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Renewable Energy Options for the Emerging Economy: Advances, Opportunities and Obstacles

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A Renewables Intensive Energy Future for Energy Security and Economic Growth

Renewable energy technologies have experienced dramatic technical and economic advances over the past several decades, and now stand at a point where they are already contributing significantly to energy and electricity production in a number of states, provinces, and nations. Over the next five decades solar and wind energy could provide well over one third of electricity demand, with biomass meeting another 20% (Herzog, *et al.*, 2001).[1] Combining this potential growth with nuclear systems that currently provide 20% of U. S. electricity, and with an acceleration of the current 1 – 2% annual rate of decarbonization and efficiency improvements, our energy system could look very different in 2050 than it does today. In sum, these technologies – all largely available today, or in the near term – could readily provide a total of 70% or more of electricity from carbon-free sources – *even for a future requiring significantly more energy than the current global supply capacity of ~10 TW demand*. A commitment to energy R&D efforts, distributed energy capacity, energy storage and market-support policies could make this future a reality. This process would be greatly facilitated if economic and accounting practices were to evolve to value the full social and environmental costs of energy, services (Kammen and Pacca, 2004).

This vision of an economically, politically, and environmentally sustainable energy future depends critically on a commitment to improving market access today, for low-carbon energy technologies today to facilitate the dramatic growth of this sector. The central message of this paper is that this transition will be require continued research and development, *but it can be achieved as an evolution from our current energy system*. To accomplish this the markets for solar, wind, and biomass energy must be dramatically expanded, and power transmission and storage systems must be overhauled to permit distributed energy management to interface with regional grids. This transformation, while entirely possible, will take a level of leadership and energy integration that we have realized to date only in brief fits and starts. A commitment will

[1] The specific energy policy recommendations I made at the July 2001 U. S. Senate Committee on Science, Commerce, and Transportation hearing chaired by Senator Kerry for a sustainable energy future are listed in Appendix I of this document.

be needed to national energy security, and to international leadership in clean energy technology development and deployment.

Technological and Market Outlook for Distributed Renewable Energy Systems

Wind energy is the world's fastest growing energy source on a percentage basis, at 32%/year growth for the past five years. Globally there was over $7 billion in wind energy investment in 2002 alone, and worldwide capacity is over 31,000 MW. In Denmark, and some regions of Spain and Germany 10 – 25% of total annual electricity generated is from wind. The north German state of Schleswig-Holstein currently meets 25% of annual electricity demand with 2,400 wind turbines that have a total capacity of 1,800 MW. Schleswig-Holstein has met over *50%* of demand for selected months during both 2001 and 2002. The state has committed to achieving 50% of electricity from wind by 2010, and is currently embarking on biomass and hydrogen energy programs as well (http://landesregierung.schleswig-holstein.de) On a regional scale, the European community anticipates 10 – 20% of total electricity from wind by 2010. Not only have wind turbines undergone a technological revolution in blade and motor design, but also in scale. Five years ago 750 kW turbines were considered large, but today 1.8 – 3 MW machines are standard in new wind farms, with even larger machines (~ 5 MW) are planned for many off-shore installations. Innovations have come at such a rate that repowering (replacing/upgrading) existing wind farms installed within the last decade has become the industry norm.

In spite of the limited market access and spasmodic R&D support that renewables have received, we are in a period of significant technical and economic evolution. Global production of photovoltaic cells has surpassed 500 MW/year, and has seen sustained growth of roughly 20%/year. With current costs of ~ $5/W for fully installed systems, a variety of studies forecast that within the next decade costs could decline to $1.50/W (see, e.g. Duke and Kammen, 1999), a critical cost range at which PV would be widely competitive with other technologies, as opposed to the current situation in which solar is attractive primarily in niche markets and in areas with specific, favorable market policies (e.g California where a 45% rebate exists for grid-tied residential systems). The rate of research and patenting in the solar industry has increased significantly recently, with exceptionally promising technological developments in the areas of thin films, conductive plastics, and now organic photocells[2].

