.

If the Merits of Basic Research Are So Obvious, Why Shouldn't Industry Pay for It?

In addition to case histories of basic research utilization, the nature of its application is important. One characteristic of the research process is a lengthy, often unpredictable, time span. This makes it difficult to calculate research incentives in a typical industrial case where there is only a narrow product line base to provide potential relevance for corporate research.

When innovations are finally made, the cause and effect relationships may be quite diffuse, even lost altogether. While most new knowledge is used (eventually), the manner of use often can not be foretold. Also the applications can be serendipitous, quite outside the original sponsor's field.

Only the largest multiproduct corporations can afford the luxury of truly basic research. The Government then is the logical sponsor of basic research, especially research offering the potential of multiple use. For example, the JANAF Tables of Thermodynamic Properties (U. S. Bureau of Standards) benefited the whole chemical and petroleum industry. Further, antitrust laws largely mitigate against industry "cooperatives" for fundamental studies.

Successful innovation is also expensive, the examples tabulated below typically costing the sponsor $10 to 60 million. But basic research *and* predevelopment studies combined usually (*4*) run only 5 to 10% of the total cost to commercialize. Hence it truly is seed money, a catalyst for invention.

Distribution of innovation costs

Research, advanced development, basic invention	5-10%
Engineering and product design	10-20%
Tooling, manufacturing engineering	40-60%
Plant start-up expenses	5-15%
Market development expenses	10-25%

Besides being relatively low in cost, basic research offers high leverage for long-range stimulation of the economy. The long-term effects of a healthy basic research posture include creation of new jobs, improved balance of payments, increased tax revenues, and an enhanced standard of living.

Edwin Mansfield presents this story in a somewhat different way (5), and his data are particularly interesting in showing the diffusion time for major innovations. Even today the time between basic research and sales dollars is many years—too long for most companies that have to manage their profit centers on a short term basis. Other countries have long recognized the legitimate role of Government in sponsoring fundamental research—Germany's Max Planck Institutes being a notable example. Perhaps

Examples of Successful Innovation

Invention	Length of R&D period*	Earlier related work
	Inventions commercialized in 0 to 5 yr.	
Ziegler polyethylene	4 yr. from invention	30 yr. on organometallics, Ziegler
Transistor	5 yr.	Considerable work at Bell Labs (1930's and World War II)
Freon	<2 yr. (inventions made in 3 days)	
Phillips polyethylene	~5 yr. from breakthrough	Probably at least 5 yr. on lube, fuel project before breakthrough
	Inventions commercialized in 6 to 9 yr.	
Butyl rubber	7 yr. from invention	5 yr. on cationic polymerization
Captan	7 yr.	
Synthetic diamond	6 yr.	Several years—GE, Harvard, etc.
Buna rubbers	8 to 9 yr.	
Molecular sieves	7 yr. at Linde	Barrer, >10 yr. before Linde
Neoprene	6 to 7 yr.	
Light polarizer	8 yr. (13 more to demise of auto polarizer)	
HP polyethylene	7.5 yr.	
Tetraethyl lead	7 yr.	
	Inventions requiring 10 or more years of R&D	
Terylene/dacron	13 to 15 yr.	
Delrin	10 yr.	
Kodachrome	11 yr.	Fischer, Siegrist, 10 yr. before Mannes & Godowsky began work
Nylon	11.5 yr.	
Orlon	9 yr. (to start-up of continuous filament plant, a failure); 11 yr. to staple yarn plant	
Penicillin	15 to 16 yr.	
Polyethylene, Indiana	~12 yr. from breakthrough	6 yr. before breakthrough
Silicones	~10 to 11 yr. (Corning) ~12 to 14 yr. (GE)	
Teflon	11 to 12 yr. (~5 yr. to semicommercial production)	

* From start of research project, unless otherwise stated.

these organizations have techniques of research justification that could be transferred to U.S. funding problems.

Some Examples of Basic Data Used by Chemical Engineers

Much new knowledge coming from university research (largely Government-funded) is absolutely indispensable to any practicing chemical engineer. Examples include:

- properties of multiphase systems
  e.g., catalysis, aerosols and particulates, lubrication, friction and wear
- multiphase flow
  e.g., new processes, reactor design, biomedical engineering, oil recovery
- thermodynamic properties
  e.g., cryogenic and superhot conditions, separation techniques
- electrochemical data
  e.g., basic corrosion information, novel batteries and fuel cells
- properties of composite materials
  e.g., new alloys, adhesion, dispersion

We could probably develop specific examples of utility, but it is much like asking how one is benefiting from his undergraduate liberal arts education.

