AC 2009-465: STRENGTHENING THE U.S. ENGINEERING WORKFORCE FOR INNOVATION: A PROGRESS REPORT OF THE NATIONAL COLLABORATIVE INITIATIVE

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Strengthening the U.S. Engineering Workforce for Innovation: A Progress Report of the National Collaborative Initiative

"America's economic and political standing are fundamentally bound to the capacity for innovation. To compete in the rapidly developing global economy, advancing a national innovation agenda must be a priority for U.S. public and private sector leadership."
Innovate America: Thriving in a Word of Challenge
- 2005 Council on Competitiveness

"... We must ensure that the United States is the premier place in the world to innovate."
Rising Above the Gathering Storm Committee
- 2006 National Academy of Sciences

Abstract

This is the first of four invited papers prepared for the special panel session of the ASEE-National Collaborative Task Force for Engineering Graduate Education Reform. This paper presents an overview of the initiative. The paper reaffirms the National Collaborative strategy that the present and future industrial strength of U.S. technology for economic prosperity and national security is ultimately reflected in the strength and innovative capacity of the nation's engineering infrastructure in industry for technology development and innovation. This strength must be sustained by a strong U.S. system of professional graduate engineering education directly relevant to the growth needs of the U.S. engineering workforce in industry which is the primary mainstay of our competitiveness as a nation.

1. Proposed ─ A Bold Initiative

The National Collaborative Task Force, comprised of leaders from industry and universities across the country, proposes to initiate, guide, and implement a major advancement in U.S. professional graduate engineering education that ─

- Recognizes that the future industrial strength of U.S. technology for economic prosperity and national security is ultimately reflected in the strength and innovative capacity of the nation's engineering infrastructure in industry for technology development and innovation.
- Recognizes the national imperative in winning the skills race and strengthening U.S. innovation through professional graduate engineering education specifically designed to unlock the creative, innovative and leadership potential of the U.S. graduate engineering workforce in America's industry.
- Provides degreed engineers, employed in industry, a new type of world-class professional graduate education that is integrative with the engineer's experience and on-going creative engineering work to improve the technological competitiveness of regional industry across the nation.
- Integrates the modern paradigm of the process of engineering for technology innovation with practice that enables the engineer to create, develop, and innovate new technology and improvements specific to his or her sponsoring company as a primary ingredient of the engineer's advanced studies program.
- Provides a coherent approach for the lifelong learning of experienced working professionals through the professional master's and professional doctor of engineering levels that enables career progression and development of leaders at all engineering levels from entry-level through chief engineer / vice president level responsibility of corporate planning, technical program making and technology policy making.

2. Engineering the Future ─
Professional Graduate Engineering Education
To Enhance U.S. Innovation in Industry for Competitiveness

Today, as never before, America's future technological strength for economic competitiveness and national security depends on continuous innovation by its engineers working in industry and government service. Their ideas are the creative well-spring of U.S. technological development. The need for innovation has been stressed by the Council on Competitiveness, which calls it "the single most important factor in determining America's success though the 21st century."[1]As such, the National Academies' report, Rising Above the Gathering Storm recommends that we *"ensure that the United States is the premier place in the world to innovate."*[2] The American Competitiveness Initiative (ACI) has been enacted with swift bipartisan support.

What Is the Problem that we want to Fix?

- The need for America to revitalize its innovative capacity for technological competitiveness has risen as a national priority to create jobs at home, to rebuild America's industry, to improve our economy by creating wealth in these troubled economic times, and to sustain our national security. But the U.S. imperative for innovation points up a disturbing imbalance in graduate education funding and emphasis that must be corrected in engineering. Over the last several decades, the United States invested wisely in research-oriented graduate education and has become preeminent in basic university research that advances science and benefits the scientific workforce for discovery. But a parallel investment and balanced emphasis ***has not*** been made in professional graduate engineering education during this same time frame to support the continued development of the U.S. engineering workforce in industry for technology development and innovation.

- One-size in graduate education doesn't fit all. Excellence in basic research and in the practice of engineering for world-class technology development and innovation are two very different pursuits. A disconnect has existed between U.S. graduate engineering education and engineering practice during the last several decades. Lack of a system of coherent professional graduate education, relevant to the creative practice of engineering, has been a contributing factor to the long-tem underdevelopment of our nation's engineering potential, threatening competitiveness.

Why Do We Want to Fix the Problem Now?

- Whereas undergraduate engineering education prepares newly minted degreed engineers for entry into the practice of engineering, it does not prepare for all levels of responsibility. As the National Academy of Engineering points out ─ "The comfortable notion that a person learns all that he or she needs to know in a four-year engineering program just is ***not*** true and ***never*** was."[3] Engineering experience and further advanced studies are yet to come. There are eight levels of progressive growth and responsibility beyond the beginning entry level.[4, 5] Growth to these increasingly progressive levels deserves further graduate education to more fully develop the creativity, innovativeness and leadership abilities of the nation's engineers for enhanced competitiveness.

- The ASEE-National Collaborative Task Force for Engineering Graduate Education Reform was deliberately created in 2000 by the ASEE-Graduate Studies Division, Corporate Members Council, and the College Industry Partnership Division to meet this challenge. Composed of leaders from industry and universities across the nation, the National Collaborative initiative has a goal of developing a new model of professional graduate engineering education for the nation's degreed engineers in industry that is integrative with the graduate's on-going practice of engineering, while fully employed in industry, and furthers his or her career-long professional growth at all levels of engineering responsibility.

What Is Our Overall Strategy for the Advancement of Professional Graduate Engineering Education?

