September 30th, 2010

Competitive Power Ventures, Inc. ("CPV") hereby submits these comments in support of the New Jersey Board of Public Utilities' ("BPU") ongoing review of the 2008 Energy Master Plan ("EMP"). CPV appreciates the BPU's efforts to solicit stakeholder input and continues to believe that new, gas-fired generation will play an important role in ensuring that New Jersey meets its power requirements and policy goals in a cost-effective, clean and reliable manner.

CPV has been an active and vocal participant throughout the stakeholder process. In addition to having participated in the BPU's stakeholder forums, CPV has provided written comments in response to the BPU's June 25, 2010 Notice of Technical Conference for Docket No. EO09110920, as well as the September 22, 2010 Stakeholder Panel Discussion addressing Energy, Environment & Economic Development. CPV would like to use this opportunity to summarize the comments it has offered to date in these various forums and to re-iterate the vital role new gas-fired generation and long-term contracts should play in New Jersey's future.

Renewable energy resources such as wind and solar are clearly important components of New Jersey's overall energy strategy. Increased renewable resources on the electric power system indisputably offer numerous benefits, such as acting as a price hedge against the potentially higher cost of carbon fuel generation and lowering overall emissions of pollutants. However, in implementing its Renewable Portfolio Standard (RPS), it is essential for New Jersey to consider the effects that increased levels of renewable generation will have on the stability and operation of the electric grid. Renewable resources in general present challenges to system operators due to their inherent variability of output. Unlike traditional resources, which are dispatchable and can be relied upon to provide firm energy on demand, renewables are by nature only able to intermittently produce power and can experience rapid changes in the level of energy they are able to produce. These characteristics can place a great deal of strain on the remainder of the electric power grid as system operators respond to these continuous and rapid variations in output.

As the state implements the RPS in New Jersey, CPV believes the best way to reliably accommodate the growth in renewables is through the development of complementary resources, namely new, firm, efficient, and clean generation that is specifically designed to start and stop quickly and frequently. This type of new facility can both support the unpredictable nature of renewables while also contributing towards turnover in the existing generation fleet by displacing those aging and less efficient facilities that were not designed to run under this paradigm. The cleanest and most dependable technologies to achieve this firming are gas-fired simple and combined cycle type projects.

Consistent, and in tandem with this concept, we believe that new gas-fired generation should be developed in transmission constrained areas that currently pay higher prices for wholesale power than the rest of PJM due to congestion. If the state provides economic incentives for the development of a few hundred megawatts of generation in strategic locations, the state will quickly recoup its investment through the savings that will be realized by ratepayers in the affected areas.[1] Those ratepayers will thereafter pay a lower price for wholesale energy across several thousands of megawatts. As we know, the wholesale cost of power comprises about half of New Jersey ratepayer's electric bills, so that is the cost area that can yield the greatest reduction in costs to New Jersey's ratepayers.

---

[1] PJM recently completed a sensitivity analysis that demonstrates the magnitude of the reduction in wholesale prices resulting from the addition of capacity in transmission constrained areas. Such analysis is referred to as the "Scenario Analysis Results" and can be obtained under the "DY 2013/1014" file available at: http://www.pjm.com/markets-and-operations/rpm/rpm-auction-user-info.aspx#Item07. Using this information, one can calculate the potential savings that ratepayers can realize by strategically located generation in various LDA's.

While there are a variety of methods available to help to incent the development of new gas-fired generation, CPV believes that the use of long term capacity contracts, such as power purchase agreements (PPAs), represents the optimal approach by which New Jersey can achieve the economic, reliability and environmental objectives benefits it has outlined. The managed procurement of power under such contracts permits control over the timing, location, type, size and environmental profile of new resources. As in other de-regulated states, electric utility de-regulation has transferred much of the control over new generation away from New Jersey into the hands of the FERC, PJM and the private sector. In this diminished state of regulatory authority to site new plants, New Jersey and other deregulated states must now rely on establishing policies and tools that can provide private-sector developers with economic and risk mitigation incentives that promote the siting and construction of new power generation facilities. The PPA is a highly effective tool that the state can use to accomplish these goals.

It is important to note that new resources that sell power under PPAs can reduce capacity and energy costs to ratepayers relative to an approach that relies entirely on shorter term resources or only existing resources. This is commonly referred to as the "portfolio approach," which has been shown in other business sectors to reduce costs and risks. By spreading the recovery of the cost of new generation over multiple years, long-term contracts reduce both a project's risk profile and the volatility of wholesale power to ratepayers. The reduced risk to the project enables the project to attract lower cost financing, which in turn lowers the overall cost of the project further helping ratepayers. The PPA is an enabler of the portfolio approach.

Of particular import in evaluating the role that natural gas fired generation will have in New Jersey's future is the recent discovery of Marcellus shale gas. Given the location and magnitude of these untapped natural gas reserves, New Jersey residents and businesses are likely well-positioned to benefit from lower gas prices for the foreseeable future. Lower gas prices will make gas-fired generation even more competitive and should help lower the cost of wholesale power to ratepayers. Encouraging the development of gas-fired generation through the use of PPA's is an enabling tool to take advantage of New Jersey's unique proximity to Marcellus shale.

In conclusion, CPV respectfully urges the state to effectuate policies in the EMP that recognize the importance of natural gas generation in New Jersey's future, that incentivize the development of new state-of-the are gas-fired generation projects that will complement the increase in renewables generation, and that recognize the use of PPA's as an effective tool by which to achieve these and other objectives. In so doing, we believe the state will achieve its stated policy of achieving affordable, clean, safe and reliable energy for New Jersey residents and businesses, thereby enhancing the quality of life for all New Jersey residents.

Respectfully Submitted,

/s/ John Seker

John Seker
Competitive Power Ventures, Inc.
50 Braintree Hill Office Park
Suite 300
Braintree, MA 02184
Telephone: (781) 848-0253
Facsimile: (781) 848-5804
jseker@cpv.com

Gentlemen:

A thought came to mind following yesterday's Stakeholder Meeting that I would like to offer.

> Concord Engineering has been involved with CHP projects in New Jersey for many years. We have seen incentive programs for these projects, both Federal and State, come and go. Each time a program is introduced there is a flurry of activity to develop new projects; however most of the programs have a limited duration. CHP projects typically take a significant amount of time to develop, sometimes several years, because they are a large capital investment, and require a significant amount of study and evaluation, and normally many layers of approvals within the organization. It is common that by the time a decision is made to go forward with the project, the incentive program has expired, and as a result the project is often shelved.
>
> We would like to see the Energy Master Plan address an incentive program for CHP projects that would be on-going, and could be counted on to be available once the decision is made to move forward with a project.

Thomas W. Iannuzzi, P.E.
Vice President, Power Services
Concord Engineering Group

CORE METRICS

September 28, 2010

Energy Master Plan
c/o NJ Board of Public Utilities
P.O. Box 350
Trenton, NJ 08625 (delivered by e-mail)

RE: EMP comments

Dear Commissioners and Staff:

I offer these comments based on my experience in resource planning for the electric power sector as an analyst and modeler. For 6 years I did analysis with the Conservation Policy Analysis Model and related tools for Bonneville Power Administration (regional planning, part of DOE). Those studies involved projecting long-term consequences of energy policy decisions for many “what if” scenarios. I can’t offer quantitative projections here, but I can identify some consequences of decisions made by policy makers and by energy users. I am an independent consultant in energy planning and investments. Most of my comments are on issues that relate directly or indirectly to energy efficiency.

I went to all 3 stakeholder meetings, and expect you received or were directed to ample data in many forms. Instead of offering even more data, the most valuable input I can offer is to address what seem to be misconceptions about energy efficiency’s costs, benefits, and how it’s treated in government resource planning and acquisition decisions. I feel obligated to address issues that surfaced at the first 2 meetings, or weren’t addressed adequately by other stakeholders.

1) The EMP process has repeatedly brought up the topic of rates and lowering rates, rather than lowering energy bills (which is a more inclusive measure). Rates are an incomplete measure of energy costs. Conceptually rates represent per unit prices and their relationship to energy demand is complex. Bills are more inclusive than rates, adding up costs over a period of time. Bills can be compared directly to income, and the ratio provides a measure of affordability. Bills reflect reduced consumption and improved affordability due to availability of efficiency programs, but rates do not. Some large industrial firms may be concerned solely with rates and publicly discourage energy efficiency programs, but catering to that minority would raise costs for the rest of New Jersey and harm the environment. Just to be clear, the reduced consumption I referred to does not imply a less prosperous New Jersey, but it’s doing more with less energy (i.e., efficiency). Money saved on energy bills can help stimulate New Jersey’s economy.

The 2008 EMP projected bill savings for the state, so I expect the current process will do similar impact analysis when modeling reaches that stage.

2) State energy efficiency programs are reliant on private sector monies and cooperation with businesses and households. As a result, recent budget cuts are counterproductive both for New Jersey's budget and for achieving New Jersey's EMP goals.
Generally speaking, energy efficiency programs *leverage* private sector dollars. They do not pay the full cost of buying and installing energy saving technologies (efficiency measures), though there are exceptions. Generally, program success depends on program participants spending some of their own money, time and effort to make energy savings a reality. Energy efficiency programs faced budget pressures around the U.S. long before New Jersey's budget crisis. Consequently, programs developed a genuine concern for spending the public's dollars wisely.

Let me elaborate on why this leverage of private spending impacts New Jersey's future budgets. When equipment that uses energy needs to be replaced, there is a brief period of time when the equipment owner is more receptive to participating in energy efficiency programs because the person or business needs to make a decision about new equipment (for example an appliance or electric motor). At that point in time, it is easier to incentivize the owner to install energy saving measures. It's "low hanging fruit" and costs programs less to incentivize energy efficient choices by the private sector. Once that equipment is in place and functioning, the owner has working equipment and an investment to protect. At that point, it becomes much harder (more costly) to incentivize the installation of energy efficient equipment. By drastically cutting back program funding, New Jersey is creating lost opportunity energy savings, missing the chance to acquire cheap energy savings that become more expensive later. This is what I mean by counterproductive to New Jersey's budget. I do not yet know how budget cutbacks hit various programs in the lost opportunity area; therefore, I cannot estimate the size of the impact. I am most concerned about buildings and equipment with long lifetimes that become lost opportunities. The consequences will show up in bigger budget needs in future years.

Cutting budgets now has the effect of deferring program costs that would have occurred in 2010 to later years so that the EMP's 2020 targets remain achievable. Furthermore, stable funding provides a signal to the private sector that the state is a reliable partner. By removing funding, the state makes things unpredictable and risks losing motivation by businesses and households to participate in well designed programs and save energy. Achieving the 2020 goals becomes harder.

3) Even though it's widely acknowledged that energy efficiency and demand-side management offer the cheapest ways to meet growing energy needs and mitigate global warming, at present traditional generation (with higher levelized

cost) gets first class treatment in NJ while energy efficiency gets second class treatment.
Many of the reasons for this disparate treatment are historical in nature (how the power system, natural gas and transportation systems evolved) so I am not trying to blame the planning process or BPU unfairly. However, the BPU has some obligation to address lopsided decision-making and funding that promotes emissions and costly generation over cheap energy savings.

An approved coal or nuclear plant gets included in the rate base and receives associated legal protections through the regulatory process, including a fair rate of return. On the other hand, energy efficiency programs are subject to state budget crises and political whims. It is not hard-nosed, tough decision-making to pull funding from energy efficiency programs; it is short-sighted false economy and will show up in higher energy bills for businesses and households, and in future New Jersey state budgets, not to mention climate impacts.

I know that BPU Commissioners are concerned with the stability of funding for Clean Energy programs. This concern came up in one of the topics President Solomon raised at the September 22 meeting.

President Solomon introduced Topic 1 on September 22, elaborating on some initial ideas for self-sustaining, creative financing that stakeholders could discuss. While these ideas may be new to EMP forums, some of the ideas are not new to energy planners. I refer you to a National Governors Association (NGA Policy Academy, June 17 2009) presentation by Richard Sedano of the Regulatory Assistance Project titled “Raising Money for Energy Efficiency”. This and other useful materials are at www.raponline.org. My point is that innovative financing has provided and will continue to provide the financial means to stretch public dollars further. Financing can help, but it can’t work miracles. That won’t stop Wall Street from trying to market miracles and needy governments from trying to claim miracles. Even when wrapped in impressive sounding jargon, financing isn’t a substitute for the political will to protect energy programs that are essential to long-term sustainability.

Regarding future energy needs, I adopt the perspective of ratepayers, or should I say billpayers, and ask what is in their best interest. Spending ratepayer money on conventional energy generation, along with its associated environmental costs, or spending their money on cheaper energy efficiency that reduces environmental externalities? Efficiency is clearly preferable, though it’s vulnerable and under-funded. In my view, funding for energy efficiency and demand-side programs should receive the same level of regulatory and legal protection as traditional generating assets enjoy. That would help address the lopsided acquisition process that favors funding new power plants. In March 2009, Northeast Energy Efficiency Partnerships (NEEP) presented the NJ Energy Efficiency Utility concept to the BPU as the #1 key recommendation among elements of an energy efficiency strategy. NEEP’s report also presents realistic cost estimates for achieving EMP goals, which are greater in scale than current Office of Clean Energy activities. New Jersey residents and businesses deserve to have an Energy Efficiency Utility with protected funding. Other states have protected funding. Why not New Jersey?

What alarmed me at the September 22 meeting was wording in the Topic 1 handout that suggested moving in the opposite direction, in the direction of favoring traditional generation even more. The handout says: "Topic 1: Self-sustaining financing of clean energy: how does NJ set up policies that are self-financing as opposed to requiring ratepayers to fund continuously?" I'll ask what seems to me a fairer question, one that doesn't handicap clean energy: Why should New Jersey ratepayers be obligated to fund new, dirty power plants and associated costs, but somehow clean energy isn't entitled to full ratepayer support? As other stakeholders pointed out, all forms of energy production get subsidies, so the mere existence of subsidies for renewable power can't answer the question. I believe the answer is because traditional power has long received regulatory protection and utility backing, but clean energy has little protection and gets hit by budget cuts.

Final points

The budget crisis has led to false economy. State funding for efficiency programs is cut, and consequently much greater costs show up elsewhere for New Jersey residents and business in the form of: higher utility bills, in environmental degradation, in increased future state budgets, and in society's ability to face a challenge to our way of life. The U.S.'s energy infrastructure was built on the premise of cheap, inexhaustible energy with limited environmental externalities. We are starting to adapt as a society to the reality of more expensive energy with greater environmental impacts. Adapting requires using energy more wisely, making informed choices as consumers and businesses, knocking down barriers to energy efficiency, and ultimately funding large scale, sustained energy efficiency programs. I urge you to stick to the energy efficiency and demand-side management goals of the 2008 EMP, and provide realistic resources and funding to progress towards those goals. Don't give in to a "penny wise, pound foolish" mentality that jeopardizes our future.

Yours truly,
Franklin Neubauer
Principal

Scott Henderson
Senior Manager, Government Relations

Covanta Energy Corporation
40 Lane Road
Fairfield, NJ 07004-2615
Tel 862 485 8649
Fax 973 882 2766
Email shenderson@covantaenergy.com
Website www.covantaholding.com

September 30, 2010

The Honorable Lee Solomon
President, Board of Public Utilities, State of New Jersey
Energy Master Plan
Two Gateway Plaza, 8th Floor
Newark, NJ 07102

Dear President Solomon:

As New Jersey begins to review the Energy Master Plan, Energy-from-Waste (EfW), also known as Waste to Energy, can play a vital role to increase renewable energy near the areas of demand, increase economic activity and create high paying jobs while at the same time reducing greenhouse gas emissions, land use and the cost to rate payers.

Every year, nearly 8 million tons of New Jersey's trash is sent to landfills, with very little, if any, energy or materials recovery. This has been the conventional option for the state and much of the nation and is certainly a responsible alternative to ocean dumping and backyard burning. However, other parts of the world have begun to take a new view of non-recycled trash: they view it as a resource.

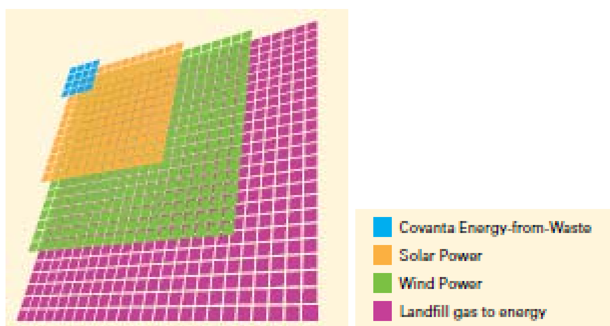
Germany, Denmark and the rest of the EU have adopted policies that have moved to phase out landfills and increase recycling and recovery of energy from waste. As a result of the EU waste policies, the largest relative reduction in EU greenhouse gas emissions has been achieved in the waste sector, with a relative reduction of 34%. This is due largely to the avoidance of the methane that is generated by landfills. If New Jersey chooses follow the EU model for solid waste management, we could achieve a similar result. In fact, even while providing for a growth in the state's recycling rate from 52% to 65%, if the State processed the remaining waste that currently goes to landfills into energy at Energy-from-Waste facilities, New Jersey could generate up to 3.5 million MWh of renewable electricity and reduce greenhouse gases by nearly 5.5 million tons.

Energy-from-waste converts regular municipal solid waste into clean renewable energy. A new EfW facility can generate as much as 750 kWh per ton of waste. In contrast, a landfill gas project can only collect 65 kWh from that same ton of garbage on average, according to a recent paper co-authored by US EPA and North Carolina State University scientists. EfW can generate more than ten times the energy than a landfill gas project can produce on a much smaller footprint. One 1,500 ton a day facility can offset the need for approximately 500,000 barrels of oil a year. In addition, EfW facilities can be located near the areas of greatest electricity need, reducing the burden on our already congested transmission system and helping to alleviate congestion and capacity charges for New Jersey ratepayers.

As an economic driver, the construction of one 1,500 ton a day energy-from-waste facility can create nearly $1 billion worth of economic activity, create between 300 to 500 direct construction jobs and about 700 to 1,000 indirect jobs during the three year construction period. There are approximately 50 permanent high paying jobs necessary to operate the facility. The average payroll at a Covanta facility is more than $60,000 a year.

Nationally, each ton of waste processed at an EfW facility leads to the reduction of a ton of carbon dioxide equivalent greenhouse gas emissions. Based on these averages, New Jersey's EfW facilities avoid approximately 1.5 million tons of GHG emissions every year. This is predominately due to the prevention of landfill methane, a GHG 25 times as potent as carbon dioxide over a 100 year time frame. Concurrently, EfW supplies baseload renewable energy to the grid, avoiding fossil fuel combustion, and recovers ferrous and non-ferrous metals, reducing the GHG emissions associated with the production of these metals from raw materials.

Energy-from-Waste is one of the most efficient uses of land per megawatt (acres/MW) among the current renewable energy solutions. Covanta's facilities require an average of 0.7 acres/MW of electricity compared with 8 acres/MW for solar, 18 acres/MW for wind, and 27 acres/MW for landfill gas to energy based on average capacity over 30 years.



Land Required Per Megawatt

Energy-from-Waste is one of the lowest cost renewable energy sources. EfW provides long term price stability for rate payers for both energy and waste disposal over the coming years and decades. New Jersey stands primed to reap the many benefits from Energy-from-Waste.

<u>Energy-from-Waste is Proven in New Jersey</u>

Energy-from-Waste is a proven technology that converts municipal solid waste into baseload steam and/or electricity. There are currently 86 such facilities operating in the United States including five in New Jersey. Covanta Energy, headquartered in Fairfield, NJ, has three facilities in New Jersey in Essex, Union and Warren counties. The Essex County Resource Recovery Facility combusts over 2,500 tons per day of municipal solid waste from 22 municipalities in Essex County as well as the surrounding region and generates approximately 65 megawatts of renewable power. The Union County Resource Recovery Facility processes up to 1,540 tons of solid waste each day from Union County as well as the surrounding region and generates 42 megawatts of renewable power. The Covanta Warren Energy Resource Facility processes 548 tons per day of solid waste from Warren County as well as the surrounding areas and generates up to 13.5 megawatts of renewable power.

<u>Energy-from-Waste is Internationally Recognized as a Key GHG Mitigation Technology</u>

The EU Landfill Directive (1999) states that member countries have to reduce the biodegradable waste going to landfill to 35% of 1995 levels by 2020. This policy has been the single most effective way to achieve increased recycling and energy recovery which has allowed the waste sector to achieve the highest relative reductions of greenhouse gases at 34%. EfW facilities, through an engineered controlled combustion process, eliminate all of the potential methane from waste disposal in landfills. Recognition of EfW as a source of GHG mitigation and inclusion of EFW as an eligible source of carbon offsets follows the long established policies of the Intergovernmental Panel on Climate Change (IPCC), the Clean Development Mechanism (CDM) of the Kyoto Protocol and the European Union. Here in the United States, the recent expansion of the Lee County Resource Recovery Facility in Florida is generating carbon offset credits under the Voluntary Carbon Standard. EfW is also defined as renewable in 26 States (including New Jersey) and by the Federal government. The World Economic Forum in its 2009 Davos Report, identified EfW as one of 8 technologies likely to make a significant contribution for a future low carbon global energy future. The 2010 Davos Report reiterated their findings but also included a recommendation to follow the European Union's model and increase Energy from Waste by phasing out use of landfills because bury waste in landfill is "increasingly considered environmentally unacceptable".

Energy-from-Waste Facilities Have a Proven Track Record of Strong Environmental Performance

The U.S. EPA states that EfW facilities produce electricity with "less environmental impact than almost any other source of electricity." Even though these facilities were built nearly 20 years ago, they employ the latest state of the art technology. The 1990 Clean Air Act included a provision that EFW facilities must comply with the Maximum Achievable Control Technology (MACT) standards. A 2007 memo from the US EPA stated that "**The performance of the MACT retrofits have been outstanding**." The table below is from that same EPA memo.

Pollutant	1990 Emissions (tpy)	2005 Emissions (tpy)	Percent Reduction
CDD/CDF, TEQ basis*	4400	15	99+%
Mercury	57	2.3	96%
Cadmium	9.6	0.4	96%
Lead	170	5.5	97%
Particulate Matter	18,600	780	96%
HC1	57,400	3,200	94%
SO_2	38,300	4,600	88%
NO_x	64,900	49,500	24%

Although NO_x emissions were reduced during the period, Covanta identified an opportunity to do even better. Through a new technology that we are beginning to implement at our facilities, Covanta has been able to reduce nitrogen oxide (NO_X) emissions dramatically. Covanta has two patent-pending processes: LN™ (low NOx) and VLN™ (very low NOx). LN™ involves modifications to the combustion air system combined with modifications to the combustion monitoring and controls systems to achieve substantial reductions in NO_x formation.

