AC 2007-285: ENABLING A STRONG U.S. ENGINEERING WORKFORCE FOR TECHNOLOGICAL INNOVATION: A NATIONAL PARTNERSHIP IN GRADUATE PROFESSIONAL EDUCATION WITH INDUSTRY TO ENHANCE U.S. COMPETITIVENESS AND ECONOMIC DEVELOPMENT

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Enabling a Strong U.S. Engineering Workforce for Technological Innovation: A National Partnership in Graduate Professional Education with Industry To Enhance U.S. Competitiveness and Economic Development

I. Introduction — Investing in America’s Future through Engineering

This is the first of four invited papers prepared for a special panel session of the National Collaborative Task Force on Engineering Graduate Education Reform that is focusing its efforts on the deliberate advancement of professional engineering graduate education to enable a strong U.S. engineering workforce for competitiveness and national security purposes.

Initiated in 2000 by the ASEE-Graduate Studies Division, College Industry Partnership Division, and Corporate Members Council, the National Collaborative Task Force is a coalition of key leaders from innovative universities and industry who are working in a unique collaboration to respond to the urgency for reshaping the U.S. system of engineering graduate education to better serve the needs of modern engineering practice to strengthen the nation’s capability for technology development and innovation.

The National Collaborative is focusing on two primary questions:

- First, can an effective system of professional engineering graduate education be created in the United States for developing our engineering talent in industry so that the continuing future of engineering practice for creative technology development & innovation in this country may be assured for economic competitiveness and national security purposes?

- Second, how can this system of professional engineering graduate education be implemented across the United States using the combined resources of universities and industry to ensure world-class engineering leadership for innovation so that each state and region can prosper over the long-term?

II. National Imperative for Technology Innovation

During the last five years of its investigation phase, the National Collaborative Task Force has examined the U.S. system of engineering graduate education and the need for universities, government, and industry to strengthen the development of the U.S. Engineering Workforce for competitiveness and national security purposes. The findings of the National Collaborative include the following:

- **Finding # 1: As the Council on Competitiveness points out — “Innovation will be the single most important factor in determining America’s success through the 21st century” … “For developed nations, no longer able to compete on cost, the capacity to innovate is the most critical element in sustaining competitiveness”… However … “The United States could lose its preeminence in technology unless a new national innovation agenda is developed.”**

- **Finding # 2: U.S. engineering progress is essential to U.S. economic competitiveness and national security.** Whereas the U.S. Scientific Workforce and the U.S. Engineering Workforce are both vital national resources for the nation’s S&T progress, they serve two distinct purposes. Continuous advancements in basic research [performed primarily at the nation’s research universities] are essential in sustaining U.S. preeminence for the nation’s scientific progress, and continuous advancements in engineering [performed primarily in the nation’s industry] are critically essential in
sustaining preeminence for U.S. engineering progress for world-class technology development & innovation for competitiveness and national security purposes.

- **Finding # 3:** The creative wellspring and backbone of America’s engineering capacity for new, improved, and breakthrough technology depends upon the development of a professionally educated and highly skilled U.S. Engineering Workforce in industry. The effective development of new, improved, and breakthrough technology depends upon a continuous flow of new “ideas and concepts” that bring forth effective engineering solutions to real-world needs — which in turn depends upon the continuous professional development of the nation’s creative talent in engineering who create these new “ideas and concepts” for new and improved technology. As the Council on Competitiveness points out: “The company’s most important assets are the people who walk in its doors every morning … talented people creating new ideas and innovative technologies keep the economy strong, and growing stronger.”

- **Finding # 4:** Educating engineers as innovators, champions, and leaders for technology innovation is a process of lifelong learning and professional development. U.S. innovative capacity over the long-term depends upon attracting America’s creative talent into the engineering profession and the further professional development of this talent throughout their productive engineering careers in industry. As reflected by the National Society of Professional Engineers (NSPE), there are “nine levels” of progressive professional responsibility and leadership abilities required in creative engineering practice. Undergraduate engineering education prepares the engineer for entry into the profession at Level I Engineer. But, it does not prepare the engineer for creative practice at all levels of engineering. Further professional studies, experience, and actual creative performance are required beyond entry-level for further professional development in engineering.

- **Finding # 5:** Revitalizing the U.S. Engineering Workforce for leadership of technological development & innovation in industry is one of the nation’s primary engines for growing our economy and sustaining our national security. Accelerating U.S. engineering progress for enhanced competitiveness is directly linked to creating a first rate system of U.S. professional engineering education that fosters the further professional development of the U.S. Engineering Workforce beyond entry-level abilities for innovation and leadership in industry — where the lion’s share of advanced engineering practice for technology development & innovation for competitiveness and national security purposes primarily occurs.

- **Finding # 6:** America is facing fierce competition as other nations are investing heavily in the further post-graduate development of their engineers for innovation — But America has not kept pace with this investment. While the United States has invested in and continues to sustain world-class preeminence in basic research for U.S. scientific progress, the nation has not invested equally in the further professional engineering graduate education of the U.S. engineering workforce in industry which is the nation’s primary creative resource for technology development & innovation. As a long-term consequence, the United States has sustained a long-term decline in its engineering capacity for technology development & innovation in too many industries across the country — which has resulted in a long-term decline of U.S. technological competitiveness.

- **Finding # 7:** The U.S. system of engineering graduate education is undergoing considerable stress with conflicting pressures. While graduate education of the nation’s future scientists and funding for basic research is vitally important in sustaining U.S. preeminence for scientific progress, the United States does not have a coherent policy of professional graduate education that fosters opportunity for the vast majority of the U.S. engineering workforce to grow beyond undergraduate entry-level engineering education for creative engineering practice in industry.
As the Committee on Science, Engineering, and Public Policy (COSEPUP) has pointed out, graduate education in engineering has evolved primarily in the United States as a byproduct of a national science policy for basic scientific research arising as a result of the 1945 report *Science: The Endless Frontier*.\(^3\,^4\) But, as the National Society of Professional Engineers (NSPE) points out, there are “nine levels” of progressive professional leadership responsibilities that extend beyond entry-level in the engineering profession — wherein undergraduate engineering education serves as the basic preparation for entry into practice at the first entry-level.\(^5\)

**Finding # 8:** U.S. engineering graduate education which serves as the primary infrastructure for the post-graduate development of the U.S. engineering workforce in industry has undergone a serious ‘*disconnect*’ with creative engineering practice. With notable exceptions, the creative engineering method that should be the hallmark of engineering practice has increasingly been abandoned in U.S. engineering graduate education. The ‘*disconnect*’ has been widening, and worsening, over a period of several years causing a “gap” in professional education for the U.S. engineering workforce in industry — contributing to a long-term decline of U.S. innovative capacity.

To further exasperate the problem, the generation of experienced engineers who have led much of the creation, development, and innovation of U.S. technology since Sputnik is now retiring. By the year 2010, estimates indicate that over 30% of America’s experienced, domestic engineering leadership base for technology innovation will have retired, causing a “*brain drain*” and a further loss in U.S. innovative capacity in engineering.

Because of long-term neglect in provision of U.S. professional engineering graduate education for creative engineering practice, the vast majority of America’s engineers are not being further educated professionally beyond entry-level undergraduate education to assume these engineering leadership positions for technology development & innovation in industry. As a consequence, the nation is now paying the price of long-term neglect in the further professional graduate education of the U.S. engineering workforce in industry, which has been a contributing factor to the long-term decline of our nation’s innovative engineering capacity in industry and to subsequent decline in U.S. technological competitiveness.

**Finding # 9:** Policy blind spot exists in U.S. Science & Technology Policy and in U.S. professional engineering education. The disconnect between U.S. engineering graduate education and creative engineering practice has neither occurred overnight nor by happenstance. It has occurred over the last four decades. While the nation has placed a deserved, increased federally funded emphasis on basic academic research and on the graduate education of the nation’s future researchers during the 1960’s, 70’s, 80’s, and 90’s [and must continue to do so], it *has not* placed a parallel and equal emphasis on advanced professional graduate education for the U.S. engineering workforce in industry during this same time period which is the nation’s primary resource for U.S. technology development & innovation for competitiveness and national security purposes.

Largely because of the pervasiveness of the belief system of 1945 Science Policy, which promoted the paradigm that basic academic research is the primary ‘*capital and forerunner*’ of the practice of engineering in industry for the development of technology, the disconnect continues to exist between the U.S. system of engineering graduate education and the professional career-paths of the U.S. engineering workforce in industry. While the linear, research-driven paradigm of 1945 science policy essentially portrayed that every new major military weapons system or civilian product must begin with basic research [performed at the universities], then followed sequentially by engineering in industry for transfer of the ‘*discoveries*’ of science into useful technology for military application or commercialization, it is now recognized in the 21st century that the [1945] basic research-driven paradigm of the practice of engineering for technology development & innovation is in error.
### Finding # 10: Paradigm shift has occurred in the practice of engineering for systematic technology development & innovation.

