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Task Force on Energy for Sustainable Development
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Summary Report
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INTRODUCTION

The achievement of sustainable development, defined as "meet[ing] the needs of the present without compromising the ability of future generations to meet their own needs," is dependent upon the ability of government actors, private corporations, citizens, and non-governmental organizations to address the world's increasing demand for energy.[1] Increased access to energy services is linked to development for the purposes of economic growth, improved educational opportunities, and basic household operations. Yet, while the benefits of increased energy access are apparent, the potential adverse effects on the local and global environment pose several challenges to policymakers.

The United Nations Commission on Sustainable Development (UNCSD or CSD), established by the General Assembly in December 1992 in order to follow up on the United Nations Conference on Environment and Development (UNCED), has chosen to focus on energy for sustainable development in its 2006/2007 cycle.[2] The Ninth Session of the CSD in 2001 also focused on energy as one of its major themes, and there, countries agreed that "stronger emphasis should be placed on the development, implementation, and transfer of cleaner, more efficient technologies and that urgent action is required to further develop and expand the role of alternative energy sources."[3] Specifically, the Johannesburg Plan of Implementation (JPOI), adopted at the World Summit on Sustainable Development in 2002, calls for several efforts to address "energy

[1] Brundtland Report of the World Commission on Environment and Development, U.N. General Assembly, A/42/427, 4 August 1987, Annex "Our Common Future." Available http://www.are.admin.ch/are/en/nachhaltig/international_uno/unterseite02330/

[2] UN Department of Economic and Social Affairs (UNDESA), Division for Sustainable Development (SD), "CSD-11: Multi-Year Programme of Work for CSD: 2004/2005 to 2016/2017," Page updated 3 August 2005, Available http://www.un.org/esa/sustdev/csd/csd11/CSD_mulityear_prog_work.htm)

[3] UNDESA, SD, "Issues: Energy for Sustainable Development," Page Updated 3 February 2006, Available http://www.un.org/esa/sustdev/sdissues/energy/enr.htm

in the context of sustainable development."[4] These JPOI calls for action include improving access to energy services that are "reliable, affordable, economically viable, socially acceptable, and environmentally sound;" increasing the use of renewable energy sources; "developing advanced, cleaner, more efficient, and cost-effective energy technologies;" and accelerating the "development, dissemination, and deployment of affordable and cleaner energy efficiency and energy conservation technologies."[5]

Consistent with these calls to action, the Princeton University Undergraduate Task Force on Energy for Sustainable Development attempts to address the question of how to increase access to sustainable sources of energy. In so doing, the Task Force analyzes several issues related to energy generation, energy efficiency, energy services in difficult-to-reach areas, and the implementation of renewable energy incentives and financing.

The Task Force is led by Professor Denise Mauzerall, and is composed of eight third-year public policy students, as well as one fourth-year "commissioner," in the Woodrow Wilson School of Public and International Affairs at Princeton University. For a semester of directed, intense study, each of the Task Force members tackled a specific issue related to generation, efficiency, development, or implementation, and compiled an individual report analyzing his or her specific issue.

As its geographic focus, the Task Force examined three countries that will have a significant effect on energy consumption trends and the resultant environmental effects of energy consumption: India, China, and the United States of America. Each country is at a different stage of economic development: in 2005, the US total GDP (purchasing power

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[4] Ibid.

[5] UNDESA, SD, Johannesburg Plan of Implementation (JPOI), Adopted 2002, Available http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/WSSD_PlanImpl.pdf

parity, hereafter PPP) was US$12.41 trillion and per capita GDP was US$42,000; China's total GDP (PPP) was US$8.182 trillion and per capita GDP was US$6,300; India's total GDP (PPP) was US$3.699 trillion and per capita GDP was US$3,400.[6] According to the UN's composite Human Development Index, the US ranks 8th; China ranks 94th, and India ranks 127th.[7] In addition, each country currently produces and consumes large and growing amounts of energy. With global electricity production at 16.5 trillion kWh in 2003, India produced 0.557 trillion kWh that same year; China produced 2.19 trillion kWh in 2004; and the U.S. produced 3.892 trillion kWh in 2003.[8]

Population growth and/or economic development are expected to contribute to the rise of energy production and consumption in each of these countries as well as throughout the globe. Between 2002 and 2025, electricity generation will likely come close to doubling, from 14.3 trillion kWh in 2002 to 26.0 trillion kWh in 2025.[9] Since the growing demand for energy services is an issue that affects policymakers in many countries, the diverse array of technologies and policies available in the three case study countries present opportunities for the discovery of overarching concerns, goals, successes, and failures.

The final in-depth report of each individual Task Force member presents findings and policy recommendations on their respective individual topic. Summaries of these reports were presented at a side-event of CSD-14 on May 12, 2006 at the United Nations in New York City. These individual reports follow this summary, which discusses

[6] Central Intelligence Agency (CIA), *The World Factbook*, updated May 2006, Available http://www.cia.gov/cia/publications/factbook/index.html
[7] United Nations Development Programme, *Human Development Report 2004,* "The Human Development Index," Available http://hdr.undp.org/docs/statistics/indices/hdi_2004.pdf
[8] CIA, 2006
[9] Energy Information Administration (EIA), *International Energy Outlook 2005,* #:DOE/EIA-0484(2005), Washington, DC, July 2005. Available http://www.eia.doe.gov/oiaf/ieo/index.html. Hereafter EIA, *IEO 2005*

current trends in energy demand and environmental repercussions, provides summaries of individual reports, and concludes with broad recommendations determined by the members of the Task Force.

CURRENT TRENDS IN ENERGY DEMAND AND ENVIRONMENTAL REPERCUSSIONS

Assessments of global energy demand forecast significant increases over the next two decades. According to the Energy Information Administration (EIA), global energy demand is predicted to increase by fifty-seven percent over the 2002-2025 time period (Figure 1).[10] Much of this growth will come from "emerging Asia," including India and China, where the predicted increase in energy demand by 2025 is more than a doubling of 2002 levels.[11]

Fossil fuels are the traditional and predominant source of energy, and forecasts predict their continued predominance (Figure 2). In 2025, oil is expected to maintain its position as the dominant source of energy, "with its share of total world energy consumption declining only slightly, from thirty-nine percent in 2002 to thirty-eight percent in 2025."[12] This continued demand for oil is consistent with the anticipated growth in the transport sector, which is expected to account for sixty percent of the predicted fifty-three percent increase in global oil demand.[13] Coal and natural gas demand are also forecast to increase as more areas of the world gain access to electricity. India and China both are home to large reserves of coal, and together, "account for 87

[10] EIA, *IEO 2005*
[11] ibid.
[12] ibid.
[13] ibid.

percent of the projected rise in coal use in the emerging economies region and 72 percent of the *total* world increase in coal demand over [2002-2005]."[14]

Figure 1. World Marketed Energy Consumption, 1970-2025.[15]

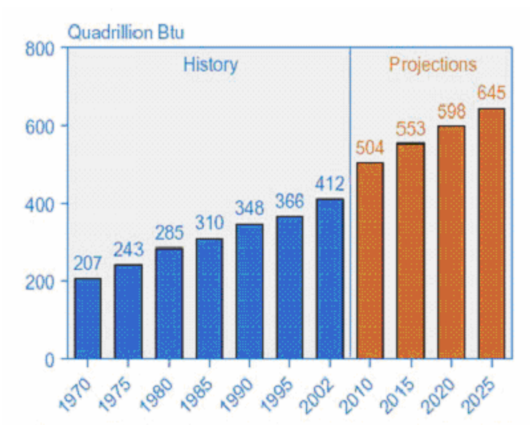
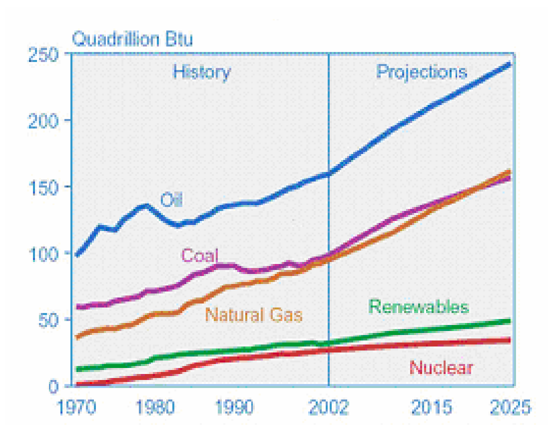


Figure 2. World Marketed Energy Use by Fuel Type, 1970-2025.[16]



Renewable energy sources are only expected to hold an eight percent share of world energy consumption from 2002-2025, as growth in demand for natural gas and coal is projected to be more rapid than that of renewable sources.[17]

With the persistence of trends in the global fuel mix over the next twenty years, individual citizens, lawmakers, and other concerned parties can expect significant environmental damage at both the local and global levels if concerted efforts to avoid such repercussions are not taken. Locally, fossil fuel combustion can lead to deteriorating air quality with further implications for ecological systems and human

[14] ibid.

[15] Energy Information Administration (EIA), *International Energy Outlook 2005*, #:DOE/EIA-0484(2005), Washington, DC, July 2005. Figure 7, Available http://www.eia.doe.gov/oiaf/ieo/figure_7.html Figure Sources : History – EIA *International Energy Annual 2002*. DOE/EIA-0219(2002) Washington, DC, March 2004, web site www.eia.doe.gov/iea/. Projections – EIA, System for the Analysis of Global Energy Markets (2005)

[16] Energy Information Administration (EIA), *International Energy Outlook 2005*, #:DOE/EIA-0484(2005), Washington, DC: July 2005. Figure 8, Available http://www.eia.doe.gov/oiaf/ieo/figure_8.html Figure Sources : History – EIA *International Energy Annual 2002*. DOE/EIA-0219(2002) Washington, DC, March 2004, web site www.eia.doe.gov/iea/. Projections – EIA, System for the Analysis of Global Energy Markets (2005)

[17] EIA, *IEO 2005*

health. The pollutants from fossil fuel combustion include sulfur dioxide and nitrogen oxides, which both are precursors to acid rain, and particulate matter, which has been linked to increased cases of and complications from respiratory illnesses like asthma and increased numbers of premature mortalities.[18]

Fossil fuel combustion results in the emissions of greenhouse gases that globally accelerate climate change.[19] Greenhouse gases affect climate by absorbing infrared wavelengths of radiation and preventing radiation of heat from the earth's surface to space. Carbon dioxide absorbs strongly in the infrared and is an increasingly abundant greenhouse gas in the atmosphere. It is the single most important anthropogenic (emitted by humans) greenhouse gas in the atmosphere. Greater concentrations of greenhouse gases mean greater average global temperatures; a rapid increase in the average global temperature will cause disruptions in the climate system. These disruptions may be both positive and negative, although scientists anticipate the negative effects to outweigh the benefits. Expected negative effects, according to the Intergovernmental Panel on Climate Change (IPCC), are:

- A general reduction in potential crop yields in most tropical and sub-tropical regions for most projected increases in temperature
- A general reduction, with some variation, in potential crop yields in most regions in mid-latitudes for increases in annual-average temperature of more than a few °C
- Decreased water availability for populations in many water-scarce regions, particularly in the sub-tropics
- An increase in the number of people exposed to vector-borne (e.g., malaria) and water-borne diseases (e.g., cholera), and an increase in heat stress mortality
- A widespread increase in the risk of flooding for many human settlements (tens of millions of inhabitants in settlements studied) from both increased heavy precipitation events and sea-level rise

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[18] EPA, "Acid Rain," Fact Sheet. Available http://www.epa.gov/acidrain/index.html, Last updated on Thursday, March 2nd, 2006. Accessed 10 May 2006. See Also Shaw, Jonathan. "Clearing the Air: How epidemiology, engineering, and experiment finger fine particles as airborne killers" Harvard Magazine, May-June 2005, pp. 28-35.

[19] The analysis from this paragraph is drawn from Lee Kump, James Kasting, and Robert Crane, The Earth System, Second Edition, Upper Saddle River, NJ: Pearson Education, Inc, 2004.

- Increased energy demand for space cooling due to higher summer temperatures.[20]

Predicted beneficial effects according to the IPCC include:

- Increased potential crop yields in some regions at mid-latitudes for increases in temperature of less than a few °C
- A potential increase in global timber supply from appropriately managed forests
- Increased water availability for populations in some water-scarce regions
- Reduced winter mortality in mid- and high-latitudes
- Reduced energy demand for space heating due to higher winter temperatures.[21]

However, the effects of climate change are most likely to be adverse in the developing countries, which are also the least likely to have the resources necessary to adapt to such effects as rising sea levels, increased incidences of vector-borne disease, and reduced agricultural yields.[22] Current trends in total and per capita carbon emissions globally and in the three focus countries are presented below in Figures 3 and 4.

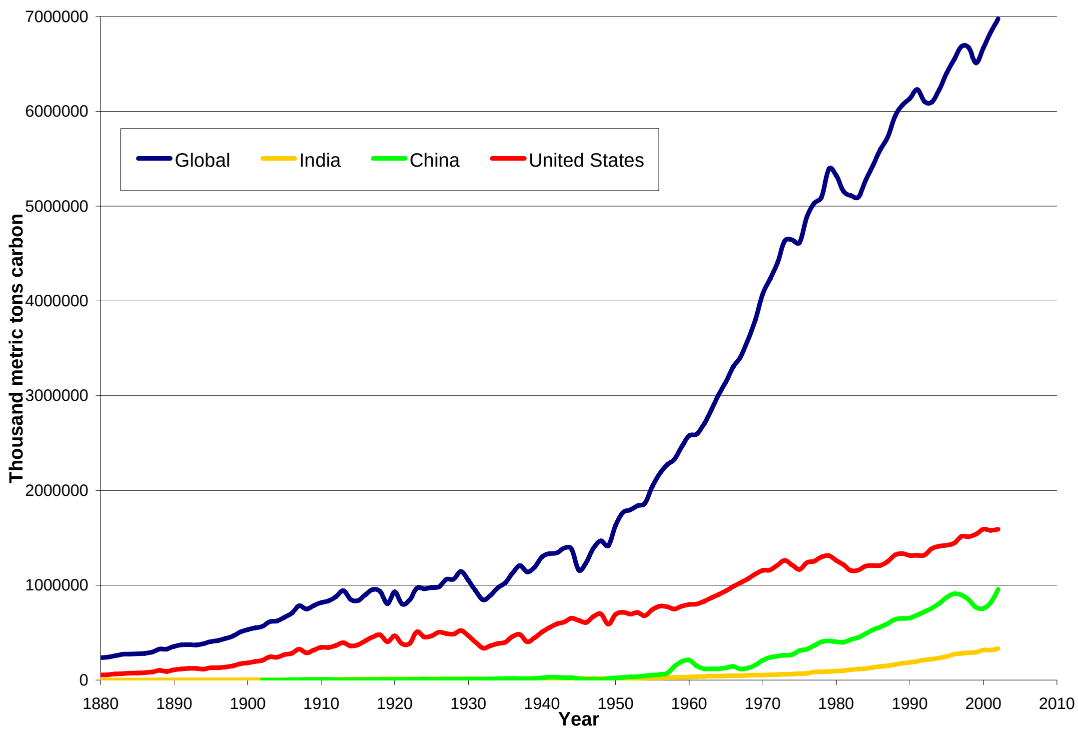
At the same time, it is true that reliance on traditional and pre-industrial sources of energy, such as wood-burning cook stoves and other forms of biomass combustion, can result in negative health effects.[23] Nearly two million children each year die from respiratory infections resulting from indoor air pollution and poor ventilation.[24] According to a 2006 UN Report, "indoor air pollution has larger health effects than urban

[20] IPCC, Impacts, Adaptation, and Vulnerability: Summary for Policymakers, http://www.grida.no/climate/ipcc_tar/wg2/008.htm#25. Because climate change is expected to cause an increase in extreme events, dry areas will become drier and wet areas may experience more intense precipitation. Water-borne diseases and vector-borne diseases will increase because the extent of tropical climate areas will increase with the trend of warming.
[21] Ibid. Note that many of these benefits will disproportionately help already developed countries, such as the United States and Europe. Countries located in the low-latitudes, which are almost all developing countries, will suffer from sea-level rise, increased disease, and higher risks from extreme weather events. Moreover, there is "high confidence that developing countries will be more vulnerable to climate change than developed countries, and medium confidence that climate change would exacerbate income inequalities within and between countries." See IPCC, Climate Change 2001: Working Group II: Impacts, Adaptation, and Vulnerability, Chapter 19, Executive Summary Available: http://www.grida.no/climate/ipcc_tar/wg2/658.htm
[22] IPCC, 2001
[23] UNDESA, *Trends in Sustainable Development*, 2006, Available http://www.un.org/esa/sustdev/publications/trends2006/index.htm
[24] Ibid.

air pollution [due to industrial activity, electricity generation, and transportation] by a large margin."[25]

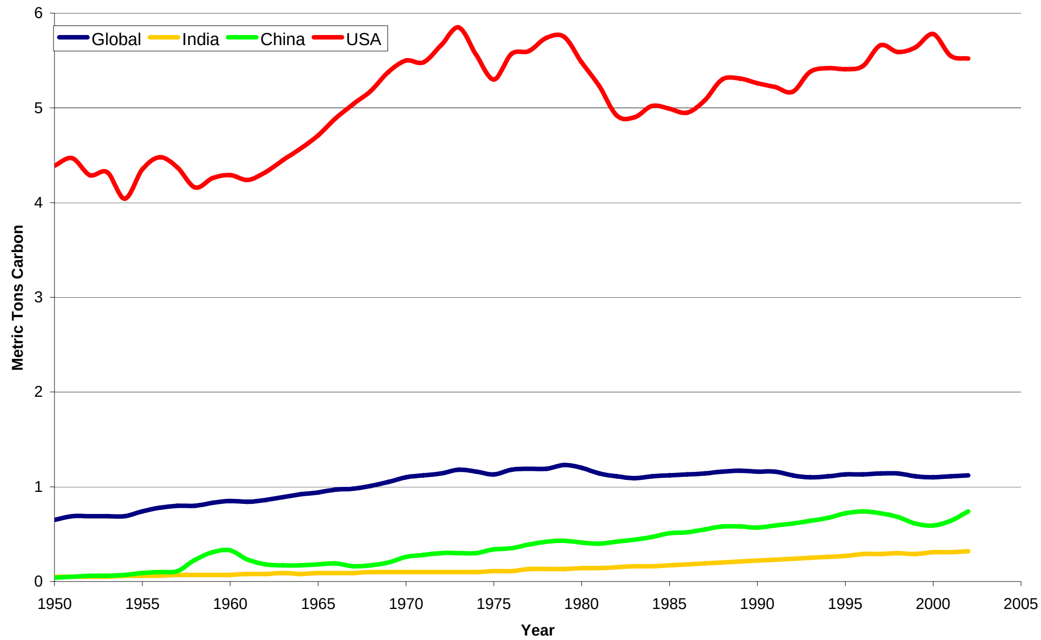
Inhibiting the modernization of energy services to the more than two billion people without electricity is clearly not the goal of sustainable development. Rather, policymakers and industry should implement available types of renewable energy sources, such as wind power or photovoltaic (PV) solar panels or small hydroelectric power plants. These forms of energy generation result in negligible amounts of air pollutants in lifecycle calculations, and during operation, emit no air pollutants or greenhouse gases. Additionally, efforts to control the emissions from fossil-fuel based energy would allow countries like India and China to utilize their existing natural resources with reduced impacts on air quality, human health, and climate change.

Figure 3.
Total Carbon Emissions from FF Combustion and Cement Production, 1880-2002.[26]



[25] Ibid.
[26] Figure created from data available at http://cdiac.ornl.gov/ftp/trends/emissions

Figure 4. Per Capita Carbon Emissions, 1950-2002.[27]



The Task Force papers proceed from the following objectives – to reduce the negative effects of fossil-fuel based energy sources, to increase the use of renewable energy sources, and overall, to improve access to energy services globally. First, the papers examine specific types of energy generation: one renewable and one adapting the use of coal. Michael Treadow analyzes the existing options and projected developments in wind energy. W. Ulysses Fowler appraises advanced coal gasification technologies and the feasibility of decarbonizing coal. Second, the papers look at ways to increase the efficiency of energy use so as to increase access to users without necessarily increasing emissions. Ben Steiner explores fuel efficiency in private vehicles and Nikki Laffel reviews the methods by which public transportation can provide gains in transport efficiency. Andrew Turco investigates methods by which efficiency in buildings, from construction to operation, can be achieved. Third, the papers discuss the extension of

[27] ibid

energy services to difficult-to-reach areas in the context of development. Antonio Lacayo surveys the opportunities for providing energy services to rural areas, and David Schaengold proposes distributed generation as a means of electrifying urban slums. Fourth, the papers determine methods by which the implementation of improved energy services might be accomplished via governmental regulation and financing options. Sabina Sequeira proposes the use of mandated market systems. My presentation, developed from my senior thesis, argues for the reform of public international financing institutions, such as the Export-Import Bank of the United States, to promote the growth and dissemination of renewable energy technologies.

PAPER SUMMARIES

"Wind Power: A Clean and Renewable Supplement to the World's Energy Mix"

Wind power harbors the potential to become a key contributor to the world's energy supply in years to come. Not only is it inexhaustible and free, but in comparison to fossil fuel sources, its environmental footprint is negligible. The major technical hurdles to wind power's growth relate to its remoteness and variability, but neither is an obstacle too great to be overcome. In many places, wind-generated electricity is already cost-competitive with traditional energy sources, and in those where it is not, capital investment is needed to prime the wind industry for competition. This paper reviews the background and technical aspects of wind power, examines the economic side of wind power, argues for general strategies that governments could use to create incentives for growth in the wind industry, and examines China as a case study. The final recommendations focus on ensuring fair grid access, taking advantage of offshore wind potential, and enacting economic measures to foster the industry's growth.

"STRENGTHENING SECURITY, HEALTH, AND ENVIRONMENT: Towards a Sustainable Coal-based Development Strategy for China"

In the next 30 years, 1400 GW of new electricity generation capacity is expected to be constructed worldwide. If all of this new generation capacity utilized coal, it would produce over its lifetime emissions of carbon dioxide 40% greater than total fossil carbon emissions from 1750 to the present. To avoid these emissions and the resulting impacts, it is imperative to develop new sources of decarbonized electricity. Integrated coal gasification and carbon capture and storage offers one of the most promising routes to decarbonized fossil fuel resources, since coal is abundant and secure and gasification is commercially viable. As such, coal gasification could play a significant role in increasing global supplies of decarbonized energy in the near and long term. However, several obstacles to implementation remain, especially in China and India where the most significant electricity growth will occur. China holds a position of special importance due to its extensive coal reserves and massive energy requirements, which together could transform China into the largest global carbon emitter within the next two decades. Both China and the world have much to gain by avoiding this outcome and instead developing China's energy system along an alternative trajectory based on advanced coal technologies. This paper examines barriers to the widespread implementation of coal gasification, including environmental policy, institutional capabilities, intellectual property rights protection, investment and trade rules, and finance and economics. The policy recommendations argue for the enforcement of existing environmental regulations and promulgation of tougher ones, the reform of the innovation process, the strengthening of intellectual property rights protection, the continuing liberalization of foreign investment, and the development of gasification-based electricity generation demonstration projects.

"Achieving Vehicle Fuel Efficiency: The CAFE Standards and Beyond"

Automobile fuel efficiency is one of the few issues in the greater global warming debate where stricter regulations are politically feasible because of the convergence of other policy goals. In particular, the United States' massive reliance on foreign oil and the coming crunch of global oil supplies have politicians concerned about energy security calling for increased fuel efficiency regulation. In addition, environmentalists have long sought more efficient vehicles and there is also a growing awareness among segments of the population of the threats caused by increased greenhouse gas emissions. Fuel efficiency is also one of the few areas in the climate change debate where the government has a history of regulation that can easily be relied upon as a basis for a new standard. Finally, the transportation sector accounts for 20% of carbon dioxide emissions in the US, so an increase in automobile fuel efficiency would significantly affect carbon concentration in the atmosphere. This paper identifies the current fuel efficiency situation in the United States and in China, and argues for policies that push for higher standards in both countries. Three policies are advocated. First, fuel efficiency standards in both countries should be increased to 36 mpg by 2015. This should be a fleet wide standard with tradable credits so improvements can occur at least cost. Second, though politically difficult to achieve in both the United States and China, a higher gas tax would curtail unnecessary driving and reduce fuel consumption while raising automobile fuel efficiency. This is the most economically efficient option. Finally, both nations should implement a feebate system that subsidizes high efficiency vehicles with taxes raised on low emissions ones, eliminating market failure by bring total gasoline lifecycle costs to the forefront.

"Promoting Public Transportation for Sustainable Development"

This policy proposal addresses the issue of public transportation as a means for sustainable development. Transportation is an issue that needs to be addressed because it has two deleterious effects on the environment. One is the effect of vehicle carbon dioxide, $CO_{2,}$ emissions on climate change and the second stems from other vehicle emissions that cause air pollution leading to negative health effects. These two issues warrant the conclusion that transportation needs to be monitored. Policies can be instituted to mitigate these negative consequences. This report focuses its policy recommendations on promoting public transportation as a means for environmental sustainability. The idea is that increased use of public transportation will lessen the demand for private transportation thereby lowering the number of vehicles on the road and thus lessening global vehicle emissions.

"Laying the Foundation for a More Energy Efficient Future: Reducing Climate Change through Green Building"

Buildings are huge energy consumers. Residential and commercial buildings account for 39% of total energy use in the US, meaning that reductions in buildings' energy demand could result in a great drop in the need for carbon-emitting power plant production of electricity. Additionally, peak electricity loads, which tend to determine the number of power plants needed and which sometimes requiring older, dirtier plants to come back online, are usually determined by the demand for lighting and cooling of buildings. Residential electricity use per capita has been increasing since the 1980's, and US energy consumption, as a whole, is expected to continue growing due to the creation of more commercial floor space, the continued increase in the use of electric appliances in residential buildings, and expanding industrial output. Essentially, decreasing energy demand from buildings could greatly reduce energy production and its accompanying carbon emissions. As things stand now, however, builders usually care more about cutting their own initial capital costs than about long term efficiency, so inefficient building stock tends to get cemented into the building infrastructure. Even the construction of buildings themselves account for about one-third of total industrial energy use.

The incorporation of cleaner, more energy efficient buildings is extremely important to address now rather than later because buildings, unlike cars for example, have a very long life time. Building infrastructure that is invested in now is very difficult to change, so, if efficiency isn't incorporated at construction, it will be very difficult to improve in this area in the future. Office space in the US is expected to increase between one and two percent per year in the coming future, so there is potential to make an impact. This paper looks at the ways that energy efficiency can be increased in the construction and operation of buildings. After examining the technologies available, the paper argues for a carbon tax with revenues used to subsidize geothermal heating systems, financial incentives for the construction of energy efficient buildings, more stringent renewable energy requirements for large buildings, better labeling of energy life-cycle costs, and the use of Type II partnerships to provide resources and an organizing framework for further collaboration on building efficiency.

"Off-Grid Energy in Rural India: Policy Recommendations for Effective UN Projects"

Rural areas in developing countries suffer significantly from energy scarcity, forcing people to rely on traditional biomass as their primary energy source. The current approach of the government of India to solve this problem focuses on extending the electricity grid, which fails to attend the real needs of poor people and is too expensive. This paper discusses the potential use of off-grid energy technologies, like improved cooking stoves, biogas digesters, and micro hydropower, as an alternative for grid extension. This is followed by four policy recommendations to ensure that UN rural energy projects are effective in complementing the government of India's efforts and attending the basic energy needs of the most poor in rural India. These recommendations are: to provide micro-credit and consulting for the promotion of off-grid renewable energy technologies (RETs); to focus on alleviating women's energy needs, particularly cooking; to include capacity building in energy projects by creating partnerships with the community and providing technical assistance; and to financially support local entrepreneurs who could either benefit from energy access or supply their communities with energy services.

"Clean Distributed Generation for Slum Electrification"

Approximately half of the world's urban poor do not have access to electricity. Usually, those without access to electricity in cities live in slums, informal urban settlements that typically enclose some of the worst standards of living in the world. While electricity is in principle available in many of these slums because of the prevalence of black-market "companies" that pilfer electricity from power lines neighboring the slum, such electricity is unsafe both to those who use it and those who provide it, and expensive, sometimes more expensive than market-rate electricity.

This paper describes the barriers preventing electricity from being brought to the slums in the traditional manner, despite high demand and a willingness on the part of many slum-dwellers to pay market-rate prices for electricity. Specifically, these fall into three main types: sociological factors, infrastructural barriers, and economic barriers. Then, the paper argues for the use of clean distributed generation technologies to electrify slum areas in the Indian city of Mumbai. A combination of solar cells and wind turbines could provide electricity for individual dwellings or a group of dwellings cheaply, and unambiguously raise the standard of living for those connected. Mumbai's two seasons, a monsoon season with strong westerly winds, and a dry season with abundant sunlight, make it climatologically perfectly suited for photovoltaic cells and wind turbines.

Policy recommendations advocate that micro-credit agencies with experience in the slums be employed to give partial-loans/partial-grants to local entrepreneurs, who should be given the freedom to experiment with different strategies for payment and the number of households connected to a single plant. In addition, government programs could channel funding for partial grants from money already allocated to development projects in the slums. Finally, the utility companies can be used as a capital source for the micro-credit agencies, since they stand to profit financially by slum electrification.

"Renewable Portfolio Standards, Feed-In Tariffs, and Tendering: Instituting Effective Mandated Market Policies in China"

The growth of China's population and demand for energy will result in large installments of fossil-fuel powered energy projects unless greater efforts to rapidly replace carbon-based fuels with renewable energy technologies are adopted. This paper discusses the challenge to the rapid expansion of renewable energy in China: RETs are characterized by high initial capital costs, compared to carbon-based sources of energy, resulting in low initial profit margins for producers. Its proposed solution is the implementation of mandated market share policies, which require that a certain quantity or proportion of a country's energy be generated from renewable energy sources by instituting a purchase obligation or creating strong incentives for renewable energy at some point along the energy supply chain. Three particular polices are discussed: renewable portfolio standards, feed-in tariffs, and tendering. In the context of China's energy needs, each policy is analyzed, and recommendations are made to develop an effective mandated market system with the help of various state and non-state actors.

"Exporting Sustainability: A Proposal to Reduce the Climate Impact of the Export-Import Bank of the United States" (Thesis available online)

One important mechanism that has not been given much attention in the policy discussion of climate change is the financing of projects in developing countries that emit large quantities of greenhouse gases. When financial flows from developed countries support inefficient, greenhouse gas-intensive projects in developing countries, the emissions constitute a source of leakage. Although the emissions are financed by developed countries, they are not counted in climate mitigation arrangements. Export credit agencies (ECAs) are financing organizations whose purpose is to promote exports. Often, they are publicly supported and operate under the governments of developed nations. The Export-Import Bank of the United States is one such ECA, and its effect on international trade is significant. Each year, it authorizes billions of dollars in the form of loans, guarantees, and insurance to facilitate export transactions. A fairly significant amount of this support is disbursed to projects that emit significant amounts of greenhouse gases: roughly one-third of financing is for power projects alone. Other exports, such as those for transportation, heavy industry, and fossil-fuel extraction, also receive significant support. The resulting emissions would place the Export-Import Bank, if it were a country, among the world's top ten contributors to greenhouse gas emissions.

Reducing the Bank's emissions therefore has the potential to mitigate global climate change. This thesis further argues that taming the Bank's emissions is politically strategic given several facts: first, the Bank historically has shown leadership in pressing other export credit agencies to adopt agreements that promote international public goods; second, the Bank is well-suited to engage developing countries and at the same time its policies do not have the potential to significantly disrupt the U.S. economy; third, if the Bank's emissions are not regulated, they represent a significant source of carbon leakage. For the purposes of this presentation, it is argued that the Bank should consider reforming its financing policies to give greater support for renewable energy technology exports.

CONCLUSION

The Task Force acknowledges that no silver bullet exists to resolve the tension between need for increased energy services and the concern for preserving environmental quality. Rather, opportunities should be taken advantage of where they arise. The overall recommendations fall under four such areas of opportunity, and could be considered general recommendations that extend beyond the case studies of India, China, and the U.S.

For energy generation, the Task Force recommends:

- Promoting advanced technology to decarbonize fossil fuels;
- Increasing the proportion of energy generated from renewable sources;
- Internalizing all costs associated with energy generation.

For energy efficiency, the Task Force recommends:

- Internalizing the costs of energy inefficiency;
- Promoting green building, from construction to operation;
- Reforming and raising fuel efficiency standards;
- Improving public transportation services.

In providing energy services to difficult-to-reach areas, the Task Force recommends:

- Financing renewable technologies that facilitate electricity generation and cooking fuels close to end-users in slums and rural areas;
- Focusing on women and capacity-building projects for community empowerment;
- Using micro-credit to support local entrepreneurs who could either benefit from energy access or supply their communities with energy services.

In implementing renewable energy technologies, the Task Force recommends:

- The use of mandated market systems where the appropriate administrative infrastructure exists;
- The use of existing public financing institutions to provide incentives for renewable energy exports.

In our research, we have found the issues surrounding energy and sustainable development to be complex and engaging. At the same time, we remember that providing energy to the world's population is about improving people's lives, and we are encouraged that so many opportunities abound for accomplishing this goal. It is our hope that this analysis will contribute to that end, and that further similar efforts will continue to seek out and find the ways that work.

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Wind Power: A Clean and Renewable Supplement to the World's Energy Mix

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Abstract: Wind power harbors the potential to become a key contributor to the world's energy supply in years to come. Not only is it inexhaustible and free, but in comparison to fossil fuel sources, its environmental footprint is negligible. The major technical hurdles to wind power's growth relate to its remoteness and variability, but neither is an obstacle too great to be overcome. In many places, wind-generated electricity is already cost-competitive with traditional energy sources, and in those where it is not, capital investment is needed to prime the wind industry for competition.

This paper represents my own work in accordance with University regulations. M.B.T.

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Introduction

As the global community moves into the twenty-first century, its patterns of energy generation and consumption stand in urgent need of reform as the ability to sustain current trends appears increasingly implausible. With the world population growing rapidly and almost exclusively in less developed regions, demand for energy is greater now than ever before and will continue to rise. Concurrently, the outlook for traditional, non-renewable forms of energy to be able to meet this rising demand is gloomy as finite fossil fuel resources such as oil experience gradual depletion. Beyond this issue, the byproducts of fossil fuel incineration pose a significant threat to the environment: escalating atmospheric levels of carbon dioxide have contributed directly to global warming, while sulfur dioxide and nitrogen oxides have significantly exacerbated particulate air pollution and acid rain. Without a curbed reliance on fossil-fuel-based energy, the emission levels of these pollutants and their associated problems will soon become far more serious and more difficult to resolve than they are at present.

In every one of these capacities, the prospect of a larger proportion of global energy supply being derived from clean and renewable sources like wind offers not merely a glimmer of hope, but a realistic and straightforward response. The process of generating energy from wind gives rise to neither greenhouse gas emissions nor other harmful atmospheric pollutants. As to efforts aimed at alleviating poverty and enhancing standards of living worldwide, the construction and operation of wind farms create income and jobs for homes and businesses. On a separate note, nations concerned with the security of their energy supply benefit from the inclusion of wind in their energy mix because the cost of its electricity generation does not rely upon the price of a fuel which is typically imported, and because such diversification inherently promotes the stability of their energy portfolio.

A final and more complex matter is whether or not wind power can help substantively in the struggle to bring electricity to the 1.6 billion people currently living without the basic luxuries it provides, over 80% of whom live in less-developed countries (IEA, 2005). This question depends on several variables: the pace of technological advancement in wind turbine design; the ability of wind to compete cost-wise with established energy sources; and the extent to which policymakers support the progression of the wind power industry via legal, financial, and environmental channels. Following investigation of each aforementioned factor, this paper concludes that wind power indeed harbors the potential to extend the availability of electricity well beyond its present reach, and to do so while conforming to fundamental principles of sustainable development.

The paper begins with relevant background information about wind power and the role it presently occupies in satisfying the world's electricity demand. Next, it offers a perspective on the technical components of harnessing wind power, paying special attention to the areas in which there is considerable room for improvement. The economic side of wind energy is subsequently examined; general strategies for governments to create incentives for more immediate and widespread evolution of the wind industry are explored, as are costs of integrating and transmitting wind-generated electricity to the grid. The paper then shifts toward a case study of wind energy's future in a developed nation, the United States, as well as in a developing nation, China. Each of these sections includes a number of recommendations which seek to maximize wind energy's penetration into utility power pools in as prompt a fashion as is practicable.

Background Information on Wind Energy

"Wind energy is a form of solar energy that is created by circulation patterns in the Earth's atmosphere that are driven by heat from the Sun" (AWEA, 2005). The blades of a wind turbine are rotated by the kinetic energy of passing air; they spin the turbine's rotor, which in turn drives the shaft of a generator that ultimately converts kinetic energy into electricity. Kinetic energy is equivalent to ½ * (mass) * $(velocity)^2$, and since the mass of an air flow through a cross-sectional area swept by a wind turbine's blades in a given period is itself dependent on the velocity of the wind, there exists a cubic relationship between potential wind energy generation and wind speed. The 'mass' term in the kinetic energy definition also correlates positively with the area swept by the blades and the density of the moving air. Clearly, though, wind velocity is the most influential factor in the calculation of hypothetical energy yield for an industrial-scale wind farm.

Wind power is classified as a renewable source of energy because it is generated via a source capable of being reused indefinitely, in contrast to the burning of a non-renewable fossil fuel. Similar to surveying and mining practices utilized to pinpoint the areas richest in fossil fuel reserves, extensive efforts to track wind quality, both in terms of its frequency and its velocity, are carefully performed by anemometers in order to assess the wind potential in a given locale. Unlike the fuel sources for non-renewable energies, wind has the quality of being extremely inconstant, and correspondingly, its usefulness for energy generation can fluctuate tremendously in even a very limited span of time. A graphical depiction of the distribution of wind velocities in a typical setting indicates that winds at high and very high speeds tend to occur at a much lower frequency than do winds at low and very low speeds [see Appendix Image 1.] Wind's intermittence has key ramifications for wind-generated power and the incorporation of wind energy into the blends of electricity sources employed by most major utilities.

In reality, natural wind speed variations afford a huge benefit to the business of wind energy production. If such variations did not exist, and wind instead gusted permanently at its arithmetic mean rate, far less energy would be attainable since a large fraction of wind energy capacity at a particular site is derived from its brief, high-speed winds. Generally, the amount of power which could be extracted if the wind at a site blew constantly at its average velocity is only about half of that procurable from a natural distribution of wind speeds in Earth's atmosphere (Windpower, 2006). This comparison demonstrates the degree to which high-speed winds contain energy relative to slower winds, and in so doing, allows the impact of the cubic relationship between wind energy and wind speed to come into still clearer focus.

A host of other factors can also have a bearing on energy generation from wind. Comparable to any loss of heat when two substances rub against one another, winds which must travel over rugged landscape experience a reduction in speed as a portion of their kinetic energy is converted to thermal energy by friction (Windpower, 2006). Not surprisingly, the less smooth a surface over which wind must pass, the greater the velocity (and energy) loss suffered on account of frictional heating. Another complication connected to wind energy arises from day-night discrepancies. This so-called diurnal variation in the wind occurs because wind's turbulence ordinarily peaks during the daytime hours. In many parts of the world, there is also an ample measure of seasonal flux in wind's behavior as temperature and weather changes serve to reconfigure local wind patterns throughout different parts of year.

Today, wind power remains a minor contributor to global electricity generation. The International Energy Agency estimated that 0.05% of total electricity production worldwide was created via wind power in 2003 (IEA, 2003). Despite wind power's seemingly inconsequential stake in the present arrangement of global electricity generation, several signals suggest it is lying right at the cusp of undergoing a critical transition period toward maturing into a major player in the world's energy production system. The price of wind-generated electricity has plummeted in recent history and is now on par with or cheaper than traditional sources (discussed later in detail). Also, global wind energy capacity grew 48.9% per year from 1971 to 2003, a rate unmatched by other energy sources (IEA, 2003). Coupling these merits with its environmental friendliness, there is every reason to expect wind power to occupy a burgeoning role in the global energy scene in coming years. Technological improvements and economic incentives to encourage wind energy generation would facilitate an even more secure position for wind power in the realm of electricity production worldwide.

Technical Issues Pertinent to Wind Energy

In order for wind power to realize its full potential to guide the world's population down a road toward sustainable development, technological advancement will need to help pave the way. It is incumbent upon the countries of the developed world to further explore and improve strategies ranging in scope from how to select the most valuable sites at which to build wind farms all the way to which wind turbine designs prove most efficient. All discoveries made will set the tone for wind power's progress in years to come, in particular as to how it may spread in the developing world.

Some of the world's windiest places are located in its most remote regions, an unfortunate fact since large-scale electricity generation is only as valuable as its connectedness to the grid. The search for areas suitable for wind farm construction is thus somewhat restricted. For instance, very cold regions often exhibit extremely windy conditions and witness increased air densities. To gauge the magnitude of air density discrepancies, the mass of a cubic meter of dry air at standard pressure and a temperature of 20°C is 1204 kg, whereas the same volume of air at -20°C has a mass of 1395 kg, a boost of more than 15% in air density (Windpower, 2006). Other considerations aside, this elevated air density would augur well for siting wind farms in frigid, blustery territory, as greater sums of energy can be extracted from heavier air. In actuality, though, very cold regions are rarely fit for wind farms owing to their remoteness as well as technical complications which arise upon exposure of turbines to freezing conditions (Lacroix, 2000).

Beyond cold weather regions, another high-wind area which may hold great promise for wind farms in the near future is the offshore setting. Wind blows faster and more uniformly at sea than on land; this means less wear on turbine components and more electricity generated per turbine (Ram, 2006). Although offshore wind farms would be somewhat more expensive than onshore farms in terms of construction, installation, and maintenance costs, it is very possible that such outlays could be compensated for by offshore sites' proximity to large populations. "Winds increase rapidly with distance from coast, so excellent wind sites exist within reasonable distances from major urban load centers, reducing the onshore concern of long distance power transmission" (Ram, 2006). In this way, the added expenses of developing a wind farm offshore could be defrayed by the associated reduction in transmission costs, which will be discussed later.

Offshore wind farms comprise a small fraction of total wind power at present, but are expected to soar in coming years. Additional offshore installations of 11 gigawatts (GW), nearly a fifth of the world's current wind energy capacity, are slated for completion by 2010, primarily by Germany and England (Ram, 2006). All will be anchored in shallow water no more than 20 meters deep. Technological strides are required before offshore wind farms can be cost-effectively constructed and operated above ocean waters beyond 20-meter depth. However, it is likely that the wind industry will quickly gain the ability to tap into such high-energy winds since offshore oil and gas drilling sectors have undergone analogous evolutions in the past (Ram, 2006). Enabling wind farms to be sited over increasingly deep waters will prove central to both the viability and value of offshore wind.

After settling upon a desirable location for wind farm construction, there are several additional factors which must also be considered in planning its layout. Because turbulence in the wind diminishes turbine lifespan, designers aim at reducing its impact when arranging a farm by spacing turbines at least three rotor diameters apart from one another (Windpower, 2006). Such a configuration enables turbines to function properly for as long a period as possible, thereby reducing the overall lifecycle cost of wind-generated power. An alternate objective in wind farm development is to counter the effects of transitory fluctuations in wind power because they impose a burden on the energy system to which the farm's electricity is supplied. This can be accomplished by dispersing clusters of turbines geographically "to create a smoothing effect on the aggregate power output with respect to time" (Milligan, 1999). Wind farm design must be tailored to the particular conditions of the surrounding site to allow for maximal efficiency in the collective effort to drive down wind energy prices.

A separate component of wind power's technical side is the perpetual refinement of the wind turbines themselves. It is not possible to extract all of the energy in the wind; the air which flows through the rotor's cross-section is not stopped completely, rather it is slowed down as it exits the opposite side. In 1919, German physicist Albert Betz proved that regardless of design, the ideal turbine decelerates passing wind by two-thirds its original speed, which allows for a theoretical yield of 59% of the wind's total energy to be convertible to electricity (Windpower, 2006). This upper bound should thus be approached as narrowly as possible if a turbine is to maximize its efficiency, but much work remains to be done on this front. Conventional propeller-style turbines often harvest less than a fifth of the wind's available energy and are constrained by a theoretical limit of 30% extraction, only half of the Betz Limit (Gorlov, 2001).

One novel approach which offers room for improvement in this regard is to orient blades about a vertical axis and hence reduce strain on turbine components—this adjustment could allow 43-45% of wind's available energy to be reaped (*Economist*, 2006). If accurate, this statistic means that about three-quarters of the theoretically obtainable (i.e. Betz Limit) energy in wind would be harnessed, representing a watershed in the field of turbine design. A related element of turbine effectiveness is its atmospheric efficiency rating, which computes the quantity of energy removed from the atmosphere and divides it into the quantity actually converted to electricity. For modern-day turbines the ratio is typically in the range of 0.47 to 0.57, but modifications to turbine design may be capable of yielding improvements on the magnitude of several tens of percents (Keith, 2004). With little doubt, the era of improved turbine efficiency has dawned and will continue evolving as innovative designs are developed.

As alluded to earlier, wind velocity decreases considerably as it travels over rough topographical features due to frictional losses. Decreased wind speeds in turn reduce potential energy yield, so turbine designers strive to avoid this undesirable phenomenon. The basic solution is to construct turbines on taller towers to minimize the influence of surface effects. A generation ago, the towers on which turbines are mounted were less than 100 feet tall, but they have since doubled to average heights above 200 feet (Oklahoma, 2002). It is inevitable that turbine towers will climb even higher in the decades to come. Another important concept to grasp in relation to turbine efficiency is that of the drag force. Since rotor blades are continuously immersed in a stream of air, it is essential that they be designed aerodynamically to avoid efficiency losses from drag. This can be achieved by reducing the area of the blades which face into the wind and by ensuring blade surfaces are as smooth as possible (Windpower, 2006).

The issue of sound is a final technical hurdle in wind turbine design. Turbines used to produce bothersome broadband noise as their blades encountered turbulence, but advances in soundproofing and aerodynamics have so successfully addressed the problem that one can now stand beneath a whirring turbine and converse without raising one's voice (AWEA, 2005). It is also worth noting that wind farms are sited in areas with above-average wind speeds that conceal the sounds produced by the turbine. Noise reduction constitutes a prime example of how advancing technical aspects of wind power can serve to propel the industry toward the forefront of the global energy order.

Economic Issues Pertinent to Wind Energy

The economic aspects of wind power are highly consistent with the tenets of a sustainable development framework. In recent years, the cost of wind-generated electricity has drawn level with and/or fallen beneath that of most non-renewable sources, illustrating the potential the wind industry has to help electrify impoverished regions of the underdeveloped world in future years. Governments have the ability to expedite this downward price trend and encourage the wind industry's continued growth, while ultimately standing to benefit from a number of positive consequences. The cost impacts of integrating wind power into larger energy mixes as well as transmitting wind energy from remote locations to densely populated demand centers are essential to the economic profile of wind energy. Yet another economic consideration is that employment opportunities are made available to those living in and around the spread of the wind industry. Sustainable development is well-served by efforts to enhance wind's role as a global energy producer and to continue its downward cost spiral into the future.

