

## R&D OPPORTUNITIES AND NEEDS FOR THE ECONOMIC TRANSITION

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Good evening, colleagues and friends. We are here because we are interested in science and technology and its impact on our organizations, our families, our country, and our world.

The “economic transition” of which I speak is the one that is evident if the United States is to succeed or even to survive in recognizable form. In recent years, the financial sector has accounted for some 40% of all profits in the United States, and this was clearly unsustainable. Like the tulip craze in Holland, or the recent Pu’er tea bubble in China, this was a bubble that could not survive. It may be a bubble that we cannot survive.

### WHERE WE HAVE BEEN—THE FISCAL MELTDOWN

The problem was (and still is to some extent) the generation of objects the only value of which is that they could be sold to someone else at a higher price than was paid for them. The higher price was justified only because it was imagined that the object or “instrument” would be of increasing value. We are all now familiar with the mechanism of this fiasco—which started with the transformation of simple mortgage loans from a bank to a home owner into a “securitized instrument.”

In order to have an instrument that looked like a bond and would not require detailed analysis on the part of the buyer, many individual mortgage loans were packaged into a mortgage-backed security—MBS-- and sold by the bank or more recently by a single-purpose organization, onto a market. Rating agencies, for a fee, provided an AAA rating, largely on the basis that many individual mortgages were bundled into a single MBS in this way, so that there was no sensitivity to an individual default.

Banks benefited from the securitization process because it provided enormously increased leverage. Instead of trading their capital for an income stream from a mortgage loan and gradual repayment, they immediately recovered their capital and could make additional loans, soon to be securitized and sold off. Single-purpose mortgage issuers

dealt with mortgage brokers who were paid “off the top” as mortgages were arranged, and were in many cases avid to provide mortgage loans, even at 100% of the cost of the house, and even to people with no income and no job.

A much larger financial bubble grew from the analog to ensuring a municipal bond against default, but in addition to the traditional bond insurance firms, this was taken up in an instrument that was exempt from regulation according to the Commodity Futures Modernization Act of 2000,

In addition to an initial purpose of insuring a purchaser against default by the bond issuer, many of the “credit default obligations--CDOs” or credit default swaps—CDSs-- were issued as pure bets. The New York Insurance Commissioner is quoted in the New York Times indicating that there were \$62 trillion of such obligations current, exceeding the GDP of all nations on Earth; he estimated that 80% of these were pure bets.

Whether there was any fundamental value underlying all this, there was certainly money to be made by one investor from another, and from the great American public, and following the Nobel Prize-winning Black-Scholes innovation in pricing instruments of given volatility, a substantial fraction of PhDs in Physics and Mathematics went into the financial sector.

#### IMPACT ON THE REAL ECONOMY

Furthermore, the greater return (profit) on investment in the financial sector sucked investment capital out of the real sectors of the economy, as well as diverting some of the best people. Salaries and bonuses exceeding \$1 million caused a lot of questioning as to why a person would want to have a job in R&D or be a college professor.

At a convocation on April 29, 2008, “Two Years Later” after the Academy report, “Rising Above the Gathering Storm,” discussants provided their assessment of progress since the 2007 report. Steve Chu, now of course our Secretary of Energy, said:

*“Many students, professors and scientists across the country are lining up and saying that the energy problem is a national and international crisis. They want to enlist, but the recruiting stations remain closed.” And “In constant dollars (adjusted for inflation), the budgets of the Department of Energy’s Office of Science from 2006 through 2008 were almost flat. For fiscal 2008, this meant that essentially no new proposals for solar energy research were funded by the DOE Office of Science, and many programs received cutbacks.”*

Arden Bement, National Science Foundation Director, noted,:

*“The four-year period from 2004 through 2007 may represent the first continuous decline in federal investment and basic R&D in colleges and universities in the past 25 years.”*

The FY 2008 appropriations bills, according to Norm Augustine, leader of “Rising Above...” represented a “systems failure,” with most federal research and development (R&D) programs receiving substantially less than requested in the President’s budget than in Congressional authorizations.