In the 21st century, the modern practice of engineering for leadership of technology development & innovation is substantially different than that reflected by the linear, research-driven paradigm of engineering practice for technology development portrayed by 1945 science policy (See Appendix A). For-the-most part, however, U.S. engineering graduate education has not reflected this paradigm shift.

Although 1945 science policy rightfully created a worthy covenant between federal government and the nation’s research universities to fund basic scientific research and to educate future researchers for academic positions at the universities [and must continue to do so], the major premise emphasizing that basic research should be funded because the nation’s primary ‘intellectual capital’ for new technology were the nation’s research scientists who performed this basic research at the universities was basically flawed. But the linear research-driven myth of ‘how technology is created and is developed’ has a background and has lingered for a long time.

As Ferguson points out: “From Bacon’s time to the present — more than 350 years — promoters of the mathematical sciences have convinced their patrons that science is the way to truth and that it is also the chief source of the progressive inventions that have changed the material world. The myth that the knowledge incorporated in any invention must originate in science is now accepted in Western culture as an article of faith, and the science policies of nations rest on that faith.”

As Ferguson notes: The myth was restated as a major premise of the 1945 report *Science: The Endless Frontier*. But, as Project Hindsight [U.S. Department of Defense] and other reports indicate, the basic research-driven paradigm of the practice of engineering for technology development & innovation is in error. As Martino, formerly of the Air Force Office of Scientific Research, noted — the linear basic research-driven paradigm of how technology is primarily created is erroneous because scientific research and engineering development serve two very different functions with different methods, which are not linear, sequential processes as the 1945 paradigm portrayed.

### III. Paradigm Shift — Modern Practice of Engineering for Continuous and Systematic Technology Development & Innovation

During the last half of the last century, one of the most notable achievements in the U.S. engineering was that of developing the practice of engineering itself as a very, systematic and purposeful practice to deliberately create (invent / design), develop, and innovate new / improved / breakthrough technology to meet the hopes, wants, and needs of society … for the advancement and betterment of human welfare (See Appendix B).

#### A) Practice of Engineering for the 21st Century

Contrary to 1945 science policy, the modern practice of engineering for needs-driven, systematic technology development & innovation and the practice of science for basic research are two very different types of pursuits that are not linear, sequential processes. Today, engineering is a purposive, needs-driven, and systematic practice for the deliberate creation (invention / design), development, and innovation of new, improved, and breakthrough technology to meet the hopes, wants, and needs of society … for the advancement and betterment of human welfare (See Appendix B).

As Sanders and Brown pointed out in 1966:

“The great discovery of our age is that technological innovation need not be haphazard. Industry and government have developed a new concept of planned an systematized innovation, founded on vastly expanded scientific and engineering efforts. These institutions are now making regular provision for
the occurrence of new and unpredictable developments. In fact, “the discovery [development] of systematized innovation may turn out to be a qualitative change in the economy — one having the same importance for future growth as the development of the concept of capital investment itself had during the past two centuries.”

B) Profound Implications of the Paradigm Shift in Engineering for Enhancement of U.S. Competitiveness and the Professional Education of the Nation’s Engineers

The National Collaborative concludes that the recognition of ‘how modern technology is purposefully created and developed’ as a systematic practice of engineering has profound implications:

- First, in reshaping U.S. Technology Policy for enhanced U.S. competitiveness and national security purposes
- Second, in engaging the correct model of engineering innovation for the creation, development, and innovation of new / improved / breakthrough technology for the nation to regain its competitive edge
- Third, in strengthening the innovative capacity of the U.S. practice of engineering in industry as a core competence for meaningful creative engineering works and purposeful technological innovation
- Fourth, in defining a coherent educational strategy for advancing the professional development of the U.S. engineering workforce in industry
- Fifth, in reshaping U.S. professionally-oriented engineering graduate education to unlock the creative, innovative, and leadership potential of the U.S. engineering workforce in industry for enhanced U.S. competitiveness and national security purposes

C) The Key Idea is that …

Engineering is a Creative Profession that Satisfies Real Human Needs

Thus, in order to advance professional engineering education more reflective of creative practice, the National Collaborative believes that there must be a shared definition of what engineers are suppose to do and an understanding of what the practice of engineering is.

The Task Force believes that what Teare noted years ago about holds true today: “The primary task of engineering is creative problem-solving.” 11 The key idea is that the practice of engineering is a very creative professional pursuit with a mission, purpose, a professional method (systematic engineering method), and an ethical value system for the continuous creation, development, and innovation of new / improved / breakthrough technology to responsibly meet the hopes, wants, and needs of people for advancement of the quality of life for human betterment. And as Rogers, noted about the nature of engineering thought, “No other one thing ties the engineering profession more closely together than this way of thinking.” 12

The Task Force notes, whereas scientific research is frequently needed in complex systems engineering development projects to gain a better understanding of phenomena, arising or anticipated in the course of technology development, it is not the primary driving force for the creative profession and the practice of engineering … And as a consequence, the nation must engage the appropriate model of purposeful engineering innovation for the creation, development, and innovation of new technology if it is to regain its competitive edge. Toward this aim, the National Collaborative Task Force is defining the practice of engineering in its broadest sense as a very creative profession — from entry-level project engineering responsibilities through the highest engineering leadership levels of technical program making, and technology policy making for meaningful creative engineering works.
D) Importance of Building Engineers as Leaders and ‘Champions’ at Every Level of Engineering Responsibility in America’s Industry for Effective Technology Innovation

Whereas Project Hindsight [Department of Defense], National Academy of Engineering studies, and other reports have shown that effective solution of real-world needs is the primary driving force of systematic engineering innovation — the needs won’t solve themselves.\(^{13, 14, 15, 16, 17}\)

As Kingston noted: successful innovation is a question of **leadership** — namely the importance of the ‘champion’ … without which effective solutions are not met.\(^{18}\) Thus, U.S. engineering progress depends upon the creative, innovative, and leadership capacity of the nation’s engineering talent in industry who create the new ‘ideas, concepts, and innovative technologies’ by applying their professional expertise, experience, engineering abilities for creative problem-solving, and responsible engineering leadership for innovation throughout their creative productive careers in professional engineering practice in industry.

As the U.S. industry competes in the 21\(^{st}\) century, the National Collaborative Task Force believes that U.S. engineering progress can be dramatically accelerated:

(a) By developing the U.S. engineering workforce beyond entry-level competencies in a manner that fosters progressive professional growth for innovation while fully-employed in industry

(b) By fostering educational cultures for innovation in U.S. industry and universities across the nation that develop engineers as ‘champions, innovators, and leaders’ at every level of responsibility

(c) By developing industry’s use of the systems engineering method as a core competence for the purposeful creation, development, and innovation of new technology for competitive advantage

E) “Thinking Out of the Box”

As Fred Gary, former corporate vice president of General Electric Company, pointed out years ago, the career pattern of the majority of the U.S. engineering workforce is not centered on scientific research, important in its own right, but rather is centered on the creative practice of engineering for the deliberate creation, development and innovation of new, improved, and breakthrough technology of new products, processes, systems, and operations for economic competitiveness and national security purposes.\(^{19}\)

As the nation competes in the innovation-driven economy, the National Collaborative believes that a deliberate advancement of professional engineering graduate education which purposefully develops the U.S. engineering workforce for the creative practice of innovation and its leadership; and focuses on the subsequent use of the systematic engineering method for the deliberate creation, development, and innovation of needs-driven technology and other creative engineering works, for effective socio / techno / economic change, is vitally important to the nation’s future economic prosperity and national security.

Because the practice of engineering and the practice of science are not identical [See Appendix B], the National Collaborative Task Force concludes that one size or type of graduate education doesn’t fit all — thus requiring two very different types of graduate education designed specifically to meet the different missions, purposes, and intents of each pursuit which necessitates major reform in engineering graduate education for professional practice. But the change that is required to yield a balanced emphasis in engineering graduate education, for both research and creative engineering practice, has been slow in fruition — and the ‘disconnect’ in U.S. engineering graduate education continues to exist at too many universities across the nation causing a long-term ‘gap’ in the further professional education of the nation’s engineers beyond entry-level in industry. As a result of this educational neglect, the U.S. engineering workforce in industry has become America’s most underdeveloped and underused national resource for technological innovation [See Appendix — F].
F) Correcting Some Popular Misconceptions —
For Deliberate and Purposeful Advancement in Engineering Education

Closure of the existing “gap” through deliberate advancement of professional engineering graduate education for innovative engineering practice in industry is vitally important in sustaining U.S. engineering preeminence for U.S. technological progress for competitiveness and for national security purposes — both for the nation’s near-term and long-term competitive advantage in the global arena.