- The National Collaborative Task Force is building its overall strategy for educational reform to enhance U.S. engineering innovation in strong agreement with Whitfield's assertion that ─

  > "It is taken as self-evident that the creative output of [any nation's] engineering will be raised quickest and over the widest area by successful efforts to improve the creativity of the engineer already in industry, specifically the engineer who has added an adequacy of experience to his or her basic technical training." [6]

- Thus, the National Collaborative strongly believes that one of the best and quickest ways to boost our nation's competitive advantage for sustained engineering innovation for global competitiveness and national security is through a deliberate, planned advancement for a new model of professional graduate engineering education that is specifically designed for lifelong learning to further develop our nation's experienced engineering talent at all leadership levels throughout their entire creative professional careers of engineering practice in industry.

- The new model of professional graduate engineering education can become a 'game changer' to enhance U.S. innovative capacity in engineering. The Task Force concludes that engineering education is not a one-time process, but a progressive process of learning, growth, and human development … and, to compete, our nation's engineers must continuously grow throughout their careers and become 'champions, innovators, and engineer-leaders' of new, improved, and breakthrough technology that continuously outpaces our competitors.

Has the Modern Process and Practice of Engineering Itself Changed for Technology Innovation?

The answer is **Yes**.

- One of the major findings that has clearly emerged from the National Collaborative Task Force analysis is the fact that the modern process and practice of engineering for creative technology development and innovation has itself changed substantially [particularly in aerospace and the nation's defense] from the outmoded, linear basic research-driven paradigm of engineering practice reflected by U.S. Science Policy established in 1945 [V. Bush ─ *Science: the Endless Frontier*]. [7]

- This subtlety is rather profound. It points to the premise that for our nation's engineers to innovate in the new innovation-driven economy, then the U.S. system of engineering education itself must reflect the correct paradigm of the modern practice of engineering for technology innovation.

- As Sanders and Brown have pointed out ─

  > "The great discovery of our age is that technological innovation need not be haphazard. Industry and government have developed a new concept of planned and systematized innovation [engineering process and method] founded on vastly expanded engineering and scientific efforts. In fact, the discovery 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." [8]

Redefining Engineering ─ What is Engineering?

- Engineering has been redefined for the 21st century. As the National Academy of Engineering points out ─ Engineering is a very creative profession ... the outcome of which is new, improved, and breakthrough technologies responsive to meaningful real-world needs of people and industry... for the advancement and betterment of human welfare. [9] As Eric Walker, former president of Pennsylvania State University and ASEE noted: *"The key idea is that engineering is a system of [leadership] that results in the satisfaction of human needs."*[10]

What is the Role of the Nation's Engineers for Innovation?

- As a creative problem-solving profession, engineering has a mission, purpose and professional value system to create, develop, and innovate new technology to meet meaningful needs of society ... for the advancement and betterment of human welfare by deliberate '*creative design*' and responsible professional leadership.

- As the National Academy of Engineering points out ─ *"**Engineering is problem recognition, formulation, and solution** …Engineering is a profoundly creative process" … wherein … Technology is the outcome of engineering."*[11] Engineering yields new, improved, and breakthrough technologies as the deliberate, planned outcome of creative engineering practice which is essentially, as the National Academy of Engineering points out is ***"design under constraint".*** And, in this creative process, as Simon Ramo notes, engineers use the 'systems approach'. [12]

- In essence, the engineering ethic and mission for purposeful innovation and improvement of the human condition in bringing about effective solutions through planned, creative problem-solving and responsible leadership in deliberately conceptualizing, developing and innovating new and improved technology as solutions to real-world, meaningful needs of people and industry is the driving force of the creative practice of engineering for technology innovation.

- Basic research is often used to gain a better understanding of phenomena involved in the engineering project, but contrary to conventional wisdom, basic research is ***not*** the primary driving force for engineering innovation which the outdated 1945 linear basic research-driven model predicted; ***nor*** is the practice of engineering sequential to basic research as conventional wisdom implies. Rather, in many large-scale technology development projects and programs, engineering frequently drives the need for further academic basic scientific research [Project Hindsight]. [13]

- The National Collaborative Task Force has identified the modern process and stages of the engineering method for innovation; and the core competencies, skill-sets, attributes, and progressive responsibilities required of graduate engineers at all leadership levels of engineering from a) early-career levels, b) mid-career levels, through c) senior-career engineering and executive levels in order for companies to compete successfully in the new innovation-driven economy.

Redefining Technology ─ What Is Technology?

- Technology has been redefined for the 21st century. Technology should no longer be misinterpreted by the outmoded myth of 1945 as the practical correlate of science [John Dewey]. By technology, we refer to the systematic body of 'ideas or concepts' so tested any where in the world yielding the same results [Alstadt]. New products, processes, systems, operations are all new technology originating by a new 'idea or concept' primarily generated by the purposeful practice of engineering to deliberately create or improve something never done before to meet a real-world hope, want, or need.

- A the National Academy of Engineering points out:

> "Technology is more than these tangible products. The knowledge and processes used to create and to operate the artifacts ─ engineering know-how, manufacturing expertise, various technical skills, and so on ─ are equally important. An especially important area of knowledge is the engineering design process, of starting with a set of criteria and constraints and working toward a solution ─ a device, say, or a process ─ that meets those conditions. Engineers generate designs and then test, refine, or discard them until they find an acceptable solution. Technology also includes the entire infrastructure necessary for the design, manufacture, operation, and repair of technological artifacts, from corporate headquarters and engineering schools to manufacturing plants and maintenance facilities. [14]

Redefining Innovation — What is Innovation?

- Innovation is a process and a systematic practice ... innovation is at the heart of engineering.

