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PHYSICS & SOCIETY

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Editor's Comments

We have a rich array of material for this edition of P&S. We open with some words from incoming Forum Chair Puspha Bhat on the role of FPS in serving the physics community and some ideas for future initiatives. Also in Forum News, elections to the FPS Executive Committee will be complete by the time this edition reaches you, but we record for posterity the statements of candidates. Jay Davis's article on nuclear downsizing in our January edition stimulated a letter to the Editor concerning some of the personalities and political pressures involved with the campaign to achieve "global zero" nuclear weapons. This long-term issue will surely be the source of commentary in P&S for decades to come. Indeed, one of our feature articles for this edition concerns possible Iranian nuclear ambitions.

This year marks the fortieth anniversary of the founding of the Forum on Physics & Society, and in our first feature article David Hafemeister – who was "present at the creation" – summarizes the history of the Forum. Our second feature article, by long-time contributor Wally Manheimer, examines how proposed atmospheric carbon-reduction scenarios could have adverse effects on the developing world, and examines possibilities for large-scale carbon-free energy sources over the coming decades. Our third feature article by Chris Hobbs is particularly timely. As I was preparing this issue it seemed that almost daily there was a fresh news headline regarding Iran's possible nuclear weapons ambitions and what should be done about them. Chris ably summarizes the November, 2011 report of the International Atomic Energy Agency on the issue.

In our book review for this edition Paul Craig summarizes papers given at a renewable energy conference held at Berkeley in March, 2011. We hope in future editions to run abridged versions of some of the papers from the conference; Paul's review makes for a nice teaser.

As always, we welcome your comments and input.

— Cameron Reed

IN THIS ISSUE

FORUM NEWS

Statement from the Incoming FPS Chair

Pushpa Bhat, Fermilab (pushpa@fnal.gov)

We live in a rapidly changing, highly interconnected and interdependent world. Science shapes our society, defines and refines our destiny. With the pace of scientific progress and innovation accelerating, science and technology issues will continue to be of ever-greater importance. Scientists have an obligation and a duty to inform and interact with society at large in guiding how the ideas and tools of science are used. The APS Forum on Physics and Society, therefore, should play a leading role in the important discussions about science and society that lie ahead.

The Forum on Physics & Society (FPS) is celebrating its 40th anniversary this year. This is a good time for us to make an effort to renew and reenergize the Forum to build a stronger future.

Over the past four decades, the FPS has been serving the physics community through activities on a variety of physics & society issues such as organizing plenary sessions at the APS annual meetings; periodically sponsoring studies, short courses and workshops on specific topics; and through the publication of its quarterly newsletters. These activities should be continued. It is also necessary that the FPS adapts to the times, and the needs, so that it is able to fulfill its role, on a continuing basis, as a facilitator of healthy dialogues about the most pressing issues of physics and society. In addition, I would like to set as a goal more direct engagement of the physics community with the broader societal issues. I outline below some new initiatives to accomplish these.

First of all, I would like to urge the FPS members to volunteer to participate and help drive the Forum's plans and activities. We are in the process of implementing a web page at the FPS website, to enable APS members to provide ideas/input/feedback and to volunteer for tasks. (Please feel free to email me with suggestions at pushpa@fnal.gov.) Some ideas and activities that I have previously advocated are: (1) The FPS could set up task forces and sponsor/support studies to develop solutions for problems and find ways to get them adopted and implemented. We could solicit collaboration of other APS units whenever there are overlapping interests. (2) The FPS could work with regional sections to hold town halls or events on topics of relevance at regional APS meetings with the help of member volunteers to engage the broader community of physicists and the general public in such discussions. (3) The FPS should also more pro-actively identify and recognize individuals who contribute to make societal impacts through promotion to fellowships in the society and through prizes/awards. We could also encourage and sponsor talks by the awardees and fellows on their work at institutions across the country.

One important activity of the Forum, as mentioned earlier, is the organization of several sessions at the annual APS meetings. As the Chair-Elect of the Forum for 2011-12, I served as the FPS program committee chair for the upcoming April 2012 meeting in Atlanta. Our March meeting programs in Boston, chaired and coordinated by Brian Schwartz, were well attended. By the time this newsletter is released, the April meeting will be underway, and there are several excellent FPS sessions scheduled. If you are at the meeting, please come and celebrate 40 years of FPS at the "Forum at Forty" session on Saturday, March 31st which features talks on the past, present and the future, and join us for an FPS-hosted reception. We also invite you to come and participate in the discussions at our "American Science & America's Future" panel session with Neal Lane, Jim Siegrist, Tim Hallman and Frank Wilczek. I hope that this discussion will provide us with ideas for action; action that we, as citizens, scientists and leaders, should undertake to help strengthen the science & technology enterprise in the United States so that the US can retain its competitive edge and scientific leadership in the global society of the 21st century. I hope to see many of you at these sessions and at the FPS business meeting. I also very much look forward to hearing from and working with many of you and the executive committee members on the FPS activities in the coming year.

The APS Forum on Physics and Society, through proper engagement, volunteerism and actions, can make a difference. It can and should play a role in the grand human endeavor to create a better world: a world with a culture that is based on reason and evidence; a civilization that is adventurous yet peaceful and prosperous, committed to universal values such as honesty, integrity, social justice, decent standards of living for all people, and caring for the planet that belongs to future generations as much as it belongs to us; a society where science is done for its own sake as well as for the benefit of humanity.

Candidates for Forum Executive Committee Positions

[Editor's note: Voting for positions on the Forum's Executive Committee will be complete by the time this edition of P&S goes to press. We record here for the record candidates' backgrounds and statements.]

VICE CHAIR

(Vote for no more than one candidate)

Richard Rowberg

Background: Dr. Rowberg is currently Deputy Executive Director for the Division of Engineering and Physical Sciences (DEPS) of the National Academy of Sciences. He has served at NAS since 2002. In 2001 he retired from the Congressional Research Service of the Library of Congress after serving there for 16 years. From 1994 to his retirement, Dr. Rowberg was a Senior Specialist in Science and Technology with the Resources, Science, and Industry Division, and from 1985 to 1994, he was Chief of the Science Policy Research Division of CRS. From 1975 to 1985 Dr. Rowberg worked for the Congressional Office of Technology Assessment where he was manager of the Energy and Materials Program from 1979 to 1985. From 1975 to 1979 he served as an analyst in and deputy manager of the OTA Energy Program. Before coming to Washington, Dr. Rowberg was a research engineer and adjunct assistant professor in the Department of Electrical Engineering of the University of Texas at Austin from 1969 to 1974. He received a BA in physics from UCLA in 1961, and a Ph.D. in plasma physics from UCLA in 1968. In 2010, Dr. Rowberg was elected a Fellow of the American Physical Society.

Statement: I joined FPS early in its life when I was at the Office of Technology Assessment. It was a natural association given my work in science policy and my physics Ph.D. For the remainder of my career at OTA, the Congressional Research Service, and now at the National Academy of Sciences, I have been a member of the FPS. I have been closely involved with many of the issues that have been the subject of FPS efforts and that have been addressed in Physics and Society. lf elected vice-chair, a major responsibility will be to maintain the strengths of the FPS. The engagement of the FPS through its various activities in critical science-driven public policy issues needs to continue as intensely as ever. The reputation of the FPS as an honest forum for debate about science in society is critical; many people have spent many years developing that reputation. Tension between the public and science-and even among scientists-appears to be growing in some areas. The increased politicization of important issues such as climate change, energy development, and environmental protection, and increasing austerity facing the Federal government are among the key reasons. I believe that FPS can play an important role in addressing that tension by engaging all sides of the debate about the role and behavior of science in these policy issues just as it has in addressing the substance of the issues. If elected, I would want the FPS to address the contribution of physics research to the cultural advancement of human kind. The direct contributions of physics to the well-being, health, and security of society are naturally very important and the focus of much of the FPS activities. The contribution to the understanding of the world and how it works for its own sake are also critical to all of us. Indeed it is likely that those contributions will be the things most remembered about our time. When much of our basic physics research focuses on those areas, engaging with the public about the cultural value of that research-especially in these periods of growing budget constraints-will be important for both science and the public. This engagement should be part of the FPS mission.

Micah Lowenthal

Background: Micah Lowenthal is the director of Committee on International Security and Arms Control (CISAC) at the National Academy of Sciences (NAS). He has worked at the NAS since 2001, serving as study director and supporting staff on over a dozen studies ranging from nuclear forensics and screening cargo for nuclear and radiological material to internationalization of the nuclear fuel cycle and U.S.-Russian cooperation on nuclear nonproliferation. He received the National Academies Distinguished Service Award in 2008. Previously Dr. Lowenthal was a lecturer and researcher in nuclear engineering at the University of California at Berkeley, working on design of both fusion and fission energy systems, as well as radioactive waste. In 1996, he was an Environmental Science and Engineering Fellow of the American Association for the Advancement of Science. Dr. Lowenthal holds an A.B. degree in physics and a Ph.D. degree in engineering from the University of California at Berkeley.

Statement: Physicists have for many decades helped leaders and society to understand a variety of issues with underlying technical components, ranging from national defense to energy and environmental damage. Nuclear technology has been the focus of my own work and has been the impetus for much of the engagement of physicists in societal issues, both to reap the enormous potential benefits and to prevent

or mitigate the similarly enormous potential harm that can be wrought with nuclear technology. Physicists have made pivotal contributions to understanding stratospheric ozone depletion and acid rain and are central to efforts to understand global climate change. Energy benefits, consequences and options have also been examined closely using the intellectual tools of physics. Not only does physics helps us understand the underlying physical phenomena, but as a discipline, physics provides a structured way of thinking about problems. The Forum on Physics and Society, its newsletter, and its sessions at the APS meetings show the value physics and physicists bring to societal issues, and it is important for both physicists and society that the Forum keeps up this work, both to inspire and inform. There are many more options today for scientists to contribute to policy discussions than were available when the Forum began. For example, the AAAS Science and Policy fellowships have enjoyed enormous success and whole academic programs focused on the interface of science and policy have arisen. The need for well-grounded scientific analysis in support of policy has grown, too, and continues to outpace the supply, so the Forum may have a more important role than ever before. We want to inspire physicists at every career stage to explore the societal implications of their work and to engage in helping society to grapple with our rapidly evolving natural and technological environments. The Forum should also continue to gather experts to discuss and, starting from a scientific foundation, debate a wide range of important issues that face society today and in the future. There is much more work ahead and I would like to see the Forum taking on the challenge.

MEMBER AT LARGE

Vote for no more than two candidates

Lawrence Krauss

Background: Lawrence M. Krauss is Foundation Professor and Director of the Origins Initiative at Arizona State University. He moved to ASU in 2008 from Case Western Reserve University, where he was Ambrose Swasey Professor of Physics, Professor of Astronomy, and Director of the Center for Education and Research in Cosmology and Astrophysics. He received his Ph.D. in Physics from MIT in 1982 then joined the Harvard Society of Fellows. In 1985 he joined the faculty of Physics at Yale University, and moved to CWRU in 1993. From 1993 to 2005 he also served as Chairman of the Physics Department. He is a Fellow of the APS and of the AAAS and the author of over 300 scientific articles, as well as numerous popular articles on physics and astronomy. In addition, he is the author of nine popular books, including the international bestsellers, The Physics of Star Trek, and A Universe from Nothing. In addition to his newspaper commentaries, he appears frequently on radio and television around the world and is a commentator for various magazines. He has testified before Congress on issues ranging from Space Exploration to support of science research in general. Prof. Krauss is the recipient of numerous awards including the AAAS 1999-2000 Award for the Public Understanding of Science and Technology, the 2001 Julius Edgar Lilienfeld Prize of the APS, the 2002 Andrew Gemant Award from the AIP, the 2002 AIP Science Writing Award, the Oersted Medal of the AAPT, and in 2005, the APS's Joseph P. Burton Forum Award for his work on Science and Society. He has been particularly active in issues of science and society. He serves on the steering committee of Science Debate 2012 and was Chair of the Forum on Physics and Society for the APS, and Chair of the Physics Division of the AAAS, and is Chair of the Board of Sponsors of the Bulletin of the Atomic Scientists, and serves on the Board of Directors of the Federation of American Scientists.