One of the recurring problems that has consistently faced the National Collaborative Task Force in its efforts to implement effective educational reform is that of determining the root cause(s) of the existing ‘disconnect’ and of uncovering several popular misconceptions arising largely as a result of the linear research-driven paradigm of engineering practice [now seen to be in error but still very much alive] portraying basic research as the primary forerunner of creative engineering practice for technology development & innovation in industry / government service.

Many of these popular misconceptions have been influenced by existing university tenure and promotion policies that focus largely on the teaching and reward criteria for research-oriented faculty whose career paths are not centered on the creative practice of engineering for technology development & innovation and the teaching thereof, but rather are centered largely on the practice of scientific research and the quest for federal support of research which is meaningful in its own right. However, the National Collaborative believes that it is timely to clarify some of these existing misconceptions between Science & Engineering (S&E) in order to make the needed advancement in engineering education for the practicing profession a reality [See Appendix G: Glossary of Terms].

IV. A Bold Initiative —
Revitalizing the U.S. Engineering Workforce for Innovation in Industry

Maintaining U.S. engineering preeminence for world-class technology development and innovation in America’s industry is critical to U.S. economic competitiveness and national security. But the United States is in danger of losing its engineering leadership as other nations are investing in their workforce.

To meet this need, in the national interest, the National Collaborative is committed to the purposeful advancement of professional engineering education to better enable the U.S. engineering workforce in industry to attain the objectives of creative professional practice in order to enhance U.S. technological competitiveness for the nation’s economic growth and national security.

A) Professional Education for Engineers —
The New Challenge in Accelerating U.S. Innovative Capacity for Competitiveness

The National Collaborative Task Force has studied the nation’s goals for technology development, the educational needs of the U.S. engineering workforce in our nation’s industry who will make this progress possible, and the formidable potential of U.S. engineering innovation that can be stimulated across the nation through deliberate reform of professional engineering graduate education in revitalizing the U.S. engineering workforce for competitiveness and national security purposes.

As the U.S. competes in the 21st century, our competitive advantage, as a nation, will depend heavily upon advancing the innovative capacity of the U.S. engineering workforce in industry on a continuous basis. But broad sweeping changes are required in the U.S. system of engineering graduate education to evolve a more relevant innovation-based, professionally oriented graduate education, as a complement to traditional research-based graduate education, that better supports the needs of the U.S. engineering workforce to create, develop, and innovate new, improved, and breakthrough technology.
The National Collaborative is guiding a major national initiative that links advanced professional engineering graduate education for the nation’s engineers with technological innovation in industry — thereby providing U.S. technology-based industry the opportunity to further develop its creative engineering workforce and new innovative technology simultaneously for world-class competitive advantage. Subsequently, if we as a nation are to sustain U.S. engineering preeminence for global economic competitiveness and national security purposes, then:

- The United States must actively engage the correct paradigm of creative engineering practice for the systematic development and continuous innovation of new, improved, and breakthrough technology
- Industry must foster an organizational culture for innovation
- U.S. engineering graduate education must reflect the modern profession of engineering for innovation and adjust accordingly if we are to educate our U.S. engineers as world-class innovators, ‘champions’, and responsible leaders of technology for meaningful purposes

B) Setting a New Direction in Professional Engineering Education — World Model for Lifelong Learning and Professional Development in Engineering

The National Collaborative proposes to implement this reform by establishing new, innovative graduate centers across the nation for the purposeful advancement of creative engineering practice and leadership of technology development and innovation in industry. In order to accomplish these goals, the National Collaborative Task Force strongly believes that U.S. engineering education should no longer be construed or constrained as a four year process; but that the education of the engineer is a lifelong learning and professional developmental process of growth not only to include the learning of knowledge but to include more importantly at the graduate levels the development of intrinsic creative potential of the engineer for leadership and innovation of meaningful, creative engineering works.

The National Collaborative is guiding the deliberate creation, development, and implementation of a new world-model for professionally-oriented graduate education that better supports the lifelong learning and professional development needs of the graduate engineering workforce in U.S. industry. The new approach that is required must be directly relevant to the creative practice of engineering and leadership of technology development to serve the needs of engineers as emerging technological leaders throughout their professional growth process. The National Collaborative Task Force believes that there are three very important stages in the life-long education and growth of the engineer. These stages include:

1. **Early Beginnings (K-12)** —
   Awareness of engineering and preparation for admission to university engineering education

2. **Undergraduate Engineering Education** —
   Preparation for entry into engineering practice

3. **Professional Engineering Education Beyond Entry-Level** —
   Professional Engineering Graduate Education Extending from Level I – IX Engineer
   - **Early career-development** — From Level I to Level IV Engineer  
     (professional Master of Engineering M.Eng.) — Project Engineering  
     [12%]
   - **Middle career-development** — From Level IV to Level VI Engineer  
     (professional Doctor of Engineering D.Eng.) — Technical Program Making  
     [59%]
   - **Senior career-development** — From Level VI to Level IX Engineer  
     (professional Engineering Fellow F.Eng.) — Technology Policy Making  
     [29%]
V. National Impact: Investing in the U.S. Engineering Workforce —
The Driving Force for U.S. Technology Development & Innovation for Competitiveness

This unique advancement in U.S. professional engineering graduate education has profound implications in strengthening the innovative capacity of the U.S. engineering workforce for technology development in industry, retaining U.S. engineering preeminence in technology innovation for economic competitiveness and national security purposes, and for creating and retaining jobs in America’s industry.

A) So Much at Stake —
Advancing Professional Engineering Education in the National Interest

As in any major effort that is worth doing, there are many obstacles and resistances to be overcome. And this major initiative for educational innovation is no exception. It is fair to say that this initiative may not succeed if a critical mass of innovative universities and industries do not truly collaborate together for common cause in the national interest beyond their own self-vested ambitions. Without a shared vision and a systems approach to guide this major educational transformation for the profession, the project would soon deteriorate into ‘a many-headed, self-serving organism, and heterogeneous mass, that never will or can steer to the same point [G. Washington].’

B) The Creative Pipeline and Primary Driver for U.S. Engineering Innovation

The time for just talking and writing papers about systemic reform of engineering graduate education for working professionals in industry has already passed. We must take action now to stay the plan for strategic change because so much is at stake in revitalizing the nation’s innovative capacity in engineering for creative technology development & innovation in each state and region of the country to continuously enhance U.S. economic competitiveness and national security.

As America competes in the 21st century, it is clear that the innovative strength of our nation will always be dependent on a highly competent, dedicated, and imaginative U.S. engineering workforce in industry who can bring about new innovative technology for the common good. It should also be clear that we can enhance our future economic strength, as a nation, by nurturing the further professional growth of this creative talent in the nation’s engineering workforce. But the facts are clear — thousands of graduate engineers are currently employed in regional industry in each state across the nation — but they are ‘not’ being fully developed as the nation’s primary resource for U.S. technological innovation.

C) Profound Impact: Leveraging Professional Engineering Education for the U.S. Engineering Workforce to support Simultaneous Development of New Technology in Industry

To correct this deficiency, the National Collaborative is committed in serving its role as a model for ‘best practice’ and as a catalyst for action at the national level to bring about needed change in professional engineering education in the national interest. As Porter points out, one of the best ways in improving national innovation is through the advancement of regional innovation in all states across the nation. Subsequently, the Task Force believes that the advancement of U.S. professional engineering graduate education — that is specifically designed to unlock the creative, innovative, and leadership potential of our U.S. engineers and to develop new innovative technologies within each state across the nation — ‘can’ have profound impact on yielding new / improved / breakthrough technologies with dramatic outcomes in enhancing U.S. economic competitiveness and national security. As such, it’s time to unleash America’s engineering ingenuity through the formidable strengths of America’s universities and industry, working together in common cause, to make this happen. The returns from new innovative technologies that result from increased engineering creativity produced by this investment far exceed the cost.
VI. Translating the Plan into Action

The National Collaborative is implementing the reform as a major national initiative using a systems approach and a very workable plan for the deliberate advancement of professional engineering education that will serve as national demonstration project that will begin with a critical mass of 5 — 10 innovative universities across the county working in collaborative participation with the practicing profession, industry, and government.