- By innovation, we refer to George Freedman's definition that:

  > "Innovation is the process of implementing new ideas, of turning creative concepts into realities. For our purposes, there is a more meaningful concept, that of 'effective innovation', which can benefit business. Effective innovation is 'the timely and efficient implementation of new ideas that results in significantly increased revenues and profits.
  >
  > … When a company decides to innovate, it makes an investment. It commits funds and resources. If the investment comes from existing businesses within the parent organization, it will show up on the respective balance sheets of each enterprise.
  >
  > If the corporate office decides to invest in a new innovation group (an action that will lead to new processes, new products, new systems, or new ventures), its commitment will often resemble that of a venture capital firm; this time the commitment will show up on the balance sheet of the corporation. In either case, an investment is being made." [15]

Education for Tomorrow: Engineering the Future —
How Can Improvement in U.S. Engineering Education Help the Economy and Competitiveness?

- Today, we need to recreate again the infrastructure and platform for innovative engineering that will revitalize the industrial strength of the United States to grow new jobs and put our people to work in meaningful employment that will sustain their futures and the economy.

- The time for transformative educational change — to bring about a better future and to develop Engineers as leaders and 'champions' who will shape a better future and economy — is now. But this educational transformation requires real change at the universities: because for the most part American universities have ***neither*** kept up with the paradigm shift in engineering for innovation ***nor*** with the changes required in professional graduate engineering education to reflect the modern process and practice of engineering for technology innovation during the last four decades.

- Emphasis on attracting federal funding for academic basic scientific research began during the late 1960's, intensified in the 70's, 80's, and 90's to the present day — resulting in the subsequent build-up of a generation of excellent research-oriented faculty at most engineering schools who are expert at scientific research, who can attract federal research funding, but who are ***not*** that proficient, experienced, interested, or rewarded in the practice of engineering or its teaching for innovation.

- As a long-term consequence, U.S. research-oriented graduate engineering education has become world preeminent and is excellent for the graduate education of future academic scientists for basic research. But a 'disconnect' exists in professional graduate engineering education for the creative practice of engineering at too many of the nation's universities — contributing to the long-term underdevelopment of the nation's graduate engineers and sequential decline of U.S. engineering for innovation. As Eric Walker, pointed out years ago: "Teaching research isn't teaching engineering."[16]

- The National Collaborative Task Force reaffirms Christopher Hill's assessment:

  > "Networks of highly creative individuals and collaborating firms will devise and produce complex new systems that meet human needs in unexpectedly new and responsive ways ... Simply redoubling our efforts to fund more research and to prepare more scientists and engineers along the models of the past is unlikely to be sufficient to meet the new needs. … Contrary to the consensus … it is not so much that we need more scientists and engineers ***but that we need new kinds of scientists and engineers."*** [17]

Should America Rebuild Its Industrial [Engineering] Infrastructure for Innovation?

The answer is **Yes.**

- Rebuilding our nation's engineering infrastructure for innovation in industry is the backbone in rebuilding America's capacity to compete economically, to prosper, and to sustain our national security against aggressors.

- The importance of rebuilding America's industrial infrastructure for innovation, through further postgraduate professional education of graduate engineers in industry, rises to a national priority as America seeks to stimulate and sustain its economic recovery. Innovation is the primary function of engineering. As Akio Morita, former chairman of Sony Corporation-Japan, pointed out ─

> "If we as engineers were to think that the systems we have today are the best we can devise and that we have no other alternative, we would stop all innovation. We engineers work constantly to come up with new ideas. The day we make an invention is the day we begin to work to improve it, which is how technology has developed to this point …
>
> It is unwise merely to do something different and then rest on your laurels. You have to do something to make a business out of a new development, and that requires that you keep updating the product and staying ahead of the market.… A main challenge to the world trading system is the rebuilding of the American industrial structure [for innovation]. [18]

What Needs to be Done ─
How Does a Nation Develop a Strong Engineering Infrastructure for Innovation?

- There are at least five major ingredients in rebuilding the U.S. engineering infrastructure:

    1) The first is to 'plant the seed of interest early', identify, and recruit our nation's young creative talent who have the potential for excellence in engineering by improving our system of K – 12 preparatory education for these young students to enter and successfully pursue undergraduate engineering education at the nation's universities.

    2) The second is to improve the context and process of undergraduate engineering education for these same students to successfully graduate and to enter the creative practice of engineering in industry or government service.

    3) The third is to recruit these young engineering graduates into effective organizations within industry of government service that provide opportunity and financial support for the graduate's further growth and professional development.

    4) The fourth is to provide opportunity through regional universities in partnership with industry that further develops these same young men and women beyond entry level to their highest potentials through high-quality postgraduate professional engineering education enabling professional growth through the professional master's of engineering and the professional doctor of engineering levels while they are fully employed as vital creative professionals in industry or government service in responsible charge of meaningful, creative and innovative engineering works.

    5) The fifth is to successfully retain these same creative experienced professionals through 'industry best practice' by providing new organizational cultures within industry and government that better utilize and are more conducive in nurturing engineering innovation to flourish, and companies to continuously grow over the long term for sustained and preeminent U.S. technological competitiveness.

How Important is the Experience and Retention Factor in Growing Our Engineers for Innovation?

- Per its findings, the National Collaborative Task Force concludes that progressive experience and organizational culture plays a vital role in an engineer's advanced professional education and in his or her ability to innovate.