The chief contributing factors to the cost of wind-generated electricity are far different than those responsible for fossil-fuel-based electricity costs. First, there is obviously no cost associated with procuring wind itself, rendering wind energy a decidedly capital-intensive technology. This characteristic amplifies the degree to which wind energy costs suffer when there is insufficient principal for financing a wind power project. Next, larger wind farms provide economies of scale, for example: "A 3-

megawatt (MW) wind plant generating electricity at 5.9 cents per kilowatt-hour (kWh) would, all other factors being equal, generate electricity at 3.6 cents per kWh if it were 51-MW in size" (AWEA, 2005). Wind-generated electricity costs are declining at a rate unparalleled by other energy sources. Over the past 20 years, onshore wind energy technology has experienced a ten-fold reduction in cost (Ram, 2006). [see Appendix Image 2.]

While electricity from wind may not have been competitive with fossil-fuel-based electricity in terms of nominal cost a decade ago, there were already indications that it would someday be able to compete. In a 1996 report issued by the California Energy Commission, energy technologies were compared based on levelized costing, and wind was found to be comparable in value to coal and gas (CEC, 1996).[28] The cost of wind-generated electricity was competitive because levelized costing took into account the full lifecycle of the energy plants, often overlooked by casual observers. Still, environmental costs attributable to the various energies' lifecycles were not included, effectively damaging wind's competitiveness since it is imposes a drastically lower cost upon the environment than do non-renewable energy sources.

This significance of this last point should not be understated, as relaxing or disregarding environmental effects allows fossil-fuel sources to appear deceptively cheap relative to renewables. In fact, "the hidden 'subsidy' that governments and markets give to polluting energy sources by partially or fully ignoring their health and environmental costs is typically much larger than direct subsidies to such energy sources" (AWEA, 2005). A 2001 study funded by the European Union found "the cost of producing

[28] Levelized costing calculates (in 1993 dollars) all capital, fuel, operating and maintenance costs associated with the plant over its lifetime and divides the total cost by the estimated output in kWh over the lifetime of the plant. The typical lifetime utilized in these estimates was a 30 year time horizon.

electricity from coal or oil would double and the cost of electricity production from gas would increase by 30% if external costs such as damage to the environment and to health were taken into account" (Europa, 2001). It is evident that governmental agencies around the world could support the growth of the wind industry simply by requiring all energy plants to internalize (at least a portion of) both their environmental and health-related externalities. Wind power's lifecycle is not only completely free of emissions, but also of ecological hazards like mining, drilling, processing, and shipping fuel (AWEA, 2005). Nonetheless, there generally exists neither economic reward for wind's environmental cleanliness nor economic sanction for fossil fuels' pollution.

Since wind power normally functions as one of several energy forms which all supply a utility power pool, it is important to look at the cost effect wind is likely to have upon such a system overall rather than merely its stand-alone price. An electric utility system is responsible for maintaining the balance between aggregate demand for electric power and total power generated by all power plants feeding the system, a sophisticated task whose associated costs are referred to as ancillary-services (Smith, 2004). Wind's incorporation in the mix complicates the task of maintaining the system's balance due to the challenges of accurately forecasting wind and coping with its persistent fluctuations. Must the full capacity of wind energy supplying a power pool be backed up to keep from jeopardizing the utility's ability to match consumer demand? In truth, wind need not be backed with such a high quantity of dispatchable generation, for "even at moderate wind penetrations, the need for additional generation to compensate for wind variations is substantially less than one-for-one and is generally small relative to the size of the wind plant" (Smith, 2004). Thus, although ancillary-services costs attributable to wind rise in correspondence with its uncertainty and variability, neither of these facts necessitates precluding wind from participation in the powering of a utility electricity pool.

Another key economic issue pertaining to the wind industry is the cost of transmitting its electricity from wind farms to substations located near population centers. Unlike other energy sources, wind's inherent intermittence prevents its plant operators from being able to precisely schedule the amount of electricity their plant will deliver to transmission lines in advance. This inability is problematic for the wind industry because utilities controlling transmission facilities often charge exorbitant fees for these so-called 'uninstructed deviations' regardless of whether they exceed or fall short of the scheduled use (Transmission, 2006). Other features of the transmission network can also prove particularly expensive for the wind industry. Often situated remotely, wind-generated electricity is disproportionately charged by utility practices such as basing transmission system usage fees upon the number of miles between generator and load center, or charging multiple access rates for transmission due to crossover of several lines of ownership, also known as 'rate pancaking' (Transmission, 2006). A final example of the wind industry incurring lopsided costs for transmission network usage is evidenced by the policy of some utilities to charge generators on the basis of peak rather than average use (Transmission, 2006). Once again, wind providers are helpless to guard against the natural fluctuations in wind and, as is the case with the other policies just discussed, will continue to be penalized undeservedly so long as government intervention fails to take place.

The last aspect of wind industry economics worth mentioning is the financial benefit it can yield to local communities. For example, creation of a 100-MW wind farm can generate 40 temporary construction jobs and 10 permanent skilled jobs (Oklahoma, 2002). And while it is sometimes contended that wind farms have a deleterious impact in terms of the attention they garner, they can also attract investment, infrastructure development, and tourism opportunities (WWEA, 2005). Wind power's economic status has seen dramatic improvement in the recent past, but can still be bolstered in years to come.

Future of American Wind Energy

The United States currently ranks third in the world in terms of installed wind capacity, with 9.149 gigawatts (GW) installed at the end of 2005, trailing only Germany and Spain (AWEA, 2005). In spite of this success, there still exists tremendous potential for further development of the American wind industry—beyond all the merits of wind power which have already been cited, the United States is fortunate to possess a vast resource of high-quality winds capable of providing clean, cost-competitive energy. To offer a perspective on its enormity, 24.8 billion kWh of electricity are anticipated to be generated from American wind in 2006, whereas the estimated potential annual yield is in excess of 10,000 billion kWh, a quantity more than double the country's overall present yearly electricity generation (AWEA, 2005). There are several, mutually-reinforcing ways that policymakers can facilitate increasing penetration levels of wind into the United States' total energy mix.

Recommendation #1: The Federal Energy Regulatory Commission (FERC) should ensure that wind-generated power does not suffer from unfair rules regarding access to the electricity transmission system in the United States. It is well-known that the nation's current grid system and associated policies were created with traditional energy sources in mind and, therefore, naturally favor non-renewables over their competitors. So long as these outdated vestiges of preferential treatment remain in place, the "burying of transmission investment charges in commodity power costs [will continue to] disguise the real cost of competing generation technologies" (Transmission, 2006). A brief glimpse at a map of United States wind power data highlights the importance of transmission concerns since the area in continental America endowed with the best quality winds (the Great Plains) is located far from major energy demand centers in coastal states. [see Appendix Image 3].

FERC itself has recognized this reality: "When purchasing firm transmission, a wind generator pays more for that transmission on a per unit basis" than do fossil-fuel generators (FERC, 2004). At least two major alternatives are available to confront this problem. The first option is to create an altogether new system in which transmission costs fall directly upon end-users of electricity rather than those generating it. This approach is sensible because 100% of embedded transmissions costs fall upon end-users irrespective of what system is in place, and it would provide a more 'level' playing field for all energy sources to compete (Transmission, 2006). A second option is to enact comprehensive reforms which would revamp the current transmission system by disallowing pricing practices that disproportionately charge wind on the basis of its remoteness and/or intermittence. Such an overhaul would necessitate the elimination of fees dependent on distance from load center, cross-over of multiple ownership lines, peak rather than average use level, and deviations from scheduled usage (Transmission, 2006). While the latter option probably requires more policymaking, either alternative could effectively support growth of the American wind industry.

Recommendation #2: The United States Department of Energy (DOE) should promote cooperation between the wind industry and the oil/gas sectors with prior experience in the offshore setting in order to expand wind farms over deep ocean waters that enjoy consistent, high-velocity winds in close proximity to major coastal populations. Such action would be beneficial to the American wind industry for a multitude of reasons. Foremost among them is the fact that the National Renewable Energy Laboratory has estimated the United States' offshore wind resource at a remarkable 1000 GW (over fifteen times current global wind capacity), 750 GW of which are located over ocean waters more than 30 meters deep (Ram, 2006). At present, however, turbines cannot be situated above depths greater than 20 meters due to technological impediments—this is the same challenge that faced offshore oil and gas companies in past decades. Coupling offshore wind development with veteran oil and gas industries would not merely offer a key to unlock massive amounts of potential wind energy, but could also work in unison with Recommendation #1 by easing wind power's dependency on transmission.

Recommendation #3: Elected officials in Washington should redouble their efforts to enhance wind power's cost competitiveness by expanding Renewables Portfolio Standards (RPS) nationwide and stabilizing the status of the Federal Production Tax Credit (PTC) for wind-generated electricity. As noted throughout this paper, economic considerations relevant to the wind-industry are unique in their overwhelming reliance on sufficient capital. RPS is a market mechanism which guarantees that a rising fraction of electricity be derived via renewable sources. It provides this assurance by mandating that every individual electricity generator possess a certain number of Credits at year's end in proportion to its total annual kWh sales (RPS, 1). Because there are no stipulations as to how the Credits are obtained, many generating companies will enter into long-term contracts with renewable generators, simultaneously providing incentive for cost-effective renewable generation as well as up-front financing needed for capital-intensive industries like wind to flourish. While twenty-one states have adopted an RPS of some sort, unifying and extending a single, sensible standard to all fifty states would strengthen the position of wind and other renewables and drive down their costs by supplying ample capital.

A second channel through which the American Government can increase cost-competitiveness for wind energy is by way of the Federal PTC, which "provides an inflation-adjusted 1.9 cents per kilowatt-hour tax credit for eligible technologies for the first 10 years of production" (DOE, 2005). Meant to counterbalance the inherent bias toward fossil fuel sources in federal energy tax code, the PTC has supported wind power since its inception in 1992, but to a limited degree. Its contribution to suppressing wind energy prices has been dulled by a series of near expirations, each of which was narrowly avoided by a temporary, last-minute extension of the PTC. This virtual "on-again, off-again" status has hobbled project development and deterred investment to the American wind industry (AWEA, 2005). Members of the U.S. financial community who still view wind power as novel and risky are only further disquieted by the PTC's erratic status (AWEA, 2005). Policymakers seeking to attract private capital to the American wind industry would strongly benefit from extending the Federal PTC beyond its present deadline of December 31, 2007 in order to foster a safe, steady environment for investing.

Future of Chinese Wind Energy

While the United States and China are an unlikely tandem in most ways, recent growth patterns of wind power in the two nations has been very similar. In fact, "China's wind power program has roots in a visit to the United States 18 years ago [when] a Chinese delegation witnessed modern wind turbines at work in Utah, then came back determined to adopt the technology at home" (French, 2005). China now ranks eighth in the world in wind power capacity with 1.260 GW, a sixty-fold increase from its 1990 level of just 20 MW (WWEA, 2005) & (Motavalli, 2005). This meteoric rise demonstrates the ability of a developing nation to borrow and implement technologies from more-developed nations and, in turn, use the newfound expertise to help meet its emerging needs in a sustainable framework.

Despite the similarities between the two, China's needs are certainly not identical to those of the United States. A major difference is that China generates over 70% of its total energy supply from coal, making the reduction of air pollution a chief priority for its policymakers: it leads to an estimated 400,000 deaths annually, not to mention the damage caused by acid rain, which affects two-thirds of the country (Motavalli, 2005). Ambitious goals have been set forth by Chinese authoritative bodies in response to this crisis, with the Ministry of Electric Power planning 3 GW of installed wind capacity by 2010 and the State Economic and Trade Commission projecting 7 GW by 2015 (Liu, 2002). High-quality wind availability will not be a limiting factor in achieving these objectives; China's wind resource is thought to exceed 600 GW (Motavalli, 2005). Instead, Chinese leaders will have to confront grid issues as well as economic barriers if they wish to maximize wind's penetration levels into their nation's overall energy supply.

Recommendation #4: China's State Planning Commission, its highest authority for energy project financing and approval, should renovate the nation's aging grid system so wind-generated electricity can be efficiently integrated into its power mix. If action is not taken in this regard, there is little hope for wind power to provide substantive relief to China's growing electricity needs. Its fragmented utility sector, which dates back to the age when provincial governments were in control, offers little or no connectedness between provinces (EIA, 2005). As such, it is inevitable that significant losses will be suffered if wind-generated power is introduced as a major component of China's electricity supply with the present grid in place. Wind's high variability requires a delicate balancing act as supply and demand levels fluctuate unremittingly, but China's antiquated grid is incapable of automatically rerouting power accordingly (French, 2005). Aside from integration difficulties, effective transmission of electricity from wind-rich, rural regions along the Mongolian border to densely populated cities on the Pacific Coast is doubtful. [see Appendix Image 4]. China's other high-velocity wind locale is the offshore setting (obviously lacking connectivity to the mainland) which would also need the State Planning Commission to oversee grid development in order for its energy potential to be realized.

Recommendation #5: The Chinese Government should drive down the price of wind-generated electricity so it draws as close to level as possible with the cost of coal-fired power. Unlike in the United States where wind is extremely cost-competitive with all sources of energy, wind in China remains unable to compete fully with coal. Two reasons for the gap in price are that the vast majority of equipment on Chinese wind farms is imported and that there is a shortage of trained personnel to manage and maintain the turbines' proper functioning (Hammons, 2004). A short-term response to these problems is for the Government to exempt the import tax on wind turbine components, which would decrease the cost of wind farm construction by 15% (Liu, 2002). In the long run, however, incentives should be provided to stimulate a homegrown Chinese wind industry which can offer real competition to the established coal-fired plants. The Government has already taken steps in this direction by providing tax incentives for alternative energy developers and by standardizing electricity rates—effectually subsidizing sources such as wind. Until wind power prices are truly on par with coal-fired ones, however, China will find it difficult to cut into air pollution in any meaningful way.

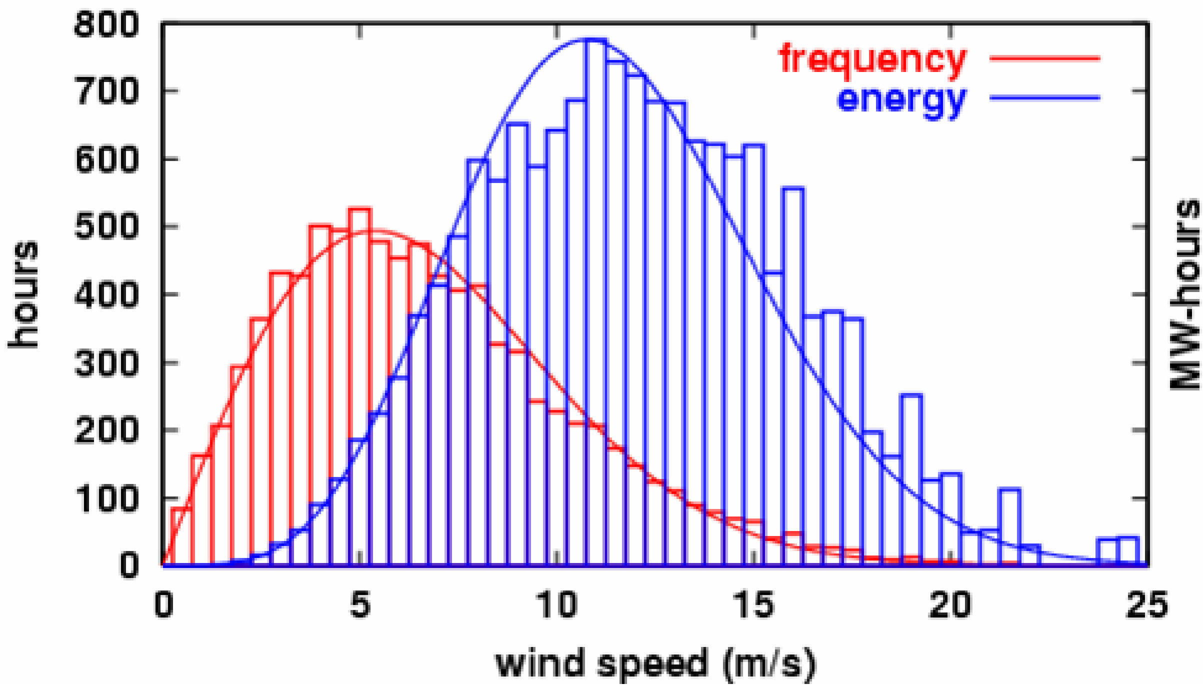
Conclusion

Wind power is a highly attractive source of energy for a host of reasons. Its fuel is free, its environmental footprint negligible, and it is incapable of being exhausted. In addition to these advantageous qualities, it is widely available and can generate electricity at a competitive cost provided it gusts at a sufficient velocity. Technological advancements in turbine design and progress in the offshore setting will only further enhance the utility of wind energy. Coupled with increased capital investment and policy measures which allow wind to compete fairly with traditional energy sources, there is every indication that wind power installations worldwide will continue to grow rapidly in the decades to come.

Whether a nation is seeking to combat global warming, reduce air pollution, provide affordable electricity to its people, or strengthen its energy portfolio through diversification, incorporating wind power into its blend of electricity can help achieve the desired aim. While intermittence and remoteness are unfortunate realities of wind, they do not overshadow the potential benefits which wind power offers to society. Governments around the globe are beginning to appreciate the many merits of wind energy and are implementing policies to encourage higher penetration levels of wind into their power mixes. The United States and China each have the potential to become world leaders on the wind energy scene owing to their enormous wind resources. With the proper support from their respective policy-making bodies, each nation will make wind power a substantial contributor to its energy portfolio.

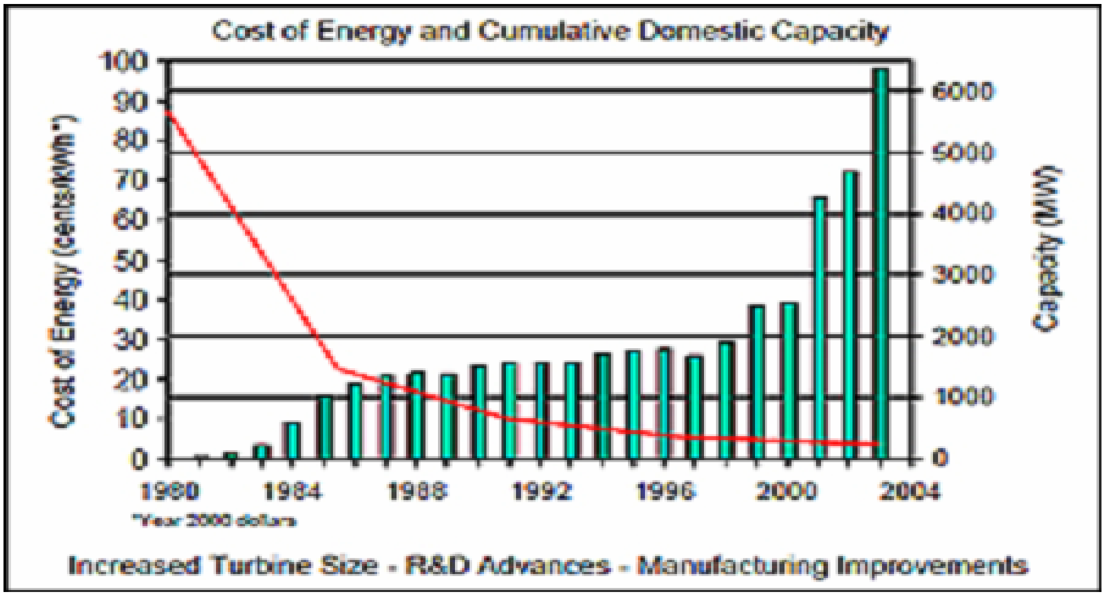
Appendix Images

Image 1. This graph depicts two phenomena simultaneously: in red, it shows a typical distribution of wind speed frequencies for a given locale; in blue, it shows the amount of energy derived at each speed across the full range of velocities experienced at the same site. It is clear that the highest levels of extractable energy occur at wind speeds around 11-12 m/s, or about double the site's mean velocity (~ 6 m/s). The highest speed winds (20-25 m/s) at the site do not furnish the highest levels of extractable energy because they are extremely infrequent.



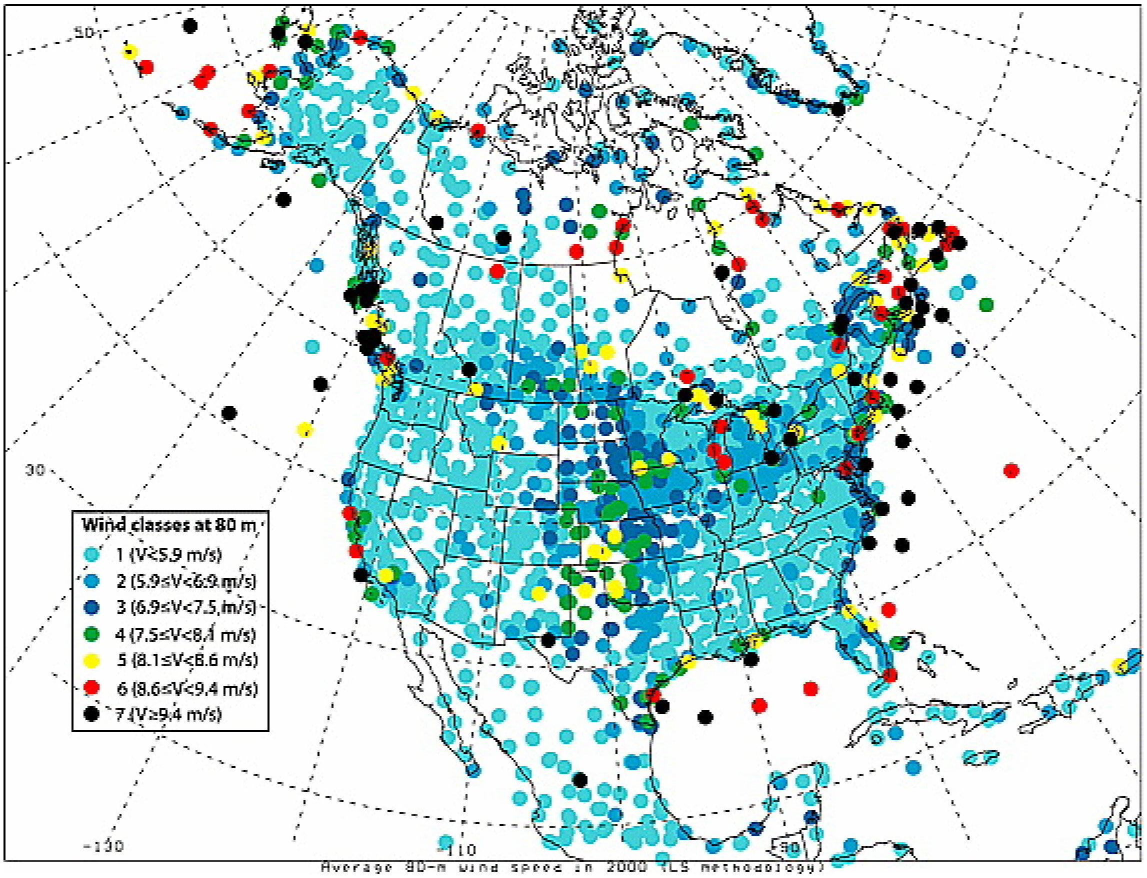
Source:
<http://www.answers.com/topic/wind-power-2>.

Image 2. This graph depicts two major trends which have occurred in the past quarter-century: the declining cost of American wind-generated electricity per kWh and the concurrent growth in total American wind energy capacity at years' end. The red line (cost) indicates a 1983 price of approximately 45¢/kWh, and a 2003 price of under 5¢/kWh, equivalent to a ten-fold reduction in cost (inflationary effects removed—constant 2000 U.S. dollars). Over the same period, the turquoise bars (total U.S. wind capacity) rose from a 1983 level of about 200 MW to a 2003 level of over 6000 MW, growth of more than 3000%.



Source:
<www.eere.energy.gov/windandhydro/windpoweringamerica/ne economics.asp>.

Image 3. This image illustrates the quality of wind power across most of North America. Light blue dots represent areas which experience comparatively low average wind velocities, while black and red dots indicate regions with very powerful winds. Intermediate colors (Class 3 and above) are generally considered appropriate for wind farm siting; note the abundance of darkly shaded dots from the Dakotas south through Texas, as well as on and immediately off of the Atlantic Coast.



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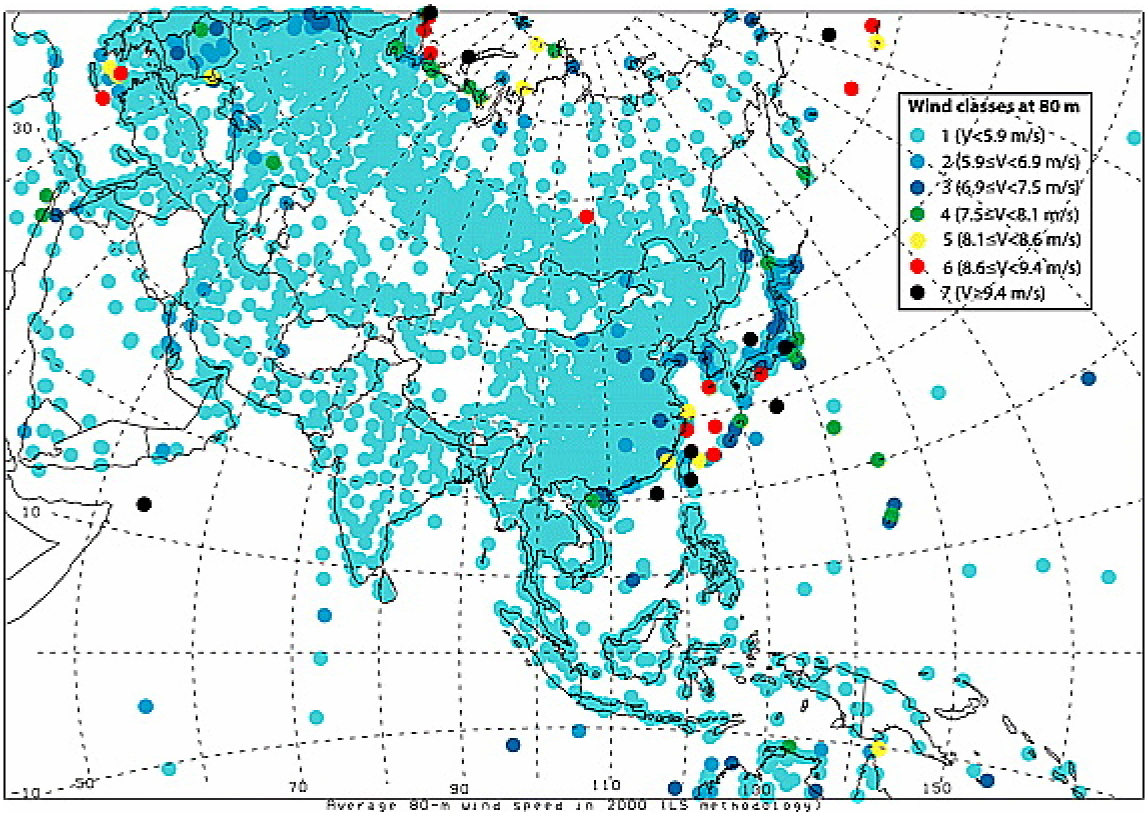
<http://www.agu.org/journals/jd/jd0512/2004JD005462/>.

Image 4. This image illustrates the quality of wind power across most of Asia. Light blue dots represent areas which experience comparatively low average wind velocities, while black and red dots indicate regions with very powerful winds. Note the two regions where Chinese wind potential is greatest: near its border with Mongolia as well as in the vicinity of its expansive coastline.



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WWS 402: Energy for Sustainable Development

Professor Denise Mauzerall

STRENGTHENING SECURITY, HEALTH, AND ENVIRONMENT
Towards a Sustainable Coal-based Development Strategy for China

William Ulysses Fowler

May 2006

This paper represents my own work in accordance with University regulations.

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EXECUTIVE SUMMARY

Background and Basis

In the next 30 years, 1400 GW of new electricity generation capacity is expected to be constructed worldwide. If all of this new generation capacity utilized coal, it would produce over its lifetime emissions of carbon dioxide 40% greater than total fossil carbon emissions from 1750 to the present. To avoid these emissions and the resulting impacts, it is imperative to develop new sources of decarbonized electricity. Integrated coal gasification and carbon capture and storage offers one of the most promising routes to decarbonized fossil fuel resources, since coal is abundant and secure and gasification is commercially viable. As such, coal gasification could play a significant role in increasing global supplies of decarbonized energy in the near and long term. However, several obstacles to implementation remain, especially in China and India where the most significant electricity growth will occur. China holds a position of special importance due to its extensive coal reserves and massive energy requirements, which together could transform China into the largest carbon emitter within the next two decades. Both China and the world have much to gain by avoiding this scenario and instead developing China's energy system along an alternative trajectory based on advanced coal technologies This paper will outline the fundamentals of China's coal dependent energy system, describe a coal gasification based alternative, identify the principal barriers to its implementation, and propose a set of policies to stimulate its development. Emphasis will be placed on minimizing carbon dioxide emissions while providing a long term supply of decarbonized energy from coal. Several categories of barriers to the implementation of coal gasification-based power plants have been identified and are followed by associated policy suggestions:

- **Environmental Policy:** Environmental regulations are poorly enforced and often inadequate to justify investment in clean technology.
- **Institutional Capabilities:** The innovation system is weak and fragmented and many companies lack commercial skills and neglect training.
- **Intellectual Property Rights Protection:** Intellectual property rights protection for advanced coal gasification technology is inadequate, hindering acquisition and diffusion of the technology.
- **Investment and Trade Rules:** Foreign ownership restrictions and complex approval processes for investments restrict foreign investor access to the potentially large Chinese market for advanced coal technologies, hindering the development of technology transfer relationships.
- **Finance and Economics:** Coal gasification-based power schemes rely on expensive imported technology and incomplete internalization of environmental and energy security externalities artificially reduce the

financial incentive for such projects. Additionally, informational barriers arise from the unfamiliarity of the power generation sector with coal gasification technology.

Policy Recommendations

Recommendation I: Environmental Policy

- Enforce existing environmental regulations to reward clean technologies.
- Install monitoring equipment more widely to enable enforcement and develop domestic monitoring equipment manufacturing capacity.
- Introduce new pollution standards more gradually to give industry time to adjust.

Recommendation II: Institutional Capabilities

- Reform the innovation process to allow coordinated research, development, demonstration, and commercialization of advanced technologies such as coal gasification.

Recommendation III: Intellectual Property Rights Protection

- Strengthen intellectual property rights protection for advanced coal technologies.

Recommendation IV: Investment and Trade Rules

- Continue liberalizing foreign investment to allow greater foreign ownership and control of firms operating in China.
- Streamline the approval process for large foreign investments, particularly those related to coal gasification development.
- Encourage the OECD to develop an information clearinghouse to provide detailed information on the Chinese energy sector tailored for use by smaller firms considering investment in China.
- Actively develop new channels for technology transfer, beginning with the acquisition of clean coal technology through the Clean Development Mechanism (CDM).
- Define priority channels for technology transfer, favoring technology acquisition through foreign direct investment (FDI) and licensing (with appropriate IPR protection) over simple equipment imports.
- Develop administrative and economic measures to support the adoption of already imported technologies to allow the absorption of imported technology. Such measures could include subsidies for goal gasification demonstration projects and risk sharing (such as through loan guarantees) for the early adopters of transferred technology.
- Adopt measures to integrate technology transfer with domestic research and development to support the establishment of an integrated innovation system.

Recommendation V: Finance and Economics

- Environmental policies that accurately reflect the costs of pollution must be implemented and enforced to create the appropriate economic incentives for clean coal financing.

- Technology transfer and absorption is also crucial to allow not only the acquisition of clean coal technologies but also the domestic manufacturing of such hardware at much lower costs than for imported equipment.
- Demonstration projects should be developed to increase familiarity with the technology and address the information barriers to gasification-based power generation. Such projects would benefit from the establishment of avenues to public finance such as loan guarantees, capital subsidies, and grants.

1 INTRODUCTION

1.1 Coal and the Global Environment: Coal is an abundant, cheap, and inherently dirty resource that has historically provided energy via its combustion to produce electricity and heat. Out of all fossil fuels, the use of coal is most damaging to both the environment and human health, adversely affecting landscapes, rivers, ecosystems, water quality, air quality, and global climate. Though environmental impacts are associated with all phases of coal use, including both extraction and transportation, this paper concentrates on issues surrounding the combustion of coal, particularly the globally significant issues of air quality and carbon emissions.

Conventional coal combustion results in emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), particulates, mercury, and other metals greatly exceeding those emissions arising from oil or natural gas combustion, aggravating local and regional pollution problems such as acid rain and ground-level ozone. Coal combustion also generates relatively high emissions of carbon dioxide, since both its hydrogen to carbon ratio and power generation efficiency are unfavorable compared to other fossil fuels (Philibert & Podkanski, 2005).

Coal is used primarily for electricity generation, although it also plays a role producing process heat for industry and comfort heat for the residential and commercial sectors. Coal has an additional small role in the transport sector, either through direct use in antiquated steam railways or through conversion to liquid fuels. Coking coal also plays a role in the steel industry (Hongtao, Zheng, Weidou, Larson, & Tingjin, 2003).

Coal currently provides 23 percent of the global total primary energy supply, resulting in 38 percent of global energy related carbon dioxide emissions. Oil is responsible for a similar percentage of carbon dioxide emissions, though it accounts for about 36 percent of total primary energy supply (Jefferson, 2006). Considering existing energy policies in both the industrialized and developing world, the International Energy Agency (IEA) projects that the contribution of coal to global total primary energy supply will decline to 22 percent as natural gas capacity increases in the next 30 years, though absolute consumption of coal will continue to increase during this period (Philibert & Podkanski, 2005). However, this global fuel switching to natural gas, stimulated by policies favoring energy efficiency improvements and cleaner energy sources, will become limited by resource availability. In the long run, while the cleaner fossil fuels (oil and natural gas) become depleted, coal will remain an abundant fossil fuel resource (See Figure 1). Unless cleaner and more efficient coal technologies are implemented, increasing use of coal will exacerbate local, regional and global pollution problems. From a global perspective, the large role of coal for the foreseeable future combined with the mounting concern for air quality and carbon dioxide emissions make the implementation of clean coal technologies essential.

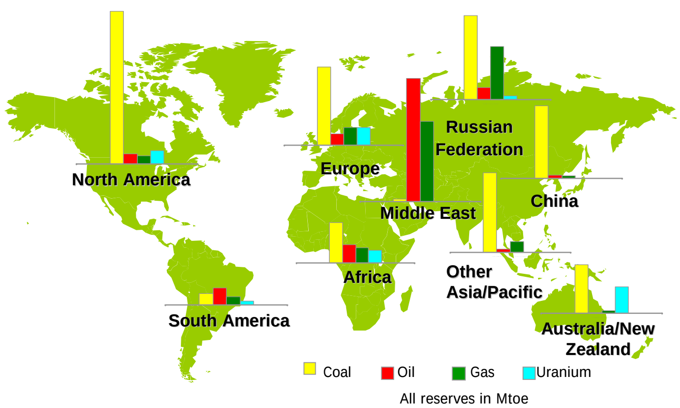

Figure 1: Coal Dominates Global Nonrenewable Fuel Reserves - Lifetimes for known reserves at current depletion levels are about 40 years for oil 65 years for gas, and 160 years for coal (500 years for some countries), using data from BP Statistical Review 2005 and WEC Survey of Energy Resources 2001.

1.2 Special Status of China: Because of its enormous potential impact, the consequences of China's economic development and associated energy development are vital not only to China, but also to the rest of the world. China is the most populous and has one of the most rapidly growing economies in the world, achieving annual GDP growth of about ten percent over the last twenty years. China ranks next to the U.S. in energy consumption, with a fifth of the Organization for Economic Cooperation and Development's (OECD) and a tenth of the world's total primary energy consumption (ZhiDong, 2003).

As a consequence of this sustained economic growth, energy demand is growing so rapidly as to jeopardize development goals, as evidenced by a widespread shortage of power in 24 of 31 provinces in 2004 (Ping, 2005). As a consequence of the size and characteristics of the energy system, China also has the largest absolute SO_2 emissions and the second largest carbon dioxide emissions in the world (Ren, Zeng, & Zhou, 2005).

1.3 Uses of Coal in China: Coal combustion accounts for more than three quarters of electricity generation in China, with capacity totaling 360 GW in 2002 (See Figure 2). However, electricity generation is responsible for only 50 percent of Chinese coal consumption, far below the global average of 69 percent.

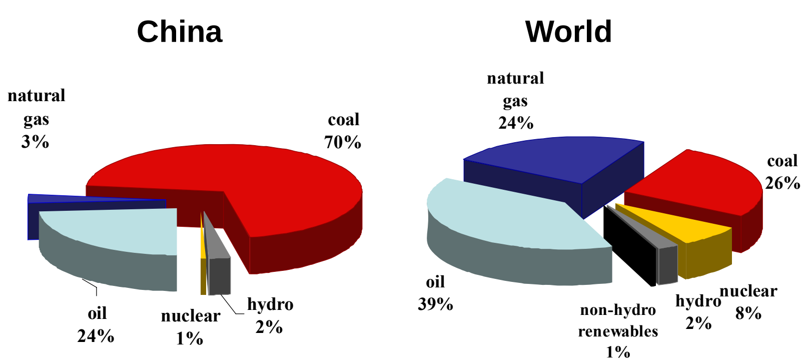

Figure 2 : Coal Use Large Percentage of China's Energy Mix Compared to World

Industry consumes the majority of the coal (42 percent of total) not used in electricity generation (Philibert & Podkanski, 2005). Residential and commercial uses account for the remaining 10 percent. Industrial boilers are used primarily in light industries that require process heat and power, such as the textile industry, and as a source of space heating for commercial buildings, apartment buildings, and district heating, especially in northern China (Philibert & Podkanski, 2005).

1.4 Growth Projections: The Chinese government has stated the goal of transforming China to a middle level developed country by 2050, focusing initially on quadrupling the size of the economy by 2020. A doubling of power generation capacity is expected by 2020, followed by a tripling by 2030 (Philibert & Podkanski, 2005; Ping, 2005). Much of the growth is expected in coal-fired power plants, whose capacity is expected to grow from 360 GW in 2002 to 776 GW in 2030 (See Figure 3) (Philibert & Podkanski, 2005). Although the share of coal in total power generation (1187 GW in 2030) is expected to fall from today's level of 75 percent due to growth in gas-fired generation and renewables, the absolute increase in coal capacity expected through 2030 is unsurpassed (IEA- 2004a Scenario) .

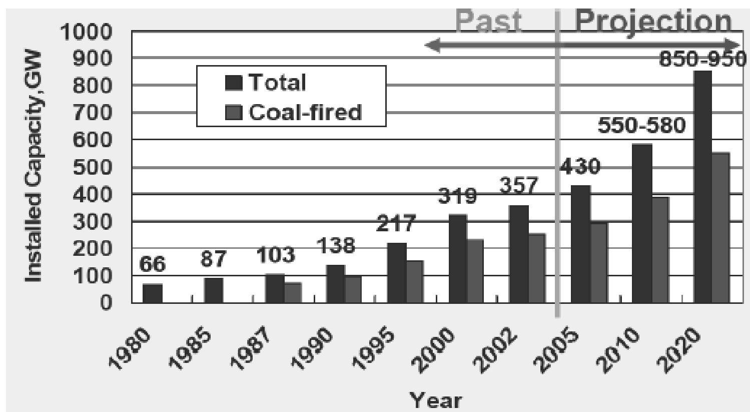

Figure 3: China's Installed Electricity Generation Capacity - Past, Present, and Future

China's dominant position in terms of coal power growth is supported by the observation that no less than 80 percent of global coal fired power plants ordered between 2001 and 2003 are destined for China (Philibert & Podkanski, 2005). Thus, the background for energy considerations in China is a rapid stable increase in energy demand and consumption, with fossil fuels remaining the dominant energy source in the coming decades (DeLaquil, Wenying, & Larson, 2003).

2 CHALLENGES TO ENERGY SECTOR GROWTH

For China to expand its economy fourfold by 2020 and meet its goals for economic development, energy security, and environmental protection, the current trajectory of energy system growth must be altered to address the challenges inherent to achieving the stated goals (Three E's of Sustainable Development, 16^{th} Party Congress, October 2002) ((TFEST), 2003). The principal challenges that must be addressed as China's energy sector expands fall into three categories: (1) air pollution; (2) energy security; and (3) carbon dioxide emissions. An additional challenge arises from two particular characteristics of the energy system and its current status in China: first, though China's energy system capacity is growing rapidly, most of this capacity is yet to be constructed; and second, once constructed, the energy system has tremendous inertia. This problem of energy system investment lock-in adds additional urgency to the consideration of policies addressing the three fundamental challenges facing China's energy system development.

2.1 Air Pollution: The role of the environment in energy development is becoming more important in China as the costs of public health and environmental damages rise. Air pollution has become the most severe of these problems, with resulting economic consequences projected to grow from over seven percent today to 13 percent of GDP in 2020 ((TFEST), 2003). In Eastern China, for example, emissions of NH_3 are expected to rise by 20 percent, non-methane volatile organic compounds (NMVOC) by 50 percent, and all other species by 130–250 percent in 2020 with reference to 2000 levels (Xiaoping

Wang et al., 2005). Similarly, total SO_2 production is expected to rise from 23 million tons in 1999 to 57 million tons by 2030. Against this projected growth, the government is aiming for a challenging total desulphurization rate of up to 65 percent by 2030, though this may reduce cloud albedo and lead to increased warming (ZhiDong, 2003). The energy sector is responsible for a large and growing share of air pollution and is coming under increasing pressure to reduce emissions levels while increasing output.

2.2 Energy Security - Avoiding Foreign Oil Dependence: China has stated a goal of meeting projected liquid fuel needs, especially for transportation, without endangering the security of energy supply by becoming excessively reliant on foreign oil imports. To achieve this goal, China would like to import a maximum of 30 percent of its crude oil ((TFEST), 2003). As found by a recent Energy Research Institute (ERI) analysis, oil imports may exceed 60 percent of total consumption by 2020 under the current energy growth trajectory (See Figure 4). Beyond China's opposition to such a significant dependence on foreign energy, more fundamental questions remain about who could provide such imports and whether China could afford them.

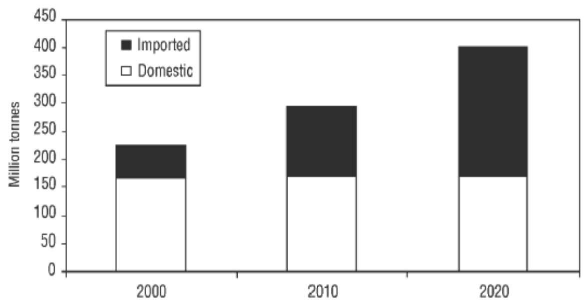

Figure 4: China's Projected Oil Consumption. Projection from the Energy Research Institute's Sustainable Energy Development and Carbon Emission Scenario 3 (high efficiency, but without coal gasification) (TFEST, 2003).

The conversion of coal to liquid fuels via advanced coal technologies is likely to play a crucial role in any effort to stem the growth of oil imports. A recent Task Force on Energy Strategies and Technologies (TFEST) analysis suggests that China could reduce projected oil imports by up to 30 percent in 2020 by aggressively pursuing an advanced coal technology strategy beginning immediately ((TFEST), 2003). Given current priorities, efforts to reduce the growth of oil imports are likely to play an active role in determining the future of China's energy sector (See **Appendix A** for more discussion).

2.3 Carbon Emissions In 2000, China emitted about 800 million tons of carbon from fuel combustion, making it the second largest carbon dioxide emitter in the world, with about 13 percent of global emissions (See Figure 5) (Chen, 2005). Between 1990 and 2004, carbon dioxide emissions from China increased by about 94 percent (about 700 million tons of carbon), equivalent to about 37 percent of the total global increase in this period. Though carbon dioxide emissions in ten other developing countries increased even more rapidly, the next highest increase (India) amounted to less than 12 percent of China's absolute increase (Jefferson, 2006). Carbon dioxide emissions from energy consumption in China are projected to increase to 2270 million tons of carbon in 2030, equivalent to about 96% of the combined total North America and OECD Europe emissions in 1999 (ZhiDong, 2003).[29]

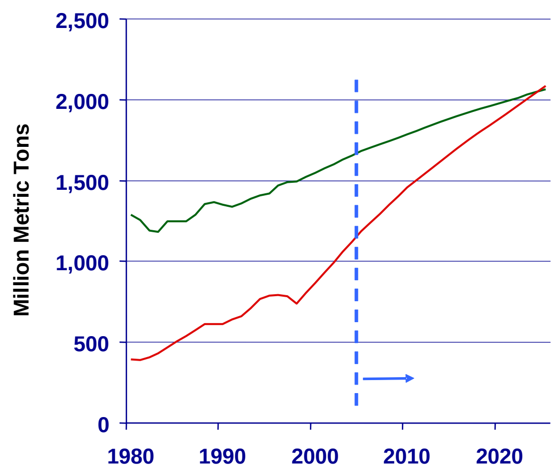

Figure 5: China's Carbon Emissions (red) Projected to Approach U.S. Levels (green) (projection from the Lawrence Berkeley National Laboratory)

As climate change impacts become more pressing, such emissions differentials will attract increasing attention, leading to mounting pressure on long term energy

[29] Although China's per capita emissions will continue to remain far below that of the OECD countries today (1.5 tons carbon per capita in 2030 for China compared with three tons carbon per capita in 1999 for OECD countries), China's contribution to global GHG emissions will become increasingly significant in absolute terms(ZhiDong, 2003).

development decisions in these countries.[30] To enable China to make a contribution to greenhouse gas emissions mitigation "on the basis of equity and in accordance with its common but differentiated responsibilities and respective capabilities," as established by the United Nations Framework Convention on Climate Change, the energy sector must develop on a new trajectory.[31]

2.4 Investment Lock-in: In addition to the challenges of air pollution, energy security, and carbon dioxide emissions discussed above, the unusual position of China early on its trajectory of energy system growth introduces an additional challenge. Policy will play a significant role in determining whether this challenge represents an opportunity or a risk.

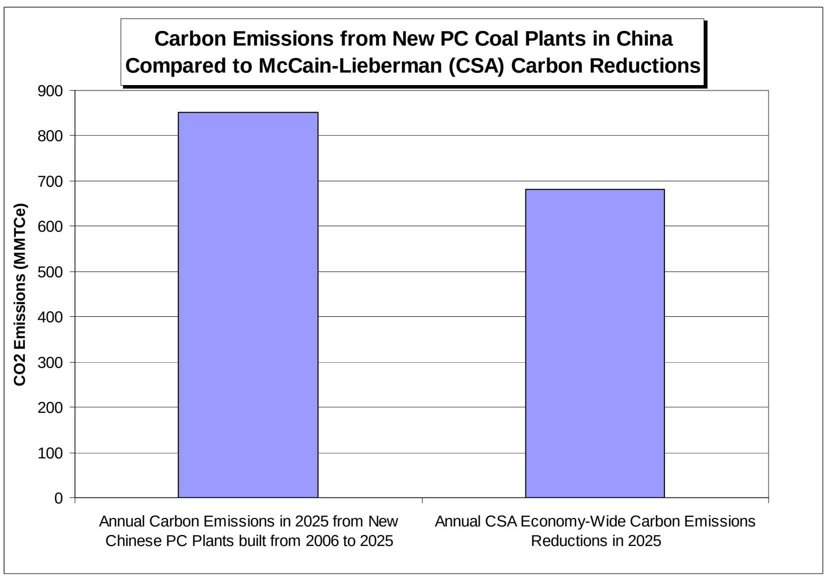

Figure 6: China's Projected New PC Power Plant CO_2 Emissions Exceed Proposed McCain-Lieberman Climate-Stewardship Act (CSA) CO_2 Reductions

The risk arises from the possibility that China's energy demand growth will be satisfied by rapid growth in new pulverized coal (PC) plant capacity. Such growth entails significant ramifications that arise from three characteristics of PC power generation: (1)

[30] In 2002, the average efficiency of coal-fired power plants in the OECD was 36 percent, compared with 30 percent for coal-fired power plants in the developing countries. As a consequence, 20 percent more carbon dioxide is emitted for each kilowatt-hour of electricity produced from coal in developing countries than from coal in the developed countries (Philibert & Podkanski, 2005).