A) Rationale —
Investing in U.S. Engineering Workforce Development for Innovation

The rationale for the national initiative builds on the following:

- We must revitalize the U.S. engineering workforce in industry for preeminence in the practice of engineering for world-class advancement of technology development & innovation to ensure our country’s future economic prosperity and national security
- There are nine progressive levels of responsibility in engineering practice beyond entry-level [National Society of Professional Engineers]
- Undergraduate education prepares the student for entry into engineering practice at Level I Engineer … Undergraduate education does not prepare the engineer for all nine levels of engineering practice
- Further professional graduate education combined with experience and engineering practice is yet to come beyond entry-level that enable engineers to reach their fullest creative, innovative, and leadership potential for technology development & innovation in industry

B) Setting a New Vision —
Professional Education that Enables Growth of U.S. Engineers for Innovation in Industry

The vision for the initiative is:

- To focus on engineering leadership for innovation
- To strengthen the innovative capacity of the U.S. Engineering Workforce for global leadership in technology development & innovation, second to none
- To create innovative Graduate Centers that will be “statewide clusters” for advanced professional education for engineering innovation and leadership in all 50 states across the nation
- To use the combined formidable teaching and human resource strengths of regional universities and industry in this process
- To create a unique working collaboration between universities and industry across the nation in developing the creative and innovative capacity of the U.S. Engineering Workforce in industry for world-preeminence in technology development & innovation
- To provide advanced professional education that enables growth of engineers beyond entry-level for responsible leadership of technology innovation in industry
- To integrate advanced studies with experience and the practice of engineering for on-going technology development in industry
- To foster lifelong learning that enables growth of the nation’s engineers throughout their careers from Entry-Level → Chief Engineer Level of responsibility for technology innovation in industry
C) Plan of Action —
National Demonstration Project

The Goals of the national initiative are:

GOAL 1: To create an innovative model for advanced professional education that is integrative with the practice of engineering, fosters lifelong learning, and enables growth of engineers beyond entry level in industry for increasing leadership responsibility of technology development & innovation to ensure U.S. technological leadership for competitiveness and national security purposes

(1) Define the nine levels of progressive growth in engineering beyond entry [NSPE / ASCE]

(2) Identify progressive innovation abilities and qualifications required of engineers for responsible leadership of technology development & innovation and creative engineering works for all levels of Engineering I - IX
   - Early career-development — From Level I to Level IV Engineer (professional Master of Engineering M.Eng. at Engineer Level IV) [12%]
   - Middle career-development — From Level IV to Level VI Engineer (professional Doctor of Engineering D.Eng. at Engineer Level VI) [59%]
   - Senior career-development — From Level VI to Level IX Engineer (professional Engineering Fellow F.Eng. at Engineer Level VII-IX) [29%]

(3) Define framework of integrative professional graduate education combined with engineering practice for all levels of engineering:
   - Leading to the professional Master of Engineering (M.Eng.) at Level IV
   - Leading to the professional Doctor of Engineering (D.Eng.) at Level VI
   - Leading to the professional Fellow of Engineering (F.Eng.) Level VII – IX

(4) Define and align a coherent program of professional curricula that is integrative with engineering practice and that matches and supports the progressive qualifications and innovative / leadership abilities required of engineers at every level of engineering responsibility in industry
   - Early career-development — From Level I to Level IV Engineer (professional Master of Engineering M.Eng. at Engineer Level IV) [12%]
   - Middle career-development — From Level IV to Level VI Engineer (professional Doctor of Engineering D.Eng. at Engineer Level VI) [59%]
   - Senior career-development — From Level VI to Level IX Engineer (professional Engineering Fellow F.Eng. at Engineer Level VII-IX) [29%]

(5) Align program direction that is integrative with practice, enables practitioner growth, and supports the progressive abilities required at every level of engineering responsibility for innovation
   - Relevant professional curricula integrative with engineering practice
   - Learner-centered approach
   - Experiential and self-directed learning
   - Innovation-based, project-centered learning
   - Creative technology development project relevant to industry’s needs
GOAL 2: To establish Graduate Centers for Advanced Studies in Engineering Leadership, Technology Innovation, and Policy as a National Demonstration Project for pilot implementation across the country

(1) Implement a National Demonstration Project beginning with a critical mass of 5 – 10 innovative universities in different states working in collaborative participation with the practicing profession in industry

(2) Use a systems approach under the guidance of a National Project office to grow all innovative Graduate Centers using a collaborative plan for implementation, continuous improvement and shared best practice

(3) Build on the formidable strengths of a combined teaching faculty from regional universities and from experts in regional industry across the nation

(4) Build on the silent successes / attributes of high-quality programs for working professionals which have been already proven across the United States (Council of Graduate Schools)

(5) Build on the strengths of an experienced student body of practitioners who are growing as innovators and engineering leaders at the cutting edge of technology development to sustain U.S. preeminence

(6) Build the Graduate Centers in partnership with regional industry and the practicing profession in engineering for success and continuous improvement

GOAL 3: To replicate the Graduate Centers in all 50 states across the country to accelerate U.S. engineering workforce development for U.S. preeminence in technological innovation to enhance competitiveness using the combined strengths of industry and regional universities that will be second to none

(1) Grow 5 Graduate Centers per year over 10 years across the United States

(2) Until all 50 states have capability of high-quality advanced professional engineering education for technology innovation and leadership for the practicing profession in their regional industry

(3) And regional industry has an increased core competence and culture for continuous technology development & innovation for global competitiveness and national security purposes

VII. Conclusions — Investing in America’s Competitiveness through Engineering

If the nation’s universities, industry, and government are to play a more decisive role in revitalizing a strong U.S. engineering workforce for world-class leadership of technological development & innovation for competitiveness and national security purposes, then the time for appropriate action to advance world-class professional engineering education for the nation’s creative engineering talent in industry is now.

What Vannevar Bush did over a half century ago to ensure U.S. preeminence in scientific research through the purposeful advancement of research-oriented graduate education and the long-term development of the nation’s scientific talent for basic research, we can do in a likewise fashion in the 21st century to ensure U.S. preeminence in engineering for technology innovation through the purposeful advancement of professional-oriented engineering education and the long-term development of the nation’s creative engineering talent who are responsible for the nation’s continued technological thrust for competitiveness and national security purposes.
Toward these objectives, the National Collaborative has initiated a bold plan of action for deliberate reform to be implemented nationally as a pilot demonstration project between coalition universities and regional industry across the country. The project is educationally sound, economically feasible, can be replicated across all regions of the nation, and has the potential to yield profound positive impact in advancing the innovative strength of the U.S. engineering workforce in industry in order to accelerate U.S. competitiveness, stimulate economic development, and to help sustain national security through innovation on a continuous basis.

Bibliography

13. Ibid.
Appendix A

Systematic Engineering Method & Practice for Deliberate Needs-Driven Technology Development & Innovation

Needs ⇒ Engineering ⇒ Technology

Directed Scientific Research to gain a better understanding of phenomena when needed or anticipated during the technology development project.
Appendix B

Functions of Creative Engineering Practice and Scientific Research

Practice of Engineering
‘Creative Technology Development’

… The role of needs-driven systematic technological development in industry and government is the purposeful invention [design] and innovation of new or improved concepts, techniques, materials, devices, products, or systems and manufacturing processes. Its aim is to meet the hopes, wants, and needs of society, through change towards its general betterment, brought about by engineering development. It is creative and non-repetitive work and ranges from exploratory development, with concept and invention, through the experimental phases of feasibility to the advanced development and design of production prototypes and introduction into manufacture or operations. The primary base of needs-driven technological development is the conceptual ideas of men and women to bring about needed change for the benefit of mankind.

“Technology does not exist to serve itself. It is there to work for people – to improve the way they live, to safeguard their health, to preserve their environment (GE)” By technology, we refer to any “systematic, organized body of applicable interrelated concepts and ideas that is rational and valid enough to stand up under the test of experimental demonstration and experimental validation, and represents a common experience regardless of the society or nation in which it is observed (Alstadt).”

Practice of Scientific Research
‘Basic’ and ‘Applied Research’

… The role of basic (fundamental) research in industry and government is the pursuit of new knowledge within specific fields of interest, which could be of potential use to the future business of the organization. Its aim is to discover and to gain a better understanding of phenomena through creative in-depth investigation at the frontiers of a scientific discipline. The results will extend the existing body of scientific knowledge useful to the organization in the future.

… The role of applied (directed-strategic) research in industry and government is the strategic pursuit of new knowledge in specific areas in direct support of development projects within the organization. Its primary aim is to discover, understand, and describe new physical phenomena useful to the understanding of specific phenomena anticipated or uncovered during the course of a technology development project. The results of this in-depth investigation and analysis will extend the existing body of scientific knowledge with committed use for the organization.