The 2008 Energy Master Plan Recognized Waste as an Important Resource

Under Action Item 3 in the 2008 Energy Master Plan, the plan calls for a 900 MW increase in biomass in the State's RPS. There is tremendous opportunity for New Jersey to generate this biomass power and reap all the benefits we have enumerated above.

The plan says, "New Jersey produces an estimated 8.2 million dry tons (MDT) of biomass annually. Almost 75% of New Jersey's biomass resources are produced directly by the State's population, a majority of which in solid waste. The state's five municipal solid waste incinerators currently convert about 17% of that solid waste into energy. New Jersey's estimated practically recoverable biomass resource of 5.5 MDT could deliver up to 1,124 MW of power or 311 million gallons of gasoline equivalent if appropriate technologies and infrastructure were in place. **The large proportion of waste-based biomass, suggests that New Jersey pursue the expansion of waste to energy technologies**".

It goes on to say, "Biomass energy potential, such as waste to energy, will also be considered as part of this effort. New Jersey has one of the highest per capita incomes in the United States, and one of the highest rates of trash generated per person. New Jersey residents generate 6.7 pounds of trash per person per day, nearly 50% higher than the national average**. This offers a significant opportunity to pursue conversion of trash into energy and fuel products.** Conversion of this waste into energy will also reduce the need for future landfill development, and consequently reduce the amount of methane, a greenhouse gas, that is emitted from these landfills. Therefore, as part of the BPU's analysis they will consider incentives, including changes to the RPS, that can be put in place to support waste to energy technologies that are more sensitive to the environment than the current methods."

However, in the final report a sentence was added, "However, due to their emissions and inherent inefficiencies, incineration technologies will not be supported as part of this effort."

Unfortunately with that one sentence, New Jersey went in the exact opposite direction of the rest of the advanced countries of the world. Besides not being supported by the facts, this one sentence is holding the State back from being able to take advantage of all the incredible benefits of EfW. What this policy has done is ensure that landfills will grow larger; prices for energy and waste disposal will increase; more greenhouse gases will be produced; and jobs will not be created. As you begin to review the 2008 Energy Master Plan, we hope you will look at the fact that EfW is clean renewable energy and remove this one sentence that is holding back the entire State.

Energy from Waste can help New Jersey produce baseload renewable energy, create new, high-paying jobs, all while reducing the price to the consumer, reduce greenhouse gas emission and reduce land use. We look forward to working together to make New Jersey an even better place to live, work and raise a family. Please feel free to contact me at (862) 485-8649 if you have any questions.

Sincerely,

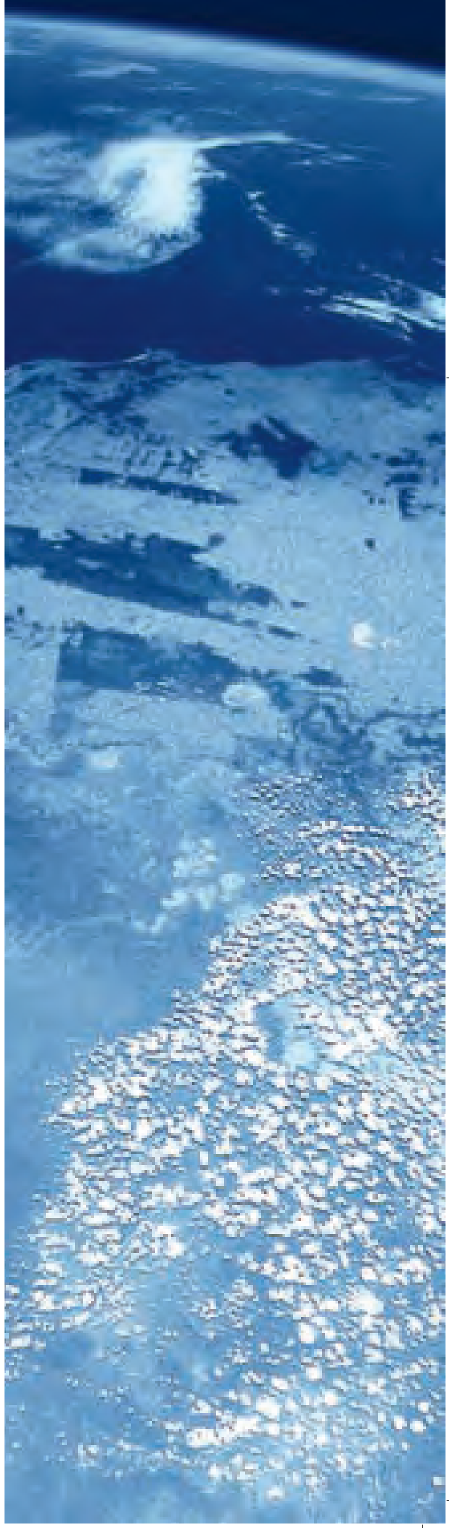
Scott Henderson
Senior Manager, Government Relations

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

Green Investing 2010

Policy Mechanisms to Bridge the Financing Gap



World Economic Forum
January 2010

The Green Investing: Towards a Clean Energy Infrastructure Report is published by the World Economic Forum. It is the result of collaboration with New Energy Finance. The Report is the work of the authors and does not represent the views of the World Economic Forum.

World Economic Forum
91-93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland
Tel.: +41 (0)22 869 1212
Fax: +41 (0)22 786 2744
E-mail: contact@weforum.org
www.weforum.org

World Economic Forum USA Inc.
3 East 54th Street
18th Floor
New York, NY 10022
Tel.: +1 212 703 2300
Fax: +1 212 703 2399
E-mail: forumusa@weforum.org
www.weforum.org/usa

REF: 200109

Contributors

Authors

From New Energy Finance

Michael Liebreich
Chairman and Chief Executive,
New Energy Finance

Chris Greenwood
Head of Research, New Energy Finance

From the World Economic Forum

Max von Bismarck
Director and Head of Investors Industries,
World Economic Forum

Anuradha Gurung
Associate Director, Investors Industries,
World Economic Forum

Expert Committee

Morgan Bazilian
Special Advisor on Energy and Climate Change to the Director-General, United Nations Industrial Development Organization

Marcel Brenninkmeijer
Founding Chairman, Good Energies AG

Wes Edens
Chairman and Chief Executive Officer,
Fortress Investment LLC

Jack Ehnes
Chief Executive Officer, California State Teachers Retirement System (CalSTRS)

Diana Farrell
Deputy Director of US National Economic Council; Former Director, McKinsey Global Institute, McKinsey & Co.

Peter Gutman
Global Head, Renewable Energy and Environmental Finance, Standard Chartered Bank

Kirsty Hamilton
Associate Fellow, Energy, Renewable Energy Finance Project, Chatham House

Wen Hsieh
Partner, Kleiner Perkins Caufield & Byers

Bruce Huber
Head of Cleantech Investment Banking,
Chairman, Technology Investment Banking and Managing Director, Jefferies International

Jeremy Kranz
Vice-President, GIC Special Investments

Marc S. Lipschultz
Member and Global Head of Energy and Infrastructure, Kohlberg, Kravis and Roberts and Co.

William E. McGlashan Jr,
Managing Partner, TPG Growth

Eric Martinot
Senior Research Director, Institute for Sustainable Energy Policies

Chris Mottershead
Vice-Principal, Research and Innovation, King's College London

Alan Salzman
Chief Executive Officer and Managing Partner,
VantagePoint Venture Partners

Eric Usher
Head, Renewable Energy and Finance Unit,
Energy Branch, DTIE, United Nations Environment Programme

Editors

Dirshaye Abate
World Economic Forum

Nancy Tranchet
World Economic Forum

Creative Design

Kamal Kimaoui
World Economic Forum

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

Contents

Introduction	6
1. Executive Summary	9
2. Clean Energy Investment in Turbulent Times	13
3. Copenhagen, Carbon Markets and Climate Policy	19
4. Ten Emerging Large-Scale Renewable Energy Sectors	23
5. Energy Efficiency	27
6. Four Key Enablers of a Low-Carbon Energy System	31
7. Policy Support Mechanisms and their Selection	35
Appendix 1 – Ten Key Renewable Energy Sectors	49
Appendix 2 – Four Key Enablers	59
Appendix 3 – Most Common Market Policy Mechanisms	67
References	69

Introduction

Max von Bismarck
Director and Head of Investors Industries
World Economic Forum

Anuradha Gurung
Associate Director, Investors Industries
World Economic Forum

The World Economic Forum is proud to release "Green Investing 2010: Policy Mechanisms to Bridge the Financing Gap" as part of our Green Investing project. The Green Investing project, which was mandated by the Forum's Investor community at the World Economic Forum Annual Meeting in Davos-Klosters in January 2008, aims to explore ways in which the world's leading investors can most effectively engage in the global effort to address climate change.

This builds on our first report, "Green Investing: Towards a Clean Energy Infrastructure"[1]. That publication, released in January 2009, highlighted viable business opportunities in the energy sector that could have high abatement potential, while enabling investors to sustain their long-term corporate assets and shareholder value. It also pointed out that although investment in clean energy reached US$ 150 billion in each of 2007 and 2008, it would need to reach US$ 500 billion per year by 2020[2] if we are to see peak CO_2 emissions by then, and we are not on track.

According to the Copenhagen Accord, endorsed by major economies at the COP meeting in December 2009, US$ 100 billion has been pledged annually by 2020 to help developing countries fight climate change in a bid to limit the rise in global temperatures to two degrees Celsius. The Quick Start funds pledged in Copenhagen which are to flow more quickly amount to only US$ 10 billion per year for three years.

However, the pledged US$ 100 billion is not sufficient, given that estimates in our first report suggest that between now and 2030 an average of US$ 250 billion per annum will need to be invested in the developing world. In addition, much work still needs to be done in order to set up the mechanisms which will unlock the US$ 100 billion investment flow.

This report provides an update on the status of investment in clean energy and how the sector has survived the financial crisis. It also provides a critical overview of the various public and private sector financing mechanisms at the national, state and local level that could help unleash further necessary investment.

The Green Investing project is conducted in conjunction with the Forum's broader Task Force on Low-Carbon Prosperity. The task force brings together business leaders, government representatives and sector experts to help catalyse a practical, focused public-private dialogue on climate change that complements the United Nations negotiation process. The outcome of the Copenhagen meeting in December 2009 will have a meaningful impact on international climate policy and on the role of the United Nations Framework Convention on Climate Change (UNFCCC). The Copenhagen meeting may not have reached an agreement on a global mechanism for price emissions, but it did create new pressure for effective, nationally-focused "bottom-up" initiatives.

Building on the recommendations of the Task Force on Low-Carbon Prosperity[3], which were delivered to Prime Minister Gordon Brown and other world leaders during UN Climate Week in September 2009, the focus of the Forum's climate initiative for 2010 is to help a network of investors, business leaders and expert organizations progress a number of public-private initiatives, including:

- Intra-industry cooperation on energy efficiency
- Smart grid demonstration projects
- Carbon capture and sequestration demonstration projects
- Building private sector readiness for Reducing Emissions from Deforestation and Forest Degradation (REDD+)
- International financial reporting standards for corporate climate disclosure

The Forum is also planning to set up an international initiative to help finance officials from major economies work closely with private investors to develop a series of regional, large-scale, low-carbon infrastructure financing arrangements. This work will be designed to develop practical mechanisms to support the implementation of the Copenhagen Accord's commitment on finance for developing countries, as officials look to develop the new

[1] To download the report go to www.weforum.org/pdf/climate/Green.pdf

[2] In last year's report we said an average annual investment of US$ 515bn is required in clean energy until 2030. Another way of looking at this is that US$ 500bn of annual investment is required by 2020.

[3] To download the recommendations go to www.weforum.org/climate

institutional arrangements for climate finance which, under the terms of the Accord, must be set out in detail during 2010.

We trust that this report will serve as useful input for the process outlined above and hope that it will contribute towards closing the financing gap between the amounts pledged in Copenhagen and the amounts that will be needed to avoid severe impact of climate change.

Guidance for the Green Investing project was provided by an actively involved Committee of Experts which included:

- **Morgan Bazilian,** Special Advisor on Energy and Climate Change to the Director-General, United Nations Industrial Development Organization
- **Marcel Brenninkmeijer**, Founding Chairman, Good Energies, Switzerland
- **Wes Edens**, Chairman and Chief Executive Officer, Fortress Investment, USA
- **Jack Ehnes**, Chief Executive Officer, California State Teachers Retirement System (CalSTRS), USA
- **Diana Farrell**, Deputy Director of US National Economic Council; Formerly, Director, McKinsey Global Institute, McKinsey & Co., USA
- **Peter Gutman**, Global Head, Renewable Energy and Environmental Finance, Standard Chartered Bank, United Kingdom
- **Kirsty Hamilton**, Associate Fellow, Energy, Renewable Energy Finance Project, Chatham House, United Kingdom
- **Wen Hsieh**, Partner, Kleiner Perkins Caufield & Byers (KPCB), USA
- **Bruce Huber**, Head of Cleantech Investment Banking; Chairman, Technology Investment Banking and Managing Director, Jefferies International, United Kingdom
- **Jeremy Kranz**, Vice-President, GIC Special Investments, GIC Real Estate, USA
- **Marc S. Lipschultz**, Member and Global Head of Energy and Infrastructure, Kohlberg, Kravis and Roberts and Co., USA
- **William E. McGlashan Jr**, Managing Partner, TPG Growth
- **Eric Martinot**, Senior Research Director, Institute for Sustainable Energy Policies
- **Chris Mottershead**, Vice-Principal, Research and Innovation, King's College London, United Kingdom
- **Alan Salzman**, Chief Executive Officer and Managing Partner, VantagePoint Venture Partners, USA
- **Eric Usher**, Head, Renewable Energy and Finance Unit, United Nations Environment Programme, France

On behalf of the World Economic Forum, we would like to express our gratitude to the Committee of Experts for their intellectual stewardship. Also thanks to Jon Quick at VantagePoint Venture Partners and Brindusa Fidanza at the World Economic Forum who provided helpful comments.

In addition, we wish to thank New Energy Finance, in particular Michael Liebreich, Chris Greenwood, Alice Hohler and Lindsay Wilson for their support in the creation of this report.

Last but not least, we are grateful to the many individuals who responded to our invitation to participate in workshops and interviews and who gave so generously of their time, energy and insights.

1. Executive Summary

In this report, we provide an update on the status of investment volumes in clean energy and an overview of the different technologies that will contribute significantly to a future low-carbon energy infrastructure, as well as the key enablers that are required in order to allow those technologies to get to scale. We also highlight developments in the carbon markets and global negotiations (in Copenhagen and beyond) which affect clean energy and greenhouse gas emissions as a whole. Finally, we provide an analytical framework to evaluate 35 different types of policy mechanisms designed to unleash private capital to facilitate the shift to a low-carbon economy.

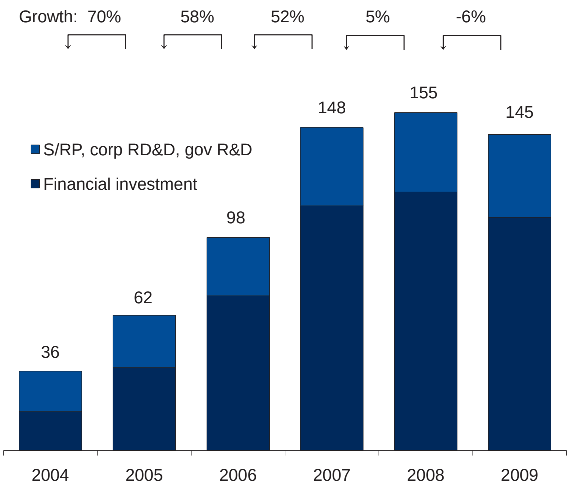
When we published the first Green Investing report, Green Investing: "Towards a Low-Carbon Energy Infrastructure", the world was in the midst of the credit crisis. Our main concern was that climate change would slip down policy-makers' agendas as they grappled with the immediate threat to the world's financial system. As we put it at the time:

> "At the very time when commentators are branding green investing as a luxury the world cannot afford, enormous investment in the world's energy infrastructure is required in order to address the twin threats of energy insecurity and climate change. Waiting for economic recovery, rather than taking decisive action now, will make the future challenge far greater. The investment demand is substantial. Despite the recent turmoil, the world's financial markets are up to the financing challenge, but they will need continued action from the world's policy-makers and leading corporations."

A year later, and the world is a very different place. On the macroeconomic stage, the concern is no longer about the collapse of our financial system, but about a protracted recession and the risk of a slow recovery. In clean energy, after stalling in the first quarter of 2009, investment activity rebounded, and in fact total investment activity will finish the year at US$ 145 billion, down only 6.5% on the total for 2008 (see Figure 1).

For much of the year it looked as though investment would be down by a much greater amount. In part, its healthy recovery was supported by the arrival of the first tranches of stimulus funding targeted at the sector around the world. HSBC estimated that governments allocated more than US$ 430 billion in fiscal stimulus globally to "climate change themes". However, this total includes rail, water and electricity infrastructure that is not specifically dedicated to clean energy. Once these are stripped out, we estimate a total of US$ 177 billion of stimulus funding has been allocated to renewable energy,

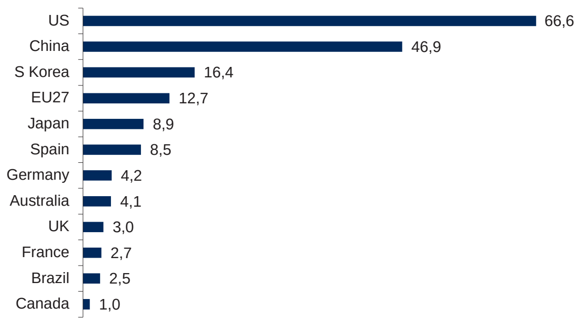
Figure 1: Total Global Annual Investment in Clean Energy 2004 to 2009, US$ billions



Note: S/RP = small/residential projects. New investment volume adjusts for re-invested equity. Total values include estimates for undisclosed deals.

Source: New Energy Finance

Figure 2: Clean Energy Stimulus by Country 2009, US$ billions



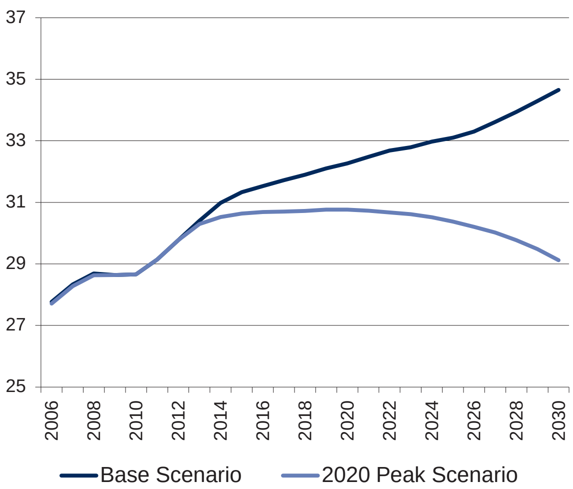
Note: Total announced by the 12 economies is US$ 177.3 billion. Includes only stimulus measures targeted specifically at clean energy; excludes general rail, water, power infrastructure

Source: New Energy Finance

energy efficiency, smart grid, advanced transportation and other core clean energy technologies (see Figure 2).

Of the US$ 177 billion, only around US$ 25 billion actually reached the front line in terms of clean energy technology providers or projects during 2009. We estimate the flow of stimulus spending will strengthen to around US$ 60 billion during 2010, which will almost certainly drive overall investment in clean energy into record territory, perhaps reaching as much as US$ 200 billion. Stimulus funding will then remain at around US$ 60 billion for 2011, before receding. One of most urgent questions

Figure 3: CO_2 Emissions from Energy, Base and 2020 Peak Scenarios, GTonnes



Source: New Energy Finance, GE2M

facing policy-makers in clean energy as elsewhere is how to stop the stimulus funding in due course without causing the industry to collapse.

Clean energy investment has survived the crisis and dropped only marginally to US$ 145 billion last year. It looks set to rise to US$ 200 billion in 2010, and to continue growing beyond that. However, this still falls far short of the investment volumes required to transform the world's energy infrastructure.

Last year we reported that if the world is to see energy-related CO_2 emissions peak by 2020 (see Figure 3) – scientists say is necessary to restrict the increase in global average temperatures to 2°C – global investment in clean energy must reach US$ 500 billion per annum by 2020. At the time New Energy Finance and others estimated that without a major new initiative to drive the shift to clean energy, the figure would likely only reach US$ 350 billion per annum. Nothing that has happened in the intervening 12 months has changed those estimates significantly.

The International Energy Agency World Energy Outlook 2009 (WEO 2009) contains a "450 Scenario", describing one way of meeting the world's energy needs while restricting emissions to a level consistent with a 2°C temperature increase. In it, renewable energy (including large hydro) grows by a total of just under 110% between now and 2030 to meet 22% of primary energy and nearly 37% of electricity needs worldwide. The IEA estimates that the 450 Scenario would require the investment between now and 2030 of US$ 38 trillion, equivalent to 2.0% of global gross domestic product; this is US$ 10.5 trillion more than required under its business-as-usual "Reference Scenario".

Regardless of which model or source is used, there is a gap between the funding flowing into clean energy and what is needed to bring emissions under control. And it is sobering to note what the IEA itself says about continuing with business as usual:

> "The Reference Scenario corresponds to a long-term concentration of 1000ppm CO_2 equivalent. The consequences of the world following the 1000 ppm trajectory implied by following the Reference Scenario to 2030 and beyond, would, based on central estimates, result in a global mean temperature rise of around 6°C. At this level, studies indicate that the environmental impacts would be severe."

While the financial crisis and resulting recession have depressed investment activity, the past year has at least brought very good news on the cost front. In previous years, soaring demand for equipment from project developers meant that manufacturers were able to maintain high margins throughout the technology supply chain. Cost reductions were not passed on to clients: turbine prices were on an upward trend, and solar module costs did not drop between 2005 and 2008, despite the steep experience curve along the sector's whole value chain.

All of that changed in 2009. The levelized cost of renewable energy – i.e. the cost per unit before taking into account any subsidies or support mechanisms – fell by an average of 10% across most sectors, including the most mature, onshore wind. In the solar sector, the fall was far more dramatic, with the price of photovoltaic modules coming down by 50% in the course of the year. This is good news for the sector, although it comes at a time when the cost of fossil-based fuel has also been dropping. The difference is that as the economy and financial markets recover, oil and gas costs will bounce back. Clean energy costs, however, will fall further, as debt spreads for projects return to long-term trend levels.