The biomass sector is also undergoing a significant transformation. Biomass is estimated to have the potential to meet 20 - 25% of global energy needs, and can be used for a combination of

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[2] In an important series of technological advances, photovoltaic thin film and plastic solar cells, long of interest to the research community, have each been engineered to provide significantly higher efficiencies than seen over the past decade. Organic cells, with the potentnial for unprecedented lost costs – well *under $0.50 per peak watt – are now being seen as a possibility.* The R&D programs needed to bring these technologies to market will be substantial, and must be managed differently than past efforts where short-term politics and not adherence to challenging, objectives, have sadly been the norm. Specific goals, such as moving *several* PV technologies to the $1/watt level, deserves a commitment akin to the Apollo project, or the efforts to sequence the genome.

electricity, heating, and transportation fuel needs. That said, significant air quality, and land-management issues need to be addressed to achieve this potential[3] (Cushman, *et al,* 2001). Biomass, most likely grasses and softwoods can be used in flexible combinations of direct, single, fuel combustion, or can be gasified and then co-mingled with other fuels such as natural gas. Efficient combustion of solid biomass is now practiced extensively in a number of countries such as Sweden where biofuels are expected to meet 20% of electricity demand by 2010,. Advances in biomass gasification that permit fuel substitution between natural gas and biofuels are now yielding commercial designs at kW to MW scales. The fact that biomass, if managed correctly, can be available on demand, i.e. is a fully dispatchable energy source, makes it even more valuable in a renewables-intensive future. Biomass can also be used as a source of hydrogen, which could play a critical enabling role in GHG reduction efforts because of its ability to serve as an energy carrier for both stationary and vehicle-based power.

At the household and community scale a fundamental transformation in energy production and use is now possible if we are prepared to invest seriously in distributed power generation *and* intelligent efficient grid systems that operate under markets that reward clean power. Most homes, buildings, and commercial businesses consume power at kW scales, and yet most power is generated at scales of hundreds of MW. This mismatch stems from the historical focus on the apparent economies of scale of large power production and transmission. The prevailing mode of power generation and distribution assumed that larger and larger power plants, generally 1,000 MW at minimum, were the preferred unit of production thermodynamically and economically. This was due to a number of factors, but can be summarized as a product of the utility monopoly model and the pursuit of technologies for larger and larger scale power plants, to the exclusion of research on alternate technical and economic models. Today 50 – 80 MW gas turbines are more energy efficient than units an order of magnitude larger, and virtually no economic analysis or real-world testing has take place to evaluate other energy management models. In particular, economic systems that reward energy efficiency and conservation, and local clean power production have never been coupled with sustained research programs on building-scale power production, storage, and management through truly ‘two-way’ grid connections[4].

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[3] The possibility to provide energy capacity from biomass on this scale is disputed, and would require globally significant amounts of land area. Importantly, however, synergistic linkages between agricultural, silvicultural, and energy research efforts could make this goal more realistic.

[4] Politically, proponents of fossil fuel systems, renewables, and nuclear power have never worked together, and generally view the other technologies as competitors, or worse. As a result no real experience exists on the very great benefits of linking these technologies physically, such as in hybrid systems, or economically, in networks that recognize that short-term least cost pricing may result in very large long-term costs (such as the price California paid for dismantling the system of non-utility ‘Qualifying Facilities’ that during the 1980s consisted a small hydro, biomass, gas turbines, solar, and wind technologies that at one point provided fully one-third of the state power needs. This diverse, distributed, power network was the best example in U. S. history of the rewards in innovation and creativity that is possible when monopoly control of the power sector was lessened.

Combined heat and power systems – now recognized and supported in many nations and by a new U. S. Department of Energy CHP initiative[5] -- hold promise to increase the effective efficiency of a range of fossil-fuel technologies by roughly 40% to over 60% through the capture and use of waste heat. CHP is primarily dependent on intelligent regional planning where facilities requiring heat are co-located or linked to those producing excess. At the same time, regional planning could open markets for small-scale decentralized power generation, such as building integrated photovoltaic systems, electricity and heat production from fuel cells. Significant business opportunities exist for developed and developing country markets for highly efficient – even net energy producing – buildings. A powerful example is the recently completed renovation of the Moscone Center in San Francisco where a 675 kW roof photovoltaic system was installed at the same time as an overhaul of the HVAC system. Undertaking both projects as a package improved the economics of each component significantly.

Near-Term Policy Options

In keeping with the changes in renewable energy technologies, an increasingly diverse set of policy measures to facilitate the commercial introduction of large-scale use of alternative energy systems are now in practical use. Foremost is the Renewable Energy Portfolio Standard (RPS), which has been adopted in different forms by 14 U. S. states, with commitments ranging up to 20% of total electricity by 2017 (California). In a significant recent setback, the 2003 Federal Energy Bill no longer includes a federal RPS, although some of the candidates for the presidency in 2004 still support such a policy. A recent U. S. Department of Energy study concluded that a 20% federal RPS by 2020 would save the country billions of dollars per year through reduced fossil fuel costs, increased investment in domestic jobs, and through reduced security costs to safeguard our access to overseas oil and gas.