Not unrelated is the quote from Bill Gates in the New York Times of April 15, 2009, stating at one time that Microsoft’s biggest competitor was Goldman Sachs, “It’s all about I.Q., ... You win with I.Q. Our only competition for I.Q. is the top investment banks.”

## THE OBAMA REVOLUTION

Fortunately, the Obama Administration has as a top priority goal a massive increase in national (public and private) R&D funding, to exceed 3% of GDP. This will provide economic stimulus and, far more than most stimulus spending, is expected to pay off in societal benefit and national strength.

R&D can provide:

- A new way of doing something.
- A new something to do.
- A cheaper way of accomplishing a goal.
- A way to eliminate a whole stream of cost or hazard.

For business in a competitive field, cost reduction is a reasonable goal. But new products may be even more important. Corporate leadership and R&D managers have this difficult task of balance. But therein lies a trap of evaluation. Even big companies may have R&D results that could contribute much more to the benefit of the nation or of the world than to their own balance sheet, and many government agencies have programs or results that are more valuable to another agency or to commercial or social activities than they are to that agency. As a result of not counting benefits accruing to other organizations, we systematically under-invest in research. The well-told story of ARPA-Net evolving into the internet is a case in point.

I was much involved in the genesis of the Global Positioning System—GPS—when I chaired for the President’s Science Advisory Committee in the 1960s and early ‘70s the Military Aircraft Panel, the Naval Warfare Panel, the Aircraft Panel, and an Air Traffic Control Panel and served on several other PSAC panels. In the mid-1960s, we argued forcefully within the government in our often classified reports as to the value of GPS to the military. We saw clearly the potential for positioning military aircraft much more accurately and doing away with many navigation aids that would be trumped by the availability of GPS. Hence greater benefits and reduced cost.

We saw the possibility of clearance of naval mines in narrow paths and the following of those cleared paths by ships using GPS in the trackless ocean.

## THE HAZARD OF RESONSIBLE REVIEW

In the context of air traffic control, we had a hardware study done by TRW that indicated that a key element of the GPS receiver-computer could be built with the technology of the early 1970s for \$1300. One of the government agencies commissioned a study of our proposed approach that indicated a cost of \$200,000, but when we met with the review group, it turned out they had not done a hardware assessment at all, but simply a regression analysis on other ways of achieving navigation accuracy and “fix time” that showed that a system of the performance that we were addressing would by these other techniques cost \$200,000. Challenged as to why this was relevant, the group responded that if our proposed system did not succeed, we would have to fall back on other technologies. Instead, we had proposed to use an important management tool—cancellation of the program.

## INTERNAL COMPETITION IS DESIRABLE

In my own experience with managing R&D, I had learned from Bill McLean, a long-time member of the PSAC Military Aircraft Panel and legendary Deputy Director of the Naval Weapons Center at China Lake, CA. Bill McLean made it a rule to have a secondary program with the same goals as his primary development program, funded at 10% of the level of the principal approach. This has several benefits:

- It provides a standard to keep the main program honest.
- It provides an option if the main program fails.
- It spurs competition and pace of the program.

As late as 1980, I had pressed the head of the uniformed Air Force, General Lew Allen, to move ahead with GPS; instead, he reprogrammed the entire \$2 M GPS allocation to another purpose, perhaps counting on restoration of funding by Secretary of Defense Harold Brown and Under Secretary for R&D Bill Perry. And when I later pleaded with the Joint Chiefs of Staff in the “tank” the Chief of Naval Operations said “Dick, I don’t have \$50 M, and if I did, I would spend it on a ship.”

## INNOVATION

We have needs for innovation across our entire society—in defense and national security, in healthcare and wellness, and in energy and education. Part of the solution is to reward innovation as we tend to reward invention. In fact, the Obama administration speaks of “Science, Technology, and Innovation,” which I think is an important step forward.