[31] Already, China is coming under pressure from the developed countries to agree to some form of voluntary commitment to greenhouse gas (GHG) reductions (Chen, 2005).

PC power plants are amongst the longest-lived energy system investments, operating for 50 – 60 years; (2) PC power plants are the most carbon intensive energy system investments; and (3) addition of carbon capture and storage technology at a future date is expected to be prohibitively expensive (Sun, 2005). However, despite these considerations, large numbers of new PC power plants are under construction today and are expected to be built over the next 25 years, especially in China and India, where PC is the dominant electricity generation technology due to its maturity, familiarity, and favorable economics (See Figure 9). If built, these new PC plants will consume more coal during their lifetimes than all of industrial society to the present and will make any stabilization plans extremely difficult by absorbing a large portion of the global carbon budget (Figure 6, 7). However, this risk also represents an opportunity; although China's energy system is expanding rapidly, most of new capacity is yet to be constructed. More specifically, two thirds of China's coal-fired electricity generation capacity projected for 2020 is yet to be built (TFEST, 2003) (See Figure 8). Since China will construct a large portion of its durable energy infrastructure in the coming years, China has a great opportunity to shape its energy

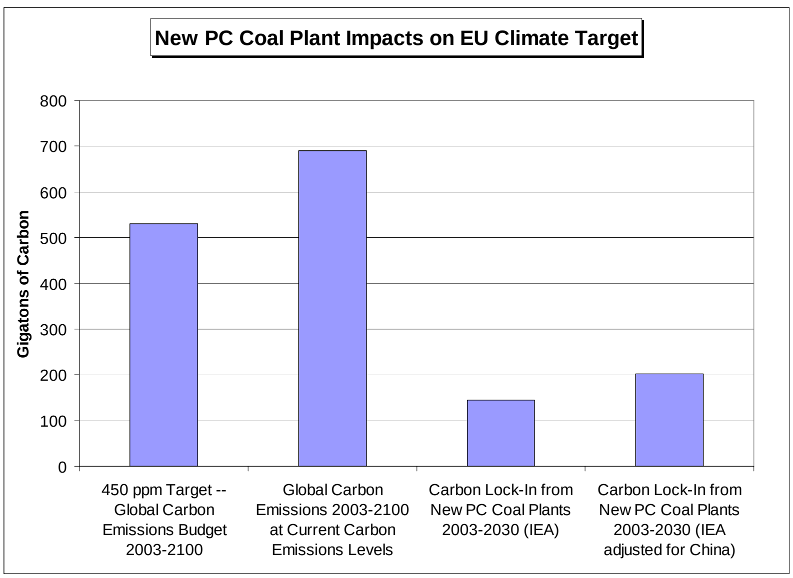

Figure 7: Projected Carbon Lock-in from New PC Plants Through 2030

sector, much more so than countries with slow growth or large amounts of sunk capital in existing infrastructure (Jin & Liu, 1999). Time is extremely important because large investments planned for electricity generation over the next decade will lock in the method of coal use in China through 2020 and for many decades following. To avoid lock-in, a significant portion of new coal-fired electricity generation capacity must be constructed on a sustainable modernized path. Though rapid growth in renewables is also a component of any sustainable energy development path, coal will continue to play a dominant role in China's electricity generation system due to its abundance, familiarity, and favorable economics. Analyses indicate that such an advanced coal technology strategy based on coal gasification would require only a small (about one percent)

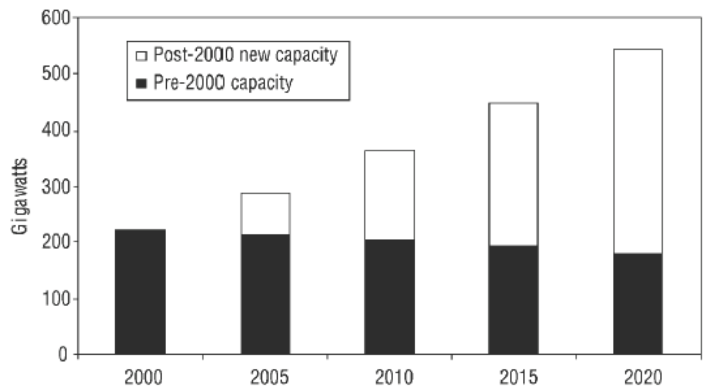

Figure 8: China's Projected Coal Power Plant Capacity - The Electric Power Technology Market Association of China estimated that two-thirds of the coal plant capacity that will be operating in 2020 is yet to be built (TFEST, 2003).

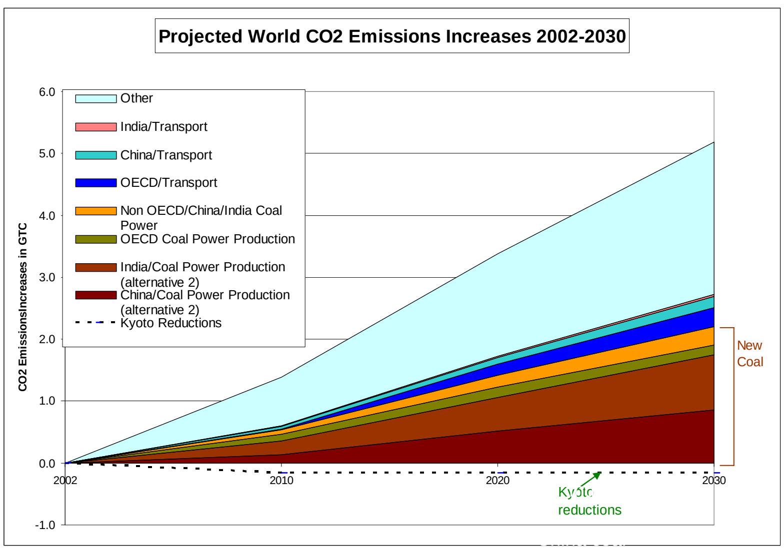

Figure 9: New Coal in China and India Dominates Projected Carbon Growth

increase in total energy system cost compared with business as usual, though it would require significantly higher capital investments in energy technologies. These higher capital costs, however, would be offset by lower energy costs, especially from reduced energy imports (DeLaquil et al., 2003). With China and India accounting for more than half of expected global growth in PC plants, the importance of coal modernization via gasification is particularly significant for energy development in these countries (See Figure 9).

3 CLEAN COAL TECHNOLOGY

3.1 Coal Gasification Technology: Gasification is the partial oxidation of a solid or liquid hydrocarbon feedstock to produce a gaseous product (synthesis gas or "syngas") composed primarily of hydrogen (H_2) and carbon monoxide (CO). This synthesis gas is a versatile product that can be used for several purposes, including (1) as a clean substitute for natural gas,[32] since impurities such as sulfur, nitrogen, particulates, and volatile mercury are removed during gasification; (2) to generate electricity efficiently using modern gas turbines in Integrated Gasification and Combined Cycle (IGCC) schemes; or (3) to produce a variety of synthetic liquid fuels, ranging from fuels compatible with existing compression-ignition engines to hydrogen for fuel cells (See Figure 11) (Watson, 2005). In addition to the air quality and energy security benefits available from coal gasification, gasification also provides a practical opportunity for carbon capture and storage. Thus, gasification represents the key technology to allow coal modernization in a manner that addresses the three fundamental challenges facing China's energy system development.

Coal gasification is based on technologies that are known and proven and is already in use extensively throughout the world (See Figure 10). There are currently about 385 utility scale gasifiers operating at over 100 projects across the globe. These gasifiers are used to produce electricity in the U.S., Europe, and Japan, chemicals and methane in the U.S., liquid fuels in South Africa, and ammonia fertilizer in China and India (Rosenberg et al., 2005). Several commercially used gasifier designs are currently available, including technologies from Shell, GE Energy, ConocoPhillips, Lurgi, and Noell (Rosenberg et al., 2005).

[32] Unprocessed synthesis gas has a slightly lower heating value than natural gas, but it can also be converted to synthetic natural gas using methanation catalysts that are commercially available (Rosenberg, Walker, & Alpern, 2005).

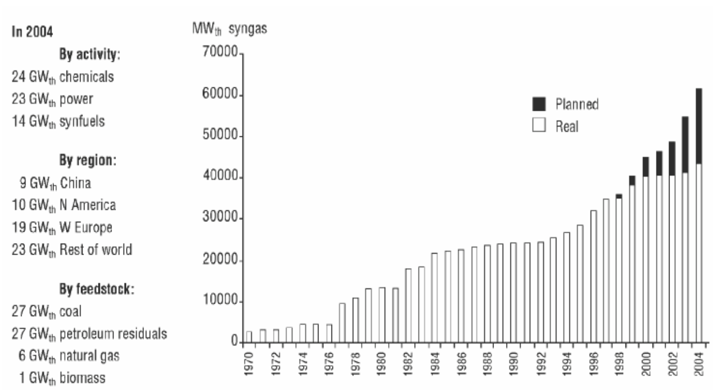

Figure 10: Cumulative Global Gasification Capacity and Growth (TFEST, 2003)

China already has extensive experience with gasification technology with about 8000 gasifiers currently installed, half of which use atmospheric fixed-bed technology to gasify coal (comprising about nine GW of capacity) (Wanwang, 1999). This capacity, however, exists in the chemical industry rather than the power industry, suggesting that cross-sector fertilization would be advantageous. Furthermore, most of these installations are small and rely on inefficient and outdated designs, though a limited number of more advanced foreign gasifiers have been constructed in China, including a handful of Texaco and Lurgi gasifiers used for fertilizer, synthetic natural gas, and methanol production (Hongtao et al., 2003). Great efficiency and emissions reduction benefits would be realized from the wider use of such cleaner more advanced gasifier designs from foreign companies. For the case of a polygeneration plant based on coal gasification, though all components are currently commercially available, integration is new and requires learning by experience. Thus, successful implementation requires integration and investment in existing technologies rather than the development of new ones.

3.2 Comparison of Coal Gasification and Boiler Technologies Gasification offers several substantial environmental advantages over the direct combustion of coal in conventional PC systems, including (1) air pollutant reductions, (2) energy security benefits, and (3) carbon emissions reduction potential. In particular, polygeneration to produce electricity, liquid fuels, and petrochemicals offers the greatest range of advantages, making it the most attractive strategy for the advancement of coal gasification.

Today's dominant PC power plants result in emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), particulates, and mercury (Moskovitz, 2000). Though these emissions can be reduced through combustion or post-combustion control processes, gasification allows pre-combustion fuel clean-up that is more cost-effective due to a greater concentration of pollutants, lower mass flow rate, and higher pressure than is found in post-combustion flue gases (Rosenberg et al., 2005). This pre-combustion synthesis gas clean-up allows more cost-effective and equal or better emissions reductions than post-combustion treatments, achieving an emissions profile similar to that for natural gas combined cycle electricity generation. Gasification also allows the effective (almost 100 percent)

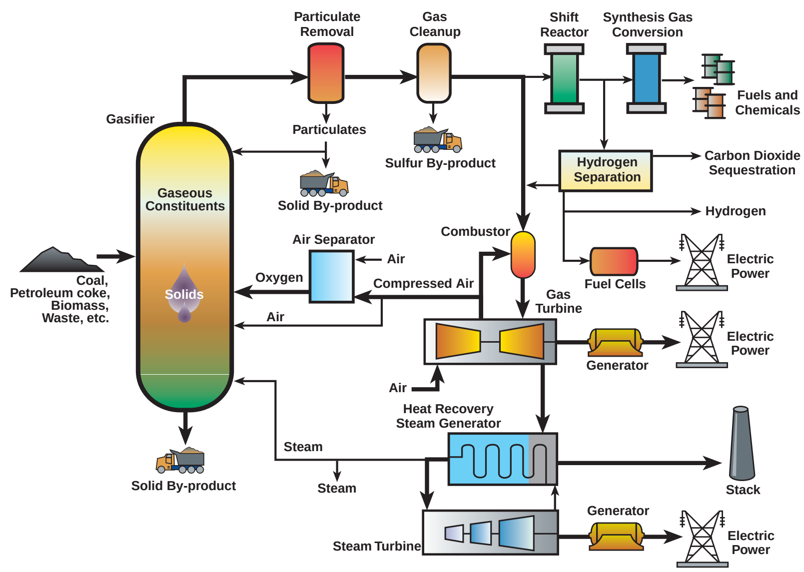

Figure 11: Gasification Technology Schematic (Gasification Technology Council, 2006)

removal of mercury through the use of carbon beds in post syngas cleanup (Rosenberg et al., 2005). Carbon beds are more cost-effective and produce significantly less solid waste than activated carbon injection at a PC plant. Furthermore, since carbon bed waste is managed as a hazardous waste, reemission is inhibited.

Gasification offers several additional environmental advantages over PC combustion. First, the use of gas turbines and combined cycles allows greater efficiency in electricity generation. Second, gasification allows 20 – 50 percent reductions in water usage compared with conventional coal plants, as well as the possibility of dry cooling to further reduce water use. Third, gasification allows approximately a 50 percent reduction by volume in solid waste production. Furthermore, the solid waste is less likely to leach toxic metals than fly ash from conventional coal plants since ash melts and is vitrified in gasification. Gasification also results in the production of marketable sulfur and non-leachable slag byproducts (Watson, 2005).

Gasification offers a means by which to counter China's growing dependence on foreign oil imports and to thereby enhance energy security, since syngas from gasification can be processed in a polygeneration plant to produce high quality liquid fuels, such as sulfur-free diesel, methanol, and dimethyl ether (DME), as well as a variety of other products, including electricity, hydrogen, steam, and petrochemicals (Larson & Tingjin, 2003).

3.3 Gasification for Electricity Production: Coal gasification can be used with a combined cycle power block to generate electricity in a process called integrated gasification combined cycle (IGCC) generation. IGCC systems produce syngas by coal gasification, clean the syngas with gas cleanup equipment, and combust the syngas in gas turbines to produce electricity. Residual heat is recovered from the turbine exhaust gas in a heat recovery boiler and used to produce additional electricity in a steam turbine generator. IGCC power plants are among the cleanest and most efficient of the advanced coal technologies, setting new standards for pollutant emissions and offering efficiencies rising above 50 percent (Philibert & Podkanski, 2005).

Although the first coal-fired IGCC plant entered into operation over 20 years ago, the technology has not exited the demonstration phase. In 2003, there were 14 IGCC projects in commercial operation, including two in Asia.[33]All have been at least partially supported with public funding.

Currently, several IGCC plants are in the approval process in the US. In Japan, a 250 MW demonstration project is coming online in 2008, funded by a consortium of utilities and government subsidies (Watson, 2005).[34] A number of other coal, petroleum coke, and heavy oil IGCC projects are currently being considered worldwide.

3.4 Polygeneration for Production of Electricity and Liquid Fuels

In addition to IGCC, the synthesis gas generated from coal gasification can be used to produce a variety of liquid fuels, process fuel feedstocks, chemicals, heat, steam, and electricity in a polygeneration plant (Figure 12) (Watson, Xue, Oldham, MacKerron, & Thomas, 2000). This scheme is attractive because after all pollutants, such as sulfur, nitrogen, and mercury, are removed from the syngas, the syngas can be used to

[33] Of these 14 IGCC projects, eight were located in Europe, four in U.S., and two in Asia; eight used solid feedstocks, such as coal and petroleum coke, and six used high sulfur heavy oil; eight used ChevronTexaco gasifiers, two used Shell technology, one used Krupp Uhde, one used ConocoPhillips E-Gas, and one used Schwarze Pumpe technology (Rosenberg et al., 2005). Additionally, gasification has been employed in many other projects producing chemicals, such as hydrogen for ammonia/urea synthesis, oxochemicals, Fischer-Tropsch liquid fuels, and hydrogen for oil refineries.

[34] At least two new IGCC plants have been approved under President Bush's Clean Coal Power Initiative, and at least two U.S. utilities have announced plans to construct new coal-fired IGCC plants in the next few years.

manufacture the chemical that best serves performance goals (such as high cetane or high octane) and emission goals (such as inherently low particulate and NOx emissions).[35]

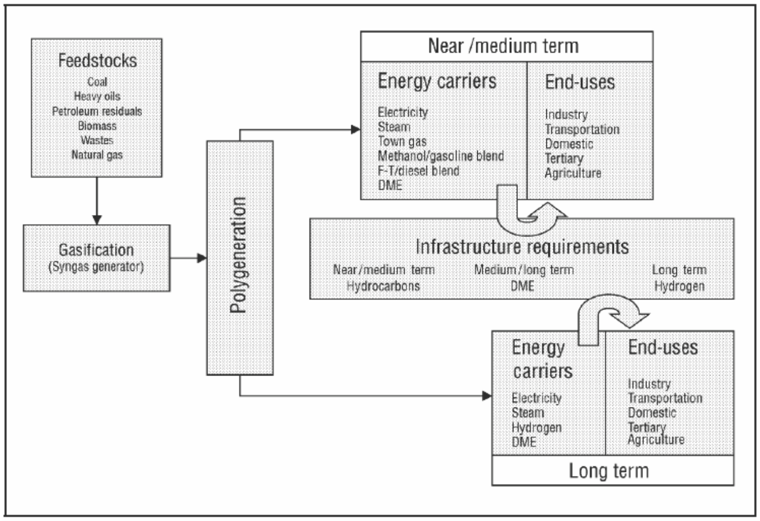

Figure 12: Polygeneration Schematic (TFEST, 2003)

Thus, in addition to providing a strategy allowing China to reduce the growth in its dependence on foreign sources of oil and natural gas, polygeneration allows the production of synthetic liquid fuels that are superior to conventional hydrocarbon fuels with regard to both performance and emissions characteristics (See **Appendix B** for a detailed description of near-term and long-term polygeneration capabilities) (Williams, 2001).

Modernization of coal via gasification introduces new infrastructure challenges and opportunities for China, but the range of potential products from polygeneration avoids the need for sudden infrastructure changes. Coal modernization also could provide opportunities for alleviating some existing infrastructure problems in China, such

[35] As air quality regulations tighten over time, procuring compliance with conventional hydrocarbon fuels will require increasingly sophisticated exhaust gas after-treatment technology and improvements in fuel quality, associated with large investments in oil refineries. These costly continual modifications of both production and end-use processes are avoided with gasification technologies since most pollutants are removed in the standard gasification process.

as the current railway infrastructure problem of coal transport utilizing 70 percent of rail capacity. If polygeneration plants were located near coal mines, fuel and electricity could be transported to market by pipeline and wire (Jin & Liu, 1999).

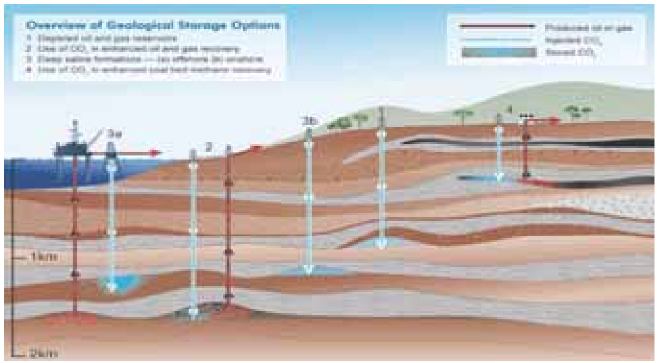

Figure 13: Geologic Sequestration Options (IPCC, 2005)

3.5 Carbon Capture and Storage (CCS): Perhaps most significant globally, gasification provides a practical opportunity for reducing carbon dioxide emissions from coal-fired electricity generation through carbon capture and storage (See Figure 13). By adding water-gas shift reactors and physical absorption processes to the treatment of syngas from oxygen-blown gasification, a nearly pure stream of carbon dioxide that can be segregated at low marginal costs is obtained (Ren et al., 2005). This approach to carbon dioxide capture is widely held to be more cost-effective than post-combustion capture with conventional coal combustion technologies (Rosenberg et al., 2005).

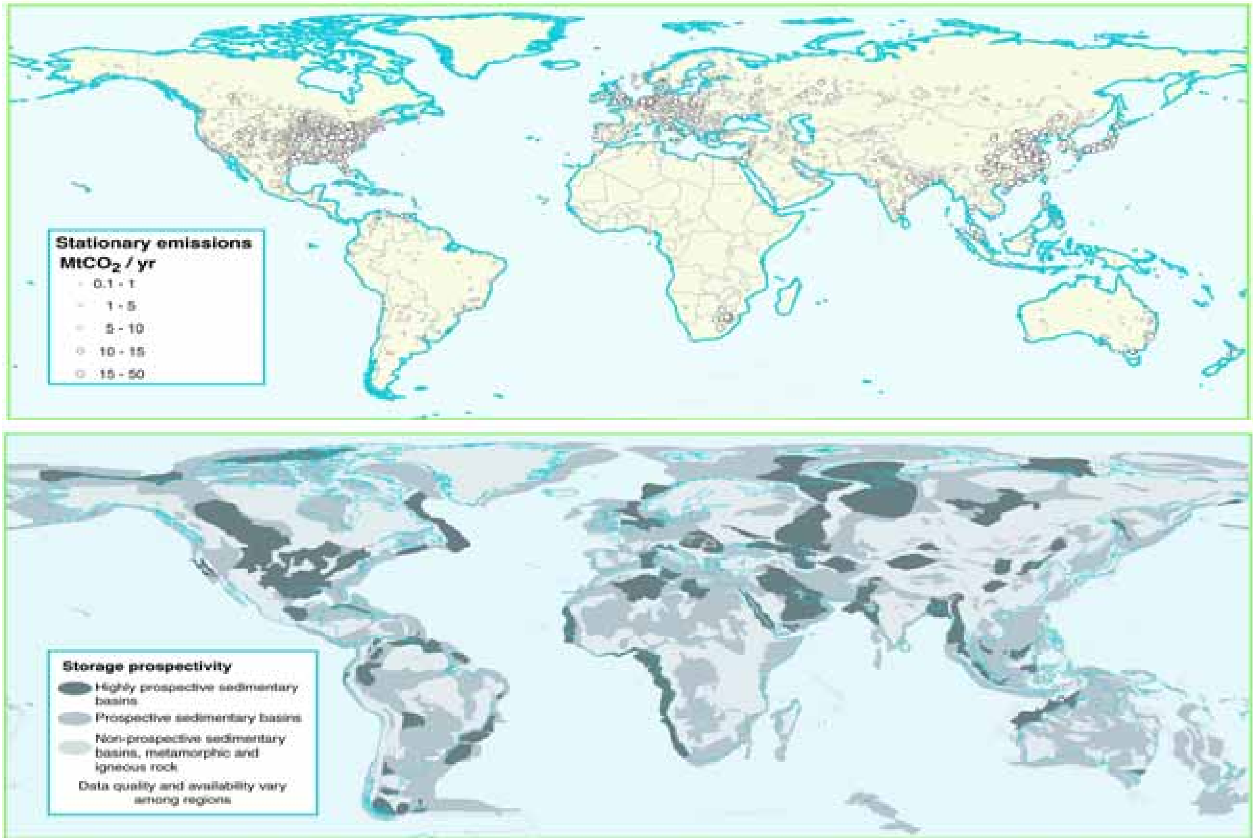

Figure 14: Good fit between global distribution of large carbon dioxide emission sources and prospective geologic storage (IPCC, 2005)

As stated by the U.S. National Commission on Energy Policy, “Coal-based integrated gasification combined cycle (IGCC) technology […] can open the door to economic carbon capture and storage, [and] holds great promise for advancing national as well as global economic, environmental, and energy security goals. The future of coal and the success of greenhouse gas mitigation policies may well hinge to a large extent on whether this technology can be successfully commercialized and deployed over the next 20 years” (Rosenberg et al., 2005). Though the significance of the issues associated with CCS cannot be overstated— the potential carbon emissions reduction benefits of coal gasification rest almost entirely on their successful resolution—it is beyond the scope of this paper to explore them (See **Appendix F** for a more lengthy discussion). However, should these issues be successfully resolved, extensive geologic storage capacity is available in China (Figure 14).

4 POLICY BARRIERS AND RECOMMENDATIONS

4.1 Policy

Challenges: Two fundamental premises underlie the need to actively modernize the growth of China's energy system. First, China is likely to sustain at least six percent annual economic growth in the next 30 years. Second, energy system growth with base technologies, utilizing coal combustion for power generation and petroleum fuels, cannot meet the development goals for air pollution, potential carbon dioxide alleviation, and especially for energy security ((TFEST), 2003). An advanced technologies strategy, utilizing a combination of energy efficiency, natural gas, renewable energy, and modernized coal, may be able to provide similar energy services at similar costs while also limiting oil and natural gas imports to about 30 percent of total supply and satisfying objectives for air pollution and carbon dioxide emissions (See Figure 15) (ZhiDong, 2003).

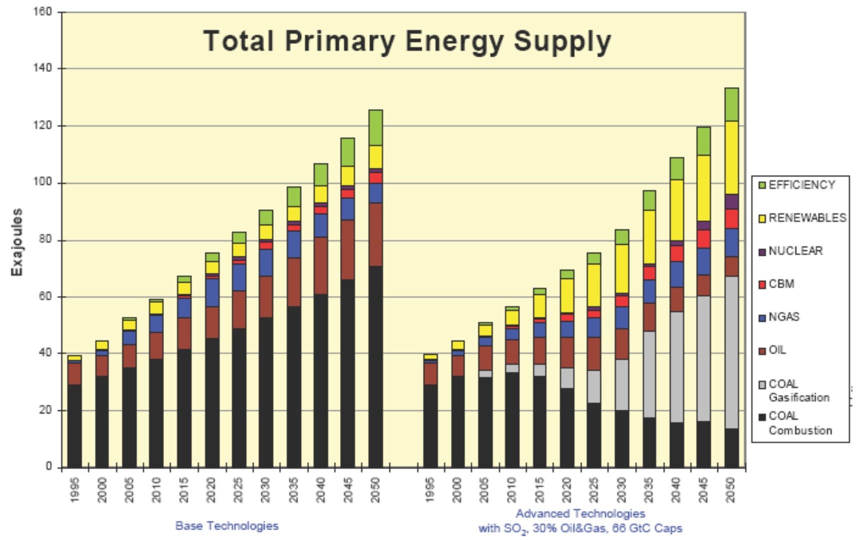

Figure 15: Coal Gasification Not Adopted in Absence of Policy - In the advanced technologies scenario SO_2 emissions are reduced from 23.7 Mt in 1995 to 16.2 Mt in 2020 and 8.8 Mt in 2050. Oil and natural gas imports are limited to 30 percent of consumption. The 66 GtC cap is China's cumulative carbon emission allowance based on CO_2 stabilization at 450ppm and year 2000 population-based apportioning of globally allowed carbon emissions (TFEST, 2003).

Energy demand growth, constrained by air pollution, potentially by carbon emissions, and by energy security, suggests a critical need to develop CCS-enabled coal gasification. Gasification based energy system growth provides an attractive alternative to pulverized coal growth in China, serving as a pathway for alleviating energy security issues arising from dependence on foreign oil imports, reducing air pollution, and providing a potential lower-cost route to reductions in carbon dioxide emissions. Despite the less favorable economics for gasification in China at present, it is becoming an increasingly attractive technology for producing synthetic natural gas, liquid fuels, ammonia, and other chemicals. Such polygeneration schemes allow the realization of the energy security benefits of coal gasification, as well as the air pollution advantages and the potential carbon dioxide mitigation benefits. Hence, the additional drivers provided by polygeneration may prove sufficient to motivate the development of IGCC in China within a favorable policy environment (Xiaohua Wang & Feng, 2003).

For deployment to proceed, a favorable policy environment must address the barriers to coal gasification. The major global barriers to widespread commercialization fall into five categories: (1) Environmental Policy; (2) Institutional Capabilities; (3) Intellectual Property Rights Protection; (4) Investment and Trade rules; and (5) Finance and Economics (See **Appendix E** for discussion of an additional issue). Each barrier is described below and followed by associated policy recommendations.

4.2 Recommendation I: Environmental Policy

Barrier: Environmental regulations are poorly enforced and often inadequate to justify investment in clean technology (Zhufeng & Jie, 2001).

This barrier is often cited as one of the most problematic obstacles to the development of clean coal technology in China, second only to the need for general economic reforms (Philibert & Podkanski, 2005). Two issues contribute to this barrier: first, existing regulations are not adequately tough to change behavior and justify investment in clean technology such as gasification; and second, existing standards are enforced weakly and inconsistently. For these reasons, existing environmental regulations have only affected the energy sector marginally; since the incentive to reduce pollution is lacking despite a growing desire to do so, environmental considerations typically fall far behind economic or social ones, especially in cases such as gasification where new technology and expertise must be acquired. Even when tougher laws are enacted, little is often achieved since the market does not respond in the absence of enforcement (See **Appendix C** for an exception where environmental regulations are strictly enforced).

In addition to the general problems for environmental enforcement such as the lack of sufficient resources in government agencies such as the State Environmental Protection Agency (SEPA) and the dominance of economic growth in decision-making, enforcement is often prohibited by the absence of appropriate monitoring equipment at many industrial installations (Philibert & Podkanski, 2005). This equipment is often costly because it is imported; thus, the acquisition of technologies and the development of domestic manufacturing capacity for such products, perhaps through joint venture companies, could lead to more widespread monitoring, enabling more effective enforcement of environmental regulations.[36]

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[36] Recent initiatives, such as efforts to strengthen the pollution fee system, indicate that pollution regulation enforcement is becoming a higher priority. In some regions, environmental policies are similar to those in

Recommendations:

(1) Enforce existing environmental regulations to reward clean technologies.

(2) Install monitoring equipment more widely to enable enforcement and develop domestic monitoring equipment manufacturing capacity.

(3) Introduce new pollution standards more gradually to give industry time to adjust.

4.3 Recommendation II: Institutional Capabilities

Barrier: The innovation system is weak and fragmented and many companies lack commercial skills and neglect appropriate training.

Though China has advanced scientific/technological capabilities in universities and research institutes and extensive manufacturing capacities in industry, the two sectors are ineffectively bridged and not connected to foreign companies, resulting in a suboptimal environment for innovation (Jin & Liu, 1999).[37] The fragmented innovation system creates barriers to the transfer and development of advanced coal technologies. Though some obstacles arise from insufficient technical expertise in Chinese organizations, the more significant problem is a general lack of commercial and organizational proficiency in the overall innovation system.

The lack of industrial organization structures that allow continuous research, development, and manufacturing obstructs not only domestic innovation, but also hinders international collaboration and technology transfer because manufacturing capacities and design capacities often reside in different institutions. This hinders technological

industrialized countries, suggesting that emphasis should be placed on implementation of existing regulations, rather than promulgation of new ones.

[37] This separation between design and manufacturing and resulting lack of commercial/innovation skills arises from the history of China's enterprise system, where design work was performed in dedicated design institutes and State-owned manufacturing enterprises relied on centrally planned production schedules. Today, commercial behavior such as competition for contracts is replacing central planning, but the disjoint between design and manufacture remains.

collaboration since foreign companies often must communicate design issues through design institutes rather than directly to manufacturers that lack advanced technological skills. The separation of design and manufacture also makes it difficult for foreign companies to locate the appropriate initial contacts (See **Appendix D** for additional discussion) (Weidou & Johansson, 2004).

An innovation scheme for the research and development of key clean coal technology is proposed here: First, the related government department originates a project utilizing clean coal technology and solicits bids from companies. The winning bidder would then select and fund research institutions as needed. The research institute would be accountable to the company, and the company in turn would be accountable to the government. This organization would effectively give the companies the leading role, facilitating coordination, research and development, and commercialization. The government department would play a role coordinating research and development and would support demonstration projects with additional incentives such as tax benefits and subsidies.

Recommendation:

(1) Reform the innovation process to allow coordinated research, development, demonstration, and commercialization of advanced technologies such as coal gasification.

4.4 Recommendation III: Intellectual Property Rights

Barrier: Intellectual property rights protection for advanced coal gasification technology is inadequate, hindering technology acquisition and diffusion (Philibert & Podkanski, 2005).

Intellectual property right issues- the concern that designs will be copied outside of license agreements- remains one of the primary obstacles to both domestic innovation and technology transfer. Within China, many institutions and universities refuse technology exchanges to preserve technological advantages and protect intellectual property rights. Similarly, foreign firms are often reluctant to transfer technology out of fear that designs will be illegally copied and utilized in China without adequate compensation.[38]

Recommendation:

(1) Strengthen intellectual property rights protection for advanced coal technologies.

4.5 Recommendation IV: Investment and Trade Rules

Barrier: Foreign ownership restrictions and complex approval processes for investments restrict foreign investor access to the potentially large Chinese market for advanced coal technologies, hindering the development of technology transfer relationships.

First, restrictions on foreign ownership in joint ventures with Chinese companies drastically reduce foreign investment and technology transfer. Although the desire of the Chinese Government to protect domestic firms and improve their capabilities through collaboration may seem legitimate, foreign investors demand a share of management control over joint venture companies in which they invest, especially if the collaboration involves technology transfer (Watson et al., 2000). Instead, however foreign money is readily accepted by joint ventures, but these joint ventures often refuse to engage in joint

[38] However, intellectual property right protection is gradually improving in China, perhaps as the commercialization or former State-owned industries strengthens respect for intellectual property rights. Nevertheless, measures should be further developed to provide a rigorous legal framework for the rights and responsibilities of clean coal technology developers, owners, and users, both domestic and foreign, so that interests are legally protected.

decision-making, leading to a situation where foreign investors contribute significant funding without gaining any managerial or financial control (Zhufeng & Jie, 2001).[39]

Second, the negotiation and approval process for foreign investments in China is significantly more arduous and complex than in many other countries; it can take months or even years to reach agreements for certain investments (Watson et al., 2000). This is particularly problematic for smaller companies that lack the resources to develop long term contacts with the Chinese Government and industries. Currently, the most active foreign firms in China tend to be large companies such as Shell International. While many smaller more focused companies in the advanced coal technology business see China as a potentially promising market for their products, expertise, and technology, due to the abundance of China's coal reserves and the size of the market, expansion into easier foreign markets is often preferred over China (Watson et al., 2000).

In addition to concern about intellectual property rights protection, smaller companies often have a difficult time obtaining the information needed to evaluate risks appropriately. An international organization could reduce this asymmetry by providing information support to smaller companies, allowing them to more accurately assess the risks and resources required for a venture (Sun, 2005).

Recommendations:

(1) Continue liberalizing foreign investment to allow greater foreign ownership and control of firms operating in China.

[39] It may even be the case that 100 percent foreign investor ownership of new installations could be better for China's environment and technology transfer in the short term by granting a foreign owner complete control over the management and operation of the facility and a higher financial interest in its efficient operation.

(2) Streamline the approval process for large foreign investments, particularly those related to coal gasification development.

(3) Encourage the OECD to develop an information clearinghouse to provide detailed information on the Chinese energy sector tailored for use by smaller firms considering investment in China.

The transfer of technology to China warrants particular attention. Ample opportunities exist for technology transfer to improve the performance of China's power generation sector, such as the provision of management and technical training, the application of advanced control systems, the installation of monitoring equipment, the implementation of improved maintenance regimes, and the development of modern technologies that could benefit from foreign expertise, such as coal gasification. Technology transfer can occur through a variety of mechanisms including joint ventures, technical assistance, and project-specific collaboration (Philibert & Podkanski, 2005).

Technology transfer is often confused with the simple export of hardware; however, successful technology acquisition also requires the wider transfer of knowledge. In some cases, knowledge transfer such as design, management, operation, and maintenance skills may be more important than hardware transfer. For both partners in technology transfer agreements, however, the transfer of tangible and prestigious hardware is often overemphasized. This leads to an incomplete transfer process if the Chinese firm lacks the wider knowledge required for optimal installation and management (Philibert & Podkanski, 2005).

Recommendations: The following recommendations, prepared for China, offer an approach to coordinating technology transfer of coal gasification technologies to allow the development of an improved innovation system in China, thereby allowing economic growth based on modernized power generation growth.

(1) Actively develop new channels for technology transfer, beginning with the acquisition of clean coal technology through the Clean Development Mechanism (CDM).

(2) Define priority channels for technology transfer, favoring technology acquisition through foreign direct investment (FDI) and licensing (with appropriate IPR protection) over simple equipment imports.

(3) Develop administrative and economic measures to support the adoption of already imported technologies to allow the absorption of imported technology. Such measures could include subsidies for goal gasification demonstration projects and risk sharing (such as through loan guarantees) for early adopters of transferred technology

(4) Adopt measures to integrate technology transfer with domestic research and development to support the establishment of an integrated innovation system. For example, the central government could initiate clean coal technology-based projects and leave the management of these projects to private firms who could select partners with the requisite technological and management capabilities.

4.6 Recommendation V: Finance and Economics

Barriers: Coal gasification-based power schemes rely on expensive imported technology and incomplete internalization of environmental and energy security externalities artificially reduce the financial incentive for such projects. Additionally, informational barriers arise from the unfamiliarity of the power generation sector with coal gasification technology (Atwood, Fung, & Clark, 2003).

Lack of finance is often cited as the most significant obstacle to the transfer and implementation of coal gasification. This lack of finance arises from several sources: (1) coal gasification power generation schemes rely on costly imported technology, introducing an additional financial barrier to implementation and underscoring the need for effective technology transfer; (2) externalities, such as those of air pollution and energy security, are not appropriately valued, thereby distorting market incentives. In this situation an economically viable project will not attract private finance until externalities are internalized such as through pollution charges or public concessional finance; (3) even when a project is both economically and financially viable, finance still may not be forthcoming due to apprehension of risks involved with lack of information or experience with a technology scheme. These information/managerial obstacles[40] can theoretically be resolved within the private financial sphere; however, public support is likely to play a crucial role (Philibert & Podkanski, 2005).[41]

Recommendations:

(1) Environmental policies that accurately reflect the costs of pollution must be implemented and enforced to create the appropriate economic incentives for clean coal financing.

[40] Such information/managerial obstacles include: (a) gasification technology is unfamiliar to the power industry, which sees it as belonging to a chemical plant not a power plant; (b) firms are reluctant to be early adopters and assume technology application risk; (c) business models for gasification IGCC or polygeneration plants are undeveloped; and (d) few IGCC or polygeneration units are in operation, many do not use coal, and many are located overseas.

[41] The deployment of advanced power generation technologies such as coal gasification for polygeneration is likely to begin with the construction of initial demonstration plants. Such demonstration projects are likely to rely on public finance such as loan guarantees, capital subsidies, or grants. This lack of finance for capital intensive demonstration projects is an obstacle throughout the world, with these technology schemes just beginning to become viable without major public support in the U.S. However, such demonstrations offer an attractive path forward for the development of coal gasification-based schemes as they serve as an integrative framework in which many barriers to gasification are addressed, including the informational/managerial obstacles and the technology transfer issues.

(2) Technology transfer and absorption is crucial to allow not only the acquisition of clean coal technologies but also the domestic manufacture of such hardware at much lower costs than for imported equipment.

(3) Demonstration projects should be developed to increase familiarity with the technology and address the information barriers to gasification-based power generation. Such projects would benefit from the establishment of avenues to public finance such as loan guarantees, capital subsidies, and grants.

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6 APPENDICES

Appendix A: Energy Security

Energy security presents a pressing challenge for the development of China's energy system. China, a country with minimal domestic oil resources, is determined to avoid a position of excessive reliance on foreign oil imports; however, as demand for liquid fuels continues to grow rapidly, especially for the transportation sector, China is projected to become increasingly dependent on foreign oil imports.

Another analysis considering both oil and natural gas and assuming self-sufficiency of coal and optimistic domestic production of crude oil and natural gas projected that the fossil fuel supply shortfall will increase to 710 Mtoe in 2030, with oil responsible for 567 Mtoe and natural gas responsible for 142 Mtoe of the shortfall. If imports rise to offset this shortfall, the share of import-dependence will rise to 76% for oil and 52% for natural gas (ZhiDong, 2003). Beyond China's opposition to such a significant dependence on foreign energy, more fundamental questions remain about who could provide such imports and whether China could afford them.

Appendix B: Polygeneration

Furthermore, polygeneration allows the evolution from one set of technological options in the near term (2006-2020) to a potentially more attractive set of options in the long term (beyond 2020). In the near term, clean synthetic fuels such as synthetic natural gas, methanol, Fischer-Tropsch (F-T) liquids, and DME could be produced in polygeneration facilities that also make electricity, providing a range of energy services for several potential markets, including transportation, urban, and rural: (1) substitute transportation fuels that require no new infrastructure, such as methanol blended with gasoline or F-T liquids blended with diesel; (2) substitute transportation fuels that require new infrastructure, such as DME for buses, trucks, and cars as compression-ignition engines become more widespread; (3) electricity and synthetic natural gas as a replacement for coal in urban domestic heating, cooking, and industrial heating; and (4) DME as a cooking fuel for rural areas, augmenting tight supplies of liquefied petroleum gas (LPG) in the existing LPG infrastructure (Larson, Zongxin, DeLaquil, Wenying, & Pengfei, 2003).

In the long term, polygeneration including CCS could allow schemes such as the production of hydrogen as an energy carrier with near-zero emissions of carbon dioxide or the production of rural electricity from biomass polygeneration facilities co-producing DME for transportation and cooking (Williams, 2001).

Appendix C: Environmental Policy

Notable exceptions to the typical lack of environmental regulations enforcement occur for energy projects based on imported equipment. Often the Chinese Government treats these installations as technological and environmental showcases, leading to unusually stringent oversight by China's State Environmental Protection Administration (SEPA), as well as international funding agencies such as the World Bank in certain situations. While these instances demonstrate that SEPA has sufficient power to enforce environmental regulations, this differential treatment biases the market against installing modern power plants that attract scrutiny and are simultaneously undercut by inefficient capacity owned by provincial power companies. Foreign companies would have a greater incentive to transfer technology if they were confident that inferior technology would be penalized. This lack of confidence that enforcement will favor cleaner technology over dirtier options, even if the laws do, significantly weakens the incentive to develop clean technologies in China (Watson et al., 2000).

The weakness of enforcement is likely to become more damaging to advanced generating capacity as the electricity industry is deregulated, since expensive but cleaner new plants will have a more difficult time competing against older depreciated State-owned plants. Unless a mechanism such as enforcement of existing environmental regulations rewards the use of clean technologies, freer pricing of electricity may harm the development of cleaner generating capacity such as gasification-based systems.

Appendix D: Institutional Barriers

The lack of innovation capacity at the manufacturing level also hinders the transfer of advanced coal technology knowledge and management skills beyond a simple hardware order. Wider collaboration beyond hardware transfer is necessary for advanced technologies such as gasification-based schemes, since gasification is an emerging industry compared with the established boiler industry, standard designs and guarantee packages for advanced gasification installations are not fully developed, and operation and maintenance are critical to the success of the technology.

Additionally, many Chinese industries rely on complex networks of national, regional and local organizations such as research institutes and manufacturing companies, making it difficult for foreign companies to find the appropriate initial contacts. This is particularly disadvantageous for smaller foreign firms lacking the resources to search exhaustively for fitting partners in China. These firms can become discouraged by the number of potential communication routes and entry points, none of which may be optimal (Watson et al., 2000).

Though Chinese research institutes have the technical capabilities to develop advanced coal technologies including gasification, the research institutes lack a history of effectively commercializing their innovations due to their typical separation from design institutes and manufacturing enterprises. The innovation process has proven more successful when manufacturing or design enterprises solicit assistance from and compensate research institutions for solving a specific problem (Zhufeng & Jie, 2001).

Appendix E: Technological Barriers

Two of the most significant remaining technological barriers to coal gasification are: (1) the currently higher capital and operating costs for gasification based power plants compared with typical coal combustion technology; (2) availability/reliability concerns that are costly to reduce with a spare train; and (3) questions remain about suitability and cost of using low quality coals, such as lignite.

At present, capital costs are typically 20 percent higher for IGCC plants than for PC plants, especially in China where IGCC plants do not have a chance of competing economically with conventional coal-steam power plants unless SO_2 and NOx emission controls are required and enforced. Reliability also remains one the principle challenges hindering extensive commercialization. Though many of the existing coal-fired IGCC power plants have reached availability levels of 75-80 percent in recent years, none has achieved the target availability level of 85 percent demanded for commercialization. Additionally, operating an integrated combined cycle and gasification plant and ensuring sufficient gas cleanup for modern gas turbines remain challenging, especially when utilizing low rank coals (Watson, 2005).

Many of the policies suggested previously- such as strengthened enforcement of environmental regulations, restructuring the innovation process, and encouraging foreign collaboration and technology transfer- would help lead to resolution of these issues by allowing accumulation of more experience.

Appendix F: Carbon Capture and Storage

The carbon dioxide emission reduction potential of coal gasification depends on realization of carbon sequestration, requiring both the resolution of remaining scientific issues and the appropriate policy environment.

Current carbon sequestration science supports the feasibility of carbon capture and storage (CCS). The International Panel on Climate Change (IPCC), for example, foresees CCS providing a large portion of total CO_2 least cost reductions during this century, reducing total carbon mitigation costs by 30% relative to the scenario where CCS is absent (See Figure 16) (IPCC, 2005). The oil and gas industry has fairly extensive experience with above ground and injection CO_2 management gained from practices such as acid gas injection, enhanced oil

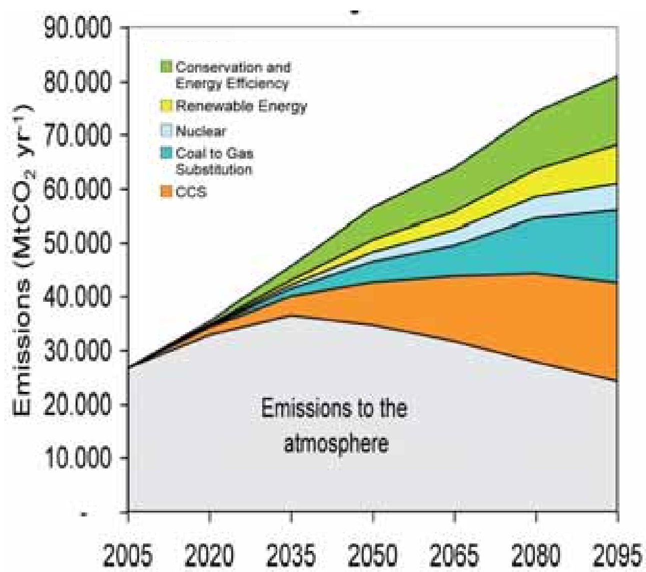

Figure 16: IPCC projects Carbon Capture and Storage Playing Major Role in Emissions Abatement (IPCC, 2005)

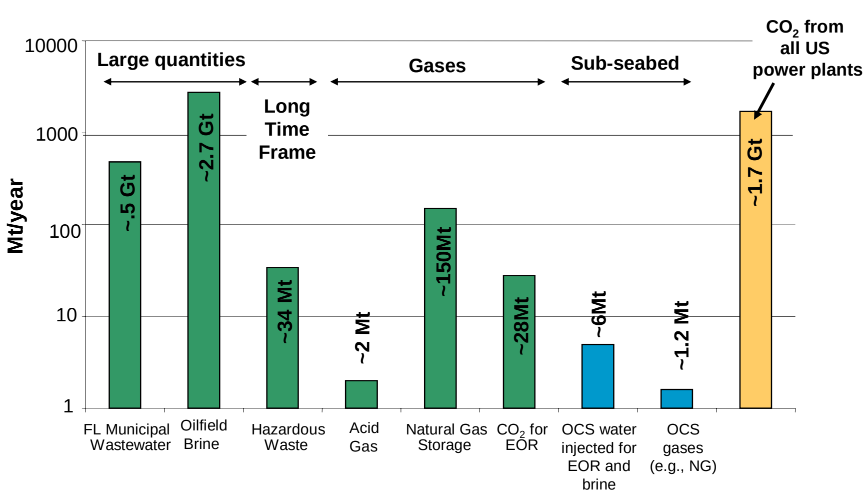

Figure 17: Current Underground Injection Practices vs U.S. Power Sector CO2 (Morgan, 2002)

recovery, natural gas storage, and CO_2 transport (See Figure 17). Thus, the remaining scientific questions about the long term viability of sequestration focus on subsurface issues that are poorly delineated by past experiences. These remaining questions include: How well do we understand storage mechanisms? What is the likelihood of CO_2 escape from injection sites? And what are the associated risks? How would leakage be detected? What rate of leakage eliminates benefits of CCS? How will injection sites be certified and guaranteed? Who will monitor and verify subsurface CO_2 storage? Large scale demonstration projects are critical to the successful resolution of these remaining issues, deployment of CCS, and development of a regulatory framework.