- As the Department of Defense study, Project HINDSIGHT, pointed out:

  > "In examining the personal histories of scientists and engineers who had contributed most heavily to the new technology of use to the Department, the employment stability of these individuals stood out as a most significant factor. Moreover, it was found that the most effective scientist or engineer ─ in terms of the probability that he (or she) will come up with something that will be profitable to the organization ─ is one who has been in the company for a number of years.
  >
  > The modal point on the distribution curve displaying length of employment against probability of making a useful contribution occurs at between seven and nine years of employment. Clearly, if the professional turn-over rate exceeds 10% to 15% per year, it will be most unlikely that the peak performance of the laboratory will ever be achieved." [19]

- Thus, it is the sense of the National Collaborative Task Force that the experience and retention factors are critical in rebuilding the nation's future strength in engineering for innovation. The experienced engineer-leaders who are about to retire in the workforce are a vital national engineering asset and corporate memory of U.S. technology. These retired engineers can play a vital role in this initiative as adjunct faculty: representing some of the 'best experienced engineering talent' within the United States. These experienced professionals, in combination with core university faculty, and other distinguished adjunct graduate faculty from industry, can provide the expertise, mentorship, and coaching roles required in this educational transformation.

- This initiative provides opportunity for our retiring experienced engineer-leaders to give back to the engineering profession by teaching at the highest levels of professional engineering education, in building great Graduate Centers [Institutes] for postgraduate professional engineering education across the nation second-to-none for global competitiveness, and in developing industry's emerging future engineer-leaders within regional industry for continued industrial growth for competitiveness.

- Programs of high–quality, graduate professional engineering education, which this initiative represents, are needed in all regions of the country, to focus on the critical U.S. engineering workforce issues [where enhancement of regional industrial innovation is a primary strategy of building U.S. competitiveness as a whole] are now more important than ever before.

What is the National Collaborative Action Plan to Get the Job Done?

- To address the fourth and fifth major ingredients of rebuilding the U.S. engineering infrastructure for competitiveness, the National Collaborative Task Force concludes that a new *seamless approach* for 'lifelong learning' and postgraduate professional education is needed in the U.S. system of graduate engineering education that:

  1) Is complementary to academic scientific research, but is specifically designed to be more relevant to the progressive growth needs of experienced degreed engineers who are emerging as engineering leaders and;

  2) Specifically advances U.S. postgraduate professional engineering education in the modern process and systematic practice of engineering and its leadership for continuous technological innovation in industry.

- To meet the challenge, the National Collaborative Task Force is embarking on a bold initiative, as a National Demonstration Project, that will enable experienced graduates in the U.S. Engineering Workforce in industry to continue their professional graduate education while fully employed, to attain their fullest creative, innovative, and leadership potentials throughout their entire professional careers to enhance their growth as creative professionals in the spirit and intent of the creative profession of engineering and U.S. economic competitiveness.

- The new model of postgraduate professional engineering education will be specifically designed as a coherent sequence to match and support the skill-sets required of engineers to grow from:

    a) Early-career level engineering leadership responsibilities
    [Project engineering levels I - III]

    b) Mid-career level engineering leadership responsibilities
    [Technical program leadership levels IV-VI]

    c) Senior-career level engineering leadership responsibilities
    [Technology policy leadership levels VII-IX]

- This educational transformation will enable an opportunity for experienced graduate engineers to grow through the professional master of engineering (M.Eng.) and the professional doctor of engineering (D.Eng.) levels of proficiency while the degreed engineer continues his or her full-time employment in industry.

- Also emerging from the National Collaborative Task Force analysis is a consensus that the new model must educate experienced graduate engineers in a professional, project-based mode of 'learning by doing,' and engage these working professionals directly in the practice of engineering as emerging leaders with "the ability to think in terms of systems and knowing how to lead systems engineering development." This much needed transformation requires a rethinking and reengineering of the U.S. engineering education system itself.

What are the Specific Tasks of the National Demonstration Project?

- The National Demonstration Project will consist of a working coalition of 5 — 10 forward thinking universities, working in strong partnership with industry, as a critical mass for educational transformation. These universities are noted for their approach to practice-oriented engineering education and outreach for innovation in industry.

- A National Project Office which will serve as a guiding base for systems engineering leadership to stimulate innovation and share best practice for cohesive educational advancement in engineering. The nine progressive responsibility levels and innovation and leadership attributes — required of engineers from beginning entry level through the chief engineer / vice president level — will serve as the guiding framework for new curricula development for professional master's of engineering and professional doctor of engineering levels of proficiency for working professionals in industry. These more relevant postgraduate professional programs and supporting educational processes will be distinct from, but complimentary to, traditional research-oriented academic graduate education.

- Regional graduate centers, established across the country, will enable the engineering workforce in the surrounding areas to further develop the professional abilities, attributes, and skill-sets required of engineers for responsible leadership of technology development and innovation, and simultaneously enabling graduates to develop new innovative technology in industry. The specific project tasks of the National Collaborative initiative will use a systems approach that includes 3 Primary Phases and 10 Specific Tasks to implement the transformation [See Appendix C].

What is the Market Potential for this Initiative?

- The potential market for this initiative, in terms of graduate level engineering education, is significant. The initiative is specifically intended for those domestic degreed engineers in industry or government service, who practice in the broad spectrum of engineering-leadership functions ─ from new product development, process development, manufacturing, production, systems and operations.

- The initiative is intended to develop a minimum of 10% to 20% of the 70,000 newly minted graduate engineers who enter the U.S. engineering workforce each year as well as to continue the postgraduate education of those already in the workforce to the next stages of their professional growth as leaders.

- The initiative will focus on postgraduate professional engineering education that supports the modern, systematic process and practice of engineering focusing on systems engineering for technology development and innovation and its responsible leadership at all leadership levels, supporting the progression of growth from Level I ─ Level IX engineering responsibilities.

Do Other Nations Have Similar Initiatives?

The answer is **Yes**.

- Other nations have been working hard to develop their systems of engineering education for innovation, and have not been standing still.

- The UK government has invested in extensive programs called TCS at the professional Master of Engineering (M.Eng.) over the past 15 years in strong partnership with industry.

- Based upon the success of the professional Master of Engineering programs, the UK government has also invested in establishing high-quality graduate centers for the professional Engineering Doctorate.

Have these Initiatives Been Successful in the UK?