Many companies have formal invention award plans, which provide recognition and monetary reward for patents or even for filing an Invention Disclosure. Those are useful, but there should also be specific recognition for those who bring into their companies or into their divisions technologies or approaches that have been pioneered elsewhere. Too often, individuals are averse to adopting innovation or best practices from elsewhere, to the extent that they intentionally or unintentionally remain unaware of such options.

## AN ALTERNATIVE TO PATENTS

Often the interest of the government or of a major corporation is to have freedom to use a discovery or invention, rather than to earn income by precluding others from using it without permission and fee. In recent years I was trying to accelerate the availability of a guided bullet to the U.S. military forces, and found a promising program in one of the national laboratories, but it was moving slowly in order to obtain patent coverage so that the U.S. would be assured of the freedom to use the technology. It turned out that the engineer who led that program (like most engineers and scientists) was unaware of the existence of the “Research Disclosure Journal,” one of several periodicals of record that invites publication of camera-ready pages at a charge of \$110 per page. No review, no acceptance criteria, and the RDJ is searched by all patent examiners to determine the novelty of a later claimed invention. These disclosure journals even accept anonymous disclosures, so that a corporation can conceal its interest in a specific field.

“Rising Above ...” recommends improvements to the U.S. Patent and Trademark Office (USPTO) and to the patenting process. But sometimes the most urgent and valuable innovations merit dispensing with the patent process. For instance, when IBM scientists at the Zurich Laboratory invented the scanning tunneling microscope, IBM asked its Science Advisory Committee, largely composed of outside scientists, for its recommendation as to the approach to be taken. IBM decided that this enormously powerful technology should not be delayed for the patent process, which, properly done, would have included a large amount of internal work to patent also alternative approaches. And it can hardly be argued that the world was worse for this decision.

## LESSONS FROM THE FAST FOURIER TRANSFORM

Similarly, when I served as midwife to bring to reality the Fast Fourier Transform of John Tukey and Jim Cooley in 1963, there was no thought of IBM patent or copyright on the approach. Instantaneous cost reduction by many orders of magnitude followed, because the FFT required a number of multiplications that was  $N \log N$  rather than  $N \times N$ . For a large dataset of  $n$  numbers, only  $\log N$  multiplications would be required per point, whereas, previous approaches required  $N$  multiplications.

For the problem I had in hand, of determining the spatial spin wave on a lattice of 20,000 He-3 spins, the speedup was by the ratio  $(20,000/(\log 20,000))$ . So we had a speedup of about a factor 2000 in this case. Fewer computers would be bought, you might ask? Absolutely not, because very few people had previously done Fourier Transforms on datasets of 20,000 points, and now it became conventional to do the FFT on a million points or more.

Indeed, the Discrete Cosine Transform—DCT—related to the FFT, underlies essentially all of the video compression used in digital TV. On an high-definition TV frame of something like 1.5 mega pixels, the FFT can be done with about 20 million operations, whereas the old-fashioned FT would have taken about 2 trillion.

Indeed, after the Cooley-Tukey algorithm was available, I wrote scores of personal letters to scientists and engineers whose work in the literature would appear to benefit from it—in fields as varied as radio astronomy, submarine detection, spacecraft vibration analysis, and seismology.

Did I really need the FFT for my experiment? No. By the time the FFT was ready (after a couple of months) I had already found a totally different way to solve my problem—by an efficient computer algorithm that I had used for reducing experimental data, applied to the energy vs.  $k$ -vector of the assumed spin wave. But it was clear that the FFT would have enormous benefit to many U.S. government programs and obviously to scientific research in general.

It turned out that the FFT had deep roots and had even previously been used. The history of this important advance and its puzzling delay in adoption was explored in a 1968 Arden House workshop on the FFT and published in the June 1969 IEEE Transactions on Audio and Electroacoustics. Evidently we are in a different world today, with the ubiquitous PC and, even more, viral marketing of applications for the Apple iPhone. But despite my efforts to spread the word, there is a no-cost tip that will greatly improve your effectiveness at internet search, still unknown to the majority of you. So if the adepts will bear with me, I'll take a minute to make it worthwhile for the rest of you to have listened to me.

