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‘We Don’t Tenure Mother Teresa’: Evolving Science and Engineering Research to Value the Planet

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Prologue: Advice from a Dean

Deans and department chairs regularly meet with their junior faculty members to evaluate their progress toward tenure. My first few annual meetings were uneventful, and were primarily concerned with the degree to which a physicist, working often on issues of rural energy in developing nations, had to ‘stray’ into disparate disciplines for the tools necessary to analyze the dynamics of energy generation, consumption, and social and environmental impact.

Then, at one memorable review, my dean looked over my projects and plans, and announced, ‘well, these are all very interesting, but you know, we don’t tenure Mother Teresa.’

There was a silence while I thought about what to say. He seemed to have said his piece, and was content to wait, or, perhaps, was even napping. After the pause grew to an uncomfortable interruption, I replied, “Maybe not, but I hope we recognize the history and value the contributions of science to society.”

At the time, in the early 1990s that was either the best I felt I could do in arguing for what is now known, generally, as ‘sustainability science’, or, it was all that my experience with the history of work in this area prepared me to answer. I would like to think that today I am able to do better. In fact, the lack of detailed reading of the rich material that does exist in this area has led me to teach a course, *Environmental Classics* that explores not only the intellectual history of this field, but also to examine how texts from the past half-century continue to impact our thinking.

My appreciation of how to define, undertake, and frame science intended to preserve or improve social and natural systems has led me to a point very different from that from which I bantered with my dean. Today the most striking feature of this ‘field’ of work is that of feedback: the more we examine this area, the more breakthroughs exist that inform and alter, fundamentally, what we know in the spheres referred to, unfortunately as, ‘basic’ and ‘applied’ science and engineering.

Defining and Doing Sustainability Science

The recognition that human activity is transforming the planet in intended and dramatically unintended ways has sparked the development of a critically important new field of research: sustainability science. Widely discussed essays (1), special issues of premier journals (2), and extensive websites (3) are now devoted to defining sustainability and identifying useful modes and topics for research. Building on this new foundation we now have a tremendous opportunity to advance the global scientific research paradigm towards the generation and implementation of sustainability science. An important lesson of this work is the conclusion that it is only by posing the question of sustainability explicitly and, where necessary, acting to repair the damage that we have caused to the biosphere, that we can begin to discover the full extent of our ability to prosper without degrading the planet.

In a seminal treatise on science policy, Vannevar Bush in wrote in 1945 that, “applied research invariably drives out pure”, to the detriment, in his view, of the national capacity for innovation (4). The resulting separation of basic and applied work shaped the evolution of science and engineering research for decades, and was a point of departure for E. F Schumacher and the “appropriate technology” movement (5). Schumacher’s work was a precursor of sustainability science that involved identifying particularly important but neglected issues for scientific study. This approach, which one of us termed “mundane science” (6), targeted projects that combined pragmatic and goal oriented applied research with possibilities to generate important advances in basic science (7). The growing recognition of the opportunity and value in supporting interdisciplinary research, and now the emergence of sustainability science, continues an important intellectual evolution in the interaction of science and society.

The scientific recognition of the reality of global environmental change (8) and the increasing political awareness of the need to act now to address greenhouse gas emissions (9), as well as the increasing disparities between the lives of the poor and the wealthy, provide an opportunity to galvanize global action that can place sustainability science at the forefront of educational, research, and career-development agendas. The next step needed to put sustainable science into action is the recognition that sustainability science can not only be fundamental science, but that entirely new avenues of inquiry are possible if we look to ecological stewardship as a guiding scientific principle. We are at a moment when this message has the potential to transform research careers, and to make sustainability a theme that researchers, public officials, and civil society can all access and embrace. The upcoming World Conference on Physics and Sustainable Development, to be held in Durban, South Africa (10), is an opportunity to bring this message widely to the research community.

In light of the current attention, debate, and trans-Atlantic division over how to provide meaningful, long-term aid and assistance for Africa, I highlight here two cases of sustainable science, engineering, and action based in developing nations that reflect the many opportunities that exist to jointly advance science and our ability to sustain both human and ecological communities.