Though CO_2 can be separated and captured more cost-effectively from a gasification-based power plant than from a conventional PC power plant, no existing IGCC power plant currently captures CO_2. However, experience with CO_2 capture technology has been gained in other industries such as hydrogen, ammonia, synthetic liquid fuels production and purification of natural gas. These processes typically have vented CO_2 to the atmosphere; however, the same technology (physical absorption of the CO_2 by a solvent) could be employed in CO_2 capture from a gasification-based power plant (Stephens, 2005).

Adding capture technology to a gasification-based power plant entails more than a simple modification: not only is the addition of CO_2 capture equipment required, but precombustion CO_2 removal increases the hydrogen content of the syngas, altering the design requirements for the gas turbine. Precombustion CO_2 capture also changes the characteristics of optimal syngas clean-up processes and increases energy (Stephens, 2005). The non-trivial changes required to incorporate CO_2 capture suggest that consideration of future CO_2 capture capabilities should play a role in planning from the initial stages to enable cost-effective future modifications.

Two means of including consideration of CO_2 capture in early planning are proposed here. First, a conceptual plan for future CCS-enabling retrofits could be required in the initial planning stages. This requirement would not entail any actual changes in the construction of the facility, but it would introduce consideration of future CO_2 CCS capability into the design of the without adding significant costs. Alternatively, allocation of sufficient space in the facility to accommodate the CO_2 capture equipment and resizing of some components to allow maintenance of power levels could be required. This would entail more significant preinvestment, estimated to increase capital costs by about 5 percent (Stephens, 2005).

However, since regulatory and economic incentives for CCS have not yet developed, the rationale for requiring CCS for coal gasification installations is debatable. In the short term, it may be most productive to focus on implementing coal gasification, perhaps with conceptual plans for future CCS-enabling retrofits, while developing CCS experience in demonstration projects. At present carbon management policies are not strong enough to incentivize CCS; however, the potential for participation in CDM agreements based on decarbonizing coal may become attractive. Alternatively, partial decarbonization of coal and CCS could be conducted as an acid gas management strategy in conjunction with synfuel production. However, the significant costs of incorporating CO_2 CCS require additional regulatory or financial incentives extending beyond support for gasification technology for integrated projects incorporating both coal gasification and CCS (Stephens, 2005).

Achieving Vehicle Fuel Efficiency: The CAFE Standards and Beyond

Abstract: As a series of political objectives converge and call for enhanced domestic automobile fuel efficiency, it is time to reassess the United States Corporate Average Fuel Economy (CAFE) standards and compare future options for limiting gasoline consumption. Unlike the situation in 1975 when CAFE standards were first imposed to limit America's oil dependence, now the greatest motive is to curb greenhouse gas emissions. Because climate change is necessarily a global issue, the developing world must work with the United States to enhance automobile fuel efficiency as part of a greater effort to promote sustainable development. This paper uses China to demonstrate the challenges faced by developing countries and also studies the particular opportunities China represents as the world's fastest growing automobile market. The paper concludes with four main recommendations for the United States and China: rework minimum fuel efficiency standards, raise the gasoline tax, implement a feebate system and create a binding bilateral agreement between the United States and China to achieve these policies.

Ben Steiner
Professor Denise L. Mauzerall
May 10, 2006

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Executive Summary

Automobile fuel efficiency is one of the few issues in the greater global warming debate where stricter regulations are politically feasible because of the convergence of other policy goals. In particular, the United States' massive reliance on foreign oil and the coming crunch of global oil supplies have politicians concerned about energy security calling for increased automobile fuel efficiency. In addition, environmentalists have long sought more efficient vehicles and there is also a growing awareness among segments of the population of the threats caused by increased greenhouse gas emissions. Polls consistently show that the US population supports higher fuel efficiency rates by a two to one ratio and that there is growing support for an increase in the federal gas tax even as sales of gas-guzzling vehicles remain high. Further, fuel efficiency is one of the few areas in the climate change debate where the government has a history of regulation that can easily be relied upon as a basis for new standards. Finally, the transportation sector accounts for 23% of carbon dioxide emissions worldwide, so an increase in automobile fuel efficiency would significantly affect carbon concentration in the atmosphere.

The current fuel efficiency situation in the United States is largely defined by the Energy Policy and Conservation Act, which established Corporate Average Fuel Economy (CAFE) standards for 1978-1981 and 1985 with the goal of doubling total fleet fuel efficiency by 1985 at 27.5 mpg. Unwilling to impose a gas tax in addition to already high oil prices in the midst of the Arab Oil Embargo, the government chose instead to mandate minimum fleet fuel efficiency levels. The NHTSA which currently administers the CAFE standards, defines them as the "sales weighted average fuel economy, expressed in miles per gallon, of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating of 8,500 lbs or less, manufactured for sale in the United States, for any model year." (NHTSA, 2006) Unfortunately, these standards have not been significantly raised since 1984 and are in need of reform.

On the other hand, China first passed fuel efficiency regulations in 2004 but the laws are already stricter than those on the books in the United States. The Chinese regulations set varying standards for automobiles in different weight classes that by 2008 will be as high as 43 mpg for the lightest vehicles. Unlike the CAFE standards, the Chinese regulations mandate that all vehicles as opposed to all fleets meet their weight class' standard. Though these standards are obviously a step in the right direction, they are still lower than levels in the EU and Japan and should be reformed along with the American regulations. The Chinese automobile market is predicted to grow to be the world's largest by 2020, making China's current choices on automobile fuel efficiency standards among the most important in determining atmospheric carbon concentrations over the next century.

This paper recommends four major policy overhauls to improve fuel efficiency in both the United States and China. First, fuel efficiency standards in both countries should be increased to 36 mpg by 2015 (around a 40% increase for both countries) as outlined in the 2002 McCain-Kerry fuel efficiency proposals. This should be a fleet wide standard with tradable credits so improvements can occur at least cost. Second, though politically difficult to achieve in both the United States and China, a higher gas tax would curtail unnecessary driving and reduce fuel consumption while raising automobile fuel efficiency. This paper recommends that both the United States and China impose gas taxes so that the average tax burden per gallon of gasoline is $1.20. This is the most economically efficient option as it would incorporate the externality costs of gasoline consumption. Third, both nations should implement a feebate system that subsidizes highly fuel efficiency vehicles with taxes raised on low emissions ones, eliminating market failure by bring total gasoline lifecycle costs to the fore-market. Finally, the United States and China should commit to a bilateral agreement which obligates both countries to implement these policies in unison and so solves the free rider problem that each individual country faces in its effort to curb automobile carbon emissions.

The Case for Increased Fuel Efficiency

The challenge of sustainable development is to “meet the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Report, 1987). This is achieved by linking the processes of economic growth and social reform with the constraint of environmental protection, which form the three "interdependent and mutually reinforcing pillars" of the theory, to ensure that progress today does not come at the cost of environmental degradation tomorrow (World Summit, 2005). Unfortunately, the achievement of these three components is increasingly in opposition. As more of the world’s inhabitants are able to attain a quality of life previously available only in the developed world, the strain on international resources is growing. Fundamentally, the world is stuck between a commitment to support the development of the least advantaged countries and a practical need to ensure the protection of the environment and its natural resources for years to come.

Most central to the tenets of sustainable development is the idea that the earth cannot support economic growth worldwide as it has been practiced in the developed world since the industrial revolution. Instead, the population of the world will need to start making hard decisions about who should be able to grow, how and at what cost? These questions, in turn, relate back to greater issues of justice. Intergenerationally, how much should future disutility be weighed against current utility and how much can we rely on technological progress to eliminate the problems we are pushing off for a future generation to solve? Intra-societally, how should the benefits of development be allocated within a nation and inter-societally, how can we limit the use of environmentally damaging technologies in the developing world when the developed world used and is continuing to use those same technologies to generate growth? This paper aims to tackle a part of one of these problems: how does the world limit automobile greenhouse gas emissions while promoting increased automobile ownership in the developing world?

One of the gravest threats to sustainable development worldwide is the growing presence of greenhouse gases in the atmosphere. Since 1955 carbon emissions have more than tripled from slightly less than two billion tons emitted per year to greater than 7 billion tons annually. These rates are expected to double by 2055 in the absence of limiting action (Socolow, 2006). As a result of these emissions, the concentration of CO_2 in the atmosphere has risen from 310 parts per million (ppm) to 380 ppm in the last 50 years and will rise to 850 ppm based on current estimates by 2055 (Socolow, 2006). Global temperatures have already risen around one degree Celsius and could rise an additional 10 degrees within the next half-century because of this dramatic increase of carbon in the Earth's atmosphere (Socolow, 2006).

The United States is the greatest culprit, releasing a quarter of the world's CO_2 emissions despite representing only 5% of its citizens. Ninety-eight percent of these CO_2 emissions can be traced to the burning of fossil fuels. In the United States fossil fuels are used for transportation (32%), industrial processes (32%) and the commercial and residential sectors (36%) (Energy Information Administration, 1998). Internationally, transportation is responsible for 23% of greenhouse gas emissions, but this value is expected to rise as cars become economically viable for millions of citizens of developing countries (Socolow, 2006). Therefore, a reduction in automobile carbon emissions would significantly impact national and global greenhouse gas emissions and is certainly an important part of the management of global climate change.

There are a number of ways to limit automobile carbon emissions, the most effective being the introduction of cars which are driven with non-carbon containing or carbon neutral energy sources. But barring unpredicted scientific breakthroughs, the internal combustion engine with the possible addition of hybrid technology will likely remain the most widely used motor of individual transportation for the next two decades, necessitating continued reliance on fossil fuels (Socolow, 2006). This paper aims to find the right mix of policy incentives to make consumers and producers willing to drive and produce more fuel efficient automobiles as defined by reducing carbon dioxide emissions per vehicle-mile.

Automobile fuel efficiency is a good place to begin the effort to limit greenhouse gas emissions because several different policy objectives independent of climate change push for decreased consumption of oil. In particular, politicians concerned about the national security implications of the massive importation of Middle Eastern oil, economists concerned about the importation's effect on the current account deficit, and public health experts concerned about the effect of automobile exhaust on cancer rates and respiratory disease all recognize harms in the nation's consumption of oil (Collina, 2005). For these reasons, the public has consistently supported efforts to mandate higher fuel efficiency by a two to one ratio even as they purchase inefficient gas-guzzling vehicles (Public Citizen, 2002). Finally, fuel efficiency is one of the few areas in the climate change debate where the government has a history of regulation which it can rely upon to legitimize its call for fuel efficiency and utilize as a mechanism of change.

Current State of US Automobile Fuel Efficiency

CAFE Regulation and Other Policies

The Arab embargo of 1973-1975 and the consequent trebling of the price of crude oil first displayed America's reliance on cheap foreign oil. A net oil producer for most of the twentieth century, America developed an appetite for large, over-powered and gas-guzzling vehicles. New car fuel efficiency had declined from a high of 14.8 miles per gallon (mpg) in 1967 to 12.9 mpg in 1974 as America's domestic oil production was gradually replaced by Middle Eastern imports (Bamberger, 2005). When the Arab exporters turned off the tap to protest the West's support of Israel in the Yom Kippur, American consumers faced skyrocketing gasoline prices, mile-long queues at gas stations and a new economic evil in stagflation.

America and its allies responded with a variety of largely permanent measures to reduce oil dependency. In 1974 Richard Nixon apointed William Simon the nation's first "energy czar" and in 1977 a cabinet level Department of Energy was created. Efforts were split between finding new sources of dependable production, largely met through offshore drilling in the North Sea and enhanced recovery of old oil fields, and maximizing end-use efficiency. The federal government launched a sophisticated advertising campaign to promote more efficient energy use, led by the Advertising Council tagline "Don't be Fuelish." The National Highway Traffic Safety Administration (NHTSA) targeted automobile fuel efficiency by immediately reducing the maximum speed on the nation's highways to 55 miles per hour, unintentionally reducing traffic fatalities 23% between 1973 and 1974 (Bamberger, 2005). Though this national speed limit was eventually repealed in 1995, a more important effort to mandate minimum fuel efficiency levels for the nation's automobile fleet continues till today.

The Energy Policy and Conservation Act established Corporate Average Fuel Economy (CAFE) standards for 1978-1981 and 1985 with the goal of doubling total fleet fuel efficiency by 1985 at 27.5 mpg (NHTSA, 2006). Unwilling to impose a gasoline tax on top of already high oil prices, Congress chose instead to mandate minimum fleet fuel efficiency levels. The NHTSA which currently administers the CAFE standards, defines them as the "sales weighted average fuel economy, expressed in miles per gallon (mpg), of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating (gvwr) of 8,500 lbs or less, manufactured for sale in the United States, for any model year" (NHTSA, 2006).

Minimum fuel efficiency standards for cars and light cars are set at different levels and so the definitions of these two types of automobiles are of critical importance. "A passenger car is any 4-wheel vehicle not designed for off-road use that is manufactured primarily for use in transporting 10 people or less. A light truck is any 4-wheel vehicle which is designed for off-road operation (has 4-wheel drive or is more than 6,000 lbs. gvwr and has physical features consistent with those of a truck); or which is designed to perform at least one of the following tasks: transport more than 10 people; provide temporary housing; provide open bed transport; permit greater cargo-carrying capacity than passenger-carrying volume; or with the use of tools can be converted to an open bed vehicle by removal of rear seats to form a flat continuous floor" (NHTSA, 2006). This definition clearly leaves great discretion at the hands of the manufacturer to define its vehicles as trucks or cars. Many sport utility vehicles (SUVs) produced today which never leave the suburbs are classified as light trucks, allowing their manufacturers far greater leeway to meet CAFE standards.

These standards have changed little since the 1985 goal date of the original legislation. Currently each manufacturer's fleet of cars must meet at least 27.5 mpg, while light trucks have to meet a standard of 20.7 mpg, rising to 22.2 by 2008. The mandated fuel efficiency level for cars has been stable since 1989 as decreed by Congress, after dipping slightly down to 26.5 mpg in the late 1980s when Reagan era economists pushed for greater free market control. On the other hand, light truck standards have been slowly creeping up since the original 1975 legislation at the discretion of the NHTSA which is ordered to place them at the "maximum feasible level" as defined by Congress to take into “consideration four factors: technological feasibility; economic practicability; the effect of other standards on fuel economy; and need of the nation to conserve energy” (NHTSA, 2006). NHTSA has followed this legislation by increasing minimum light truck fleet efficiency very conservatively from 17.2 mpg in 1979 to 22.2 in 2008 (NHTSA, 2006). Currently the NHTSA is legally obligated to set standards for both cars and trucks by the feasibility standard, but in practice the agency has publicly stated a willingness to protect domestic manufacturers, which disproportionately produce fuel inefficient cars, explaining the NHTSA’s wariness to increase standards (NHTSA, 2006).

Manufacturer fleet efficiency is calculated in a slightly confusing fashion. First, 30% of car models are randomly selected by the Environmental Protection Agency (EPA) for fuel efficiency testing. These vehicles are chosen off the lot and their exhaust is monitored for CO_2 levels while driven in controlled conditions to test for “laboratory fuel efficiency.” Any discrepancy between manufacturer stated fuel efficiency and the value the EPA finds is punishable (NHTSA, 2006). Manufacturers test the remaining 70% of vehicles. Then the fuel efficiency ratings of each model are averaged together, weighted by their sales volume, to create three fleet averages for each manufacturer. Each of these three fleets, domestic cars, imported cars and light trucks, for each of the manufacturers must meet its own standard (NHTSA, 2006). Domestic cars are defined as having over 50% of their total components manufactured in the United States; anything less is counted as an imported car. Finally, dual fuel vehicles that can run on gasoline or another non-refined crude oil fuel (ex. ethanol) have special rules that enable them to report significantly higher efficiency ratings (NHTSA, 2006).

The penalty for non-compliance is currently $5.5 for every 0.1 mpg under the standard per vehicle (NHTSA, 2006). So if a manufacturer’s imported car fleet of 100,000 cars only makes 27 mpg, the company must pay a fine of (5.5 * 5 *100,000) = $2.75 million. Over the history of the program domestic and Japanese manufacturers have never paid a penalty while some luxury European producers have treated the fee as simply the annual cost of doing business in America. Civil penalties for the CAFE standards have exceeded $618 million over the life of the program (DeGaspari, 2004).

Problems with Current Regulation

The most obvious and important disappointment of current automobile fuel efficiency regulation has been its inability to increase total fleet fuel efficiency significantly since 1985. Overall fleet fuel efficiency in the United States peaked in 1987 at 26.2 mpg but has decreased since to 25.2 mpg today (Gerard et al., 2003). Further, United States crude oil consumption has risen from its 1982 low of 6.2 million barrels a day (mmbd) to 9.1 mmbd as of October 2005 (CRS, 2005). In short, the CAFE program has failed to wean Americans off oil. Four main elements drive this failure to significantly affect fossil fuel consumption and continue to limit the effectiveness of CAFE standards.

First, Americans continue to buy more cars and drive them more miles as economic growth increases household incomes and population growth increases the number of potential drivers. Just as economic growth is leading to increased demand for personal transportation in the developing world, higher incomes have led to greater demand for automobiles in America. The number of vehicles on the road has increased from 147.5 million in 1988 to 191 million in 2005 (Energy Information Administration, 2006). Further, the number of miles each car is driven per year has increased from 10,200 miles to 12,040 miles (Energy Information Administration, 2006). These changes are attributable to the decreased marginal cost of driving (partially the result of higher fuel efficiency, as well as greater reliability), the greater sprawl of suburbs around urban areas and the direct effect of increased income on driving consumption.

Second, Congress has shown a continued interest in limiting the NHTSA's ability to raise fuel efficiency standards as new technologies make higher fuel efficiency levels feasible. In 1994 NHTSA initiated the process of raising CAFE standards by issuing a notice of proposed rulemaking on light duty trucks. Congress responded in fiscal years 1996 through 2001 by outlawing any expenditure in each year by the Department of Transportation, which oversees the NHTSA, on studying changes of CAFE rules thereby freezing the standards (Bamberger, 2005). In 2001 Congress changed its mind and agreed to a one-time National Academy of Sciences (NAS) report on the standards to be submitted June 30, 2001. That reported advocated an expansion of the program and recognized a potential 40% improvement in car and light truck fuel economy in the next 10-15 years using existing and available technology with zero cost over the lifecycle of the vehicle (Portney, 2002). Following this report, Senators McCain and Kerry agreed to jointly sponsor a bill that would mandate a 36 mpg minimum fuel efficiency standard across the entire automobile fleet by 2015, but the Senate instead voted for the NHTSA to study CAFE standards again (Kerry, 2002). NHTSA proposed a more modest increase in light truck fuel efficiency, but this too was limited by a bill sponsored by Senator Miller to allow "pickup trucks" to remain at the old 20.7 mpg standard (Bamberger, 2005). Politicians generally oppose any enhancements of the CAFE standards because of intense lobbying by the oil or automobile industries who claim they will be disproportionately affected compared to their foreign competitors. In particular, the big three Detroit automakers, which are already in bad financial shape, are almost totally reliant on profits from gas-guzzling SUVs; some politicians feel that more stringent standards would push the industry off the edge of the cliff and into bankruptcy. Surveys of citizens, on the other hand, show that even rural, "red state" Republicans strongly favor higher fuel efficiency standards (Public Citizen, 2006).

Current regulation places the passenger car CAFE standard at 27.5 mpg through 2008 and mandates 22.2 mpg for light trucks by that year excluding pickup trucks (NHTSA, 2006). The NHTSA has now mandated new rules for 2009-2011 that break the light truck segment into six categories as differentiated by footprint, calculated by wheelbase multiplied by track width. Each of these categories will face higher fuel efficiency requirements and the smallest light trucks will actually be required to surpass passenger car fuel efficiency minimums (NHTSA, 2006). These rules are a step in the right direction, but there is no guarantee Congress will not intervene again to limit their effectiveness.

Third, the dramatic growth in the light truck portion of the market has led to a decrease in overall fleet fuel efficiency. In 1979 total sales volume was 1.16 million for light trucks and 10.75 million for passenger cars. By 2004, the order had flipped and light trucks surpassed passenger cars in sales volume 8.38 million to 8.02 million (Finneran, 2005). Surveys suggest that consumers prefer the roominess of SUVs, the largest component of the light truck segment, and their 4-wheel drive capability (Bamberger, 2005). Further, lower fuel efficiency standards may have allowed manufacturers to place the money they would have spent on efficiency for a passenger car to invest in superior performance for a SUV. In other words, the lower CAFE standards for light trucks may have actually made them more appealing to consumers as compared to cars. Whatever the reason, the dramatic migration from passenger cars to light trucks has affected total fleet fuel efficiency. As of 2005 the total passenger car fleet operated at 30.0 mpg, while the total light truck fleet operated at 21.8 mpg (Finneran, 2005). Clearly, a shift from the former to the latter will decrease total automobile fleet fuel efficiency.

Finally, CAFE standards fail to address the underlying market dynamics that lead consumers to purchase gas-guzzling vehicles even as they appear to support higher fuel efficiency in polls. One of the major reasons fleet fuel efficiency levels remain so low is that consumers fail to adequately consider fuel efficiency savings when purchasing a new vehicle. The 2001 NAS study concludes that consumers only consider the first three years of fuel savings when choosing a new car, though the average vehicle's life is 14 years (Portney, 2002). The result is a 60% underestimation of fuel savings, creating a marketplace that only demands fuel efficiency technology up to 40% of the breakeven price. This analysis is reflected in the internal documents of auto companies: Honda of America, for example, models consumer preferences so that they only consider fuel savings potential over the first 50,000 miles of an automobile (Portney, 2002). A result of this irrationally short payback period is the cost savings potential of fuel efficiency technologies on the margin. In other words, currently available technology could raise fuel efficiency and lower the total lifecycle price of vehicles. This technology is proven effective and already being used; higher fuel efficiency regulations in Europe show that the Unites States could easily increase its fleet fuel efficiency 40% with no lifecycle cost increase (Portney, 2002). David Greene sums up the data when he explains "there may be an important market failure with respect to consumers' decision-making about fuel efficiency" (Greene et al., 2005). So long as the market fails to demand fuel efficiency technologies, no level of government regulation will succeed in forcing them on the public. The problem is not the technology, but the economic incentives.

Another major problem with current fuel efficiency regulations is their detrimental effect on passenger safety. The 2001 NAS report attributed 1,300-2,600 additional fatalities to the decrease in average vehicle weight concurrent with the increase in CAFE standards in the 1970s and 1980s (Portney, 2002). The working theory explaining the fatalities is that manufacturers cut vehicle weight to meet the rising minimum fuel efficiency levels through using lighter and weaker materials that increased fatality risk. Though this was certainly not the only way to comply, it may have been the cheapest option available to manufacturers. Robert Noland's literature review confirms this analysis that in the "early years of the CAFE standards there was an increase in fatalities associated with improvements in fuel efficiency" (Noland, 2004). Noland also finds, however, that the results are "consistent with suggestions that increased bimodal weight distributions in the vehicle fleet explain much of the effect on fatalities of changes in the fuel efficiency standards" (Noland, 2004). In other words, safety is not directly harmed by lighter cars, but rather by the greater weight difference between light and heavy cars. The current CAFE regulations offer manufacturers incentives to either raise vehicle weight above 6,000 lbs. to gain a light truck classification or to lower weight as much as possible to improve fuel efficiency within the passenger car classification. The overall effect has been a bimodal distribution of vehicle weights which has led to increased fatality risk for drivers of the lighter automobiles. Therefore, current efforts to increase light truck CAFE standards relative to passenger car standards may increase safety by narrowing the weight gap between light trucks and passenger cars.

Finally, current fuel efficiency efforts in the United States fail to address the growing international complexity of the issue, relying on a purely domestic approach that will lose effectiveness as the United States' dominant share of the automobile market subsides. CAFE standards and the other energy conservation efforts of the 1970s and 1980s were enacted primarily to secure America's energy independence from Middle Eastern producers. Though energy security still plays a role in justifying the fuel efficiency standards, the primary current challenge is to curb global transportation greenhouse gas emissions. It does not matter whether CO_2 is released in California, China or Indonesia; the effect on the global climate remains the same. Projections indicate that though the United States is currently responsible for about half of global personal transportation greenhouse gas emissions, the developing world will quickly become the largest contributor. As China and India join the global economy their demand for cars is bound to increase dramatically. Goldman Sachs predicts that by 2050 one third of all vehicles will be operated in these markets (Asia Times, 2005). Unless more stringently regulated now, these vehicles are also likely to be among the least efficient and thus the largest contributors to greenhouse gas emissions. Therefore, any effort to decrease automobile greenhouse gas emissions must incorporate the developing world or risk failure. This paper will briefly analyze the situation in China as an example for potential policy options for the developing world.

Current State of Chinese Automobile Fuel Efficiency

As the world's most populous country, China's rapid economic growth poses grave dangers to the global effort to curb carbon emissions. The choices China makes now in how it develops its energy services infrastructure are among the most crucial in determining global greenhouse gas emissions over the next half century. Unfortunately, though Chinese government officials recognize the existence of human influenced global warming and its potential threat to China, they do not rank curbing emissions as high a priority as most of the developed world does. Nonetheless, the convergence of other policy goals may allow the Chinese to become a leader in automobile fuel efficiency regulation and consequently an ally in the effort to curb emissions. In particular, China is very concerned about its growing reliance on foreign oil and the environmental effects of a continued increase in the number of personal automobiles.

China is now the world's second largest consumer of crude oil and the third largest importer after the United States and Japan (He et al., 2005). Oil demand has increased 40% since 2001 to 7 mmbd and is expected to double by 2025 to 14.2 mmbd (Washington Times, 2006). A 2003 internal study by the Chinese government concluded that this growth in consumption cannot be met with domestic production and that Middle Eastern oil imports will dramatically increase, equaling half of oil consumption by 2007 (China Daily, 2003). Transportation is one of the central causes of this dramatic increase as passenger and freight road transportation have grown 8 and 15 times, respectively, over the last twenty years and automobiles have become a dominant part of the transportation infrastructure (Wang, 2000). This trend will increase over the next twenty years as the three primary drivers of increases in vehicle fleets are all present in China: population growth, urbanization, and economic growth (Walsh, 2003). These factors are predicted to lead to an increase in China's vehicle fleet to 120 million automobiles by 2030 and to make it the world's largest market for new automobiles by 2025 (He et al., 2003) (Automotive Industries, 2004). Further Kebin He explains, "even though the share of oil consumption by China's road transport out of its total oil consumption is much lower than that in developed countries, the share in China will certainly increase in the future" (He et al. 2005) .

China addressed this rapid growth in the transportation sector's oil consumption in 2004 by imposing the country's first fuel efficiency standards on new automobiles. The most critical difference with the CAFE standards is that the Chinese regulations apply to every model, not each manufacturer's fleet, so a company cannot offset a gas-guzzling model with a fuel efficient one. To allow for heavier and less naturally fuel efficient vehicles, the Chinese regulations apply different standards to sixteen different weight classes using a system similar to the reformed CAFE light truck standards but substituting weight for footprint. In addition, manufacturers must separately meet the standards for their standard and automatic transmission automobiles. The standards applied immediately to new cars in model year 2005 at levels ranging from 19 mpg for the heaviest trucks to 38 mpg for the lightest cars and they are scheduled to increase to 21 mpg and 43 mpg, respectively, in 2008 (Richard, 2005). The standards are stricter than their equivalents in the United States but less stringent than regulations in Europe and Japan. An analysis by the World Resource Institute finds that the Chinese standards represent a 5% increase over current United States automobile fleet fuel efficiency and will be a 10% improvement in 2008 (Sauer, 2004). One of the largest remaining issues is uncertainty over whether and to what degree Chinese authorities will enforce the regulations. Although all manufacturers have met the 2005 standards, it is unclear whether China will impose the 2008 regulations on time and also how the government will penalize non-compliance (Sauer, 2004). These issues will become increasingly more pressing as 2008 approaches and manufacturers face difficult choices between pulling vehicles from their lineups and investing in new fuel efficiency technology. As of now, General Motors and DaimlerChrysler both appear unlikely to meet the higher regulations (Sauer, 2004).

Policy Recommendations

Because the current automobile fuel efficiency situation is much the same in the United States and China now that China has imposed fuel efficiency standards, this paper's first three recommendations are the same for each country—a reworking of fuel efficiency standards, an increase in the gas tax, and the imposition of a feebate system. Much of the current literature on fuel efficiency focuses on choosing among these options. The following analysis will show the relative advantages and drawbacks of each, but I think it is foolish to pursue only one solution to the problem. I contend that each of these three policy options has unique merits in either its feasibility or efficacy and that because of this each mutually reinforces the others to strengthen all three policies' effect on fuel efficiency. Therefore, I advocate all three policies but recognize that each one individually achieves the majority of the benefits of the total package. The final recommendation tackles the international aspect of the issue by calling for a bilateral agreement between the United States and China to impose these new policies together. Representing the world's largest and fastest growing automobile markets, the United States and China could implement a *de facto* global standard for automobile fuel efficiency if they acted together in implementing this paper's first three proposals. Further, a bilateral agreement would force both countries to comply with the plan to improve fuel efficiency and so would solve the free rider problem that each individual country faces in its effort to curb automobile carbon emissions.

First, the United States should raise and reform CAFE standards and suggest improvements in Chinese fuel efficiency standards. For all their problems, CAFE standards have a crucial benefit in their current existence. Unlike the other options to be explored later, the CAFE system has a functioning bureaucracy and series of rules that can be easily expanded and wielded to enforce higher fuel efficiency standards through direct regulation of manufacturers. Further, the public has shown strong support for CAFE standards since their inception in the 1970s and Congress has shown a recent willingness to stiffen them. Unlike passing a gas tax or feebate system, reforming CAFE is politically possible, and thus must be seen as the first option in increasing fuel efficiency. Similarly, China's recent fuel efficiency regulations show that imposing standards is politically feasible there even as China tries to enhance personal ownership of automobiles. Further, the recent nature of the legislation and the scheduled 2008 alterations of it offer an opportunity to institute the reforms I suggest here.

Beyond the political expediency of the option, reforming fuel efficiency standards exclusively enables directly setting minimum fuel efficiency levels, sidestepping consumers who fail to consider total fuel savings over the life of a vehicle. Greene explains that "setting fuel economy standards would be a more effective approach [than increasing the gasoline tax] because regulation circumvents the market failure" of consumers and instead "manufacturers would accurately weigh the costs and benefits of increasing MPG so as to avoid fees and capture rebates" (Greene et al., 2005). Further, CAFE standards guarantee success in achieving whatever fuel efficiency level the government demands. Because the other options indirectly affect consumer behavior by taxing fuel use or fuel efficiency rather than setting efficiency levels, the government cannot easily determine what the exact effect of these policies on fuel efficiency will be. The costs of gasoline and vehicles fluctuate independent of potential taxes. A market based approach would thus result in fluctuating fuel efficiency levels. The only way to guarantee a minimum fuel efficiency level is through instituting standards through a reformed CAFE system and an equivalent in China.

In the United States recently agreed upon rules for a reformed CAFE system in 2009 are steps in the right direction, but they must be followed by a greater transformation that simplifies the standards. Starting in 2009, car manufacturers will have the choice of complying with either the traditional "unreformed" light truck standard of 23.1 mpg, or a "reformed" sliding scale of standards determined by a vehicles' footprint (NHTSA, 2006). These changes will enable the NHTSA to more accurately target specific types of light trucks for fuel efficiency improvements. Small SUVs, which are clearly capable of high fuel efficiency, can be regulated at a higher level than massive cargo hauling trucks that are more difficult to make highly efficient. Further, the change diminishes the incentive manufacturers have to develop a fleet with a bimodal weight distribution as fuel efficiency minimums more smoothly increase as size increases.

Though I believe this effort a strong start, the ultimate goal for fuel efficiency standards should be a unified standard for the entire fleet. Collapsing the passenger car and light truck segments will force manufacturers to deal with the increased popularity of SUVs by either making them more efficient or raising their price to stimulate more passenger car purchases. The imported and domestic fleet distinction should also be removed. Instead, all manufacturers should face a single 36 mpg standard for all of their vehicles by 2015 as suggested by the proposed Kerry-McCain fuel efficiency legislation of 2002 (Kerry, 2002). A 36 mpg target approximates the 40% increase the NAS report found would not increase total vehicle lifecycle costs (Portney, 2002). Further, the plan already has bipartisan support in the Senate and should be used as a starting point for fuel efficiency standards reform. The NHTSA and its Chinese equivalent should set standards for the intervening years ramping up to this fuel efficiency goal. A quick back of the envelope calculation suggests that implementing this plan would ultimately lower gasoline consumption by 25% in the United States and China once the car infrastructure totally transitions to the new standard over a period of fourteen years assuming exogenous forces do not affect the market (Parry, 2005).

To make sure fuel efficiency is increased resourcefully, the new standards should allow credit trading between car manufacturers. For example, if in 2015 the Nissan fleet of 100,000 new vehicles sold in China exceeds the 36 mpg standard by 1 mpg, Nissan should be able to sell this excess fuel efficiency to Kia whose fleet of 50,000 vehicles averages 2 mpg below standards. Kia could then claim the excess efficiency credits bought from Nissan when complying with fuel efficiency standards. Though manufacturers can trade credits between models and model years under the current CAFE system in the United States, they are unable to trade them between each other, and in China companies can't even trade credits between models because every model must meet the standard. Credit trading would allow the marketplace to increase fuel efficiency only where it is cheapest to do so, minimizing the cost of fuel efficiency increases. The Congressional Budget Office finds that allowing credit trading on a theoretical 10% increase in CAFE standards would save $600 million in total welfare annually (Austin, 2003).

To ensure that companies trade credits rather than accept annual penalties as certain luxury European manufacturers currently do, the penalty rate should quadruple to $22.00 per 0.1 mpg over the standard per vehicle. This rate is roughly equivalent to the inflation adjusted original 1975 penalty and should be effective in promoting trading rather than non-compliance (NHTSA, 2005). All manufacturers should be forced to ensure that their fleet complies with standards by either increasing its fuel efficiency or buying credits from a fleet that exceeds the standard. If significant numbers of manufacturers continue to fail to comply the penalty should be raised until virtually all manufacturers meet the standard through innovation or trading.

Finally, the NHTSA and its Chinese equivalent should set up committees that verify that design changes made to reach the higher standards do not affect vehicle safety. Reworking standards may improve safety in the United States by eliminating the weight gap between light trucks and passenger cars. On the other hand, manufacturers may be tempted to improve efficiency by decreasing vehicle weight below a safe level. Therefore, if the NHTSA or Chinese safety committee deems a new, lighter vehicle design detrimental to passenger safety, the manufacturer should be punished by removing the vehicle from its fleet fuel efficiency calculation provided that the vehicle surpasses the fuel efficiency standard.

Second, The United States should raise the federal gasoline tax so that the total tax burden averages out to $1.20 a gallon across the country and should suggest raising gas tax rates in China to similar levels. Despite their unpopularity, excise taxes on gasoline have a long history in American politics. Oregon enacted the first tax on motor fuels in 1919 and by 1932 every state and the District of Columbia had imposed a levy of between two and seven cents on each gallon pumped within their borders. The federal government followed suit in that same year with a one cent tax to address a budget shortfall caused by the disappearance of liquor taxes during prohibition (Talley, 2000). Currently, total gasoline tax rates vary by state from 26.4¢/gallon in Alaska to 53.5¢/gallon in Hawaii with a national average of 42¢/gallon (API, 2002). On the other hand, China has never had a fuel tax and currently charges no more than the VAT and consumption tax it imposes on all consumer purchases. However, there is increasing pressure to levy one at around 60¢/gallon to ward of a potential energy crisis by easing the growth in gasoline consumption (Dashan, 2004). By way of contrast, the Netherlands imposes a tax of $3.25/gallon exclusive of their 19% VAT, making two thirds of the price of gasoline directly attributable to the Dutch government (Wikipedia, 2006). Most of the developed world has tax rates close to the Dutch model, demonstrating the considerable room for growth in American and Chinese gas tax rates.

The externality costs born by society of gasoline consumption should be incorporated into the price of gasoline through greater taxation. In the most complete study to date, Ian W.H Parry and Kenneth Small determined what they termed the "proper rate of gasoline taxes" by estimating the cost per vehicle mile of various externalities, converting these costs to a per gallon basis and accounting for the endogeneity of fuel economy, that is that higher taxes will lead consumers to purchase more fuel efficient vehicles in addition to driving fewer miles (Parry, 2005). Parry and Small conclude that the market would allocate resources most efficiently if the United States set gasoline taxes at $1.01/gallon (Parry, 2005). These rates include a 6¢/gallon charge for greenhouse gas emissions derived from a theoretical $25 tax on each ton of carbon emitted. The other major externality costs include, in order of importance: traffic congestion, traffic accidents and local air pollution (Parry, 2005). Although the study suggests that current gasoline taxes are too low, it does not even consider the significant externality cost inherent in the United States' dependence on foreign oil and, further, it uses a carbon tax rate half of the conventional value of $50/ton emitted. For these reasons, I view this $1.01/gallon estimate as the lower bound of an efficient gas tax estimate and advocate a slightly higher $1.20/gallon rate which incorporates a 13¢/gallon charge for energy security externalities as well as a 12¢/gallon charge for greenhouse gas emissions which is equivalent to $50/ton of carbon emitted. Though this is only a rough and ready estimate, I find it hard to believe that the energy security costs of gasoline consumption are less than 13¢/gallon when the relative costs of foreign policy entanglements in the Middle East are compared to the combined costs of congestion and traffic accidents (responsible for 29¢/gallon and 24¢/gallon respectively) (Parry, 2005). I further claim that the externality costs of gasoline consumption in China are comparable to those in the United States so that a $1.20/gallon tax is applicable there as well. Therefore, gasoline taxes in the United States can be nearly tripled and in China they should be enacted for the first time at $1.20/gallon. The impact of this tax on gas consumption would depend on the price of gasoline, but a back of the envelope calculation suggests that in the United States the imposition of the tax in addition to the recent increase in the price of gasoline from ~$1.80/gallon to the current $3/gallon would decrease gasoline consumption in the long-term by 42.2% as compared to 25.3% if the tax were not implemented (Parry, 2005).

A major benefit of imposing a gasoline tax rather than improving fuel efficiency through directly raising fuel efficiency standards is the elimination of the "rebound effect" which leads to increased driving when the marginal cost per mile decreases. By increasing the fuel efficiency of vehicles, a higher standard would lead consumers to choose to drive more because each additional mile is cheaper as fuel costs per mile decrease. This effect is variously estimated at between 10% and 40% but is generally found to hover around 20% (Van Dender, 2005). Therefore an increase in fuel efficiency to 36 mpg from the current fleet-wide 25.2 mpg in the United States would only reap 80% of the benefits in fuel consumption shrinkage and would be equivalent to an increase to 33.8 mpg if driving habits remained the same (Finneran, 2005). Increasing the gasoline tax directly raises the price of vehicle travel and therefore is a more effective mechanism to reduce gasoline consumption and hence greenhouse gas emissions. Further, a gasoline tax affects all drivers immediately while an increase in fuel efficiency standards only affects drivers of new cars. Therefore, a gasoline tax is a far more effective mechanism in the near-term to decrease gas consumption. A recent joint study by the Century Foundation and Brookings Institution confirmed these benefits of a tax over direct regulation when they found that imposing a 25¢/gallon increase in the gasoline tax in 1975 would have saved more oil than the entire CAFE system since its inception (Nivola, 2000).

On the other hand, the major drawbacks of a gasoline tax are its political infeasibility and regressive wealth distribution effects. With gasoline prices skyrocketing, Congress is looking into legislation that would subsidize gasoline, not tax it further and suggesting gasoline taxes has long been a road to political suicide. China has also had difficulty in imposing a gas tax as farmers and their supporters have galvanized a populist movement against them (China Daily, 2003). Further, there is a fear that higher gasoline taxes would tend to affect individuals fairly equally across the income spectrum and hence would proportionately hit the poor hardest. Any increase in gasoline taxes could significantly affect the tax burdens of different income classes, making the tax code more regressive unless other taxes are altered accordingly to offset the change. However, a 1991 study by MIT economist James Poterba concluded that "low expenditure households devote a smaller share of their budget to gasoline than do their counterparts in the middle of the expenditure distribution" (Mankiw, 1999). Further, European countries have combined extremely high gasoline taxes with a social structure far more progressive than that of the Unites States by providing tax breaks for the poor through other means. The United States could follow this model if there are concerns about income distribution effects.

Third, the United States and China should implement a feebate system that subsidizes fuel efficient vehicles with revenues raised from fines on gas-guzzling ones. Though enacting a gasoline tax would be effective in increasing the marginal cost of driving and thus pushing greenhouse gas emissions down as drivers choose to drive less, it would not address the market failure where consumers of new automobiles fail to consider the total lifecycle costs of their new vehicle. Instead of discounting the total fourteen year operating costs of a new automobile, consumers seem only to consider the first three years of costs (Portney, 2002). David L. Greene, Philip Patterson, Margaret Singh and Jia Li find that without this irrational decision making the total fleet fuel-efficiency would currently be 32 mpg (Greene et al., 2005).

Therefore, I propose that the United States and China impose a feebate system which eliminates consumer irrationality by pushing total lifecycle costs up the point of purchase. The system would work by setting a subsidy and tax rate for each unit of fuel efficiency a vehicle is above or below the pivot point between subsidized and taxed vehicles. In the system I propose, the government would set this level at $1,000 per .01 gallons per mile (gpm). Therefore, if the pivot point was set at 20 mpg, an automobile that operated at 25 mpg would be subsidized $1,000 and a vehicle that operated at 16.7 mpg would be taxed $1,000. One of the major benefits of this system is that depending on where the pivot is set, the government can make the entire policy a tax, a subsidy, or revenue-neutral. I propose that the pivot point be originally set at the fuel efficiency regulation standard and then raised accordingly each year to ensure revenue-neutrality. This system at $1,000 per .01 gpm would ultimately result in a fleet-wide fuel efficiency of 32.3

mpg, approximating the fuel efficiency level the market would allocate without irrational behavior (Greene et al., 2005). The proposal would result in a 21.6% decrease in annual fuel consumption by 2030 assuming exogenous factors did not affect the market (Greene et al, 2005).

In addition to rectifying a market inefficiency, a feebate system would also provide a constant incentive for innovation in fuel efficiency technology for all manufacturers. Though the reformed fuel efficiency standards explained in this paper offer an incentive to manufacturers already complying with fuel efficiency regulations to continue to improve fuel efficiency so they can sell their credits to non-complying manufacturers, the worth of these credits is dependent on the fuel efficiency level of the total vehicle fleet. If most manufacturers are complying with the standard, then the price complying manufacturers can sell credits for decreases and there is little incentive to improve fuel efficiency. On the other hand, this feebate system sets a price for fuel efficiency improvements at $1,000 per .01 gallons per mile and promotes any improvement in fuel efficiency that is cheaper than this rate. In short, it would lead to greater innovation and fuel efficiency from manufacturers who already meet the fuel efficiency standard and thus have a track record in successfully developing fuel efficiency technology.

These three proposals combined offer very powerful incentives to increase fuel efficiency. Increasing fuel efficiency standards provides a minimum floor for efficiency improvements and is by far the most political feasible option. This proposal offers clear guidelines to manufacturers and guarantees a certain level of success. A higher gas tax rate leads to market efficiency and decreases vehicle miles driven by increasing the marginal cost of driving. Once a car is purchased this proposal is the most effective in limiting greenhouse gas emissions. Further, it has the most immediate effect as it applies to all cars, not only new ones. Finally, a feebate system solves the consumer irrationality issue by pushing total lifecycle costs to the purchase point. This proposal also provides a constant incentive to manufacturers to innovate and develop new fuel efficiency technologies for the future. The final proposal maximizes the effects of these first three.

Finally, the United States and China should agree to a binding agreement to implement these policies simultaneously in both countries and use the revenues raised by

the policies on a joint project to develop more fuel efficient vehicles. If the United States and China opted to work together and implement these policies on a timeline, virtually every car manufactured around the world would have to meet them as these two countries represent the present and future of the automobile industry. Further, an agreement solves two major impediments to progress in the fuel efficiency effort. First, it limits the effectiveness of internal interest groups to limit or alter the policy goals. As time passes and the immediacy of the current oil crunch subsides, oil companies, car manufacturers and other interest groups may be more successful in convincing both the Chinese and American governments to limit policies intended to improve fleet-wide fuel efficiency for their own particular interests. A bilateral agreement backed by the various trade penalties either country can impose on the other commits both nations to the effort and ensures that the policies will be implemented and enforced. Second, an agreement eliminates the free-rider problem. Because greenhouse gas emissions affect the entire earth, the incentive of any one nation to limit its own emissions is not as large as the incentive the entire earth has to limit them. This tragedy of the commons dilemma whereby each country feels no need to limit its own emissions because of their insignificant effect on the total problem leads to inaction and finger pointing. A bilateral agreement between the United States and China would eliminate this problem by committing a good portion of the world to the effort to curb gasoline consumption.

In addition, China and the United States should seize the opportunity this agreement provides to work together in developing more fuel efficient vehicles. In particular, under the agreement the countries should pool a portion of the revenues raised from gasoline taxes and penalties in this plan to fund laboratories investigating further fuel efficiency innovation. Finally, some of this revenue should be allocated to facilitate technology transfer from the United States to China, using the technological expertise and resources of the United States to help China meet and implement the reformed fuel efficiency policies.

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Promoting Public Transportation for Sustainable Development

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WWS 402-S04

I pledge my honor that I have not violated the honor code in writing this paper.

ABSTRACT

This policy proposal will address the issue of public transportation as a means for sustainable development. Transportation is an issue that needs to be addressed because it has two deleterious effects on the environment. One is the effect of vehicle carbon dioxide, CO_2, emissions on climate change and the second stems from other vehicle emissions that cause air pollution leading to negative health effects. These two issues warrant the conclusion that transportation needs to be monitored. Policies can be instituted to mitigate these negative consequences. This report will focus its policy recommendations on promoting public transportation as a means for environmental sustainability. The idea is that increased use of public transportation will lessen the demand for private transportation thereby lowering the number of vehicles on the road and thus lessening global vehicle emissions.

INTRODUCTION

Addressing issues of sustainability allows societies to meet their present needs without compromising the environment for future generations. This policy proposal will address the promotion of public transportation systems as a means for sustainable development. A more sustainable approach to transportation will lead to less environmental damage before it occurs rather than as a reaction to the damage that results from vehicle emissions (Fergusson and Skinner, 1999). There are two important aspects of environmental damage: the first is CO_2 emissions that cause climate change and the second is other emissions that contribute to air pollution and subsequent health effects.