A secondary purpose is to provide technical consultation to other divisions of the organization whenever the existing body of specialized knowledge within the research group is needed for immediate problems.
Appendix C

Stages of Professional Maturation, Autonomy, and Responsibilities in the Practice of Engineering for Responsible Leadership of Technology (NSPE / ASCE)

<table>
<thead>
<tr>
<th>Stages of Growth</th>
<th>Typical Responsibilities-Autonomy-Judgment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGINEER IX</td>
<td>An engineer-leader at this level is in responsible charge of programs so extensive and complex as to require staff and resources of sizeable magnitude to meet the overall engineering objectives of the organization.</td>
</tr>
<tr>
<td>(GS-16, 17, 18)</td>
<td></td>
</tr>
<tr>
<td>ENGINEER VIII</td>
<td>An engineer-leader at this level demonstrates a high degree of creativity, foresight, and mature judgment in planning, organizing, and guiding extensive engineering programs and activities of outstanding novelty and importance. Is responsible for deciding the kind and extent of engineering and related programs needed for accomplishing the objectives of the organization.</td>
</tr>
<tr>
<td>(GS 15 or Academic Dean)</td>
<td></td>
</tr>
<tr>
<td>ENGINEER VII</td>
<td>In a leadership capacity, is responsible for an important segment of the engineering program of an organization with extensive and diversified engineering requirements. The overall engineering program contains critical problems, the solutions of which require major technological advances and opens the way for extensive related development.</td>
</tr>
<tr>
<td>(GS 14 or Distinguished Professor or Academic Department Head)</td>
<td></td>
</tr>
<tr>
<td>ENGINEER VI</td>
<td>In a leadership capacity, plans, develops, coordinates, and directs a number of large and important projects or a project of major scope and importance. Or, as a senior engineer, conceives, plans, and conducts development in problem areas of considerable scope and complexity. The problems are difficult to define and unprecedented. This involves exploration of subject area, definition of scope, and selection of important problems for development.</td>
</tr>
<tr>
<td>(GS 13 or Full Professor)</td>
<td></td>
</tr>
<tr>
<td>ENGINEER V</td>
<td>In a leadership capacity, plans, develops, coordinates, and directs a large and important project or a number of small projects with many complex features. Or, as an individual principle engineer, carries out complex or novel assignments requiring the development of new or improved techniques and procedures. Work is expected to result in the development of new or refined equipment, materials, processes, or products. Technical judgment knowledge, and expertise for this level usually result from progressive experience.</td>
</tr>
<tr>
<td>(GS 12 or Associate Professor)</td>
<td></td>
</tr>
<tr>
<td>ENGINEER IV</td>
<td>Plans, schedules, conducts, or coordinates detailed phases of engineering work in part of a major project or in a total project of moderate scope. Fully competent engineer in all conventional aspects of the subject matter of the functional areas of assignments. Devises new approaches to problems encountered. Independently performs most assignments requiring technical judgment.</td>
</tr>
<tr>
<td>(GS-11 or Assistant Professor)</td>
<td></td>
</tr>
<tr>
<td>ENGINEER III</td>
<td>Performs work that involves conventional types of plans, investigations, or equipment with relatively few complex features for which there are precedents. Requires knowledge of principles and techniques commonly employed in the specific narrow areas of assignments.</td>
</tr>
<tr>
<td>(GS-9 or Academic Instructor)</td>
<td></td>
</tr>
<tr>
<td>ENGINEER II / I</td>
<td>Requires knowledge and application of known laws and data. Using prescribed methods, applies standard practices/techniques under direction of an experienced Engineer.</td>
</tr>
<tr>
<td>(GS-7 / GS-5)</td>
<td></td>
</tr>
</tbody>
</table>

Reference: Nine levels of engineering — NSPE, ASCE and U.S. Department of Labor.
Appendix D

Progressive Critical Skill-Sets, Knowledge, and Experience Required in Engineering Practice for Leadership of Technology Development And Innovation in Industry and Government Service

Core Qualifications - Senior Executive Engineer Levels

Top Levels of Corporate Technology Leadership

Engineers at the top levels of corporate technology leadership act in responsible charge for defining the core character, mission, vision, goals, and objectives of the technology-based organization; for setting responsible technology policy; for building an organizational culture that fosters a core value system of ethical responsibility; for planning, staffing, organizing, and allocating financial, professional, and material resources to enhance the organization’s overall technological thrust; and for building an innovative culture that continually fosters the organization’s core competence and innovative capacity for constant technology development and innovation such that industrial creativity and innovation can flourish to sustain the organization’s competitive advantage responsive to customer needs.

Engineer IX  (GS-16, 17, 18)  20+ years of progressive experience
Vice President of Engineering and Technology

Critical Skills-Sets, Knowledge, and Experience Required as Defined by Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Broad overall knowledge of corporate systems technology
- External awareness of competitive technology
- Strategic vision
- Leading change
- Leading people
- Results driven
- Business acumen
- Building coalitions/communications
- Technology policy making
- Ethical value judgment
- Integrity
Core Qualifications - Executive Engineer Levels

Third Level of Technology Leadership

Engineers at the third level of corporate technology leadership act in responsible charge for defining, planning, organizing, integrating, and leading the overall technological development of new or improved large scale/complex programs, systems, or operations responsive to corporate objectives, goals, vision and mission of the technology-based organization.

Engineer VIII (GS-15) 20+ years of progressive experience
Director of Engineering

Engineer VII (GS-14) 15+ years of progressive experience
Department/Division Manager

Critical Skills-Sets, Knowledge, and Experience Required as Defined by Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Expert knowledge of corporate systems technology
- Broad understanding of emerging sciences relevant to organization’s technological thrust
- Leading major systems engineering and cross functional teams
- Financial management/understanding of the economics of technology development and innovation
- Human resources management and development of engineering profession
- Organizational development of innovative cultures for technology development
- Corporate decision analysis/decision making for innovative technology programs
- Value judgment and ethical decision-making regarding safety issues, environmental issues, understanding systems failures, and prevention
- Mentoring of creative professionals for future leadership positions
Core Qualifications - Senior Engineer/Project Management Levels

Second Level of Technology Leadership

Engineers at the second level of corporate technology leadership act in responsible charge for defining, planning, organizing, integrating, and leading the development and innovation of large-scale complex programs within functional technological areas.

Engineer VI (GS-13) 12+ years of progressive experience
Functional Area Manager

Engineer V (GS-12) 9+ years of progressive experience
Senior Engineer/Principal Engineer/Project Leader/Group Leader

Critical Skills-Sets, Knowledge, and Experience Required as Defined by Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Expert knowledge of functional area technology
- Core systems engineering and multidisciplinary thinking with responsible charge
- Needs-finding and identification of problems/opportunities for technology program-making
- Innovative thinking and strategic vision for program development planning from phases of conceptual exploratory development through advanced engineering development, and recognizing the need for directed research to gain a better understanding of anticipated or unknown phenomenon during technology development programs
- Contracting processes and regulations
- Project leadership and tracking
- Teambuilding
- Coaching of creative professionals
- Customer orientation
- Quality focus
Core Qualifications – Project Engineer Levels

First Levels of Technology Leadership

Engineers at the first levels of corporate technology leadership are fully competent engineering professionals and act in responsible charge for development and innovation of new or improved components of a subsystem or project.

Engineer IV  (GS-11)  7+ years of progressive experience  
Project Engineer/Process Engineer

Engineer III  (GS-9)  5+ years of progressive experience  
Design/Development Engineer

Critical Skills-Sets, Knowledge, and Experience Required as Defined by Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Expert knowledge of core project technology/process technology/product technology
- Competency in engineering method for systematic technology development and innovation
- Creative problem solving for innovative solutions to open-ended problems/opportunities
- Ethical judgment relevant to safety issues and environmental issues
- Engineering-technical judgment
- Project engineering
- Communication
- Critical thinking
- Self-directed learning
Core Qualifications - Entry Level Engineer

Entry Level– Trainee Level

Engineers at the entry-level of technology responsibility work at the level of known laws and data under close supervision of an experienced engineer on specific and limited portions of a broader assignment using prescribed methods, standard techniques, and procedures.