Strategies for Congressional Hearings on Research Funding

In addition to speaking to the questions you posed, it seemed appropriate to cite our strong concern over the need to educate Congress and the public at large on the workings of the nation's R&D enterprise. We have been talking too long among ourselves, so that it is hardly surprising that our motives are questioned and our results suspect.

We have perhaps been too bent on seeking case histories of spectacular and highly visible fallout from basic studies, when the real payout comes from the pervasive, though hard to trace, influence of fundamental research on *all* invention and innovation.

To this end, officers of professional societies could testify on the role of research in their fields, members could be solicited to make their views known to their Congressional representatives, and questionnaires could be developed to obtain specific examples of how professional society members use basic data in their everyday work. Other ideas could be developed, but the point here is new faces before Congress, faces that would speak up for the technical constituency and play up the beneficial role of technology serving man's needs.

A real effort must also be made to reach the nation's scientific and technical press. Leaders, such as Walter Sullivan of *The New York Times,* have pointed out that these important molders of public opinion are bombarded with technical material from special interest groups. What are they to believe about nuclear power plant safety, for instance, or the effect of the SST on the upper atmosphere. Here is another problem area where the professional societies might be able to help.

Technology Must Be Sold before Basic Research Can Be Justified

We also wonder whether the Congress is sold on the net benefits of technology at large. While there is rightful concern over environmental impairment due to such achievements as pesticides, internal combustion engines, and atomic energy, would any reasoning person trade our world for the hours of work, the standard of living, and the life span of 1900 or 1850? What population could we support as an agrarian nation?

Many studies have cited the connection between R&D investment and growth. (*4*) Just three technology-intensive industries—television, jet travel, and computers —went from nothing in 1945 to contributing 900,000 new jobs and $13 billion to our GNP just 20 years later. They also affected the quality of our life in a real and largely beneficial way. Growth rates of research-intensive companies like 3M, Polaroid, and Xerox run five to eight times the GNP growth rate.

Net royalty payments to the U. S.—a measure of our international technological stature—have contributed handsomely to our balance of payments. The effect of R&D on trade balances is also striking. In the decade ending 1965 exports of (low technology) cotton and wool fell from $187 to 125 million, while those of high technology synthetics rose from $158 to 241 million.

It seems clear that such major social problem areas as environmental pollution, urban redevelopment, highway safety, and government effectiveness must look to technology for adequate solutions. Yet has this story been conveyed to the public? We can hardly expect support for basic research if the overall role of technology in our lives is unappreciated or misunderstood.

In Summary

We are sure you appreciate the relatively inexpensive nature of basic research and the difficulty of shutting it off and turning it on due to the vagaries of Government financing. Many excellent studies (*6*) on invention are available and perhaps some of these could be redone in lay language to illustrate the pervasive role of basic research. Our point again is that the Congress does not seem to appreciate either the salient features of fundamental research or its role in the invention/innovation process. A broad program of public education seems justified to get things back in their proper perspective. We must tie our story to such concerns as new jobs, improved balance of payments, and enhanced quality of life, and not merely cite "fallout," "spin-offs," and other serendipitous happenings that only reinforce popular impressions that research is a very expensive game of chance played with tax dollars.

We have covered considerable ground here and hope some of our comments and concerns are useful. We would be pleased to elaborate on those that are particularly suited to your purpose.

Sincerely yours,

J. J. MARTIN
PRESIDENT, AIChE

References Cited

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2. National Academy of Sciences, "Applied Science and Technological Progress" (1967).
3. National Research Council (Materials Advisory Board), "Report of the Ad Hoc Committee on Principles of Research-Engineering Interaction" (1966).
4. For example, the U. S. Dept. of Commerce Study: "Technical Innovation; Its Environment and Management" (1966).
5. Presidential Commission on "Technology, Automation and the Economy," Appendix VI (1965).
6. Particularly Jewkes et al., "The Sources of Invention (1959); Killeffer, "The Gains of Industrial Research" (1948); Garrett, "The Flash of Genius" (1963); Mueller, "The Rate and Direction of Inventive Activity" (1962); Clements, "Modern Chemical Discoveries" (1963); and various articles in *Fortune* magazine.