These two problems are exacerbated by the increasing trend for private vehicles. The trend calls for more vehicles on the road which means more vehicle emissions and thus more deleterious environmental effects. If public transportation is used more frequently, this can serve as a way to reduce the number of vehicles on the road and subsequently reduce emissions (Uhl and Anderson, 2001).

Specifically, this report will analyze the United States' transportation systems. Trends in the US transportation sector tend to be 20 years ahead of those in other industrialized countries. In turn, the carbon emissions from the US transportation sector amount to 5% of the global carbon emissions. That amounts to more than those of any other sector in any other country. In fact, the US automotive industry is a key player in the world market and thus is in a good position to initiate change and become a model of best practice (Hardin, 2002).

In addition, an analysis of the public transportation systems in the developing countries, with specific examples from China and India, will be presented. These are important countries to address because they have risen as global economic powers with overwhelmingly large populations. These nations have expanding middle classes with growing needs for better housing, more consumer goods, and better transportation (Lehman, 2005).

China is particularly important because it is a major source of urban air pollution world wide (Zhao et al, 2004). In fact, China is currently the world's second-leading emitter of carbon dioxide and other greenhouse gases (described below) which contribute to global climate change. It is projected to surpass the US and become the world's top emitter by 2020 (Esty and Dunn, 1997). India's CO_2 emissions account for only 2-4% of the world's total but are important to address because India is a country rapidly expanding beyond a billion people who have increasing demands for transportation (Tiwari, 2003). Although per capita CO_2 emissions in India are below a quarter of the world average, the national growth rate exceeds the global rate, which ultimately means an increasing global share of emissions (Tiwari, 2003).

This paper will first discuss how vehicle emissions present an environmental problem. Next the paper will review the current situations in the US and in the developing countries, China and India. The paper will end with policy recommendations aimed at making transportation more sustainable through decreasing vehicle emissions by lowering the trend for personal vehicle travel and replacing this with public transit. Policy recommendations for reaching this goal involve improving current public transportation systems, encouraging the use of public transportation systems, discouraging the use of private vehicles, and changing urban plans and city designs.

THE PROBLEM

Vehicle emissions have two negative effects on the environment: one is global climate change and the other is air pollution and its negative health repercussions. With the increasingly mobile population in the United States and greater numbers of middle class and wealthy individuals in developing countries who can afford private vehicles, these problems are worsening (Tiwari, 2003). Driving one's own car is often considered a benefit of economic success but due to increasingly adverse environmental and health effects related to vehicle emissions, universal car ownership is an issue that can no longer be ignored (Tiwari, 2003).

Climate change is a result of increasing carbon dioxide, CO_2, emissions. The climate change of concern is increasing global temperatures that are attributed to the "greenhouse" effect. The greenhouse effect results from carbon dioxide, the most important of the greenhouse gases[42], which acts like a blanket around the earth, keeping surface temperatures at warm levels. Increasing the CO_2 concentration in the earth's atmosphere effectively adds another blanket which warms the Earth's surface even more (Hare, 1997).

As a result of this warming, world temperatures have risen by about 0.5 degrees Celsius in the past century (Hare, 1997). If the trend of increasing CO_2 emissions continues, scientists project that the global temperature will increase by 3 degrees Celsius in the next century (some US agencies assume an even higher increase of 4-5 degrees Celsius; Suess, 1993). The results of this temperature increase would also mean a global average increase in sea-level of 0.66 m due to melting of the polar icecaps, causing a loss of some coastal areas. There may also be desertification – the conversion of formerly productive land to desert- in some areas which would contribute to poverty, famine, and food insecurity (Cunningham et al, 2006; Suess, 1993).

It is estimated that approximately 50% of these effects are caused by CO_2. More importantly, about 20% of CO_2 emissions in the US come from motor vehicles. In the developing countries too, increasing modernization has led to an increased presence of motor vehicles which means a large percentage of CO_2 emissions in these countries comes from motor vehicles as well (Harrington and McConnell, 2003). Thus, in order to control climate change, the issue of vehicle CO_2 emissions needs to be addressed.

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[42] Other greenhouse gases include water vapor, methane, and nitrous oxide (Cunningham et al, 2006).

In addition to CO_2 emissions and the resulting climate change, other vehicle emissions contribute to air pollution. Vehicles account for most of the carbon monoxide (CO) and a large share of the hydrocarbons (HC), nitrogen oxides (NOx), and particulates found in the atmosphere in major urban areas. Nitrogen oxide (NO) results when nitrogen in the fuel or in the combustion of air heats to temperatures above 1,200 degrees Fahrenheit in the presence of oxygen. This reaction occurs in most car engines today. Nitric oxide (NO) is the initial product and oxidizes to nitrogen dioxide (NO_2). Nitrogen oxides also combine with water leading to a component of atmospheric acidification, specifically nitric acid (HNO_3). In turn, this leads to “acid” rain. The general term “NOx” is used to describe this family of emissions (Cunningham et al, 2006). Vehicle emissions constitute the greatest individual source of nitrogen oxides in industrialized courtiers (Suess, 1993). Table 1 below shows the contribution of vehicle emissions to pollution in the atmosphere and their resultant effects.

Table 1: Air Pollution from Motor Vehicles (Federal Highway Administration, 2002; Harrington and McConnell, 2003)

Air Pollutant	**Proportion from On-Road Motor Vehicles in US**	**Effects**
Hydrocarbons	48%	Antecedent to ground-level ozone (smog)
Oxides of Nitrogen (NOx)	43%	Antecedent to ground-level ozone (smog)
Carbon Monoxide (CO)	66%	Contributes to smog production, poisonous in high concentrations
Particulate Matter ($PM_{10)}$	10%	Health problems when passing through the throat, nose, and entering lungs

It is clear that much of these air pollutants in the US are due to vehicle emissions. More importantly, these air pollutants have deleterious health effects. Particulate emissions specifically are linked to increased risks of asthma, heart attacks, and reduced lung function (Simms, 2004).

It is important to note too, that not only has air pollution reached critical levels in the US, but it has in other developing countries as well. In fact, the pollution in these other places may be worse. Table 2 below compares the air pollution in main cities in the US, China, and India.

Table 2: Air Pollution Indicators in Mega-Cities in US, China, and India (Gan, 2003; The World Bank, 2001)

City	**Population (millions, 2000)**	**Total Suspended particulates (μg/m^3, 1995)**	**Sulfur Dioxide (μg/m^3, 1998)**	**Nitrogen Dioxide (μg/m^3, 1998)**
New York	16.6	61	26	79
Los Angeles	13.1	49	9	74
Beijing	10.8	377	90	122
Shanghai	12.9	246	53	73
Guangzhou	3.9	295	57	136
Delhi	11.7	415	24	41
Mumbai	18.0	240	33	39
Calcutta	12.9	375	49	34

Thus for example, China's and India's big cities are affected by air pollution problems caused by high levels of total suspended particulates, sulfur dioxide, and nitrogen dioxide. It is exhaust pollution from vehicle emissions that has increasingly become the source of air pollution in these cities (Gan, 2004). Clearly, there is increasing concern at the local, national, and global levels about the adverse environmental and health effects of air pollution directly attributable to transportation. It is apparent that transportation's impact on the environment needs to be addressed; transportation needs to become more sustainable (Fergusson and Skinner, 1999).

There are several ways to make transportation more environmentally sustainable. One strategy implemented by car manufacturers in the US involves increasing fuel efficiency through the corporate average fuel economy (CAFE). CAFE standards set an average gas mileage requirement for a car manufacturer's fleet, rather than for individual cars. The fuel economy of all the cars sold by a manufacturer in any given year must average 27.5 miles/gallon and the fuel economy of all light trucks sold must average 20.7 miles/gallon. However, many opponents to this approach offer that in the absence of higher gasoline prices, improved fuel economy encourages people to drive an extra 10-20% more miles than they otherwise would, thus potentially negating the positive impact of the increased fuel efficiency (Holzman, 2005).

Whether or not the CAFE standards work however is not the issue here. It is more important to focus upon the ongoing problem created by the many high polluting vehicles still on the roads and the trend for increased private vehicles use that that comes with the increasing wealth of the US and developing countries (Harrington and McConnell, 2003). With affluence, people develop preferences for lifestyles that tend to center around an increased use of personal vehicles even if public transportation systems exist. This lifestyle preference leads to an increase in the negative environmental effects previously discussed (Gan, 2003).

It is clear then, that climate change and air pollution are issues that need to be addressed in order to move cities and regions towards a more sustainable existence. More public transportation use will mean fewer vehicles on the road, which will mean fewer emissions and less negative effects on climate and health. Society needs to act now to promote public transportation in order to save our environment from further climate change and to avoid the serious health effects of air pollutants.

TYPES OF PUBLIC TRANSPORTATION

General public transportation falls into the category of Mass Rapid Transit (MRT), or modes of urban transportation that carry large volumes of passengers quickly. MRT can be further subdivided into two categories: road based and rail based transportation. The categorization of transportation systems can be further broken down into five different types of transportation (including bus, tramway, light rapid transit, metro, and rail, discussed below) that encompass the MRT system (Fouracre et al, 2002).

The first type of public transit involves buses that use dedicated rights of way (ROW), such as bus lanes or bus ways. Effective bus way transit features high passenger capacity, efficient fee collection methods, well-designed bus stops, organized operations, and handicap accessibility. Bus way transit provides good services at a reasonable cost but often falls victim to stigmatization as a negative, unsafe travel modality. People find bus transit to be dirty, slow, noisy, and a generally poor quality ride meant to serve low-income residents without cars (Hardin, 2002).

The second type of MRT system is tramways, which are light, electrically powered cars that travel paths that may be completely or partially shared with other traffic. The third type of MRT system is known as Light Rapid Transit (LRT). It employs a fully segregated travel path and advanced control systems. The trains are light, like modern tramcars, and are often seen as intermediates between metro and bus systems in terms of cost and capacity (Fouracre et al, 2003).

The fourth type of MRT is metros. Metros feature fully segregated and grade-separated tracks and may be underground or elevated. These metros, also known as trains (or subways), are made up of heavy cars and can provide the highest levels of service - in terms of frequency and speed - but are also the most expensive. In addition, metros can carry the greatest numbers of passengers over any other public transportation system. The final type of MRT is suburban rail which transports passengers from suburban to urban areas. This system tends to exist as a larger rail network often separated from road traffic. It functions in the context of a wider network demand and is characterized by higher headways and longer station spacing (Fouracre et al, 2003).

EXISTING PUBLIC TRANSPORTATION

United States

The vast majority of people in the US use private transportation mechanisms for commuting. In fact, public transit systems only serve 1% of the transportation demand in this country (Lee, 2000). Several factors account for this observation. First, many locations nationwide simply lack public transportation systems. Additionally, in the locations where public transportation systems do exist, they may be inadequate and in need of improvements and enhancements.

Furthermore, in many cases, if US citizens can afford private transportation, they choose to use it. In fact, because time has become such a valued commodity in our current society, many people shift towards more convenient methods for commuting to work in order to match their own unique needs. This time factor has the effect of moving people from public transportation and car pooling to private vehicle use (Robinson, 2004).

Private vehicle use is regarded as more convenient and appealing in contrast to the highly stigmatized reputation that public transportation holds in society. Many people view public transit as unreliable, unattractive, unclean, and not worth the wait (Hardin, 2002; Lee, 2000). Travelers prefer the independence and flexibility of their personal automobile. As evidence of this, a Federal Highway Administration study found that in 1960, 69% of workers nationwide (41 million workers) used private vehicles to commute to work and in 2000, this number had increased to 88% (113 million workers; McGuckin and Srinivasan, 2003). In addition, the percentage of overall workers who used mass transit dropped from 6.2% to 5.3% from 1980 to 2000 (McGuckin and Srinivasan, 2003).

The cities that do have public transportation systems tend to be those that have highly developed expertise in urban control and management. This is due to the fact that transit mechanisms require a high degree of operational integrity as a prerequisite for their successful implementation and use (Fouracre et al, 2003). Places like Chicago, New York, San Francisco, Philadelphia, Washington, Cleveland, Miami, Buffalo, Baltimore, and Atlanta satisfy these requirements.

New York serves as a good example of public transportation in the US. With 230 miles of track, New York accounts for the bulk of US subway travel. Subways have minimal operating costs and are the most energy-efficient form of public transportation. Compared to bus transportation which requires one driver for about 50 people, one New York subway conductor can transport about 1,400 people (Schumer, 1980).

Chicago serves as another good example of the public transportation in this country. The Chicago Transit Authority (CTA) operates the second largest public transit system in the United States and serves the city of Chicago and its 38 surrounding suburbs. The CTA provides 1.5 million rides on an average weekday. This includes 560,000 trips to work (Welch et al, 2005). In addition to New York and Chicago, other cities, such as Atlanta, have large public transportation systems (Holsendolph, 1981). In Atlanta, 45% of all trips to work are taken by mass transit (Salisbury, 1982).

While it is true that public transportation systems do exist in some locations in the US, the systems are by no means adequate. Thus, the public transportation demand is not being met by the current infrastructure (Tumlin et al, 2003).

Developing Countries

The investment needed for the development of public transportation systems varies worldwide depending on location and the existent transportation infrastructure. In fact, the current level of investment in transportation is lower in developing counties than in the rest of the world. The figure below indicates the numbers of rail based systems used in the developing countries compared to other countries (Fouracre et al, 2003).

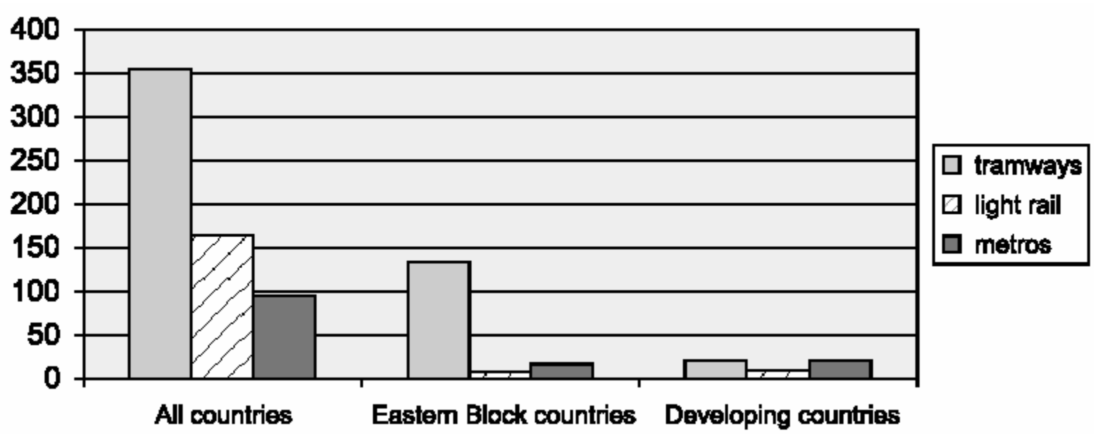

Figure 1. Numbers of urban rail-based systems by location. Source: LRTA (2001).

Despite a significant proportion of the world's population residing in developing countries, especially in China and India, these countries currently have the smallest numbers of urban rail-based systems as shown in the graph. Although a similar graph of bus way transit and suburban rail systems is not available, it is known that suburban rail systems are used in large, developing cities such as Mumbai (Bombay), Madras, Calcutta, and Colombo. However, the trend is that the suburban systems in the developing cities do no meet commuter demands (Fouracre et al, 2003). To be more specific, the current public transportation systems in China and India will be reviewed.

China

The current transportation system in China has been growing in response to the economic demands and the increased standard of living in that country. There is an increased demand for quality, convenient, and flexible transportation (Gan, 2003). Further, much like the trend in developing countries, the wealthy and middle class citizens in China prefer private car use (Gan, 2003). In response to these changing trends, China is building its transportation infrastructure with a high dependency for on-road transportation and extensive use of automobiles. This has led to traffic congestion and environmental problems (Phipott, 1995). In certain locations, like Guangzhou, as of 1998, less than 18% of Guangzhou citizens use public transportation for commuting. The majority of citizens (42%) commute on foot and 22% commute on bicycle (Zhao et al, 2004).

Despite these compelling statistics, there are some useful public transportation systems in China worth noting. For example, there is an impressive magnetic-levitation rail link in China that uses powerful magnetic fields to elevate trains above tracks. It operates between Shanghai and that port city's main international airport. This 820 mile rail line is designed for speeds reaching a maximum of 220 miles/hr. Additional work will begin at the end of 2006 aimed at extending the line from Shanghai to Hangzhou (Wall Street Journal, 2006).

India

The current transportation system in India displays a similar trend to that of China: the increased living standard has led to an increased demand for quality transportation that is both convenient and flexible in nature (Gan, 2003). In this regard, wealthy citizens and the middle class prefer private car use. Table 3 below shows the estimated shares of transportation modalities in Delhi stratified by income category.

Table 3: Estimated Shares of Transport Modes in Delhi in 1999 (Tiwari, 2003)

Mode	**Low-income (% population)**	**High-income (% population)**	**% Total Population**
Cycles	39	3	24
Buses	31	36	33
Scooter/Motorcycles	3	29	14
Walking	22	2	14
Cars	0	28	12
Rail	1	0	1
3 wheel scootertaxis	1	2	1
Other Vehicles	3	0	1

The table reveals that scooter/motorcycles, walking, and cars each contribute a similar percentage to the total population's transport modes. However, use of cars and scooter/motorcycles results almost exclusively from high income citizens while walking is the transport mode mainly of low income citizens. Additionally, the data also reveal that the rail system in Delhi is not widespread because only 1% of the total population uses rail. Finally, the bus system seems to be the most effective form of public transit in Delhi; it is the category with the highest percentage of the total population's use, amounting to 33%. Even among citizens in the high income category, buses are used more than cars - 36% compared to 28%, respectively.

Like Delhi, citizens of Mumbai frequently use their bus system. This, along with the suburban rail system, functions as the most used types of transportation in Mumbai. These two public transportation systems carry about 86% of commuter trips (Larkin, 2006). Walking, biking, private motorized vehicles, auto-rickshaw, and taxis are also used but mainly to access the rail transit stations and bus stops in the city (Rastogi and Rao, 2003).

A successful public transportation system is also in place in Calcutta, India where there exists a 17 km metro. It took 22 years to build and remains state of the art in quality. It is quite impressive, marked by its speed, punctuality, cleanliness, and use of tokens and smart cards at the ticket barriers (Perry, 2006).

China and India

However, similar to the United States' lack of public transportation in all locations nationwide, the systems in Shanghai, Delhi, Mumbai, and Calcutta are not matched in other urban locales throughout China and India (Fouracre et al, 2003). Public transportation in these developing countries is certainly non-ubiquitous in nature (Badami, 2003; Larkin, 2006). The current public transportation systems are not able to meet the increasing demand for commuter transport that comes with China's and India's rapid urbanization. This factor, coupled with the increase in the number of wealthy people who can afford private vehicles, has led to an increase in the number of private vehicles in these countries. Table 4 below shows data reflecting this increase in vehicles.

Table 4: Per Capita Vehicle Ownership (vehicles per 1000 population) (Energy Information Administration, 2001)[43]

	History (estimates)			**Projections**				**% annual change**
	1990	**1998**	**1999**	**2005**	**2010**	**2015**	**2020**	**1990-2020**
US	765	775	777	787	792	795	797	0.1
China	5	11	12	18	27	40	50	7.5
India	5	9	10	15	22	33	44	7.6

It is clear from the above table that the United States has significant per capita vehicle ownership with more than three quarters owning cars (>750 per 1000 population). The per capita vehicle ownership in the developing countries is significantly smaller. India, for example, falls in the bottom 10 countries with few per capita motor vehicles owed per 1000 people. The only countries (for which data are available) that have less are Pakistan, Cambodia, Uganda, Ethiopia, and Bangladesh (International Band for Reconstruction and Development, 2004). In 1999, only 1.2% and 1% of the population in China and India, respectively, had their own vehicles whereas 78% of the US population had their own vehicles. However, the projected annual growth rate in per capita vehicle ownership over the next decade and a half for China and India is significant at 7.5% and 7.6%, respectively. With public transportation systems requiring remedial efforts in these countries, citizens of high incomes are increasingly turning to the convenience and comfort of private vehicles. Furthermore, since these two countries have a significant

[43] Totals may not equal sum of components due to independent rounding.

proportion of the world's population, these increases represent a significant number of additional vehicles overall (Gan, 2003; Tiwari, 2003).

The increase in the per capital vehicle ownership in the developing countries is problematic for the global environment. China's vehicle emissions, for example, have become a major source of urban air pollution world wide. In fact, China is currently the world's second-leading emitter of carbon dioxide and other greenhouse gases that contribute to global climate change. It is projected to surpass the US and become the world's top emitter by 2020 (Esty and Dunn, 1997).

India's CO_2 emissions account for only 2-4% of the world's total. But in a country rapidly expanding beyond a billion people, there are profound implications for future impact on climate change. Although per capita CO_2 emissions are low (below a quarter of the world average), the national growth rate exceeds the global rate, which leads ultimately to an increasing global share (Toman et al, 2003). Transportation accounts for 24% of India's energy use and like China's transportation system, needs improvements for environmental sustainability (Feldstein, 2006).

In some instances, there has already been a push to improve the sustainability of the environment. In India, for example, there have been some advances in the public transportation systems in order to reduce pollution in certain parts of that country. As a statement of need for these enhancements, Delhi had been one of the most polluted capitals on earth. People have been plagued with asthma and bronchitis. Improvements began in the mid 1990s after a law suit forced Delhi's taxis and buses to use a cleaner-burning compressed natural gas (CNG) as fuel (Perry, 2006). In July 1998, the Indian Supreme Court ruled in favor of this proposal and ordered a ban on leaded fuel, and conversion of all diesel-powered buses to CNG along with the scrapping of old diesel taxis. Delhi's efforts to clean its air has led to stabilization of air pollution. This has attracted international attention from numerous countries including Kenya and Indonesia where there are attempts to mimic what Delhi has accomplished regarding limitations on air pollution (Perry, 2006).

However, more needs to be done to reduce climate change and air pollution. This can be accomplished through changes in public transportation. This report will end with policy recommendations aimed at encouraging the use of and improving the infrastructure for public transportation systems in the US and in the two developing countries, China and India. These policies focus on meeting the population's commuting demands in a more environmentally sustainable way.

THE SOLUTION: POLICY RECOMMENDATIONS

It is clear that vehicle emissions present global climate and air pollution problems. One obvious way to mitigate these effects is to lower the number of cars on the road. Lowering the number of cars on the road could be accomplished through the promotion of public transportation rather than private transportation in the United States and by slowing the growth of private transportation in the developing countries. Policy recommendations will fall into four categories: improving public transportation systems, encouraging the use of public transportation systems, discouraging the use of private transportation systems, and changing urban plans and city designs. All these recommendations can be applied globally to help transportation become more environmentally sustainable. Table 5 below outlines the main policy recommendations; more in-depth descriptions of each recommendation will follow.

Table 5: Policy Recommendations

- Allocate more money to build new subway and bus systems and expand or improve old systems
- Encourage citizens to use public transportation systems
  - subsidize mass transit fees for employees
  - reward carpooling
  - educate citizens to dismantle negative stigmas of public transportation
- Discourage citizens from using personal vehicles for travel
  - increase the price of personal vehicle travel
  - reduce the number of vehicles allowed in urban areas
- Change urban plans and city designs
  - build more walking and biking paths and bike racks

First and foremost, governments can prioritize their budgets to allocate more money in order to build new public transportation systems and expand or improve upon old ones. For example, in many cases there is an inadequate public transportation system linking cities to more suburban areas. This makes the commute to work more easily accomplished through personal vehicle transportation. In fact, Americans spend more than 100 hours per year commuting to work. That means that in 2003, the average daily commute to work lasted 24.3 minutes (Amour, 2005). If this commute could be accomplished through subway systems and buses, vehicle emissions would be lessoned. Once the public transportation systems are improved, then governments can encourage citizens to use them in lieu of personal vehicle transportation.

The next step then is to encourage the use of public transportation systems. One approach would require that employers subsidize mass transit fees for their employees. This could be effective, for example, in areas with bus systems for which the employers would give bus passes to their employees. This strategy is used effectively in Portland, Oregon; Boulder, Colorado; and Santa Clara Country, California (Tumlin et al, 2003).

For example, Silicon Valley companies give their employees Eco-Passes that are good for unlimited rides on the Santa Clara Valley light rail and buses. As a result, employee parking demand at these locations declined by 19% as public transit rider-ship increased (Tumlin et al, 2003).

A second policy aimed at encouraging the use of public transportation is to reward carpooling. There should be “carpool lanes” and “bus lanes” that can only be used by vehicles that are carrying more than one person. This would allow carpoolers to cut traffic in order to get to their destination. Other rewards of carpooling might include healthcare subsidies. Healthcare subsidies can be increased for employees who participate in car pool programs. For example, Children’s Health care of Atlanta has doubled its monthly subsidy from $30 to $60 for the carpooling participants (Armour, 2005). Another reward of carpooling could be closer parking access. For example, in Torrance, California, Honda has reserved parking in the areas closest to its building only for car poolers. There can even be a cash incentive for carpooling. This would be based on how many days an employee carpools to work or how many people are in the car pool. Honda for example, provides cash incentives for its employees in Torrance, California who carpool, ride public transit, or bike to work. Ninety of their total 300 employees (a rise from 70 earlier in 2005) today fall into one of these three categories (Armour, 2005).

Some employers are already taking steps to encourage their employees to commute to work using public transportation. According to a 2005 survey by the Society of Human Resource Management, about 14% of employers offer transit subsidies and 5% offer car-pooling subsidies. According to the 2000 US Census bureau, about 12% of employees carpool to work and 5% take public transportation. Working to reduce these numbers further can aid in reducing vehicle emissions.

A third policy to encourage the use of public transportation involves educating the citizens and dismantling negative stigmas that pervade society's perception of public transportation. For example, pamphlets could be administered and/or posters could be displayed around town attesting to the benefits of public transportation in an easy-to-follow and appealing manner. In addition, technologies can be put in place to make public transportation more tempting to the consumer. For example, instead of the stigmatized annoyance of late busses and broken trains, technologies could exist that display updates of when the next bus, train, or metro, etc, will arrive and the exact trip fare expected (Lee, 2000).

In addition to encouraging the use of public transportation systems, there can be programs that discourage the use of private vehicle travel. This can serve as an additional policy recommendation for making transportation more environmentally sustainable. One approach would require that the price of private vehicle travel be increased. Such an increase could include high parking fees, tolls, registration fees, gasoline taxes, and insurance fees proportional to the distance driven. If citizens had to pay more for parking, for example, they would be discouraged from driving (Tumlin et al, 2003; Uhl and Anderson, 2001). In addition, taxing gasoline could function as a carbon tax and, in turn, address carbon dioxide emissions and the resulting climate change. Finally, payments from insurance charges that are directly proportional to vehicle miles traveled, known as the Pay as You Drive (PAYD) system, would be a deterrent to private vehicle travel and could function in a similar manner to the gas tax described above (Harrington and McConnell, 2003).

Another way to discourage the use of private vehicle travel would be to reduce the number of vehicles allowed in urban areas. Urban areas can set vehicle quotas and require permits. This would help to define the notion that having a car is a privilege, and not a right (Suess, 1993). One such quota system could involve allowing vehicles with even numbered license plates to drive in central, congested urban areas on certain days and vehicles with odd numbered plates on other days. This system works effectively today in Rome, Italy (Burtz, personal communication, May 5, 2006).

A final policy recommendation that addresses the issue of sustainability for transportation concerns urban planning and city design. For example, governments can stop allocating funds that are aimed at building car oriented roads and highways in cities. Rather, these funds can be used by the cities to build more walking and biking paths and bike racks (Tumlin, 2003). Some places, such as the National Aquarium in Baltimore, are installing bike racks to encourage employees to bike rather than drive (Armour, 2005). In urban planning, cities can be rebuilt or rezoned such that residential areas can be linked to business zones. As a result, commuting time to work would be shortened and, in turn, there would be less vehicle emissions and less unwanted environmental effects. If future urban designs allow for more compact development that combines shopping, housing, and employment, then much can be accomplished with less travel (Harrington and McConnell, 2003). Once again, less travel means less emissions and a more sustainable environment.

CONCLUSION

It is evident that vehicle emissions are problematic to the global environment. CO_2 specifically leads to climate change and other vehicle emissions contribute to air pollution causing negative health effects for the world's inhabitants. A logical way to reduce these negative impacts would be to decrease vehicle emissions; to catch the problem before it worsens. This can be accomplished through lowering the number of vehicles on the road. The increasing trend for private vehicle ownership can be replaced by increased reliance on public transportation. Policy recommendations for reaching this goal involve improving current public transportation systems, encouraging the use of public transportation systems, discouraging the use of private vehicles, and changing urban plans and city designs.

It would be incorrect to assume that all countries will follow in the deleterious footsteps of the US regarding the transportation sector to date. Indeed, there are many geographic, social, economic, and political reasons why they should not. If the trends of the US transportation sector were replicated elsewhere, there would be even more damage to the global environment. However, in the US as well as the developing countries, China and India, the issue of vehicle emissions can be addressed by improving and promoting public transportation. However, the reality is that cars are not going to leave society's framework anytime soon. Thus, the more we can reduce their impact upon our environment and our health, the better it will be for the sustainability of all mankind (Holzman, 2005).

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Laying the Foundation for a More Energy Efficient Future:
Reducing Climate Change through Green Building

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Task Force, Spring 2006
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Global Warming Context

In 2001, the Intergovernmental Panel on Climate Change (IPCC), which subscribes to the most rigorous standards, released its full climate change report and confirmed that the average global temperature is increasing as a result of human activity, with possibly catastrophic consequences for life on earth (Shaw, 2002).[44] The release of high quantities of CO_2 has been shown to be the primary cause of this increasing temperature. Quick reductions are especially important since these emissions remains in the atmosphere for at least a century, meaning that actions taken now will have long term consequences (Shaw, 2002).

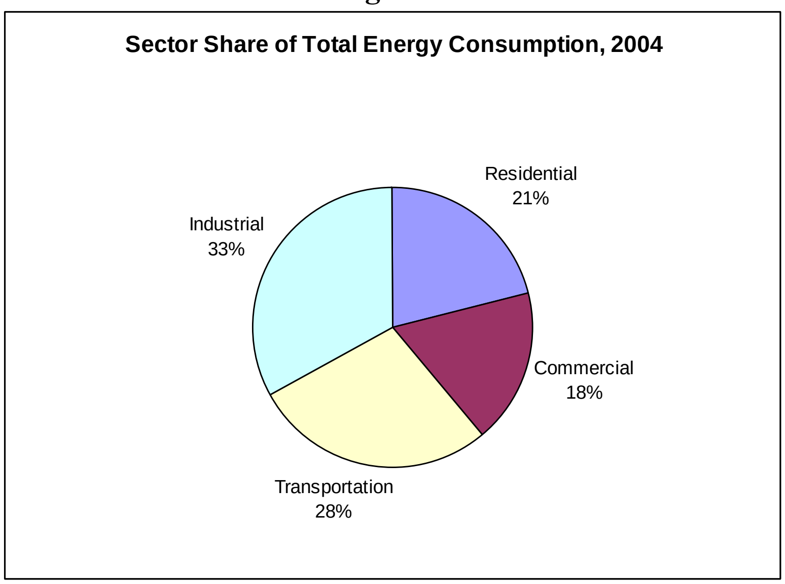
There are essentially two ways to reduce greenhouse gas emissions. One approach focuses on the supply side and attempts to minimize the production of greenhouse gases through cleaner energy production. The other method looks at the demand side and tries to reduce the amount of energy required by the world's population by increasing efficiency and reducing energy demand. Realistically, a combination of both approaches needs to be taken in order to tackle the problem effectively, and Steven Pacala and Robert Socolow have developed a stabilization wedges concept to addresses how global warming can begin to be tackled with a combination of existing technologies. According to the two professors, the basic tools needed to solve the carbon and climate problem for the next fifty years already exist and simply need to be implemented (Pacala and Socolow, 2004). No one technology will solve the problem by itself, but a piecemeal combination can prevent climate change from worsening (Pacala and Socolow, 2004). The wedges model divides the necessary reduction of CO_2 emissions into seven equal parts, with one wedge being "More Efficient Buildings" (Pacala and Socolow, 2004).

[44] The full IPCC report can be seen at www.ipcc.ch

Why Target Buildings

Buildings are huge energy consumers. As is shown in Figure 1, residential and commercial buildings account for 39% of total energy use in the US, (Energy Information Administration, 2004) meaning that reductions in buildings' energy demand could result in a great drop in the need for carbon-emitting power plant production. Additionally, peak electricity loads, which tend to determine the number of power plants needed and which sometimes requiring older, dirtier plants to come back online, are usually determined by the demand for lighting and cooling of buildings (Tester et al, 2005).

Figure 1



(Data Source: Energy Information Administration, 2004)

Residential electricity use per capita has been increasing since the 1980's, and US energy consumption, as a whole, is expected to continue growing due to the creation of more commercial floor space, the continued increase in the use of electric appliances in residential buildings, and expanding industrial output (Energy Information Administration, 2006). Essentially, decrease energy demand from buildings could greatly reduce energy production and its accompanying carbon emissions. As things stand now, however, builders usually care more about cutting their own initial capital costs than about long term efficiency, so inefficient building stock tends to get cemented into the building infrastructure. Even the construction of buildings themselves account for about one-third of total industrial energy use (Tester et al, 2005).

The incorporation of cleaner, more energy efficient buildings is extremely important to address now rather than later because buildings, unlike cars for example, have a very long life time. Building infrastructure that is invested in now is very difficult to change, so, if efficiency isn't incorporated at construction, it will be very difficult to improve in this area in the future. Office space in the US is expected to increase between one and two percent per year in the coming future (Energy Information Administration, 2006), so there is potential to make an impact.

The US and China

As the US is the biggest CO_2 emitter, this paper and its policy recommendations focus mainly on the US; however, since Asia accounts for 50% of the growth in the demand for energy every year (World Summit on Sustainable Development, 2002) and since China is a rising power with increasing wealth, some of the recommendations can be applied to China as well. China is currently experiencing a massive building boom, which will affect the country's building infrastructure for decades to come. The urban housing stock in China is expected to more than double within just the next twenty years, and commercial buildings are going up at a similarly rapid rate (World Bank, 2006). Additionally, heating energy per floor area in China is at least double the energy needed for comparable spaces in Western Europe and North America due to poor insulation, leakage, and thin building materials (World Bank, 2006). This high level of energy consumption means that there is feasible room for improvement. Additionally, since the US joined with China and other Asian nations for the aim of working to reduce global climate change through the "Asia-Pacific Partnership on Clean Development and Climate" and since one of the purposes of this alliance was "Strengthening [the] adoption and use of building and appliance efficiency standards," (US Department of State, 2006) it is rational to explore how improvements in the US's green building practices could be similarly applied to China.

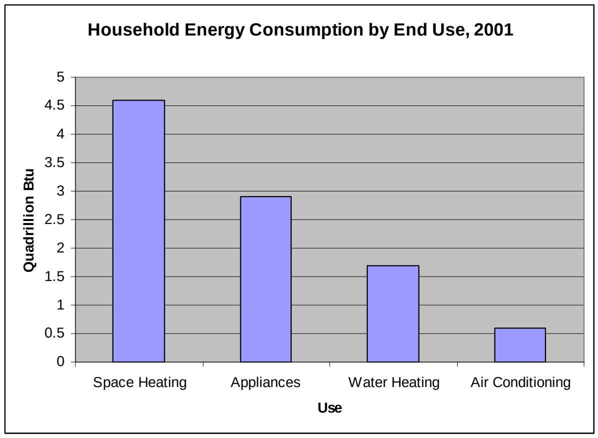
Increased Efficiency through Construction

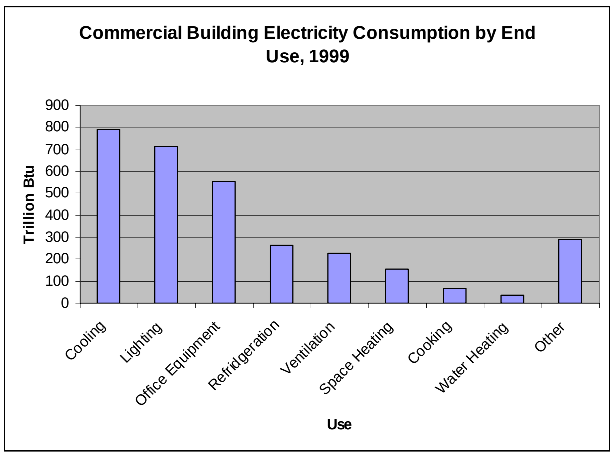
Before operational efficiencies are addressed within the building envelope, inefficiencies during the initial design and construction are important to take into consideration. Different building materials have different levels of embodied energy, due to their production and transportation to site, (Tester et al, 2005) which should be factored into the overall energy use of buildings. Since lots of energy and toxins are used during the production of many building materials, (Williams, 2006) there is a need to reduce energy consumption and toxic content on the production side of building materials, even before their uses within structure is analyzed.

Certain materials take little energy to produce and do not require far, energy-intensive transportation. Concrete made from fly ash, ashes from waste incineration, for example, uses significantly less energy to produce than regular concrete (Williams, 2006). Sustainably grown wood also avoids further deforestation and therefore has a smaller negative effect on CO_2 absorption. In order to encourage the use of these more energy efficient building materials, California's Integrated Waste Management Board has developed a labeling system that takes into account the various environmental effects of the production of building materials (California Integrated Waste Management Board, 2006). This kind of labeling could be prominently implemented throughout the country and could also include scales that show how the material's production energy level compares with other, similar products. Additionally, the ability of consumers to see these labels might encourage more energy efficient choices, and it is possible that material energy consumption could be included in building plans. The most efficient way to reduce energy use during production is to reuse and recycle existing products and to readapt existing structures instead of demolishing them. Government could facilitate the reuse of materials by organizing exchanges and recycled material depots, where builders could discard or pick up previously used materials.

Overall, though, the amount of energy used in construction is much less than the amount consumed over the lifetime of a building's operation (Tester et al, 2005). Heating and cooling systems are the biggest energy consumers in residential and commercial buildings, as is shown in Figure 2. Certain design decisions that are made before and during construction, however, can greatly impact a building's eventual heating, cooling, and general electricity needs.

Figure 2





(Data Source: Energy Information Administration, 2004)

Improved Insulation and Sealing

Insulation and a tight building envelope can greatly reduce the amount of energy needed to cool and heat a structure by minimizing the leakage of conditioned air into the outside environment. Adding wall insulation effectively diminishes heat loss and gain through the outside shell of the house and can be easily installed. The biggest savings and easiest place in a house to insulate insulation is usually in the attic (Energy Star, 2006). Additionally, sunspaces or vestibules in houses or commercial buildings act as thermal buffers, reducing the heat exchange between indoor and outdoor spaces every time someone enters or exists the building (Growther, 1992). If these buffer spaces are lined with windows, they can additionally often reheat themselves during winter months from the sun's heat, eliminating the neat to heat even these smaller areas (Growther, 1992).

Sealing the building envelope, in general, can reduce drafts and the need for more conditioned air production. Air leakage is an important component to address since it accounts for 25-40% of energy used by heating and cooling systems in the average house (Energy Star, 2006). The biggest gaps in residential houses are usually found in attics and basements and can be easily remedied, even retroactively, through wraps, tapes, spray foam, caulk, and weather stripping (Energy Star, 2006). Sealing is cost effective because it minimizes the need for conditioned air (Energy Star, 2006). Another way in which leakage and insulation can be addressed is by creating tight, insulated air ducts. Leaky ducts cause at least 25% of the energy used in conditioned air to be lost before it even reaches its final destination (Energy Star, 2006). As a remedy, ducts should be tightly sealed, insulated, and should not run through areas of the house, such as attics or garages, that are not temperature controlled (Energy Star, 2006).

Windows and Solar Use

Window type and placement during construction can also play a large role in determining the amount of energy that a building will require for heating, cooling, and lighting. Heat gain and loss through windows typically causes 25-50% of a building's heating and cooling needs, (Energy Star, 2006) and window area can determine the amount of artificial light needed. Thermal glass, as well as double glazing, can help keep indoor air at its desired temperature by preventing warming from the sun and by preventing exchange of heat through window surfaces. Additionally, insulating materials and tightly sealed window frames can help reduce heat exchange (Energy Star, 2006). The US Environmental Protection Agency's Energy Star programs labels windows that have these efficiency components.

The sun is the most direct source of energy, and its heat and light can be easily incorporated into the architectural system through the placement and size of windows. Large, vertical banks of windows on the south sides of buildings are the most efficient for taking advantage of the sun's energy because vertical glass walls avoid overheating the interior in the non-winter seasons and eliminate the annoyance of direct radiance, which often results from skylights. Thermal mass, such as dark concrete, brick, stone, marble, and tile can then be placed in the path of the incoming sunlight, and the heat that these materials absorb can be redistributed throughout the house with the use of interior air blowers, preventing the heat from simply reradiating back out through the windows (Growther, 1992). Minimal interior walls, feasible in many office and commercial buildings, in particular, can help reduce the need for artificial light (Pogrebin, 2006), and studies have shown that the use of natural instead of artificial light improves performance by between 20-25% (Pogrebin, 2006). Lastly, sealed windows in tall buildings are not necessarily the most efficient for climate control, as natural ventilation can sometimes provide more comfort with less energy (Tester et al, 2005).

Siting and Landscape

Older ideas about siting and passive climate control have mostly faded in the US, where builders don't always think about the efficiency of their structures (Tester et al, 2005). Incorporating features such as overhangs, canopies, awnings, and recessed windows, however, can minimize unwanted heating in the summer, (Growther, 1992) and trees can be placed strategically for shade in hot climates and for windbreak in colder ones (Growther, 1992). Low, dense evergreens block winter winds, and deciduous trees allow for sun in the winter but shade in the summer (Growther, 1992). Native landscaping also does not require high upkeep and reduces the need for pollution-emitting machines, such as leaf blowers and lawnmowers (Growther, 1992). Roof gardens not only provide for the reclamation of natural space, but they also serve as huge insulators and can produce a fifty percent reduction in air conditioning needs in most buildings (Whiting, 2006). In addition to these siting improvements, counter to the current trend in the US, smaller buildings are inherently more efficient because they have less space to heat, cool, and light.

Though the limited length of this paper does not allow for an in-depth discussion on siting within the urban context, decisions relating to this field are also extremely important. Energy efficiency can be improved through the use of smart growth practices, where buildings are clustered in dense, multi-use, walkable areas with access to public transportation. Not only does proximity to public transportation reduce reliance on carbon-emitting private cars, but density ensures the feasibility of public transportation infrastructure in the first place and walkable, multi-use clustering reduces the need travel far distances in the first place. Changes in land use practices, however, will not happen on their own and require policy intervention, through updated building codes and zoning regulations.

Building Operation: Heating and Cooling

As Figure 2 illustrates, heating and cooling remain the two largest energy consumers in US buildings, followed by lighting and appliances. Energy use can be greatly diminished through operational choices in these three areas. With the US population moving farther South and West, electricity demand for air conditioning in homes and commercial spaces is burdening the electrical grid; (Energy Information Administration, 2006) however, there are many non-energy intensive ways in which a comfortable temperature can be maintained. With the advent of advanced electronics, energy and conditioning use can be controlled more selectively. Thermostats with daytime-nighttime settings and thermostats on timers can increase efficiency for buildings used at selective times (Tester et al, 2005). Humidity control and increased air circulation, with such simple equipment as desiccants and fans, can provide more comfort with less energy, as moving, dry air allows people to comfortably tolerate higher temperatures (Lechner, 1991, as sited in Tester et al, 2005).

In the new Hearst Building in New York, architects have focused on reducing heating and cooling costs by incorporating an indoor waterfall that chills and humidifies the air and by installing a lobby floor of radiant stone, which will generate heat in the winter and absorb heat in the summer through water that flows just below its surface (Pogrebin, 2006). Running this water system has lower cost and is less energy intensive than conditioning the air of the entire lobby, especially since people only come into contact with air several feet above the floor anyway (Pogrebin, 2006). Similar to the overall wedge model, when thinking about improving buildings' energy efficiency, one should not just focus on the primary energy source but also on how complimentary energy sources and reused energy can be harnessed to increase efficiency.

Geothermal Heat Pumps

Location, regional geography, and tectonics all play a role in determining the depth, position, and temperature of geothermal energy sources, but geothermal systems exist worldwide (Tester et al, 2005). Spontaneous geothermal systems have the potential to provide large amounts of energy but are not always located near markets; however, the constant temperature of the earth's subsurface ground can be harnessed everywhere in order to aid in the heating and cooling of individual buildings (Tester et al, 2005). A reliance on the constant temperature of the ground as a heat source or sink would decrease the need for other heating and cooling energy generation, currently the largest aspect of buildings' energy demand.

Essentially, geothermal heating and cooling works by drilling into the ground and installing a closed loop pipe horizontally beneath the frost zone, at depths ranging from 100-400 feet depending on the latitude. Geothermal heat pumps (GHP) then circulate a liquid solution through these pipes, and this solution absorbs or releases heat into the consistently temperature of the ground. The solution is then cycled through the above building, heating or cooling it in the process (Tester et al, 2005).

Geothermal heat systems are actually fairly cost competitive with other energy sources and can reduce energy consumption by 63-72% over electrical heating and standard air conditioning (L'Ecuyer et al., 1993, as cited in Tester et al, 2005). Granted, there is a higher initial investment in than with traditional heating and cooling systems, but the additional initial cost is returned in energy savings within five to ten years (US Department of Energy, 2005). Since the system life is twenty-five years for the outside components and over fifty years for the ground loops (US Department of Energy, 2005), geothermal systems are not only a carbon free way of heating and cooling buildings but are also cost advantageous.

As of 2005, there were 2 million GHPs heating and cooling buildings worldwide (Renewable Energy Policy Network, 2005). Forty thousand are installed in the US every year (US Department of Energy, 2005), and the instillation of GHPs has been growing at a rate of 15% per year in the last decade (Tester et al, 2005); however, with relatively low costs for gas and heating oil, there is an insufficient incentive for consumers to make the initial investment in geothermal heating (Tester et al, 2005). This is the case even though geothermal heating is cost effective and carbon free and though it takes up very little surface area, which is a benefit among renewable energy sources. Barring significant policy or energy price changes, the use of on-site solar electricity and GHPs is expected to more than double between 2006 and 2030; however, these energy sources would still comprise less than one percent of total delivered residential energy use during that period (Energy Information Administration, 2006). For these reasons, the US government should continue to promote and aid in the instillation of GHPs. In addition to benefiting the US by providing reduced reliance on carbon-emitting energy sources, rapidly growing countries like China, which still face occasional energy shortages, would also benefit from increased industrial and economic production if GHPs could provide a base level of uninterrupted heat (Tester et al, 2005).

Other On-Site Clean Energy Sources

Just like GHPs, other onsite renewable energy sources can be helpful in reducing the demand for carbon-emitting energy production. Photovoltaic solar collectors (PVC) can be especially helpful in meeting additional energy demand from air conditioning and hot water heating. Peak loads on the electrical grid in the US can be diminished, for example, with solar powered air conditioners (Tester et al, 2005). The US could also learn from the rest of the world, where rooftop PVC panels provide hot water for 40 million households, the majority of which are in China (Renewable Energy Policy Network, 2005). Instillation of GHPs and PVCs shows that a building does not need to convert completely to renewable energy sources for renewables to effectively reduce carbon-emitting energy production.