In last year's report we took an in-depth look at eight renewable energy technologies which will contribute substantially to the clean energy infrastructure of the future. This year we have added two new sectors which have also shown great promise. Of our ten chosen sectors, eight are power-generating technologies, the other two produce liquid biofuels. Between them they are expected to absorb cumulative investment of US$ 7.5 trillion between now and 2030 (see Figure 4). The ten technologies are as follows:

1: Onshore wind
2: Offshore wind
3: Solar photovoltaic power
4: Solar thermal electricity generation
5: Biomass
6: Municipal solid waste-to-energy
7: Geothermal power
8: Small-scale hydro
9: Sugar-based first-generation biofuel
10: Cellulosic, algal and other second-generation biofuels
These may be the frontrunners but they are by no means the only possible contributors to a cleaner energy future: many other emerging technologies have potential in the longer term. Nuclear power will be a major part of the future energy system, but it is beyond the remit of this report.

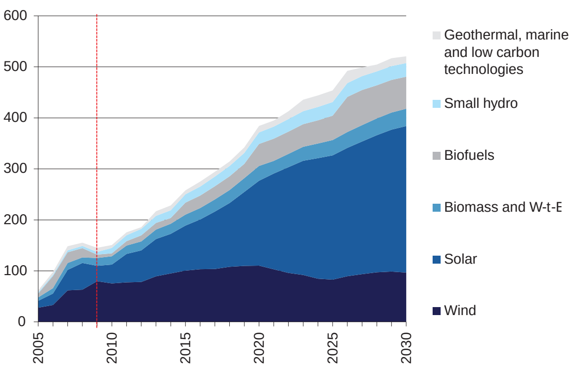
Last year we also identified a number of key enablers, where investment is essential if the energy system is to be able to absorb and use all of the renewable energy it can produce, and still meet the world's energy needs. These key enablers are energy efficiency, smart grid, power storage and carbon capture and sequestration. This year we have added advanced transportation as a key enabler, and upgraded energy efficiency to its own section.

Almost all models of future energy supply demonstrate that energy efficiency must be responsible for half or more of all reductions in CO_2 emissions between now and 2030. A lot of work has been done in the past few years by McKinsey and others on the opportunity to improve energy efficiency at very low – or even negative cost. Yet the paradox remains: persuading energy users to avail themselves of all these opportunities to save money continues to prove extremely difficult. We look here at the reasons why this is so, and what can be done about it.

The COP 15 meeting in Copenhagen could probably never have lived up to the world's expectations. As things turned out, it was neither the success that some may to claim, nor was it the failure depicted by its detractors.

The Copenhagen Accord, "noted" by the Plenary on the final day of the 15th Conference of the meeting enshrines the continuation of the Kyoto Protocol and contains a long-awaited commitment to mobilise resources to control deforestation. It recognises the need to limit temperature increases to 2°C, and contains a promise to look at the science behind a 1.5°C limit by 2015. On the financing front, developed countries committed themselves to "a goal of mobilizing jointly US$ 100 billion a year by 2020 to address the needs of developing countries", but left the mechanics to be agreed later.

Figure 4: Expected Clean Energy Investment per annum 2007 to 2030, US$ billions



Source: New Energy Finance

The only concrete financial commitment that was forthcoming at Copenhagen was a pledge by developed countries to provide developing countries with US$ 10 billion per year for three years in the form of "Quick Start" funds, to be shared between clean energy, REDD (Reducing Emissions from Deforestation and Forest-Degradation) and adaptation initiatives. Even if leveraged five-to-one with private funding, the scale of the pledge is an order of magnitude less than required. The IEA estimates that subsidies for fossil fuels in the largest 20 non-OECD economies alone amount to US$ 310 billion per annum.

The world's carbon markets spent 2009 somewhat in limbo, waiting for the outcome of Copenhagen and for progress on domestic cap-and-trade in the US and Australia. They were disappointed on all three fronts. Nevertheless, the existing markets persevered, with around US$ 120 billion of trading activity in 2009, and the US's Regional Greenhouse Gas Initiative provided the success story: it started operation and in its first year raised over US$ 400m from the auctioning of credits to be invested in renewable energy projects in the North-East and mid-Atlantic states.

Attention on the international climate scene now switches to the task of trying to build a legally binding agreement around the Copenhagen Accord. Negotiations will resume during 2010, first in Bonn in June, and then in Mexico City at COP 16 in December.

Meanwhile, Copenhagen did not deliver a binding global deal and hence will have the inevitable effect of shifting the focus of policy-makers to the national and local level. Over the past four years, there have been no fewer than 696 pieces of legislation in favour of clean energy – renewable energy and energy efficiency – around the world, many in anticipation of a global deal. Over the coming four years, we will no doubt see the trend continue.

Clean energy is a story of multiple technologies, at different stages of maturity, requiring different policy instruments. Supporting them can be achieved in multiple ways: by modifying the rules of the energy markets, by promoting equity or debt investment, by means of tax rules or by creating carbon markets. The choice of mechanism must depend on local political and economic conditions.

In the final chapter of this report we look at 35 different policy mechanisms that either have been used or are under discussion to promote the world's shift to a low-carbon energy system. We map the mechanisms against the sectors and situations in which they are most likely to be productively used. We also provide a rating, indicating how well we think they are likely to perform on three key questions: whether they scale; whether they are economically efficient; and whether they can catalyse private investment over and above their cost to the public purse.

We do not expect our evaluation of the policy mechanisms to be the final word on how to maintain and accelerate the world's progress towards a clean energy infrastructure. However, we hope it provides a useful framework and fuels a vital debate.

Last year's inaugural Green Investing report was subtitled "Towards a Clean Energy Infrastructure". Looking back a year later, the good news is that the world has continued to make progress towards a clean energy infrastructure in the midst of a period of unprecedented financial and economic turmoil. The bad news is that progress may not been fast enough, and is not accelerating at the rate required to address the critical issue of climate change. While, the world's investors may be ready to invest in clean energy companies and projects, they still have questions over the policy environment in which they operate.

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

2. Clean Energy Investment in Turbulent Times

For much of 2009 it looked as though investment activity in clean energy would be down considerably on 2008. In its World Energy Outlook 2009, published in November, the IEA was still expecting that investment in renewable energy generating capacity “could drop by as much as a fifth”. In the end, however, the year finished with total clean energy investment of US$ 145 billion, a drop of only 6.5% from US$ 155 billion in 2008 (see Figure 5).

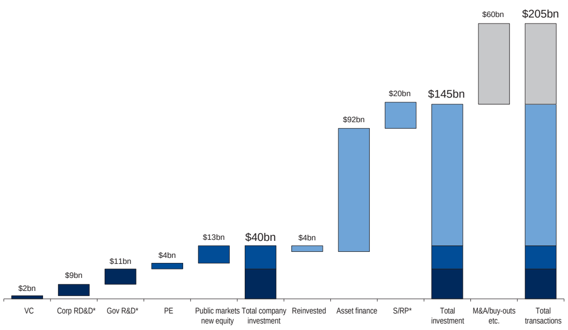
While new financial investment – i.e. excluding corporate and government research, development and deployment and small distributed projects – fell 15% in the EMEA region in 2009, and 26% in the Americas, it increased in Asia-Oceania by nearly 25%, mainly driven by the wind sector. As a result, in 2009, for the first time, total new financial investment in clean energy in Asia-Oceania (US $37.3bn) outstripped that in the Americas (US$ 29 billion). Europe, Middle East and Africa continued to lead the world with investment of US$ 45.3 billion.

The period 2004 to 2008 had seen a surge in investment in clean energy across almost all technology sectors, geographies and asset classes, from a total of US$ 33 billion to a total of US$ 155 billion, as described in last year’s Green Investing report. By the second half of 2008, however, with the financial crisis biting, the increase had stalled. The low-point came in Q1 2009, when financial investment in clean energy (i.e. excluding government and corporate R&D) fell by over 50% from its peak just over a year before.

Investment activity was, however, quick to bounce back, driven by rapid growth in China, some long-awaited large offshore wind farm financings, and a steady recovery in the financial markets. Prompt action by a number of development banks and a trickle of money starting to flow from stimulus programmes spurred private sector activity, albeit at a slower rate than in previous years.

By year end total financial investment in clean energy (i.e. excluding corporate and government RD&D) was US$ 112 billion, with Q3 and Q4 each seeing an average of US$ 30 billion of deals (see Figure 6). The recovery in the second half of 2009 was mainly due to financing of specific types of projects in individual countries, such as the wind mega-bases in China, offshore wind farms in the United Kingdom, and solar thermal electricity generation plants in Spain. Asset Financing accounted for US$ 92 billion of the total investment of US$ 145 billion in 2009, while equipment manufacturers and technology companies raised US$ 13 billion from the public markets, and US$ 6.6 billion from venture capital and private equity investors. Government and corporate research and development spending, plus small-scale projects accounted for the remaining investment.

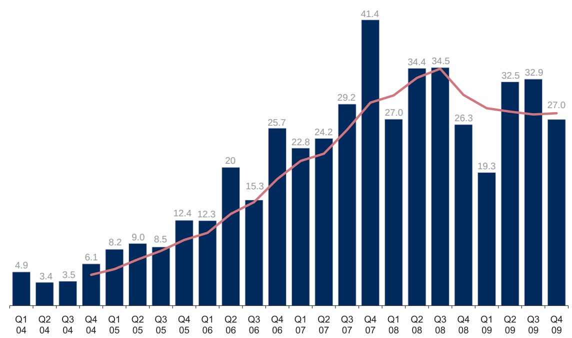
Figure 5: Global Clean Energy Investment Types & Flows 2009, US$ billions



Note: S/RP = small/residential projects. Total values include estimates for undisclosed deals. *Data based on estimates from various industry sources.

Source: New Energy Finance

Figure 6: Total Quarterly Financial Investment in Clean Energy 2004 to 2009, US$ billions



Note: Includes 4 quarter running average. Financial sector investment only (i.e. excludes corp RD&D, gov R&D and S/RP). Investment volume is not adjusted for re-invested equity. Total values include estimates for undisclosed deals.

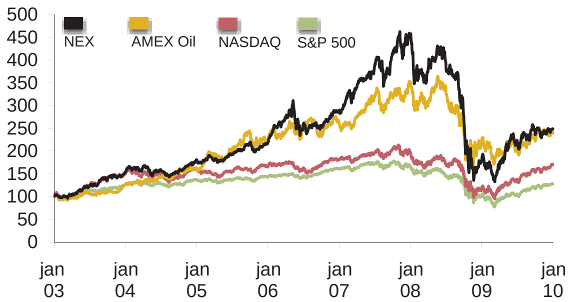
Source: New Energy Finance

Public Markets

In last year’s Green Investing report, we noted that “historically, clean energy stocks have been more volatile than those of other sectors [but] their returns have been consistently higher, making them an attractive investment proposition on a risk-adjusted basis”. The past 12 months turned out to be no different.

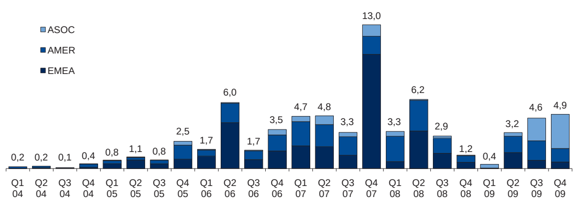
Publicly-quoted clean energy stocks initially held up well during the credit crisis. The WilderHill New Energy Global Innovation Index (ticker symbol “NEX”) tracks around 80 clean energy companies listed on 25 exchanges worldwide. Indexed to 100 at the start of 2003, it had traded as high as 450 at the end of 2007 (see Figure 7). It remained in the 350 – 400 range through the first three quarters of 2008, outperforming the rest of the market.

Figure 7: Performance of NEX vs. Major Indices 2003 to 2009



Source: New Energy Finance

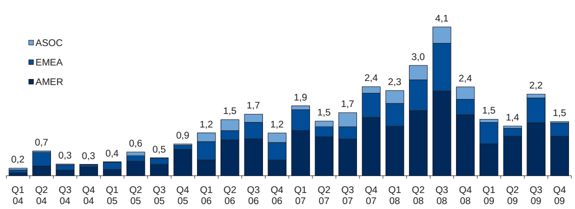
Figure 8: Quarterly Public Market Investment in Clean Energy by Region 2004 to 2009, US$ billions



Note: Financial sector investment only (i.e. excludes corporate RD&D, government R&D and S/RP). Investment volume is not adjusted for re-invested equity. Total values include estimates for undisclosed deals.

Source: New Energy Finance

Figure 9: Quarterly Venture Capital and Private Investment in Clean Energy by Region 2004 to 2009, US$ billions



Note: Financial sector investment only (i.e. excludes corporate RD&D, government R&D and S/RP). Investment volume is not adjusted for re-invested equity. Total values include estimates for undisclosed deals.

Source: New Energy Finance

When investment bank Lehman Brothers collapsed, however, all this changed. The NEX finished 2008 at 178, and by March 2009 had collapsed to 132. That marked a 70% fall from its peak and was lower than its value throughout 2005, the year of Hurricane Katrina, the Inconvenient Truth and the ratification of the Kyoto Protocol.

Since then, however, the NEX has recovered to close 2009 at just under 250 – up 39% during the year and up 87% from its lowest point in March. The compounded annual capital appreciation of the NEX over the seven years from the beginning of 2003 to the end of 2009 was still 13.8% - a respectable return when compared with almost any major asset class.

The volume of clean energy investment on the public markets, which came to a complete standstill in Q1, finished the year down just 4% on 2008 at US$ 13 billion (see Figure 8). Shortfalls in initial public offerings in Europe and the US were offset by fund raising in Asia, particularly China and Taiwan.

Venture Capital and Private Equity

2009 saw a significant drop in the volume of venture capital and private equity investment in clean energy. Investment had soared between 2004 and 2007, with no fewer than 1,573 funds targeting technology investments in the sector by the end of that period.

Initially, as the credit crisis broke, investment volumes held up well. With the IPO route cut-off due to the market downturn, some late stage technology companies instead turned to private equity funds. However, by Q1 2009, investment volumes had dropped and although they recovered in H2 2009, they did not return to the levels seen during 2007 (see Figure 9).

Consequently, overall venture capital and private equity investment in clean energy during 2009 was US$ 6.6 billion, down 44% on 2008, mainly due to lower financing of solar and biofuels companies especially in the US. Encouragingly investment in efficiency technologies held up almost unchanged.

On a positive note, the last quarter of the year saw a number of venture capital and private equity managers close new funds ready for investment in 2010.

In terms of returns to venture capital investors, the 12 months to June 2009 was a different story from the 12 months to June 2008. Back then, according to the annual International Clean Energy Returns Analysis study (ICTRA 2009), venture investors were boasting average internal rates of return from their investments in clean technology portfolio companies (before accounting for management and transaction fees, carry, etc) of 68%. Even adjusting for the impact of a small number of very successful investments, which yielded exits in the hundreds of millions and rates of return of more than 50%, the average clean technology venture investment over the period 2000 to mid-2008 had yielded a healthy 14.5% (see Figure 10).

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

According to ICTRA 2009, the year from mid-2008 to mid-2009 saw the holdings of venture investors in clean technologies in Europe and North America collapse in value by 81.4%. Much of this drop, however, arose from holdings in a small number of post-IPO stocks, mainly in the solar sector. The value of stock in private companies held by venture capitalists declined by only 15.3%, compared to a decline in both the NEX and the NASDAQ over the same period of 43%.

Asset Finance

Asset financing – the type of funding required to build wind-farms, solar projects, biofuels plants and the like – was hit particularly hard by the financial crisis. Not only did lower energy prices squeeze margins, but capital became scarcer and more expensive around the world. Asset investment dropped from US$ 21 billion in Q1 2008 to just US$ 17 billion a year later, before recovering to an average of US$ 24 billion in each of the final two quarters of the year (see Figure 11).

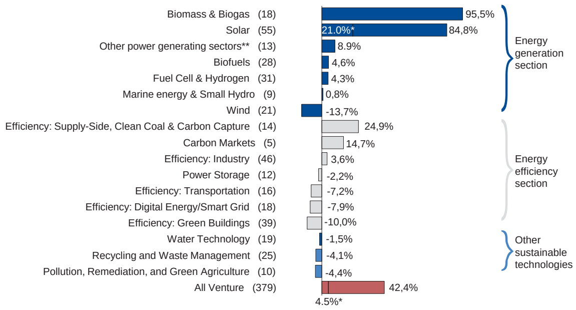
In Europe, despite central bank rates falling dramatically since August 2008, actual borrowing costs rose, as several lenders left the infrastructure finance business and the remaining banks demanded higher spreads. As a result, the all-in cost of debt remains over 100 basis points higher for clean energy projects now than it was during 2005 to 2007, despite historically low interest rates.

Take the example of a typical medium-sized wind project (see Figure 12). While the European Central Bank rate fell from 4.25% to 1.0% between summer 2008 and spring 2009, increases in term swap rates (the price charged by banks to lend over 10 or 15 years, rather than short-term) and project spreads caused the actual cost of borrowing to rise. In 2009, typical project spreads peaked at more than 300 basis points for established technologies like onshore wind and solar PV, with projects such as offshore wind and biofuels considerably more expensive. Spreads have now eased slightly, to around 280 basis points, but they remain well above their 2007 low point of around 80 basis points.

Higher-than-trend spreads is not the end of the story. Debt-to-equity ratios have also fallen since the days of easy credit, from as high as 90% debt to 70-75% on a normal project, or 50-60% for higher risk projects (if they can be financed at all). Loan tenors have also contracted, with historically typical loan agreement tenors of up to 18 years all but disappearing, and banks focusing on periods of 10 years or less in order to reduce their tenor mismatch with short-term deposits or money market finance.

All of this has significantly changed the economics of clean energy projects. Good projects can still be

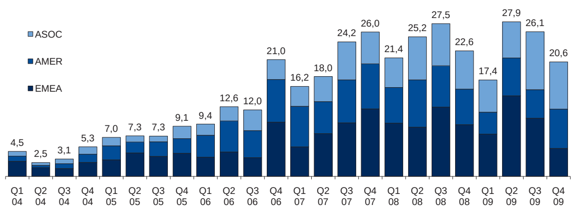
Figure 10: Cumulative Venture Capital IRR by Clean Technology Sector Europe and North America 2000 to 2008 based on ICTRA sample, %



Notes: Analysis covers 379 portfolio companies across all clean technology sectors in Europe and North America. Returns are calculated at the portfolio company level, i.e. before accounting for management and transaction fees, management carry etc.. Data is self-reported on-line in confidence and anonymised. Figures are shown including and excluding (marked with an asterisk) the impact of investments which returned IRRs over 50% and exit size of over €250m. "Other" includes nuclear, waste-to-energy and geothermal.

Source: New Energy Finance / European Energy Venture Fair - International Clean Technology Returns Analysis 2009

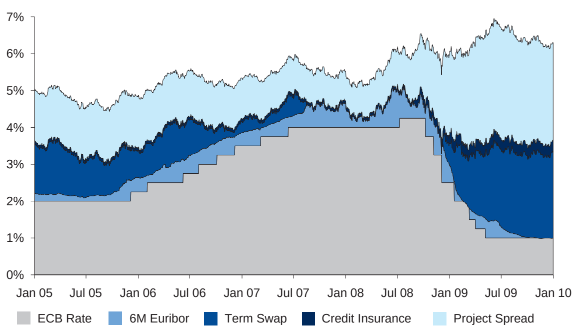
Figure 11: Quarterly Asset Investment in Clean Energy by Region 2004-2009, US$ billions



Note: Total announced by the 12 economies is US$ 177.3 billion. Includes only stimulus measures targeted specifically at clean energy; excludes general rail, water, power infrastructure.

Source: New Energy Finance

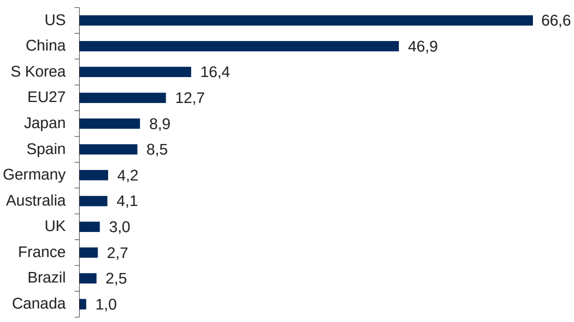
Figure 12: Cost of Debt for a Euro Area Onshore Wind Project, %



Notes: Data as of 31 December 2009

Source: New Energy Finance, Bloomberg

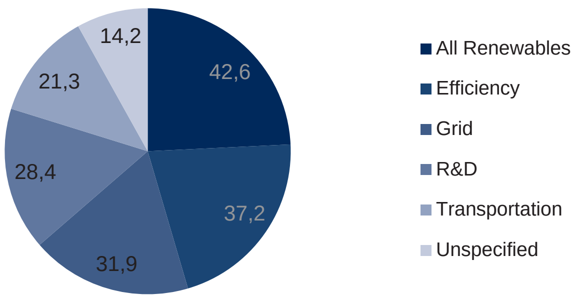
Figure 13: Clean Energy Stimuli by Country 2009, US$ billions



Notes: Data as of 31 December 2009

Source: New Energy Finance

Figure 14: Clean Energy Stimuli by Sector 2009, US$ billions



Source: New Energy Finance

financed, but marginal ones are simply waiting on the drawing board for conditions to improve. It has also meant that public sector debt providers, such as Germany's KfW and the European Investment Bank have had to play an unusually important role in financing large projects, especially offshore wind. In Brazil, the national development bank BNDES has been involved in almost all financings of new sugar-cane ethanol capacity.

In the US, asset financing for renewable energy projects was particularly hard hit by the credit crisis, due not just to the economic downturn but by the particular nature of the Production Tax Credit (PTC) scheme offered historically by the federal government.

Until the crisis, the country's US$ 21/MWh Production Tax Credit was a key driver of new investment. However, those credits were usually not put to use directly by project developers due to their relatively small size, lack of consistent profitability and, therefore, lack of tax exposure. Instead, they typically sold their credits to third-party "tax equity providers," which were large, consistently-profitable institutions, who could put money into clean energy projects in exchange for a guaranteed stream of tax credits – as long as they had taxable profits to shelter. This form of financing largely displaced more traditional debt funding for US wind projects, and a fairly narrow pool of tax equity investors developed, led by JP Morgan Chase and GE Capital.

In fall 2008, however, as financial institutions found themselves pushed into losses by the impact of the crisis, tax equity capital dried up. So-called "tax equity yields" (returns on investment required by providers) jumped from 6-6.5% to 9% or higher. Many otherwise attractive projects were put on hold. Seeking to address this issue, the Obama Administration in February 2009, as part of the American Recovery and Reinvestment Act (ARRA), offered developers the opportunity to take their subsidies in the form of cash grants, rather than tax credits. It took quite a few months to clarify the rules and put the infrastructure in place to distribute the funds, so asset financing for new projects ground almost completely to a halt for the first quarter of 2009, but by summer, after the new programme came on line, the market sputtered back to life.

All in all, the US finished the year down from 2008, but the ARRA grant programme clearly helped avoid total calamity.