Statement: The interface of Physics and Society is of profound interest to me, and I have devoted a substantial fraction of my time as a physicist to promoting public welfare, and public education. I have had extensive experience with the Forum and with the APS. I served as Chair of the Forum and twice served on the Panel of Public Affairs of the APS. Thus I believe I am in particularly good position to serve on the FPS executive committee as I am fully aware of the ongoing issues that have governed activities in the Forum over the past few years. In addition, my longstanding interest and activities associated with physics and society should help me provide valuable perspectives for the Forum, as well as useful connections to other organizations. I am excited about the possibility of being able to continuing to contribute to the Forum and its activities.

David Kulp

Background: David Kulp is an AAAS Science and Technology Fellow in the Office of the Assistant to the Secretary of Defense for Nuclear, Chemical & Biological Defense Programs. He earned his PhD in physics at the Georgia Institute of Technology, leading experimental teams at national laboratories to elucidate the internal degrees of freedom realized in the atomic nucleus through gamma-ray and particle spectroscopy. His MS in physics is from Emory University, where he studied fractal surface growth. A Trident Scholar and graduate with distinction from the United States Naval Academy, David's undergraduate research employed ion beam analysis in the characterization of archaeological artifacts. A

former Chair of the User Executive Committee at TRIUMF, Canada's Laboratory for Particle and Nuclear Physics, David served on multiple committees at the laboratory, including the Subatomic Experimental Evaluation Committee and the Writing Committee for TRIUMF's Five-Year Plan. As an advisor to the IAEA International Network of Nuclear Structure and Decay Data Evaluators and the U.S. Nuclear Data Project, he has firsthand experience with the direct benefits to society from basic research in nuclear science, applied research in nuclear technology, and from cooperative international exchange of nuclear data. A past Fellow in the Sam Nunn Security Program at the Georgia Tech, David's recent work has focused on the detection of special nuclear materials, the development of nuclear forensics, reducing the availability of nuclear and other radioactive source materials for use in weapons, and reducing the threat of radiological and nuclear terrorism.

Statement: Physicists have critical roles to play in society, including performing basic and applied research, educating the public, and informing policymakers about science and technology. Through its newsletter, meeting sessions, and short courses, the Forum on Physics and Society explores topics in national security, energy, education, space, the environment, and other areas where science can inform public policy. These topics are sensitive enough that political leaders have so far avoided participating in a Science Debate based on fourteen questions posed by the American science and innovation community. Yet the issues are of widespread interest to the public and significantly important that informed debate needs to take place, and the Forum provides such a venue for physicists to engage in discussion across disciplinary lines. If I am elected, I will work to stimulate further informed discussion by encouraging academic outreach beyond teaching and publishing, such as participation at the community level through local school science nights and science fairs. I will work within the APS to draw more active members into the Forum for discussion, and work with other scientific societies to raise awareness of the need for open discussion of science policy and issues where science informs policy. I will also work to stimulate action beyond the Forum, working with the Executive Committee to convey the interests of the Forum to the public and engage policymakers to look to our membership for scientific opinion on critical issues.

Douglas Wright

Background: Douglas Wright is an experimental high energy physicist who has, over the past twenty years, combined a conventional career in basic science with applications of radiation detection for national security. He leads the LLNL collider physics efforts at the LHC (CMS) as well as an experimental program to demonstrate the capability of bremsstrahlung gamma-ray beams to detect terrorist nuclear weapons. He received a B.A. in physics and mathematics from the U. of Pennsylvania in 1983 and Ph.D. in physics from Princeton University in 1993. He lived at CERN for two years while completing his Ph.D. and then joined LLNL to work on an SSC experiment. He went on to lead physics and detector efforts at SLAC (BABAR), Fermilab (MINOS and MIPP), and CERN (CMS), was group leader for HEP at LLNL for eight years, and is now Program Development Leader of Nuclear/Particle Physics at LLNL. Over this same time period, he worked on a novel technology for using proton accelerators to dynamically image implosions and helped develop advanced gamma-ray imaging detectors for nuclear non-proliferation applications. He created and distributes open-source physics simulation software used by the broader radiation detection community. Currently he leads the experimental test program for the first practical active interrogation system for detecting terrorist nuclear weapons at significant stand-off distances.

Statement: I am fortunate to have had the opportunity to work closely with scientists and technical leaders in radically different arenas: from the purely academic community and international accelerator laboratories, to multiple government entities in DOE, DHS, and DOD, and private industry both large and small. From this broad exposure I have learned two extremely important lessons. First, the necessity of establishing trust with decision makers, since they are constantly bombarded by opinions from many sources with varying agendas. Second, that understanding and addressing the practical implementation and political realities are just as important as the scientific details. While we often focus on outreach, to educate the public or high-level policy-makers about scientific truths, I believe that we also need to build bridges of trust at multiple levels between decision makers and the scientific community via continual and consistent contact. This is also a two-way street. We the scientific community need to learn about the practical realities facing those whom we counsel and craft solutions that address both the technical and non-technical aspects of the issues. As a candidate for the executive committee, I would like to apply these lessons and foster more bi-directional interaction of our physics community with the outside world. As chair of an upcoming FPS session, I helped bring decision makers to discuss their needs in the area of countering nuclear terrorism. As members of this forum, we are all acutely aware of other major challenges facing our global society in energy, climate, healthcare, financial systems, and more. In the future, I would like to explore new ways of increasing direct communication between scientists and policy makers in all these areas,

perhaps using panel discussions, live online chat events, or focus group meetings. I ask for your support, your ideas, and your increased involvement in this Forum.

Andrew Zentner

Background: Andrew Zentner is an associate professor in the Department of Physics and Astronomy at the University of Pittsburgh, where he has been a member of the faculty since 2007. Andrew is also a member of the executive committee of the Pittsburgh Particle physics, Astrophysics, and Cosmology Center at the University of Pittsburgh. Prior to joining the faculty of the University of Pittsburgh, Andrew earned a B. S in electrical engineering from The Cooper Union for the Advancement of Science and Art in New York City in 1998 and a Ph.D. in physics from The Ohio State University in 2003. Andrew conducted postdoctoral research in theoretical cosmology at the University of Chicago where he was a fellow of the Kavli Institute for Cosmological Physics (2003-2006) and a National Science Foundation Fellow (2006-2007). His primary research interests are theoretical cosmology, interpreted broadly to include early universe physics, the evolution of structure and the formation of galaxies, and the quests to identify the dark matter and dark energy that dominate the energy budget of the Universe. He has published over 50 refereed journal articles on these subjects. Andrew maintains an active interest in education and outreach and organizes an Education and Outreach partnership between the University of Pittsburgh and the Carnegie Science Center. One of his current education projects is to develop a general education program for non-science majors at the University of Pittsburgh aimed at improving upon the appreciation of physics as a field of discovery and the importance of physics as a basis for understanding energy, climate, and technological issues that affect society.

Statement: To FPS members, it is evident that physics bears ever more directly on societal issues. This pertinence stems from the specific knowledge and expertise of physicists as well as the general methods of quantitative science. An active community of physicists enriches our culture and lays the foundation for technological and economic progress. As a highly-trained component of society, it is the obligation of physicists to communicate scientific perspectives on societal issues. The FPS can help physicists better meet their obligation in a number of ways. The FPS can expand upon its already successful programs, including the popular APS sessions and in particular by providing for further Forum Studies. Renewed effort must be placed in "grassroots" efforts to invigorate physicists to participate in societal debates and public education. The Forum should reach out to professional colleagues to encourage physicists to participate in service, education, and outreach. Young physicists often feel that such activity is impossible because service is not valued highly as a consideration for promotion and career advancement (or is thought not to be valued highly). Successful, high-profile, education and outreach programs can change this perception. It is also incumbent upon the FPS to emphasize the value of service to society and change these perceptions in order to broaden participation by active physicists. Society decides the effective value of input from physicists and if physicists do not actively engage in societal decision making, this input will be undervalued. The FPS must strive to encourage and empower its membership to be active in their communities. Local activity of this nature will exhibit the power of the scientific approach, better equip the general public with the tools to address issues some of which are fundamentally quantitative, and exemplify part of the value of supporting an active community of physicists as an important piece of modern society. I hope to serve the FPS in order to help cultivate stronger relationships among physicists as well as between physicists and the general public for the benefit of both society and our profession.

COUNCILOR

Vote for no more than one candidate

Lowell Brown

Background: A.B. in Physics, University of California, Berkeley, 1956. Ph.D. in Physics, Harvard University, 1961. National Science Foundation Predoctoral Fellow, 1956-1961. National Science Foundation Postdoctoral Fellow, Istituto di Fisica Dell Universita, Rome, 1961-1962, and Imperial College of Science and Technology, London, 1962-1963. Research Associate, Yale University, 1963-1964. Assistant Professor, Yale University, 1964-1966. Associate Professor, Yale University, 1966-1968. Associate Professor, University of Washington, 1968-1971. Professor, University of Washington, 1971-2001. Staff Scientist, Los Alamos National Laboratory, 2001-. National Science Foundation Senior Postdoctoral Fellow, Imperial College of Science and Technology, London, 1971-1972. Fellow, American Physical Society; Fellow, American Association for the Advancement of Science; Laboratory Fellow, Los Alamos National Laboratory; Member, Phi Beta Kappa, Sigma Xi. American Physical Society: Member, Editorial Board of Physical Review D, 1978-80; Member, Publication Committee, 1983-86; Editor, Physical Review D, 1987-95; Member, Panel on Public Affairs, 1979; Member, Executive Committee, Division of Particles and

Fields, 1982-83, 1988-91; Member, Nominating Committee, 1994-96. Consultant, Los Alamos National Laboratory, 1974-2001; Member, Theory Division External Advisory Committee, Los Alamos National Laboratory, 1990-1993; Chairman, Theoretical Physics Panel, U.S. D.O.E. Technical Assessment Committee on University Programs, 1982-83; Member, Elementary Particle Physics Panel, Physics Survey of National Research Council, 1983-85; Member, Board of Trustees, Aspen Center for Physics, 1982-88; Member, Advisory Board, Aspen Center for Physics, 1988-90; General Member, Aspen Center for Physics, 1990-; Member, Scientific Advisory Board, Theoretical Advanced Study Institute in Elementary Particle Physics, 1984-89; Correspondent, Comments on Nuclear and Particle Physics, 1984-92.

Statement: I will work to convey the views of the FPS members as stated by their Executive Committee to the APS Council in a fair and objective fashion — including not only the consensus opinion of the majority of the members, but also the differing range of opinions that the rest of the members may hold. I generally agree with the candidates for FPS positions statements made over the years about the many serious issues that we face. However, I am also very much concerned by the present irrational, anti-scientific climate that is present in too large a segment of our schools and universities and which has spread throughout our society. An example is the prevalence of Postmodernism thought which, as stated in the Wikipedia, " ... claims that there is no absolute truth and that the way people perceive the world is subjective." We must emphasize the importance of empirical facts, and the rational basis that science has made in understanding the world around us. As a corollary, we must use science to understand problems that we face and then take actions based on this understanding, rather than demeaning science by cherry picking selected results to justify preconceived policies or ideologies.

Don Prosnitz

Background: Don Prosnitz received his B.S. from Yale University and his Ph.D. in Physics from the Massachusetts Institute of Technology. He then spent two years as an Assistant Professor in the Engineering and Applied Science Department at Yale University before joining Lawrence Livermore National Laboratory as an experimental laser physicist. Over the next three decades, he conducted research on lasers, particle accelerators, high power microwaves, free electron lasers, and remote sensing and managed the design, construction, and operation of numerous research facilities. In 1999, Dr. Prosnitz was named the first Chief Science and Technology Advisor for the Department of Justice (DOJ) by Attorney General Janet Reno. In this newly created position, he was responsible for coordinating technology policy among the DOJ's component agencies and with state and local law enforcement entities on science and technology projects and programs including forensics, information systems and wireless communication. He returned to Livermore in 2003 and assumed the role of Deputy Associate Director (Programs) for Non-Proliferation, Homeland and International Security and was responsible for overseeing all of the directorate's technical programs. He is presently a Sr. Principal Researcher (adjunct) at RAND Corporation, a visiting scholar at the physics department of the University of California, Berkeley, and an independent technical consultant. His current activities include research on free-electron lasers and a range of studies, from examining the impact of new technologies on privacy to climate and immigration policy. In 1990, he was awarded the U.S. Particle Accelerator Award for Achievement in Accelerator Physics and Technology. In 2002, he was named a Fellow of the American Physical Society. He is a former chair of the American Physical Society Forum on Physics and Society, was an ex-officio member of the APS bylaws committee and served for five years as a member of the National Academies of Science Board on Chemical Sciences and Technology. He has been a member of multiple National Academies panels.