In the near-term an RPS is an innovative and critically important measure because it utilizes a transparent regulatory policy to open markets for clean energy technologies. At present wind is the cheapest form of renewable energy in many locations, and care needs to be exercised to open markets to a range of renewables, such as in the Nevada RPS, where a specific set-aside exists for solar energy. Allowing regional differentiation could also be a significant benefit, so that biomas-rich regions, such as the Southeast or Midwest, could adopt initial set-asides for biomass-based renewable fuels. Related measures are: introducing renewable energy or – or 'green' – credits into energy markets and 'feebates' provide the economic tools to encourage clean energy production and use. Renewable energy credits – based on units of clean, carbon free energy produced, or for energy saved – permit trading in market where low-or no-carbon energy sales and use are rewarded. 'Feebates' are an attractive and under-used policy measure

[5] The U. S DoE established in 2003 a series of regional research and applications centers focused on CHP systems. See: (see: http://socrates.berkeley.edu/~rael/CIDER.htm).

where a technologies – from stationary power plants and refrigerators, to vehicles – are rewarded with a rebate when they meet a specified standard, and taxed when the fall below this level. Like the success seen in the Clean Air Act, 'feebates' can be used to simultaneously reward sustainable systems and tax polluting ones, and can be 'ratcheted' up to encourage continued innovation'.

At the local level a variety of significant new policy instruments have emerged. The City of San Francisco approved a $100 million solar revenue bond in 2001 which will finance the installation of over 40 MW of peak capacity of photovolatics on city buildings and – most importantly – on cooperating local businesses and residences. The state of Hawaii, the state of new Mexico, and a number of California municipalities as well as the European Community are in the process of adopting or are considering similar solar bond financing mechanisms. In Hawaii and Japan high cost for electricity have encouraged the introduction of solar, biomass, wind, and ocean-thermal energy systems.

Missing from this suite of immediate policy actions is the mechanism that many researchers consider to be the most effective and economically efficient tool at our disposal: pollution fees. There is near universal agreement that the prices of fossil fuels far fall short of their social and environmental cost. The introduction of taxes to reflect these costs – which could readily be made revenue-neutral through compensating reductions in income tax – would be an efficient way to encourage cleaner forms of energy generation. A carbon tax of $10/ton – which would result in gas prices still less than we see in parts of Europe today – would encourage a wave of clean energy research and market implementation. Analysis from my laboratory indicates that a tax of this magnitude, particularly if introduced over time – would close the economic gap between essentially all renewables and fossil fuels, and would generate a wave of new clean energy innovation that would, in time, transform the U. S. energy economy.

Opportunities and Barriers

In the 2010 time-frame, a number of measures need to be continued, and a number of major issues need to be addressed to move the energy economy toward one with renewable energy utilized economically on a large scale.

In many respects the greatest hurdle that must be addressed to take advantage of the opportunities for CHP systems, local building-integrated renewables (primarily solar), and to focus greater attention on the value of efficiency is the role of utilities. In most areas the present utilities see few attractive revenue opportunities through encouraging greater efficiency, and in particular distributed generation appears as a simple loss of revenue. The opportunities for utilities to both encourage and to profit from clean, local, power production is one area critically in need of attention. As the conduit of electricity, utilities could become the entities that manage power transactions between houses, businesses, and industry that buy and sell in a real-time, distributed market. Beyond that, utilities themselves could transform the power industry by becoming an agent of regional planning: entering into performance-based contracts for both electricity efficiency, and CHP transactions; and developing local energy storage capacity (pumped hydro, spinning reserves, flywheels, hydrogen/electricity stations).

At present the U. S. utilities correctly see little benefit, and great expense, in investing the infrastructure needed to make distributed power generation/use the norm. R&D programs, subsidies, and other incentives for local, clean generation merely steal or divert customers from the utilities. Performance contracts based on clean power production and demonstrated energy savings by customers would be two ways to both reward clean energy innovations, and would make these programs economically attractive to the utilities.

Market Barriers: Market barriers to renewable energy technologies severely limit their ability to expand market share even when they are economically competitive on a technology-to-technology comparison. If a given energy technology has a 1% or smaller market share, its economics are dominated by a niche application, or by a specific regulatory provision. By contrast, roughly a 10% market share is one that is, for many technologies, one of economic competitiveness. The threshold to move from niche to viability is thus likely somewhere between 1 and 10%,. An RPS provides one clear mechanism to move these promising but marginalized technologies to the point where they can compete in the marketplace. As examples, in the case of both photovoltaics and wind,, multiple routes exist to move into this 'competitive' category. Both technologies can be deployed in stand-alone, distributed grid-connected, and central-station applications. R&D efforts for teach technology provide returns across all these scales. A second mechanism that should be employed are aggressive, 'DG milestones', such as energy autonomous buildings and appliances that, on average, produce as much energy as they consume.