Stimulus Spending and the Clean Energy Sector

In response to the financial crisis, almost every major government worldwide announced a fiscal stimulus package, and in almost every case a significant portion was earmarked for 'green' initiatives.

HSBC estimated that around the world, governments allocated more than US$ 430 billion in fiscal stimulus to "climate change themes". However, this total includes rail, water and electricity infrastructure that is not specifically dedicated to clean energy. Once these are stripped out, an estimated total of US$ 177 billion of stimulus funding has been allocated to renewable energy, energy efficiency, advanced transportation, smart grid and other core clean energy technologies (see Figure 13).

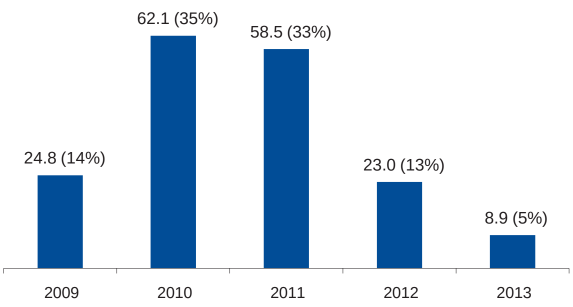
For the most part the spending is dominated by efficiency, renewable energy, electrical grid, general R&D and transportation (see Figure 14). Energy efficiency, generally in the form of grants for the improvement of public sector buildings and for weatherizing homes, is set to take the largest slice of clean energy stimulus funds with US$ 42 billion globally. It is seen as a sector which not only can have a significant impact on emission reductions and reduce household energy expenditure, but can also be quickly ramped up and, critically, create local unskilled and semi-skilled "green jobs" – ideal characteristics for stimulus funds.

Grid improvements are also earmarked for a significant amount of stimulus spending, at US$ 32 billion, particularly in China and the US where they are being supported by loans and grants respectively. The Chinese funding is largely earmarked for grid extension to some of the areas where excess renewable energy is currently being produced, while much of the US spending is for the deployment of smart grid technology.

A key weakness of the stimulus approach, however, is that only around US$ 25 billion – 14% of the total allocated – actually reached clean energy technology providers or project developers during 2009 (see Figure 15). The flow of stimulus spending will strengthen to around US$ 60 billion during 2010, which will almost certainly drive overall investment in clean energy into record territory, perhaps reaching as much as US$ 200 billion. Stimulus funding will then remain at around US$ 60 billion for 2011, before receding. One of most urgent questions facing policy-makers in clean energy as elsewhere is how to close the stimulus funding taps in due course without causing the industry to collapse.

There is also some concern that as the global economy emerges from recession, governments will reconsider their spending plans, faced by increasing public debt and concerns over the state of their finances, and that money for green schemes may be diverted elsewhere. In particular, the new Japanese government is considering possible withdrawal from about half of its predecessor's overall stimulus commitments. Similarly, Spain has declared that funds announced for environment measures will now be divided between ecology, social care, technology development and other projects.

Figure 15: Expected Clean Energy Stimulus Spending by Year, US$ billions (% of total)



Source: New Energy Finance

Clean Energy Stimulus in the US

The American Recovery and Reinvestment Act (ARRA) was signed into law by President Obama in Febuary 2009. US$67 billion out of a total stimulus package of US$788 billion was set aside to promote clean energy.

Among the various countries providing stimulus support, the US has moved relatively quickly to allocate funds. At the end of the year, US$ 25 billion (37%) of the US's overall clean energy commitment had been allocated. But New Energy Finance estimates that only about half of that has actually been deployed into the marketplace. Many of the allocated funds remain in government hands.

While the intention is for the full US$67 billion to be disbursed by the end of 2010, it will probably be 2011 and beyond before all the funds are actually at work.

Clean Energy Stimulus in China

Early in 2009, China's National Development and Reform Commission (NDRC) unveiled a US$ 60 billion low-carbon stimulus package. As details slowly emerged, however, the total shrank to US$ 46.9 billion when it became clear that the majority of the funds allocated to "ecology projects" are to be spent on waste & water treatment and reforestation, with only US$ 7.3 billion destined for energy savings.

US$ 1.5 billion will go to developing clean vehicles and an estimated US$ 19 billion to each of grid infrastructure and advanced technology. On the renewable generation side, the Golden Sun initiative provides central government grants of up to 50% of the installation costs of PV power plants, which must have an installed capacity of at least 300kW and minimum investment value of US$ 14.6 million. At the same time, polysilicon and 2MW turbines were removed from the 'Encouraged Import List', providing a boost to China's domestic clean technology industry.

Overall the Chinese stimulus is likely to flow faster than European or US packages because much of the money will take the form of loans rather than grants.

Clean Energy Stimulus in Europe

Of all the European green stimuli, the Community-level one (US$ 12.7 billion) is likely to be the fastest in reaching the sector. With the disbursement rules already in place, the relevant projects must apply for funds, which are likely to be assessed swiftly, with offshore wind developers expected to benefit first.

Funds for carbon capture and storage demonstration projects may take a little longer, but the successful applicants should receive funds in early 2010. The developers that gain cash are then required to "spend" the money by the end of 2010. Any funds not allocated to projects by the end of 2010 must be returned to the commission, providing a strong incentive for speedy implementation.

Individual member states, such as Spain (US$ 8.5 billion), Germany (US$ 4.2 billion), the United Kingdom (US$ 3 billion) and France (US$ 2.7 billion), have announced their own stimulus packages, targeting a range of clean energy technologies, including energy efficiency, wind, solar and smart grid. However, some funds have been allocated to existing programmes, and clean energy allocation does not mean the intended recipients are close to getting the cash as administrative operations must first be established to handle the funds.

Clean Energy Stimulus in Japan

In August 2009, the Democratic Party of Japan won power with a manifesto containing ambitious green policies, including an overall 25% emissions cut by 2020 over 1990 levels. This target does not include the associated cost estimates or funding.

The previous administration had announced stimulus measures totalling US$ 8.9 billion in several supplementary budgets for 2009 and 2010. In September, however, it was reported that only 45% of the total (green and other) stimulus package had been disbursed (i.e. transferred from central administration), and that the Democratic party now hoped to hold back the untapped 55% before it was transferred to local governments.

So while up to US$ 4 billion is on its way into the hands of Japan's energy-efficiency and solar companies, the remaining US$ 4.9 billion of announced funding may not be disbursed until 2010. In December 2009, the government revealed a further US$ 9 billion of expenditure on environmental measures in a fresh stimulus package, encompassing energy efficient housing renovation, home appliances, and fuel-efficient vehicles.

Clean Energy Stimulus in South Korea

In July 2009, the Korean government announced three action plans, which would lead to the country becoming one of "the greenest" in the world by 2050. The three plans – Climate Change and Energy Independence, New Growth Engine, and Quality of Life – comprise 10 policies and specific spending commitments over a five-year period totalling US$ 43 billion.

The announcements provided much-needed clarification of the stimulus package announced at the beginning of the year. Although the government pledged to spend roughly 2% of national GDP on the overall programme, calculations suggest that less than half of the declared figure (approximately US$ 16.4 billion) will arrive in some form of public spending, with the balance expected to come through private investment. To date, Korea is estimated to have spent no more than 5-12% of its announced green stimulus, although this is still a higher percentage than most other countries.

Through its support for manufacturing, the government plans to increase the Korean share of overseas clean energy markets by 8%, mainly through export of LEDs, solar cells, hybrid cars and other low-carbon technologies. Along with these announcements, the government also indicated the trial of a carbon emission trading scheme in 2011, with formal implementation targeted for the following year.

3. Copenhagen, Carbon Markets and Climate Policy

The 15th Conference of the Parties to the UN Framework Convention on Climate Change (COP 15), held in Copenhagen, Denmark, in December 2009 involved a complex economic negotiation requiring unanimity between 190 countries – with positions as diverse as Tuvalu and China, the US and Cuba .

As things turned out, the "Copenhagen Accord" put to the Plenary on the final day of the conference was not adopted by all parties, but simply "noted". Probably the most significant aspect of the Accord is that it enshrines the continuation of the Kyoto Protocol, at the demand of China, India and the rest of the G77 group of developing world countries, as it gives them comfort that "common and differentiated" responsibilities will be maintained. It also recognizes the requirement to limit any global temperature increase to 2°C, although without a clear mechanism to ensure that developed country targets will provide comparable action, and contains a promise to look at the science behind a 1.5°C limit by 2015. The Accord also contains a long-awaited commitment to mobilise resources to control deforestation.

One of the great objectives for Copenhagen was that it would resolve the uncertainty over a replacement mechanism, but this did not happen. Investment in clean energy has surged throughout the developed world, Brazil, China and some rapidly-emerging economies over the past five years, but what is clearly missing is large-scale funding for the deployment of renewable energy to address the issue of energy poverty in the developing world. The Clean Development Mechanism (CDM) provided billions of dollars of funding under the Kyoto Protocol, but by 2012, when the mechanism falls into abeyance, these flows will have all but ceased.

The financing that was forthcoming at Copenhagen was a pledge by developed countries to provide developing countries with US$ 10 billion per annum in the form of "Quick Start" funds to bridge the period 2010 to 2012. The money has to be shared between clean energy, REDD (Reducing Emissions from Deforestation and Forest-Degradation) and adaptation initiatives. However, the scale of these funds is insufficient: even if leveraged five-to-one with private funding it is an order of magnitude less than required. By means of comparison, the four largest western oil companies (ExxonMobil, Royal Dutch Shell, BP and Chevron) had combined revenue in 2008 of US$ 1.4 trillion and earnings of US$ 126 billion; the IEA estimates that subsidies for fossil fuels in the largest 20 non-OECD economies alone amount to US$ 310 billion per annum. In addition, the Accord does state an annual goal of US$ 100 billion for mitigation and adaptation by 2020, although it contains no concrete measures to get there: these are left for subsequent negotiating rounds in Bonn or Mexico in 2010, or beyond.

Copenhagen was able to elicit concessions from half a dozen heads of state of major developing countries that they will take measurable, verifiable and reported action to control their emissions growth. This is progress in and of itself, but it also increases the chance of a climate bill in the US passing the Senate in the coming year. In the case of China, Premier Wen Jiabao committed China to curbing its emissions. This is very much in line with business-as-usual plans for China's economic development.

On the downside, Copenhagen did not deliver on all the terms of the Bali Action Plan laid out in 2007: it did not reach a global agreement on quantified emission reduction targets to clarify the terms of the post-2012 carbon market or set a new deadline for a post 2012 agreement.

Attention will now switch to the task of trying to build a legally binding agreement around the uncertain architecture of the Copenhagen Accord. Countries have been asked to confirm their emission reduction targets by 31 January 2010.

The negotiations move on to Bonn in June 2010 and Mexico for COP 16 in December with significant issues between the major players still to be resolved.

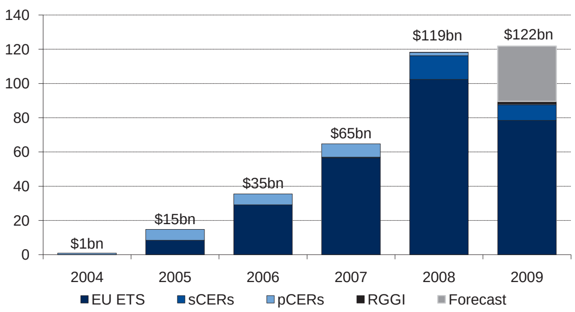
Carbon Market Update

The world's carbon markets spent 2009 somewhat in limbo, waiting for the outcome of Copenhagen and for progress on domestic cap-and-trade in the US and Australia. The carbon trading community was disappointed on all three fronts. The existing markets – the EU-ETS in Europe, the Kyoto market for CDM and JI credits[4] and various voluntary markets – all survived, and the start-up of the US's Regional Greenhouse Gas Initiative provided the year's real success story.

The total worldwide volume of carbon credit trading in 2009 is expected to be around US$ 120 billion, according to New Energy Finance, up only marginally over 2008 after 83% growth between 2007 and 2008

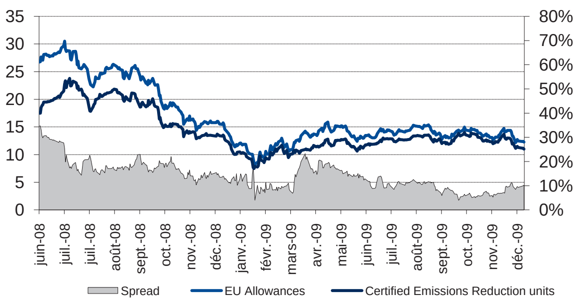
[4] Credits resulting from projects in the developing world and economies in transition which reduce emissions relative to business-as-usual.

Figure 16: Global Carbon Credit Trading Volume 2004 to 2009, US$ billions



Source: Carbon Market Exchanges, LEBA, New Energy Finance.

Figure 17: EU-ETS Price History April 2008 to December 2009, € per tonne CO_2e



Source: European Climate Exchange

(see Figure 16). Although a significantly greater volume of transactions is expected to be processed, lower carbon prices during 2009 have acted to restrict the growth by value (see Figure 17).

EU-ETS

The EU-ETS, which is now in its second phase (2008-2012), covers around 45% of Europe's total greenhouse gas emissions. It remains the most liquid of the world's existing carbon markets, accounting for 71% of emissions traded by volume, and 83% by value.

During 2009, the average settlement price of European Union Emissions Allowances continued its downward trend, closing the year at around 14 euros (US$ 21) per tonne. The ferocity of the recession in the European manufacturing industry has resulted in many companies having excess credits for sale, while utilities facing lower electricity demand have not had to buy as many credits as expected.

Despite the current oversupply of credits, New Energy Finance expects prices to rise above US$ 20 per tonne by 2015 as the scheme moves into its third phase. As the EU-ETS heads towards 2020 prices are likely to continue to rise due to the tightening of the cap in line with Europe's commitment to achieve a cut in emissions of 20% – and perhaps 30% depending on other countries' commitments.

Kyoto Market

The Kyoto market allows governments in the developed world to buy credits from emissions-reducing projects to use towards their reduction commitments. These are either generated in the developing world under the Clean Development Mechanism (CDM), or in "economies in transition" – i.e. former Soviet Bloc countries – under the Joint Implementation Mechanism (JI). CDM credits, known as Certified Emission Reductions (CERs), accounted for 17% by value of carbon trading under the EU-ETS in 2009.

Early on in the life of CDM, it was criticized for overpaying for reductions in the manufacture of hydrofluorocarbons, industrial gases used in refrigeration. In 2008 and 2009, however, 60% of all CDM projects, producing 37% of credits, were based on renewable energy or energy efficiency. This proportion is expected to grow to nearly 60% by 2012 as the potential for industrial gas projects has largely been exhausted.

By the end of 2012, New Energy Finance estimates that the CDM will have caused around US$ 15 billion to flow from developed to developing countries for investment in low-carbon projects. The supply of CDM credits is currently dominated by China (59% of expected annual CERs), followed by India (11%).

Voluntary Markets

The voluntary carbon market has seen a severe decline in trading volume during 2009 as companies and individuals have cut back on discretionary spending. In 2007 and the first half of 2008 not a week went by without a major retailer or bank announcing the intention to go "carbon neutral". In 2009 almost no such announcements were made.

New Energy Finance expects the global value of this market to fall to US$ 171-261 million in 2009, a drop of 60-75% from 2008. The market has, however, begun to recover during the second half of 2009 thanks to the passage of the American Clean Energy and Security Act; the potential arrival of cap-and-trade in the US has led some companies to start securing credits in the voluntary market which they hope eventually to be able to use to meet their compliance needs.

USA

The year 2009 saw a Federal cap-and-trade scheme edge a little closer in the US. The Waxman-Markey American Clean Energy and Security Act passed the House of Representatives in June. It pledges to cut US emissions by 17% from 2005 levels by 2020, and 83% by 2050 and it includes a cap-and-trade provision. However, the majority of the cap-and-trade permits – 85% – will be given away to the most heavily-emitting industries rather than auctioned.

This risks distorting the incentives of the scheme by allowing existing heavily-polluting industries (such as coal-fired generation) to continue to function with minimal change in costs. This could also miss the opportunity to raise significant sums for clean energy and energy efficiency projects. Free allocations also risk creating windfall profits by giving companies more allowances than they need or by allowing them to increase prices without incurring additional costs. Although Waxman-Markey was a significant development, given that the House had not previously passed legislation agreeing to emissions reductions of any sort, it may not pass the Senate in its current form.

The Senate, meanwhile, spent the second half of 2009 focused on healthcare reform. Despite this, the Kerry-Boxer Climate Bill has been working its way through committee stages, and may reach the floor early in 2010. It is similar to Waxman-Markey in many ways, for example in terms of sector coverage and point of regulation, but would set a more stringent target of a 20% reduction from 2005 levels by 2020. It also places greater emphasis on the use of domestic rather than international offsets and would give the President more control over what types of offsets would be eligible under the scheme.

At the state level, California has continued to make progress towards introducing cap-and-trade in 2012 as a way of meeting the requirements for emissions reductions under its landmark AB32 legislation.

The year's most notable landmark for emissions trading in the US, however, has been the Regional Greenhouse Gas Initiative (RGGI) - the modest cap-and-trade scheme covering ten Northeast and Mid-Atlantic states – which began its first three-year compliance period at the start of 2009. Although the scheme has been criticized for making too many allowances (which resulted in a steady decline in RGGI carbon prices throughout 2009), RGGI is important in two respects. First, it is significant that the scheme was established at all in a country that has not yet signed up to any international emission reduction targets. Second, RGGI's quarterly emission auctions have so far generated proceeds of over US$430 million which have been distributed back to the states to invest in energy efficiency and renewable energy.

Australia

In Australia, 2009 has been a year of intense debate on the climate change front, following the release at the end of 2008 of a government White Paper on its proposed Carbon Pollution Reduction Scheme (CPRS). The initial proposal suggested a scheme that would cover 75% of Australia's greenhouse gas emissions – making it the world's second largest cap-and-trade scheme after Europe's – with a start date as early as 2010 (although the start was soon reset to 2011). The targets up to the end of 2012 would be in line with Australia's commitments under the Kyoto Protocol, with the target for 2020 left to depend on the outcome of the Copenhagen talks – ranging between 5% and 15% on 2000 levels.

New Zealand

New Zealand is also considering cap-and-trade legislation. The design of the mechanism has been modified a number of times since its proposal in November 2008, more recently to align itself with that of Australia's proposed CPRS in the hope of future linkages between the two markets. The government's long-term target currently stands at a 10%-20% cut in GHG emissions by 2020 on 1990 levels.

Japan

Following the election of the Democratic Party of Japan (DPJ) in August, Prime Minister Yukio Hatoyama stated that Japan was to step up its efforts to tackle climate change, announcing a target of 25% reduction on 1990 by 2020, a significant acceleration relative to the 8% commitment by the previous administration. Even if the 25% target is not introduced, the change in government signals a shift in approach.

4. Ten Emerging Large-Scale Renewable Energy Sectors

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

In last year's Green Investing Report, we asserted that "any future low-carbon energy infrastructure will have to include a significant proportion of energy generated from renewable sources". Nothing that happened during 2009 has changed this. The impact of the recession will reduce the long-term growth in energy demand somewhat, but any analysis of how that demand can be met shows that renewable energy will play a much expanded role.

The 2009 edition of the IEA's World Energy Outlook (*WEO* 2009) contains the usual Reference Scenario, showing the future of the world's energy system under business-as-usual conditions – not taking into account any future policy measures to shift to low-carbon energy. This shows renewable energy's contribution growing by 57% in absolute terms between 2007 and 2030, and from 12.6% of primary energy to 14.2%. In terms of electricity generation, the growth of clean energy is even more pronounced: renewable power (including large-scale hydro) is expected to grow by nearly 140%, and from 18.1% of consumption in 2007 to 22.3% in 2030.

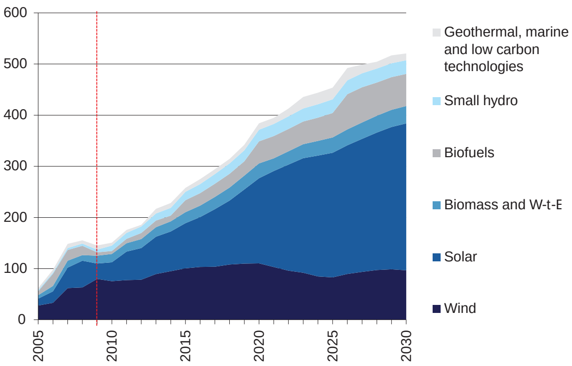
However, the IEA itself admits: "The Reference Scenario corresponds to a long-term concentration of 1000ppm CO_2 equivalent. The consequences of the world following the 1000 ppm trajectory implied by following the Reference Scenario to 2030 and beyond, would, based on central estimates, result in a global mean temperature rise of around 6°C. At this level, studies indicate that the environmental impacts would be severe."

The IEA's release of *WEO* 2009 came around the same time as the breaking of "Climategate", the release of thousands documents stolen from the server of the Climatic Research Unit of the United Kingdom's University of East Anglia.

WEO 2009 also contains a "450 Scenario", describing one way of meeting the world's energy needs while restricting emissions to a level consistent with a 2°C temperature increase. The figures are even more dramatic: renewable energy grows by just under 110% to meet 22% of primary energy demand by 2030, supplying nearly 37% of all electricity needs worldwide.

In terms of finance, the IEA estimates that the Reference Scenario would require the investment of US$ 26 trillion between now and 2030, equivalent to 1.4% of global gross domestic product. The 450 Scenario entails additional investment of US$ 10.5 trillion. This is, however, offset by a reduction in energy bills of US$ 8.6 trillion globally in the period 2008-2030 alone, with more savings resulting thereafter. There are also benefits in terms of public health, as the level of pollutants under the 450 Scenario is significantly lower.

Figure 18: Clean Energy Asset Finance by sector 2007 to 2030, US$ billions



Source: New Energy Finance, GE2M

These figures are broadly in line with scenarios from other sources, including New Energy Finance's Global Energy & Emissions Model (GE2M). This model predicts investment in clean energy growing to US$ 384 billion by 2020, an increase of approximately 180% over 2009, but still not sufficient to achieve peak CO_2 emissions by 2020. In terms of asset finance, the model shows that the recession will reduce investment growth in the near term, but the long-term trend looks even healthier than in last year's report, due to the reductions in the cost of clean energy and new legislation supporting the sector around the world (see).

In last year's Green Investing Report we highlighted eight renewable energy technologies which we believed would prove to be major contributors to the energy supply of the future, based on their potential scale and cost competitiveness with conventional energy. This was not intended to be an exhaustive list, and this year we are pleased to add two more: small hydro and the broader biomass sector beyond municipal solid waste. Both have demonstrated good technical and economic progress in the past year.