Engineer I/II (GS-5,7)
Entry Level Engineer/Engineer-in-Training

Critical Skills- Sets, Knowledge, and Experience Required as Defined by Tasks and Responsibilities of Engineering Practice and Technology Leadership:

- Graduate of ABET approved program in engineering or technology
- Initiative, enthusiasm, ability to work well with others, and high growth potential for technology development and leadership of innovation in industry
- Attainment of ABET requirements at the basic educational level for entry into engineering practice
  a) an ability to apply knowledge of mathematics, science, and engineering
  b) an ability to design and conduct experiments, as well as to analyze and interpret data
  c) an ability to design a system, component, or process to meet desired needs
  d) an ability to function on multi-disciplinary teams
  e) an ability to identify, formulate, and solve engineering problems
  f) an understanding of professional and ethical responsibility
  g) an ability to communicate effectively
  h) the broad education necessary to understand the impact of engineering solutions in a global and societal context
  i) a recognition of the need for, and an ability to engage in lifelong learning
  j) a knowledge of contemporary issues
  k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
Appendix E

Professional Characteristics, Leadership Responsibilities, And Growth Levels in Engineering Practice – (NSPE / ASCE)

Engineer IX

Equivalent Federal General Schedule Grade
Senior Executive Service GS – 16, 17, 18

General Characteristics. An engineer in this level is either: 1) in charge of programs so extensive and complex as to require staff and resources of sizable magnitude (e.g., research and development, a department of government responsible for extensive engineering programs, or the major components of an organization responsible for the engineering required to meet the objectives of the organization); or 2) is an individual researcher or consultant who is recognized as a national and/or international authority and leader in an area of engineering or scientific interest and investigation.

Typical Position Titles. Director of Engineering, General Manager, Vice President, President, Partner, Dean, Director of Public Works

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Member Grade), Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks
**Engineer VIII**

Equivalent Federal General Schedule Grade
GS-15

**General Characteristics.** Make decisions and recommendations that are recognized as authoritative and have a far-reaching impact on extensive engineering and related activities of the company. Negotiates critical and controversial issues with top-level engineers and officers of other organizations and companies. Individuals at this level demonstrate a high degree of creativity, foresight, and mature judgment in planning, organizing and guiding extensive engineering programs and activities of outstanding novelty and importance.

**Direction Received.** Receives general administrative direction

**Typical Duties & Responsibilities.** One or both of the following: 1) In a supervisory capacity is responsible for a) an important segment of a very extensive and highly diversified engineering program, or b) the entire engineering program when the program is of moderate scope. The programs are of such complexity that they are of critical importance to overall objectives, include problems of extraordinary difficulty that often have resisted solution and consist of several segments requiring subordinate supervisors. Is responsible for deciding the kind and extent of engineering and related programs needed for accomplishing the objectives of the organization, for choosing the scientific approaches, for planning and organizing facilities and programs, and for interpreting results; 2) As an individual practitioner and consultant, formulates and guides the attack on problems of exceptional difficulty and marked importance to the organization or industry. Problems are characterized by their lack of scientific precedents and source material, or lack of success of prior research and analysis so that their solution would represent an advance of great significance and importance. Performs advisory and consulting work for the organization as a recognized authority for broad program areas or in an intensely specialized area of considerable novelty and importance.

**Responsibility For Direction of Others.** Supervises several subordinate supervisors or team leaders, some of whose positions are comparable to Engineer VII, or individual researchers some who whose positions are comparable to Engineer VII. As an individual researcher and consultant may be assisted on individual projects with other engineers and technicians.

**Typical Position Titles.** Chief Engineer, Bureau Engineer, Director of Research, Department Head or Dean, County Engineer, City Engineer, Director of Public Works, Senior Fellow, Senior Staff, Senior Advisor, Senior Consultant, Engineering Manager.

**Education.** Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

**Licensure Status.** Licensed Professional Engineer

**Typical Professional Attainments.** Member of Professional Society (Member Grade), Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks
Engineer VII

Equivalent Federal General Schedule Grade
GS-14

**General Characteristics.** Make decisions and recommendations that are recognized as authoritative and have an important impact on extensive engineering activities. Initiates and maintains extensive contacts with key engineers and officials of other organizations and companies, requiring skill in persuasion and negotiation of critical issues. At this level individuals will have demonstrated creativity, foresight, and mature engineering judgment in anticipating and solving unprecedented engineering problems, determining program objectives and requirements, organizing programs and projects, and developing standards and guides for diverse engineering activities.

**Direction Received.** Supervision received is essentially administrative with assignments given in terms of broad general objectives and limits.

**Typical Duties & Responsibilities.** One or both of the following: 1) in a supervisory capacity is responsible for a) an important segment of the engineering program of an organization with extensive and diversified engineering requirements, or b) the entire engineering program of an organization when it is more limited in scope. The overall engineering program contains critical problems the solution of which requires major technological advances and opens the way for extensive related development. The extent of responsibilities generally requires several subordinate organizational segments or teams. Recommends facilities, personnel, and funds required to carry out programs which are directly related with and directed toward fulfillment of overall organization objectives; 2) As an individual practitioner and consultant is a recognized leader and authority in the organization in a broad area of specialization or in a narrow but intensely specialized field. Selects research problems to further the organization's objectives. Conceives and plans investigations of broad areas of considerable novelty and importance for which engineering precedents are lacking in areas critical to the overall engineering program. Is consulted extensively by associates and others with a high degree of reliance placed on the scientific interpretations and advice. Typically, will have contributed inventions, new designs, or techniques which are regarded as major advances in the field.

**Responsibility For Direction of Others.** Directs several subordinate supervisors or team leaders, some of whom are in a position comparable to Engineer VI, or as individual researcher and consultant, may be assisted on individual projects by other engineers and technicians.

**Typical Position Titles.** Principal Engineer, Division or District Engineer, Department Manager, Director or Assistant Director of Research, Consultant, professor, Distinguished Professor or Department Head, Assistant Chief or Chief Engineer, City or County Engineer.

**Education.** Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

**Licensure Status.** Licensed Professional Engineer

**Typical Professional Attainments.** Member of Professional Society (Member Grade), Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks
Engineer VI

Equivalent Federal General Schedule Grade
GS-13

General Characteristics. Has full technical responsibility for interpreting, organizing, executing, and coordinating assignments. Plans and develops engineering projects concerned with unique or controversial problems which have an important effect on major organization programs. This involves exploration of subject area, definition of scope and selection of problems for investigation and development of novel concepts and approaches. Maintains Liaison with individuals and units within or outside the organization with responsibility for acting independently on technical matters pertaining to the field. Work at this level usually requires extensive progressive experience.

Direction Received. Supervision received is essentially administrative, with assignments given in terms of broad general objectives and limits.

Typical Duties & Responsibilities. One or more of the following: 1) in a supervisory capacity a) plans, develops, coordinates, and directs a number of large and important projects or a project of major scope and importance; or b) is responsible for the entire engineering program of an organization when the program is of limited complexity and scope. The extent of his or her responsibilities generally requires a few (3 to 5) subordinate supervisors or team leaders with at least one in a position comparable to level V; 2) As an individual practitioner or worker conceives, plans and conducts research in problem areas of considerable scope and complexity. The problems must be approached through a series of complete and conceptually related studies, are difficult to define, require unconventional or novel approaches, and require sophisticated research techniques. Available guides and precedents contain critical gaps, are only partially related to the problem or may be largely lacking due to the novel character of the project. At this level, the individual researcher generally will have contributed inventions, new designs, or techniques which are of material significance in the solution of important problems; 3) As a staff specialist serves as the technical specialist for the organization (division or company) in the application of advanced theories, concepts, principles, and processes for an assigned area of responsibility (i.e. subject matter, function, type of facility or equipment, or product). Keeps abreast of new scientific methods and developments affecting the organization for the purpose of recommending changes in emphasis of programs or new programs warranted by such developments.

Responsibility For Direction of Others. Plans, organizes, and supervises the work of a staff of engineers and technicians. Evaluates progress of the staff and results obtained and recommend major changes to achieve overall objectives. Or, as an individual practitioner or staff specialist they may be assisted on individual projects by other engineers or technicians.

Typical Position Titles. Senior or Principal Engineer, Division or District Engineer, Production Engineer, Assistant Division, District or Chief Engineer, Consultant, Professor, City or County Engineer.

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Member Grade).Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks
Engineer V
Equivalent Federal General Schedule Grade
GS-12

**General Characteristics.** Applies intensive and diversified knowledge of engineering principles and practices in broad areas of assignments and related fields. Make decisions independently on engineering problems and methods, and represents the organization in conferences to resolve important questions and to plan and coordinate work. Requires the use of advanced techniques and the modifications and extension of theories, precepts and practices of the field and related sciences and disciplines. The knowledge and expertise required for this level of work usually result from progressive experience.

**Direction Received.** Supervision and guidance relate largely to overall objectives, critical issues, new concepts, and policy matters. Consults with supervisor concerning unusual problems and developments.