Operation: Lighting and Appliances

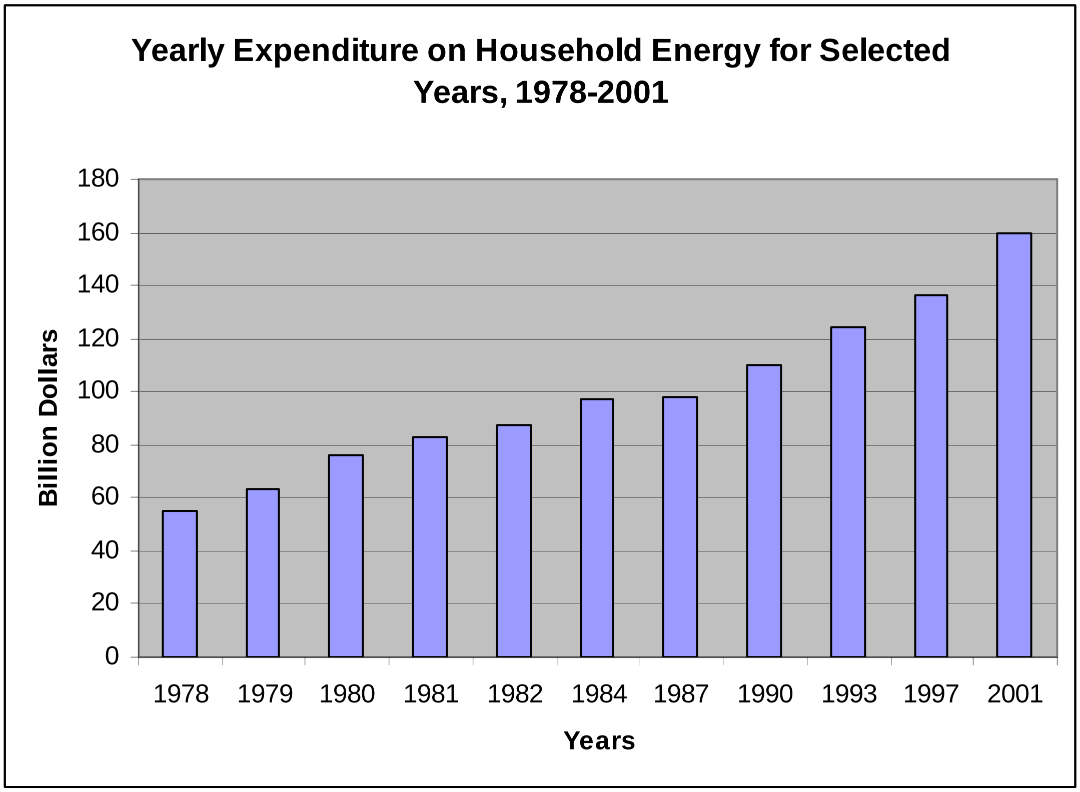
Lighting and appliances play the second largest role in buildings' energy demand (Energy Star, 2006), and consumer choices can greatly affect the energy consumption of these products. In the early 1990's, the US government launched the Energy Star program, which facilitates making environmentally smart choices through a voluntary labeling program that identifies energy efficient products (Energy Star, 2006). Energy Star products meet the strictest energy efficiency guidelines set by the Environmental Protection Agency and the US Department of Energy and are labeled as such as a way of encouraging their purchase (Energy Star, 2006). A typical US household has a yearly energy bill of $1,500; however, by changing over to all Energy Star certified appliances, lighting, and electronics, and by following Energy Star recommendations for insulation and sealing, the typical household would reduce their energy bill by 30% (Energy Star, 2006).

Energy Star certified compact fluorescent lights (CFL) consume 66% less than the typical incandescent bulb and last ten times longer (Energy Star, 2006). If every household in the US replaced one existing incandescent bulb with an Energy Star CFL bulb, the effects on carbon emission resulting from reduced energy consumption would be the equivalent of removing 1 million cars from the road (Energy Star, 2006). If every US family did the same thing with five light bulbs, the US would eliminate 1 trillion pounds of greenhouse production, and it would be the equivalent of taking more than 8 million cars off the road or twenty-one power plants off line (Energy Star, 2006). Not only would the carbon savings be great, but the energy savings would reduce operating costs too. Replacing a 100-watt incandescent bulb with its CFL equivalent would save $30 in energy cost over the lifetime of the bulb, more than added cost of buying a CFL bulb (Energy Star, 2006). Occupancy and brightness-intensity sensors can additionally be used to cut down on excessive lighting in commercial buildings, where lighting consumes 13% of those buildings' energy demand (Energy Star, 2006).

Additional Advantages to Green Building

In addition to the environmental benefits of green building, becoming more energy efficient, in the long run, brings down costs and reduces waste. The geothermal payback period and the savings resulting from the use of CFL bulbs are two examples of how energy efficiency is cost effective. This reduced cost is significant in the face of consistent increases in household energy expenditures, as shown in Figure 3. Sustainable architecture once added up to 20% to the cost of a project, but, now, because of the availability of new materials, it adds only between 1 and 5% (Pogrebin, 2006).

Figure 3



Data Source: (Energy Information Administration, 2004)

Many office developers are also finding that building green is cheaper than expected, increases a property's value, and attracts tenants (Roeder, 2006). There is simply a greater upfront cost, since the majority of green technology requires higher than normal initial investment. Over time, however, returns more than make up for the added cost. Some builders believe that it is very worthwhile to get the US Green Building Certification because it produces savings for tenants and therefore justifies higher rents, especially in an atmosphere where many corporations are beginning to include environmental consciousness in their company values (Roeder, 2006). This increasing efficiency of office buildings is encouraging since these buildings are the largest commercial building energy consumers, at 767 trillion Btu, in comparison to the next highest 521 trillion (Energy Information Administration, 2004).

Another added benefit to increased energy efficiency is the reduced need for power plant construction. Especially in the US, where finding sites to build power plants can be extremely controversial, there would seem to be broad support for policies that reduce the need for new power generators. In countries like China, where there is such rapidly rising energy demand, there is an increasing awareness that energy efficiency and better construction is cheaper than building new power plants (Tester et al, 2005), illustrating that more energy efficient buildings can benefit developing countries too and showing to the US that energy efficiency is a logical goal, irrelevant of its environmental consequences.

Obstacles towards Green Buildings

Unfortunately, many US citizens do not realize the benefits of increased building efficiency. In Europe and Japan, where energy costs are much higher than in the US, operating costs play a bigger role in buyers' decisions (Tester et al, 2005), showing that higher energy costs make people realize the consequences of inefficient energy use. Because of the present price structure for energy and materials, people and companies are constructing ever larger buildings because they can easily afford the needed energy (Tester et al, 2005). People do not factor in energy conservation into their decisions; they simply buy as much as they can (Tester et al, 2005). US policy should harness this information and make it less cost effective for consumers to be inefficient. In the early 1980's, energy demand dropped due to recession and high energy prices, but, by the mid-

1980's, energy consumption had increased again due to declining prices and an economic upturn (Energy Information Administration, 2006). This historical fact shows that the ease with which people can buy energy and the price of energy greatly affects consumption. The US, therefore, must devise a policy that valuates the cost of inefficiencies through taxes, that makes excessive energy consumption expensive, and that creates other disincentives for inefficient energy use. Building codes in Japan and Europe also usually emphasize higher levels of efficiency than US codes do (Tester et al, 2005). Zoning efficiency requirements in the US could mandate a certain level of energy efficiency but leave the means with which the goals are met up to the builder or owner.

In addition to energy costs, environmental costs are also not always given much attention in the US because there are few visible or immediate consequences. Because of this ignorance, the externality of environmental damage is not usually factored into design, construction, or purchasing decisions. US policy would therefore benefit by internalizing the cost of carbon emissions for consumers and producers.

Lastly, an obstacle towards green building is that energy efficient equipment and infrastructure usually requires higher capital investment than traditional energy infrastructure. Government policy, therefore, needs to find a way to bring down the initial cost by either subsidizing green investment or by increasing demand enough to make energy efficient materials, equipment, and generators common and cheap. Currently, technology that has the ability to reduce commercial energy consumption by up to 50% through more efficient air conditioning compressors is available, but, when businesses consider equipment purchases, they often place more weight on additional capital investment required for the most efficient technologies than they do on future energy savings (Energy Information Administration, 2006). This kind of thinking limits the adoption of efficient technologies (Energy Information Administration, 2006). The US government should therefore try to take actions that would cause people to internalize the life-cycle cost of their buildings and products rather than just the upfront investment.

Though some players in the building industry will create sustainability standards in the current climate, the entire industry will not incorporate green building practices on its own; it will only happen through regulation or market pressure (Tester et al, 2005). Governmental organizations should therefore facilitate alliance based around green building practices and should implement requirements through building codes and zoning that require increased efficiency and reduced carbon footprints.

Useful Policy Models

Existing and proposed policies can serve as effective models in formulating policies that can promote green building. Over the years, there has been discussion about increasing the gasoline tax as a way of increasing the number of fuel efficient vehicles, reducing unnecessary and inefficient driving, and making public transportation more attractive. Since there is a similar lack of awareness about inefficiencies and the environmental costs associated with excessive energy use in the building sector, a similar carbon tax could be applied to energy consumption coming from carbon-emitting sources in order to discourage inefficiency.

Additionally, current policies that aid home buying could incorporate green building requirements or could be applied in different ways so as to encourage the purchase of green homes. Fannie Mae and Freddie Mac offer government-sponsored mortgages to lower income citizens and first time home-buyers in order to help them purchase houses. If these or additional mortgage aid could be applied to the purchase of green houses, the demand for and, therefore, the supply of energy efficient, green buildings would increase, and lower income residents would have the added benefit of lower operation costs.

Models in the private sector also exist and can be built upon. The creation of the international, private partnership Sustainable Building and Construction Initiative (SBCI), which aims to promote environmentally friendly building practices in the building industry (National Environmental Education and Training Foundation, 2006), shows that there is demand for increased green building even among builders. This alliance has the objective of adopting sustainable building practices, encouraging legislation and building standards that include sustainability impacts, and encouraging a “life-cycle approach,” an approach that takes into consideration the cost, environmental impact, and energy consumption of a building over its entire lifetime (National Environmental Education and Training Foundation, 2006). These types of organizations should be further promoted by the UN and the US.

In general, there is a need to expand US policy in the area of green building and renewable energy. Regulations should move beyond simply requiring industrial energy efficiency and should begin to target the biggest segment of the energy consumption pie: buildings. By requiring higher standards for heating, appliances, weatherization, and building codes and by targeting consumers, policies can help drive producers to respond with more appropriate equipment. The US’s hesitation to clamp down seriously on global warming and energy use could eventually put the country at an economic disadvantage if other countries, spurred by requirements for greater efficiency, develop technologies that the US ends up having to import.

Currently, the US federal government offers tax credits and subsidies for energy efficient appliances (Tester et al, 2005). Capital grants, rebates, and investment tax credits for solar hot water heating usually cover about 20-40% of the system cost (Renewable Energy Policy Network, 2005), and federal and state governments began giving tax credits and incentives for the use of geothermal heat in the 1970's (Tester et al, 2005). Additionally, states offer a variety of their own incentives, such as Maine's $7,000 rebate for the cost of solar panels (Williams, 2006). Further reducing the investment needing to be made by individuals or companies in green building equipment and materials will serve to increase the adoption of green building practices. Federal buildings are some of the biggest users of energy-efficient technologies due to congressional and executive mandates (Palmer, 2006). The prevalence green components in these buildings shows that the technology is available but just needs to be fostered, that increased demand reduces prices and makes energy efficient equipment more accessible to everyone, and that incentives and requirements can effectively cause people to adopt better practices.

Providing more information to consumers about the true costs of their investments will also help consumers make more rational choices that factor in life-cycle energy costs. This knowledge would rationally cause them to gravitate towards energy efficient offerings. Energy Star certifies a range of building materials and equipment based on their efficiency and long-term cost savings already. Its certification is also available for homes that incorporate a certain number of energy efficient components. The fact that, in

2004, 8% of new single-family homes were Energy Star certified (Energy Information Administration, 2006) shows that these more stringent efficiency guidelines are feasible. In 2005, more than 2500 buildings in the US earned the Energy Star, and, combined, these certified buildings save an estimated $349 million annually in lower energy bills and save 1.8 billion pounds of greenhouse gas emissions (Energy Star, 2006).

The US Green Building Council (USGBC) also has a certification program designed to promote environmentally responsible, profitable, healthy buildings. It uses the Leadership in Energy and Environmental Design (LEED) certification system that awards different levels of certificates to buildings based on how green and efficient the building is, using a point system to determine qualification (US Green Building Council, 2005). Part of the attractiveness of the LEED program is that it includes different levels of certification, which pushes builders to seek out continual increases in efficiency even after they have reached the baseline requirement. A similar approach could be applied to Energy Star's energy efficiency labeling and would serve to encourage further efficiency improvement even after the initial goals have been met.

The incentive to get LEED certified is the positive visibility that results from certification. The USGBC provides recognition and allows companies to promote their certification status (Roeder, 2006). This visibility is what pushed both the new 7 World Trade Center and Hearst Building in New York to get LEED certified. John Buck Company, a green office building firm in Chicago, says that following LEED guidelines adds about 1-2% to the cost of a building's construction but add considerable resale value, (Roeder, 2006) implying that going green is cost effective and showing that there is demand for green building but not enough supply.

Some municipalities have decided to actually mandate certain green building requirements through building codes. Israel requires solar hot water heaters in all new construction, and many cities, such as Barcelona, have requirements mandating a certain amount of solar use (Renewable Energy Policy Network, 2005). In Barcelona, buildings over a certain size must heat 60% of their hot water with solar thermal collectors (Renewable Energy Policy Network, 2005). Even within the US, New York City mandated in October of 2005 that non-residential public buildings costing $2 million or more and any private projects receiving $10 million or more than half of its budget from public funds must be built to LEED standards (Pogrebin, 2006). These policies show that energy efficiency requirements are feasible and are probably more realistic when applied to larger projects, where the initial cost of green infrastructure will not overwhelm the budget.

Building codes in China that require certain energy efficient components continue to show that mandated efficiency is a feasible and effective way to ensure the construction of greener buildings. After the 1996 Energy Conservation Design Standard went into effect in Beijing, which mandated improved insulation, better windows, and lower air filtration, there has been a 59% drop in the annual heat load between 1996 and 2001 (Glicksman et al., 2001, as cited in Tester et al, 2005).

In addition to mandates, which have shown significant results, making consumers pay for their specific heat consumption is also believed to be responsible for greatly reducing wasteful heat consumption. Throughout most of China, there are no incentives to conserve heat or use it efficiently because the country do not meter heat use; consumers simply pay on a per square foot basis, irrelevant of their level of consumption

(World Bank, 2006). Developers have no incentives to construct energy efficient buildings since consumers do not care (World Bank, 2006). The World Bank is currently engaged in a project with the Ministry of Construction of China that aims to increase energy efficiency in urban residential buildings partly by reforming heat pricing and billing through metering and consumption-based billing (World Bank, 2006). If these efforts succeed, the World Bank estimates that energy use in new residential buildings will be halved and that the savings would be 13 million tons of coal and the avoidance of 10 million metric tons of carbon emissions from the six target cities over twenty years (World Bank, 2006). The program was decided on because officials have discovered that an integrated approach is needed to address building efficiency, meaning that consumers need to have incentives to be energy efficient or disincentives to be inefficient at the same time that codes must mandate more energy efficient components to create supply for any new demand (World Bank, 2006). These lessons from China can be applied to the US and justify a multi-pronged attack in increasing building efficiency.

Policy Recommendations:

1) Impose a carbon tax on consumers for the consumption of electricity originating from carbon-emitting sources.

Since the externality of climate change is not strongly factored into people's electricity consumption habits and since higher prices have been shown to reduce consumption, this tax could effectively discourage consumers from inefficiency and would spur electric companies to respond with renewable power generation, which they would be able to sell to end consumers for less money. Additionally, the revenue gained from this “dirty electricity tax” should be used to subsidize renewable energy infrastructure.

2) Increase subsidies for the initial cost of geothermal heating and cooling systems, using funds obtained from the “dirty electricity tax.”

The instillation of GHPs has been shown to be an effective and efficient way of reducing the need for carbon-emitting heating and cooling, the largest energy consumers in buildings. Additionally, GHPs are feasible country-wide. The main obstacle in the way of their widespread use is the high initial investment, which increased subsidies would help ease.

3) Create a mortgage program through Fannie Mae and Freddie Mac that offers concessionary rates for mortgages on energy efficient buildings.

Making green buildings financially more attractive would increase demand and would also eventually increase supply.

4) Mandate LEED certification or a certain renewable energy component for buildings over a certain size.

Although the capital investment in efficient equipment and renewable energy sources can be expensive, these costs are less of a burden for larger and already more expensive projects. The Barcelona and New York models have shown the feasibility of such requirement policies. Additionally, this requirement would both serve to increase efficiency in these buildings and expand the market for green equipment and materials, eventually serving to bring down prices and make them more feasible for others.

5) Incorporate estimated life-cycle and yearly energy operating costs on the labels of all appliances, lighting, and other energy consuming equipment.

Since consumers are resistant to spend the premiums that accompany greener, more efficient materials and equipment, labeling the estimated energy cost for operation would help consumers evaluate the true cost of equipment ownership. Additionally, unlike the current Energy Star program and more similar to the LEED program, including levels instead of just an efficiency baseline would further encourage manufactures to increase the efficiency of their products.

6) Use Type II partnerships to provide resources and an organizing framework for those in the building industry to come together in the creation of green building alliances.

Due to SBCI and the advantages that many builders are beginning to see in green building, it seems as though there is a growing movement within parts of the building industry to advance energy efficient and environmentally related goals, which governmental organizations should foster and help succeed.

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Clean Distributed Generation for Slum Electrification: The Case of Mumbai

This paper discusses the lack of electrification in slums in India, focusing on the slums in the city of Mumbai as a case study. Electrification is important for the quality of life of the slum-dwellers, and is a path towards further development. For a variety of sociological, infrastructural, and economic reasons, traditional electric service is not available in the slums. A unique solution to this problem is the use of renewable distributed generation technologies, specifically solar photovoltaic and wind power. Because they are flexible, cheap, suited for Mumbai's climate, and empower the community, solar/wind arrays should be made available through micro-credit to slum-dwellers in Mumbai.

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8 May, 2006 Princeton, NJ

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1.5 billion people, about a quarter of the world's population, do not have access to electricity, according to United Nations estimates. In South Asia alone, according to the same estimates, 800 million people have no access to electricity. While many of those in both the world and South Asia live in rural areas, remote from power generators, a rising number live in the informal urban settlements called slums. Approximately one-third of the world's urban residents, totaling over 1 billion people), live in such slums. While some of these slums do have access to electricity, many do not. In total, some 40% of the world's urban poor have little or no access to electricity (UN MDG, 2005). Lack of electricity can bring more hardships to the urban poor than the rural, as the urban poor have no agricultural economic system on which to rely. Electrification can raise the quality of life in slums dramatically, as well as serve as a gateway for further development. These slums that do not have access to electricity therefore constitute a unique problem for sustainable development.

This paper will first lay out precisely the nature of the problem, then discuss why traditional electricity service is not provided in many slums. It will then proceed to suggest that a combination of photovoltaic and wind power are uniquely able to address the difficulties of electrifying the slums of Mumbai, and similar slums situated on the Indian coast. Lastly, the paper will discuss how to implement electrification projects that rely on photovoltaic and wind power.

The slums of Mumbai, home to more than half the city's 16 million inhabitants in 2335 distinct settlements, are used as a case-study throughout this paper (Maharashtra provincial website). While some of the principles are applicable to slums in general, the reasoning and data present herein are intended to be valid with respect primarily to the slums of Mumbai.

Throughout the paper, the word “slum” and “slum-dweller” will be used to refer to informal urban settlements and the residents of these settlements, respectively. These settlements, though traditionally extralegal, may be legally constituted. Used in this sense, in accordance with accepted academic usage, “slum” is a technical term, and is not intended to connote any sort of value judgment about these informal settlements.

Why electrification is important

The United Nations’ guide to Energy Services for Millennium Development Goals, written by the UN Millennium Project, UN Development Program (UNDP), The World Bank, and the joint UNDP-World Bank Energy Sector Management Assistance Programme (ESMAP) writes concerning the need for energy in poor urban settlements:

> “The fact that electricity is often ‘tapped off’ illegally in urban poor areas is a testament to the desire of the poor to have access to the benefits that electricity provides, such as illumination, radio and television, and the ability to use machines and appliances that create jobs and incomes. In many cases, the fees recovered by informal sector middlemen who charge for these services outside of the utility structure testifies to poor families’ willingness to pay for electricity, even at a high cost. (UN MDG)”

The demand for electricity is immense among slum-dwellers. The UN report on Millennium Development Goals links this demand with the immense benefits for quality of life associated with access to electricity.

In a report on electricity for the world’s poor, the World Bank outlines a series of different kinds of benefits that electricity brings to the impoverished. The report divides the benefits of electricity for the poor into (1) Direct effects on well-being, (2) Direct effects on health, (3) Direct effects on education, (4) Direct effects on economic opportunities for the poor, (5) Trickle-down effects of increased productivity, and (6) Fiscal space (coupled with pro-poor policies)

The first category defines goods such as lighting and non-biomass fuel as constitutive of well-being. The second category, perhaps the most compelling, includes reduced fire hazard, improved potential for effective health services (through refrigeration lighting, etc), and perhaps most importantly for slums, improved air quality. Replacing old wood stoves, which cause chronic respiratory problems with habitual use, with heating elements can substantially ameliorate health conditions among slum-dwellers. The third category includes lighting to increase time for studying, the fourth more disposable income (since labor for collecting biomass can instead be turned to income-generating endeavors and lighting at night extends the work-day), easier establishment of businesses, infrastructure development, and employment. (Waddams Price 2000).

The conclusion is clear. Electricity is vital, not only for its direct benefits on health and welfare, but also because it can serve as a gateway for other kinds of development by means of increased access to information, facilitation of education, and reduced workload for certain mechanical tasks. A study by the World Bank and the Asia Development Bank set out to study the link between electrification (among other infrastructural projects) and standard of living, and found that while electrification is not correlated with income growth, it does allow better access to information, education, and increases quality of life (Chatterjee, S, et al. 2004).

Current electrification in slums

USAID's report on access to electricity in slums states that electricity is nearly universally available, due to the effect of *ad hoc* “companies” that systematically steal electricity by tapping into overhead lines and selling to slum-dwellers (USAID 2005). While little information exists about these systematic efforts, many other documents mention practices of a similar nature, including the establishment of interconnections between households that are connected to the grid and those that are not, and more isolated incidences of theft (Melo, F.C., et. al. 2001; PN Energy Services 1999).

Why traditional service is not brought to the slums

Since the prices charged per unit by these illegal “companies” are often quite high, rivaling and sometimes exceeding market-rate electricity (USAID), it is worthwhile to analyze precisely why traditional service is not brought to the slums, and perhaps more importantly, why attempts to bring traditional electricity service to the slums have repeatedly failed.

A. Sociological barriers to traditional service

To begin with, there are a number of sociological problems inherent in the task of extending traditional electricity service to the slums. In some cases, there may be a “culture of non-payment,” which can mean either that the slum-dwellers are not accustomed to paying for electricity, and can resist being asked to pay, or that they are accustomed to paying for electricity when and as they are able, more as one might purchase a good in the marketplace, and not as a regularly recurring, formal bill (USAID).

In addition, slum-dwellers, though they can constitute a large proportion of a city’s population —in Mumbai’s case, around half— play only a small role in the society at large. They are marginalized and ignored by the political, economic, and social systems that surround them. Efforts to incorporate them into the society around them, such as by extending ordinary electrical services to them, are not always seen as unambiguously positive. For instance, the periodical *The South Asian*, targeted at South Asians living in the United States, writes in a 1 March, 2005 article that slums "…are the cause of all criminal activity in our cities. They encroach on our roads, steal electricity from our wires, and illegally occupy land. They are ugly spots on our urban development. They are unhygienic and the source of much disease. / They must be rooted out, and demolished." This attitude perpetuates the desperate conditions of slum-dwellers, and obstructs projects aimed at their betterment.

B. Infrastructural barriers to traditional service

Other factors that prevent traditional service from being extended to slums are infrastructural in nature. To begin with, slum-dwellers often have no legal status. This can make dealing with them exceedingly complicated for utility companies. If, for instance, a company wanted to pursue judicial action against a slum-dweller for non-payment of a bill, it is unclear whether courts would in fact be able to accommodate this possibility.

In addition, slum-dwellers are typically squatters. That is, there is no official connection between slum-dwellers residences and themselves, and consequently, utility companies would find it extremely difficult to bill a slum-dweller successfully. Without mail service in the slums, companies would be obliged to set up their own collection service at great expense.

Finally, the very physical structure of the slums makes extending traditional service there difficult. The streets tend to be narrow and are rarely straight, making vehicular access, such as would be necessary to maintain power cables, either impossible or dangerous.

C. Economic barriers to traditional service

There are also some important economic reasons why traditional service has not been extended to most slums. The first, and most important, is that slum-dwellers are generally extremely impoverished, and simply cannot afford to pay for it. The poverty of slum-dwellers is only a partial explanation, however, since they are often willing to pay higher than market rates to illegal companies for electricity. Perhaps rather than mere poverty, it is the structure of income that most slum-dwellers earn that makes traditional bill payment difficult. Many slum-dwellers work informally, and work when they can. This means that their income, regardless of size[45], is often occasional in nature, cannot be depended upon like a salary (Bhowmik, et al. 2001)

Even if the previous barriers were not sufficient, utility companies have scant incentive to expand to slums. Despite the enormous populations of many slums, the per-capita demand in slums is quite small compared to that in regular settlements. The same economic dilemma that faces utility companies with regard to rural settlements also applies to slums. Reaching slum residences requires a substantial investment in the expansion of their distribution network, but the potential payoff is small, even if they succeed in collecting payment. Despite that utility companies can lose as much as 3-5% of their total revenue to "non-technical losses," (that is, thievery), it is not economically feasible for them to electrify the slums (USAID 2005).

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[45] The income variation is quite great. Sundar Burra notes that even doctors and lawyers are sometimes forced to live in slums (Burra, 2005).

Clean Distributed Generation (DG) technologies in the slums

Two renewable distributed generation technologies provide a uniquely sustainable solution to the problem of electrification in impoverished urban areas where traditional service is not possible, specifically small wind turbines and photovoltaic cell clusters to power a small number of geographically adjacent structures, whether a few houses, a block, a set of businesses, or a neighborhood.

A. *Distributed generation superior to traditional generation*

Distributed generation is often talked about as a solution for rural electrification needs, but it is generally assumed that in urban areas, traditional service is more economically feasible. A paper written for the World Bank on distributed generation in the developing world defines an economic tipping point past which distributed generation is superior to traditional service. Distributed generation becomes economically advantageous when "customer locations are very remote or expensive to reach," and the demand for electricity on a per-household basis is relatively small (World Bank, Wills, et al.). The paper did not mention urban distributed generation at all, but counter-intuitively, slums are similar to rural areas in terms of the economics of electrification. While slum areas are not by any means remote or dispersed, they are expensive to reach on account of their density, their legally ambiguous status, and endemic thievery. Moreover, percapita electricity demand is, at least for the present, quite small, as is per-capita income, and some of the specific uses for urban electricity are similar to those in rural areas.

Distributed generation has many advantages over traditional generation for slums. To begin with, the initial investment required to construct a distributed generation plant, that is, a photovoltaic-cell and turbine combination is relatively small, on the order of hundreds of dollars for individual home units, or a few thousand for more ambitious projects. On the other hand, while stringing up power lines that tap existing sources of electricity is much cheaper than establishing distributed generation plants, it may be necessary to establish sub-stations to electrify some slums, which requires a substantially larger initial investment than distributed generation plants. Since no development project is ever assured of success, the size of the initial investment ought to be an important consideration in any slum policy. Distributed generation plants, in addition to having relatively low initial costs, are physically reusable. If a distributed generation plant meets with little success in one slum, it is possible to move the physical equipment to a different slum without loss to the value of the equipment, though of course installation and siting costs will be lost.

In addition, distributed generation projects are not subject to electricity thievery, as all projects involving additional power cables certainly would be. This thievery can endanger the reliability of traditional service, and drive market prices for slum electricity higher. For distributed generation projects, thievery will not be a large problem for the simple reason that the amount of power cables will be small, and visibly connected from the source to residences. Coupled with a Low-cost Secondary Service Network — low-voltage cables placed in steel tubes on the ground (Mello, et. al. 2001)— thievery can be reduced to nothing. Not until a large majority of residences in the slum have access to electricity will thievery from existing power lines cease to be a problem.

Distributed generation does introduce a new element of theft, however, in that the distributed generation equipment itself could be stolen. There are several possible strategies for pre-empting equipment theft. To begin with, all generators should be mounted to metal frames, themselves securely mounted to buildings. This will make attempted theft apparent and visible, at the least, since the generators could only be removed from the frames with considerable effort, and this might deter potential thieves. A more promising solution, perhaps, is placing generators that benefit entire communities in public places. Because members of the community will value these generators, they are likely to react quickly and negatively if anyone attempts to steal them.

Another compelling advantage distributed generation has over traditional service is that can directly empower residents of the slums, who are usually marginalized in their societies at large. Because it occurs on a small scale, metering, bill collection, and even basic maintenance can be performed, with proper instruction, by actors who are themselves beneficiaries of the service. This "localness" not only empowers slum-dwellers by giving them electricity and control over that electricity simultaneously, but also in many situations might lead to better service, as municipal authorities in Indian cities have been notoriously subject to corruption and often fail to perform tasks in the slums, where there is little accountability for them (Burra et al., 1999; USAID), and local actors have a better understanding of the social fabric of the slums. The specific sociological impacts of distributed generation plans administered by neighborhood will be discussed below.

B. *Clean Renewable DG has no fuel costs*

One might justly ask, however, if using renewable technologies specifically is justified, since non-renewable technologies, such as the diesel generators often used in distributed generation projects, can provide a larger amount of power and a greater degree of consistency than wind and solar power. There are at least two compelling reasons why renewable technologies are superior in slum contexts to non-renewable sources, which usually means fossil-fuel sources. The first is that, unlike non-renewable generators, wind and photovoltaic technologies have few recurring fuel costs. This is a potent objection to non-renewable sources, because one of the historic difficulties in electrifying slums is that slum-dwellers often have difficulty paying a recurring, regular expense, such as would be necessary to pay the fuel costs of a non-renewable generator (USAID 2005). Moreover, some of the same problems that prevent traditional service from reaching the slums would make establishing a fuel distribution network that reliably delivers fuel to generators extremely difficult.

However, problems with the recurring cost of fuel and fuel distribution are a less important objection to fossil-fuel generators than their demonstrated pernicious health effects in densely populated areas. One study by the University of California Energy Institute (UCEI 2005) investigated the effects of a variety of relatively clean, but non-renewable distributed generation technologies on air quality in California. They found that because distributed generators are by definition much closer to the areas whose power they supply, their negative air quality effects are much worse than traditional non-renewable plants. Specifically, for California, the number of people exposed to pollutants emitted by distributed generation plants is an order of magnitude larger than those exposed to pollutants from traditional plants, and the total amount of pollutant inhaled from distributed generation plants is three orders of magnitude greater than pollutant inhaled from traditional plants, per unit of electricity (UCEI 2005). While California and

Mumbai are very different places, Californians generally live further apart than inhabitants of Mumbai, and the distributed generation technologies assessed all met California's state pollution standards. Given the extreme population densities of Mumbai's slums, and slums generally, and the greater likelihood the technologies that do not conform to California's air pollution standards will not be used in Mumbai, the consequences of fossil-fuel-based distributed generation for respiratory health are likely to be much worse for slum-dwellers than for Californians. Because of the prevalence of wood-burning stoves used for cooking indoors, chronic respiratory problems are already endemic in the slums. While the electricity provided by a fossil-fuel generator could diminish the use of wood-burning stoves indoors, and thus provide some health benefits, these would be reduced by the exhaust from the generator.

Wind and photovoltaic power have neither of these drawbacks. The only costs involved with them are the initial investment and occasional maintenance. This avoids the problem of regularly recurring costs for slum-dwellers and well as the difficulty of distributing fuel. In addition, wind and photovoltaic power are completely emissions free. The only known negative environmental impact either has is that large wind turbines can affect avian migration routes, but this is not a problem for small turbines, and is a small concern compared with potentially exacerbating the air quality problems that pervade many slums and contributing to global climate change through carbon dioxide emissions. In consequence, every watt generated by photovoltaic or wind power directly assists the slum population, and has the potential even to impact air quality positively by reducing dependence on wood-fuelled stoves.

C. The question of reliability

A powerful drawback of PV and wind power, however, is that they cannot provide electricity as reliably as a fossil-fuel-based generator can. Even during times of regular wind or sunlight, the electricity provided by turbines and PV cells will be intermittent, unless additional power has been stored in batteries, and even with batteries, spells of cloudiness or windlessness will not allow the technologies to provide perfectly reliable electrification.

One of the unique advantages of PV and Wind power in the slums of Mumbai, however, is that reliability is not as important for slum-dwellers as it is for inhabitants of legal settlements, and consequently one of the most important objections to the widespread use of the technologies is not fatal. While reliable, legal electricity is important for the slums, and should continue to be a long-term goal, access to even occasional electricity could improve quality of life for slum-dwellers dramatically in the areas of lighting, cooking, and telecommunications, for instance. It is tempting to consider reliability a *sine qua non* in improving slum conditions, but if reliability entails plugging slums into the regional grid and demanding fees for service, slums will continue to be left out in the cold for a long time to come. In fact, the difference between the reliability of standard generation and the reliability of PV and Wind in slums may be narrower than one would suppose, since ordinary power lines are subject to leakage and theft, and the loss of a single line can sometimes mean an outage for large sections of the slum, whereas there is little leakage and little potential for theft with PV and Wind, and individual units can be repaired, replaced, or upgraded without loss of power for large areas of the slum.

While some uses for electricity, most notably refrigeration, require uninterrupted power to be of any use, many energy uses in slums can be useful even with intermittent service. Most notably, these are lighting, possibly cooking, and telecommunications.[46] Lighting is useful for slum dwellers because it can substantially augment individual productivity. Work that involves any degree of precision after nightfall will be greatly facilitated by electrification, since traditional lighting methods such as candles are less luminous than light-bulbs, generally. Incremental increases in lighting will yield incremental increases in productivity, and access to electrification at certain times will produce increases in productivity during those times.

The advantages of cooking with an electric heating element are also non-discrete. There are two principle disadvantages over biomass-fuelled stoves, the primary cooking tool in the slums. First, the daily expense for fuel often sometimes represents a large percentage of a slum family's daily income. Though a World Bank report found daily energy expenditures for the poorest quintile in a wide-range of countries to be under 5% of total income, the time required to gather fuel can have a substantial opportunity cost (Townsend 2000). Secondly, and perhaps more importantly, burning biomass without proper ventilation, as it is usually burned in the slums, has highly pernicious long-term health effects. Cooking by electric heating element, even if not always available, can save money for families dependent on biomass cooking whenever it is, since, as noted, families often spend large amounts of time collecting fuel.

[46] While electricity is used for cooking typically at the higher end of the energy ladder, most likely for a variety of sociological (resistance to cooking without fire) and technical (stoves typically require higher voltage and amperage compared to other appliances) reasons, this paper will treat cooking as a potential application of electrification in slums. It should be born in mind, however, that this use for electricity is unlikely to become widespread immediately after electrification without additional projects implemented, such as low-voltage heating elements that can generate sufficient heat to cook, or education about the health utility of electric cooking over against biomass cooking

Moreover, every occasion when a family uses electric cooking instead of burning biomass represents the diminishment of the health-risks associated with inhaling smoke, which will eventually result in a lower community-wide incidence of chronic respiratory problems.[47]

Telecommunications is another potential use for even intermittent electric power, though its precise utility is less concrete. Telecommunications, in the form of radio, television, and possibly even two-way communications (e.g. community cell phones) are powerful instruments for political and social empowerment within a society. Any small amount of access to information about the world outside the slum is empowering, and incrementally more empowering as the level of access increases.

In addition, one of the unique benefits of distributed generation technology in slums is that those most directly interested in reliability can take responsibility for power generation in their neighborhood. Turbines and PV panels, set up for small neighborhoods or blocks, thereby become the responsibility of those receiving power from them in that neighborhood, simultaneously allowing for empowerment of slum-dwellers, and giving them incentives to find ways to improve reliability.

D. Local conditions suited for PV and Wind

Of course, renewable technologies must be implemented in a manner that is informed by local climate conditions. The city of Mumbai is well suited to a combination of photovoltaic and wind power, as would be most tropical and sub-

[47] Though it is important to note that proper ventilation and other methods might be more effective in rapidly improving respiratory health.

tropical coastal cities.

There are two main seasons in Mumbai, namely a monsoon season and a dry season. The monsoon season is characterized by heavy rainfall and strong, persistent westerly winds, conditions ideal for wind power. The dry season is characterized by heat and sunlight, conditions ideal for photovoltaic power (Maharashtra provincial website).

The use of Vertical Axis Wind Turbines (VAWT) instead of traditional horizontal axis turbines could be quite effective. To begin with, some VAWT systems are capable of 45% efficiency, where regular turbines are usually closer to 25-40%. More importantly, however, VAWTs are capable of safe operation in much higher velocity winds than regular turbines, which is important for Mumbai, since during the monsoon season winds regularly reach extreme velocities. In addition, VAWT components, unlike traditional wind turbine propellers, do not need to be precisely and delicately manufactured (Economist 2006)

Implementing Clean DG in slums

Distributed generation plant costs are relatively cheap to manufacture and install. A wind turbine costs around $1000 per kilowatt of capacity, and has a footprint on the order of 0.01 kilowatts per square meter. Due to the poor construction of many slum settlements, wind turbines would need to be supported at ground level. Wind turbine operation costs for distributed generation vary with the size of the rotor, wind "density" (very high in a low-lying city like Mumbai), and average wind-speed. Typically they fall between 4¢ and 12¢ per kilowatt-hour. For photovoltaic cells, a much higher cost of $6000 per kilowatt of capacity is necessary, though most of the proposed distributed generation arrays will not have close to a kilowatt of capacity. PV footprint size is also much larger than for wind turbines, but because it can be easily mounted on rooftops, this is of small concern. Operational costs for PV cells fall between 18¢ and 20¢ per kilowatt hour (Petrie, et al.).

The financing of the initial investment ought to involve both actors in the slums who will be directly affected through micro-credit options, and utility companies, who want to see theft eliminated, since it can amount to 3-5% of total revenue (USAID 2005). Entrepreneurship in implementing these projects should arise from within the slums and NGOs that work closely with slum-dwellers. The materielle necessary for construction of such plants should be provided by a third party that specializes in their construction, possibly a private company under long-term contract to the Indian Renewable Energy Development Agency (IREDA), which is an agency within the Indian government responsible for promoting renewables and financing their implementation. The World Bank and the Asian Development Bank have both extended large ($195 million and $150 million, respectively) lines of credit to IREDA for renewable energy projects, and some of this credit should be mobilized in the service of slum electrification through renewable distributed generation (IREDA).

Since IREDA is not a micro-credit agency, and the capital costs for photovoltaic and wind arrays will be smaller than the bank typically deals with, this credit should be distributed by micro-credit banks, such as the Grameen Bank, for whom the IREDA credit would minimize risk (since defaulting clients would not diminish capital holdings), or, since this model has not been used before, a new micro-credit sub-bank dealing exclusively with such projects could be created by the Indian government as part of IREDA, or in connection with local municipal or provincial governments. The capital for micro-credit loans would then simply be earmarked for this purpose, and the sub-bank would receive proposals for projects from NGOs and possibly individual slum-dwellers.

IREDA does not give loans exceeding 80% of total project cost or 90% of equipment cost (IREDA). The remainder of the capital required could come from the slum-dwellers, other micro-credit banks, or possibly the utility companies themselves, who have a financial incentive to provide loan capital to the sub-bank as a step towards eliminating electricity theft. In addition, these companies could provide subsidized assistance or expert advice on the installation of wiring, including transformers and transmission.

Throughout the process, the local entrepreneurs, whether NGOs or individuals, should be given the freedom to experiment with different strategies for payment and the number of households connected to a single plant. For instance, metering could be conducted in non-traditional manners such as upfront payment. In the past this approach has worked well in slums (PN Energy Services 1999).

Though allowing for entrepreneurship from local actors guarantees some measure of sociological sensitivity, there are several factors the whatever agent is ultimately responsible for micro-credit must keep in mind while making decisions about credit to ensure that the benefits of projects will extend throughout the community. While providing loans for single-dwelling units, for instance, is not likely to hurt the community, projects that focus on neighborhoods (for instance, a collectively used array or streetlight installation) will be especially useful in promoting neighborhood investment in projects. One of the single most important factors in successful infrastructural development projects that benefit the slum community is gender-consciousness. A multitude of past experience has taught the world that women are not only the beneficiaries of electrification, they are much more likely to take responsibility for the development (Batliwala, Srilatha & Amulya K.N. Reddy 2003).

If possible, the agencies providing credit for the projects should request that the third-party companies that will procure and install the equipment use slum labor in the process of installation. This will both bring income into the slums and encourage slum-dwellers to view the projects as long-term investments.

Conclusion and Recommendations

Renewable distributed generation technologies can provide sustainable energy services for the slum-dwellers of Mumbai. While no approach to slum electrification in Mumbai to date has made use of renewables[48] (Burra, email), the ever-falling costs of wind power due to technical innovations and Mumbai's climate make the city's slums perfect for a distributed-generation-with-micro-credit approach. The following actions are recommended:

The government of India, in cooperation with local governments around Mumbai, should direct IREDA either to establish a micro-credit sub-bank or form partnerships with existing micro-credit institutions to establish a line of micro-credit for

[48] Attempts at slum electrification in Mumbai have been sporadic, and have mostly focused on extending traditional service (Burra, 2005)

distributed generation projects using renewable technologies in the slums of Mumbai.

The sub-bank, or micro-credit banks, should receive as clients both NGOs and qualified individuals from within the slums who wish to establish photovoltaic and small VAWT arrays, allowing for flexible business models and experimental approaches.

This sub-bank, or micro-credit banks, should consult with local companies capable of procuring and installing photovoltaic and small VAWT arrays, and encourage the entrepreneurs to insist on the use of local labor during installation by contract, if possible.

This sub-bank should work with entrepreneurs to find capital sources for costs not covered by IREDA capital, looking to other micro-credit banks, utility companies, and individual slum-dwellers.

The Commission on Sustainable Development should indicate to the Indian government that a distributed generation electrification project using renewables in India's slums would further the policy goals of the Johannesburg Plan of Implementation, thus acknowledging the importance of electrification for the urban poor and giving their pre-emptive support to such a project.

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Off-grid Energy in Rural India:

Policy Recommendations for

Effective UN Projects

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This paper represents my own work according to University Regulations.

Abstract

Rural areas in developing countries suffer significantly from energy scarcity, forcing people to rely on traditional biomass as their primary energy source. The current approach of the government of India (GOI) to solve this problem focuses on extending the electricity grid, which fails to attend the real needs of poor people and is too expensive. This paper discusses the potential use of off-grid energy technologies, like improved cooking stoves, biogas digesters, and micro hydropower, as an alternative for grid extension. This is followed by four policy recommendations to ensure that UN rural energy projects are effective in complementing the GOI's efforts and attending the basic energy needs of the most poor in rural India. These recommendations are: to provide micro-credit and consulting for the promotion of off-grid renewable energy technologies (RETs); to focus on alleviating women's energy needs, particularly cooking; to include capacity building in energy projects by creating partnerships with the community and providing technical assistance; and to financially support local entrepreneurs who could either benefit from energy access or supply their communities with energy services.

Timeline

I. Introduction

II. Understanding the Energy problem

- *A. Lack of Energy in Rural Areas*
- *B. Dependence on Traditional Biomass*
- *C. Climbing the Energy Ladder*
- *D. Negative Effects of Energy Scarcity*
- *E. Energy and Development*

III. Off-Grid Alternative Technologies

IV. Government of India (GOI) Approach

- *A. An Impossible Challenge*
  - *- Policy Recommendations*

V. Elements for Effective Rural Energy Development

- *A. Using Renewable Energy Technologies (RETs)*
  - *- Policy Recommendations*
- *B. Targeting Women's Energy Needs*
  - *- Policy Recommendations*
- *C. Capacity Building and the use of Local Resources*
  - *- Policy Recommendations*
- *D. Increasing Energy Penetration through Wealth Creation*
  - *- Policy Recommendations*

VII. Conclusion

I. Introduction

Energy, an essential need for every individual and for economic development, has always been particularly lacking in rural areas of developing countries, were rural areas are defined as sparsely separated, faraway from large cities and in many cases, in difficult terrain. Most people who live in rural areas rely primarily on farming, although some times they have small businesses or the main income-providers commute for jobs in urban centers. Rural areas in developing countries are severely deprived of dependable energy, which they need primarily for household use (mainly cooking), water pumping for agriculture and domestic use, and small scale industry, as shown in table 1. Most of the energy needs in rural areas are met with traditional biomass for household uses, and human and animal power for agriculture.

This paper will first analyze the main problems involving energy provision for poor people in rural areas of developing countries, with a focus in India. Although the focus of this paper is energy, not electricity, access to electric connectivity and the reasons for low electrification rates in rural areas will be analyzed in order to show the urban-rural differences and the challenges for the government in rural areas. Other topics that will be covered are: the dependence on biomass, the energy ladder, the negative effects of energy scarcity, and the additional benefits for development that are possible with access to energy. This paper will then review available off-grid technologies that can be promoted by the UN, development institutions, and NGOs in rural India. These technologies focus on particular end-uses, like efficient wood-fueled cooking stoves, biogas digesters for fuel production, or wind turbines for water pumping, as well as independent electricity systems for households and village micro-grids.

This will be followed by an explanation and analysis of the Government of India's (GOIs) approach and goals in respect to rural electrification. Considering that the GOI's plans are over-ambitious and that they do not attempt to solve the main energy needs of the most poor, this paper will then discuss and offer recommendations on four elements that must be included in the United Nation's rural energy projects in order to complement the GOI's efforts and make off-grid energy affordable and available in rural India. The focus of these elements will be on the end-use of alternative off-grid technologies that meet the needs of families and individuals who suffer the most from energy scarcity. It is important to note that this paper does not aim to either improve government rural electrification programs or improve projects the UN has done in the past. These four elements are: the use of renewable energy technologies (RETs), the importance of prioritizing women's energy needs, the need for capacity building and technology development with local resources, and the importance of linking increase in energy access to income generation and wealth creation.

II. Understanding the Energy Problem

A. Lack of Energy in Rural Areas

Although this paper is about energy needs, not necessarily electric connectivity, electrification rates are a good benchmark to measure urban-rural differences. Currently, there are 1.6 billion people in the world who lack electric connectivity in their homes, and four fifths of these people, or about 1.3 billion, live in rural areas, most of them in Africa and Asia (Priddle 2002).[49] It is important to note that even in rural areas where

[49] Although this number is staggeringly high, there have been connectivity rate increases in the past 30 years, as world rural electricity rates have gone from 12% in 1970 to 57% in 2000 (Priddle 2002). Most of this improvement, which has occurred primarily in the last 15 years, has taken place in China, a country that has extended rural electrification to about 500 million people since 1990 (McDade 2004). Despite the

electricity is accessible, connectivity is often severely interrupted, resulting in high rate of burnouts of pumps, motors, and transformers (Rizvi 2004, p. 9). With 580 million people lacking electricity connection, India is the country with the most people without access to electricity in the world. Just about 56% of its population has access to electricity at the national level, and 44% in rural areas (Priddle 2002). This means that more than 400 million people in rural areas are still lacking access to electric services (Rizvi 2004).[50]

The main reason for lower electrification rates and higher costs in rural areas worldwide is that grid extension is more expensive in rural than in urban areas. The high transmission and distribution costs in rural areas make it unattractive, especially since most people are poor and thus unable to pay for electric services (Johansson et. al. 2004).[51] In other cases, when subsidized grid extension does reach rural areas, the tariffs are too high for people to pay because the existent demand is too low (United Nations 2005). For example in India, according a report from the International Energy Agency, "the electricity network is technically within reach of 90% of the population, [but] only 43% are actually connected because people cannot afford the cost of connection" (Priddle 2002, p. 376).