This year's report, therefore, looks in more detail at ten promising clean energy sectors. The first eight are power generating technologies, the last two produce liquid biofuels. These leading sectors are described in Appendix 1 and their details are summarised below:

1 Onshore wind
2 Offshore wind
3 Solar photovoltaic power
4 Solar thermal electricity generation
5 Biomass
6 Municipal solid waste-to-energy
7 Geothermal power
8 Small-scale hydro
9 Sugar-based first-generation biofuel
10 Cellulosic, algal and other second-generation biofuels

Table 1. Summary Table of Emerging Large-Scale Renewable Energy Sectors (See Appendix 1 for further details)

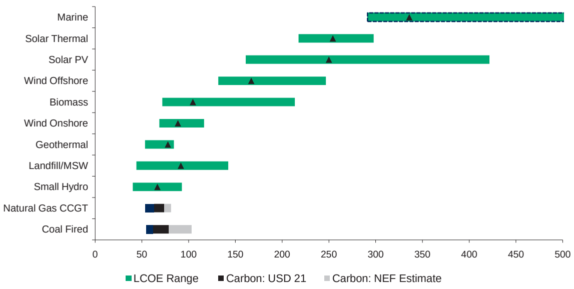
	Installed Capacity Worldwide, 2009	Potential Capacity by 2030	Market Readiness / Levelized Cost of Energy	Technology Gaps	Potential Bottlenecks	Policy Requirement
1. Onshore wind	140GW	800GW	$68-109/MWh	• Existing technology adequate, drive train improvements required to increase reliability and decrease costs • Larger turbines • Power storage (to reduce impact of intermittency)	• Short term: capital availability and slow speed of planning applications • Long term: geographic isolation of wind resource areas	• Stable implementation of existing policies • Modest rate support in the form of Renewable Portfolio Standard, feed-in tariff or green certificates • Accelerated planning processes • Incentives / regulation to require integration and remove grid bottlenecks
2. Offshore wind	2.2-2.4GW	120GW	$109-205/MWh	• Reliability of offshore turbines still a key concern • New dedicated "marinized" technology at larger scale being rolled out over next five years	• Short term: capital availability, offshore wind may fall in investment priorities of utilities due to low returns • Long term: innovation in and industrial supply of turbines, potentially slow due to uncertainty of demand	• Continued, stable support in Germany and United Kingdom, growing support in Nordic markets, Benelux, China and US • Increased support from export credit agencies and government backed banks to reduce the cost and increase the availability of financing • Incentives / funding for grid development • Accelerated planning processes
3. Solar PV (Grid scale and Residenti al)	20GW	1000GW	$170-450/MWh)	• Continued scale-up of entire crystalline silicon supply chain; process engineering to reduce costs • Mass manufacture of scalable, high-efficiency thin film	• Capital • Access to transmission grid and net metering for residential customers. Capped incentive regimes • Planning permission	• Substantial support, long-term but declining over time and easily adjusted to falls in technology price • Mandatory net metering by utilities • Attractive tax treatment of R&D • Public research funds
4. Solar thermal electricity generation (STEG)	616MW	80GW	$190-250/MWh	• Proof of concept for most up-and-coming technologies	• Capital, especially for unproven technologies • Links to transmission grid • Permitting	• Incentives, especially for designs not used before e.g. non-parabolic designs or new heat transfer fluids • Clear direction on permitting for large projects which cannot currently get planning permission in the US • Attractive tax treatment of RD&
5. Biomass incinerat-ion/ gasificat-ion/ anaerobic digestion	45GW	150GW	$70-148/MWh $90-170/MWh $80-189/MWh	• Proven technology available (combustion) • Gasification still requires R&D • AD monitoring as efficiency is highly dependent on operation	• Short term: capital availability • Feedstock: supply and prices – lack of transparent market and hedging instruments • Turnkey/equipment provider	• Long-term and stable financial support in form of feed-in tariffs or green certificates • Incentives for farmers to produce energy crops • Incentives for foresters to collect residues
6. Municipal Solid Waste-to-Energy	18GW	50GW	$38-157/MWh	• Proven technology available (combustion) • Gasification still requires development	• Slow permitting process (public opposition) • Turnkey provider • Long lead time for boilers and turbines	• Landfill diversion targets or ban on biodegradable waste landfill • Increasing gate fees/taxes

Energy					• Long lead time for boilers and turbines	
7. Geothermal	10GW	40GW	$55-83/MWh	• Enhanced Geothermal Systems (EGS) using hot dry rocks • Improving resource exploration technology • Smaller plug-and-play modules for low-grade resource power conversion	• Drilling rig availability • Power plant construction delays • Permitting delays	• Rate support in the form of Renewable Portfolio Standard, feed-in tariff or green certificates • Country goals specific for geothermal • Accelerated planning process
8. Small hydro	60GW	190GW	$70-120/MWh	• Mature technology, but variability as a result of rainfall volumes (intermittent) • Improvement of run-of-river turbines and technologies to be more efficient	• Better resources are far away from grid and from consumer centres • Environmental and social issues when project is not well planned and studied • Depends on rainfall volumes • General opinion still doesn't differentiate small from large hydro and their benefits / disadvantages	• Clear and objective environmental legislation • Accelerated / streamlined approval processes (as these projects are small hydro, and not large) • Incentives / regulation to remove grid bottlenecks
9. Sugar-based ethanol	80 billion litres per annum	250+ billion litres per annum	Competitive with oil at around US$45 per barrel	• Mass adoption of efficient cogeneration equipment • Ability to use efficiently all cane residues • Biotechnology for longer term / geographical viability: transgenic cane • Adoption of flexible fuel vehicles in different countries • Transfer of technology to different sugar-producing countries	• Import tariffs/corn ethanol subsidies • Lack of hedging instruments/no liquid futures market or long term contracts • Logistics to keep costs low and increase export capability: transport, storage and port facilities • Price of oil below US$ 50 for external market	• Definition of sustainability criteria and international standards • End of import tariffs in EU, US, Japan • Adoption of blend targets • Brazil: legislation to allow for use of transgenic cane
10. Next Generation biofuels	100 million litres per annum	100+ billion litres per annum	Competitive with oil at around US$ 150 per barrel	• Selection or development of economically optimal feedstocks • Lower biomass conversion costs using enzymes, bacteria, fungi, heat and pressure • Development of algae-based biofuels	• Feedstock production to quantity and quality required • Cost of feedstock collection/delivery to biorefineries • Ability of existing infrastructure to cope with next generation biofuels volume	• Capital support from governments for demonstration-scale projects • Blending subsidies to ensure demand – especially during periods of low oil prices • Incentives for farmers to produce energy crops • Attractive tax treatment of RD&D

Note: RPS = Renewable Portfolio Standard; PTC = Production Tax Credit

Source: New Energy Finance

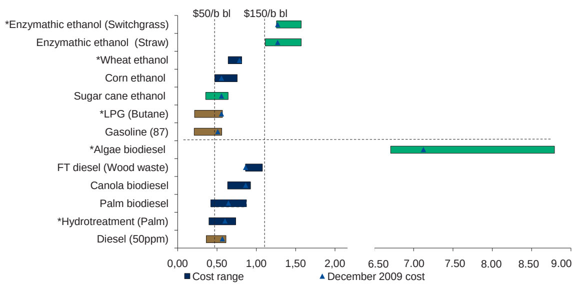
Figure 19: Levelized Costs of Energy Q3 2009, US$ per MWh



Note: Levelized cost of energy (LCOE) is the US$/MWh price for an inflation-adjusted fixed-price off-take agreement that offers the project developer the minimum equity return necessary to undertake the project. For example, an LCOE of US$100/MWh for a wind farm indicates that after factoring in cost of development time and cost, construction, turbine costs, balance of plant, short and long-term financing and operating costs, signing a power purchase agreement at US$100/MWh would return the owner of the project exactly their 'hurdle rate'. The central scenario is based on a 10% equity IRR as a hurdle rate for all technologies, to represent the perspective of a "technology agnostic" developer. Central scenario assumes cost of back-up capacity is not borne at the project level. Eight leading power generation technologies included, plus marine for comparison purposes.

Source: New Energy Finance

Figure 20: Levelized Costs of Liquid fuels Q3 2009, US$ per barrel



Note: The cost range for each technology is based on minimum and maximum feedstock cost in the analyzed period and the minimum and maximum conversion cost for each technology. Central scenario is based on a 10% equity IRR as a hurdle rate for all technologies, to represent the perspective of a "technology agnostic" developer.

* Palm-based biofuels have not been chosen here as "key" technologies due to persistent concerns about their role in deforestation. Canola, wheat, corn and other feedstocks have been excluded due to their competition with food agriculture.

Source: New Energy Finance

These technologies may be the frontrunners but they are by no means the only possible contributors to a cleaner energy future. Many other emerging technologies have potential in the longer term.

Nuclear power will play a growing role in the future energy mix, subject to the successful resolution of concerns over costs, safety concerns, waste disposal and proliferation. It has accounted for around 16% of total electricity production worldwide since the 1980s, and is poised for a renaissance in many countries around the world. However, a full discussion of the merits, problems and possible role of nuclear power is beyond the scope of this report.

One of the most striking developments of the past 18 months has been the precipitous drop in the price of clean energy (see Figure 19 and Figure 20). Over the four previous years, the best manufacturers and technology providers had been working behind the scenes to drive down their costs. However, the soaring demand for equipment from project developers meant that these cost reductions were not passed on to clients. Turbine prices were on an upward trend, and solar module costs did not drop between 2005 and 2008, despite the steep experience curve along the sector's whole value chain.

All of that changed in 2009. In most sectors, the levelized cost of renewable energy – i.e. the cost per unit before taking into account any subsidies or support mechanisms – fell by an average of 10%. In onshore wind, turbine prices fell to their lowest levels for many years, finishing 2009 up to 20% below early 2008 levels. This was, however, somewhat offset by higher financing costs, leaving the levelized cost some 10% down for the year. In the solar sector, the fall was far more dramatic, with the price of solar photovoltaic modules coming down by 50% in the course of the year.

Offshore wind alone bucked the trend: costs continued to rise as projects moved into deeper waters, facing increasingly complex construction and capital costs, and as the rush in project financings – particularly in the United Kingdom – has brought into sharp focus the predicted bottlenecks in installation ships and high-voltage cables.

As the capital markets recover, the net cost of financing for renewable energy will drop sharply. Although bank rates are expected to rise from their historic lows as the global economy slowly emerges from recession, this will be more than offset by the reduction in risk premiums, which remain at unprecedented levels. For almost all clean energy technologies – wind, solar, geothermal, marine, hydro and energy efficiency – the bulk of costs are borne up-front, with no fuel costs during the life of a project, making them more sensitive to higher net interest rates than fossil fuels. An improvement in the capital markets can therefore be expected to have a significant impact on the competitiveness of renewable energy sources.

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

5. Energy Efficiency

In last year's Green Investing report, we listed energy efficiency as one of four Key Enablers of any shift to a low-carbon energy infrastructure. However, a number of people pointed out that this under-emphasizes the importance of energy efficiency in moving to a more sustainable energy mix. We agree, so this year we have created a new section for energy efficiency, on par with the Ten Emerging Large-Scale Renewable Energy Sectors, and replaced it in our Key Enablers section with Advanced Transportation.

Scale of the Opportunity

According to the IEA's World Energy Outlook 2009: "End-use efficiency is the largest contributor to CO_2 emissions abatement in 2030, accounting for half of total savings in the 450 (emission-limited) Scenario compared with the Reference (business-as-usual) Scenario."

The US Department of Energy estimates that eking 5% more efficiency out of the country's electrical power network would be equivalent (in terms of fuel and greenhouse emissions) to taking 53 million cars permanently off the road. A McKinsey & Co report published in July 2009 *(Unlocking Energy Efficiency in the US Economy)* shows that by using energy more efficiently, the US economy could cut annual non-transport energy consumption by about 23% by 2020. This would eliminate over US$ 1.2 trillion in waste – well beyond the US$ 520 billion upfront investment (not including programme costs) required for energy efficiency. The reduced energy use would also abate 1.1 gigatons of CO_2 emissions annually.

Using less energy at peak times can have a particularly significant impact. According to a recent Brattle Group study, cutting the level of peak demand in the US by 5% would eliminate the demand for around 625 infrequently-used peaking power plants, equivalent to annual savings of approximately US$ 3 billion.

The opportunity does not lie only in the US or the rest of the developed world. In the run-up to Copenhagen, neither China nor India accepted any sort of absolute cap on their carbon emissions, but agreed to reduce emissions per unit of gross domestic product. China has pledged to reduce emissions by 40-45% per unit of GDP by 2020. In India's case the figure is 24%. In part, this will be achieved by shifting the economic mix: as countries move from agriculture to industry, CO_2 emissions per unit GDP increase. As they move to light manufacturing and services, it reduces. But there are also significant opportunities to improve energy efficiency in both China and India. Indeed McKinsey research suggests that the cost of abating a unit of energy is 35% lower in developing countries.

Perhaps the biggest opportunity to reduce energy consumption worldwide lies in the built environment. According to the US Energy Information Agency, residential and commercial buildings account for 41% of the energy and 74% of the electricity used in the US. And many energy efficiency measures are relatively low-tech, such as insulating buildings, installing double-glazing windows, improving building management or reducing the number of appliances that are (or can be) left on stand-by.

Barriers to Implementing Energy Efficiency

A lot of energy efficiency opportunities with positive net present values still exist, however, there are also significant and widespread barriers to boosting energy efficiency.

Although heavy commercial users of energy are highly responsive to price signals, many retail consumers and small businesses are not. In addition, there are asymmetries of benefit – otherwise known as agency problems – whereby investments must be made by landlords that benefit tenants, or vice-versa, and this can stymie investment in more efficient buildings. Consumers may lack access to finance. Even if the returns on investment are high, consumers may worry that they move before they can recoup their investment in double glazing or loft insulation. So the money may sit in a savings account instead, and an investment with a positive NPV will not be made.

One of the most significant barriers to improving energy efficiency is a pervasive lack of information. Retail users have no information on which appliances drive their energy usage or the potential benefits of upgrading their homes. Commercial users in multi-tenant buildings may not be separately metered. Even professional architects and engineers may not know the relatively modest costs of improving the energy-efficiency of the buildings they design.

In "Greening our Built World", Greg Katz reports on the costs and benefits of green buildings, based on a detailed investigation of 170 LEED-certified developments. He found that the average incremental cost over conventional building was a paltry 1.5%. Yet a 2007 survey of business leaders by the World Business Council for Sustainable Development found that they expected the median cost differential to be 17%. Katz's survey found that the incremental construction costs in the range of US$ 3 to US$ 4 resulted in net savings in water and electricity alone of US$ 8 to US$ 10 over the first 20 years of a building's life – and that is without including health benefits, productivity benefits, wider societal benefits or reduced capital expenditure elsewhere in the infrastructure. He goes on to demonstrate that green community design has further economic advantages over and above green buildings alone.

Finally, the sheer time taken to replace existing building stock, typically 30 to 50 years, creates inertia in the system. Retrofitting buildings to make them energy-efficient is expensive and so has a slower payback time than building right the first time.

Policy Responses

Exploiting the opportunity to improve energy efficiency will require a range of policy interventions. These will include the following:

- **Changes in utility regulation:** At present most utility and network regulation centres on unit cost of supply. In future, regulation will need to ensure utilities have incentives to help drive improvements in end-use efficiency.
- **Appliance efficiency standards:** These have been proven effective at driving energy efficiency in a wide range of countries over a long period, particularly where consumers have been proven not to be price-sensitive.
- **Building codes:** Implementing stringent building codes for new buildings and buildings changing hands may be the single most powerful long-term driver of energy efficiency in the built environment.
- **Best available technology rules:** Governments around the world have started to ban high-power incandescent light-bulbs.
- **Availability of finance:** Where energy consumers have insufficient access to finance for energy efficiency improvements, legislation is required to enable the creation of new pools of money that allow third parties to invest on their behalf and share the resulting cost savings.
- **Information-sharing:** Often the reason energy efficiency improvements are not implemented is that consumers do not have access to information on their energy use or on ways of reducing it.
- **"Smart Grid"** (see separate section): In and of itself, smart grid technology does not save energy, but is an essential part of moving to more a rational pattern of energy use.
- **Plug-in hybrids:** electric vehicles and other advanced transportation (see separate section).

Investment Opportunities

Historically it has been hard for private investors to benefit from the drive for energy efficiency. Over the past few years, however, the trickle of specialist technology providers raising venture or private equity money has been growing strongly, covering lighting, light-responsive windows, energy-efficient building products, HVAC equipment and control software, industrial technologies, energy-efficient electronics and controllers and other technologies. With US$ 38 billion dedicated to energy efficiency around the world in the stimulus packages alone, the market for these technologies can only grow over the next few years.

Other ways for investors to access the push towards energy efficiency include the large number of green property developers and funds on the market. It is also possible to invest directly in energy reductions, via Energy Service Contracts, whereby a third party funds the cost of an efficiency improvement, and is paid out of the savings – Honeywell International's Energy Performance Contracts have been used to realize more than US$ 2 billion in annual savings by 2,000 customers worldwide – and a secondary market in these contracts could emerge as the market matures.

In June 2009, APG Asset Management (which manages the € 173 billion pension plan for Dutch civil servants) closed a US$ 100 million fund targeting energy efficiency investments in China's manufacturing sector. The fund will provide Chinese companies with financing to adopt energy efficient technologies and will take a share of the resulting savings. Also in China, the China Energy Conservation Investment Corporation, with nearly 180 group companies and 11,000 employees, focuses on energy conservation and environmental protection in China, providing a range of services including waste remediation, energy efficiency and clean energy investment. In 2008 the United Kingdom's Carbon Trust announced a joint venture with CECIC to explore opportunities in China for British clean energy technology.

From Incandescent Bulbs to Compact Fluorescent to Light-Emitting Diodes

Lighting, which according to the US Department of Energy accounts for 24% of US electricity consumption, is an obvious target area for efficiency improvement. Replacing incandescent bulbs with Compact Fluorescent Light (CFL) bulbs reduces energy consumption by around 75%; Light-Emitting Diodes (LEDs), which are just coming onto the market, could reduce energy consumption even further, by up to 90% over incandescent bulbs.

At current prices for bulbs and electricity, the cost winner is the CFL (see Table 2). However, that is likely to change as the price of LED bulbs comes down. In the end the LED's 60,000-hour life, low power use and lack of mercury content will make it the winning technology.

Table 2. Lighting Technology Comparison

	Incandescent	**Compact Fluorescent**	**LED**
Power (W)	57	14	6
Light (Lumens)	765	900	336
Directionality	Diffuse	Diffuse	Directional
Start-up time (seconds	0	~ 5	0
Pollutant	None	Mercury	None
Life (hours)	1,500	10,000	60,000
Price/bulb (US$)	0.65	1.50	39.95
Cost (assuming 10 years at 8 h/day and electricity at 12 US$ cents / kWh)			
Number of bulb changes	20	3	1
Electricity consumed	1664.4 kWh	408.8 kWh	175.2 kWh
Electricity cost	US$ 199.73	US$ 49.06	US$ 21.02
Total cost*	**US$ 212.73**	**US$ 53.55**	**US$ 60.97**

* Assuming no maintenance cost to change bulbs

If every US household replaced its 60W bulbs with LEDs, venture capital investor VantagePoint estimates this would result in US$ 30 billion of annual savings for households and 200Mtoe CO_2 emissions eliminated, equivalent of taking 38 million cars off the road. This would also reduce the need for utilities to build new generation capacity or turn on expensive (and often dirty) peak capacity. However, even if the cost comes down to US$ 15 per bulb when they become widely available, LED bulbs will be seen as relatively expensive and consumers are generally reluctant to pay upfront for benefits that accrue only over time. Rapid, mass adoption of LEDs in the retail market will require regulation – mandating their use, giving them away free, or rewarding utilities for investing in energy savings in the same way as they are rewarded for investing in generating capacity.

China is already establishing itself as the leader in LED manufacturing, representing a third of global production. China's share of the market was worth an estimated US$ 400 million at the end of 2008, and this is expected to grow to US$ 1.5 billion by 2012.

SOURCE: VantagePoint Venture Partners and New Energy Finance

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

6. Four Key Enablers

The rise of renewable energy has turned the spotlight on ways to integrate increasing amounts of energy from diverse sources, make the most of an ever-broadening array of new technologies and use energy more efficiently. In this section, we provide an overview of four key enablers whose progress (or otherwise) will foster or hinder the adoption of renewable energy and related technologies.

Although these four key enablers are discussed individually, they are interlinked with one another, as well as with renewable energy and energy efficiency: the smart grid will rely on power storage and on electric vehicles if and when vehicle-to-grid happens (where cars communicate with the grid to supply or absorb power depending on prevailing demand patterns); energy efficiency will drive the smart grid, particularly in the context of buildings and electric vehicles have a two-way relationship with power storage. Further details of each enabler are provided in Appendix 2.

Smart Grid

Discussions about the smart grid have moved from the periphery to the heart of discussions about future energy supply. The smart grid is an essential part of any future energy scenario: the world's existing electricity grids simply cannot cope with the increasing diversity of energy sources, many from variable and decentralised renewable resources, and do not allow energy supply and demand to be managed efficiently. With global energy consumption set to triple between now and 2050, intelligent power management will be vital.

Today's grid is not interactive – energy flows from generator to consumer, with no corresponding flow of information about energy prices, demand patterns and so on in either direction. This data flow is essential if we are to manage our energy consumption more efficiently, make the most of energy from distributed sources such as roof-top PV, and tap into the power storage capabilities of domestic appliances and electric cars.

There are many questions about who will build the smart grid, who will pay for it and how long it will take to build. What kind of policy mix will motivate utilities to adopt smart grid technologies and solutions while stimulating innovation, economic efficiency and competition? Trillions of dollars will have to be invested in upgrading and repairing the current transmission and distribution network, and in incorporating interactive elements such as sensors and smart meters. It looks likely that only regulation will drive this investment, but at the moment, most regulators remain in wait-and-see mode.

Government support is taking different forms. In the US, US$ 3.4 billion of stimulus funding in the form of grants were awarded in 2009 to 100 smart grid projects, designed to rollout a total of 18 million smart meters. According to the US Department of Energy (DoE), the total amount of private and public funds that will be invested in smart grid projects through this programme will be US$ 8.1 billion. The DoE had already granted US$ 7 billion to two federal-owned power administrations to build transmission that will eventually deliver renewable energy to the US's Western states.

Meanwhile the EU has stipulated that 80% of European households should have smart meters by 2020, with 100% coverage by the year 2022. Finland is spearheading smart grid roll-out, with a new law requiring utilities to install smart meters in 80% of Finnish homes by the end of 2013. Sweden completed a near-100% roll-out during 2009, and other Scandinavian countries are taking a lead in smart meter installation. The United Kingdom is aiming for smart meters to be installed in every house by 2020. According to a recent report published by the United Kingdom's Department of Energy and Climate Change *(Smarter Grids: The Opportunity)*, £8.6 billion will be spent on replacing 47 million gas and electricity meters, with an expected benefit of £14.6 billion over the next 20 years.