## THE “SITE:” PARTICLE

(4 Slides)

## NUCLEAR POWER

Reducing the FFT to practice was an example of non-system-specific advanced development. We do far too little of that in this country. That is the sort of work that was proposed by several committees chaired by John P. Holdren as a member of previous President's Council of Advisors on Science and Technology (PCAST), in the context of energy R&D, and in particular R&D on fission energy.

The purpose was not so much to support the deployment of new reactors, but to provide better understanding of the options for nuclear power.

Right now, about 20% of U.S. electrical power comes from nuclear reactors, and we know how to build them. At least, there are people and firms who have built nuclear reactors in recent years, although not in the United States.

Tremendously important, though, is informed analysis, as contrasted with R&D. That is, buyers and users need to model and to simulate their possible options. Some oppose the use of nuclear power because of its potential for the proliferation of nuclear weapons to additional states or to terrorist organizations. Others oppose it because of the potential

for large-scale accidents or its vulnerability to terrorist attack. The nuclear power sector, however, is not homogeneous. Reactors themselves, if they operate with leased fuel so that there is no need for enrichment and no need for disposal of spent fuel locally, do not contribute to nuclear proliferation.

To be brief, I recommend the equivalent of a world breeder reactor laboratory, with the purpose of working on three quite specific choices of breeder reactor, including their fuel form and fuel cycle. This laboratory would develop and use an advanced and evolving state-of-the-art suite of computer simulations tools, with the purpose of providing reliable simulation and modeling of the performance of each of the reactor types. If, after 10 or 20 years, the effort yielded a proposed system that was demonstrated in credible simulation to be as safe as existing light-water reactors and economically competitive with them, then a prototype could be built to verify the simulations. I believe that this is the way to make progress most rapidly in this important sector, but it is, obviously, only one of the approaches that we could have been following all these years, and it won't help at all for 15 years or more..

Do we need a “Manhattan Project” to wean the United States from imported oil or from fossil fuels in general? I think that some aspects of the analogy are defective, since the Manhattan Project had a single goal, of providing nuclear weapons at a time when it was highly probable that enrichment technologies for production of highly enriched uranium had been identified, and that the reactor option for the production of plutonium would succeed. This was, however, shortly before Fermi's demonstration in Chicago of the chain reacting pile

#### URANIUM FROM SEAWATER.

More than 400 power reactors in the world today provide more than 300 million kW of electrical output, about 15% of the world's electricity supply. Each of these reactors fissions about one ton of U-235 per year, obtained from about 200 tons per year of natural uranium per reactor. So the world's nuclear power complex at present “burns” about 0.06 million tons of NU per year. To make even a modest contribution to reducing the output of carbon dioxide, the world's power reactor population would need to grow by a factor three to ten. Even a threefold increase would now burn about 0.2 million tons of NU per year, and the assured “reserve” is about 4 million tons of uranium—evidently inadequate to fuel reactors for expected 60-yr life. Economic geology argues that far more uranium of lower grade ore will be found at producible and affordable prices, but as we see from experience with oil, oil producible at less than \$20/bbl has sold for \$140/bbl in the last year or so.

Nevertheless, it is important to understand the availability of uranium and, if possible, to set a cap on the cost of production. In this regard the tiny concentration of uranium in seawater—3.3 ppb—amounts to 4000 million tons of uranium in the oceans of the world—a thousand times greater than the 4 million tons of reserve.

Programs for reprocessing of spent fuel have been active in France and have been done technically very well. Japan is following in this mode, with a reprocessing plant at Rokkasho-mura that has cost more than \$20 billion and that has a capacity to treat 800 tons of spent fuel per year. If this reprocessing cost is ascribed to saving uranium input (and it can save almost 20% of the uranium otherwise required) it does so at a very high price of more than \$1000/kg of uranium saved. In fact, the previous administration introduced in February 2006 the Global Nuclear Energy Partnership (GNEP) program, that, in addition to its international objectives of providing reactor operators with an assured supply of fuel and the disposition of spent fuel, was to begin reprocessing the currently arising spent fuel from the 103 domestic U.S. nuclear power plants. Suffice it to say that “domestic” aspect of GNEP had certainly not been thought through and is no longer with us. More can be found in my congressional testimony of April, 2006.