Distributed Generation Research: DG systems have great promise for tailoring the amount of power generated to local demands. To accomplish this a significant program of research is needed on smart-grid technologies to permit monitoring and flexible re-routing of small amounts of power surplus and demand. Building integrated power production could become the norm – with many buildings self-sufficient in energy supply from clean sources – but will require a new generation of grid hardware to make this practical. At the same time, new financial tools are required to make the support of DG attractive to utilities. A step in the right direction is the new U. S. Department of Energy Combined Heat and Power research and outreach network, which we are fortunate to host the Pacific Center at the University of California.

Making R&D A Sustained Priority: A critical failing in our current energy economy is the fickle and intermittent nature of renewable energy research and development support (R&D). Many R&D programs have exhibited roller-coaster funding cycles, at times doing more harm than good to the sustained development and deployment of specific technologies (Margolis and Kammen, 1999). At the same time, the R&D portfolios we have adopted for many renewable energy technologies have been tremendously risk -- and hence potential benefit – averse. In particular, our R&D programs for solar and fuel cell systems have not been focused on short- or long-term goals that we were committed to achieve, but instead to spend available funds, which often had to be justified on unrealistically short timetables. Energy production and efficiency goals, and not specific programmatic or technological subsidies, need to guide the long-term direction of our R&D portfolio.

Each of the technologies discussed above has areas where R&D is critically needed. For solar this is largely in the efficiency increases and cost decreases needed in thin film technologies, and in the huge but unrealized potential of ultra-low cost organic cells. For both wind and PV technology power storage technologies would dramatically enhance their attractiveness. In hydrogen it is in both the cost and durability of fuel cell membranes, and in the cost of hydrogen production.

Technology, Practice, or Policy	**Timing**	**Issues**
Implement a federal Renewable Energy Portfolio Standard (e.g. 20% renewables by 2010 and reward states that meet and particularly exceed this level. As part of this process, the job creation, environmental sustainability, and international security benefits of clean energy must be integrated into national economic planning.	Immediate	A RPS is presently the most effective mechanism to bring new renewable energy technologies technologies to market, which in turn is the most effective way to foster additional innovation. Lack of experience with these technologies in large-scale power systems and reluctance to diversity the energy market are major roadblocks
Introduce Feebates and a Market for Clean Energy Credits	Immediate	Clean energy credits are hindered by the same issues noted above that impact the RPS. Feebates require oversight and enforcement.
Re-engage the U. S. in International Negotiations on Greenhouse Gas Reductions	Immediate	The precise form and requirement of the Kyoto protocol are far less important than a *real* commitment to climate leadership (and further, great latitude exists for an engaged U. S. to shape the actual plan). The global community is crippled by lack of U. S. involvement.
Design a *Goal-Oriented* Clean Energy Policy. A reasonable goal would be to eliminate the need for overseas oil and gas import while reducing GHG emissions	Immediate beginning; 20 years to fully implement new oil & gas policy.	Clean energy provides political and environmental security and stability, yet the few past efforts have focused on political or economic opportunities, not important targets.
Reinvent the U. S. Electricity the Grid to facilitate local power generation and consumption in ways that make this new model attractive to utilities, and promote energy storage technologies	One – two decades; although investment should begin at once, this should be a gradual process	The estimated price of this ‘upgrade’ is $100 billion, and current market practices do not reward this investment in infrastructure.

Regain global leadership in the development and sales of clean energy systems. Specific goals could include: • $1/W solar cells through a range of specific technologies • Global leadership in wind turbine sales • Develop biological hydrogen production on an industrial scale • Link energy and agricultural output goals with specific targets	One - two decades	Solar, wind, and fuel cell technologies were extensively innovated in the U. S. over the past decades, yet through inaction the U. S. has lost its leadership position in many of these areas. Clean distributed energy is a growth industry that we should lead and reap the rewards, not lag.