Preliminary estimates indicate that by 2020, around 200m smart meters could be operational in Europe and the US, meaning a rosy future for meter manufacturers such as Landis+Gyr (which is providing 150,000 Finnish consumers with smart meters), Itron, Silver Spring, GE and Echelon.

Power Storage

The ability to store energy efficiently will open up a wealth of opportunities for low-carbon technologies. Advanced batteries will provide power for electric vehicles and many other mobile applications, while utility-scale storage will allow fluctuations in electricity demand to be smoothed, generation to be managed to meet varying demand, and intermittent renewable generation to be accommodated.

The most obvious form of energy storage on the demand side is batteries, commonly used to power mobile, portable and remote devices from computers to cars. Electric vehicles are a Holy Grail for battery developers, although even the likely earlier take-off of plug-in hybrids offers a very substantial market.

Finding a solution for grid-scale power storage is becoming increasingly urgent for utilities. At grid scale, power storage has two main applications: energy management, where stored energy is used to provide additional supply when demand rises; and power quality management, where short sharp bursts of energy are used to stabilize the grid by smoothing out irregularities in supply or demand. Technology improvements and increased government support for advanced batteries, ultra-capacitors and other technologies could push the grid storage market from a projected US$ 1.5 billion market by 2012 to US$ 8.3 billion by 2016 according to a NanoMarkets report: *Batteries and Ultra-Capacitors for the Smart Power Grid: Market Opportunities 2009-2016*.

Developing advanced batteries is a priority for grid-scale energy management; battery technology developments currently being pursued include shortening recharging times, extending life, making portable batteries lighter and more compact and reducing cost.

On the power quality management side, flywheels and ultra-capacitors are relatively new technologies used to balance short-term grid fluctuations. Flywheels store power as kinetic energy, while ultra-capacitors store it as electrical energy. Flywheel technology has been proven at utility-scale and commercialization could halve its capital costs from US$ 1.5 million/MW currently to US$ 0.75 million/MW. Ultra-capacitors are a promising technology, but remain expensive and not yet proven at scale.

Advanced Transportation

Transport accounts for more than 27% of all final energy consumed (8,286 Mtoe), according to the International Energy Agency, and 23% of global CO_2 emissions. The transport sector is almost entirely reliant on oil to fuel it (94%). The scale of the problem (and therefore the opportunity) has propelled advanced transport into the limelight. If only 10% of the global fleet were to consist of electric vehicles, this market will be worth US$ 300 billion in 2020 for the cars alone, with batteries an additional US$ 100 billion and the lifetime mileage worth an additional US$ 250 billion according to the US Department of Transportation's Research and Innovative Technology Administration.

There are multiple technologies aimed at improving transportation efficiency: mass transit, biofuels, artificially-synthesized fuels, improvement to the internal combustion engine and fuel cells. The dominant technologies are plug-in vehicles: both plug-in hybrids (PHEVs) and full battery electric vehicles (BEVs). The critical enabling technology for vehicle electrification has been lithium-ion batteries, giving electric cars minimum ranges of 100 miles and top speeds of at least 90mph.

Electric vehicles are a nascent industry being accelerated by government support. The Boston Consulting Group has estimated that as of November 2009 governments around the world had pledged over US$ 15 billion to support the electric vehicles ecosystem, including direct vehicle subsidies (e.g. US$ 7,500 in the US, 5,000 euros in France, 60,000 rmb in China) and support for battery manufacturing and infrastructure (France has pledged 1.5 billion euros). This is all in addition to tax incentives. The political wildcard is the introduction of regulatory emission/fuel economy standards. European and Japanese governments have proposed emissions standards with punitive financial penalties that car companies are unlikely to be able to meet without sizable EV penetration. If passed, and matched by US-based legislation, this legislation will ensure meaningful EV deployments by 2020.

Electric vehicles' role in a low-carbon future goes beyond pure transport – many experts see mass penetration of electric vehicles as the key for higher levels of renewable energy generation, and the most powerful driver for a smart grid. Electric vehicles act as distributed large-scale storage devices. Current utility scale storage solutions come in 2MW increments; 50k EVs offer 1GW worth of storage, 500 times that amount. The benefits to the grid are that EVs provide load-levelling by increasing night-time electricity demand, However at present the cost of a battery cycle for Lithium-ion batteries makes vehicle-to-grid prohibitively expensive.

Widespread EV adoption faces three roadblocks that need to be addressed: infrastructure; psychological barriers/range extension; and availability and cost competitiveness of vehicles. From a total cost of ownership perspective, EVs are cheaper as the lower cost per mile more than offsets the upfront costs of the battery.

Carbon Capture & Storage (CCS)

In a world dependent on coal for its energy for the foreseeable future, technology that captures and stores the CO_2 emissions has an important role to play in the shift to a low-carbon energy future. Industrializing countries, notably China, have rich domestic coal reserves that will be used to support economic growth, especially as other energy resources elsewhere in the world diminish and fuel prices rise.

Demand for CCS could reach 160-240MtCO_2e/year by 2020, equivalent to the emissions from 26-44 coal-fired power stations or 8-12% of emission reductions required under global emission trading schemes. However, the funding so far committed worldwide – US$ 24 billion – will be insufficient even to complete the commercial and demonstration projects in all stages of development, equivalent to an injection rate of 95MtCO_2e/yr in 2020.

Before CCS can begin to fulfil even this potential, scaled-up demonstration projects must be built - and as yet, none have. The costs involved - US$ 1-2.5 billion for 100-300MW plants or US$ 57-91/tCO_2e avoided – are prohibitive in these tight economic times without any clear market incentives. The bottom line is that it is far more expensive to use CCS to deal with a tonne of CO_2 than it is to buy carbon credits on the ETS, even on the most aggressive price estimates. Funding for the first demonstration plants must therefore come directly from governments if CCS is to scale the gaping "Valley of Death" currently lying between it and commercialization.

Governments are making commitments to CCS projects. The G20 has a goal of 20 demonstration projects by 2020. The European Commission intends to facilitate construction of 10-12 demonstration projects, and the United Kingdom has said it will back four CCS demonstration plants. The EU has so far committed just over 8 billion euros (US$ 11.9 billion) to CCS, funded by EU-ETS' New Entrants Reserve, EU member states and the European Economic Recovery Plan. The US, Canada and Australia have also outlined plans to build large-scale projects. In June 2009, the US resuscitated the previously abandoned FutureGen project to build a 275MW CCS-equipped Integrated Gasification Combined Cycle (IGCC) plant. Under their clean energy stimulus plans, the US has pledged US$ 4 billion, Canada US$ 2.6 billion and Australia US$ 6.4 billion to CCS.

However, these commitments only close a small amount of the funding gap, estimated to be US$ 80 billion between now and 2020. This early-stage gap will probably be plugged by further direct government funding either in the form of grants or incentives combined with investment from those in the private sector who stand to benefit most from CCS (or lose most by not dealing with their CO_2 emissions), such as companies in the oil & gas and utility sectors, which have already emerged as leaders in CCS.

Once the first demonstration projects have been built, other forms of financing will be needed. Later projects could be funded via levies on electricity or fossil fuel production (effectively a direct tax on those producing the CO_2 that CCS is designed to mitigate), and ultimately CO_2 financing where market incentives (carbon credits) would attract private sector investment. Carbon prices are expected to rise to a suitable level to achieve this in Europe by 2020, and subsequently in other regions and countries.

Technological improvements could reduce the cost of CCS by 50%, to US$ 30-60/tCO_2e in the medium to long term. However, the cost is likely to rise in the short term as capture technologies are scaled up for the first time and need to be optimised.

7. Policy Support Mechanisms and their Selection

A portfolio of policies in each region, country, state or municipality which – taken as a whole – is needed to efficiently drive the transformation of the current energy infrastructure. Or, in the case of the developing world, drive a leapfrogging over the developed world's historic carbon-intensive technology choices, in favour of newer and cleaner alternatives.

But how should the right policy portfolio be assembled? First and foremost, any policy mechanism needs to be chosen according to the stage of development of the technologies that are to be developed or deployed, and hence the type of financing that the private capital markets should be encouraged to commit (see Figure 21).

Modern wind turbines are the result of over 30 years of development work, improving their size, yield and reliability. Wind energy provides around ten percent of the electrical power requirement of major developed countries like Spain, Germany and Denmark. It is clear that the right policy to encourage its further uptake will be very different from the policy required to encourage further laboratory research into advanced battery chemistries or to ensure that the first few cellulosic ethanol biorefineries are built.

For the purposes of our analysis we will use a model of technology development based on four stages. Although some models separate early stage R&D from proof-of-concept, we treat them together as the boundary between the two is often blurred.

Figure 21: Clean Energy Technologies by Stage of Maturity and Private Funding Sources

Stage of Technology Development	Early R&D, Proof of Concept	Demonstration & Scale-Up	Commercial Roll-Out	Diffusion & Maturity
Examples of Clean Energy Sectors	• Advanced battery chemistries • Algal biofuels • Artificial photosynthesis • Fuel cells (automotive) • Hydrogen storage • Integrated biorefineries • Material science • Next-generation solar • Osmotic power • Synthetic genomics	• Carbon Capture & Storage • Cellulosic biofuels • Enhanced geothermal power • Floating offshore wind • Fuel cells (distributed generation) • Grid-scale power storage • Marine (wave, tide) • Plug-in hybrids • Solar Thermal Electricity Generation • Smart grid	• Biodigestors • Coal-bed methane • Fuel Cells (UPS) • Heat pumps • Hybrids • Industrial energy efficiency • LED lighting • Offshore wind • Solar photovoltaics • Small-scale hydro • Smart meters	• Building insulation • Bicycles • Compact Fluorescent Lights • Condensing boilers • Large-scale hydro • Municipal solid waste • Onshore wind • Public transport • Sugar-cane based ethanol • Traditional geothermal power • Waste methane capture

Relevant Source of Private Finance

- Venture Capital
- Private Equity
- Public (Equity) Markets
- Credit (Debt) Markets

1. Early R&D/Proof of Concept

Encouraging innovation at a very early stage is the essential first step of bringing new ideas to market. Research and development can be undertaken by major corporations or small private companies; it can be funded by government either directly or through national labs or universities, or it can be funded by venture investors or the capital markets; it can be helped by incubators or angel networks.

Different clean energy technologies have very different characteristics in terms of capital intensity, level of innovation and intellectual property content, so a healthy system to accelerate and increase the volume of early-stage innovation is likely to bring together a range of different policy measures.

2. Demonstration & Scale-Up

Companies seeking to move their technology from the laboratory to the marketplace must bridge the notorious funding gap known as the 'valley of death': the point when the lab work and proof-of-concept have been completed, and it is time to build the first few full-scale projects or manufacturing plants.

Energy technologies appear to suffer particularly high attrition at this point in the development cycle. The first full-scale facility may require raising funds from new types of investor – usually debt providers who prefer not to take on technology or policy risk. Venture capital investors, meanwhile, are generally uncomfortable financing "steel in the ground": they are not experienced at project finance structuring or managing construction risk, and the returns on capital-intensive businesses are rarely high enough to satisfy the venture capital investment model.

The focus of policy to bridge this stage of technology development needs to be on mechanisms which bring forward access to traditionally later-stage financing by absorbing those risks – and only those risks – which the capital markets are not able to take.

3. Commercial Roll-Out

Proving that a new energy technology works at the required scale of project or manufacturing plant is not the end of the story. Fossil-based technologies, whether coal-fired power plants or internal combustion engines, benefit from over a hundred years' worth of technology development and trillions of dollars of cumulative investment in their supply chains. It is no wonder that their levelized cost – the cost without any subsidies or support mechanisms – is lower than those of new clean energy technologies.

During the commercial roll-out stage, the accent is on gaining experience and scaling as quickly and as efficiently as possible. Technologies in this stage need economic support, but the key is to make sure such support is reduced at exactly the right speed: too fast, and you get boom-bust cycles; too slow and you create an expensive and distortive long-term subsidy.

In addition, these technologies are often held back by barriers to rapid roll-out. These must be identified and removed by determined policy-makers.

4. Diffusion & Maturity

In an ideal world, once they have reached maturity, clean energy technologies would be able to compete on an unsubsidised basis with fossil fuels and win. In the very long term, this will no doubt be the case, as experience effects relentlessly drive down the cost of clean energy and depletion drives up the cost of fossil fuels.

Nevertheless, there are a number of reasons why policy interventions may still be needed to encourage the adoption of even mature clean energy technologies.

- **Fossil-based energy rarely pays for the externality costs it incurs.** An increasing carbon price over time, whether arising as a result of international negotiations or unilaterally in individual regions, countries or states, will serve to reduce the need for long-term support mechanisms for mature clean energy technologies. Were fossil fuels also to bear the public health and security costs they incur, the playing field for mature clean energy technologies would be more level.
- **Energy diversity has value to society, but not to individual energy producers.** Drawing on a mix of energy sources helps to insulate an economy against energy price spikes. Distributed energy is local energy, and therefore by definition more secure than imported energy sources. Yet if these public goods are not priced into the energy markets, then there is no incentive for developers to choose anything other than the lowest-cost solution.
- **Insufficient information.** Energy users may not have sufficient information to make informed choices – for instance when home-owners cannot see the impact of individual appliances or energy-saving investments, or when commercial tenants do not have individual meters within a building.
- **Insufficient access to finance.** While utilities and heavy industry can generally be relied on to make value-maximizing investment decisions, individuals and smaller businesses often simply do not have sufficient

access to finance to make investments, even when these would make economic sense.

- **In many markets fossil fuels are subsidized.** According to the International Energy Agency, fossil fuel subsidies in the largest 20 non-OECD countries alone amounted to US$ 310 billion in 2007. At its Summit in Pittsburgh in 2009, the G20 members agreed to phase out such subsidies “in the medium term”. This will – assuming it actually happens – clearly help mature clean energy technologies to compete on a level playing field.

Comparison of Policy Mechanisms

Policy-makers face different challenges in encouraging the development and deployment of clean energy technologies depending on their stage of maturity. And at each stage, there are a range of possible policy mechanisms that can be deployed, falling into five different types: changes to the nature or regulation of energy markets; support for equity investment; support for debt investment; changes to the tax code; or the creation of markets to trade emission credits. (See Figure 22)

What we have done is assemble what we hope is a useful list of 35 different types of policy intervention which can be used to spur the transition to a low-carbon energy infrastructure. In the charts which follow, we have sought to match the policy tools to the most relevant stage of maturity of the technologies they seek to promote. We have then rated each policy tool on three key dimensions:

- **Scale:** Can the mechanism quickly operate across multiple technologies and projects in multiple environments, or is it only applicable to a niche opportunity?

- **Efficiency:** Can the mechanism be targeted in an economically efficient way at supporting clean energy, without unintended consequences and without creating new bureaucratic overhead?

- **Multiplier:** Does each dollar of public money attract follow-on funds from private investors? Does each dollar double-task in terms of creating jobs or other social benefits?

Finally, we have indicated whether each mechanism is likely to be suitable in the developed world, in emerging markets – broadly those which are industrializing rapidly and already have a fairly well-developed energy infrastructure in place – or in the slower-developing world.

No simple rating system can attempt to capture all the nuances of any mechanism, its appropriateness or otherwise in a particular local context. In addition, careful design can counteract the natural weaknesses of almost any mechanism and likewise poor implementation can render the most elegant plans ineffective. This material therefore cannot be used as a fully-developed tool-kit for policy-makers. Rather it is intended to further understanding of the broad range of mechanisms at policy-makers’ disposal, and promote debate on how to choose between them.

In this effort we did not aim to be fully comprehensive: we have not covered mechanisms to slow or reverse deforestation, or to shift to low-carbon agricultural methods. We also have not looked at mechanisms specifically targeted at the promotion of nuclear power or the protection of jobs (such as local content regulations), which are beyond the remit of this report. In addition, we have made no attempt here to look at interactions between different policies.

Figure 22: Clean Energy Technologies by Stage of Maturity and Private Funding Sources

Stage of Technology Development	Early R&D, Proof of Concept	Demonstration & Scale-Up	Commercial Roll-Out	Diffusion & Maturity
Key Policy Challenges	• Increase the volume of early-stage research • Improve the flow of funding to promising research • Transfer academic research into commercial environment • Don't write off promising technologies too early	• Identify scalable, lab-proven technologies • Increase availability of equity • Provide soft debt where it is required for equity to achieve target returns • Establish clear performance milestones • Avoid chasing fads • Don't try to pick winners, but cull losers aggressively	• Develop a replicable blueprint for large-volume roll-out • Provide support to close cost gap with mature technologies • Ensure availability of debt despite technology, market and policy risk • Ensure energy system can absorb new technologies and remain stable • Support/create lead customers	• Ensure energy diversity, if necessary providing long-term support for higher-cost technologies • Protect public budgets • Avoid locking in uncompetitive market structures • Shift emphasis to "polluter pays" rather than maintaining subsidies forever

The Policy Mechanisms:

	Early R&D, Proof of Concept	Demonstration & Scale-Up	Commercial Roll-Out	Diffusion & Maturity
Energy Market Mechanisms		• National/State/local Procurement	• Feed-in Tariffs • Reverse Auctions/Requests for Contract • RPS/Green Certificates • Renewable Fuel Standards	• Best Available Technology Requirements • Utility Regulation
Equity Finance Mechanisms	• Incubators • National Laboratories • Prizes • National/State-Funded VC • National/State-Run VC • R&D Grants	• Project Grants		• Technology Transfer Funds • National/State/Local Infrastructure Funds
Debt Finance Mechanisms		• Mezzanine/ Subordinated Debt Funds • Venture Loan Guarantees	• Green Bonds • Loan Softening/Loan Guarantees • Senior Debt Funds	• Export Trade Credit • Microfinance • Sovereign/Policy Risk Insurance • National/State/Local ESCO Funds
Tax-based Mechanisms	• Capital Gains Tax Waivers • R&D Tax Credits	• Development Zones	• Accelerated Depreciation • Investment Tax Credits • Production Tax Credits	• Carbon Tax
Carbon Market Mechanisms				• Domestic Carbon Cap and Trade • Project-Based Carbon Credits • National & Multilateral Carbon Funds

Early R&D / Proof of Concept					
Mechanism	**Description**	**Type of Mechanism**	**Scale**	**Efficiency**	**Multiplier**
Incubators	Business development advisories for start-ups	Equity			
National Laboratories / Research Centers	Creation of national centers for research	Equity			
Prizes	Awards used to get early-stage ideas into the marketplace	Equity			
National/State-Funded Venture Capital	Investment of public money into commercially-run venture capital funds	Equity			
National/State-Run Venture Capital	Creation and management of venture capital investment operations by national or state governments	Equity			
R&D Grants	Grants for early-stage technologies	Equity			
Capital Gains Tax Waivers	Waivers on capital gains tax to stimulate investment	Tax			
R&D Tax Credits	Provision of tax credits for investment in clean energy R&D	Tax			

Definitions
* **Scale** Can the mechanism quickly operate across multiple technologies and projects in multiple environments, or is it only applicable to a niche opportunity?
** **Efficiency** Can the mechanism be targeted economically efficiently at supporting clean energy, without unintended consequences and without creating new bureaucratic overhead?
*** **Multiplier** Does each dollar of public money attract follow-on funds from private investors? Does each dollar double-task in terms of creating jobs or other social benefits?

Note: Equity is used to describe grants as well as true equity investments, since a grant effectivly replaces equity finance

Key:		
	(green)	High
	(yellow)	Medium
	(red)	Low

Comment	Examples	Suitability for: Developed Markets	Emerging Markets	Developing Markets
Over 160 incubators worldwide are working on commercialising clean energy. Quality of support is patchy and successes rare.	UK Carbon Trust's incubator programme provides start-ups with consulting services Austin Technology Incubator CIIE India CIETEC Brazil IIE Mexico.	☑	☑	☑
Many energy and communications technologies we now take for granted arose from work undertaken in national labs. They can create critical mass in pre-commercial research, should not crowd out private funding, and have long time horizons.	Energy Research Centre of the Netherlands Risø National Laboratory for Sustainable Energy Denmark UK Energy Research Centre National Renewable Energy Laboratory USA Oak Ridge National Laboratory COPPE & CEPEL, Brazil Fraunhofer Institute Germany.	☑	☑	☒
Suitable for technologies which require a single breakthrough, rather than process improvement, and where non-traditional answers are sought. Growing in popularity even when not appropriate.	X Prizes for super-efficient passenger vehicles and for biofuels Zayed Future Energy Prize ConocoPhilips Energy Prize UK Government £1bn prize for large-scale CCS US DOE's L Prize for efficient light bulbs & H Prize for hydrogen storage Scotland's Saltire Prize for wave and tidal energy.	☑	☒	☒
Becoming more popular than directly creating publicly-run venture capital operations. Some evidence of good track record, and can also create significant multiplier effect.	CalPERS/CalSTRS pioneering "Green Wave" initiative, 2004 CalCEF Asian Development Bank recently invested in several privately managed funds US's planned Cleantech Fund CVC Reef Australia Cleantech Australia Fund.	☑	☒	☒
Popular around the world as solution to perceived equity gaps challenges include attracting top investing talent and maintaining investment discipline. Poor track record of success.	UK's Carbon Trust Investments initially operated as a state-funded VC, but was later spun out. Sitra Finland, Massachusetts Green Energy Fund ITI Energy Scotland Sustainable Development Technology Canada.	☑	☑	☒
Can be an efficient way of routing funding to promising technology. Risk of bureaucratic overload and slow responsiveness of programmes. Small companies can find it hard to access grant process.	In 2009 stimulus packages alone, R&D grants were made in the US (ARPA-E), Canada, Japan, Germany, France, UK, Spain, Italy and Australia. DG Research of the EC administers substantial European funds from the 7th Framework Programme.	☑	☒	☒
Widespread use to spur venture-type investment by high-rate taxpayers. Prone to being "gamed" by dressing up safe investments as R&D.	No examples known of specific CGT waivers targeted at investment in clean energy.	☑	☒	☒
Widespread and successful use over a long period to increase research spending in industry. Suitable for sectors which large incumbents (with stable profits to shelter) are expected to dominate.	No trend yet towards targeted tax credits for clean energy research.	☑	☒	☒

Demonstration & Scale-Up

Mechanism	Description	Type of Mechanism	Scale	Efficiency	Multiplier
National/State/Local Procurement	Requirement that public entities procure clean energy or use emerging efficient technologies	Market			
Project Grants	Project-specific grants to encourage deployment of a particular technology	Equity			
Mezzanine/Subordinated Debt Funds	Credit lines for subordinated debt onlending to projects	Debt			
Venture Loan Guarantees	Public guarantees for private loans to technologically risky projects or companies which would not otherwise have access to debt	Debt			
Development Zones	Tax exemptions and funding to encourage innovation	Tax			

Definitions
* **Scale** Can the mechanism quickly operate across multiple technologies and projects in multiple environments, or is it only applicable to a niche opportunity?
** **Efficiency** Can the mechanism be targeted economically efficiently at supporting clean energy, without unintended consequences and without creating new bureaucratic overhead?
*** **Multiplier** Does each dollar of public money attract follow-on funds from private investors? Does each dollar double-task in terms of creating jobs or other social benefits?