The Energy-Health-Ecology Nexus

Household use of solid fuels is one of the leading causes of death and disease in developing countries throughout the world – particularly among women and children (11). Over the past decade I directed a series of studies of the efficiency and efficacy of programs to design and disseminate improved household stoves, ***and*** efforts to develop and implement sustainable forestry and fuel (often charcoal) production practices in Africa. We have found that combined attention to both stove and forestry programs can simultaneously lead to dramatic improvements in human health, ecological sustainability, and local economic development (12), as seen in Figure 1. Further, comparatively simple materials and design modifications in household stoves are now known to dramatically improve both energy efficiency and reduce particulate and greenhouse gas emissions (13).

These benefits can be achieved at exceptionally low cost (14), a few dollars per life saved, with the added benefit that atmospheric carbon mitigation is possible, also at a few dollars/ton of carbon. By contrast, carbon now trades for roughly $15 - 18/ton on the London exchange, a price that reflects greenhouse gas impacts alone. The potential to address both local health and development needs ***and*** global environmental protection with such economic efficiency becomes a natural component of any comprehensive Africa assistance strategy.

This work also led to a number of advances in 'basic' science that were not envisioned when the work began. The high pollution concentrations observed in rural African homes – up to 100 times higher than those observed in urban areas of many industrialized nations – provided an important laboratory to examine the epidemiology of exposure-response in a pollution regime far beyond what had been studied to date (15). This work, therefore, complements and greatly extends cutting-edge epidemiological work taking place largely in developed nations (16).

Solar Electricity Markets in Developing Nations

Household solar photovoltaics (PV) have emerged as the leading alternative to grid-based rural electrification in many developing countries. In Kenya, 30,000 PV are sold annually, making it a global leader, per capita, in residential renewable energy system sales (Figure 2). While a number of factors have contributed to the emergence and growth of the Kenya solar market, advances in amorphous silicon (a-Si) PV technology that led to the development of small, low cost a-Si PV modules have played a critical role (17). Key aspects of this work have involved minimizing the initial light induced Staebler-Wronski degradation of a-Si modules, a poorly understood materials issue that has significant implications for low-cost solar cells (18), and the development of cost-effective sealant materials and methods to prevent moisture induced delamination. While these advances have been broadly important in the PV industry, they have had particular significance for rural electrification with solar energy in developing countries. In contrast to celebrated, and useful, laboratory and commercial rivalries over who produces the thermodynamically most efficient solar cells, the firms active in manufacturing a-Si PV modules for developing country markets have focused on creating lower efficiency, but significantly less expensive, products (19). The resulting 12 - 20 Watt a-Si PV modules now available in Kenya and elsewhere retail at prices 50% lower than comparable crystalline silicon PV modules (20), and they are by far the top selling solar product in the region.

The dissemination of a-Si PV technology in Kenya has not, however, been without complications. In an extensive market survey (Figure 3) my student Arne Jacobson and I found that while most of the manufacturers produce high quality products, one prominent brand performed well below its advertised levels. Our previous study from 1999 demonstrated a similar pattern, albeit one involving a different low performing brand (21). Thus, while advances in a-Si technology have played a key role in enabling the rapid expansion of rural electrification with solar energy, successful deployment of the technology requires attention to market institutions that ensure quality and protect the public interest. This work combining technical studies of solar equipment performance with analyses of Kenyan market development, socio-cultural dynamics, and regulatory policy, has led to practical progress towards eliminating low performing products from the market as well as important insights into institutional aspects of renewable energy market development (22).

What can we do to make sustainable science for society projects the norm?

Firstly, we must recognize and make widely known that these projects are no more difficult than more traditional research -- and are arguably easier given the shorter history of work in this area -- once the funding and research/action team is assembled. To be effective, however, projects cannot remain exclusively in the academic or laboratory setting, nor should these projects sit entirely in the sphere of non-profit organizations or local governments, no matter how talented. To take maximum advantage of both the emerging science as well as the implementation capacity for sustainability efforts, we need to demonstrate our support for these sorts of efforts, through our actions as well as our funding priorities, in each of the professional tracks that must come together to make this work happen.