Statement: I am seeking to represent the Forum on Physics and Society on the Council of the American Physical Society because I believe our Forum's members are particularly well suited to help guide the APS in the coming years. The present combination of increased public concern with advanced technologies and, in some cases distrust of scientists and scientific research combined with difficult economic times makes it even more critical that the APS operate as an institution cognizant of the interaction between physics research and the public. We must reach out and educate while operating as a transparent organization, never losing sight of the fact that fundamentally we represent physicists and the research they conduct. I am an APS fellow and a former chair of the Forum on Physics and Society. I helped the Committee on Constitution & Bylaws draft a new bylaw concerning APS Public Policy Statements. Professionally, I am a former Lawrence Livermore National Laboratory employee and was, for a number of years, the Chief Science and Technology Advisor for the U.S. Department of Justice. I am currently an adjunct researcher at RAND, a consultant at several national labs working on national security issues, a member of two National Academies of Science panels, and a visiting Scholar at UC Berkeley working on free electron lasers. I am also an active member of my hometown Community Emergency Response Team (CERT.) I strongly believe that as a council member I must represent the membership of the Forum. If elected, I will actively seek the opinions of Forum members on issues

of importance that come before the Council, and provide updates on Council issues to members either through e-mail or the Forum newsletter.

REPRESENTATIVE TO POPA

Vote for no more than one candidate

Milton Cole

Background: 1/11-9/11 Editor in Chief, Journal of Low Temperature Physics 4/08-6/09 Co-chair, Intercollege Minor in Civic and Community Engagement 5/07-6/07 Visiting Professor, Ecole Normale Superieure, Paris 1/02 -6/09 Distinguished Professor of Materials Science and Engineering 1/00 -Distinguished Professor of Physics 11/97-3/99 Co-director, Penn State Center for Materials Physics 9/91-2/98 Director, NSF-sponsored Materials Research Group (Physical Adsorption) 1/90-5/90 Fulbright Scholar, Physical Chemistry Laboratory, Oxford University 6/85-7/85 Visiting Professor, Universities of Marseille and Padua 6/83-8/83 Visiting Research Physicist, University of California, Santa Barbara 9/82-6/83 Visiting Professor of Physics, California Institute of Technology 3/82-8/82 Visiting Professor of Physics and Chemistry, Brown University 9/81-3/82 Visiting Associate, California Institute of Technology 9/75-8/76 Associate Professor of Physics, Brooklyn College of CUNY 9/74-9/81 Assistant → Full Professor of Physics, Penn State University American Physical Society Committee on International Freedom of Scientists (1/12-12/14) Advisory Board to the Editor in Chief, Journal of Low Temperature Physics, 2005-2011 Advisory Board, Committee of Concerned Scientists, 2009 Co-organizer, workshop 'Adsorption at the Nanoscale', U. Missouri, September, 2011 Co-editor, J. Phys. Cond. Matt., special Peter Eklund issue, 'Physics of Fullerenes', 2010 Co-editor of special issue 'Wetting, spreading and filling', J. Low Temp. Phys., November, 2009 Co-creator and director of Penn State Science-U summer camp for 2nd and 3rd grade students, June, 2009: Catch the Wave: Adventures in Sound and Light. Fellow of the American Physical Society (1979) Fulbright Scholarship to Oxford University (1989) Penn State Faculty Scholar Medal for Outstanding Achievement in Physical Sciences and Engineering (1993) National Academy of Sciences Award for Scientific Reviewing (2001) Women in Science and Engineering Faculty Mentoring Recognition Award (2008)

Statement: I am honored to be considered for the position of Forum representative on the APS Panel on Public Affairs. My longstanding membership in the Forum reflects, among other things, an ongoing interest in the role physics plays in understanding and advancing technologies. As a researcher in theoretical surface physics, I have investigated both energy and environmental issues (e.g., hydrogen storage, lubrication and CO_2 sequestration,) but my most meaningful role is that of a teacher, in both the university classroom and summer camps for K-12 students (e.g., one we are launching this summer, "Engineering a Sustainable World"). POPA's activities and reports have served a significant function in our national "conversation" about the impacts of science and it would be a privilege to witness and participate in them.

Philip Taylor

Background: Philip Taylor is Distinguished University Professor and the Perkins Professor of Physics at Case Western Reserve University. He is the author of over 200 publications on theoretical condensed-matter physics and on more general topics ranging from earthquakes to epidemiology. He is a Fellow of the American Physical Society and of the American Association for the Advancement of Science, and has been on the editorial boards of several journals, including Physical Review B. He obtained his Ph.D. in theoretical physics from the Cavendish Laboratory at the University of Cambridge and came to the US for a postdoctoral position at Case Western Reserve University in 1962. He has remained at Case ever since, except for visiting appointments at the universities of Washington, Oregon, Cambridge, Utrecht, Manchester, and Bonn. In 1987 he initiated and directed a year-long celebration of the centenary of the Michelson-Morley experiment. This included organizing symposia on physics and the history of science, and raising funds to commission artists and composers to produce works interpreting the themes of light, space, and time. His interests include the study of the role that energy plays in modern society, and he is a frequent lecturer on the topics of climate change and alternative energy sources. Since 1978 he has formed and led an interdisciplinary team in teaching the course Energy & Society, in which faculty from Political Science, History, Economics, Geology and Engineering join with those from Physics in leading students through the complexities of world energy utilization. He has been active in Forum affairs, organizing sessions at APS meetings and chairing the FPS Nominating Committee from 2007 to 2009.

Statement: The quality of the advice that a government receives on scientific issues is becoming more and more vital to its ability to make sound policy decisions. It is alarming, even horrifying, to see how far certain elements of our own government have moved in attempting to bypass almost every mechanism by which impartial advice on scientific and technical matters can be delivered to our decision makers. Committee after committee has held one-sided hearings in which

testimony has been limited to individuals whose political orthodoxy far exceeds their competence to judge matters having any science component. Against this backdrop, the Panel on Public Affairs of the APS stands as a beacon of reason and a respected voice of scientific authority. Its reports on scarce energy-critical elements, on integrating renewable electricity into the grid, and on technical steps to support downsizing our nuclear arsenal have provided sound guidance, and have pointed out the best feasible pathways to the solution of some serious societal problems. There remain, however a myriad of issues yet to be addressed, and the members of the Forum on Physics and Society are well positioned to offer suggestions as to how these should be prioritized. I would hope to be a channel for conducting the views of Forum members to the POPA leadership. The world's headlong race to nuclear proliferation, our inadequate response to the growing threat of climate change, and the frequent inappropriate insertion of religious doctrine into the scientific education of our youth are but three of a multitude of issues that threaten our very existence as a civilized society. As a community of physicists we must speak, loudly but not stridently, rationally but not dispassionately, and direct our scientific knowledge and our public spirit into strengthened efforts to steer our society away from the potential disasters toward which we are headed.

LETTERS

Thanks for including in your January issue the comprehensive and informed article by Jay Davis on technical and policy issues for nuclear weapon reductions. It was particularly refreshing to see him debunk the Cold War myth that there were "viable war-fighting theories for [nuclear weapons targeted on nuclear weapons]." Few individuals from the weapons complex have ever acknowledged the "pretense," as Davis put it. Indeed, the grizzly fact was that, as Davis cites, "deterrence is in the end established by targeting cities and populations."

Regrettably, two of the "Gang of Four" that Davis admires — Henry Kissinger and George Schultz — were a major part of that horrifying pretense that supported Cold War nuclear fighting. It's quite unlikely that "the climate for arms control" has now been meaningfully changed by their conversion to the "concept" of a "world without nuclear weapons." On the contrary, a goal of global zero distracts from the more meaningful and achievable concept of gradual and mutual reductions in nuclear armaments. Kissinger and Schultz's belated conversion to the cause of global zero is another pretense that needs to be debunked, or simply ignored.

Although Davis recognizes a multiplicity of public and political constituencies affecting nuclear-weapons reductions — such as the Executive Branch, Congress, and military services — he does not mention the vigorous, long-standing self-promotional role that the weapons laboratories engage in for retaining nuclear arsenals.

For a more comprehensive treatment of prospects for nuclear-arms reductions, as well as a thorough history and assessment of the nuclear arms race, I modestly recommend my trilogy of volumes on these matters, which are available in print or electronically [1].

[1] A. DeVolpi, Nuclear Insights: The Cold War Legacy (DeVolpi, Inc., 2009-2011).

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ARTICLES

Reflections on the Forum at Forty

David Hafemeister

[Editor's note: A fuller version of Prof. Hafemeister's history can be found on the Forum's homepage at www.aps.org/units/fps/]

This year marks the 40th anniversary of the founding of the Forum on Physics and Society. Because physics principles underlie so many societal issues (nuclear arms, energy, climate change, technical innovation …) and because physics offers a way to quantify some aspects of them, members of the American Physical Society (APS) should be encouraged to understand, analyze and debate them. This is precisely why APS members formed the FPS at the 1972 APS San Francisco meeting. In this article, I review the history of FPS and some of its accomplishments, and offer some brief thoughts for the future.

The Early Years: Getting Established and Winning Respect

The FPS was born in the tumultuous 1960's and 70's. The issues of that era - the Vietnam War, the Anti-Ballistic Missile system, and the energy crisis—along with the start of the environmental movement and the civil/human rights revolution, impelled that generation of physicists to consider their professional responsibilities. Many felt that the APS should have a division or forum in which appropriate science and society issues could be debated by informed participants before the APS membership. An excellent review of the early days of the Forum was published by Barry ("Mike") Casper in the May 1974 issue of *Physics Today* [1].

In its early days, the Forum was looked upon with suspicion by the APS leadership, which was concerned that the Forum would move issues too far and too fast. Because of this concern, the APS Council appointed a senior APS member to attend Forum Executive Committee meetings to make sure that the Forum did not embarrass the APS. Embarrassment never happened, and the FPS has long since won the respect of the APS Council; they no longer appoint a representative to the Forum Executive Committee. Indeed, the Forum is regarded as a source of manpower and ideas for the APS to utilize in preparing its public positions. As of January 2011, the Forum had just over 6,100 members, 12.7% of the total APS membership of nearly 48,300. Of 38 chairs of the APS Panel on Public Affairs (POPA; see below) from 1975 to 2012, six have also been chairs of the FPS.

The Forum has had many excellent leaders over its 40 years. I would like to describe briefly the four "founding fathers" pictured in Casper's article: Earl Callen (American University), Martin Perl (SLAC), Mike Casper (Carleton College) and Brian Schwartz (then MIT, now CUNY). Callen was the founding chair of the Forum. Although his particular interest was international human rights of scientists, the major goals of his term were building membership, developing a reputation within the APS membership for quality and objectivity, and establishing effective working relationships with the APS Council.

Martin Perl can only be described as a phenomenon. While acting as the second chair of the Forum in 1973-74, he discovered the tau meson, for which he was awarded a share of the 1995 Nobel Prize in physics. In his spare time, Perl established and edited the forum's newsletter, *Physics and Society*, from 1972-79, and mobilized two Penn State Conferences on graduate physics education (1974, 1977). Casper, the Forum's third chair, established the two Forum Awards. After that, he actively worked on arms control and became a senior advisor to the late Senator Paul Wellstone. Schwartz, the ninth chair of the FPS, served brilliantly and creatively in the crucial job of organizing the first Forum panels at APS meetings. He has gone on to be an APS insider, serving as the Society's Education Officer and Associate Executive Secretary. He was also responsible for much of the planning for the APS centennial activities in 1999.