B. Dependence on Traditional Biomass

Poor people lacking adequate energy services in rural areas rely mainly on traditional biomass: firewood, charcoal, and animal dung. In fact, for the purposes of this paper, the use of traditional biomass is a better standard than electric connectivity to help

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percentage drop, the number of people without access to electricity in rural areas has remained the same because of population increase (Johansson et. al. 2004).

[50] Of the 138 million households in rural areas, just about 60 million have access to electricity (Rizvi 2004).

[51] According to a World Bank study on several developing countries, "grid extension to rural areas typically ranges from $ 8,000-$ 10,000 per kilometer, not including the cost of materials, which adds an additional $ 7,000. This high cost, coupled with low capacity utilization of such grids due to very small loads, makes extension economically unviable to utilities" (Aeck et. al. 2005, p. 17).

understand the breadth of the energy problem and the urban-rural differences in regards to energy. As shown in table 1, cooking is the main use of energy in rural households, consuming up to 85% of the total energy use (Aeck et. al. 2005). Currently, about 2.4 billion people, mostly in developing countries, depend on traditional biomass, representing 40% of the world population.[52] The use of traditional biomass is more prevalent in rural areas, simply because biomass is more available and other fuels are harder to get (Aeck et. al. 2005). This number is greater than the number of people who lack electric connectivity because cooking with electricity is too expensive, and thus many people who do have electricity access continue to rely on biomass until they move up to kerosene or liquefied petroleum gas (LPG). In India, the number of people still using traditional biomass lies at about 585 million, representing 58 % of the population (Priddle 2002, p. 11). As Rangan Banerjee points out in *Energy Policy*, overall “biomass (fuel wood, crop residues and cattle dung) accounts for about 40% of India’s primary energy use,” with the largest portion being consumed in rural areas (Banerjee 2006, p. 106).

C. Climbing the Energy Ladder

The “energy ladder” is a concept that describes the resources and end uses of energy in poor rural areas relative to income, showing how poor people in rural areas meet their energy needs as their income increases. For household use, the first footstep of the ladder is biomass, with the second step being kerosene and LPG, and finally electricity, as shown in table 2. It must be noted that for different uses, like agriculture

[52] About 50% of the population in Africa, 25% in Asia and 18% of the population in Latin America depend on biomass (Martinot 2005).

and small businesses, there variations to the energy ladder, particularly with the increased used of animal and human power.

As this paper tries to analyze alternative solutions to the traditional energy sources, there are three issues of the energy ladder that are of paramount importance: the first one is that biomass is the hardest footstep to move past because it is regarded as "free;" families in rural areas simply gather firewood, there is no monetary cost involved. Thus, the idea of paying for technology, especially renewable energy technologies (RETs, which have high capital costs), does not make sense for poor people in rural areas. The second issue is that, as an International Energy Agency report indicates, there is a "widespread misconception that electricity substitutes for biomass. Poor families use electricity selectively – mostly for lighting and communication devices. They often continue to cook and heat with wood or dung, or with fossil-based fuels like LPG and kerosene" (Priddle 2002, p. 369). Thus, moving up the energy ladder includes both, innovative technologies for specific end-uses and modern improved uses of traditional fuels. Finally, the third issue is that there is a misconception that moving up the energy ladder is completely dependent on affordability (or income), but it must be noted that availability and cultural acceptance are equally important (Priddle 2002).

D. Negative Effects of Energy Scarcity

Before looking into potential solutions to the energy problem, the negative social and environmental effects of lacking energy in rural areas must be visited in order to have a clearer understanding of what issues need to be addressed. One of the worst effects of energy scarcity is the time spent by women and children finding firewood, particularly for cooking. According to Practical Action, an international NGO that aims to provide practical solutions to poverty and sustainable development, "poor people spend up to a third of their time on energy, mostly to cook food. Women, in particular, devote considerable amount of time collecting, processing and using traditional fuels for cooking. In India, two to seven hours each day can be devoted to the collection of fuel for cooking" (Practical Action 2005, p. 7). Aside from the cost and time, women are exposed to snake bites, threats, assault, and health problems like back pain, neck pain and fatigue from carrying heavy loads for long distances (McDade 2004). The time that women spend finding firewood and water for the household could be used for income-generating activities, and the time children spend could be spent in schools. Indoor air pollution is also a major negative effect of dependence on biomass because of the emissions of carbon monoxide, nitrogen oxides and most importantly, particulate matter. Up to one billion people, mostly women and children, are daily exposed to indoor air pollution at levels exceeding WHO guidelines by 100 times, causing respiratory illnesses to children, premature deaths, and miscarriages to pregnant women. Approximately 1.6 million people die from indoor pollution every year, making indoor smoke the fourth greatest health-associated killer (Wilkins 2002, p. 27; Practical Action 2006b, p. 2).[53] A third negative effect is the harm caused to the environment, since the use of firewood for households is not done in a sustainable fashion, although it is much less than the deforestation caused by the clearing of land for agriculture and grazing (United Nations 2003).[54] One final problem is the trade-off between using biomass for energy versus

[53] This accounts for 20% of child deaths, more than those from malaria (McDade 2004). "In India, the pollution from household solid fuel use causes an estimated 500,000 premature deaths a year in women and children under the age of five" (Wilkins 2002, p. 30).
[54] It must be noted that there is a common misconception that firewood for energy is a major cause of deforestation, but the reality is that most people who fetch firewood get already dead wood.

agricultural purposes, particularly when the biomass used is animal dung, since it could be used as fertilizer (Priddle 2002).

E. Energy and Rural Development

Aside from cooking, energy could also benefit families in rural communities by providing thermal comfort and allowing them to pump water for drinking and irrigation. Electricity is used mainly for lighting and electronic equipments used for information and communications, like TVs, radios, and telephones. However, with domestic access to electricity it is hard to know its final effect on a family's wellbeing. According to a study by the United Nations, "rural electrification benefits higher-income segments of populations more than lower-income segments, and it often exacerbates rural poverty gaps and gender inequities" (United Nations 2005, p. 33). Other experts show that the difference between connectivity and no connectivity (even if the use of energy is minimal) is significant. Akanksha Chaurey, in *Energy Policy*, points out that the "positive contribution of electricity to the Human Development Index is strongest for the first kilowatt-hour" (Chaurey et. al. 2004, p. 1).

At a community level, energy needs such as water pumping are absolutely necessary, yet the best way to improve wellbeing is with electricity. For example, electricity can have a major positive effect on education, as it enables the use of photocopiers, computers and other educational media, opens the possibility of having night classes, mainly for the education of adults, and attracts teachers that would otherwise be shied away, especially if their accommodations have electricity (Aeck et. al. 2005). Energy services are also beneficial for health as it provides improved access to better medical facilities, including refrigeration, equipment sterilization, and operating theatres (McDade 2004).

Energy services also enable income-generating activities and micro-enterprise, a topic that will be emphasized strongly in this paper given that the most effective policies for increasing energy access and electrification rates have to go hand-in-hand with increasing income, creating jobs, and empowering poor rural communities. Some forms of energy (that are not electricity) for business in poor rural areas can range from food processing, brick making, pottery and water pumping for irrigation (Rogers et. al. 2000). In India, most of the energy use in rural areas is for agriculture irrigation, and this energy is mostly met with animal and human power. Electricity is also beneficial for business as they allow longer operating hours, cleaner and safer working conditions, consumer draw (radio, fans, and televisions), mechanization/automation, product preservation (refrigeration), ice making, communications and workers' training (Rogers et. al. 2000).

III. Off-Grid Alternative Technologies

Before analyzing the elements that must be included in UN projects for rural energy, this paper will review some off-grid technologies that can serve as solutions to the rural energy problem in India. The following sections lay out the available off-grid technologies, analyzes their advantages and disadvantages, and helps understand the different end-uses each technology can meet. Both, off-grid technologies for different direct-uses and technologies for electric-micro-grids are considered.

As mentioned above and as shown in table 1, poor families use energy mainly for cooking. The cooking stoves they use are mainly made of mud and brick, and According to Practical Action, they are 10-15% efficient. Thus, the first technology to be considered for improved access in rural areas are more efficient cooking stoves, called improved chulas (IC) in India, which continue to burn wood, but have much higher efficiencies, reaching up to 40% (Practical Action 2006). Today, a number of low-priced modern wood-fueled ICs have been developed, with improvements based on enclosure to retain heat, maximization of heat transfer to the pot and improvement in combustion. Aside from being more efficient and thus enabling women to spend less time finding wood, emissions of indoor pollutants are also reduced. An International Energy Agency report states that "because biomass with continue to dominate energy demand in developing countries in the foreseeable future, the development of more efficient biomass technologies is vita for alleviating poverty, creating employment and expanding rural markets" (Priddle 2002, p 390). A second technology for cooking is thermal solar cooking, which uses the heat from the sun (Rogers et. al. 2000). Solar thermal cookers can be 30% to 70% more efficient than regular cooking stoves, and the production costs are decreasing dramatically. The main problem with solar thermal energy is the drastic differences with traditional uses for cooking, which might result in significant cultural barriers.

Biogas digesters also hold great promise in delivering change in rural areas, especially in India, where there are large amounts of cattle. Biogas is produced from animal and human waste through a process known as anaerobic digestion, done with organic matter.[55] The marsh gas, or methane, produced, can be used as fuel, replacing traditional biomass or even kerosene and LPG. Some of the advantages of biogas are that there are lots of animals in India, thus it can be produced at low cost, and that the

[55] The waste is fed into a digester and an anaerobic decomposition inside the digester produces methane and carbon dioxide (in a ration of about 6:4) (Practical Action 2006).

technology to make biogas can be produced locally as well. Furthermore, as Practical Action states, "small-scale biogas production in rural areas is now a well-established technology," particularly China and India (Practical Action 2006).

Other modern uses of biomass are also great alternatives for replacement of traditional forms, especially in India. Alternative biomass consists mainly of agricultural residues, like rice and coffee husk, and sugar bagasse. The biggest problem with agricultural residues for energy is the low energy per volume, which makes it difficult to handle and transport, but there are several ways of solving this problem, like the making of briquettes (pieces of condensed agricultural residues). One of the main advantages of biomass residues is that they can replace traditional fuel wood directly.

Solar Photovoltaic (PV) Panels have recently become a popular solution to target energy problems in disconnected areas. PV panels are particularly good for independent systems for the production of electricity, like street lighting, community facilities, or solar home systems (SHS) (Rodolico 2005).[56] This is different from hydropower, for instance, where a minimum size is required and there are expansionary limits based on the size of the river and the capacity of the turbine. Another advantage of PV panels is that most of them have proven to be reliable, durable, require low maintenance, and last up to 30 years.[57] The main problems with PV panels for SHS are the high capital cost (as well as installation cost), the need of a battery, which has to be replaced every four to five years thus increasing operating costs, and the fact that they cannot be produced locally and that spares are expensive. Larger PV panels can be used for electricity-micro grids, although the technology might still be too expensive.

[56] SHS consist of a PV module with 18-75 W capacity and a battery (Chaurey et. al. 2005, p. 15).
[57] This is true for panels from certified producers; there are also many low-quality PV panels for which this statement does not apply.

A second technology that has become increasingly popular in the last years for rural energy supply is wind energy.[58] One of the main advantages of wind turbine generators is that they can be used for both, a household system, or an integrated grid. In the same way as PV panels, the more windmills are installed, the more energy is generated. One of the problems with wind, however, is its intermittence, and thus they are not as reliable as other sources. Using wind for electricity might also be too expensive due to the high replacement costs of batteries. However, for other applications like mechanical energy for water pumping, wind can be extremely beneficial. One final advantage of wind power is that the larger part of the structure can be locally produced, with laminated wood, plastics and welded or galvanized steel for the tower, and thus communities would only have to import the generator and gearbox.

For electricity micro-grids, there are two particular technologies that have a great potential in India: micro hydropower, and biomass gasifiers.[59] Small hydropower (SHP), of about 5 kW to 100 kW, basically consists of a small channel that takes the water from a small river or creek to a settling basin and then to a forebay tank, where the water is stored at a higher altitude so that it gets potential energy. The water is then fed into a tube or penstock that brings the water down to a power house in the form of mechanical power, where the mechanical power itself can be used or a turbine can generate electricity. The main advantages of SHP are that hydropower is technologically mature, easy to maintain, reliable (as long as the river has a continuous flow), and has low operating costs. Its main disadvantage is, similar to other RETs, the high capital costs.

[58] A typical small wind generator has capacity between 50 W and two kW, "has a rotor that is directly coupled to the generator which produces electricity" (Practical Action 2006).

[59] "A mini-grid refers to small power plants that supply 220 volts 50 Hz three-phase AC electricity through low-tension distribution networks to households for domestic power, commercial activities, and community requirements such as drinking water supply and street lighting" (Chaurey et. al. 2005, p. 16).

SHPs are particularly good for micro-grids, but they can also be used for mechanical power.

Another technology that could be used for production of electricity and has a great potential in India is biomass gasification. Biomass gasifiers basically convert biomass into "producer gas" through a thermo-chemical process, the producer gas is then cleaned, and then powers and internal combustion engine for generation of electricity. This method is particularly good for small capacities in the kW range (Chaurey et. al. 2005). Biomass gasifiers are advantageous because they use local resources in a sustainable manner, yet they have higher operation and maintenance costs and the technology is not fully developed yet (Chaurey et. al. 2005). For more details on the status of different energy technologies for rural India, see table 3 and table 4.

IV. Government of India's (GOI) Rural Electrification Program

A. An Impossible Challenge

The main approach of the GOI to increase energy access in rural areas is by increasing electric connectivity through subsidies. There are two main problems with the government's rural electrification plans. First, rural electrification focuses on supply, as they just aim to ensure that houses are simply connected to the grid, but fail to solve the real challenges of rural energy mentioned in sections *II.D* and *II.E*. In other words, rural electrification programs provide electricity for the sake of increasing access, but do not provide solutions to the basic energy needs for poverty alleviation, which are mainly cooking and water pumping. The second problem is, as explained below, that it is simply too expensive.

Currently, the GOI has two goals with respect to rural electrification: extending electricity to all rural villages by 2008 and to all households by 2012 (Rizvi 2004). These goals form part of the Rural Electricity Act 2003, which as Rangan Banerjee points out in *Energy Policy*, has "made it a statutory obligation to supply electricity to all areas including villages and hamlets" (Banjaree 2006, p. 102). More details of this act can be found in table 6. Right now, about one million new rural customers are connected every year, but there are 1.85 million new customers ever year, so the growth rate is currently higher than the connectivity increase rate (Rizvi 2004, p. 9). According a World Bank report the total necessary investment to meet these goals is approximately $ 95 billion, equaling about 15 billion per year, or 2.1 % of GDP. This number is significantly larger than the current budget for rural electrification (1997-2002), currently at about 350 million per year (Rizvi 2004, p. 10).

Furthermore, the GOI's method of electrification has several deficiencies. The same report from the World Bank explains that there are three different institutions working on this endeavor without sufficiently coordination between each other and with "overlapping mandates for rural electrification oversight and funding" (Rizvi 2004, p. 16). Furthermore, the majority of the rural connections do not have a meter because they have a flat tariff, leading to major inefficiencies. These inefficiencies, together with poor collection practices, have led the Indian electricity sector into a financial crisis (Rizvi 2004, p. 19).

Aside from expansion of rural electricity from the central grid, independent providers have played a big role in making electricity accessible in rural India. These providers, known as Rural Electric Cooperatives (RECs), are inefficient because the government has imposed strict regulations on them. Two of these regulations are: low tariffs and forced supply of free electricity for street lighting and irrigation pumping (Rizvi 2004, p. 27). Furthermore, licenses for new providers are complicated and hard to get (Rizvi 2004, p. 23). These issues must be considered because even if UN projects for energy in rural India have the right approach, technologies and finance mechanisms, government impediments can drastically limit their ability to effect change.

Policy recommendations

To improve the conditions for off-grid energy providers in rural India, the United Nations could propose to the GOI to facilitate the entrance and operation of individual electricity providers by:

- *Simplifying licensing and reducing regulations for providers of off-grid alternative energy services and micro-grid electricity.*

V. Elements for Effective Rural Energy Development

The next sections address the four main issues and policy recommendations that should be considered by the UN in order to have rural energy projects in India that one, complement the GOI's rural electrification program, and two, meet the basic energy needs of the most poor by focusing on the end-use of off-grid alternative technologies.

A. Using Renewable Energy Technologies (RETs)

Traditionally, there has been a misconception that energy development in rural areas is specifically electricity provision for home lighting and appliances, diesel for engines producing mechanical power, and LPG and Kerosene for cooking. However, with renewable energy technologies (RETs), which have a plethora of end-uses, this misconception and limitation, could be overcome. RETs, defined as technologies that are powered by self-producing and self-maintaining resources, including sustainable use of biomass are advantageous because they can replace and improve the specific end-uses of many energy-requiring needs, overcoming the limitations of traditional use of firewood and decreasing the dependence on fuels that in many cases are inaccessible, as shown in table 5. Secondly, RETs have lower transmission and distribution costs than fossil fuels and extension of electricity grid lines. Third, RETs are advantageous because they are environmentally clean, both in terms of pollution that is harmful for human health as well as lower emissions of greenhouse gases (GHGs) that contribute to global climate change (Aeck et. al. 2005).

Finally, RETs have high capital costs but low operating costs, unlike the traditional technologies that have higher operating costs. Thus, as an expert from the Renewable Energy Policy Network for the 21st Century states, "over time the low operating costs of renewable energy systems offset their high capital costs through avoided fuel expenses" (Aeck et. al. 2005, p. 17). Furthermore, the cost of making RETs is decreasing due to technological advances, economies of scale, declining costs and political support, hence they are becoming even more attractive and almost cost-competitive (for initial purchase) with traditional technologies (Aeck et. al. 2005). These high costs, both capital and operating, are even further decreased if local materials and skills are used for the production, maintenance and reparations of RETs. According to Gill Wilkins, an expert on RETs and author of *Technology Transfer for Renewable Energy*, the main impediment to the dissemination of RETs has been information exchange, education, and training, and not necessarily the lack of developed technologies (Wilkins 2002). This means that one of the most important factors for the promotion of

RETs is the dissemination of information about the low operating costs and other benefits.

Policy Recommendations

To introduce RETs in rural India and overcome their higher capital costs:

- *The UN's rural energy projects in India should focus on micro-credit provision, allowing poor families to purchase direct-use energy technologies. The UN should encourage NGOs and other development institutions to focus on micro-credit projects as well.*
- *The UN should institute education campaigns and provide consultancy to families in rural areas explaining the advantages of RETs, like long-term economic benefits and health benefits.*
- *The UN should ensure that any social project it finances (e.g. education and health) in rural India includes RETs for provision of energy as part of the project.*

B. Targeting Women's Energy Needs

Focusing on solving the energy problems that women face is one of the most important factors when assessing energy policies in rural areas. While energy policies and projects have technically been gender-neutral, the needs of women are different from those of men and they must be acknowledged in order for projects and policies to have a net positive effect on the wellbeing of families. While men see energy as a luxury enabling more time for leisure, energy helps women accomplish their daily tasks. According to a report from the UNDP, "in many cases, the provision of electricity without attention to the provision of modern cooking fuels or appliances has resulted in rural electrification that in fact increases the hardships of women because the working day is prolonged while the traditional fuel use patterns remain in place" (McDade 2004, p. 10).

There are three main reasons for why UN projects should focus on helping women with energy development in rural areas: first, most of the burden of not having adequate energy services falls on women, as they waste large parts of their time finding energy and as women are who suffer the most from indoor air pollution. Women are also in charge of getting water for the household, a task that could be facilitated with access to mechanical or electrical energy for water pumping. Secondly, 70% of the people living in poverty worldwide are women, which means that if their needs are attended, the chances of decreasing poverty are increased. Finally, since women are responsible of meeting household needs, benefits to women are more likely to have a positive impact on the wellbeing of the whole family (than benefits to men). Thus policies should not be gender neutral, but rather attempt to solve women's problems specifically.

This prioritization of women can be done at the household level, by meeting women's energy needs: at the community level, like street-lighting; and at the micro-enterprise level, recognizing that the businesses that women tend to be involved in are different from men's businesses. This last point of income generation must be prioritized so that women who are saving time due to improved energy services can have income-generating activities that keeps them busy and allows them to pay for energy service.

Targeting women through improved energy services does not entail a particular challenge, bur rather a change in focus that will make energy projects effective.

Policy Recommendations

Considering that women in rural areas suffer the most from energy scarcity and that by helping women there is a higher net positive effect on families:

- *The UN should make assessments of the main energy needs of women in rural communities in India and focus on supporting energy development projects that are consistent with those energy needs, particularly energy for cooking and water pumping. The UN should encourage the GOI, development institutions and NGOs to do the same.*
- *The UN should support income-generating activities for women that depend on energy by providing technical assistance and consultancy, like baking and pottery.*

C. Capacity Building and the use of Local Resources

A third consideration is the need for technology development to be carried on with as many local resources as possible; local resources referring to both human capital and materials. This is extremely important because it lowers the production and maintenance costs, creates wealth within the benefited community, promotes innovation, and increases the social acceptance of the developed technology. In fact, many studies have shown that the best way to improve technology penetration is having the community members as partners (Practical Action 2004). As Practical Action states, "projects characterized by high levels of community engagement will typically generate a greater sense of community empowerment, ensure that improvements are tailored to a community's specific needs, and create a much higher chance that the improvement will be well maintained by the community after installation" (Practical Action 2005, p. 30). This has not been the case in traditional ways of providing energy services in rural areas since grid extension does not involve people from the community and since there is a large disjunction between those who produce technologies and the users. According to Wilkins, "'technology' should be regarded not only as the equipment, but also as the information, skills and knowledge which are needed to fund, manufacture, install, operate and maintain the equipment. 'Transfer' should be regarded as putting the technical concepts into practice locally in a sustainable framework so that local people can understand the technology, use it in a sustainable manner, and replicate projects to speed up sustainable implementation" (Wilkins 2002, p. 44). Eventually, as human capacity is built, individuals gain the confidence to maintain and repair their own equipment, as well as the experience to be self-sufficient.

Capacity building and the use of local resources are also effective in overcoming cultural barriers in rural areas. Cultural barriers are of great importance since most people in rural areas are poor and thus the levels of education are low. The idea behind this focus on capacity building is to "empower" the poor, and help them lift themselves from poverty, cutting the reliance on subsidies and hand-outs from NGOs.

Policy Recommendations

To promote capacity building and development of energy with local resources:

- *The UN should make local assessments of the skills and resources in different rural communities in India in order to identify local skills and materials that could be used for off-grid energy technology development; the UN should use these assessments to inform and provide consultancy to communities of potential solutions to their energy problems based on their own resources.*

- *The UN should include capacity building in every energy development project it promotes, whereby members of the community are taught the necessary technical skills to operate, maintain and repair the equipment and energy systems.*
- *UN projects should focus on the development of technologies and provision of energy services with strong local partners through energy service companies, where villagers are the main suppliers of energy services and technologies for their own community.*

D. Increasing Energy Penetration through Wealth Creation

Finally, and most importantly, energy technologies must be closely linked with income-generation, creation of jobs, sustainability, and empowerment in order to have a real effect on income and people's wellbeing for a sustained period of time, an idea that shares a consensus between different experts and institutions (United Nations 2003). This idea has proven true not only for energy but for development in general, because even though billions of dollars have gone into helping development in the past years, they have not created the necessary framework to break the cycle of poverty. According to the Rural Energy Enterprise Development, a part of the United Nations Environmental Program, "in the energy sector, international development stakeholders and investors have too often ignored the potential of innovative local enterprises to deliver essential energy services" mainly for three reasons: the small size, operation in remote areas, and focus in centralized programs for electrification by government and international institutions (Wirth et. al. 2003, p. 4). Energy for income-generation has two different potentials: increasing income by allowing locals to produce and sell energy services to their community, and increasing productivity by the added value that the use of energy-for-business provides, allowing entrepreneurs to start certain businesses and allowing already-existent business to grow (Aeck et. al. 2005).

One particular innovative way of creating alternatives for business development using energy is creating a micro enterprise zone (MEZ), defined by the National Renewable Energy Laboratory (NREL) as "a facility powered by a centralized electrical system that serves a strategically located cluster of micro enterprises in an area without access to the electric grid. The MEZ can function both as a business incubator and a permanent business haven conducive to nurturing income-producing activities in rural, lower-income areas" (Rogers et. al. 2000, p. 35). It is important to note, however, that not all enterprises need electrical power. In fact, one of the major energy needs for industry is heat (for bakeries and brick makers, among others), which in many cases comprises up to three quarters of the total production cost.

Policy Recommendations

To promote the use of energy for wealth creation and not simply for improved wellbeing:

- *The UN should identify entrepreneurs and already existent businesses that could benefit from the use of energy and finance them to improve productivity and expand their markets.*
- *The UN should identify entrepreneurs and already existent businesses that could provide energy services, and finance them to improve productivity and expand their markets.*

- *The UN should provide financing for the creation of micro-enterprise zones, and encourage NGOs and other development institutions to work with micro-enterprise zones as well.*

VII. Conclusion

As explained above, the policies in this paper do not aim to improve past projects of the United Nations, but rather discuss and give recommendations on four elements that would add great value to the UN's energy projects. The inclusion of these elements ensures that UN rural energy projects in India complement the GOI's rural electrification program and are effective in tackling the energy problems of the most poor, focusing on the end-use of different off-grid technologies. These four elements are: the use of RETs, the focus on women, capacity building, and energy for micro-enterprise. The main policies for their promotion are: increase micro-credit programs to overcome the high capital cost of RETs; energy programs that promote improved cooking practices and efficient water pumping to alleviate women's hurdles; including capacity building with any UN rural energy projects, as well as making strong partnerships with locals for the provision of energy services; and the use of energy for micro-enterprise as a stepping stone for energy access. The backbone of these polices is to empower the poor and allow them to use energy in a sustainable fashion, braking the cycle of poverty that has traditionally made them dependent on the subsidized extension of the central grid and hand-outs from NGOs.

Table 1: Supply and Demand of Energy in Rural Areas

Energy consumption in rural areas	Energy supply in rural areas
• **Households** are the biggest energy consuming sector in rural areas. • Cooking is the major end use, about 85% of total rural energy use. • Cooking devices are inefficient, inconvenient, and dirty. • Household lighting consumes about 2 to 10% of total rural energy use. • Energy use for household appliances (radio, TV, etc.) is insignificant.	• **Wood fuels and crops residues** meet 80 to 90% of total energy needs in rural households. • **Kerosene and electricity** supply energy for lighting about 10 to 15% of rural households have access to electricity. • **Batteries and electricity** supply energy for operation of small appliances.
• The **agriculture sector** consumes about 2 to 8% of total energy use in rural areas. • Energy is used for irrigation and mechanical farm equipment.	• **Petroleum fuels and electricity** meet energy needs for irrigation and mechanical farm equipment use.
• Energy consumption in **rural industries**, including both cottage industries and village level enterprises, amounts to less than 10% of total energy use in Asian developing countries. The low level of energy consumption is one indication of the low level of industrial and enterprise activities in rural areas. • Energy is used for heating and operation of mechanical and electrical equipment.	• **Human and animal power** meet bulk of energy needed for mechanical energy use in agriculture and other rural activities. • **Wood fuels** meet energy for heating needs of rural industries. • **Electricity** also provides motive power for rural industries, but at an insignificant level.
• Electricity demand curves have high peaks in the early evening hours and low overall load. • Religious festivals, celebrations, burials and other occasional functions produce 'spikes' in energy demand, which are usually unaccounted in total annual energy consumption estimates. • Rural women play a key role in managing household energy needs, shouldering the responsibility of collective, processing and using biomass fuels. As a result, it is the women who are the worst impacted by biomass scarcities as well as from exposure to health hazards leading to respiratory infections, chronic lung disease and eye problems related to indoor cooking fires.	

(United Nations 2003, p. 18)

Table 2: Domestic Energy Ladder

		ICT: *electricity* Cooling: *electricity* Other Appliances: *electricity*
	Water pump: *diesel electricity* Refrigeration: *electricity, batteries* Basic Appliances: *electricity, batteries* Transport: *oil*	Refrigeration: *electricity* Basic Appliances: *electricity* Transport: *oil*
Cooking: *biomass* Heating: *biomass, candles* Lighting: *candles, batteries*	Cooking: *biomass, kerosene, LPG* Heating: *biomass, coal* Lighting: *kerosene, batteries, electricity*	Cooking: *gas, electricity, LPG* Heating: *gas, coal, oil* Lighting: *electricty*

INCOME →

(NOTE: this energy ladder does not include human and animal power, which is used for many purposes, especially getting water).

(Priddle 2002, p. 370)

Table 3: Example of End-uses for Energy Off-Grid Technologies

Technology	Application	Pros	Cons
Small biomass plants	*Water pumps* *Mills* *Refrigeration* *Lighting and communication*	*Allows for income-generating activities* *Base load operation, continuous operation possible*	*Noxious emissions*
Mini-hydro	*Mills* *Lighting, communication and other*	*Long life, high reliability* *Allows for income-generating activities*	*Site-specific* *Intermittent* *Water availability*
Wind	*Lighting and communication* *Mills* *Pumps*	*No fuel cost*	*Expensive batteries* *Intermittent energy services*
PV/Solar	*Basic lighting and electronic equipment*	*No fuel cost*	*High capital costs* *High cost of battery replacement* *Needs further R&D*

(Priddle 2002, p.382)

Table 4: Status of Technologies for Micro-Grids in India

Technologies	Degree of Maturity	Degree of Penetration	Advantages	Disadvantages	Minimum requirement for application	Cost $
Small hydro	*High*	*Medium*	*Low structure (installation and O&M), easy maintenance, indigenous manufacturing of all components, low energy cost*	*Very less power in lean period, most hydro sites are inaccessible*	*For 1 kW, if head is 30 m then minimum flow rate should be 4* L/s^2	*$2500-3000/kW*
Solar PV (for minigrid)	*High*	*High*	*Negligible O&M cost, easy maintenance, environment friendly, easy installation, certainty in availability of resources*	*High initial investment, battery replacement in interval of around 5 years*	*Minimum 4-4.5 KWh/sw.m/day of solar insolation*	*$7335-7780/kW*
Biomass gasifer	*Medium*	*Low*	*Low cost of installation, local manufacturing of all components, low energy cost*	*Community mobilization is needed*	*1.5-2 kg of biomass for producing one unit of electricity*	*$2225-2250/kW*
Wind mills	*High*	*Medium*			*Start up wind speed of 2.5-3 m/s*	*$2225-2250/kW for small aero generator*

(Chaurey et. al. 2005, p. 20)

Table 5: Renewable Energy Technologies (RETs) for Rural Areas

Rural areas that are not connected to the national grid:

Energy Service	**Renewable Energy Application**	**Conventional Alternatives**
Cooking	*Efficient cookstoves* *Biogas* *Solar cookers*	*LPG, Kerosene*
Lighting and other small electronic needs (homes, schools, street, telecom).	*Pico- and micro-hydropower, biogas and biomass gasifier, solar/wind mini-grids, solar home-systems*	*Candles, kerosene, batteries, diesel generators*
Small industry	*Small hydropower, biomass for generation.*	*Diesel engines and generators*
Water pumping (agriculture and drinking)	*Wind and PV pumps*	*Diesel pumps*
Heating and cooling (water, space, crop drying).	*Biomass for combustion, biogas digesters, solar water heaters, food preservation.*	*LPG, kerosene, diesel generators*

(Martinot 2005, p. 30)

Table 6: India's "Electricity Act 2003"

Electricity Act 2003 – India's New Sector Legislation *The Electricity Act 2003, recently approved by Parliament, contains provisions supportive of the rural-electrification approach proposed in this paper. In particular, it provides for:* *i. The principle that distribution licenses should not grant exclusive right to provide service.* *ii. Distribution licensees to subcontract of franchise electricity supply within their service area without the need to obtain additional licenses.* *iii. Exemptions form the requirement for licensing the generation and distribution of electricity in rural areas (as determined by the State Government).* *iv. Regulatory commissions, when determining tariffs, to differentiate prices according to geographical location, among other things.* *v. Open access to distribution of transmission networks, opening the possibility for consumers and distributors to develop their own generation in locations far from the point of consumption and competition for retail supply.* *vi. Preparation of a national policy permitting stand-alone systems for supply in rural areas.* *vii. Preparation of a national policy for rural electricity supply by Panchayat Institutions, user associations, cooperative organizations, NGOs, and franchises.*

(Rizvi 2004, p. 21)

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WWS 402d: Energy for Sustainable Development

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Renewable Portfolio Standards, Feed-In Tariffs, and Tendering: Instituting Effective Mandated Market Policies in China

Sabina Sequeira

May 8, 2006

This paper represents my own work in accordance with University regulations.

Map of China

Source: CIA Maps and Publications, 2001.

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Executive Summary

China faces the challenge of accommodating the ever-growing energy demands, increased pollution, and rising greenhouse gas emissions. Renewable energy technologies represent a fundamental part of the strategy for tackling this challenge. However, high initial costs, investor uncertainty, and other market barriers prevent the expansion of renewable energy (RE) capacity in the free market. Consequently, mandated market share (MMS) systems, which create incentives for investment by establishing a purchase obligation for renewables somewhere along the production supply chain, have the potential to overcome these barriers and facilitate RE expansion. MMS systems, which aim primarily to reduce the costs of RE technologies through competition, economies of scale, and learning, have been implemented with success in the US and Europe, among other regions, and often take one of three different forms:

- Renewable Portfolio Standards, which create a purchase obligation for utilities and can offer a system of tradable renewable credits.
- Feed-in Tariffs, which allow the government to set the price of renewable energy.
- Tendering systems, which allow energy suppliers to competitively bid for RE obligations.

Lessons from an examination of these policies stress the importance of knowing market conditions to craft policy designs to take into account a lack of market competition, deadweight losses to producers and consumers, geographic RE resource capacities, and the potential for cost reduction. They also shed light on how these policies can be designed to have both flexibility for electric utilities and targeted support for different RE technologies.

This targeted support is important for the growth of both China's solar photovoltaic (PV) and wind industries, which are most easily exploitable in different geographic locations: solar PV in the southwest, and wind in the east. This difference, coupled with urban/rural regional differences, create a diverse set of market conditions among different provinces in China and the challenge of aligning potential rural energy supply with demand in the urban eastern coastal area.

Energy policy over the past two decades, set out in China's Five-Year Plans, have been characterized by a lack of concrete, specific targets and rules, as well as a lack of coordination between policy-making bodies.

To overcome the challenges touched upon above, the following recommendations are made in 3 categories, to the government of China, international institutions, NGOs, and the CSD:

- Policy design: promotion of a flexible decentralized hybrid system of the three MMS policies, with an emphasis placed on feed-in tariffs for rural areas lacking competition, tendering for areas suitable for large-scale RE development that might not otherwise gain competition, and RPS for urban areas.
- Administration and enforcement: the creation of a ministry of energy to coordinate local RE MMS policies with the national scheme, the extension of local energy centers to cover RE issues, a national tradable renewable credits system to lower administrative and compliance costs.
- Costs: Government outlays for costs of policy rather than direct funding of projects, spread of the cost burden across all parties involved, Government R&D

investment in restructuring of transmission to dramatically increase effectiveness of MMS policies.

Role of the CSD: provision of research on purchase obligations, prices, and market conditions, encouragement of foreign investment, and of export industries.

Introduction

China's rates of economic growth have remained in the double digits for a large part of the past two decades, contributing to an ever-growing demand for energy as the country develops and its population grows (Martinot, 2001).[60] As the world's second largest producer of carbon emissions, China faces the prospect of becoming the world's largest emitter of greenhouse gases by 2020, hastening the serious negative global effects of climate change and producing serious health hazards for many of its urban residents in the form of pollution. Furthermore, China is projected to experience a large energy shortfall by 2050 under a business-as-usual scheme (Larson et al, 2003). Thus China faces the challenge of accommodating the energy demands that spring from population growth coupled with urbanization and development, all while fighting pollution and greenhouse gas emissions.

This challenge makes clear the need to rapidly replace carbon-based fuels with renewable energy technologies (RETs), which eliminate carbon emissions while deriving energy from inexhaustible sources such as the solar energy and the wind.[61] However, a significant challenge exists to the rapid expansion of renewable energy in China: RETs are characterized by high initial capital costs, compared to carbon-based sources of energy, resulting in low initial profit margins for producers. And although once established, many RE technologies such as wind farms provide low-cost, efficient energy,

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[60] For example, meeting the millennium development goals of halving poverty, reducing hunger, diseases, and mortality, fostering universal primary education, and working towards environmental sustainability all depend heavily on adequate access to energy services which often depend on the electrification of rural areas (van der Linden et al, 2003).

[61] The widespread development of renewable energy (RE) is essential as part of a combined strategy that includes increasing energy efficiency, changing how resources are used to produce energy, and investing and developing new technologies for energy production (Larson et al, 2003). This strategy is exemplified in Pacala, S. and R. Socolow. "Stabilization Wedges: Solving the Climate Problem for the Next 50 years with Current Technologies." *Science*. Aug 13, 2004. Vol. 305.

the demand around these areas, which might often be rural, would not keep up with the energy that could potentially be supplied. And in other areas where the demand is high, large-scale RE production may not be geographically feasible. Consequently, government support is extremely important at the initial stages of the development of markets for renewable energy to provide means to overcome these barriers (van der Linden et al, 2003).

One strong measure a government can take to develop RE markets is through mandated market share (MMS) policies[62], which require that a certain quantity or proportion of a country's energy be generated from renewable energy sources by instituting a purchase obligation or creating strong incentives for renewable energy at some point along the energy supply chain (van der Linden et al, 2003). Mandated market shares for renewable energy can be created by instituting one of 3 policies, or a combination of them:

- Renewable Portfolio Standards, whereby the government requires that all electricity carriers produce a certain amount of renewable energy annually, or buy tradable credits for that amount of energy.
- Feed-in Tariffs allow the government to set the price of renewable energy and guarantee that all renewable energy produced will be purchased and fed to the grid at the specified price for a specific period of time.
- Tendering systems are a combination of the previous two policies, which allows energy suppliers to competitively bid for renewable energy obligations.

This paper will examine RPS policies, feed-in tariffs, and tendering policies, both in theory and in practice, to shed insight into how China might potentially implement MMS policies to combat climate change while meeting its energy demands through renewable energy production.[63] In order to evaluate these policies, criteria for mandated

[62] This term will be used as it is defined in Van der linden, 2003 (paraphrased above).
[63] Renewable energy in this paper will refer to what is sometimes termed "new" renewable energy: wind, solar photovoltaic, solar thermal, geothermal, as well as small hydro (under 30GW).

market systems will first be established, followed by a discussion of the advantages and disadvantages of RPS, feed-in tariff, and tendering with case studies on their implementation in the US and Europe. China's energy market and capacity for future growth will then be considered, with a specific emphasis placed on opportunities for wind and solar photovoltaic (PV) energy growth, followed by an evaluation of renewable energy policy in China to date. This paper will then explore the challenges particular to China in instituting a mandated market share system, and then offer suggestions to the Chinese government, NGOs, international institutions, and the UN Commission on Sustainable Development (CSD) on how to support the implementation of an effective MMS system in China.

Criteria for evaluating an MMS policy

The value and success of the three MMS policies will be evaluated according to the broad criteria shown in Figure 1, which are formed under three categories: Outcome criteria, which evaluate the overall impact of the policies; policy design criteria, which examine the elements of policy design that affect its success; and market criteria, which make clearer the market conditions under which these policies succeed (Wiser et al, 2005).[64] The MMS policies will also be evaluated in terms of three primary goals of MMS systems for China: to increase the production capacity of energy from renewable sources, drive down the price of renewable energy, and provide a viable alternative to coal-based energy production, creating methods for energy production that can compete effectively with fossil fuels (van der Linden et al, 2003).

[64] Explicit three-way comparisons of the policies against the criteria in Figure 1 are made in Table A1 of the Appendix.

Finally, one fundamental, underlying criterion must always be considered in the evaluation of different MMS systems: the cost of the policies themselves. Because these policies require revenue to cover incentives in the form of purchase obligations, above-market fixed prices, power purchase agreements, and administrative costs, the question of who will bear the burden of these costs is an important and politically significant one. Traditionally, the costs can be borne in four ways: incremental costs are passed on the nation's domestic energy consumer base in the form of a small KWh surcharge or tariff, electric utilities are forced to bear extra costs that are then passed on to consumers, the costs are covered by public funds provided by the government or donors, or they are paid for by a carbon tax on fossil fuel consumption (World Bank, 2006). Thus the issue of policy cost is related to debates on production and consumption distortions introduced by protectionist measures as well as those of political viability.

Figure 1: MMS policy Evaluation Criteria

1. Outcome Criteria:

Cost Minimization: minimizing the cost of generation and maximizing the amount of competition in the renewable energy sector (to the extent this will contribute to minimizing costs)
Price Minimization: minimizing the price that is paid for renewables in the marketplace
Maintaining Targets for Renewable Energy: ability to establish and meet firm development targets for renewables
Local Industry and Manufacturing Development: ability of the policy to increase local renewable infrastructure and create a local renewable energy manufacturing industry that will have economic development and employment benefits
Resource Diversity: ability of the policy to encourage diversity in renewable energy supply sources
Market for Power from Renewable Facilities: the creation or maintenance of a sustainable market for purchases of renewable energy that supports the funding of new facilities
Full Compliance: all electric utilities are able to and chose to comply with the policy

2. Policy Design Criteria

Simplicity: the simplicity of policy design, administration and enforcement
Compatibility with the Electricity Industry and Regulatory Structure: compatibility of policy with increased competition being introduced into the electricity sector
Policy Stability: ability of the policy to create a durable renewable energy industry with access to reasonable financing
Competitive Parity: ability of the policy to spread the cost of renewable energy fairly and evenly across market participants
Complementation: ability of the policy to complement and be complemented by other incentive mechanisms created by the government for RE production
Credible and Effective Enforcement: Critical for renewable developers to be confident of their investment

3. Market Context Criteria

Integration: ability of the policy to integrate renewable energy into the larger electricity system and to reduce institutional barriers to renewable development
Political and Regulatory Support: Necessary to minimize uncertainty about the duration of the policy
Adequate and Accessible Developable Resource Potential: Policies must take into account geographic RE capacity, transmission costs, interconnection barriers and wholesale market rules to be effective
Presence of Long-Term, Credit-Worthy Power Purchasers: Crucial to the alignment of supply and demand of renewable energy within regions

Source: Wiser et al, 2002; Wiser et al, 2005.

Discussion of MMS Policies

Renewable Portfolio Standards

Description of the policy

Renewable Portfolio Standards allow the government to require that all electric utilities generate a stipulated quantity, proportion or capacity of renewable energy annually, often giving them the option to buy tradable credits for that amount of energy if they are unable to produce it themselves. An RPS policy can be designed to encourage the development of renewable energy technologies (RETs) beyond the one that is cheapest at present with ‘tiers’, in which a separate purchase obligation or standard exists for different RETs such as wind and solar photovoltaic, or through ‘credit multipliers, in which utilities receive more credit towards their purchase obligation by buying more expensive RE from less developed technologies.[65]

<u>Benefits</u>

The Renewable Portfolio Standard has a number of clear advantages that comes about as a function of its inherent structure (Wiser et al, 2005):

- It is a mechanism through which a specific quantity of renewable energy will be produced; it effectively sets target levels for RE development.
- RPS promotes off-grid supply because the generation cost of off-grid power from renewables is lowered through income from sale of tradable credits.
- It gives producers an incentive to produce RE in the most efficient manner possible since it does not set a specific cost, but rather gives them the flexibility to produce it in the manner they see fit.
- The policy creates a mechanism through which market competition can drive the cost of RE down.
- Certificate based trading lowers administrative and compliance costs, because it increases the ease with which electric utilities are able to comply with the policy.
- RPS offers the most equitable policy approach in that it does not favor specific bidders or developers.
- The policy has shown to be effective at the state level in the US (see below).

<u>Disadvantages</u>

Many of the disadvantages to be found in an RPS stem from the same qualities that provide strong advantages (Wiser et al, 2005):

- The price variability introduces profit uncertainty for investors.
- Success depends on how well the policy is designed; the optimal purchase obligation may be difficult to determine and must use parameters such as potential RE capacity in the country as well as projected consumer burden.
- RPS policies can be complicated and difficult to implement and enforce, especially if tiers or multipliers are introduced. The added complexity makes it

[65] Elements of the policy design are detailed more comprehensively in Figure A2 of the Appendix.

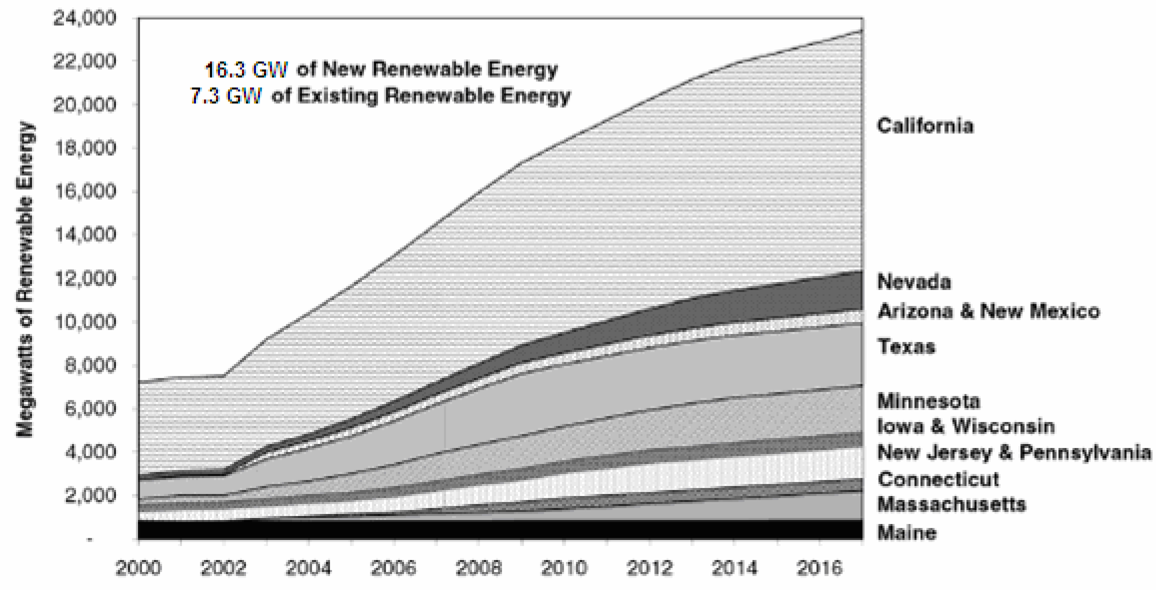
more difficult and costly for the government to monitor whether electric utilities have complied properly with the policy.

- Without tiers or multipliers, the policy may encourage the growth of just one type of renewable--whatever is the most cost-effective at the time.
- It can be less flexible in offering targeted support to specific groups, such as small utility carriers, than other policies, unless specific provisions are made for these groups.
- National RPS policies can have high administrative costs without local enforcement support.