Secondly, we need to make sustainability science a basic precept of what secondary school, college, and post-graduate student learn to do, and thus to appreciate. Already, pre-college students have demonstrated a tremendous aptitude to work in what would be described as interdisciplinary areas. We must nurture and reward this interest with junior high school and college courses on energy, the environment, and the social drivers of resource degradation. The Upward Bound Math-Science Program (23) and the Summer Science Program (24) each serve as highly successful models that could be adapted to the theme of sustainability science. The launch of Sputnik in 1957 mobilized U. S. science and technology to an unprecedented extent, and should serve as a lesson in how powerful a use-inspired drive to innovate can become. The Spring 2005 Yale Environment Survey (25) found overwhelming interest in energy and environmental sustainability. Contrast that interest with the results of the Third International Mathematics and Science Study (TIMSS) where American secondary school students ranked 19th out of 21 countries in both math and science general knowledge (26). The TIMMS authors further concluded that science and mathematics education was failing because it lacked direction, vision, and motivation. Sustainability science provides one such rudder and motivating force to give science and engineering education renewed meaning and immediacy, with paradigm changing possibilities in developed and developing nations.

Thirdly, we could establish sustainability awards – modeled after the successful efforts of the Ashoka Innovators awards, the Ansari X Prize for space vehicle launch, and the Ashden Awards for sustainable energy (27) - that draw together developed and developing nation partners from academia, industry, civil society, and government. These initiatives would support and encourage groups to take action on critical sustainability projects they collectively identify, and to develop creative solutions. Ideally such awards would be jointly sponsored by private foundations and state or federal governments to encourage and take advantage of the diversity of perspectives and skills that these teams would bring together.

Finally, we must recognize and address the principal weakness in the economies of many poor nations: lack of capacity to compete in the global marketplace. Recent discussions of debt-forgiveness for impoverished countries in Africa and elsewhere is a laudable and important step (28), but it has already come under criticism by African leaders who note that aid alone is no panacea. Estimates of the percent of overall economic growth that stems from innovation in science and technology are as high as 90% (29), with virtually all of that taking placed in industrialized nations. Developing economies would be energized if investment in indigenous innovation could be dramatically increased. A natural way to do that would be to reward investment in science and technology capacity for sustainable development with additional debt relief or more favorable trade arrangements. Now is a perfect time for the G8 to adopt this plan and assist all nations to invest in environmentally conscious innovation.

Figures:

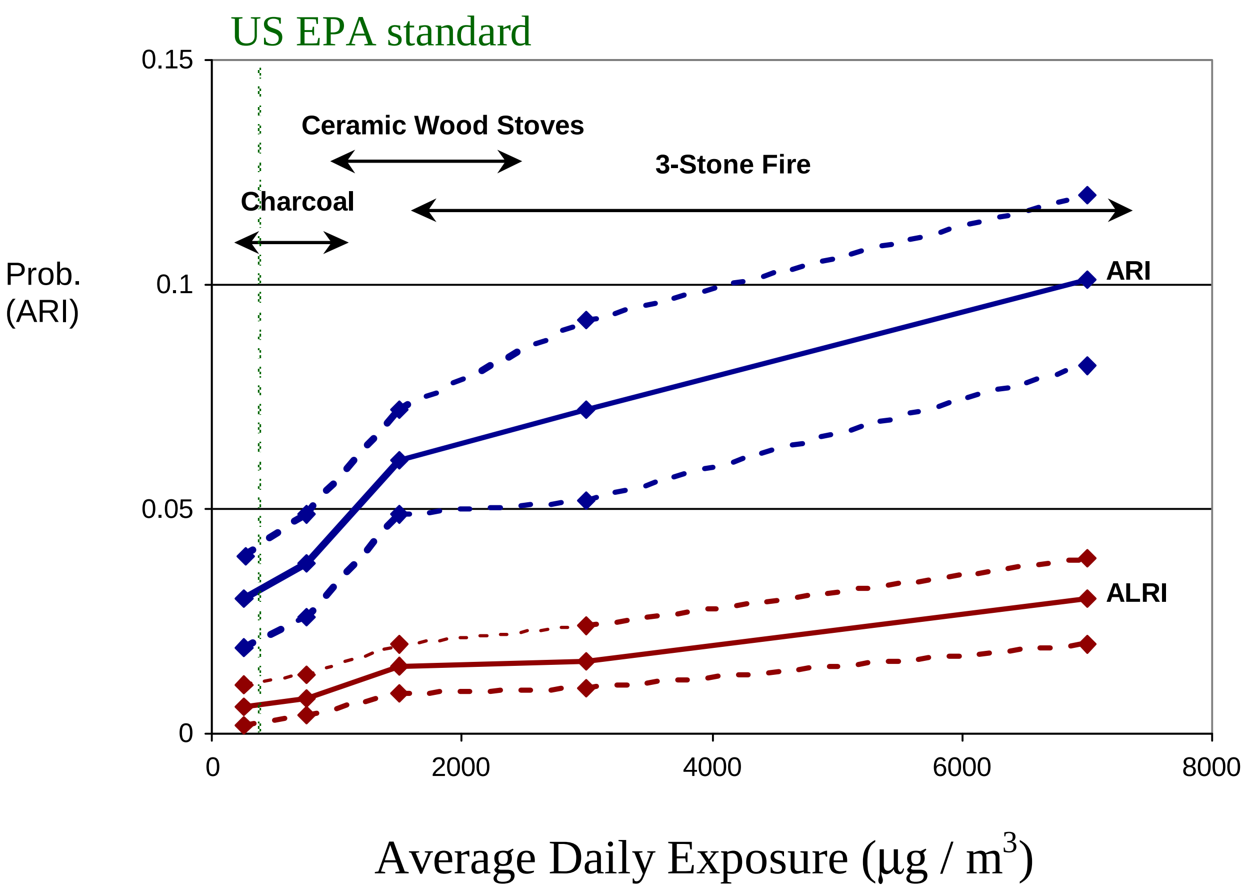

Figure 1. The exposure-response graph developed by Ezzati and Kammen (2001b) from the six year, 500 person, exposure and stove intervention trial in Kenya. The vertical axis is percentage of time subjects presented at bi-weekly health examinations with ARI, which refers to acute respiratory infection, while ALRI is acute lower respiratory infection. The US EPA particulate exposure standard of 200 μg/m^3 is indicated in green, which forms a lower bound to the exposure range observed in the Kenya project. The stove and fuel combinations indicate resulting exposure ranges seen in individuals using these as their primary fuels.

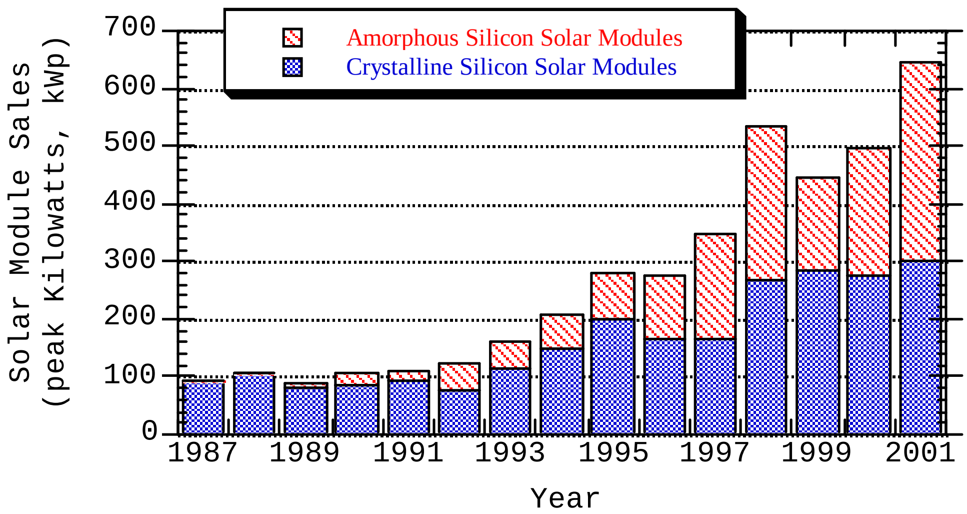

Figure 2. Solar Module Sales from 1987 to 2001 in Kenya, showing the dramatic growth in amorphous silicon solar cell sales. With average system sizes under 20 Wp, these sales today represent over 30,000 individual solar electricity home systems. Crystalline solar system sales are largely institutional systems, and international project donations and grant in aid efforts. Data sources: Acker and Kammen, 1996; Hankins, 2000; Jacobson and Kammen, 2005.