The FPS was the first APS Forum. Recognizing that the Forum would attract members from across disciplinary lines, the APS waived the additional dues that are traditionally charged to members for joining a Division. With the subsequent creation of additional fora, APS instituted a charge for membership in each forum over two per member. The success of this approach induced APS to create other fora, such as those on the History of Physics (1980), International Physics (1985), Education (1991), Industrial and Applied Physics (1995), Graduate Student Affairs (2001), and Outreach and Engaging the Public (2010). The FPS can be said to have incubated subsequent Forums.

Some of the issues with which the FPS becomes involved are contentious and have led to awkward situations, but these have generally been dealt with even-handedly. I recall two cases in particular. The first concerns an amendment to the APS Constitution proposed by Robert March, which would have required the APS to "shun activities which contributed harmfully to the welfare of mankind." It was very difficult to obtain a speaker to oppose March's amendment at an April-1972 FPS session. Earl Callen stepped forward and filled that role, in which he believed. His presentation helped to defeat the amendment. The second example concerns the publication of a very political cartoon by the editor of Physics and Society. The editor was warned not to run any more such one-sided cartoons, but he ignored the warning, and the Forum Executive Committee was forced to adhere to the principle of objectivity and fire him.

Physics and Society

P&S is in its 41st year. Martin Perl was founding editor (1972-79). He was succeeded in 1980 by the late John Dowling (1980-86, Mansfield University). Art Hobson (University of Arkansas) was editor from 1987 to 1996. Al Saperstein (Wayne State University) was editor from 1997 to 2003, when Jeff Marque joined him as Co-Editor until 2009, after which Cameron Reed (Alma College) became the current editor. *P&S* fulfills an extremely important function by informing FPS members of current topics and providing a non-peer reviewed forum for the exchange of ideas. With the passage of time, the contents of *P&S* have shifted from more general commentary to more technical aspects of physics and public policy issues.

With the exception of issues from Volume 1 (1972) and the July, 1973, and April, 1980, editions, all back issues of *P&S* are freely available on the FPS website, along with an Index arranged by topic.

Summaries of many FPS symposia are published in *P&S*. A partial list serves as an informative snapshot of the evolution of issues: SDI (September 1986), land-based intercontinental ballistic missiles (July 1988), energy research (July 1989), pseudoscience (July 1990), energy (October 1991), power lines and public health (January 1992), climate change (October 1992), environmental physics (July 1993), theater ballistic missiles (October 1994), legacy of radiation from cold war (July 1995), sustainable technologies (October 1995), linear low dose radiation (January 1997), monitoring nuclear materials (July 2006), reflections of presidential science advisors (October 2006, January 2007), and the role of nuclear weapons (October 2007, April 2008). Among the talks in these various symposia, one of my favorites is the one by James Randi (October 1989) on "Fooling Some Scientists Some of the Time." The juxtaposition of Randi's talk and the debate on "cold fusion" at the 1989 Baltimore APS meeting was timely, albeit unplanned. On many occasions an editor (and the editorial board) has disagreed sharply with the contents of letters and articles, but openness has often dictated their publication as long as the view makes some logical points in a respectful manner.

A highly-publicized controversy occurred with the newsletter in 2008. The editors wanted to promote a debate between those who accepted the scientific findings that man's activities were having an impact on the climate and those who did not. Unfortunately, they chose a highly controversial and outspoken non-scientist, Christopher Monckton, to represent the arguments of the climate-change deniers. Monckton subsequently presented his piece to journalists as a peer-reviewed paper from a "learned journal" and touted it as evidence for APS support of his position. The newsletter subsequently tightened its editorial oversight and now adds a disclaimer to every article that it has not been peer reviewed.

FPS Sessions

One of the most important activities of the FPS has been to sponsor sessions at APS meetings on topical science-and-society issues. Some FPS sessions have had more than 1,000 attendees. Over the first 27 years up to 1999, the FPS offered 197 sessions, and between 2000 and 2012, offered 111 sessions. This rise is somewhat remarkable since sessions are now rarely held in Washington, DC, an easy source for experts on policy-related issues. Sessions continue to be vibrant and well-attended.

A look at the topics of sessions over the years reveals that interest in some issues has remained essentially constant, particularly National Security, Policy Process, Awards, Education, and Environment. But each area has had changes of content. For example, National Security moved from SS-18s and Star Wars to Terrorism and Proliferation. Energy topics have dropped in frequency, although two short courses in this area held in 2008 and 2011 at UC-Berkeley produced some 1000 pages in AIP Conference Proceedings. "Miscellaneous" sessions have risen dramatically, implying that FPS is becoming more eclectic as we consider topics such as the debate over biological evolution, physics and art, physics and entertainment, and more. Contributed Paper sessions were dropped after 1999 as it was decided that the diverse collection of ten-minute papers lacked focus.

The goal of Forum sessions is to present the best arguments on both sides of an issue in a no-holds-barred debate. Unfortunately, this goal is occasionally abused by people

who wish to offer views that are unscientific or that confuse the debate. For instance, at the spring 1986 APS meeting in Washington, the Forum held a session on the Strategic Defense Initiative (SDI). Organizers invited representatives from the Reagan administration and from the Congressional Office of Technology Assessment, along with some university faculty. It never occurred to us to invite Lyndon LaRouche's Fusion Energy Foundation. However, this group felt they should have been invited, and attempted to shut down the session. As Forum Chair at the time, it was my task to go head-to-head and threaten them with police action if they would not be quiet and allow the session to continue. They did so, and the details of lasers in space were quantified and debated. It can be difficult to define when a position should be categorized as "unscientific".

The Panel on Public Affairs and the Forum

There often is confusion on the roles of the two APS entities that deal with physics and society issues. The Panel on Public Affairs (POPA) was established in 1974 under the leadership of Wolfgang Panofsky, two years after the Forum was established. The major distinction is that POPA is an APS committee whose members are elected by the APS Council and whose role is to advise the APS Council, whereas the FPS is a membership organization whose executive board is elected by the members and whose roles include publishing a newsletter and sponsoring invited sessions at APS meetings. As a membership unit, the FPS is a responsible to the FPS membership and not the Council. In practice, these distinctions become somewhat blurred in that all divisions and fora are responsible to the Council if the actions of the APS units run counter to the goals of the APS.

POPA has sponsored studies of certain issues, after receiving outside grants to pay the expenses of experts; the most famous is probably the 1987 Directed Energy Weapons Study. POPA also prepares reports by POPA members, and gives advice to the Council on a wide variety of issues. The advice from POPA generates about 3 APS resolutions and 5-10 letters for the APS leadership to send out per year. On the other hand, the Forum organizes sessions to raise technical issues in a public arena, publishes *Physics and Society*, carries out Forum studies, offers short courses, and organizes the presentation of two APS Awards each year.

Other Forum Activities

Forum Studies – The FPS has sponsored three studies, on Civil Defense (1986), the future of land-based strategic missiles (1989), and energy (1991). All were published by AIP Press. These studies arose after a small group of individuals decided to study a selected issue in depth. The individuals contributed their own time, talent and energy, and FPS contributed some funds toward helping the authors hold occasional meetings. Time has eclipsed many civil defense issues and there has been progress on strategic arms control, but the energy volume, prepared by Ruth Howes and Anthony Fainberg, remains a valuable resource on the timeless principles involved with energy supply.

Employment – The first "job crisis" for young PhD's took place in the early 1970's. The Forum responded by organizing two conferences at Pennsylvania State University (August 19-23, 1974 and August 1-3, 1977). Martin Perl and Roland Good were the driving forces behind these conferences, which examined the data and possible responses by the physics academic community. The results of the first conference, on "Technology Change in Physics Graduate Education", were published in the February 1975, issue of *Physics and Society*, which still remains the newsletter's largest single edition. The results of the second conference, "Changing Career Opportunities for Physicists" were edited by Martin Perl and published in the AIP Conference Series. These studies were a precursor to the later studies by the APS Committee on Careers and Professional Development and the Young Scientists Network.

The Political Arena – A number of our members have moved on from Forum activities to larger political roles. Former Executive Board member Vern Ehlers, once a Physics Department Chair from Calvin College, served as a Republican Congressman for nine terms from Michigan (1993-2011). Rush Holt, former Assistant Director of the Princeton Plasma Physics Laboratory, is serving in his 7th term as a Democratic Congressman from New Jersey. They were joined by Bill Foster, a particle physicist from the Fermi National Laboratory, who served in Congress from 2008-2011. I like to think that the Forum's examination of the critical aspects of science and society issues not only helped send them on their way, but also shaped their approach to some of the issues that they deal with today.

Education – Over the years, the Forum organized some 30 sessions on education issues. Former FPS chairs Ruth Howes and Ken Ford took an active role in organizing the Forum on Education in 1991. FPS maintains an active interest in physics education issues, but is now in a supportive role with the existence of the Forum on Education and the APS Committee on Education.

Short Courses – In order to help members study physics and society issues more deeply, the Forum has organized a

series of short courses, which last for 2 to 3 days. Participants hear some 20 hours of lectures from 24 assorted experts; later, they receive copies of the AIP Conference Proceedings. The Forum has offered three such courses on arms-race matters, three on energy, and one on climate change. The last two short courses, both on sustainable energy, attracted 200 attendees each.

APS (Forum) Awards – The FPS presents nominees to the APS Council for two APS awards, the Joseph A. Burton Forum Award and the Leo Szilard Lectureship. The Burton-Forum Award "recognizes outstanding contributions to the public understanding or resolution of issues involving the interface of physics and society," while the Szilard Lectureship "recognizes outstanding accomplishments by physicists in promoting the use of physics for the benefit of society in such areas as environment, arms control and science policy."

The Awards were first offered by the FPS (not the entire APS) in 1974. David Inglis received the first Szilard Award and Ralph Lapp earned the first Forum Award. Initially, a modest honorarium of $250 was given, along with a handsomely scripted scroll. The honorarium became even more modest in 1985 when the Szilard Award was shared among the seven dominant authors of the papers on the "Nuclear Winter" calculations. This motivated a move from monetary awards to symbolic art plus a travel stipend for recipients to receive their awards. Two California artists created statues whose bases are engraved with the names of the awardees. The winners kept the statues for one year, after which they passed them on to the next year's winners. The statue accompanying the Szilard Award, which was created by David Smith, is a dolphin, the symbol of Szilard's novella, *The Voice of the Dolphins*. The Forum Award statue is an abstract spherical model of the Earth created by Crissa Hewitt. After many years of transcontinental shipping, the awards now reside in this author's backyard as a statue (Burton-Forum) and in my home-office (Szilard).

In 1986, the two Awards were promoted to awards of the entire APS. This promotion in status came with pressure to create a permanent endowment for them. In 1997, the Forum Award was endowed with $70,000 from the Apker Award Endowment, creating an annual honorarium of $3000 plus travel expenses to the April meeting. The Forum Award was renamed the Joseph A. Burton Forum Award in honor of Joe Burton, a former APS Treasurer and long-time FPS supporter. In 1998, the Szilard Award received an endowment of $70,000 from the MacArthur Foundation, the Energy Foundation, the Packard Foundation, the FPS, and a number of individual donors. In order to create a climate for graduate students to consider careers in physics and society, the award was changed to a lectureship, and its name was changed to the Leo Szilard Lectureship Award. Starting in 1999, the recipient has received a $1000 honorarium and travel money to present talks at an APS meeting and at universities or research laboratories.

The Current Situation and a Look to the Future

There has been trend in the evolution of the make-up of the Forum leadership over the years. Early Forum leaders were essentially all from academia, but this is not true today. This year, the Past Chair, Chair, Chair-Elect, Vice Chair, Secretary-Treasurer, and the *Physics and Society* Editor hail from a variety of locations: 2 national laboratories, 2 universities, 1 federal agency, and 1 non-governmental organization. This is a good overall mixture since each individual contributes a different perspective.