		Key:		
			(green)	High
			(yellow)	Medium
			(red)	Low
		Suitability for:		
Comment	**Examples**	**Developed Markets**	**Emerging Markets**	**Developing Markets**
Given the volume of energy used by public bodies, clear statement of intent to procure clean energy should be a powerful and underused mechanism in creating markets. This is an under-used mechanism.	Bill Clinton broke new ground in 2000 with Executive Order 13149 mandating use of biofuels in the Federal vehicle fleet Spanish Ministry of Environment Finland targeting 30% public procurement of renewable energy by 2010.	☑	☑	☒
Widely used to encourage first roll-out of new technologies. Giving grants avoids the unpleasantness of having to write off poor investments. Still involves trying to pick winners.	$500m grant programme in US for advanced biofuels facilities Danish govt co-funding for Inbicon cellulosic bioethanol plant wood pellet project grants in Austria and Germany European grants for CCS, including Connecticut Clean Energy Fund invests in projects.	☑	☑	☒
Useful for projects which may have timing/construction risk or highly volatile returns, since debt payment is flexible.	The FIDEME fund (public & private money) lends subordinated debt, mainly to wind, but also biofuels, hydro and recycling projects in France.	☑	☑	☒
In essence acts as a form of insurance against technology, business model or other "proof-of-concept" risk	American Recovery and Reinvestment Act 2009 contained a provision for loan guarantees to newer technologies.	☑	☑	☒
Commonly used at a local government level to attract companies to their area.	China and India have a number of development zones focused on clean energy Oregon (US) has a Rural Renewable Energy Development Zone In the UK, One North East tries to attract clean energy businesses. Utah and other US states passed legislation in 2009 to set up renewable energy development zones.	☑	☑	☒

Commercial Roll-Out

Mechanism	Description	Type of Mechanism	Scale	Efficiency	Multiplier
Feed-in Tariffs	Guarantee of power prices above the average market rate, depending on renewable technology used	Market			
Reverse Auctions / Requests for Contract	Competitive tender for power purchase deals targeted at a specific technology	Market			
RPS / Green Certificates	Requirement for utilities to source a specific % of power from renewable sources	Market			
Renewable Fuel Standards	Requirement that a proportion of transport fuel is supplied by biofuels or some other low-carbon alternative	Market			
Green Bonds	Debt raised by a highly-rated issuer to lend to clean energy projects with otherwise high capital costs	Debt			
Loan Softening / Loan Guarantees	Programmes designed to reduce the cost of private lending and improve project economics	Debt			
Senior Debt Funds	Credit lines for senior debt lending to projects	Debt			
Accelerated Depreciation	Granting the right to depreciate certain types of clean energy equipment over an accelerated time-frame to reduce tax liabilities	Tax			
Investment Tax Credits	Faster write-off of investment to reduce tax paid in the early years of a project	Tax			
Production Tax Credits	Credits to encourage consumers and businesses in invest in specific products or projects	Tax			

Definitions
* **Scale** Can the mechanism quickly operate across multiple technologies and projects in multiple environments, or is it only applicable to a niche opportunity?
** **Efficiency** Can the mechanism be targeted economically efficiently at supporting clean energy, without unintended consequences and without creating new bureaucratic overhead?
*** **Multiplier** Does each dollar of public money attract follow-on funds from private investors? Does each dollar double-task in terms of creating jobs or other social benefits?

Key:		
	(green)	High
	(yellow)	Medium
	(red)	Low

Suitability (colour key)	Comment	Examples	Developed Markets	Emerging Markets	Developing Markets
High	Much loved by industry for removing all risks. Successful at encouraging scale and supply-chain investment, but hard to choose right tariff so market distortive and hard to dismantle. Simple and effective for retail market along with net metering.	Credited with jumpstarting the solar sector in Germany and Spain. Also in place in Italy, Ontario, Czech Republic and elsewhere China, UK and other countries looking to introduce feed-in-tariffs for selected markets.	✓	✓	✗
High	Auctions are more bureacratic than feed-in tariffs, but have the benefit of allowing price discovery they keep the industry focused on cost reduction, not lobbying. Risk of gaming/non-delivery.	China (wind and solar), Canada and Brazil (wind) have led the way being tried in California for solar from 2012.	✓	✓	✗
Medium	Many schemes in Europe and the US. Less loved by the industry than feed-in tariffs, but experience from Texas and UK offshore wind show it can be made to work.	UK ROCs Sweden Italy and Poland - Green Certificates Romania, Netherlands and US - RECs. Sweden looking to link its scheme with Norway.	✓	✗	✗
High	Can be a very quick and effective way of spurring a shift to low-carbon fuel if the standard is set too high, can lead to wild fluctuations in biofuel and feedstock prices risk of pushing up food prices.	US Energy Policy Act 2005 Renewable Fuel Standard California Low-Carbon Fuel Standard European Biofuels Directive.	✓	✓	✗
Medium	Suitable for stable technologies being deployed by smaller developers or in markets with high capital costs.	World Bank $350m issue of green bonds in 2009 to invest in developing countries US Treasury $2.2bn Clean Energy Renewable Bonds (CREBs).	✓	✗	✗
Medium	Widely used for renewable energy and efficiency projects - spurring private financial institutions to lend on terms not otherwise available.	Offered by many governments (eg India, China, Thailand) and multilateral lenders (ADB, EBRD, IFC) especially in developing countries. US's 2005 Energy Act and ARRA stimulus programme included loan guarantees IFC also provides loan guarantees.	✓	✓	✓
Low	Suitable for large scale renewable and grid projects.	European Investment Bank loans to offshore wind IFC Sustainable Energy Finance Programme supports national financial institutions Asia Development Bank loans to wind and waste projects.	✗	✓	✗
Medium	Suitable for established technologies at the roll-out stage, esp those with high capital costs.	MACRS provisions in the American Recovery & Reinvestment Act 2009 California (solar) Europe (offshore wind) Netherlands offered a long-running programme with some success Federal Economic Stimulus Act 2008 provided 50% bonus depreciation.	✓	✗	✗
Medium	Similar to accelerated depreciation, but calculated as % of investment and deducted from tax liability, rather than via depreciation.	The main support mechanism for large-scale solar in the US.	✓	✗	✗
Medium	Popular way of improving the economics of clean energy, particularly wind. Shifts burden of support from utilities / state to Federal budget. Limited by availability of corporate profits and subject to political whims.	Important driver of wind installations in the US until 2008. Also used in Japan, Brazil and Australia.	✓	✓	✗

Diffusion & Maturity

Mechanism	Description	Type of Mechanism	Scale	Efficiency	Multiplier
Best Available Technology Requirements	Rules preventing the use of technologies that don't match best in class	Market			
Utility Regulation	Restructuring regulation so that utilities have incentive to sell less power, not more	Market			
Technology Transfer Funds	Funds aimed at purchasing IP rights to technology for dissemination in the developing world	Equity			
National/State/Local Infrastructure Funds	Public investment in equity or debt funds invested in clean energy projects	Equity/Debt			
Export Trade Credit	Soft loans either to overseas buyers of technology or to domestic manufacturers	Debt			
Microfinance	Provision of debt to fund clean energy equipment such as solar lanterns or biodigestors or irrigation pumps	Debt			
Sovereign / Policy Risk Insurance	Provision of insurance to private investors against sovereign or energy policy risk	Debt			
National/State/Local ESCO Funds	Municipal or other public funds lent to home-owners and businesses for efficiency retrofits and repaid from savings	Debt			
Carbon Tax	Tax levied on dirty energy production in order to discourage it	Tax			
Domestic Carbon Cap and Trade	Creation of tradeable emission permits, which can can be given to historic emitters free or bought by them	Carbon			
Project-Based Carbon Credits	Allowing projects that reduce emissions vs business-as-usual to sell credits into mature market cap-and-trade schemes	Carbon			
National & Multilateral Carbon Funds	Financial support for carbon credit production to improve project margins	Carbon			

Definitions
* **Scale** Can the mechanism quickly operate across multiple technologies and projects in multiple environments, or is it only applicable to a niche opportunity?
** **Efficiency** Can the mechanism be targeted economically efficiently at supporting clean energy, without unintended consequences and without creating new bureaucratic overhead?
*** **Multiplier** Does each dollar of public money attract follow-on funds from private investors? Does each dollar double-task in terms of creating jobs or other social benefits?

Key: Green = High; Yellow = Medium; Red = Low

Comment	Examples	Suitability for: Developed Markets	Emerging Markets	Developing Markets
Much used to drive appliance efficiency and vehicle gas mileage improvements. Much discussion about broadening use.	US CAFE standards EU phase-out of incandescent light-bulbs.	✔	✔	☒
Key element in the drive for energy efficiency does not encourage renewable energy.	California requires electricity utilities to invest in energy efficiency Idaho (Idaho Power) Ohio (Duke Energy) Nevada utilities earn higher return on efficiency investment.	✔	☒	☒
Attractive to developing countries wanting to move away from resource and labour-based economies, but proponents rarely explain incentive for technology developers to co-operate.	In pharmaceutical sector, Global Fund for Aids no examples yet of clean energy technologies being acquired for free distribution.	☒	☒	✔
Good way of getting a number of projects done, but little in the way of multiplication. May crowd out private money.	Building Canada Fund, Canadian Clean Energy Fund.	✔	✔	☒
Designed to promote domestic manufacturers, but with high risk of distorting markets. Will need to gain in importance if developing world thirst for clean energy investment is to be slaked.	Export-Import Bank of the US OPIC EKF Export Credit Fund Denmark Austrade etc.	✔	✔	☒
The combination of microfinance with low-cost distributed energy is a marriage made in heaven, offering.	Grameen Shakti, Selco India, Solar Electri Light Fund, D-Light Design and others run microfinance programmes in various countries. E&Co funds a number of microfinance providers.	☒	☒	✔
Very much in vogue as way of unlocking private investment in clean energy in developing world. Only problem is that risk remains with developed world's tax-payers, who are also the investors, leading to potential systemic risk.	Multilateral Investment Guarantee Agency.	☒	✔	✔
Getting the ESCO model to work at scale is the holy grail to drive building energy efficiency. To date, however, it has proven bureaucratic and take-up is limited.	PlaNYC offers US$ 16 million revolving Energy Efficiency & Conservation Block Grant fund UK GB£ 84 million Social Housing Energy Saving Programme London GB£ 4 million London Green Fund EBRD/EIB/KfW/EU EUR 95 million Southeast Europe Energy Efficiency Fund	✔	✔	✔
Promoted by many as the simplest way to shift from fossil fuels. However, unilateral implementation risks driving industry overseas, and hypothecating tax to spend on clean energy is usually politically impossible.	Credited with much success in Sweden, but seen as failure in Denmark in 1990s. In other countries (eg UK Fossil Fuel Levy) set too low to drive switching behaviour. France carbon tax legislation currently stalled.	✔	☒	☒
Ideally provides a price signal which shifts investment decisions towards lower-carbon technologies. Proven to have driven switching from coal to gas in Europe, but price level & volatility too low to promoterenewable energy or CCS.	EU-ETS in Europe RGGI in North-East US New Zealand. Markets under discussion include California, US Federal market, Australia, Japan, Canada.	✔	☒	☒
Effective source of finance for projects under Kyoto, but seen by some flawed since they allow emissions to exceed caps in the developed world, and reward developers only vs business-as-usual. Also highly bureaucratic and open to fraud.	Kyoto Clean Development Mechanism (CDM) and Joint Initiatives (JI) voluntary carbon markets, including Gold Standard credits.	☒	✔	✔
Initial creation of UN Prototype Carbon Fund was important to jump-start trading. Should not be needed except to hit national goals. Will only spur renewable energy if given that mandate.	Many national carbon funds KfW Carbon Fund, a joint initiative between the German government and the EIB.	✔	✔	☒

Appendix 1 – Overview of Key Renewable Energy Technologies

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

1. Onshore Wind

The most mature of the renewable energy sectors, the onshore wind industry saw a record 27GW built in 2008, bringing installed capacity worldwide to over 120GW. This increased to an estimated 140GW during 2009. The US overtook Germany as the country with the largest installed wind capacity, adding nearly 4GW during 2008. China's installed wind capacity also surged, more than doubling between 2007 and 2008 to top 12GW. The Global Wind Energy Council forecasts that the global wind market could grow to reach installed capacity of over 1,000GW by 2020, saving 1.6 billion tonnes CO_2e pa.

Electricity from onshore wind can be generated at prices of US$ 7-12 cents/kWh. While this is 50% more expensive than natural gas CCGT, onshore wind can compete with conventional generation without subsidy, where wind speeds are high enough.

Table 3. Onshore Wind – Economic Overview

Potential Scale	Greater than 800GW, of which only 140GW has been exploited.
Market Readiness	LCOE = $68-116/MWh
Project Returns	10-20% depending on market and resources

Source: New Energy Finance

Policy Status and Gaps

There is no doubt that subsidy support, in the form of feed-in tariffs and tax credits, has spurred onshore wind development in countries such as Spain, Germany and the US, and increasingly in China. However, accelerated planning processes and incentives/regulation to spur integration and remove grid bottlenecks are needed.

Table 4. Top Five Wind Markets by Capacity 2008

Market	Capacity (GW)
US	25.2
Germany	23.9
Spain	16.8
China	12.2
India	9.6

Source: New Energy Finance, GWEC

Technology Gaps

Onshore wind is a mature sector, so advances in onshore turbine technology tend to focus on refining existing designs and increasing turbine size. More recently, though, very high demand growth has meant that market incumbents have been unable to keep pace and the sector is now seeing a re-emergence of older technologies and new manufacturers to commercialize them. This includes simplified two bladed turbines, downwind two bladed turbines and major innovations in offshore wind systems (see next section).

Other areas where better technology would boost the onshore wind sector include:

- Drive-train improvements to increase reliability and reduce costs
- Ever-larger turbines. The world's largest turbine is currently Enercon's E-126, which has a rating of 6MW, but is likely to generate in excess of 7MW.
- Supporting infrastructure for wind farms in power storage (to reduce impact of intermittency), resource forecasting (high technology required) and grid expansion (mainly capital)

Potential Bottlenecks

Raising finance remains a bottleneck in the short term, as for all energy projects. This is partly because capital is in tighter supply, and also because lending margins have widened.

Slower demand in 2009 combined with supply improvements have caused blade and turbine costs to fall 15% during the year, so the anticipated supply bottleneck has not materialized.

Planning permission remains an issue, particularly in the most heavily populated and mature European markets, such as the United Kingdom where the government has agreed to a one-year decision process.

In the longer term, the geographic isolation of wind resource areas is a potential bottleneck, as the most accessible onshore sites are exploited.

2. Offshore Wind

After the best sites for onshore wind have been developed, such as in Northern Europe, the next place to look is offshore. Offshore wind offers enormous potential, with stronger, more predictable winds and almost unlimited space for turbines. Planning permission can be easier to obtain, farms can be built at scales impossible on land, and the availability of space is almost unlimited if deep waters are mastered. However, offshore wind faces some logistical and design challenges, including the high cost of grid connection from offshore sites, more wear and tear, and difficult operation and maintenance.

Offshore wind is relatively unexploited compared to onshore wind, with around 2.4GW of capacity installed worldwide, and a further 38GW granted planning permission or under construction.

At present, the cost of electricity from offshore wind is still high – more than 13 US$ cents/kWh, but this has fallen by nearly 25% over the last year, and continues to fall as more project experience is gained. Long lead times, substantial capital spending (US$ 300 million+ per project) and long-term operating risk mean that investors (primarily oil and gas firms and utilities) have made cautious moves offshore.

Policy Status and Gaps

Offshore wind tariffs and support mechanisms are currently being put in place to spur significant growth in Northern Europe, particularly in the United Kingdom and Germany where more than 1GW per year is expected to be commissioned over the next five years (see Figure 23). There is also growing support in Nordic markets, Benelux, China and the US.

In December 2009, Germany, France, Belgium, the Netherlands, Luxembourg, Denmark, Sweden, Ireland and the United Kingdom signed the “North Seas Countries’ Offshore Grid Initiative”. The plan, to develop a European offshore wind grid in the North and Irish Seas connecting 40GW of wind generation, will take shape during 2010.

Technology Gaps

Offshore wind faces a far harsher environment than onshore wind, with the result that early versions of onshore turbines installed offshore suffered high-profile and expensive reliability problems. Significant work by Siemens, Vestas, REpower and others have strengthened components and insulated internal mechanisms from salt-laden sea air, improving offshore turbine reliability.

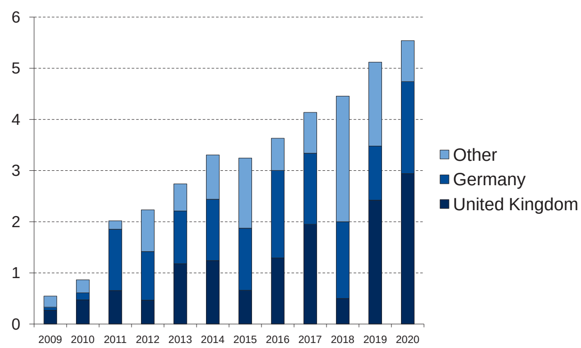
New dedicated “marinized” technology at a larger scale will be rolled out over the next five years. As size

Table 5. Offshore Wind – Economic Overview

Potential Scale	2.4GW capacity installed currently. 120GW potential by 2030
Market Readiness	LCOE = $131-245/MWh
Project Returns	Marginal

Source: New Energy Finance

Figure 23. Current and planned offshore wind projects by expected commissioning date, GW



Note: Based on an analysis of over 110GW of planned offshore wind projects in Europe

Source: Companies, Wind Associations (various), New Energy Finance

increases, manufacturers are focused on reducing the weight of the nacelle (at the top of the tower) by removing or replacing electrical components, gearboxes or blades. Improving turbine reliability has come at the cost of increased weight, and turbine innovations and deeper water foundations will improve the economics of offshore wind.

Potential Bottlenecks

Offshore turbines have lower profit margins than onshore turbines, so manufacturers are mainly focused on producing onshore devices, creating a potential bottleneck for offshore ones. Developers may continue to favour onshore wind as access to capital is still limited, and the risk-return ratio on offshore wind returns remains relatively unattractive.

3. Solar – Photovoltaics (PV)

PV technology has made very rapid strides in the past four years, in terms of reducing the cost of crystalline silicon (its main component) and commercialising thin film technology. However, PV remains one of the most expensive renewable energy sources in nearly all applications. The main growth market is grid-connected power plants supported by generous incentives. PV will become increasingly cost-competitive in some mainstream retail markets, which will unlock substantial demand, but not for several years.

In 2009, new build PV improved on 2008's record levels, with an estimated 6.4GW installed during the year (see Figure 24) to reach approximately 21GW of global capacity.

Solar project costs have fallen sharply. 2009 saw new solar-grade silicon capacity coming on line and a collapse in demand from Spain. These influences unblocked the supply bottleneck and halved the price of PV modules compared with 2008. Large-scale projects using conventional PV modules can now be built for under US$ 4/W - the cost of the modules alone in 2008. Thin-film PV projects have been announced and built for as little as US$ 3/W. As a result, unsubsidised large-scale PV generation costs in sunny parts of the world with moderate capital costs are similar to daytime peak retail electricity prices of approximately 17 US$ cents/kWh.

Now that the silicon bottleneck has eased, with prices falling to US$ 1.80/W for conventional silicon modules and forecast to be below US$ 1.50/W in 2010, thin-film technologies are less obviously attractive. Thin-film has taken an increasing share of the global PV market (from 14% in 2007 to 18% in 2008), but this rate of growth slowed in 2009, sustained mostly by thin-film leader First Solar which produced 1GW at an average cost of below US$ 1/W.

Policy Status and Gaps

Incentives in the form of feed-in tariffs, grants and/or tax credits are by far the most significant driver of the PV market, for example in Japan, Germany, Spain, and California. Conversely, where subsidies are being capped or phased out, as now in Japan and Spain, installation slows.

Sympathetic tax treatment for R&D would help stimulate technology development, for example to boost thin-film and crystalline silicon efficiency and the development of new PV products.

Technology Gaps

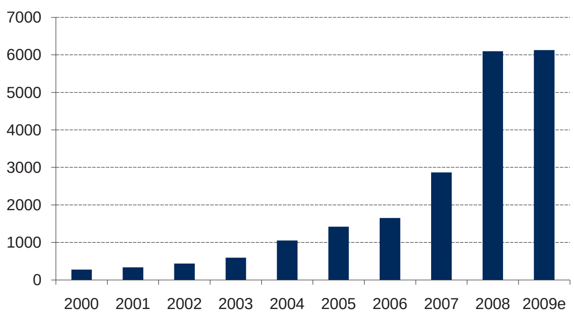
The PV industry's key challenges remain the mass manufacture of scalable, high-efficiency thin-film modules and continuing to reduce the cost of crystalline silicon modules. During 2009, PV made promising steps towards being cost-competitive in its own right, but how these trends develop over the next few years will be crucial.

Table 6. Solar PV – Economic Overview

Potential Scale	21GW currently installed. Potential capacity limited only by economics – 1000GW could be installed by 2030
Market Readiness	LCOE = $170-450/MWh Currently uneconomical but costs have fallen dramatically during 2009, and will continue to fall
Project Returns	Heavily dependent on incentive regime

Source: New Energy Finance

Figure 24. Global New Build PV 2000 to 2009, MW



Source: IEA, EPIA, individual government sources and industry associations, New Energy Finance

Potential Bottlenecks

The main constraints to the PV industry's growth are: shortage of affordable capital (PV projects are extremely sensitive to interest rates because nearly all the cost is upfront), caps to incentive regimes, customer inertia, slow planning permission and transmission bottlenecks. Oversupply of modules will continue in the short term, with the price likely to fall to the marginal cost of production, representing a further 15% fall in price for crystalline silicon modules.

4. Solar Thermal Electricity Generation (STEG)

Solar thermal electricity generation (STEG; also known as concentrated solar power or CSP) is the utility-scale cousin to PV, historically the project developer's choice for central station generation plants (50MW+). Where PV generates electricity photo-electrically (by converting light directly into energy), STEG is thermo-electric. It converts light into heat by concentrating the sun's rays onto a heat collection system, and then converts this heat into electricity via either a heat engine, or a boiler which drives a steam turbine.