The uranium resource of the oceans is very dilute, and it is quite possible to expend more energy on extracting the uranium than could be returned by fission in a light-water reactor. But Japanese work over the last few years has demonstrated attractive approaches, by which ion-exchange resin in the form of non-woven fabric is moored in a warm ocean current. After a month’s immersion, it has been demonstrated that 1 kg of polyethylene-based resin accumulates 1 g of uranium, which can readily be extracted by elution with dilute acid, restoring the resin to its receptive state for another cycle in the ocean.

The U.S. should explore the cost of uranium from seawater not so much in the expectation of large production from that source, but to have a limit on what might be paid to save uranium by reprocessing or even by the use of fast breeder reactors. Such exploration needs to evaluate direct costs but also, from the first, environmental impacts—costs and benefits—such as the inevitable drag on the warm current (e.g., the Gulf Stream) resulting from the much larger fraction of momentum removed than of uranium removed. Insightful evaluation of the influence of this drag should be done now, rather than after learning uranium from seawater direct costs.

#### DETAILS OF TRANSMISSION OF DISEASES—e.g. INFLUENZA.

A few years ago, I joined with others to try to understand how to meet the challenge of avian flu if it should become highly transmissible among humans. Looking at general features of epidemics, usually characterized by a reproduction factor  $R$  and a reproduction interval  $I$ , we were interested to find that  $R$  of 2 or 3 appeared to be common, raising the possibility that a pandemic could be conquered (prevented) with non-specific, non-pharmaceutical measures. Of course, the most effective approach is a proper vaccine, but in the absence of substantial vaccination, it should be possible essentially to eliminate a pandemic by reducing the reproduction factor below unity.

We looked at this in the case of intentionally induced contagious disease by terrorist act, and also natural disease. We were appalled to learn that not much more was known about practical measures than was available in the influenza epidemic of 1918-19. There seemed to be no good evidence or consensus as to whether ordinary seasonal influenza is

spread by droplets, by aerosols (that is, particles so small that they remain suspended for minutes rather than falling to a surface in time of order of seconds) or by transmission from objects in the environment to the hand, and then to the nose, mouth, or eyes.

Protective measures are different for these different paths, and the reason for continued ignorance is perhaps because this knowledge is not at the cutting edge of science. However, it is tremendously valuable for society to acquire it.

In these days of burgeoning swine flu in Mexico, and a small foothold thus far in the United States, it is important for people to be informed how best to protect themselves. Our report from the Center at Erice, Sicily, recognizes that understanding effective protective measures is a small part of the solution. The advice must be agreed by authorities, encapsulated in effective messages, transmitted and made available when needed, tested in the population in various languages and customs. Since one person, family, or school cannot fully protect themselves against an epidemic by their own actions, there needs to be some persuasion or even enforcement of measures taken to reduce  $R$  below one. In that case, the epidemic itself could be conquered, in the sense that a few hundred cases traveling to the protected society might result in a total of 1000, rather than in tens of millions. Whether society can maintain the discipline to do this is far from clear.

## SIMULATION AND MODELING

The vast scope of federal funding for R&D means that I know almost nothing about most of it. On the other hand, there are tools that are generally applicable, and these should not be neglected. We need to expand funding of the very best young people, especially in small-scale research projects that may, however, be pursued in an institution that provides modern tools for nanotechnology, characterization, and the like. Small effects such as radiation pressure of light, not important under most circumstances, brought us in 1952 the hydrogen bomb and more recently the ability to manipulate and to measure microscopic entities and biological molecules. It provides the capability not only to determine accurately the position of an object but to fix it in place more securely than if it were held by a steel support.