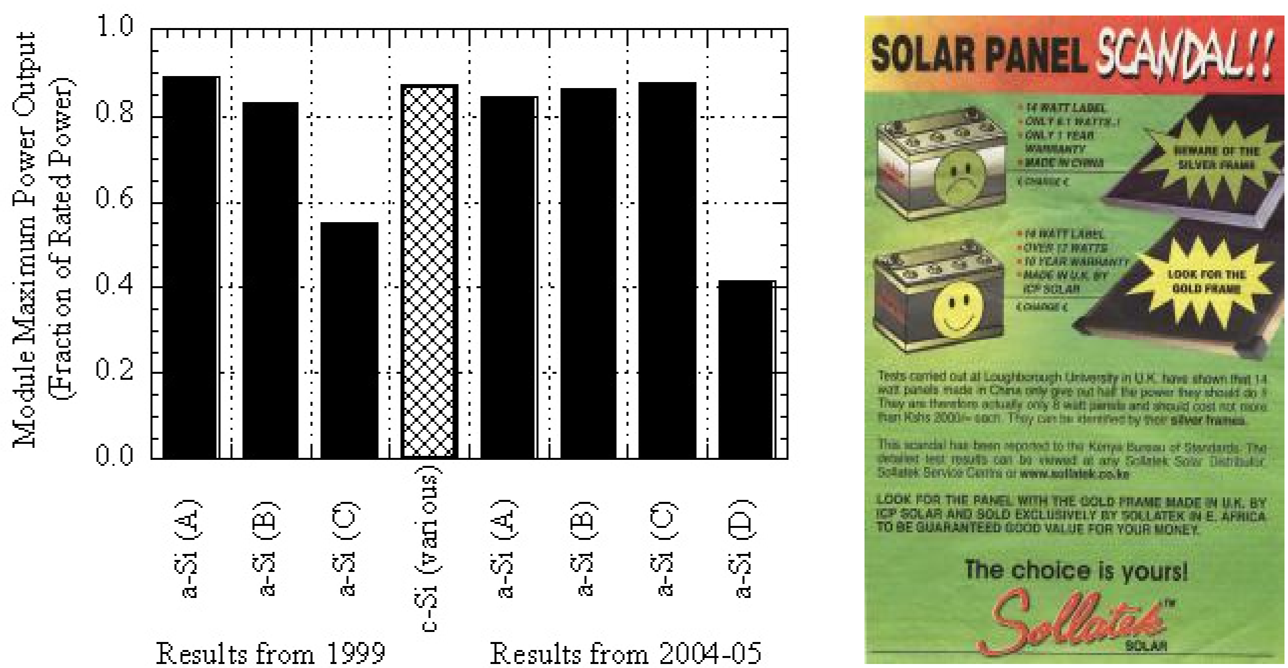

Figure 3. Average stabilized maximum power output results from 1999 and 2004-05 for amorphous silicon solar modules sold in Kenya (30; see footnote for brand names). Aggregate

test results for several brands of crystalline silicon (c-Si) modules are included for comparison. The results indicate that while most a-Si brands have power output levels that are similar to the more expensive crystalline silicon modules, some brands perform well below their advertised power ratings. The presence of the low performing brands has led to considerable acrimony in the Kenya solar industry, as indicated in the "Solar Scandal" advertisement (31). Brand D's market presence dropped recently following the release of the 2004-05 results in Kenya.

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[1] A. J. McMichael, C. D. Butler, C. Folke, *Science*, **302**, 1919 (2003); T. Clarke, *Nature*, **418**, 812 (2002); D. Kennedy, *Science*, **302**, 1861 (2003); R. Swart, *et al.*, *Science*, **297**, 1994 (2002); R. W. Kates, *et al.*, *Science*, **292**, 641 (2001).

[2] A special section of the July 8, 2003 issue of the *Proceedings of the National Academy of Sciences*, **100 (14)** is devoted to science in support of sustainability.

[3] The Forum on Science and Technology for Sustainability, http://sustsci.harvard.edu/, grew out of interdisciplinary meetings in 2000, and includes both a diverse editorial board, and provides access to a broad range of publications relevant to sustainability studies.

[4] V. Bush, *Science The Endless Frontier - A Report to the President* (United States Government Printing Office, Washington: 1945).

[5] E. F. Schumacher *Small is Beautiful* (Harper & Row: New York, 1973).

[6] D. M. Kammen and M. R. Dove, *Environment*, **39,** 10 (1997).

[7] A particularly clear and important statement of which was the concept of 'use inspired basic research', explored in D. Stokes, *Pasteur's Quadrant* (Brookings Institute Press: Washington, DC, 1997).

[8] J. Hansen, *et al., Science*, **308**, 1431 (2005).

[9] D. Kennedy, *Science*, **308**, 1713 (2005).

[10] http://www.saip.org.za/physics2005/WCPSD2005.html

[11] K. R. Smith S. Mehta and M Maeusezahl-Feuz, "Indoor air pollution from household use of solid fuels," in *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors*, M. Ezzati, et al., Editors, (World Health Organization: Geneva)1435 (2004).