Experience in the United States

The Renewable Portfolio Standard is the most popular MMS policy in the US, and has been instituted in the 21 states. A 2005 study by Global Energy Decisions estimates that current state RPS laws will require an additional 52 GW of renewable energy by 2020, more than double the existing U.S. renewables capacity (Martinot et al, 2005). Figure 2 illustrates a similar increase, in which the states depicted are projected to produce more than 16 GW of new renewable energy by 2017 under their various RPS policies. As the graph shows, the RPS policies of California and Texas in particular have had—and are projected to have—much more success than that of Maine and New Jersey, which has had moderate success. The RPS policies of these four states will thus be examined to explore what elements of the policies have led to strong successes or failures.

Figure 2: The Impact of State RPS Policies



Source: Wiser et al, 2005.

Texas

Texas has a relatively well-established state RPS policy, first enacted in December of 1999, which fulfills many of the outcome criteria listed in Figure 1. It contains a modest target of 2GW of additional renewables by 2009 (2.5% of total current state energy consumption), with steady incremental targets of .4 GW by 2003, .85 GW by 2005, 1.4 GW by 2007, and finally 2 GW by 2009, sustained through 2019. In 2001, it began the nation's first comprehensive certification program, administered by the Electric Reliability Council of Texas (ERCOT), to allow trading of renewable credits (RECs). The policy includes explicit penalties for non-compliance enforced by the Texas Public Utilities Commission, stipulating that electric utilities with up to a 5% deficit in RECs must make up the deficit in the next annual compliance period, and that those over 5% may pay $50/MWh of RE deficiency or pay 200% of the average market value of the credits deficient for that compliance period. Additional flexibility exists in the policy in that existing renewable generation is allowed to offset retail energy suppliers' new renewable purchase obligations (Wiser and Longniss, 2001; Wiser et al, 2005).

RPS compliance costs for electric utilities in Texas have appeared to be almost negligible because as of 2004, long-term wind power contracts averaged at 3 cents/KWh, which is equivalent to or below the cost of conventional power (REPP, 2004).[66] Furthermore, electric utilities have exhibited full compliance with the policy. These results provide strong evidence that the modest Texas RPS had visible success in promoting economies of scale for wind that have been driving the price/KWh of wind energy down (Wiser et al, 2005).

California

California has established an extremely aggressive, complex RPS policy in 2002 that has since been updated to be even more ambitious due to the initial success of the policy. Its targets now require additions of at least 2% each year (up from the initial goal of 1% yearly increases) to RE production, until a 20% target is met by 2010, with a goal of at least 33% by 2020 (DSIRE, 2006). The California Public Utilities Commission (CPUC) is in charge of overseeing and enforcing this growth and is in the midst of determining rules and specific but flexible compliance penalties that will apply to investor owned utilities (IOUs). The state has created the Renewable Resource Trust Fund, funded with a .2-.3 cents/KWh charge (a fraction of a cent) on all retail sales of electricity, which is being used as supplemental payments to eligible renewable energy resources to offset above-market costs of compliance with the policy (REPP, 2004A). The CPUC and the California state legislature have been carefully planning how to implement and

[66] This is in part because of a 1.7 cent/KWh tax credit that is simultaneously being offered to Texan electric utilities.

enforce the policy in the simplest, most transparent manner possible (CEC, 2005). California shows how ambitious but carefully designed RPS can be used to drive remarkable growth in RE markets over a period of 10-20 years.

Maine

Maine nominally set out in 2000 what appeared to be an aggressive standard, requiring that 30% of energy consumed in Maine be generated from renewable sources. However, because both existing and new renewable generation are eligible to meet the targets, the resource types eligible to meet compliance are particularly broad, including fossil-fuelled cogeneration, large hydropower, and biomass, and RE resources need not be located in state. Maine's RPS, though currently the highest in the country, is unlikely to spur the growth of additional RE production capacity in Maine as projected in Figure 2 (Wiser et al, 2005; REPP, 2004B).

New Jersey

New Jersey has avoided the problem that Maine has faced in defining acceptable RE too broadly by creating two-tiered RPS with two distinct classes. Class I includes wind, solar, geothermal, fuel cells, ocean power, landfill gas, and specific biomass technologies, while Class II includes some types of hydropower and municipal solid waste facilities. As of 2003, the purchase obligation Class I technologies started at 0.5% in 2001 and would increase to 4% by 2012; the purchase obligation for Class II resources would stay constant at 2.5% through 2012 (Wiser et al, 2005). In April of 2006, the New Jersey Board of Public Utilities followed California's lead, and increased the state's Class I standard to 20% by 2021, with 2.12% generated from solar PV sources, resulting in the production of more than 1.5 GW of PV power in New Jersey by this date (DSIRE, 2006A). This revision shows how RPS policies have been used to spur targeted growth of specific RE technologies such as solar PV.

Feed-In Tariffs

Description of the policy

Also called a pricing system, this policy obligates electric utilities to let renewable energy plants connect to the grid, and requires that the utilities purchase all electricity that they produce at or above a set minimum price, which is above the market price for energy and is guaranteed typically for a lengthy period of time so that renewable energy producers can be sure of gaining a small profit margin (Sawin, 2004).

Benefits

- The fixed price (usually for 15 to 20 years) allows for more investor certainty.
- The price also stimulates investment, since it is guaranteed to sell at above the market price.
- Different types of renewable energy (ie. Wind, solar photovoltaic, or geothermal) can have different fixed prices depending on their current costs to ensure a profit for producers and create strong financial incentives for investment across technologies.[67]
- This policy can be combined with a standard or purchase obligation (similar to that of an RPS) to create a second mechanism that ensures RE produced is fed to the grid.[68]
- Can be designed in a simple manner and has low administrative costs (Wingate, 2003).
- Needs less of a competitive environment than RPS and tendering policies to be successful.

Disadvantages

- Does not encourage a specific quantity of RE production or set targets unless combined with a standard (which can be done with powerful results).

[67] Economies of scale and learning could then facilitate the transition to free market conditions once the tariff expires.

[68] This system would place the burden of higher costs on electric utilities fulfilling their purchase obligations, which could be lessoned by subsidies from a public benefits fund that derives revenue from a small, flat tax on all retail electricity.

- Fixed price may engender inefficiency, and result in the overcompensation of market actors.
- The costs to electric utilities in paying the tariff may often be high—however, caps can be placed on the total amount each utility is required to pay.
- Determining effective prices is a complex and difficult task (Teri, 2006).

<u>Experience</u>

US

The renewable energy industry in California saw considerable growth in the 1980s due to the 1978 Public Utilities Regulatory Policy Act (PURPA) which was essentially a feed-in tariff, coupling long-term contracts with a mandatory fixed price. Today, California remains one of the leading states in installed energy capacity as a result of its strong start in the 1980s. California's interpretation of the act along with favorable tax incentives resulted in the production of 12 GW of renewable energy in the US in the 1980s (Wiser, 2002; Martinot et al, 2005A). Thus feed-in tariffs played a large role in the strategic creation of RE markets in the US. However, through the 1990s, the repeal of federal and state incentives, a long period of electric power sector restructuring, and changes in market conditions such as a drop in natural gas prices caused very little growth in RE capacity. Nevertheless, PURPA highlights the usefulness of feed-in tariffs in developing small RE markets still in their very initial stages. Currently, several states still implement PURPA as a feed-in tariff for small projects; examples of this can be found in Idaho, Minnesota, and Oregon (Martinot et al, 2005A).

Europe

Germany, Denmark, and Spain have instituted effective, successful feed-in tariff systems, and have the three most successful renewable energy programs in Europe. The three countries have been able to implement attractive pricing formulas and have seen extensive wind power growth:

In Germany, though feed-in laws have frequently been protested in the electric utility industry, it has had strong results—Germany has one of the largest wind and solar markets in the world, with wide-scale manufacturing bases for both technologies. Initiated in 1990, the feed-in law required that wind power, solar, hydropower, and biomass receive 90% of the residential retail price of electricity until 2000 (from 9.5 cents/kWh in 1991 to 8.8 cents/kWh in 1999) (Wiser et al, 2002). The regulatory authority set the tariffs every year based on the value of the average utility revenue per kWh sold, which stimulated wind growth in particular. The result of the tariff was that installed capacity expanded substantially from 1.1 GW in 1995 to 6.1 GW in 2000 (Sijm, 2002). However, the tariff was funded ultimately from the revenues of utilities rather than taxes, distorting competition between utilities. It also left the tariffs variable since they were based on utility revenues; when the electricity prices dropped, so did the tariffs (ECN, 2003). Germany's feed-in tariff shows not only how the policy can bring about strong positive results in RE capacity development, but also highlights the risk of market distortions with the implementation of a tariff attractive to RE investors.

Denmark's feed-in laws have been cited as particularly successful due to complementary policies implemented along with them that include specific capital subsidies, tax incentives, low-cost financing opportunities, and R&D funding. Between 1990 and 2000, wind capacity in Denmark grew by 21 percent per year on average to about 2.3 GW in 2000 (Sijm, 2002).In 1997, Denmark produced almost 60% of worldwide wind power sales (though it has now been overtaken in absolute terms of installed wind capacity by Germany and Spain), providing evidence that feed-in tariffs can be notably strengthened by well-designed tax and subsidy incentives (Wiser et al, 2002).

Spain's feed-in tariff, established in 1994, has resulted in dramatic recent wind power growth with the establishment of several of the largest wind farms in the world, each over .1GW/KWh in capacity, and the development of a sizeable wind-power equipment manufacturing industry, which has lowered investment costs due to economies of scale and learning (Junginger et al, 2005).[69] Between 1995 and 2000, installed (onshore) wind capacity in Spain almost doubled every year, expanding from .114 GW in 1995 to more than 2.8 GW in 2000 (Sijm, 2002).Green power producers operating under the system can choose between a fixed price and a premium on top of the market price of traditional energy, and make agreements regarding grid connection for a minimum of five years (ECN, 2003A). These design elements of the tariff allows those under the tariff more choice and gives the policy flexibility in capturing market trends, and thus spurs additional investment.

Tendering

Description of the Policy

Tendering systems use government-supervised competitive processes to meet planned targets by making long-term power purchase agreements with renewable energy generators. Tendering policies are similar in some respects to feed-in laws and renewable portfolio standards; in that both the price and targets are set, but here the price and the RE projects eligible for government support at the specified price are chosen through a

[69] 12% of installed capacity is in wind farms is below .015GW, 40% is in wind farms between .015 and .025GW, and 48% of installed capacity is in wind farms over .025GW in capacity. Several parks exist with around and above a .100GW installed capacity (Junginger et al, 2005).

competitive bidding process, in which bidders submit project proposals with the price they are able to offer (Wiser et al, 2002).

Benefits

- The guaranteed power purchase agreement reduces investor risk and uncertainty.
- Separation of competitive bidding between technologies allows diversity in the industry to emerge.
- Allows government to easily target the development of specific technologies.

Disadvantages[70]

- The amount of power acquired may depend on the prices bid. This can potentially be avoided if a mandatory quantity to be produced and a ceiling on the maximum price is set.
- May or may not reduce RE costs over time, depending on the quality of proposals and the level of competition.
- The intense price competition common to this method favors large RE developers with more size and experience (so they could reduce their bidding costs), making market entry for small developers who don't have government support much more difficult.
- Large companies may not find it necessary to develop a domestic infrastructure manufacturing industry since they can import equipment more easily.
- Multiple bidders and a competitive industry is necessary for policy to work.

Experience in the U.K.

A large, successful tendering process has taken place in the U.K. with its Non-Fossil Fuel Obligation (NFFO), which has placed five successive competitive bid orders for renewable energy between 1990 and 1999, which aimed to bring 1.5 GW of new renewable capacity to the grid (roughly 3% of the total U.K. electricity supply). Twelve regional electric companies were required to buy all power from these NFFO projects. The policy awards contracts on a competitive basis within specific technology types (so wind projects compete against other wind projects), accepting projects that projected to generate RE at the lowest price/KWh among each technology type. This process proved to be highly successful in reducing the price of wind. For example, the average price for large wind energy dropped from around 18 cents/kWh to 4.5 cents/kWh over five years.

[70] Inferred from Wiser et al, 2002.

However, a substantial number of the RE projects that won bids under the NFFO have never been developed, due to the inherent design of the policy, where some degree of speculative bidding by renewable energy developers takes place as groups may understate the price they are capable of offering as they jockey for contracts (Wiser et al, 2002). Thus while the NFFO example shows that tendering can dramatically reduce costs over a short period of time, precautions must be taken in policy design to ensure a realistic bidding process.

China's Economic, Structural, and Geographic Climate for Renewables

Energy Use and Environmental Impacts

Trends in China's growth show that it would have much to gain from the strategic implementation of MMS policies to rapidly advance the development of renewable energy in China. Most of China's growth is occurring on its Eastern coastal areas, which is where highly concentrated energy demand lies. As of 2000, this region contains 13.6% of China's land area and 38.8% of China's population, but 63.2% of the total GDP of the country (Fan et al, 2005).

Pollution has become a significant problem, as production is heavily coal-based. In 1999, for example, coal production and consumption accounted for 60.3% and 69.0% of total energy production and consumption for China (Fan et al, 2005). The result is that this region emits 69375 X $10^8 m^3$ of industrial gas emissions waste (50.3% of the country's total emissions) and 683 X $10^4 t$ sulfur dioxide emissions (42.3% of the country's total of this pollutant) (Fan et al, 2005). Although 97% of the population does have access to electricity, the area outside the eastern coastal region contains rural villages unconnected to the grid with 30 million Chinese residents still without electricity (NREL, 2004).

Potential Capacity for Renewables

The potential for the expansion of China's renewable energy capacity is significant (See Figure 3). However, though demand is concentrated in the Eastern Coastal areas, much of the potential wind and solar PV supply is spread over regions with low energy demand. As Figures 4 and 5 show, Wind energy is in fact concentrated on the eastern half of China, with significant opportunities for offshore production, whereas solar PV potential is concentrated in the western half of China, with an abundance of solar energy available in the southwest region where Tibet is located. Though the total technically exploitable capacity of onshore wind is 253 GW, and onshore potential capacity is as much as 750 GW, and the exploitable capacity of solar PV, if China covered 1% of its land area with solar panels, is approximately 240 GW, the areas with a significant potential capacity of RE are not necessarily those with the greatest energy demands (Zhengming et al, 2000; Yixin et al, 1999).[71] For example, the provinces of Inner Mongolia and Xinjiang have substantive potential capacities for PV and wind, but these areas have little energy demand in comparison to the eastern coastal areas,

[71] The solar PV estimate, an extremely rough figure, was derived from figures cited in Yixin et al, 1999. The paper states that annual solar insolation (incoming solar radiation) is $50*10^{18}$KJ, which is roughly equal to 170 Btce (billion tons coal equivalent). This figure (170 Btce/year) was converted to GW using conversion tables published in Mutiga, 2001 and IEA, 2006 through the following process: 170 Btce/year x 1year/365 days x 1 day/24 h x 10^9 tce/1 Btce x 29.3 GJ/1 tce x 10^9 J/1 GJ x 1TJ/ 10^{12} J x 1 GWh/3.6 TJ = 157,946 GW. Solar PV panels were assumed to have a 15% level of efficiency, as per NREL, 2006, meaning that about 23,691GW would be exploitable from solar insolation to China. Because estimates as to the surface area of land that China could use for PV purposes and the intensity of incoming solar radiation is unavailable, an estimate of energy derived PV panels peppered across 1% of China's total land area (~100,000 km^2 as per CIA, 2006) yields 240 GW. This number might potentially be significantly higher if PV panels were concentrated in China's western regions with higher levels of incoming solar radiation.

presenting a considerable challenge for China align to demand and potential supply (Zhengming et al, 2000).

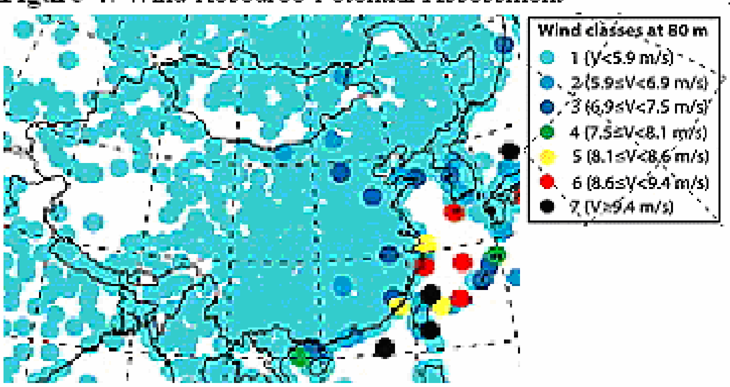
Figure 3: *Overview of technically exploitable potential and currently installed capacity of renewable energy for power generation in China in 2002*

Renewable energy source	Technically exploitable potential	Installed capacity [MW]
Grid connected RE power production		
Bagasse fired power generation	21.2 mln. ton bagasse	807
Wind energy	253 GW*	440
Large and small hydropower	265 GW	90,200
Geothermal	5.8 GW	30
Tidal energy	110 GW	5.9
Decentralised RE power production		
Solar PV		43
Wind Energy		25
Mini-hydro (< 10kW)	80 GW	154

Sources: Iberdrola technology study; 'Renewable Energy Development in China: The potential and the challenges: Zhang Zhengmin et al

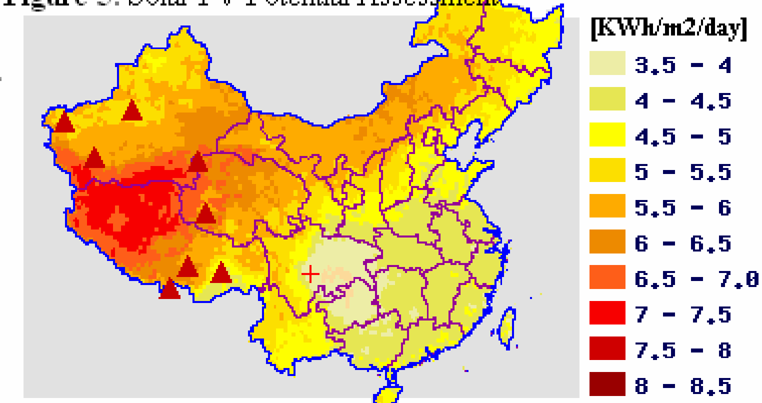
* Based on an evaluation of winds at 10 metres above ground.

Figure 4: Wind Resource Potential Assessment



Source: Archer et al, 2005.

Figure 5: Solar PV Potential Assessment



Source: SWERA, 2006.

Markets and the Development of Renewables

The successful implementation of MMS policies in RE in China not only depend on considerations of geographic resource capacities, but also the different stages of market development of the different technologies, outlined in Figure 6. For example, as of 2000, solar water heating in China was moving into Phase V while large-scale wind generation was in Phase II. Furthermore, a technology may not have fully completed all parts of a phase before starting developing aspects of subsequent phases. However, attempting to force a shift in phases without the presence of an adequate foundation in the other phases creates a high risk for the failure of MMS and other policies. For example, if a new RE technology was forcibly moved into a competitive market situation to reduce the price of the technology before sufficient infrastructure, such as a domestic manufacturing base able to produce the technology, existed, price reductions would be unlikely to occur (Zhengming et al, 2000).[72]

Figure 6: Typical Renewable Energy Developmental Phases

Phase I. Research, Development and Demonstration of New Technologies
* Resource Assessment
* Technology Development and Demonstration

Phase II. Wholesale Market Development
* Establishment of stable wholesale market rules and processes
* Establishment of companies willing and able to undertake resource development (usually IPPs)
* Establishment of manufacturing facilities
* Development of a financing framework

Phase III. Cost Reduction
* Project experience (multiple projects by individual companies)
* Increased manufacturing volume
* Development of related infrastructure and service companies to support the technology
* Standardized product

Phase IV. Price Reduction
* Assured volume/long-term opportunities
* Competitive market

Phase V. Retail Market Development
* Clear market rules
* Four or more individual companies
* Public education/information

Source: Zhengming et al, 2000.

[72] The development of each industry is visible to an extent through an examination of its installed capacity. Table 4-1 of the Appendix examines details on the installed capacity of wind and solar PV technologies in the context of other renewables.

In recent years, the development of wind and solar PV have taken significant strides, both are in the process of moving from Phase III to Phase IV, developing increased manufacturing volume and related infrastructure for both technologies. While wind energy in China has been making headlines due to projections for substantive short-term increases in installed wind capacity, the solar photovoltaic manufacturing industry in China has swelled, expanding to produce all components necessary for solar photovoltaic cells, including polysilicon feedstock, wafers, cell, and module production. China's module capacity of .45 GW is projected to rise to 1.2 GW, its solar cell-making capacity from .2 GW to 1.2 GW, and its wafer capacity from .1 GW to .8 GW by 2008 (Pichel, 2006).

The Price of Renewables

Wind energy in China currently is priced at between 7.6 to 10 cents/KWh and solar at around 42 cents/KWh (Liu, 2005; Asia Pulse, 2005). However, as Larson et al have shown, there is promise that renewables costs will decline for China as the development of RE technologies increase. Larson et al's Markal model makes a strong case, using a broad range of economic and political factors, that "even when significant limitations on carbon emissions were stipulated, the model calculated that an advanced energy technology strategy using our technology-cost assumptions would not incur a higher cumulative (1995–2050) total discounted energy system cost than the business-as-usual strategy" (Larson et al, 2003). Thus there exists a cost-based argument to be made for policy market drivers in China, in addition to the environmental and energy demand factors discussed.

National Energy Policies in China

Figure 7: A Timeline of Energy Policy in China According to Classification

First Level	
1983	Suggestions to Reinforce the Development of Rural Energy
1992	China Agenda 21
1992	Ten Strategies on China's Environment and Development
1995	State Science and Technology Commission (SSTC) Blue Paper No. 4: China Energy Technology Policy
1995	Outline on New and Renewable Energy Development in China, State Planning Commission (SPC), SSTC, State Economic and Trade Commission (SETC)
1995	Electric Power Law
1996	Guidelines for the Ninth Five-Year Plan and 2010: Long-Term Objectives on Economic and Social Development of China
1996	State Energy Technology Policy
1997	Energy Saving Law
2003	Renewable Energy Promotion Law
Second Level	
1994	Brightness Program and Ride the Wind Program, formulated by SPC
1995	New and Renewable Energy Development Projects in Priority (1996-2010) China, by SSTC, State Power Corporation, and SETC
1996	Ninth Five-Year Plan and 2010 Plan of Energy Conservation and New Energy Development by the State Power Corporation
1996	Ninth Five-Year Plan of Industrialization of New and Renewable Energy by SETC
1998	Incentive Policies for Renewable Energy Technology Localization by State Development and Planning Commission (SDPC) and Ministry of Science & Technology (MOST)
2001	Tenth Five-Year Plan for New and Renewable Energy Commercialization Development by SETC
2003	Rural Energy Development Plan to 2020 for Western Areas
Third Level	
1997	Circular of the Communication and Energy Department of SPC on Issuing the Provisional Regulations on the Management of New Energy Capital Construction Project
1999	Circular of MOST and SDPC on Further Supporting the Development of Renewable Energy
2001	Adjustment of Value-Added Tax for Some Resource Comprehensive Utilization Products by Ministry of Finance (MOF) and State Tax Administration
2001	Electricity Facility Construction in Non-Electrification Townships in Western Provinces of China or Township Electrification Program by SDPC and MOF

Classifications

China's energy policies can be placed in 3 classifications (Yao, 2005): The first level consists of those policies that provide general direction and guidance. Second level policies set objectives and form development plans. Third level policies create specific rules, incentives, and "managerial guidelines", such as non-compliance penalties.

General Energy Policy: the Five Year Plans

Government policy in China first shifted toward environmental concerns in 1978, and then, beginning in the 1980s, the Sixth, Seventh, Eighth, Ninth, Tenth, and Eleventh Five-Year Plans have shown a growing attentiveness to energy concerns (Yao, 2005; NREL, 2004):

The Sixth Five-Year Plan (1981-1985) put the equivalent of 10% of energy supply investment into energy conservation projects. This policy continued in the Seventh Five Year Plan, though the percentage was reduced to 8%. The Ninth Five-Year Plan (1996-2000) took important steps from this point, implementing Agenda 21[73], and allowing the National Environment Protection Agency (NEPA) to set up a long-term "Green Project Plan" (Yao, 2005).

The Tenth Five-Year Plan (2001-2005) made renewable a specific priority, introducing a Tenth Five-Year Plan for Sustainable Development, as well as a Tenth Five-Year Plan for Renewable Energy Commercialization Development. The plan stipulates that "the production capacity of solar energy, wind energy, and geothermal energy should be increased" (NREL, 2004A). However, the plan offers general objectives for the most part, making loose recommendations for the development of MMS policies for RE development, including tendering programs, and a national RPS or feed-in tariff.

The Eleventh Five-Year Plan (2006-2010) will support the implementation of the Renewable Energy Law (effective January 1, 2006), the most direct step China has taken towards the development of the RE industry. Under the direction of China's Center for Renewable Energy Development (CRED), the law aims to meet short term energy needs with long-term clean energy objectives, offering specific incentives to spur growth by guaranteeing grid access to renewable energy producers while spreading its cost across the industry, primarily through purchase obligations (IFC, 2006). In addition, the Renewable Energy Law announced a goal of producing 60 GW, or 10% of its power supply, with renewables by 2020 (Jing, 2005), a goal which was increased to 15% in

[73] After the 1992 Rio de Janeiro UN Summit on Global Environment and Development, China issued its "Agenda 21", which expressed that 'priority should be given to the development of renewable energy in the state energy development strategy, and to encourage energy-saving, energy efficiency and developing renewable energy should become the fundamental state policy'" (Yao, et al., 2005).

March 2006 (China Daily, 2005).[74] The law requires that utilities purchase 100% of the output generated from eligible renewable energy facilities, designates the NDRC as the regulatory body responsible for implementation of the law, and provides a national fund and tax incentives to foster development, including a 50% tax break for investment in solar, wind, and biomass energy (Jing, 2005; EF China, 2005). The Renewable Energy Law marks a shift in energy policy toward the use of policy to spur the growth of dynamic market of renewables for China.

Policy Trends

As the discussion of the Five-Year Plans have shown, a great deal of China's national energy policy is broad and overarching, often lacking quantitative targets with specific enforcement rules, as well as clear and transparent operational rules (Fan et al, 2005). Figure 7 provides an overview of the policies China has enacted since the 1980s, according to classification. Between 1997 and 2001, however, four national level-three energy policies with more specific, concrete regulations were passed, illuminating the trend that China has been picking up the pace on national efforts to meet future energy demands.[75]

Evidence exists that the gap between overarching energy policies and clear implementation are present as a result of a lack of coordination between policy-making and regulatory bodies. Throughout the 1990s, energy policy was developed by the State Planning Commissions, the State Economic and Trade Commission, the State Science and Technology Commissions, the Ministry of Finance, and the State Environmental

[74] This goal was hailed as a strong indication that a National RPS would follow for China, but at present the 15% is a goal without a set purchase obligation for electric utilities.
[75] Table 12-1 of the Appendix catalogues the various incentives that province has in place for the development of renewables.

Protection Agency, among others. In 2003, the government took a major step in creating the NDRC to replace the state commissions (Andrews-Speed, 2004). In May 2005, it further corrected the problem by establishing the National Energy Leading Group (NELG) to coordinate energy policy. However, many experts have recommended that a department of energy be created on the ministry level of the government to further develop coordination (Andrews-Speed, 2004).

The Next Steps: China's Progress in Deploying MMS Policies

The Wind Concession program

In 2002, China created the Wind Power Concession program under the NDRC, which called on international and domestic investors to develop .1 GW wind farms on potential wind sites. Winning bidders' proposals were approved for the development of the sites, given a power purchase agreement (PPA) for the first 30,000 hours of the projects' operations, assured grid interconnection, financial support for extension of the grid and roads, and other tax, subsidy, and loan support. These measures are used to create a low-risk investment environment for wind farm developers. In October 2003, two bids were accepted. However, these winning bid prices were excessively low, dipping below long-run marginal costs for the projects. As a result, the developers chosen have not been able to obtain financing, and the projects have yet to go forward. A second round of bidding brought forth even fewer proposals (World Bank, 2006). In eight of the concession rounds that have taken place since 2003, seven of them have been won by state-owned power companies, at prices around 5 cents/KWh, which may have been too low for private and foreign companies unwilling to incur losses to compete (Liu, 2006). Another concern is the potential burden on consumers-- In 1998, five wind farm projects with PPAs funded by the World Bank and Global Environment Facility under the China Renewable Energy Development Project (CREDP) ran into difficulties when the surrounding regional grids could not support the spread of the higher price across the grid (Raufer, 2002). However, though the tendering system has been a source of concern, if adjusted to better reflect private developer and consumer concerns according to market conditions, it could be the source of the rapid establishment of numerous large-scale wind farms for China, though these adjustments are extremely difficult to make in light of the difficulty in assessing market factors in nascent industries.

A National Feed-in Tariff?

The November 2005 draft of the Renewable Energy Law indicated that the Chinese government would pass a feed-in tariff for wind power fed to the grid, specifying that this measure would take into account the "nominal tariff of local desulfurized coal-fired power plants" and add subsidy of (US) 2.8 cents/KWh, funded through a small (less than .1 cent/KWh) tax on domestic energy consumers. However, the final version of the regulation, approved at the end of March 2006, does not include this language, leaving the Wind Concession program as the primary market driver policy of wind development, a policy which, as mentioned above, many developers have deemed too risky to provide an incentive to enter the market, as remarkably low price proposals are needed to win bids (Liu, 2006).

Challenges

The Chinese government, at present, has stepped away from a national feed-in tariff, has not yet had consistent success with the wind concession approach, and may not, on the whole, have markets sufficiently developed for a national RPS. What would be the best, most efficient and cost-effective way for China to proceed? In any national MMS policy it puts forward, it will need to consider several challenging factors about its market conditions: the discrepancy between potential supply and demand across provinces and urban and rural regions, and the deadweight losses to consumers and producers, and the different developmental stages of particular RE technologies. To do so, it must carefully weigh the elements of policy design to determine which set of policies will achieve the most success, taking an integrated approach to fulfill the three main branches of policy criteria set out in Figure 1. Thus, an MMS system must explicitly address issues of price, availability of capital, manufacturing and service capabilities, institutional arrangements, and lack of competition (Raufer et al, 2002). Because of the difficulty of demonstrating and quantifying the impacts of these systems beyond case-study experience, their theoretical qualities will be compared to the situation in China, supported by various case studies, to sketch out how China should create an optimal MMS system (Thiruchelvam et al, 2003).

Recommendations

Because developing an effective mandated market system for renewable energy in China can be encouraged and facilitated by a wide rage of groups and actors, policy recommendations will be made to the government of China, NGOs, and international institutions, with an emphasis made towards the UN CSD.

Policy Design

A joint effort between China, NGOs, international institutions, and the CSD to implement a strong decentralized MMS with the following characteristics would have many advantages:

As the analysis of MMS policies have indicated, a homogenous mandated market system (such as a national RPS policy) appears disadvantageous because of its lack of flexibility toward the unique market conditions in each region of China. Implementing a policy flexible towards the needs of specific regions and cities has clear advantages for the government of China.

Because of the lack of competition in rural areas, feed-in tariffs appear to be the best initial policy for these areas for at least the next 10 years. This will reduce investor uncertainty and increase investment, and will also support community-based development more than the other policies. As competition and development increase in these regions, the province-level governments of China can move to RPS policies. The MMS policies for rural regions will benefit from working to first develop capacity in underdeveloped regions at a reasonable price, and then work to drive this price down.

In high-capacity sites in rural areas, primarily in the Western region, China, energy-affiliated NGOs, and the CSD will find it beneficial to encourage investment from the eastern coastal area and abroad, in order to garner enough competition so that a competitive bidding process can be undertaken with efficient results that will make sure that these areas are made productive (Fan et al, 2005). However, proposals accepted must be evaluated carefully and determined to be realistic in terms of the bid price.

In urban areas, the province-level governments of these areas would find clear advantages in implementing ambitious RPS policies locally. In the presence of sufficient market competition and capital, the RPS provides a market atmosphere through which installed renewable capacity can rapidly expand and evolve under the forces of competition that spurs innovation. China would gain from setting strong but realistic purchase obligations for utility carriers in these areas and undertake measures to garner political support for these policies so they are not made too mild and thus useless (Fan et al, 2005).

The government of China and the CSD would also benefit from encouraging the development of renewable energy technology for export, and supporting the growth of the solar manufacturing industry. This will potentially allow Chinese companies to engage in economies of scale that would reduce material costs over time, helping the progress of the growth of renewable energy both at home and abroad.

MMS policies would gain from strategic supplements of other financial incentives as in the case of Denmark, especially because renewables must also compete against many hidden subsidies for conventional fuels (Martinot et al, 2002). For example, these incentives may come in the form of low import duties on renewables components. China has been doing well to bolster investment in renewable energy with tax breaks at this point in time.

Administration and Enforcement

Though homogenous MMS policies do not have the flexibility to best support RE growth in China, policy coordination to ensure policy complementation across provinces is essential. Thus, China would have much to gain from the establishment of a ministry of energy that coordinates and clearly defines the roles of the various agencies as national or province-based regulatory bodies in implementing and enforcing specific MMS policies.

Transparency, information flows, and coordination must be excellent so that evolving market conditions are known to make accurate policy adjustments. The Ministry of Agriculture has established over 1700 rural energy offices at county, district, and township levels that provide a variety of services, which include information, subsidies, and technical support. These centers could be asked to track RE development and the impact of local policies, reporting this information to the ministry of energy, if created. The responsibilities of these already-established centers could also potentially be extended to administer specific enforcement rules and noncompliance penalties for MMS policies tailored to fit the areas they serve (Martinot et al, 2002).

A national RPS has been cited to have high administrative costs and difficulty of enforcement. However, because the presence of a tradable renewable credits system greatly lowers these costs, the urban RPS systems would benefit from a complementary national tradable renewable credits system by which urban electric utilities can purchase tradable credits from rural or off-grid areas. This will also help electrify off-grid regions and address some of the disparity between potential renewable energy supply and demand across the country.

Costs

China has reported that it hopes to spend $1.84 billion by 2020 on renewable energy projects and costs (Jing, 2005). This fund could effectively be made to support a carefully designed MMS system, rather than directly fund projects, and might potentially see more real returns to this approach. By strategically using MMS policies to engage the private sector, far more investment will flow into RE development than government funded RE projects alone.

Because the burden of an MMS policy as a protectionist measure can be substantial, care can be taken to spread the burden over all parties who benefit (even indirectly) from the implementation of the MMS. Thus the government of China can use a combination of policies to cover the incremental cost of its MMS: through a very small (less than .1 cent/KWh) surcharge on electricity consumed, a government or donor-based public fund, and a small carbon tax. Though the latter will be politically unfavorable, the change can be seen as a reduction in carbon subsidies rather than a carbon tax.

Finally, China, and donors in the form of NGO's and international institutions, would benefit immeasurably from making a large investment from money allocated to RE development causes to restructure China's transmission systems, funding R&D measures to close the regional gap between potential supply and demand. Removal of this gap provides perhaps the only route for China to fully exploit its wealth of RE resources and fully reap the benefits of a high installed capacity of RE.

The Role of the CSD

The CSD is in an important position to provide invaluable assistance to China in its development of MMS systems. It might potentially help to bring foreign investment to Chinese RE projects, especially those located in rural regions or other areas lacking in competition. The CSD can also encourage expansion of renewables and development of a domestic RE equipment manufacturing industry in an environmentally friendly manner by promoting RET exports from China. It can make sure, in addition, that donor programs, which are often cost less to consumers, do not upset market competition (Martinot et al, 2002). Finally, the CSD can work closely with China to study its energy markets to effectively determine optimal purchase obligations and prices to design policies given current levels of RET development that will find the same level of success as those in Germany, Denmark, Spain, and parts of the US. Determining the nature of market conditions for nascent industries can be extremely difficult, thus the CSD (and international organizations) could provide valuable help in the form of research to China in this area.

Conclusion

Weidou et al (2004) have stated that "On balance, the strength conferred by the sheer scale of the internal market and forecasted demand for China's energy products outweighs the very real challenges of distance and terrain." The effective implementation of well-structured MMS systems have the enormous potential to play a critical role in the process of RE development across distance and terrain in China. Used effectively, these policies will offer real support towards efforts to slow the pace of global climate change for many years to come, and make reaching the MDGs and other sustainable development goals possible for China.

Appendix

Acronyms

CEC	California Energy Commission
CPUC	California Public Utilities Commission
CRED	Center for Renewable Development
CREDP	Center for Renewable Development Project
CSD	Commission on Sustainable Development
ERCOT	Electric Reliability Council of Texas
GDP	Gross Domestic Product
GW	Gigawatt
KWh	Kilowatt Hour
IOU	Investor Owned Utilities
NDRC	National Development and Reform System
NELG	National Energy Leading Group
NEPA	National Environment Protection Agency
NGO	Non-Governmental Organization
NFFO	Non-Fossil Fuel Obligation
PPA	Power Purchase Agreement
PURPA	Public Utilities Regulatory Policy Act
PV	Photovoltaic
RE	Renewable Energy
RET	Renewable Energy Technology
RPS	Renewable Portfolio Standard
MMS	Mandated Market Share System
UN CSD	United Nations Commission on Sustainable Development

Table A1: Comparing the Policies

Table 1. Comparing the Policies

Policy Objective	RPS	Feed-in	Tendering
Incentives for cost and price minimization	Policy creates incentives for generators to lower RE prices in order to compete for contracts; does not inherently reduce costs of generation except those related to technology learning and efficiencies of scale	Few inherent incentives to minimize market prices for renewable energy, though there are likely to be project cost reductions related to technology learning and manufacturing volume	Policy creates significant competitive pressures for price minimization that will be linked to cost minimization where there is sufficient competition, technology learning and manufacturing volume
Ability to maintain targets for renewable energy	Purchase obligation can be effective at meeting RE targets provided RPS is well-designed	Ability of feed-in tariff to help government meet RE targets is variable depending on host of factors	Ability of tendering policy to help government meet RE targets is variable depending on host of factors
Assurance of resource diversity	Diversity possible with bands and tiers, but has administrative drawbacks	Can successfully stimulate a more diverse set of resources by setting one price that many technologies can meet or setting a separate price for each technology band.	Diversity possible with bands, but as with targets, policy does not guarantee that projects will be built
Sustainable market for power	All three policies build markets for RE power – RPS may be more technically & politically sustainable.	Can be vulnerable to political 'tinkering' and if viewed as 'subsidy' makes it less economically and politically sustainable	Tends to be tied to a resource planning process that can make it more politically vulnerable if planning out of favor
Political viability	Depends on circumstances – unclear in China	Depends on circumstances – unclear in China	Depends on circumstances – unclear in China
Local industry development	Needs companion policies to ensure local development	Feed-in tariffs can create local manufacturing and development infrastructure benefits	Will favor least cost generation over local industry development; benefits established industry
Compatibility with electricity industry and regulatory structure	RPS is compatible with industry and regulatory structure in China, though appropriate phase-in and enforcement are important.	Compatible with existing regulatory and industry structure but current tariff structure needs fixing to work	Tendering is compatible with industry and regulatory structure in China and can be used by utilities in conjunction with an RPS.
Policy stability	Provides less certainty than feed-in tariffs, must be carefully designed	Provides high degree of certainty and stability	Can provide high degree of certainty and stability, but only if well designed
Competitive parity	Creates competitive parity as the same standard applies to utilities and developers equally	Parity achieved only if cost sharing mechanisms are established that spread the costs broadly	Policy favors established market players over new market entrants and can allow market manipulation by existing companies
Integration of renewable energy supplies	Creates incentives for full integration and barrier reduction	Fewer incentives than under RPS to reduce institutional barriers	Neutral- doesn't help reduce institutional barriers
Simplicity	More challenging policy to design and administer, and more complex contractual and development process for generators as compared to feed-in	Most simple design, administration, enforcement, contractual, and development simplicity	More complex than feed-in laws, because requires the development of a system to raise money for the incremental costs of RE.

Source: Wiser et al, 2005.

Figure A2: RPS Design Elements

Structure, Size, and Application of the RPS

- Percentage purchase obligation targets over time
- Start date for purchase obligations
- Duration of purchase obligations
- Structure (e.g., single % requirement, or multiple % requirements for each technology group)
- Renewable resource diversity requirements or incentives
- Application to electric utilities – who must meet the obligations

Eligibility

- Resource type eligibility
- Allow imports, or just in-state facilities
- Eligibility of existing renewable generation
- Definition of new/incremental generation
- Eligibility of customer-sited renewable facilities

Administration

- Regulatory oversight body(ies)
- Verifying compliance – RECs or contract-path
- Certification of eligible generators
- Compliance filing requirements
- Enforcement mechanisms (i.e., penalties)
- Existence of cost caps
- Compliance flexibility mechanisms
- Contracting standards for regulated electric utilities
- Cost recovery for regulated electric utilities

Interactions Between the RPS and Other Policies

- Interactions with other renewable energy policies
- Linkages with emissions credits policies

Source: Wiser et al, 2005.

Table 4-1 Chinese Renewable Energy Resource and Development Potential

Variety	Recoverable Resource	Developed amount in 2000	Undeveloped resource
Small-scale hydropower	1.Small-scale hydropower under 25MW is 75GW, generable electricity is 240TWh, equivalent to 87.1Mtce 2.Micro-scale hydropower under 0.1-10kW is 80GW,g generable electricity is 125TWh, equivalent to 45.3Mtce Subtotal: 132.4Mtce	Installed capacity of small-scale hydropower is 24.8GW, taking up 33% of recoverable resource; installed capacity of micro-hydropower is 167.7MW, taking up 0.2% of recoverable resource, generated power is 261.9GWh;subtotal is 29.1Mtce, development rate is 22%	Small-scale hydropower: 50.2GW; micro-scale hydropower is 79.8GW Subtotal: 103.3Mtce
Solar energy	Two thirds of land has sufficient solar energy, annual radiate amount is over $6GJ/m^2$.	Water heater, passive solar house, solar oven, and photovoltaic battery. Total: 3.84Mtce	Development potential is huge

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Wind power	Wind resource above 10m height is 253GW; offshore wind resource is 750GW; wind resource above 50m height is 1000GW; Total: 2000GW, 4700TWh, equivalent to 1706.1Mtce	Installed capacity of interconnection wind generator is 344MW, generated power is 930GWh; small and micro-scale wind generator is 17MW, generated power 35GWh. Developed rate is 0.018%	Developed amount is small and undeveloped amount is more than 2000GW, equivalent to 1700Mtce
Biomass	Resource is about 700Mtce, crop and straw is 120Mtce, fuel wood 90Mtce, livestock and birds feces, the waste and organic waster water are 390Mtce. With agricultural development, improvement of living condition, and implementation of large-scale project of returning land for farming to forestry, resources of straw, fuel wood, faces, waste and energy crop will increase, and will reach 900-1000Mtce in 2020.	Biomass through traditional measures is 219.1Mtce (straw and fuel wood), accounting for 104.3% of total resource (excessive consumption); biomass through new technology is 3.3Mtce, accounting for 0.8%	With the development of new technology, biomass through traditional measures will decrease. the potential of biomass through new technology is large, and can reach over 800Mtce in 2020.
Geothermal energy	Recoverable geothermal energy resource is 3158Mtce/a, geothermal energy spots are over 2900	Generation and heat use of geothermal energy are 0.65Mtce	Development potential is huge
Ocean energy	Recoverable resource is abundant and over 48.58GW, tidal energy is 21.79GW, wave energy is 12.85GW, tidal flow energy is 13.94GW	7 small-scale tidal energy generation stations with 6MW; 1 tidal flood energy generation station with 5MW, total is 11MW	Development potential is huge

Source: Zhenmin et al, 2005.

Table 12.1: Incentives for Wind/Solar Energy Development

	Inner Mongolia
Current Status	14.5 MW of large wind power generators, 18.5 MW of small wind power generation; household photovoltaic (PV) systems dominated by 10 –20Wp.
Subsidy policies	Rmb 25 million to users in 1986-90; Rmb 200 for each 100W wind power generator purchased or each 16W PV unit from financial budget. Annual subsidies of Rmb 300,000 for R&D activities; Working capital provided by local authorities for establishment of extension station in 56 counties.
Taxation policies	3% VAT surtax on wind power generation; income tax relief for 2 years; 10.69-14.43 Yuan for VAT surtax on PV units of 16Wp –21.6Wp.

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Pricing policies	Tariff calculated on repayment of principal and interest. 713Yuan/MWh including VAT in 1995 and 609 Yuan/MWh not including VAT; the difference is shared by grid and subscribers with 200 Yuan/MWh by grid and rest by subscribers in the form of subsidies 2.5 Yuan/kWh.
Loan policies	Rmb 400 million for wind power by State Economic and Trade Commission; Danish Government loans for wind power generation.
Other	Land use policies: Land tax collected on the land actually occupied;5 year income tax holiday for occupying arable land;10 year land tax holiday for occupying the unused land.
	Xinjiang
Current Status	16.7MW of large wind power generation; 8000 household PV systems dominated by 10-20Wp.
Subsidy policies	50-200 Yuan for PV unit and small wind power generation unit purchased; 1 million Yuan for R&D; Working capital for extension stations; 300 Yuan subsidies for PV users.
Taxation policies	2 year tax holidays, 3 year tax relief and 5 year 15% income tax for foreign invested or joint venture with an operational life for 10 years. VAT holiday for products export. Monthly collected VAT and surtax at 17% and 10% respectively. Seasonal collected income tax at 15-33%; Import tariff and VAT at 12% and 17% respectively, with duty free for international donation.
Pricing policies	Tariff calculated on repayment of principal and interest. 698 Yuan/ MWh including VAT in 1995. The regular grid tariff is 118 Yuan/MWh in the area; The difference is shared by grid and subscribers. The added 2 cents/kWh with 0.5 cent for difference with rest borne by grid.
	Gansu
Current Status	5000 household PV units mainly of 20Wp
Subsidy Policies	300 Yuan for each PV unit purchased; Subsidies for R&D; Support for extension station
Taxation policies	Policies similar to that of Xinjiang in taxation on PV system with only exception for monthly collected value added tax on non-donated PV system.
Loan policies	Guarantee by local government for household PV system to secure a loan with interest rate at 3%. The subsidies came from additional tariff by 3 Yuan/MWh and 20% interest subsidized from financial budget.
	Qinghai
Current	15000 household village PV station of 23 kW

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Status	
Subsidy policies	300 Yuan for each PV unit purchased; Rmb 500,000 for R&D; Working capital for extension stations
Pricing policies	Addition tariff 2 Yuan/MWh, with some of the revenues used to finance installation PV system
	Northeast Grid
Current Status	6 MW of wind generation
Taxation policies	6% VAT on wind generation. No tax relief for high power tariff (900Yuan/MWh) in Henshan, Liaonin. 6% for Donggang, Liaonin (100Yuan/MWh).
Pricing policies	Tariff calculated on repayment of principal and interest
Loan policies	Discount loans for wind power
Other	Land use fee paid on the area actually occupied by wind power generation with preferential treatment as foreign invested businesses
	Gaungdong
Current Status	11.7MW of wind power generation
Taxation policies	VAT collected at 20 Yuan/MWh and 15% for income tax
Pricing policies	Tariff calculated on repayment of principal and interest; Grid tariff 770Yuan/MWh with difference shared by subscribers
	Zhejiang
Current Status	1MW of wind power generation
Pricing policies	Tariff calculated on repayment of principal and interest;

Data sources: Draft Final Report on Financial Policies Promoting China's Renewable Energy Development by World Bank and China.

Source: Zhengming et al, 2000.

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