The answer is **Yes**.

- Initially, the UK established 10 Graduate Centers for the professional Engineering Doctorate (Eng.D.) based on recommendations of the Parnaby Report.[19]

- Then these programs grew to 20 Graduate Centers offering the professional Engineering Doctorate (Eng.D.).

- And now the UK Government will grow 20 more centers this year to raise the total to 40 Graduate Centers offering the professional Engineering Doctorate (Eng.D.) across the UK. [20]

- The success of these centers is spreading. Recent UK government reports citing the relevance, returns and good response of these postgraduate programs to stakeholders and industry are extremely impressive. [21]

What are the Differences between the Research MSc / PhD and the Professional M.Eng. / D.Eng.?

- Whereas traditional MSc and PhD programs focus on the relatively small group of young graduates who remain at the universities to pursue academic research careers, postgraduate professional M.Eng. and D.Eng. programs focus on the majority of the nation's graduates who enter industry or government service immediately upon graduation and who are pursuing professional careers in engineering practice.

- Whereas traditional MSc and PhD programs are research-oriented, and are intended to develop the next generation of academic research scientists for scientific ‘discovery’ purposes at the universities, postgraduate professional M.Eng. and D.Eng programs are practice-oriented, and are intended to develop both the existing and future professional base of the nation’s experienced graduate engineers in industry / government service for the deliberate creation, development, and innovation of new, improved, and breakthrough technologies responsive to real-world needs of people and industry.

- Whereas traditional MSc and PhD programs focus on the teaching and learning methods for inquiry-based learning and the scientific method for discovery, postgraduate professional M.Eng. and D.Eng. programs focus on the teaching and learning methods for project-based, problem centered learning and the engineering method for purposeful technology development and innovation.

- Whereas U.S. federal government often funds the tuition and salary of resident domestic graduate students [and foreign nationals] through research grants who are pursuing traditional MSc and PhD programs, America’s private industry will pay the tuition and salary of its employed engineers to further their postgraduate professional education through the M.Eng. and D.Eng. programs.

- Whereas the traditional MSc and PhD programs yield academic scientific output in terms of Master’s theses and Doctoral dissertations, there is no measurable output in terms of direct technological impact. However, the postgraduate professional M.Eng. and D.Eng. programs yield direct measurable impact in terms of value added worth of $200,000 per each directed engineering development project to regional industry.

What are the Unique Distinctive Differences Between the UK Initiative and the US Initiative?

- Whereas the UK postgraduate professional M.Eng. and Eng.D. initiatives focus on the further education of young inexperienced graduate engineers, who are preparing for careers in industry, the US initiatives focus on the further education of experienced graduate engineers, who are already employed within industry / government service with an already established competency in their technological field.

- Whereas the UK government pays for the tuition and salary of the degreed engineer, America’s private industry and mission-oriented government service will pay the tuition and salary of the graduate.

What is the Start-Up Cost of this Initiative?

- The start-up costs for each Graduate Center is expected to be a modest $500,000 per center per year.

- The returns in terms of tuition revenue and potential engagement partnerships with industry as a result of these centers, will far exceed the start-up cost.

- It is expected that over a five year start-up period and initial operations that each center will be self sustaining with the build-up of any needed external funding acquired by using similar financial model(s) that professional law schools employ.

What is the Impact of this Initiative to the Nation, Industry, Universities, States and Regions?

- The potential impact of this initiative is exponential to America’s industry, locales, regions, and participating universities across the nation. Winning the skills-race in developing our nation’s creative ‘human capital’ in innovative engineering is of major importance to America’s future economic growth.

- Partnering this initiative with the practicing engineering profession in America's industry will stimulate significant regional innovation, new technology developments and economic growth across the country, and ensure that the nation's engineers in America's industry develop the core skills they need to grow from the newly minted degreed engineer's entry-level competencies to the highest levels of engineering leadership responsibility required for world-class technological innovation.

- The innovative returns from this unique initiative in developing the potential of our domestic creative human capital in advanced engineering far exceed the modest start-up cost of financial investment per Graduate Center. The Task Force has already demonstrated the expected value added impact to regional industry in stimulation the economy through each graduate's creative and productive innovation project, in creating new and improved technologies or reduction of operating costs, is typically \$200,000. Thus, for a typical Graduate Center educating 100 graduate-practitioners, producing an innovation worth of \$200,000 per project, this amounts to 100 x \$200,000 = \$20 million return value added impact per the modest start-up investment of \$ .5 million per Graduate Center.

What is the Worst Case Scenario If We Do Not Invest In Our Creative U.S. Engineers?

- The worst case scenario if we do ***not*** make this modest investment in the further professional graduate engineering education of our creative engineering talent is that we will probably sustain the status quo and ***not*** reverse the steady decline of U.S. innovative competitiveness through continued neglect of America's primary engineering resource for innovation to grow to their fullest creative, innovative, and leadership engineering potentials in industry to compete.

- In these trouble economic times, if we don't invest in the development of our creative engineers who have the potential to bring about a better economic future through purposeful creative engineering and technological change, then the consequences are predictable ─
  - we will continue to lose our technological competitiveness and companies will continue to fail;
  - we will ***not*** regain our technological leadership in the global economy; ***nor*** will we grow our nation's graduate engineers who can create, develop, and innovate the future technologies that people call for in the spectrum of technologies from energy, transportation, aerospace, medical ... to technologies yet dreamed of that should be key engineering challenges of the 21st century.

3. Recommendations and Next Steps ─

Can the National Collaborative Implement this Much Needed Transformation Across the Nation?

The answer is **Yes**.

- Other nations are ***not*** standing still nor waiting for America to invest in our Science and Engineering infrastructure. These competitor nations have already been investing in their people for quite some time now. The results of their forward thinking are now showing up in their regained engineering strength for innovation.