What is remarkable in reviewing the clean, largely distributed energy options we now see entering commercial markets is the degree to which the bulk of our energy needs could come from low-carbon energy. Achieving the 70% or more reductions in carbon emissions that ecological assessments of climatic change now see as necessary is, in fact, eminently achievable. Critical to accomplishing this change is to recognize that we do not today know what energy mix we will likely want in 50 years, but that we do not need to either pin our hopes on exotic technologies, nor do we need to hope for miracles. The near-term policy options we have to open markets to current renewable energy systems will both clean and diversify our energy mix, and will provide the essential proof-of-market that the private sector needs to make clean energy a priority. Major areas of federal R&D support are needed, but the opportunity today to mix market-mechanisms and sustained public sector support provides options that were until recently largely unrealized.

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Appendix I:
Energy Policy Recommendations from D. M. Kammen's
Testimony for the July 10, 2001 Hearing on Technology and Policy Options to Address Climate Change, Committee on Commerce, Science, and Transportation, United States Senate

Energy Policy Recommendations

• Increase Federal R&D Funding for Renewable Energy and Energy Efficiency Technologies

Federal investment in renewable energy and energy efficient technologies has been sparse and erratic, with each year producing an appropriations battle that is often lost. A combination of increased, steady, funding and active political leadership would transform the clean energy sector from a good idea to a pillar of the new economy.

• Provide Tax Incentives for Companies the Develop and Use Renewable Energy and Energy Efficiency Technologies

Support for the production and further development of renewable fuels, all found domestically, would have a greater long-term effect on the energy system than any expansion of fossil-fuel capacity, with major health and environmental benefits as an added bonus. We should extend the existing production tax credits (PTC) for electricity generated from windpower and biomass for five years. I also support a minimum of a 15 percent investment tax credit for residential solar electric and water heating systems. In addition, I support a 30 percent investment tax credit being proposed for small (75 kW and below) windpower systems.

• Improved Federal Standards for Vehicle Fuel Economy and Increased Incentives for High Fuel Economy Vehicles

We need to first remove the separate fuel economy standards for cars and light trucks (i.e., close the light truck 'loophole' as proposed in S. 804 by Senators Feinstein and Snowe and H.R. 1815 by Representative Olver). I then believe that a 40 mpg combined car and light truck fuel economy standard could be accomplished in the 2008 to 2012 timeframe with negligible net cost. I support tax credits for hybrid electric vehicles, battery electric vehicles, and fuel cell vehicles, and an incentive scheme for energy-use performance that rewards both fuel savings and lower emissions, as is proposed in the CLEAR Act, S. 760, introduced by Senators Hatch, Rockefeller, and Jeffords, and its companion bill (H.R. 1864) introduced by Representative Camp.

• A Federal Renewable Portfolio Standard (RPS) to Help Build Renewable Energy Markets

I support a 20 percent RPS by 2020. A number of studies indicate that this would result in renewable energy development in every region of the country with most coming from wind, biomass, and geothermal sources. A clear and properly constructed federal standard is needed to set a clear target for industry research, development, and market growth. I recommend a renewable energy component of 2 percent in 2002, growing to 10 percent in 2010 and 20 percent by 2020 that would include wind, biomass, geothermal, solar, and landfill gas. This standard is similar to the one proposed by Senators Jeffords and Lieberman in the 106th Congress (S. 1369).

• Federal Standards and Credits to Support Distributed Small-Scale Energy Generation and Cogeneration (CHP)

Small scale distributed electricity generation has several advantages over traditional central-station utility service, including reducing line losses, deferring the need for new transmission capacity and substation upgrades, providing voltage support, and reducing the demand for spinning reserve capacity. In addition, locating generating equipment close to the end use allows waste heat to be utilized to meet heating and hot water demands, significantly boosting overall system efficiency. I support at least a 10 percent investment tax credit and seven-year depreciation period for renewable energy systems or combined heat and power systems with an overall efficiency of at least 60-70 percent depending on system size.

- **Enact New and Strengthen Current Efficiency Standards for Buildings, Equipment, and Appliances**

Significant advances in heating and cooling systems, motor and appliance efficiency have been made in recent years, but more improvements are technologically possible and economically feasible. A clear federal statement of desired improvements in system efficiency is needed to remove uncertainty and reduce the economic costs of implementing these changes. Under such a federal mandate, efficiency standards for equipment and appliances could be steadily increased, helping to expand the market share of existing high efficiency systems.

- **Institute a National Public Benefits Fund**

I recommend a public benefits fund financed, for example, through a $0.002/kWh charge on all electricity sales. Such a fund could match state funds to assist in continuing or expanding energy efficiency programs, low-income services, the deployment of renewables, research and development, as well as public purpose programs the costs of which have traditionally been incorporated into electricity rates by regulated utilities.