For the future, it is very important for the Forum to continue to present the issues and to show students that there are career paths other than the academic route. Most important, it is imperative that the Forum keep the candle of professional responsibility well-lit. We cannot slip back to the old days when APS meetings had no sessions on physics and society issues. The FPS continues to be a way for physicists in all fields to keep abreast of the technical aspects of problems facing society. At the personal level, the Forum's members and activities have been a great source of friendship, knowledge and inspiration to me and the other members.

Reference

1. *B. M. Casper, "Physicists and Public Policy: the "Forum" and APS,"* Physics Today ***27****(5), 31-38 (1974).*

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American Physics, Climate Change, and Energy

Wallace M. Manheimer

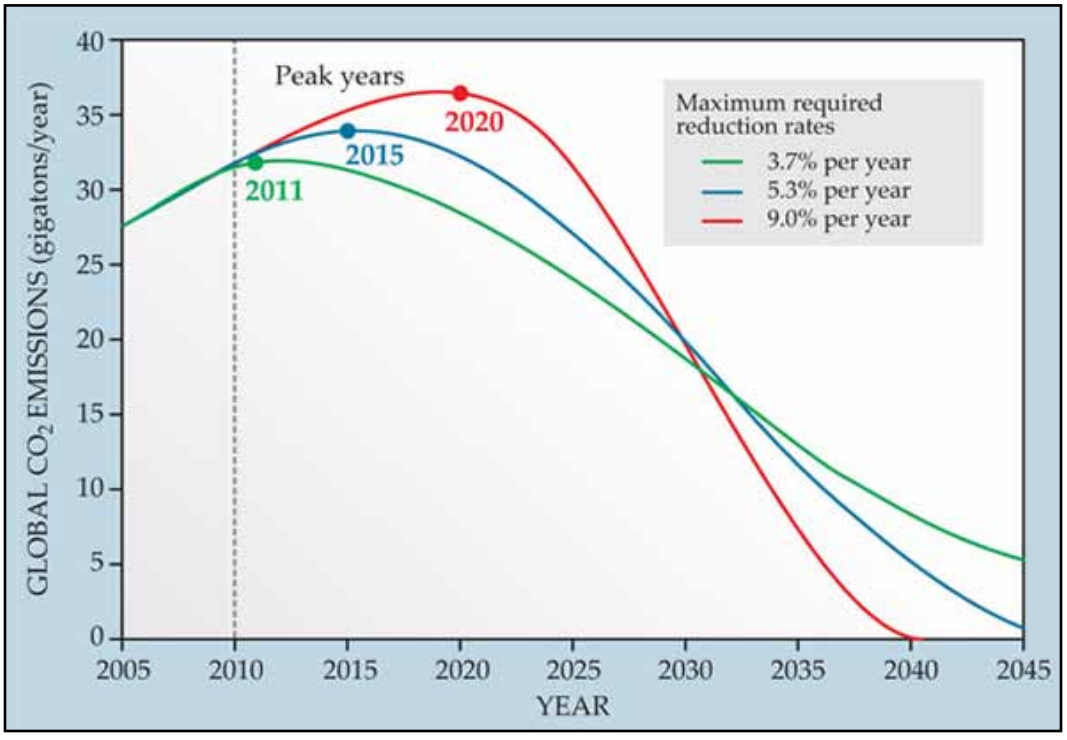
1. Introduction: American Physics Organizations and Climate Change

The issue of climate change is an important and polarizing one. For lack of better terms, I will call the two most extreme camps climate change alarmists and climate change deniers; most people are in-between. The American Physical Society (APS) has come out firmly in the camp of the alarmists. In 2007 it issued a statement that included the phrases "The evidence is incontrovertible: Global warming is occurring", and "We must reduce emissions of greenhouse gases beginning now" (1). It is unusual for a scientific society to offer such unwavering policy advice to society, and several APS members, including a Nobel-prize winner, resigned in protest. Objections included the belief that man-made global warming is not real, that the APS should not put itself in the position of giving unsolicited advice to society and governments, and that while global warming may be a problem, we still need energy (2, 3, 4, www.sepp.org). The APS reconsidered but ultimately reaffirmed its original statement, adding a lengthy explanation.

More recently, the American Institute of Physics published two articles in a single issue of its flagship publication, *Physics Today*, which made the case that global warming is a scientific certainty and we must take immediate action to prevent catastrophe (5,6). For instance, Ref. 5 dismisses all doubt with statements such as: "Greenhouse warming today faces an even greater array of bogus counterarguments based on the uninformed interpretation of data from ice cores, erroneous views about natural carbon sources, alleged but unobserved alternative drivers of climate change, naive expectations of the time scales over which models and observations should match, and various forms of statistical chicanery and logical fallacy." The alarmism in Ref. 6 is apparent by quotes such as: "The urgency of taking action to limit manmade climate change combines subjective considerations with scientific ones," "Some recent research suggests that severe climate change, including very large sea-level rises, can occur even with a 2 °C ceiling," and "The science tells us that meeting the policy goals requires urgent action." Figure 1 shows Figure 5 of reference (6): the necessary future course of carbon input into the atmosphere if we are to keep the total CO_2 emissions to 750 Gt over the period 2010-2050. In all cases, carbon input into the atmosphere must end in about 30 years.

FIGURE 1

Three scenarios, each of which would limit the total global emission of carbon dioxide from fossil-fuel burning and industrial processes to 750 Gt over the period 2010–50



In the opinion of this author, there is a serious problem with this alarmism and proposed reductions scenario: That they almost certainly condemn the vast majority of the human family to abject poverty. Another inconvenient truth is that civilization and development need energy, and lots of it. As argued below, to bring much of the world to a reasonable level of prosperity would require some 10-30 terawatts (TW) of additional power, preferably carbon free, by around mid-century (7).

In this article, I advance the case that the standard 'renewable' energies, solar and sequestration, are nowhere near ready to provide for societal energy needs, and likely never will be. This leaves efficiency enhancement, nuclear reactors, and fossil fuels as possible sources. In the following sections, I examine the current status of worldwide energy use and carbon emissions (Sect. 2) and the circumstances for various possible carbon-free energy sources and fossil fuels (Sect. 3). Section 4 offers a brief summary and conclusion.

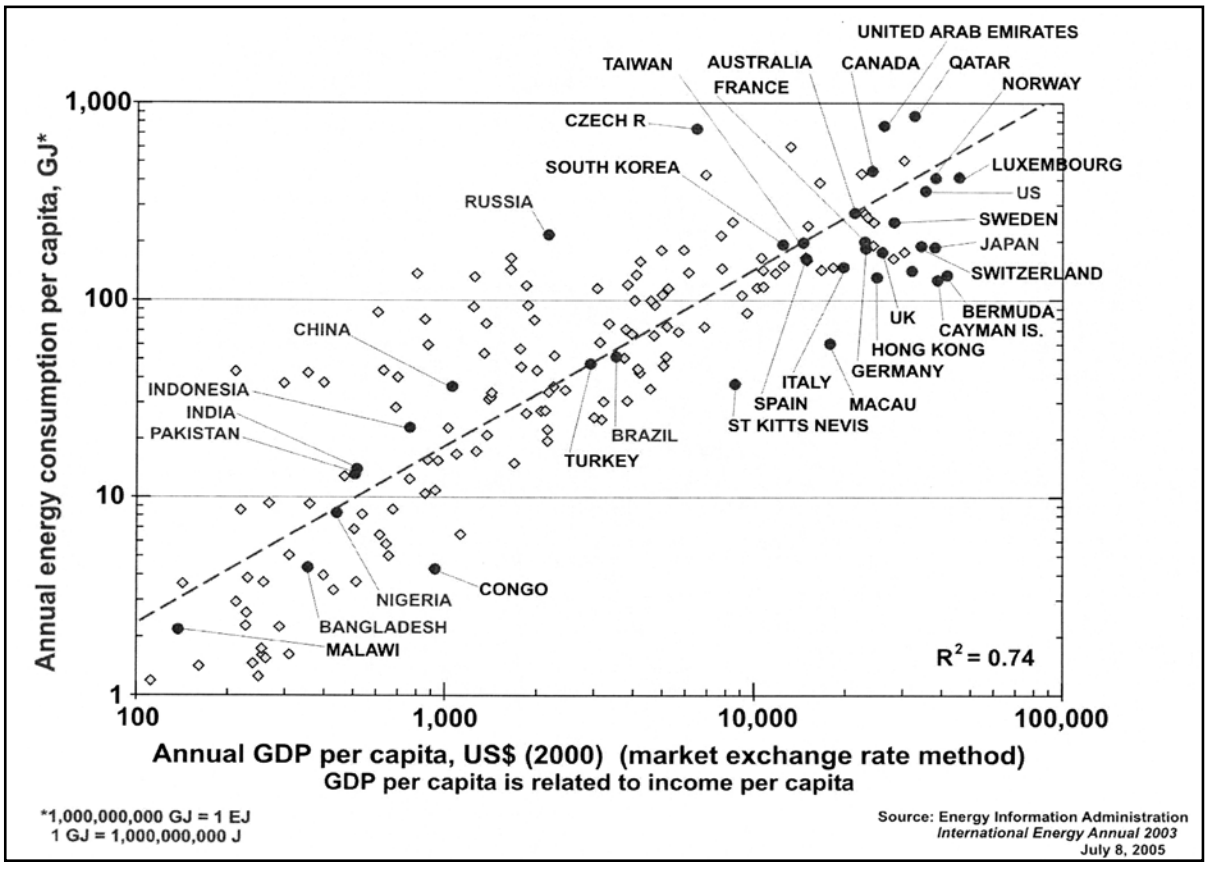
2. Energy and Civilization

To see the relation between energy use and civilization, Figure 2 shows yearly per capita energy use versus yearly per capita GDP in year 2000 for a number of countries. The two are very strongly correlated; there are no rich countries that use little energy per capita. Countries high up on the graph have more educated populations who live more pleasant, longer lives, and who live in cleaner environments than countries lower down on the graph. [Chart compiled by D. Lightfoot from information available from Energy Information Agency (EIA), (www.eia.doe.gov/emeu); see also www.mcgill.ca/gec3/gec3members/lightfoot].

Total world power use in 2005 was about 13 TW, about 85% of which derived from fossil fuel. The United States, which is home to about 5% of the world's population, uses about 2.5 TW. If we in the U.S. cut our energy use by 40%, our standard of living (going down parallel to the line) would be about like Italy's. Actually, it would be much worse because distances are much greater in the United States, it is colder here, and we have responsibilities as a major world power that Italy does not have. However, the undeniable and overriding goal of world development is presumably to bring all countries up the curve, so let us imagine that all people enjoyed an Italy-level standard of living. This would increase world power use to 30 TW in 2005 and to 50 TW by 2050 when the world population reaches 10 billion. Clearly, conserva-

FIGURE 2

Annual energy consumption versus annual GDP per capita



tion, efficiency enhancement, *and* new sources of energy are essential for development to continue.

As regards carbon emissions, the Kyoto Accord mandates that each signatory reduce its carbon input to the atmosphere by 10% from its 1990 levels. Table 1 shows yearly carbon input to the atmosphere (in million of metric tons) from burning fuels, in both 1990 and 2005 for a number of countries. European countries in bold type are countries that have never been part of the Warsaw Pact.

Several things are clear from this table. First, one way to decrease carbon input is to have a command economy, which has no regard for environmental standards, is uncoupled from a free market, and then suffers some form of collapse (Poland, Bulgaria, Romania, Russia). Second, other than former Warsaw pact countries, the only major country even close to meeting its Kyoto mandate is Britain, which completed a large change from coal to natural gas in the 1990's. Third, France emits less carbon than other European countries its size. The reason for this is that France has embraced nuclear power to a very great extent. Nuclear power really does reduce carbon emission, and is in fact affordable, at least for the French. Fourth, the role of developing countries is crucial as regards future carbon input. The cases of India and China are well known; in 2009 China became the world's largest carbon emitter. But other less well-known places are rapidly increasing their carbon input. Even tiny, impoverished Malawi, the lowest-named country in Figure 2, is unwilling to stay where it is. The poorer parts of the world will do whatever it takes to share in the life style we in the west enjoy, and who can blame them? A more prosperous world will make for a more peaceful one. In any event, despite Kyoto, Cancun, and Durban, the world certainly seems to be doing the carbon-input experiment. We had better hope the fears of the alarmists prove to be unfounded.