- Thus, the question is ... will we, as a nation, choose to continue to lead the world in advanced engineering for technological innovation for economic prosperity and national security purposes or will we continue to decline? ─ The choice is ours.

- The human resources are at hand within regional industry and within regional universities in every state and region across the country; the cause of the National Collaborative is right-on-target; and the projected impact is significant.

- The National Collaborative has demonstrated the passion, commitment and educational leadership to bring this major national initiative in professional engineering graduate education about. However, the National Collaborative can not do the job alone or without sufficient federal funding to implement the concept. The National Collaborative has gained widespread support, based on the impact that will be felt in every state from enhancing the innovative capacity of the regional industrial workforce. It's a 'win-win' situation, where industry grows, regional universities grow, our nation's degreed engineers grow to their full potential and the United States grows.

- Given the critical challenges facing our nation, this initiative is more important now in the current economic downturn than ever before to create jobs and to enable the nations' engineers in industry to compete in the global market for economic growth and sustain national security through innovative engineering. In many ways, the transformative effects of the National Collaborative initiative will parallel or equal returns from investment in science for basic research during the last decades. These returns are measurable and directly affect the U.S. economy and our ability to compete as a nation.

- We now are at a crisis and at a 'tipping point' when America must decide to innovate and invest in revitalizing our creative talent in engineering in industry to regain our competitive edge for engineering innovation. As the New York Times reports, "The competitive edge of the United States economy has eroded sharply over the last decade, according to a new study" from the Information Technology and Innovation Foundation which "found that the United States ranked sixth among 40 countries and regions, based on 16 indicators of innovation and competitiveness[February 25, 2009 Steve Lohr]." [22]

- America must regain its competitive edge. As President Obama has often said, our future international prosperity will depend on the United States becoming an "innovation economy [Lohr]." Although investment in specific technologies through the economic recovery package will have a vital positive impact to the nation's future, educational investment in the broader human resource development of the nation's engineers ─ who primarily bring forth new technology developments and innovations across all regions and industries of the nation ─ will have an arguably even greater positive multiplying national impact on the whole for our future competitive edge in innovation in all U.S. technology as a national resource.

- No longer can we afford to ponder the question … ***We must invest in our engineering infrastructure for innovation and better improve the graduate professional educational infrastructure that supports this vital national resource.*** As Charles F. Kettering, one of America's greatest engineers in industry often remarked in building America's competitive edge for innovation … "Look to the future ─ for that is where we will spend the rest of our lives."[23]

- Today, in troubled times. We must look to the future. And the time to invest in America's engineering strength is now. The U.S. engineering profession should become and serve as an example of leadership for innovation in the world … thinking globally, innovating locally in every region across the United States. Failure of America ***not*** to invest in rebuilding our engineering strength for innovation is not an option.

- The stakes are too high for our future economic growth and for our national security not to invest in the National Collaborative initiative. All it takes is a critical mass of those industrial and government leaders in the United States who understand that engineering is a process for innovation, and who ***will*** determine that this initiative must be done with their fervent support and adequate resources in the national interest. The National Collaborative initiative is educationally sound, cost-effective and attainable that will yield far reaching and multiplying effects to improve our U.S. competitive advantage and economic prosperity through investment in our people for years to come.

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Appendix: A

Stages of Professional Maturation, Autonomy, and Responsibilities in Engineering Practice for Responsible Technology Leadership

Stages of Growth	**Typical Responsibilities-Autonomy-Judgment**
ENGINEER IX	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.
ENGINEER VIII	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.
ENGINEER VII	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.
ENGINEER VI	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.
ENGINEER V	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 principal 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.
ENGINEER IV	Plans, schedules, conducts, or coordinates detailed phases of engineering work in part of a major project or in a total project of moderate scope. A 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.
ENGINEER III	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.
ENGINEER I/II (Entry Level Engineer)	Requires knowledge and application of known laws and data. Using prescribed methods, applies standard practices/techniques under direction of an experienced Engineer.

Appendix B

The Modern Paradigm of the Practice of Engineering for Creative Technology Development and Innovation Responsive to Real-World Needs of Industry and Society

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Needs ⇨ Engineering ⇨ Technology

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Directed Basic Scientific Research to gain a better understanding of natural phenomena when needed or anticipated during the technology development project

Appendix C

Action Plan for the National Demonstration Project to Transform Postgraduate Professional Engineering Education for Innovative Engineering Practice in Industry

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PHASE I: Definition Phase

Task #1: Define Progressive Growth Levels of Engineering Beyond Entry [I – IX]

Assess the progressive stages of growth and levels of increasing responsibility in the practice of engineering for leadership of responsible technology development and innovation in industry [See Appendix A]

Task #2: Identify Core Progressive Skill-Sets in Engineering for all Levels

Identify the professional skill-sets, experience factor, and knowledge required at all growth levels for engineering-leadership of technology development and innovation

a) Early-career Level I – III Engineer

b) Mid-career Level IV–VI Engineer

c) Senior-career Level VII–IX Engineer

Task #3: Integrative Framework of Professional Graduate Education and Practice

Define a coherent and integrative framework of high-quality, postgraduate professional engineering education that is combined with the graduate's ongoing practice of engineering for creative technology development and innovation in industry leading to:

a) The professional Master of Engineering (M.Eng.) at Level III Engineer

b) The professional Doctor of Engineering (D.Eng.) at Level VI Engineer

PHASE II: Curricular Development Phase

Task #4: Define and Align Professional Curricula to Support Progressive Skill-Sets