**Typical Duties & Responsibilities.** One or more of the following: 1) In a supervisory capacity, plans, develops, coordinates, and directs a large and important engineering project or a number of small projects with many complex features. A substantial portion of the work supervised is comparable to that described for engineer IV; 2) As an individual practitioner or worker, carries out complex or novel assignments requiring the development of new or improved techniques and procedures. Work is expected to result in the development of new or improved techniques and procedures. Work is expected to result in the development of new or refined equipment, materials, processes, products, and/or scientific methods; 3) As staff specialist, develops and evaluates plans and criteria for a variety of projects and activities to be carried out by others. Assesses the feasibility and soundness of proposed engineering evaluation tests, products, or equipment when necessary data are insufficient or confirmation by testing is advisable. Usually performs as a staff advisor and consultant as to a technical specialty, a type of facility or equipment, or a program function.

**Responsibility For Direction of Others.** Supervises, coordinates, and reviews the work of a small staff of engineers and technicians, estimates personnel needs and schedules and assigns work to meet completion date. Or, as individual researcher or staff specialist may be assisted on projects by other engineers or technicians.

**Typical Position Titles.** Senior or Principal Engineer: Resident, Project, Office, Design, Process, Research, Assistant Division Engineer, Associate Professor, Project Leader.

**Education.** Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

**Licensure Status.** Licensed Professional Engineer

**Typical Professional Attainments.** Member of Professional Society (Member Grade), Member of Technical Societies (Member Grade); Publishes engineering papers, articles, textbooks
Engineer IV

Equivalent Federal General Schedule Grade
GS-11

General Characteristics. As a fully competent engineer in all conventional aspects of the subject matter of the functional area of the assignments, plans and conducts work requiring judgment in the independent evaluation, selection, and substantial adaptation and modification of standard techniques, procedures, and criteria. Devises new approaches to problems encountered. Requires sufficient professional experience to assure competence as a fully trained worker, or, for positions primarily of a research nature, completion of all requirements for a doctoral degree may be substituted for experience.

Direction Received. Independently performs most assignments with instructions as to the general results expected. Receives technical guidance on unusual or complex problems and supervisory approval on proposed plans for projects.

Typical Duties & Responsibilities. Plans, schedules, conducts, or coordinates detailed phases of the engineering work in a part of a major project or in a total project of moderate scope. Performs work which involves conventional engineering practice but may include a variety of complex features such as conflicting design requirements, unsuitability of conventional materials, and difficult coordination requirements. Work requires a broad knowledge of precedents in the specialty area and a good knowledge of and practices of related specialties.

Responsibility For Direction of Others. May supervise or coordinate the work of engineers, drafters, technicians, and others who assist in specific assignments.

Typical Position Titles. Engineer or Assistant Engineer, Resident, Project, Plant, Office, Design, Process, Research, Chief Inspector, Assistant Professor.

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Licensed Professional Engineer

Typical Professional Attainments. Member of Professional Society (Member Grade), Member of Technical Societies (Associate Grade or Equivalent)/Member of Technical Societies (Member Grade); Publishes engineering papers, articles, text books
Engineer III

Equivalent Federal General Schedule Grade
GS-9

**General Characteristics.** Independently evaluates, selects, and applies standard engineering techniques, procedures, and criteria, using judgment in making minor adaptations and modifications. Assignments have clear and specified objectives and require the investigation of a limited number of variables. Performance at this level requires developmental experience in a professional position or equivalent graduate level education.

**Direction Received.** Receives instructions on specific assignment objectives, complex features, and possible solutions. Assistance is furnished on unusual problems and work is reviewed for application of sound professional judgment.

**Typical Duties & Responsibilities.** Performs work which involves conventional types of plans, investigations, surveys, structures, or equipment with relatively few complex features for which there are precedents. Assignments usually include one or more of the following: Equipment design and development, test of materials, preparation of specifications, process study, research investigations, report preparation, and other activities of limited scope requiring knowledge of principles and techniques commonly employed in the specific narrow area of assignments.

**Responsibility For Direction of Others.** May supervise or coordinate the work of drafters, technicians, and others who assist in specific assignments.

**Typical Position Titles.** Engineer or Assistant Engineer, Project, Plant, Office, Design, Process, Research Chief Inspector, Assistant Professor

**Education.** Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

**Licensure Status.** Certified Engineer Intern/Licensed Professional Engineer

**Typical Professional Attainments.** Member of Professional Society (Associate Grade/Member Grade), Member of Technical Societies (Associate Grade or Equivalent)
Engineer I/II

Equivalent Federal General Schedule Grade
GS- 5, 7

General Characteristics. This is the entry level for professional work. Performs assignments designed to develop professional works knowledge and abilities, requiring application of standard techniques, procedures, and criteria in carrying out a sequence of related engineering tasks. Limited exercise of judgment is required on details of work and in making preliminary selections and adaptations of engineering alternatives.

Direction Received. Supervisor screens assignments for unusual or difficult problems and selects techniques and procedures to be applied on non-routine work. Receives close supervision on new aspects of assignments.

Typical Duties & Responsibilities. Using prescribed methods, performs specific and limited portions of a broader assignment of an experienced engineer. Applies standard practices and techniques in specific situations, adjusts and correlates data, recognizes discrepancies in results, and follows operations through a series of related detailed steps or processes.

Responsibility For Direction of Others. May be assisted by a few aides or technicians.

Typical Position Titles. Junior Engineer, Associate Detail Engineer, Engineer-in-Training, Assistant Research Engineer, Construction Inspector.

Education. Bachelor's Degree in engineering from an ABET accredited curriculum, or equivalent, plus appropriate continuing education.

Licensure Status. Certified Engineer Intern/Engineering-In-Training

Typical Professional Attainments. Member of Professional Society (Associate Grade), Member of Technical Societies (Associate Grade or Equivalent)
Appendix F

Demographics of the U.S. Engineering Workforce:
The Untapped Resource for Technological Innovation

Professional Education for Engineers –

Demographics of the U.S. Engineering Workforce:
The Untapped Resource for Technological Innovation

Total for U.S and Territories: 2,489,070

*Data from the United States Bureau of Labor Statistics

National Collaborative Task Force – Developing the U.S. Engineering Workforce in Industry
Appendix G

Glossary of Terms: Definitions of the Practice of Engineering for Leadership of Creative Technology Development & Innovation

Glossary of Terms

Research & Development

A) Differentiating between ‘Research’ and ‘Development’

During the course of its investigation phase the National Collaborative Task Force has uncovered the fact that there is popular misconception and confusion between the words ‘research’ and ‘development’; and often the confusion exists within the minds of scientists and engineers themselves.

First, whereas scientists in the nation’s Science & Engineering (S&E) system bring forth new ‘discoveries’ to gain a better understanding of natural phenomena in the world and universe around us to advance the progress of science, the nation’s engineers bring forth new innovative technology in the S&E system to purposefully bring about effective solutions that meet real-world human needs. As a primary outcome of the systematic creative practice and method of engineering — for continuous improvement, development, and breakthrough innovation — the new innovative technology is deliberately conceptualized [created / invented / designed] and further developed in the form of new / improved / breakthrough products, processes, systems or operations that are specifically designed to meet real-world hopes, wants, and needs for continual improvement in the quality of life, economic development, or nation’s defense and security.

As Martino, formerly of the U.S. Air Force Office of Scientific Research, pointed out there is a meaningful distinction between the practice of scientific research to advance the progress of science [research] and the practice of engineering [engineering] to advance the progress of technology development and innovation to bring about effective solutions that meet the hopes, wants, and needs of society for its general betterment:

(a) “Research and development are two entirely different categories of activity … The term research is defined here as an attempt to acquire new knowledge about some phenomenon in the universe, or about some phenomenon in an abstract model of a portion of the universe. The definition makes no distinction between basic and applied research.”

(b) “There is, however, a meaningful distinction between research and development: development is an attempt to construct, assemble, or prepare for the first time, a device, material, technique, or procedure, meeting a prescribed set of specifications or desired characteristics and intended to solve a specific problem. This definition includes not only mechanical devices and hardware, but such things as computer programs, chemicals and other materials. The essence of this definition is that development is intended to meet some set of specifications in order to solve a specific problem.”

(c) “The interaction between research and development as shown depicts a common model [linear] of the way research progresses into products.