TABLE 1

Carbon Emissions, millions of metric tons

COUNTRY	1990	2005	CHANGE
Europe:			
England	**598**	**577**	
France	**366**	**415**	
Italy	**413**	**466**	
Holland	**206**	**270**	
Belgium	**124**	**136**	
Spain	**235**	**387**	
Norway	**34**	**52**	
Sweden	**54**	**59**	
Denmark	**56**	**51**	
Greece	**80**	**103**	
Sum of above	**2166**	**2516**	**16%**
Poland	330	284	
Romania	174	99	
Bulgaria	73	50	
Russia*	2044	1696	
Sum of above	2621	2129	-19%
Germany**	923	844	-9%
United States	4747	5289	11%
Asia:			
Japan	935	1075	15%
China	1454	2844	96%
India	288	862	199%
Indonesia	85	213	150%
Latin America:			
Mexico	230	288	25%
Brazil***	185	218	18%
Africa:			
Nigeria	68	100	47%
Egypt	42	98	133%
South Africa	312	423	36%
Malawi	0.53	0.86	62%
World	**18,330**	**21990**	**20%**

Source: Data is taken from the DoE web site, www.eia.doe.gov/environment/html; follow prompts to international emission data.]

European countries in boldface were never Warsaw Pact members.

** Starting 1992 when Russia separated from the Soviet Union*

*** In 1989 West Germany absorbed East Germany, which had a Warsaw pact economy, so Germany is partially like Warsaw pact countries.*

****Brazil is in the fortunate situation of being able to generate most of its electricity from hydropower.*

3. Possible carbon-free energy sources & fossil fuel

The requirement of 50 TW of carbon free power by mid century is daunting. Anything that can be done to reduce this number will make the task of energy supply much easier. Accordingly in Part A of this section, I look into efficiency enhancement. Part B examines nuclear power. It seems to this author that these are the two tall poles which could support mid-century civilization. In Part C I consider fossil fuel, which would play a lesser but still an important role. Then I examine other options, which likely will play much smaller roles. Solar power (actually direct solar, wind and biofuel) is discussed in Part D. Carbon sequestration is discussed in Part E. Generally, I do not give specific references for numbers given; these can be confirmed by internet searches.

3A. Efficiency and conservation

The APS has long been concerned with energy efficiency, and recently put out a report of a study group, chaired by Burton Richter (8). However, it is also important to realize that improving efficiency is the natural extension of a long-term trend of reducing the energy intensity. This is the power used (worldwide) divided by the world's inflation adjusted gross national product. It has been declining by about 1% per year over a long period (9). Enhanced efficiency and conservation are part of this. Reference 8 is concerned only with transportation and buildings in the United States; the concern of Reference (9) and this paper is worldwide.

As regards transportation, which uses about 20% of American power, Ref. (8) points out that without sacrificing safety or comfort, auto gas mileage could be increased from about 30 to 50 miles per gallon (p12). Part of this increase would come from reduction in weight, advances in materials, batteries, etc. Regarding buildings, which use about 40% of the nation's power, it speaks of improving efficiency up to 35% (p 60). Private buildings used about 45% of their power for space and water heating, mostly from fossil fuels in liquid or gaseous form, and 55% for other uses, mostly powered by electricity. For commercial buildings the fractions are about 25% and 75%. Enhanced efficiency might result from better insulation, windows, heating and cooling systems, and improved appliances. On-site elements of a more efficient building could be voltaic cells or solar water heaters on the roof.

3B. Nuclear Power

There are some 400 reactors in the world today, generating some 400 GWe (GWe is gigawatt electric, GWth is thermal, generally 3GWth~1GWe, due to Carnot efficiency). Many more are in various stages of construction and planning, and nuclear fission will surely play a significant role in meeting energy needs for decades to come. But we cannot ignore the recent Fukushima disaster. What should the response to Fukushima be? One approach is that of Germany, which has decided to decommission its 17 nuclear power plants which provide 23% of that nation's electricity. But then what will they do? Live without them and enormously increase the price of electricity? Build 17 coal fired plants? Install miles of solar collectors in cold, cloudy northern Europe? Install 17 GWe (50-60 GWe nameplate value) wind turbines, which may or may not provide power when it is needed? This would take up about 17,000 km^2, about 5% of German land area (Sec. 3D). One possible scenario is that France builds 8-10 nuclear plants near their eastern border, while Poland builds an equal number of coal fired plants near their western border, and they both sell power to Germany. The Germans will then have clear consciences.

Fukushima should be regarded not only as a disaster but also as a learning experience. The lessons to be learned are beyond the expertise of this author, but might include the fact that the danger of a nuclear disaster is much more to land than to people, who have time to get away; do not locate nuclear plants in populated areas; have a second line of defense, such as generators nearby that could be moved in for cooling spent fuel, even in the midst of a chaotic situation; and do research to see if there are ways to decontaminate the land.

Other issues associated with nuclear energy are waste disposal, proliferation, and fuel supply. On the first two, the current science and engineering are ahead of societal acceptance. One method of dealing with actinide waste is to burn it with fast-neutron reactors (10). Until this technology is sufficiently mature (several of these demonstration reactors have been built at various power levels), one could store the waste in a geological repository such as Yucca Mountain, and remove it later for burning. Burning the actinide waste solves both the proliferation problem and a large part of the waste disposal problem. In this author's opinion, this would have to be a part of any sustainable nuclear option. The other part of the waste is the intermediate atomic number radioactive fission products. While highly radioactive, these pose no proliferation risk. Some have commercial value and could be separated out and sold. The rest could be left to decay over several centuries, a time human society can reasonably plan for. After a few centuries they will have decayed so much that they are basically inert.

The other problem with nuclear energy is fuel supply. Light-water reactors use only about 1% of the available fuel, the part of the ore that is ^{235}U. Any sustainable option would have to find a way to use the rest. In this case, not only would all uranium be available for fuel, but all of the world's thorium would be as well; there is three times as much thorium as uranium. To get an idea of the magnitude of this resource, nuclear power has supplied about 400 GWe for about 40 years. Hence, in depleted uranium alone, there is fuel for 4 TWe for 400 years!

There are at least three approaches, in various stages of readiness, to using all the world's uranium and thorium. These are sodium-cooled fast neutron reactors such as the integral fast reactor (IFR) (10), molten salt thorium reactors (11), and breeding fuel via hybrid fusion, which has been advocated by this author (12). Research and development are required before any of these are ready for market. My own opinion is that such research has enormous upside potential. But whatever option or options are chosen, nuclear power does have the potential of supplying the world with carbon free power at 5-10 TWe safely, economically, environmentally soundly, and with negligible proliferation risk, at least as far into the future as the dawn of civilization was in the past.

3C. Fossil fuels

Civilization not only needs energy, it also needs liquid and gaseous fuel. Until manufactured fuel (i.e. hydrogen, ammonium,…) becomes economical and has an infrastructure in place, we are stuck with fossil fuel. There is no real substitute for transportation and space heating. While electricity might be used for space heating, it is inefficient. Fuel is turned to heat at the power plant, then one third of this heat is turned into electricity, two thirds are wasted, and then this electricity is converted back to heat at the building. The key is to minimize liquid fuel use via conservation and efficiency enhancement.

Conventional oil and gas, as well as newly economical supplies from shale and tar sands, are available and amenable to efficiency improvements. It is also important to note that coal can be converted to oil or gasoline via the Fischer-Tropsch or Berguis process. These were perfected by two nations cut off from the world oil market, Nazi Germany and South Africa during the apartheid era. The South African company, Sasol, still exists and China has contracted with it to produce 2 million barrels of oil or gas per day, in China, from Chinese coal (13). Thus fossil fuel, most likely without sequestration, would provide an important part of the energy budget. With enhanced efficiency in the transportation and building sector, and little use of solid coal to generate electricity, fossil fuel would be reduced, but not consigned to history.

3D. Solar-Derived Power: Direct Solar, Wind, and Biofuel

I treat direct solar, wind, and biofuel together here as, directly or indirectly, all have the sun as their source. Many of these approaches have received government subsidies in one way or another. But how does one measure and compare subsidies for various power sources? It is far from simple to do this. For example, a government which favors coal power might give a tax credit of $5 for every ton as a depletion allowance, whereas an environmentally conscious government might offer homeowners a subsidy of $100/year if they hook up to a wind power source. How can we compare these on some sort of level playing field?

One approach is to examine subsidies per kilowatt hour (kWh). Let us imagine, again hypothetically, that the total tax credit for coal is $20 billion and the total subsidy for wind power is $10 billion. Who gets the larger subsidy? Wind delivers about 10 GW in the United States, so its subsidy is about 10 cents per kWh. Coal delivers about 300 GW, so its subsidy is about 2/3 cent per kWh, much less than that for wind.

It is not easy to track down figures for government subsidies in cents per kWh, but some have been published. In 2002, Hydro Quebec subsidized wind power at a rate of 9 Canadian cents per kWh, as opposed to its commercial rate for hydro power of 3 cents per kWh (Hydro Quebec press release, Oct 4, 2002, ***www.hydroquebec.com***). Eon-Netz, the largest wind power provider in Germany, had 7 GW of "nameplate" wind power installed in 2005, but only delivered about 1.3 GW to the grid, due to the intermittent nature of wind (***www.eon-netz.com***). It received a subsidy of about 9 Euro cents per kWh. The Japanese, in the wake of Fukushima, are understandably wary of nuclear power, and the government plans to subsidize wind power at 25 cents per kWh and solar voltaic power at 60 cents per kWh (14).

If the user were to pay the full cost in these scenarios, our electric bills would at least double, and more likely quadruple. I for one could not afford it. The scale of these subsidies leads one to believe that if they were removed, the most of these industries, would simply collapse, as Solyndra recently did, even with its large subsidy (15).

Any solar-derived power source is limited by two fundamental constraints: the incident solar power, and the efficiency by which that power is converted to electricity (or the desired format). At mid-latitudes at high noon on a sunny day, the solar power incident is about one kW/m^2. However, averaging over day and night and over sunny and rainy periods, the average is about 200 W/m^2, or about 200 MW/km^2. In evaluating any of these schemes it is important to know whether the published power is the peak or the average power. In my own experience, it is almost always the peak, or nameplate power that is given, which makes the particular scheme look about four or five times more attractive than it really is.

Now let us consider the efficiencies of various solar energy sources. The most efficient is probably solar thermal, where a large number of mirrors focus the sun's rays on a small volume of liquid, heat it, and use this heat to run a generator and produce electricity. An advantage of this scheme is that mirrors are cheap compared to the high-tech surfaces needed for solar voltaic systems. The efficiency at which the solar heat is transferred to the liquid is about 70%, and the efficiency of producing electric power thermally is about 30%, so the total efficiency of solar to electricity is roughly 20%. An additional advantage of solar thermal is that the hot liquid can be stored and used to run a generator at night. However, there will almost certainly be at least some thermal losses at night, so the 20% is most likely an upper limit. Hence the potential for solar thermal is about 40 MWe/km^2. A 1 GWe power station would occupy about 25 km^2, and 1 TWe about 25,000 km^2, an area about equal to the floor space of all buildings in the United States, assuming that each individual has 100 m^2 in his house and workplace. Such systems would most likely be set up in dry, dusty, desert environments, where keeping the mirrors clean could be a challenge.

Solar voltaic systems use planar semiconductors to convert sunlight into electricity. Their conversion efficiency is about 10%, so they have about half the efficiency, and would take up about twice the land area of solar thermal systems. However, they convert directly to electricity without going through a thermal cycle. Further research might improve the efficiency of solar voltaic systems. The land devoted to large power stations could not be used for anything else, but small rooftop systems could use land more efficiently.