Define and align relevant professional curricula that match and support the progressive skill-sets, required of graduate engineers for engineering leadership of technology development and innovation from:

a) Early-career Level I – III Engineer

b) Mid-career Level IV –VI Engineer

c) Senior-career Level VII – IX Engineer

Task #5: Professional Course and Module Development

Develop core professional course materials, modules, seminars, independent studies, and provision for electives required to support coherent postgraduate professional engineering programs through:

a) The professional Master of Engineering (M.Eng.) at Level III Engineer

b) The professional Doctor of Engineering (D.Eng.) at Level VI Engineer

PHASE III: Organizational Development Phase

Task #6: Faculty Recruitment and Development

a) Recruit Distinguished Experienced Faculty

Identify and recruit a core cadre of experienced faculty from within the university combined with a core cadre of experienced, distinguished adjunct faculty from regional industry or government service who are capable to teach and help other experienced graduates learn in this mode of postgraduate professional education

b) Develop Faculty

Develop faculty through teaching workshops focused on attributes that enable experienced practicing professionals to further learn, grow, and develop to the next levels of excellence in practice [Conrad and Haworth]

Task #7: Recruitment of Graduate Practitioner Students in Industry

Recruit qualified, experienced degreed engineers within regional industry and government service who are qualified, capable, and want to continue their professional growth in the practice of engineering for responsible leadership of effective technology development and innovation relevant to their organization's or societal needs

PHASE IV: Implementation Phase

Task #8: Establish Regional Graduate Centers

Establish 5 – 10 high-quality Graduate Centers (Institutes) of Advanced Studies for Engineering Leadership of Technology Innovation in different states across the nation

Task #9: Roll-Out and Start-Up Operations

Roll-out and start-up operations of new high-quality programs of professional graduate engineering education in partnership with regional industry for pilot demonstration and replication across the United States

Task #10: Continuous Improvement and Replication

Define mechanism to continuously assess needs of degreed engineers within regional industry to develop a relevant dynamic professional curriculum for sustainable growth

Appendix D

Comparison of Integrative Framework for the Professional Master's of Engineering and the Professional Doctor of Engineering

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Professional Master of Engineering ─ For Creative Engineering Practice and Leadership
Level III Engineer – Skill-Sets / Outcomes

Focus: Professional Development of Emerging Engineer-Leaders in Industry For Creative Technology Development and Innovation at Project Engineering Leadership Level

- **Curricular Components Integrative with Creative Engineering Practice**

Core Professional Courses: 18 Credit Hrs.
Emphasis on the professional dimensions, knowledge, and critical skill-sets required in engineering practice (at Level III Engineer) for engineering leadership, professional responsibility, and creative problem solving at project engineering level for technology development and innovation in industry / government service. (Six Professional Courses)

Professional Electives: 6 Credit Hrs.
Emphasis on flexibility in tailoring program electives to be relevant to the participant's field of technology/or other professional needs to be selected by the participant with approval of oversight committee; including self-directed learning and independent study in special topics, as well as formal courses/modules. (Two Elective Courses)

Directed Technology Development Project: 6 Credit Hrs.
Emphasis on gaining real-world experience in creative problem-solving through project-based (problem-centered learning) focusing on innovation through a quality tangible experience of meaningful significance that is directly relevant to the technology development and innovation needs of the participant's sponsoring industry. This work should represent innovative development at the project engineering leadership level wherein the graduate participant is in responsible charge (Level III Engineer).

Total 30 Credit Hrs.

Professional Doctor of Engineering ─ For Creative Engineering Practice and Leadership
Level VI Engineer - Skill-Sets / Outcomes

Focus: Professional Development of Experienced Engineer-Leaders in Industry For Creative Technology Development and Innovation at Program and Policy Leadership Levels

- **Curricular Components Integrative with Creative Engineering Practice**

Core Professional Courses 12 Credit Hrs.
Emphasis on the professional dimensions, knowledge, and critical skill-sets required in engineering practice (at Level VI Engineer) for engineering leadership, professional responsibility, and creative problem solving at program and policy levels for technology development and innovation in industry/government service. (Four Professional Courses)

Professional Electives 6 Credit Hrs.
Emphasis on flexibility in tailoring the program electives to be relevant to the participant's field of technology or other professional needs to be selected by the participant with approval of oversight committee; including self-directed learning and independent study in special topics, as well as formal courses/modules. (Two Elective Courses)

Directed Technology Development Project: 12 Credit Hrs.
Emphasis on gaining real-world experience in creative problem-solving through project-based (problem-centered learning) focusing on innovation through a quality tangible experience of meaningful significance that is directly relevant to the technology development and innovation needs of the participant's sponsoring industry. This work should represent significant innovative development at program / policy levels wherein the graduate participant is in responsible charge at (Level VI Engineer).

Total 30 Credit Hrs.

Professional Master of Engineering (cont'd)

- **Professional Maturation Components**
  - **Residency Component**
    Full-time employment in engineering practice in industry/government service
  - **Progressive Experience Component Beyond Entry-Level**
    Minimum of 2 to 5 years of progressive experience beyond entry-level in engineering practice
  - **Technical Competency Component**
    Demonstrated growth from novice to competent professional in a specific technological field
- **Admission Requirements to Program**
  Graduate of ABET program in engineering; Minimum of at least 6 months beyond entry-level experience in engineering practice; Level II Engineer; plus strong letters of recommendation from the graduate participant's sponsor; or from distinguished practicing professionals in engineering; and the FE when appropriate

Professional Doctor of Engineering (cont'd)

- **Professional Maturation Components**
  - **Residency Component**
    Full-time employment in engineering practice in industry/government service
  - **Progressive Experience Component Beyond Entry-Level**
    Minimum of 6 to 10 years of progressive experience beyond entry-level in engineering practice
  - **Technical Competency Component**
    Demonstrated growth from competent professional to expert in a technological field
- **Admission Requirements to Program**
  Holder of the professional Master of Engineering (M.Eng.) degree or equivalent; six years of progressive experience in engineering practice beyond entry-level; Level IV Engineer; plus strong letters of recommendation from the graduate participant's sponsor; or from distinguished practicing professionals in engineering; and the PE when appropriate.