[Basic research ⇨ Applied research ⇨ Engineering Development ⇨ Technology]

The kindest thing one can say for the [linear] model is that it is erroneous — Research and development are two entirely different categories of activity, and there is no neat linear progression from one into the other, as this model would imply.”
**Science & Engineering (S & E)**

**B) Differentiating between Science & Engineering**

- Second, contrary to conventional wisdom: Science & Engineering are not linear sequential activities as portrayed by 1945 science policy. Neither should engineering development be mistakenly defined any longer as the transfer of fundamental (basic) research results into commercialization. As Martino pointed out — There is a meaningful distinction between engineering development and scientific research:

(a) **Engineering** — [Conceptualization / Invention / Development and Innovation of Technology]

Engineering development is a very purposive, creative, and needs-driven process and systematic practice using the engineering method that produces new, improved, and breakthrough technology in the form of products, processes, systems and operations to bring about an effective solution to a real need. As a creative pursuit, the essence of engineering development is to purposefully construct, assemble, or prepare for the first time, a device, material, technique, or procedure, meeting a prescribed set of specifications or desired characteristics and intended to solve a specific problem. The operant verb is ‘creativity’.

Engineering development includes:

- **Exploratory engineering development** — [6.2]
  Conceptual stages of technology development including recognition of meaningful real-world need(s) through preliminary conceptual design / invention, and testing for proof of feasibility of the ‘idea or concept’ to meet the need

- **Advanced engineering development** — [6.3]
  Advanced stages of technology development including further creative improvements, testing, and modifications required to take proven feasibility of concept to the next levels of sophistication required for advanced prototype evaluation

- **Systems engineering development** — [6.4]
  Operational stages of technology development including further creative improvements, testing, and modifications to take advanced prototypes to the next levels of sophistication required for full-scale manufacturing, production, or operational use

(b) **Scientific Research** — [Fundamental Research (Basic) or Directed Research (Applied)]

Scientific research is a purposive process using the systematic scientific method to gain a better understanding of phenomena and to thereby add to the existing body of scientific knowledge [science] to advance scientific progress. The operant verb is ‘discovery’.

Scientific research includes:

- **Basic Research** [Fundamental scientific research (curiosity driven)] — [6.1]
  To gain a better understanding of phenomena and thereby add to the existing body of scientific knowledge (science) to advance the progress of science; results are not needed immediately

- **Applied Research** [Directed -Strategic scientific research (strategic driven)] — [6.1]
  To gain a better understanding of phenomena [either anticipated or is unexpectedly occurring] in the course of the development of technology, which needs to be better known, and thereby add to the existing body of scientific knowledge (science) in the organization’s strategic areas of interest; results are immediately useful.

- The National Collaborative Task Force notes that research is research … is research — whether performed as basic scientific research (curiosity driven) or as applied scientific research (strategic driven). Both designations use the same systematic scientific method and neither is less important than the other. But, ‘applied research’ does not mean the conversion of scientific research results into manufactured goods as too often misconstrued [linear model] nor should the term ‘applied research’ be misconstrued as ‘engineering development’.
Third, the pursuits of the practice of engineering and the practice of science are not identical, nor sequential—and they never have been. The term that engineering is ‘applied’ is a subtle misnomer. Although engineering operates within the practical realm of human affairs, engineering is a very purposeful ‘creative problem solving’ pursuit. The terms ‘research and applications’ is an erroneous outgrowth of 1945 science policy [linear-model] portraying the research-driven model of engineering practice, which has contributed largely to the current misconceptions of the practice of engineering, and to the current ‘gap’ in the advanced professional education of the U.S. engineering workforce for responsible leadership of the creative technology development & innovation process in industry / government service.

The systematic method of scientific research [scientific method] for ‘inquiry’ and ‘discovery’ purposes for advancing the progress of new science and the systematic method of engineering [engineering method] for creating new useful technology are quite different because the missions, purposes, and talents required of these two pursuits are quite different.

C) Redefining Technology for the 21st Century

Fourth, although engineering operates within the practical realm of human affairs—technology is not the practical correlate of science as the philosopher John Dewey frequently defined technology during America’s progressive era of the 1920’s and 1930’s. As Ferguson points out, Dewey’s belief system was pervasive during this era and fostered the root cause of the linear, research-driven myth promoted by 1945 science policy. But, a major finding of the National Collaborative Task Force is that ‘technology’ is purposefully created and developed as a primary outcome of the deliberate and purposeful practice of engineering, which uses the systematic engineering method in this very creative pursuit and practice.

What is Technology?
As the National Academy of Engineering [Technically Speaking] points out—“In its broadest sense, technology is the process by which humans modify nature to meet their needs and wants. However, most people think of technology only in terms of its artifacts: computers and software, aircraft, pesticides, water-treatment plants, birth-control pills, and micro-wave ovens, to name a few. But technology is more that its tangible products. An equally important aspect of technology is the knowledge and processes necessary to create and operate those products, such as engineering know-how and design, manufacturing expertise, various technical skills, and so on. Technology also includes all of the infrastructure necessary for the design, manufacture, operation, and repair of technological artifacts, from corporate headquarters and engineering schools to manufacturing plants and maintenance facilities.”

“Technology comprises the entire system of people and organizations, knowledge, processes, and devices that go into creating and operating technological artifacts, as well as the artifacts themselves [NAE]”

D) Redefining Engineering for the 21st Century

Fifth, contrary to popular misconceptions, as the National Academy Engineering reports [Technically Speaking, The Engineer of 2020 - Report I, and Educating the Engineer of 2020 - Report II ] point out—Engineering is not ‘applied science’ nor is technology ‘applied science’.

As Wm. Wulf, president of the National Academy of Engineering, points out—‘Engineering is design under constraint’.

Sixth, because of the paradigm shift in modern practice, the National Collaborative Task Force believes that a redefinition of the practice of engineering is in order for the 21st century. As Ferguson pointed out, the 1945 Vannevar Bush report [Science: The Endless Frontier] which placed singular emphasis on basic research and on the linear science-driven model of technology innovation, has virtually ignored use of the purposeful creative engineering method performed by innovative engineers in the nation’s technology-based industry and mission-oriented government service.
Whereas the linear research-driven model in the past has narrowly defined technology development as ‘applied science’ and has narrowly defined the practice of engineering development as primarily a secondary follow-on, conversion process that ‘converted the results of basic research and new scientific knowledge, generated at the research universities into technology’, new definitions of purposeful systematic engineering and creative technology development have emerged through ‘innovation best practice’ in U.S. industry and mission-oriented government service.

Rather than defining basic scientific research as the forerunner of the practice of engineering in the U.S. Science & Engineering [S&E] innovation system, American engineering is now being defined differently and proactively by a different driver, wherein scientific research is now seen to be a contributor in the technological innovation process rather than the initiator.

Sixth, the National Collaborative Task Force is defining engineering as a very creative profession and as a systematic professional practice with a mission, purpose, and method. The National Collaborative Task Force believes that—

“Engineering is a very ‘creative profession’ and a ‘purposeful systematic practice, wherein by its very nature, the essence of engineering is ‘creative problem-solving’ — to meet the hopes, wants, and needs of society ... for the advancement and betterment of human welfare.”

Accordingly, the National Collaborative Task Force concludes that Engineers must now be educated to reflect the practice of engineering to bring forth new useful technology as a result of creating effective solutions in meeting meaningful real-world needs — from entry level engineering responsibilities through chief engineer / vice president level of engineering responsibilities. In professional engineering work, engineers must understand not only the theory but the ‘constraints’ of science that they are operating within for creative technology development and meaningful engineering works.

During the engineering process and creative practice of engineering for large scale systems technology development & innovation projects, engineers quite often call for and direct the corporate requirement for directed scientific research [applied research] to be performed in order to better understand phenomena that is either anticipated or that they feel needs to be better understood during the systematic process of developing new/improved/breakthrough technology.

Seventh, contrary to popular belief, the vast majority of advancements in engineering practice for technology development & innovation are brought forth by experienced, reflective engineering practitioners in industry / government service. These experienced practitioners are the ‘champions, innovators, and leaders’ of the nation’s future technological thrust for U.S. economic competitiveness and national security.

Eighth, in its broadest sense, engineering is neither applications of research nor applied as commonly perceived. Rather, as the National Academy of Engineering points out — Engineering is a very creative endeavor. Engineering is neither ‘discovery’ ... nor ‘application’ — the essence of engineering is ‘creative problem solving and responsible leadership’ in meeting unsolved human needs. Less than 5% of the engineering profession is engaged in discovery and scientific research in the United States.

Professional Engineering Education — Going Beyond the Traditional Linear Model

E) Redefining Professional Education in Engineering for the 21st Century

The National Collaborative Task Force believes that not only are the corrections of these misconceptions important in the S&E system, but that they necessitate also a new paradigm shift in U.S. professional education that must go beyond the limiting perspective of the linear model of traditional education [generation, transmission, and acquisition of knowledge] to a new paradigm shift for the professional education of engineers as a growth process that enables the further intrinsic intellectual development of their creative, innovative, and leadership abilities for new meaningful creative engineering works.