Wind power is more sporadic and less efficient than solar. Since the energy flux in the wind varies as the cube of the velocity, wind mills are only optimal for a narrow range of wind speeds. Too low a wind speed and there is insufficient power; too high and the turbine cannot handle it, and to protect itself goes off-line. Wind power has much more random variation than does solar thermal or solar voltaic. Accordingly, the average power generated is typically only about 1/5 of the nameplate value. It is not easy to determine the efficiency of wind installations, but empirically one can use the size of wind farms as compared to solar thermal farms to estimate how their efficiencies compare. An example is provided by the Elk River Wind farm near Beaumont, KS, a rather windy area of the country. It has a nameplate capacity of 150 MWe, and most likely delivers an average power of about 40 MWe. It covers about 40 km^2, so it generates about 1 MWe/km^2, indicating an efficiency of solar energy to electrical energy via wind of about 0.5% to 1%. However, land used for wind farms can be used for other purposes as well. But since wind turbines are very noisy, the land near a wind farm is generally not appropriate for humans. Also, the maintenance cost of direct solar and wind installations appears to be very high, as maintenance personnel would have to drive back and forth over many tens of km to service a single 1 GWe facility.

Historically, biofuel from waste products has been used to generate a small portion of American electricity. For instance, paper mills use excess wood chips in this way to generate a few percent of American electricity. More recently, biofuel has meant the growing of plants to provide fuel, for example, deriving ethanol from corn or sugar. For most plants the conversion efficiency of photosynthesis is less than 1%. Right now, at least 25% of America's corn crop goes to manufacture ethanol, and this replaces 1% of our gasoline. This gives an idea of the inefficiency of biofuel as compared to conventional fuel. But it takes nearly as much gasoline to produce ethanol (to drive the tractors, fertilize the land, etc.), so that 1% becomes more like ~ 0.2-0.3%. One result of this is rapidly increasing food prices, causing great hardship in poorer parts of the world. To grow plants for fuel means taking away land that could be used to produce food, lumber, cotton, or which could be conserved. One could describe subsidies for ethanol production as taking food from stomachs of the world's poorest in order to add a minute amount of fuel to the cars in the richest parts of the world. This author considers it to be a crime against humanity. There are certainly significant moral issues regarding biofuel. Future research might lead to the production of biofuels from non-food crops and marginal lands, but this remains to be seen. At the end of 2011, two federal ethanol subsidy programs were allowed to expire. However, subsidies still remain for ethanol developed from cellulosic feedstocks, and Department of Energy loan guarantees remain for research and development programs.

3E. Sequestration

Coal for power plants is available on the required scale for quite some time, but unless the CO_2 is sequestered, coal burning could have adverse environmental effects. However, sequestration appears to be extremely difficult. One must first economically separate the CO_2 from the other much more abundant gases in the waste stream (i.e. nitrogen). If the CO_2 is sequestered in gaseous form, there is the real possibility of a catastrophic release, which would be enormously destructive. There are natural precedents. There are several lakes in Africa which are saturated with CO_2. One of them, Lake Nyos in Cameroon, abruptly out- gassed in 1986 and released about 1.5 million tons of CO_2. About 1700 people and 3500 heads of livestock were killed, basically everyone within 25 kilometers down-wind from the lake. However, as we see from Fig (1), we would have to sequester about 30 billion tons of CO_2 every year, assuming it can be done economically at all. There are extremely important safety issues related to sequestration, which have hardly been examined at all. If the CO_2 is sequestered as a solid, say calcium carbonate, its weight and volume are much greater than that of the original coal. For every coal train going to a power plant, there would be five or ten times as many going the other way.

4. Conclusion

How might we achieve the 50 TW needed by mid century to bring the world up to an 'Italian' standard of living? It is difficult to estimate how much energy can be saved by conservation and enhanced efficiency. As a very simple estimate we will use the examples of Sec 3A to estimate that enhanced efficiency and conservation (8) can reduce required power from 50 to 30 TW. This is consistent with a 1% per year decrease in energy intensity (9).

But the world still needs 30 TW. Of this, imagine scaling nuclear power up by a factor of about 15 to about 20 TWth. It would be used to generate all electricity, as well as power trains (electrically) and large ships, which could have their

own reactors. Another 6-8 TW would be provided by fossil fuel, mostly in liquid or gaseous form. This would be used for other means of transportation such as cars, buses, small ships and airplanes, as well as for space heating. Until nuclear is fully poised to take over, natural gas could also be used instead of coal to generate electricity. Finally a small amount, perhaps 3-4 TW would be provided by renewable sources, mostly hydroelectricity and biofuel from waste products (not food!), as well as direct solar and wind. One advantage of such an energy budget is that each major element is a proven supplier of energy, i.e. it takes maximum advantage of today's existing infrastructure. This neither ignores the threat of CO_2-induced global warming and climate change, nor regards it as an extreme planetary emergency.

It could do a world of good if the APS and AIP advocated a moderate, balanced approach to climate and energy, one that recognizes that global warming is not the only threat to civilization, and perhaps not even the most serious. There are, after all, competing priorities. But instead, American physics organizations have unfortunately taken a one-sided stand on the contentious and extremely complicated issue of climate change. The climate and energy dilemmas are inextricably linked; one cannot talk about climate and ignore energy supply. Yet, these organizations have done just that. Blindly following this advice would end any hope that less-developed parts of the world would have of achieving a western standard of living, and would also greatly reduce living standards in the west. To focus exclusively on climate change (where physicists have limited expertise) and to ignore completely the crucial role of energy for civilization (where physicists are the world's experts) is the height of irresponsibility. A more balanced and even-handed approach is needed. If we do not do so, this APS life-member Fellow fears that we will be on the wrong side of history, and posterity will judge our physics societies harshly.

The goal of world development should be to raise the nations low on Figure 2 upward. But without additional energy sources, preferably carbon-free, this will not only be impossible, but the nations high up will begin to slide down. This is the real threat to civilization.

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Understanding the Recent IAEA Report on Iran

Christopher Hobbs

On November 8, 2011, the Board of Governors (BoG) of the International Atomic Energy Agency (IAEA) released a highly-anticipated report on Iran's nuclear programme [1]. While the IAEA's BoG produces several reports on Iran every year which consistently find Tehran to be lacking in terms of its safeguards obligations under the Non-Proliferation Treaty (NPT), the most recent report was particularly significant in that it contained unprecedented detail on Iranian activities that could be relevant to development of a nuclear weapon. Its publication has increased concerns as to the true nature of Iran's nuclear programme and has provoked a strong response from the international community. On November 18 the IAEA BoG adopted a resolution in which it expressed "deep and increasing concern about the unresolved issues regarding the Iranian nuclear programme" [2]. On November 21, the United States reacted by adopting new sanctions aimed at Iran's petrochemical, energy and financial sectors [3]. The European Union, currently the destination for one-fifth of Iran's petrochemical exports, followed suit with an "unprecedented" oil embargo in January 2012, a move that has potentially damaging consequences for Iranian oil revenues [4].

In the international press the BoG report has been widely interpreted as confirmation that Iran is intent on acquiring a nuclear weapon and is close to fulfilling this goal. Some analysts now argue that the benefits of a pre-emptive strike against Iran's nuclear facilities now outweigh the costs [5]. Israel, the country perceived by many as most likely to carry out such an attack, remains determined to prevent Iran from "turning nuclear" [6]. Iran, by contrast, has been consistent in its claim that its nuclear programme is peaceful and for the purposes of energy production. Iranian officials described the BoG report as "unbalanced" and "politically motivated" [7]. In this context, Tehran has responded defiantly to new and increased sanctions by repeatedly threatening to close the Strait of Hormuz, through which passes 20 percent of the world's oil. Iran's rhetoric has in turn prompted the US, the UK and France to increase their military presence in the area [8]. International tensions will likely escalate further in the coming months.

In this article I examine the key technical issues surrounding Iran's nuclear programme and the significance of the November 8 BoG report.

Nuclear Hedging

At the core of all nuclear weapons is fissile material, either highly enriched uranium (HEU) or plutonium (Pu) [9]. These materials do not occur naturally in significant quantities and must be produced, either through the enrichment of uranium or its irradiation in a nuclear reactor to produce plutonium. The acquisition of fissile material is seen as the key hurdle in the development of nuclear weapons although the construction of a nuclear warhead is also a complex task for which specific research and development work, collectively referred to as weaponization, must be carried out and coordinated with the development of a delivery system. However, a nuclear weapons programme cannot be definitively inferred from progress in these areas. Fissile material is used in nuclear power reactors; experiments relevant to weaponization can have civil or other military applications; and delivery systems such as ballistic missiles are also used to deliver conventional payloads. Given the dual uses of these materials and technologies it is possible for a state to develop an indigenous technical capacity ostensibly for civil nuclear purposes but with the option to produce nuclear weapons in a short time frame, which may range from several weeks to a couple years [10]. This is a strategy commonly referred to as "nuclear hedging" which can leave a state within months or years of having nuclear weapons while maintaining its non nuclear weapon state (NNWS) status under the NPT. Nuclear hedging has in the past been used to describe the programmes of highly industrialised countries such as Japan, South Korea and Germany before increased transparency in their nuclear development and greater international oversight through implementation of measures, such as the Additional Protocol for the application of safeguards, served to allay international concerns.

Iran's low-enriched uranium stockpile

Iran has steadily expanded its uranium enrichment programme since the introduction of uranium hexafluoride to its Fuel Enrichment Plant at Natanz in February 2007. According to the most recent BoG report released in February 2012, this facility has been used to produce just less than 5,500 kg of 3-5% low enriched uranium (LEU), with approximately 100 kg of 19.75% LEU produced at the adjacent Pilot Fuel Enrichment Plant (PFEP). To put these percentages in perspective, bomb-grade material is considered to be 90% U-235. In December 2011 uranium enrichment was started at a second site, the Fordow Fuel Enrichment Plant (FFEP) near the city of Qom, and just over 10 kg of 19.75% LEU has been produced as of February 2012. Enrichment to date has utilized the relatively inefficient Ir-1 centrifuge, which is based on

1970's gas centrifuge technology, with approximately 9,000 currently installed at Natanz. Iranian scientists are also carrying out research and development on more advanced designs, the Ir-2m and the Ir-4, which use carbon fibre rotors (as opposed to high strength aluminium) and would likely have separative capacities many times greater than the Ir-1. In mid-February 2012 Iran announced 'huge' nuclear progress with the production of a 4th generation centrifuge and plans to install three variants, the Ir-5, Ir-6 and Ir-6s, at the PFEP. However, the very fact that Iran will now be conducting trials on three new centrifuge models alongside the Ir-2m and Ir-4 models implies that they are still some way from mastering advanced centrifuge technology and deploying a next generation centrifuge design.

Iran's enrichment programme is a source of continuing international concern due to its illicit procurement of technology, covert development, and the absence of a credible civil rationale. Tehran initially acquired gas centrifuge designs and components from the A.Q. Khan proliferation network in the 1980's, which provided similar technology for Libya's and North Korea's nuclear weapons programmes. The enrichment site at Natanz was first revealed to the international community by the National Council of Resistance of Iran (NCRI), an exiled opposition group, more than a decade after Iran began work on enrichment. This pattern of opaque nuclear development was repeated with the FFEP, which Tehran first reported to the IAEA in September 2009 just days before the US, UK and France presented clear evidence that it had been under construction for many years. Finally, while Iran's stated rationale for its nuclear programme is energy generation to meet future requirements, there are currently no nuclear power plants (NPP) in Iran where the LEU produced could be used. The Bushehr NPP uses Russian fuel while the NPP planned at Dvorkin is by optimistic estimates a decade away from completion.

Iran's growing stockpile of LEU is of particular concern to those worried about Iran's nuclear intentions because it provides a source of material that could be further enriched to a level suitable for use in nuclear weapons. While estimates vary as to how long this would take (from two to six months), it would certainly be much quicker than having to start from natural uranium [11]. Consequently, recent diplomatic efforts have focused on reducing this stockpile, which is now sufficient to produce several nuclear weapons. In October 2009, for example, the IAEA proposed that Iran send a significant proportion of its stockpile to Russia and France for conversion into fuel for the Tehran Research Reactor. While this measure was agreed to in principle, implementations terms acceptable to all parties were not reached and the initiative collapsed in May 2010.

A parallel weaponization program?