Relatively new tools, with much improvement still to be made, are those of modeling and simulation. When I served in 1969 on the New Technologies Panel of the National Commission on Health Manpower, I and others recognized that the health-care non-system needed to be understood and to be transformed, but to what? In fact, it is often easier to engineer an artificial system than to understand a natural system. Applying constraints may, in principle, limit the performance of the system below optimum, but it is likely, on the other hand, to allow achieving performance far better than normally exists in the absence of constraints.

The Boeing 777 aircraft was designed **\*\*RLG check.\*\*** without blueprints or even whiteprints. This enabled design teams in different parts of the country or the world to share and update design documents and specifications. Turbine blades can be designed

with an otherwise free surface allowed to shape itself to maximize a measure of performance. When I was involved a few years ago in trying to understand what could be done about as possible influenza pandemic, I was much impressed by a simulation by Tim Germann, et al., from Los Alamos, which I will now show briefly.

SLIDES: “Day 50; Day 90; Day 130”

*It's probably not going to be practical to contain a potential pandemic by merely trying to limit contact between people (such as by travel restrictions, quarantine or even closing schools), but we find that these measures are useful in buying time to produce and distribute sufficient quantities of vaccine and antiviral drugs,” said Germann of Los Alamos’ Applied Physics Division.*

*“Based on our results, combinations of mitigation strategies such as stockpiling vaccines or antiviral agents, along with social distancing measures could be particularly effective in slowing pandemic flu spread in the U.S.,” added Longini.*

## SIMULATION AND MODELING FOR PUBLIC POLICY

Although modeling and simulation is widely used now in engineering design, such as the 777 aircraft, and it is sometimes used in crude form in making a business plan for a product, its use in the public sector is far less well developed. Had the California legislature had the benefit of a reasonable simulation of the electrical supply and consumption system in California at the time it deregulated electrical supply for that state, it could have avoided being held victim by Enron and other intermediates and suppliers.

Similarly, when we were studying in 1977 the role of nuclear power in the U.S. electrical supply, a simple conceptual model included only a single energy sector. So if the price of nuclear power increased, the usage of nuclear electricity decreased, and so did that of all other forms of electricity! That was soon remedied, with the not very surprising result that when the price of nuclear electricity increased, the usage of other forms of electricity went up, instead of down.

In my work on air traffic control, I visited an FAA facility in Atlantic City, where there were hundreds of individuals sitting at desks or tables simulating pilots of individual commercial or general aviation aircraft. They would navigate their “airplanes” and maintain voice communication with actual air traffic controllers, and in this way the “human element” could be injected into the system simulation. It would have been good to have characterized the performance of these individuals (who had received brief instruction as to what they should have been doing) so that they could all have been simulated by a computer. But this should not be a one size fits all simulation. It ought to be sufficiently flexible so that individuals (even summer interns) could provide different characterizations of some of the people, as would be desirable for people finding out how to “game” the system of electrical power supply deregulation or, for that matter, the financial “derivatives” that have caused such havoc to our overall system.

The fact that these derivatives were exempt from regulation as a result of the 2000 Act should not have prevented analysis and simulation of the system, which could, then, have

led to further congressional legislation to have prevented the harm foreseeable from the 2000 Act.

## MODELING THE U.S. “STEM” EDUCATIONAL FLOW

The loss of interested and capable students from the Science, Technology, Engineering, and Mathematics field is currently a major concern. System dynamics is being applied to the stocks and flows of students and teachers by a group at Raytheon with the sponsorship of the Business-Higher Education Forum—BHEF—in an effort to evaluate the impact of parameters such as class size, teacher pay, and teacher quality. The computer model is to be made available as open-source software in Summer 2009 after its initial validation.

## CONCLUSION

Modeling and simulation has finally come into its own. It remains to be seen whether this new currency will be properly valued. Not only do the models need to be challenged and validated, but the assumptions need to be carefully inspected

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