[12] D. M. Kammen (1995) *Scientific American*, **273**,72 (1995).

[13] R. Bailis, M. Ezzati and D. M. Kammen, *Science*, 98 (2005).

[14] M. Ezzati and D. M. Kammen, *Energy Policy*, **30**, 815 (2001a).

[15] M. Ezzati and D.M. Kammen, *The Lancet*, **358**, 619 (2001b).

[16] D. Q. Rich, *et al., Am. J. Epidemiology*, **161**, 1123 (2005).

[17] M. Hankins *Energy Services for the World's Poor* (ESMAP, World Bank: Washington, DC, 2000).

[18] The power output of a-Si solar modules typically decreases by 15-40% during the first few months of exposure to solar radiation due to Staebler-Wronski degradation. After this initial period of degradation, the power output stabilizes. The rated power of high quality modules corresponds to the final, stabilized power output under standard test conditions of 1000 W/m^2 and 25ºC. Recent research links the Staebler-Wronski effect to hydrogen-related defects in the amorphous silicon semi-conductor material. See D.L. Staebler, and C.R. Wronski *Applied Physics Letters*, **31,** 292 (1977) and T. Su, P.C. Taylor, G. Ganguly, and D.E. Carlson, *Physical Review Letters*, **89**, 015502-1 (2002).

[19] Low cost, single junction amorphous silicon modules convert solar energy to electricity at a conversion efficiency of 2-4%. By comparison, commercially available mono-crystalline solar PV modules regularly operate at efficiencies ranging from 10-16%. See M. A. Green, *et al., Progress in Photovoltaics: Research and Applications*, **13**, 387. (2005).

[20] In Kenya, small amorphous silicon PV modules retail for $4-5/Watt, while similar sizes of crystalline PV modules sell at $7-8/Watt.

[21] Following the 1999 study, the main company associated with the low performing brands made considerable investments to improve the quality of its products, and these a-Si PV modules are now among the high performing brands listed in Figure 2. However, a new line of low performing modules entered the Kenya market during 2002-2003. This highlights the importance of long term market monitoring and institutional solutions that require high quality for all available brands (Report available as S1).

[22] R. Acker and D. M. Kammen, *Energy Policy,* **24,** 81 (1996); R. Duke, A. Jacobson, D.M. Kammen, *Energy Policy*, **30**, 477 (2002); A. Jacobson *Connective Power: Solar Electrification and Social Change in Kenya*, Ph.D. Dissertation, University of California, Berkeley (2004).

[23] http://www.ed.gov/programs/triomathsci/index.html

[24] http://www.summerscience.org/home/index.php

[25] http://www.yale.edu/envirocenter/environmentalpoll.htm

[26] W. H. Schmidt, S. A. Raizen, and C. C. McKnight, *A Splintered Vision: An Investigation of U.S. Science and Mathematics Education* (U.S. National Research Center for the Third International Mathematics and Science Study, 1997).

[27] http://www.ashoka.org; http://www.xprizefoundation.com; http://www.ashdenawards.org

[28] J. D. Sachs "Four easy pieces", *New York Times*, June 25 (2005) A15.

[29] R. M. Solow, *Growth theory: an exposition* (Oxford University Press, Oxford, UK, 2000).

[30] The reported maximum power results are for standard test conditions of 1000 W/m^2 and 25°C. The a-Si module brands, listed with the country of origin in parenthesis, are as follows: A: Free Energy Europe (France), B: Solar Cells (Croatia), C: Intersolar (1999 results, UK) & ICP-Solar (2004-05 results, UK) {note that the Intersolar factory in Wales, UK, was purchased by ICP-Solar in 2003}, D: Shenzhen Topray (China). The 1999 test results are based on field measurements of 130 a-Si modules and 17 c-Si modules, while the 2004-05 study involved 20 a-Si modules that were randomly selected from Kenyan retail shops. In 1999, the Free Energy Europe and Solar Cells modules were rated by the respective manufacturers at 12 Watts, while the Intersolar module had a 14 Watt rating. The crystalline modules had ratings ranging from 10-40 Watts. All of the solar modules from the 2004-05 study were nominally rated at 14 Watts.

[31] Advertisement from the *East African Standard* newspaper, Nairobi, Kenya, May 2, 2004.

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