As well as detailing Iran's enrichment and other fuel cycle activities, the BoG report contains a 14-page annex on possible military dimensions to Iran's nuclear programme. The Annex presents a record of procurement, research, development and testing activities stretching back many years. While the IAEA has been aware of this for some time and previous BoG reports have expressed concern at many of these activities the Agency has never before released such a comprehensive account. The report, described in the following paragraphs, strongly suggests that Iran has made significant progress in accomplishing most if not all of the technical steps necessary to produce and deliver an implosion-type nuclear weapon [12].

According to the report, in 1987 Iran acquired a document via the A.Q. Khan network which describes how to convert gaseous UF_6 into uranium metal and produce hemispheres of enriched uranium (the shape and form necessary for use in a nuclear weapon). It is alleged that Iranian scientists have since performed experiments on the conversion of uranium compounds into metal. While Iran has admitted that it received the aforementioned document it claims that it was part of a package of information on centrifuge technology and that it "had not been requested" [13]. The report also claims that Iran has performed research into the simultaneous detonation of high explosives and carried out at least one large scale test in 2003 to generate a converging shockwave. In a nuclear weapon such a system is used to compress the fissile core to a critical density capable of sustaining a nuclear chain reaction. Moreover, the BoG report claims that Iran has recently experimented with materials and components capable of producing bursts of neutrons, which are used in nuclear weapons to trigger the chain reaction. In support of these activities, hydrodynamic tests where fissile and nuclear materials are simulated by other materials for the purpose of design optimization are also reported to have been carried out through the early 2000s, while modelling studies on the shock compression of the HEU core of a nuclear weapon are said to have been carried out in 2008 and 2009. With regard to the delivery of a nuclear weapon it is alleged that between 2002 and 2003, Iran conducted engineering studies on how to integrate a spherical payload of suitable mass and dimensions for a nuclear warhead into the re-entry vehicle of its Shahab-3 missile. Research is also said to have been performed into the development of a firing system to enable this payload to explode at a height greater than 600 m above a target or upon impact with the ground. An airburst detonation at this height strongly implies a nuclear payload – the nuclear bomb dropped on Hiroshima in 1945 was exploded at a height of 580 meters.

The IAEA previously shared the bulk of this evidence with Iran in early 2008. Tehran responded in May of that year with a 117-page assessment which confirmed certain basic details (people, places and organizations), but dismissed all allegations of work towards nuclear weaponization, claiming that the information supporting these claims had been fabricated. The reliability of the information upon which the IAEA's assessment is based remains a key source of contention due to a significant portion being derived from covert intelligence supplied by member states. However, the IAEA has sought to address this issue in the BoG report by emphasising that intelligence was received from multiple member states and was consistent with other independent sources such as IAEA verification activities, interviews carried out with individuals involved in Iran's nuclear programme, satellite imagery, and grey literature.

Significance of the IAEA report

While the IAEA November report has been held up by some as proof that Iran has made the decision to acquire nuclear weapons and may do so imminently, it does not contain definitive conclusions as to the direction of Iran's nuclear programme or provide timelines. Furthermore, much of the information regarding Iranian activities set out in the report is not new; the report simply draws together and confirm information presented through other sources. For example, the report is broadly consistent with unclassified summary of the 2007 US National Intelligence Estimate, which concluded with high confidence that Iran's nuclear weapons programme was halted in 2003, while keeping open the possibility that Iran may continue with nuclear weapon relevant research. This said, the IAEA goes further in that the BoG report implies that weapons- relevant activities were restarted in 2006 or earlier, even if they were not part of a full scale nuclear weapons programme. In general terms, however, the IAEA report has reinforced pre-existing concerns rather than presenting damning revelations, with technical indicators implying that Tehran is moving slowly but steadily towards a nuclear hedging capability.

What is perhaps more interesting about the report is the fact that it demonstrates what appears to be a significant change in approach on the part of the IAEA. Past reports from the BoG have been characterized by their reluctance to court controversy and have presented the Iranian case in more abstract terms. Under the leadership of new Director General Yukiya Amano, however, the IAEA seems increasingly willing to pursue evidence on the military-relevant dimensions of Iran's programme. This development has important implications in terms of legitimizing the increasingly severe international measures aimed at halting, or even reversing, Iran's nuclear programme. A new round of talks between Iran and the P5+1 (US, UK, France, Russia, China and Germany), the first since January 2011, are expected to take place in Turkey in April 2012, although it is too early to tell whether recently increased pressure will be sufficient to force Iran into serious negotiations on its nuclear programme.

Over the past four and a half years Tehran has been the subject of four UN Security Council Resolutions and multiple rounds of sanctions, yet has continued to push steadily ahead with its nuclear development. Still, the most recent IAEA visit to Iran at the end of January 2012 was potentially significant in that it included two senior weapons specialists in the visiting delegation; in the past, delegations have not usually included inspectors with such experience and knowledge. This has led some analysts to believe that Iran may be prepared to begin meaningful discussions on the possible military aspects to its programme for the first time. However, this optimism must be tempered by Iran's refusal in late February to allow IAEA inspectors to visit the Parchin military site, south of Tehran, where Iranian scientists in the past are suspected of carrying out hydrodynamic tests in support of nuclear warhead design optimisation. In any case, with EU sanctions set to come into full effect in June and the negotiations between the West and Iran set to resume in April 2012, the BoG report has added a new dimension to the Iranian nuclear question.

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REVIEWS

Physics of Sustainable Energy II: Using Energy Efficiently and Producing it Renewably

Edited by David Hafemeister, Daniel Kammen, Barbara G. Levi, and Peter Schwartz, AIP Conference Proceedings, University of California, Berkeley, 5-6 March 2011, (American Institute of Physics, Melville, NY, 2011)

The modern energy era began with the oil crisis and embargo of October, 1973. Within a few years US electricity growth rates dropped from the post-WWII rate of about 8%/yr to about 2%/yr, and total US energy use growth rate dropped from 2%/yr to almost zero, where it remains today.

A few physicists leaped on this new bandwagon and shifted their careers. In my own case I left Brookhaven Laboratory for Washington where I discovered opportunities that changed my life. I found myself working for the President's Science Advisor providing advice on energy R&D to the Office of Management and Budget, and starting energy programs at universities and national laboratories. Washington was and is a great place for a career shift, a place where one gains access to the nation's and the world's best experts, and makes lifelong friends. It's hard for anyone to resist a phone message or an e-mail saying "Washington's calling."

My Washington experience made it easy to move to academia, where I spent the rest of my active career teaching energy and environmental policy at UC Davis. My shift to energy roughly divides my lifetime to date in half. It was a good decision!

Only a handful of physicists shifted in the early days– but a very meaningful handful. Space permits mentioning only a few. Two became Presidential Science Advisors: Jack Gibbons and John Holdren. Art Rosenfeld started the Lawrence Berkeley Laboratory energy program. Bob Budnitz was head of research at the NRC during the heady days of Three-Mile Island. Dave Hafemeister decided to devote his career to energy and arms control. Lee Schipper, John Holdren's first graduate student, shifted from astrophysics to energy and became a global transportation guru.

The first APS energy study took place in 1973 [1]. It remains the "go-to" review of the fundamental physics principles underlying energy technology. Several of the authors remain active today, including Art Rosenfeld and Rob Socolow. Since 1973 APS has sponsored many physics-and-society studies, conferences, and APS meeting sessions.

Energy technologies are massive, all-pervading, and expensive. It takes a long time – a half century or more – for new technologies to have significant impact. The field of

energy efficiency is following the same slow trajectory as other energy technologies. Now about 40 years old, energy efficiency is finally becoming institutionalized. Energy efficiency has been by far the largest contributor to savings in the US energy system during these four decades, with no limits in sight: Art Rosenfeld argues that since 1973, efficiency has lead to a current savings of $1 trillion per year over what costs would have been had pre-1973 trends continued. Solar and wind energy have been around for over a century, and are being reinvented in that technologies to utilize them have changed significantly. It's too early to know their ultimate market impact, and there have been major setbacks.

In March, 2008, a short course on the physics of sustainable energy was held at UC-Berkeley; the proceedings were reviewed in the July, 2009 edition of P&S. The volume under review here, "Physics of Sustainable Energy II," includes articles from a second such conference, which was held in March, 2011. This volume is an excellent roadmap for young scientists seeking exciting careers solving the nation's and the world's huge energy and carbon problems. The book is divided into sections focusing on policy, environmental effects, transportation, buildings, and renewable energy. I wish I had space to review them all.

The first section applauds Art Rosenfeld, the father of modern energy efficiency. Art describes his early work and how it gradually gained influence. Former California Public Utilities Commission commissioner Dian Grueneich discusses how California today is leading the world toward new energy technology.

The environmental section emphasizes issues surrounding global climate change. Ben Santer's testimony to Congress concisely summarizes the science and key controversies. The transportation section shows how hard it will be to move beyond oil. Promising technologies exist, but remain elusive even after decades of research. The buildings section includes a wonderful analysis from Texas A&M of lower limits of energy use in commercial buildings. The result? A feasible building would use less than 1% of the energy used by typical current US office building. This "physics style" analysis compellingly shows the enormous promise for energy reduction.

I was fascinated by a solar energy paper by Ben Bierman of Solyndra Corporation. He writes: "As of this writing in May, 2011, Solyndra has consolidated operations in a new, 800,000 square foot manufacturing facility" in Fremont, CA. Despite the technology looking great, only a few months later in August 2011 the company declared bankruptcy and laid off all employees. This proved embarrassing to the DoE, which had heavily subsidized Solyndra. Solyndra is as good an example as one can imagine to demonstrate the huge risk of energy investments. One of the big sources of risk is that your own good ideas may not be enough. Competitors have good ideas too. It's easy to get bypassed.

The government has proven adept at supporting basic research, but often stumbles when attempting to choose winners and losers. The many unanticipated successes from government-supported basic research investment should make us all proud. Government should stick to what is essential and to what it does well.

Bob Budnitz's nuclear safety contribution to this volume expresses optimism about the nuclear industry. He makes a compelling case that the safety of US reactors has increased greatly. Having worked on high level nuclear waste and Yucca Mountain, and knowing Bob well, I wouldn't personally mind living next to a US reactor. But I'm not the public. Bob seems off base in his assessment of the Fukushima accident. In a "note inserted later" (after the conference) he writes: "The Fukushima accident did not result in a 'large release' by the common definition of such…" I expect the Japanese who lost their homes and were relocated due to contamination wouldn't agree.

Fukushima will haunt the nuclear industry for decades [2]. Physicists thinking of making careers in energy should recognize that such careers almost inevitably will intersect with public policy and the sometimes strange and implausible views of the public.

During the heyday of the Atomic Energy Commission in the 1950s and 60s, dreamy-eyed forecasts of nuclear power penetration abounded. Today the US operates about 100 aged reactors that provide about 20% of US electricity. Will the future see this number go up or down? It's impossible to know. Can the industry compete with wind, solar and efficiency? The nuclear industry has managed in the past to reduce its risk and lower investor costs through heavy use of government subsidies. Government subsidies do and no doubt will continue to tilt energy playing fields.

The conference proceedings include extensive appendices with key data and conversion factors. I especially like the energy flow chart on page 470. It represents a real step forward, replacing a long-used but massively misleading chart still produced by LLNL which divides energy into 'useful' and 'waste' [3].

Over the years, I have held lots of opinions on what the future would hold. My track record is abysmal–but so too is everyone else's! The history of energy forecasts is littered with amazing failures. Today US energy use is far below what anyone thought plausible in 1975 [4]. The last pre-embargo government forecast, from about 1970, got the year-2000 energy wrong by a factor of two (nearly 200 quads/yr forecast versus about 100 actual). Currently much focus is on carbon

emissions, but, to the consternation of the climate change community and the frustration of forecasters, global carbon emissions are rising faster than just about everyone thought.

Energy efficiency is at last becoming institutionalized. Efficiency and renewables are 'gifts that keep on giving'. I rejoice in having played a small role in the beginnings of the current energy transition. The turnout at the Berkeley conference and the competence and energy of the participants shows that young physicists appreciate the career opportunities [5]. They will push the field to new highs. The sky is the limit, and the need is without limit.

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