Appendix E

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

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First Levels ─ Technology Leadership

Early Career Development

[Levels I thru III Engineer]

Project Levels

Project Engineer Levels
Position Titles:

- □ Engineer III – Project Engineer
- □ Engineer II – Design Engineer, Development Engineer, Manufacturing Engineer, Process Engineer
- □ Engineer I – Entry Level

□ Core Characteristics ─

Degreed Engineers, at the first levels of technology leadership, grow from entry-level novice to fully competent experienced engineers:

- Performing non-routine assignments, assuming greater responsibility at project levels
- Growing in-depth competency of company knowledge relevant to projects, products, processes or operations technology
- Gaining real-world experience in the practice of engineering and use of the engineering method for:
  - ➢ Creative problem-solving for generating effective solutions to open-ended practical problems
  - ➢ Continuous incremental improvement, development and innovation of components within a subsystem or project technology

Mid Levels ─ Technology Leadership

Mid-Career Development

[Levels IV thru VI Engineer]

Program/Systems Levels

Senior Engineer Levels
Position Titles:

- □ Engineer VI - Functional Area Manager
- □ Engineer V - Senior Engineer Principal Engineer, Project Leader, Group Leader
- □ Engineer IV – Senior Project Engineer, Process Engineer

□ Core Characteristics ─

Degreed Engineers, at the mid levels of technology leadership, grow from fully competent engineer to fully competent engineer-leader for a functional technological area/program/system in responsible charge for:

- Gaining in depth expertise in needs-finding and planning, organizing, leading original development and innovation of large-scale complex projects / programs / systems within functional areas
- Growing in depth and breadth of company knowledge of complex programs and systems technology
- Gaining in depth competency in leading effective teams for collaborative creativity and innovation
- Gaining in depth competency in leading and 'championing' needs-driven technological change and innovation

Top Levels Corporate ─ Technology Leadership

Senior Career Development

[Levels VII thru IX Engineer]

Corporate Policy Levels

Executive Engineer Levels
Position Titles:

- □ Engineer IX **-** Vice President of Engineering and Technology
- □ Engineer VIII - Director of Engineering
- □ Engineer VII - Department Division Manager

□ Core Characteristics ─

Degreed Engineers, at the senior levels of technology leadership, grow from fully competent engineer-leader for a functional program / system area to executive engineer-leader with broad skills in responsible charge for:

- Building an overall corporate organization of trust and engineering purpose that fosters a culture for continuous learning and collaborative creativity for meaningful innovation to flourish
- Setting the overall values of corporate engineering for safety issues, environmental issues, financial issues, and socio issues
- Defining the mission, and goals of the technology organization
- Setting overall vision, technology policy, planning, and staffing for continuous technology innovation
- Allocating adequate financial and manpower resources to sustain the company's overall innovative technological thrust

Early Career (cont.)

[Early Engineering Levels of <u>known laws and data</u> under mentoring, guidance and supervision]

□ Core Competency
Skill-Sets as Defined by Tasks of Engineering Practice

- Gaining in depth competency of project / product / process technology
- Gaining in depth competency of creative problem solving
- Engineering ethics relevant to safety / environmental issues
- Concepts of systems engineering
- Project engineering management
- Knowledge of Six Sigma
- Communication skills
- Customer oriented
- Understanding of engineering methodology for innovation
- Understanding of financial metrics for investment in projects
- Self-directed learning skills

Qualifications for Entry Level Degreed Engineer [ABET] 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

Mid-Career (cont.)

[Mid Engineering Levels of <u>technical judgment</u>, decision making, tactical planning and responsible charge]

□ Core Competency
Skill-Sets as Defined by Tasks of Engineering Practice

- Gaining in depth corporate expertise of technical programs and systems technology
- Gaining in depth expertise in creative vision [invention, innovation, thinking out of the box] at program / systems level
- Gaining in depth expertise in systems architecture
- Engineering ethics relevant to technology / socio issues
- Expertise in technical judgment
- Gaining a systems perspective
- Systems engineering leadership
- Global perspective of technology and economic competitiveness
- Communication skills
- Needs-finding, vision and program formulation skills
- Strategic thinking
- Understanding core principles of business
- Understanding financial metrics of corporate decision making for investment in innovation
- Understanding root causes and scenarios of systems failures and their prevention
- Gaining expertise in learning skills of reflective practitioners ─ how professionals think in action
- Self-assessment skills for continuous professional improvement
- Awareness of emerging technologies and sciences
- Gaining expertise in people skills for leading effective innovative teams and collaborative creativity ─ what motivates / de-motivates creative engineers in actual work
- Understanding modern concepts of how creative engineers learn, grow / develop as professionals
- Understanding concepts of statistics and variations for continuous improvements
- Understanding concepts of operations research in planning and allocating resources for development programs

Senior Career (cont.)

[Senior Engineering Levels of <u>value judgment</u>, decision making, strategic planning, and responsible charge]

□ Core Competency
Skill-Sets as Defined by Tasks of Engineering Practice

- Broad overall knowledge of corporate systems technology
- Awareness of competitive technologies
- Strategic vision
- Engineering ethics relevant to technology / socio issues
- Value judgment
- Leading people
- Results driven
- Business acumen
- Building coalitions
- Corporate communications
- Technology policy making
- Integrity

Appendix F

The Modern Paradigm of the Practice of Engineering Yielding Technology Readiness Levels of New Technology for Real-World Needs of Industry and Society

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Technology Readiness Level (TRL)