STEG has historically been the solar market front-runner for lowest Levelized costs of energy and cost per W installed. However, the dramatic decline in PV prices means that STEG no longer holds the cost advantage on a per-kWh basis, though it will always be a competitive renewable energy technology due to its favourable performance characteristics.

There is very little installed STEG capacity worldwide; just 616MW, although there is a strong forward pipeline of projects. The conditions for STEG are particularly attractive in Spain and the US, in terms of both incentives and resource, and projects here will add more than 5GW between now and the end of 2013 (see Figure 25). There are also several projects backed by government tenders in the Middle East and World Bank funding of US$ 5.5 billion in North Africa, where the Desertec Industrial Initiative has attracted heavyweight financial backers, such as Munich Re, Siemens, Deutsche Bank and MAN Solar Millennium. Mexico, Australia and the Persian Gulf are emerging STEG markets.

Policy Status and Gaps

Like PV, STEG is highly subsidy-dependent, and there are only two near-term markets: Spain (using feed-in tariffs) and the US (Investment Tax Credit & DoE Loan Guarantee programme). In other markets, progress on government tenders and development projects is slow.

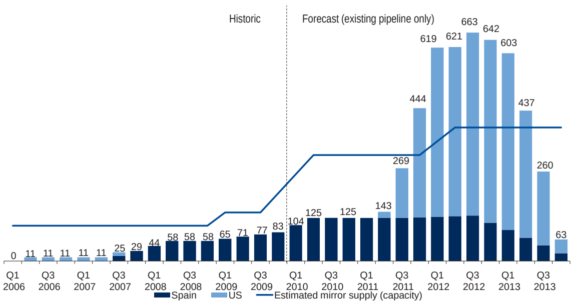
Technology Gaps

The STEG supply chain is dominated by established multinational corporations and increasingly well-funded specialists who continue to refine their technologies. While parabolic trough is essentially a mature technology, and turbine design is unlikely to see any breakthroughs, tower and heliostat STEG designs have the potential for the highest heat and efficiency, and lowest Levelized cost.

The addition of thermal energy storage, where solar radiation is stored as heat rather than electricity, can allow for systems that operate 16 hours a day at LCOEs potentially lower than any other solar technology.

Table 7. Solar Thermal – Economic Overview	
Potential Scale	616MW currently; potential to reach 80GW by 2030 Scale limited only by space and grid connection
Market Readiness	LCOE = $190-250/MWh Uneconomic at present
Project Returns	n/a
Source: New Energy Finance	

Figure 25. STEG project pipeline in US and Spain by quarter, MW



Note: Includes only projects approved for Spanish FiT (661/2007) as well as US projects with power purchase agreements and projects in advanced stages of project financing a planning/ permission.

Source: New Energy Finance

However, storage remains market-driven, rather than economics-driven.

For all STEG projects besides parabolic trough, funding the first large-scale plants will be difficult as they will involve technology risks that have not yet been tested at scale.

Potential Bottlenecks

In Spain, there are no bottlenecks for those with projects in the pipeline. In the US, however, arranging project permissions and transmission access is a multi-year process, and even once achieved, does not mean that the necessary financing will be available.

5. Biomass

Biomass includes a range of feedstocks, such as wood, energy crops and agricultural residues, which absorb carbon from the atmosphere while growing, and return it when broken down through burning, gasification or decay. Biomass feedstock from constantly replenished sources, such as waste, coppiced woodland or rotational cropping, means a closed carbon cycle is maintained with no net increase in CO_2 levels. Biomass is used to produce electricity through incineration, gasification and pyrolysis (thermal conversion) or anaerobic digestion (chemical conversion).

There is currently 45GW of installed biomass capacity worldwide, mainly incineration. Investment held up well in 2009 (see Figure 26), with European biomass attracting a significant share, including two 20MW plants in the United Kingdom and a 20MW, 40-plant biogas park in Germany.

Gasification has several advantages over incineration, including higher efficiencies (38-41%) and an intermediary syngas (similar to natural gas) used in electricity and heat generation and transport fuels. Commissioned gasification capacity is only 124MW. Germany is currently the largest biogas market (1.6GW).

Policy Status and Gaps

Long-term support, such as feed-in tariffs or green certificates, exists in most European countries. Subsidies for co-firing biomass in coal power stations are not usually generous. There is no subsidy for syngas production, which would help to commercialise gasification technology. A federal RPS in the US might be a big driver for the biomass industry, particularly in the southeastern US states, where other renewable resources are scarce. Policy is needed to build feedstock supply; through incentives to farmers to grow energy crops, or to forestry firms to collect their residues.

Technology Gaps

Incineration is a proven technology and is a low-tech process with little scope for refinement. Gasification still requires R&D to resolve technical issues and reduce the high capital costs that prevent use at commercial scale. Improved quality of the syngas is also needed. Improved monitoring of the operation of anaerobic digestion plants would increase their efficiency.

Potential Bottlenecks

Feedstock-related issues represent the industry's main bottleneck. Long-term availability and price security cannot be guaranteed by suppliers, and there is a lack of pricing transparency, as biomass is mostly bilaterally traded. The wood pellet supply chain is relatively well-developed, with reasonably transparent pricing and established supply routes. However, wood pellets are generally used for residential power, and rarely in dedicated power plants because they are more than twice as expensive as other biomass feedstock.

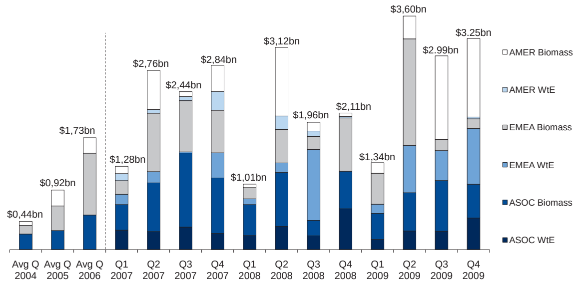
Other biomass bottlenecks include the availability of capital and turnkey construction providers, and long lead times for boilers and turbines due to recent high demand.

Table 8. Biomass – Economic Overview

Potential Scale	45GW capacity currently installed. 150GW potential capacity by 2030
Market Readiness	LCOE = $70-148/MWh (incineration) $90-170/MWh (gasification) $80-189/MWh (anaerobic digestion)
Project Returns	around 10%, depending on location and availability of feed-in tariffs

Source: New Energy Finance

Figure 26. Biomass and Waste-to-Energy New Build, US$ billion



Note: Grossed-up values based on disclosed deals for new build assets (excluding acquisitions and refinancing). Average quarters for 2004 – 2006 combine Biomass and WtE investment.

Source: New Energy Finance

6. Municipal Solid Waste-to-Energy

Solid waste-to-energy (WtE) uses the same conversion technologies as biomass, but its economics are fundamentally different. Whereas biomass generators have to buy in feedstock, sometimes over long distances, WtE plant operators are paid to take and treat municipal solid waste (MSW). WtE therefore has a very low levelized cost of energy, producing electricity as cheaply as 4 US$ cents/kWh. However, to date, only 18GW of capacity has been installed worldwide, and WtE's long-term potential is limited - up to 50GW by 2030, far less than wind, solar or biomass.

In the short term, prospects are good as waste legislation tightens and alternatives to dumping waste in landfill are sought. As landfill gate fees rise and burying rubbish is increasingly considered environmentally unacceptable, burning waste will become more attractive. However, most major markets will have reached their targets by 2020 and in the medium term the growth rate will be low.

For the time being, though, waste-to-energy remains a viable way of cutting landfill, and plants continue to attract investors. For example, a 420,000-tonnes-per-year, 100MW WtE plant is being built in Cheshire, United Kingdom by Ineos Chlor, Viridor Waste Management and John Laing.

As well as incineration, waste can also be gasified, with the resulting gases (largely methane and carbon dioxide) being used to fuel rubbish trucks and other municipal vehicles, generate power or burnt off. While gasification has tended to use agricultural residues and non-food grasses as feedstock in recent years, now municipal and industrial waste are dominant as feedstock for new gasification plants coming on stream.

Incineration remains the dominant process for both biomass and WTE (see Figure 27). Anaerobic digestion has taken over from landfill gas as the dominant gasification technology in Europe.

Policy Status and Gaps

Policy in many countries currently supports municipal waste-to-energy by making landfill expensive. Increasing gate fees and other taxes on waste will increase incentives further. The EU Landfill Directive (1999) stipulates that member countries must reduce the amount of biodegradable waste going to landfill to 35% of 1995 levels by 2020, and some countries have started to tackle the problem at source by cutting down on rubbish collection or making householders pay for collections.

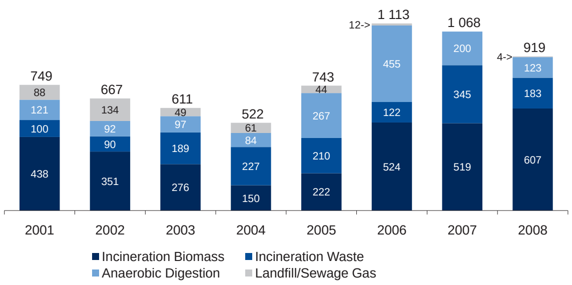
As incineration of MSW usually provides good revenues there are subsidies in only a few countries. However, to promote the gasification of MSW, feed-in tariffs or similar incentives are required.

Table 9. Municipal Solid Waste-to-Energy – Economic Overview

Potential Scale	18GW capacity currently installed. 50GW potential capacity by 2030
Market Readiness	LCOE = $38-157/kWh
Project Returns	around 12%

Source: New Energy Finance

Figure 27. Commissioned Biomass & WtE capacity in Europe by technology 2001 to 2008, MW



Source: New Energy Finance, Platts, German Biogas Association

Technology Gaps

As with biomass, incineration is a proven technology, while there is still scope for technology development in gasification.

Potential Bottlenecks

Permitting remains a major bottleneck, both in terms of speed and also public opposition.

As in the biomass power industry, there are few turnkey providers in the WtE industry and there are long lead times for boilers and turbines due to recent high demand.

7. Geothermal

Geothermal power is a particularly attractive renewable energy source as it can be used as predictable baseload energy, unlike wind and solar power. Geothermal can also provide electricity, heating and cooling.

Global installed capacity at the end of 2009 was estimated to be 10.5GW. The US has the world's highest installed geothermal capacity (3GW, 80% of which is in California), followed by the Philippines (1.9GW), where geothermal provides 20% of the country's electricity. In Iceland, geothermal produces 26% of the country's power and 87% of its building heating. Emerging geothermal markets include Australia and Chile.

Until now, only a fraction of conventional global geothermal resources have been tapped, but a raft of new approaches, such as Enhanced Geothermal Systems (EGS), aim to make it viable across a wider area. Spurred in part by regulatory support and incentive structures, there is now a geothermal development pipeline of 12.4GW (see Figure 28), with the US responsible for 4GW.

Geothermal energy remains the lowest cost form of renewable energy at US$ 59-83/MWh. However, projects are long (see Figure 18) and capital costs are high due in part to expensive and risky exploration drilling. Geothermal projects can produce at 90%+ capacity for 30 years or more.

Policy Status and Gaps

As baseload power, geothermal contracts are typically signed at lower rates than other renewable sources, but the high capacity factor yields more favorable project economics. In the US, geothermal is included in the Renewable Portfolio Standard (RPS), and benefits from tax credits such as the PTC and ITC, as well as loan guarantees and green stimulus grants worth US$ 400 million.

Technology Gaps

Enhanced Geothermal Systems (EGS) "enhance" or even create geothermal systems where natural fractures provide inadequate flow rates. The resource potential for EGS is vast – estimated at 517GW for just the US – and the technology has been proven, although currently only two EGS plants are operational worldwide. Australia has the world's largest EGS plant (5-10GW) under construction.

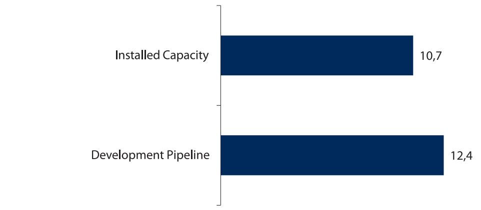
For conventional geothermal, improvements in exploration technology would facilitate development of resources with no surface manifestations, and improve the current drilling success rate of just 20% in greenfield sites, dramatically cutting development costs.

Table 10. Geothermal – Economic Overview

Potential Scale	10GW currently installed 40GW potential capacity by 2030
Market Readiness	LCOE = $55-83/MWh
Project Returns	12-37%

Source: New Energy Finance

Figure 28. Global Commissioned and Development Geothermal Capacity 2009, GW



Source: New Energy Finance

Potential Bottlenecks

As more companies become involved in developing geothermal projects, the higher demand risks creating a construction bottleneck, increasing lead times and capital costs. This is encouraging vertical integration (developers buying drilling companies) as well as developers forming 'drilling clubs' to book up rigs for long periods. With depressed oil prices, oil and gas drill contractors are increasingly venturing into geothermal as a means of keeping their rigs busy.

For turbines and surface equipment, there is a backlog of plant orders as manufacturers struggle to keep pace with demand from the large project pipeline. Long lead times for land siting, permitting and rights of way are other major bottlenecks for the geothermal sector. This could be eased by relaxing certain rules and streamlining the process.

8. Small Hydro

Hydro is a well-established renewable source of electricity worldwide; large-scale and small hydro together account for 16% of global power. However, because large hydro can have negative environmental consequences, and because the most accessible large hydro resources have already been tapped, only small hydro (up to 50MW) is considered here. Installed small hydro capacity is currently 92GW, with the potential to expand more than threefold to 328GW by 2030.

Hydro is a mature technology, but it is a variable source of power, dependent on rainfall patterns and therefore often seasonal. In the longer term, climate change may make some existing hydro unviable. However, hydro remains an important part of the clean energy mix because 90% of the unexploited resource is in developing countries, in Sub-Saharan Africa, South & East Asia and South America, where cheap, renewable power, particularly for remote rural communities, is a priority. Africa, for example, exploits just 8% of its hydropower. Its other advantages are a long life span (50-100 years) and, in pumped hydro, a system for storing freshwater supplies.

In China, the government has set a target for small hydro to increase from 55GW currently to 75GW by 2020, although this will be eclipsed by large hydro, whose target is 225GW. Also, China may favour solar and wind development on the basis that these industries offer better export potential for its manufacturing base.

In Brazil, installed capacity for small hydro (up to 50MW) is 4.2GW, and there are over 1,000 projects, or 8.2GW, approved or under study by the Brazilian Energy Regulator (ANEEL). However, these projects face several bottlenecks, such as regulatory bureaucracy and environmental issues.

In Europe, small-hydro expansion has been constrained by the implementation of the EU Water Framework Directive, introduced to protect aquatic ecosystems and water quality. This is likely to result in a reduction in small hydro generation in the EU. Activity in Eastern Europe is also expected to fall following several years of high investment and intensifying competition for sites.

Small hydro has proved relatively resistant to the economic downturn as projects are perceived as relatively low risk and their size means many can be financed by a single commercial or development bank. During 2009, nearly 150 new small hydro projects were announced, totalling 2GW of capacity.

Table 11. Small Hydro – Economic Overview

Potential Scale	92GW installed capacity 328GW potential capacity by 2030
Market Readiness	LCOE = $70-120/MWh
Project Returns	8-13%

Source: New Energy Finance

Policy Status and Gaps

Renewable Portfolio Standards, Rural Electrification Programs and other target-based mechanisms support small hydro. Streamlining planning processes would help increase small hydro capacity, in particular accelerating permitting for small hydro projects. Access to the grid is another bottleneck that policy could help unblock. The EU Water Framework Directive will make it harder for small hydro capacity to expand in the EU, with developers under increased pressure to integrate their schemes into the environment.

Technology Gaps

Hydro is a mature technology, so there are few technology gaps. Improving run-of-river turbines and technologies would improve operating efficiency.

Potential Bottlenecks

The often remote location of remaining hydro resources is a bottleneck, as connection to the grid and/or directly to consumers (as in remote rural locations) is expensive and time-consuming.

Environmental and social resistance to hydro schemes is another bottleneck, particularly as general opinion often does not distinguish between small and large-scale hydro, which is often controversial (such as the Three Gorges Dam Project on the Yangtze River, China).

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

9. Sugar-based Ethanol

Global ethanol production capacity is 80 billion litres per annum (Lpa), with Brazil and the US the two largest ethanol producers in the world. Brazil has plentiful low-cost sugarcane feedstock, thanks to advanced agri-industrial techniques, which does not jeopardizing food production, and also benefits from strong political support. The Brazilian government has mandated blending for gasoline (currently 25% ethanol), and since 2003 car manufacturers have sold flex-fuel vehicles that can run on any blend of gasoline and ethanol. Ethanol has a 50% market share of the gasoline-fuelled fleet in Brazil, and accounts for 16.7% of the country's total automotive energy consumption.

Sugar cane is the most cost-efficient and environmentally friendly feedstock for ethanol production, with 70-90% fewer CO_2 emissions than gasoline. Brazilian sugar-based ethanol is competitive with gasoline when oil is at $40-45 a barrel, but ethanol from other feedstocks, such as maize, is not economic without subsidy. During 2009, however, corn ethanol margins in the US and Europe have started to recover on the back of lower corn prices and rising oil prices. Conversely, Brazilian ethanol has become significantly less competitive due to a revaluation of its currency and increases in the prices of both sugar and raw sugar cane, and investment has fallen (see Figure 29).

Policy Status and Gaps

Most countries seeking to promote ethanol use do so by offering subsidies and imposing a minimum blending requirement, although the well-established markets of Brazil and the US now have discretionary blending. In Europe, demand is generally mandated, although a generous subsidy regime in Germany and lower feedstock prices stimulated some discretionary demand in 2009.

Brazilian ethanol production would benefit from legislation to allow ethanol to be traded freely among market players; for gasoline prices to fluctuate in a free market; and for the use of transgenic (genetically modified) cane, currently banned by the Brazilian Ministry of Science and Technology.

Technology Gaps

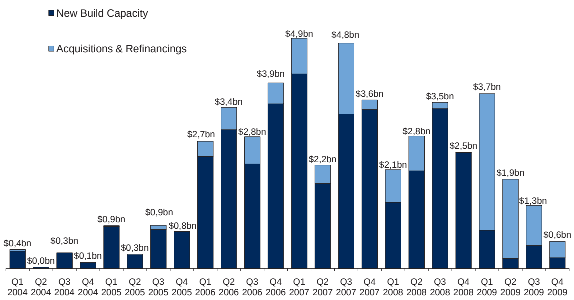
Sugar-based ethanol is produced from sugar cane juice, but technology is being developed so that all cane residues – leaves, straw and bagasse – can be used for ethanol production, through processes like hydrolysis, which would increase sugar-based ethanol productivity significantly.

Table 12. Sugar-based Ethanol – Economic Overview

Potential Scale	80 billion Lpa commissioned production capacity Global production estimated to reach 350 billion Lpa by 2030
Market Readiness	Brazilian sugar ethanol is market-ready i.e. competitive in its own right with oil at $40 - 45barrel
Project Returns	8-15%

Source: New Energy Finance

Figure 29. Asset Finance Investment in Ethanol 2004 to 2009, US$ millions



Source: New Energy Finance

Potential Bottlenecks

Import tariffs and local subsidies create a major bottleneck for sugar-based ethanol. Once these are removed, market mechanisms such as hedging instruments and a futures market will help build a transparent global ethanol market.

Another bottleneck is the continued lack of definition of sustainability criteria and methodology used to work out emission reductions from biofuels in the US and Europe.

10. Next Generation Biofuels

In most regions, there is sufficient land to increase biofuels production from the current 3% of transport fuels to 5% without impacting on food availability. But beyond this point, the only way to increase biofuels output will be to use feedstocks that do not compete with food production.

As well as using by-products of other crops, such as wheat straw, sugar cane leaves and forestry waste, crops are being grown specifically to produce biofuels, including jatropha (being trialed in India), miscanthus, and switchgrass. These crops have the added advantage of being able to grow in areas considered marginal for arable use, such as desert areas (jatropha) and very wet land (miscanthus). New technologies have been developed to cope with these more varied feedstocks, including enzymatic hydrolysis and gasification.

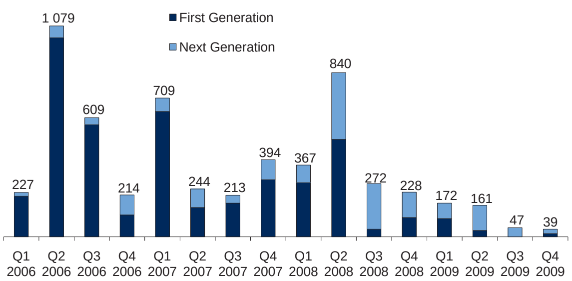
Global production of next-generation biofuels is currently small at around 250 million Lpa, or just 0.3% of global bioethanol production. However, production volumes are expected to rise as new feedstocks are grown, technologies are proven and scaled up, and as the cost of production falls. Early-stage investment in next generation biofuels continues to surpass first generation investment (see Figure 30).

Table 15. Next-Generation Biofuels – Economic Overview

Potential Scale	100 mLpa commissioned production capacity currently. Scope for 315 billion Lpa by 2030.
Market Readiness	Some technologies are 4-7 years away from being cost-competitive with fossil fuels
Project Returns	n/a

Source: New Energy Finance

Figure 30. Venture Capital & Private Equity Investment – First vs. Next Generation Biofuels 2006 to 2009, US$ millions



Source: New Energy Finance

Policy Status and Gaps

Policies supporting next generation biofuels are essentially the same as those relating to sugar-based ethanol, including blending mandates, tax breaks, producers' and feedstock cultivation subsidies. The US mandate within the renewable fuel standard for a specific proportion of next-generation biofuels is, however, currently constrained by production capacity. Loan guarantees (such as the USDA Biorefinery Assistance Program) and grants are also encouraging industry development.

Blending subsidies, in the form of tax breaks, offered to oil companies mixing next-generation biofuels over a reasonably long time horizon (4-8 years), should help reduce operating costs and give farmers, producers and developers a clear incentive to innovate and invest.

Technology Gaps

The key challenge for next-generation biofuels is to lower production costs sufficiently to compete with first-generation biofuels, particularly sugar-based ethanol. Advances using enzymes, bacteria, fungi, heat and pressure to lower biomass conversion costs will move next-generation biofuels closer to cost-competitiveness. Research and development is still focusing on which crops can be grown economically on marginal land, such as jatropha in India. Algae-based biofuels are being developed, as a CO_2-positive (i.e. net CO_2 absorbing) fuel which would not compete with land-based food/fuel production. Next-generation biofuel conversion technologies that fit easily and inexpensively into the existing production capacity have the best chance of success.

Potential Bottlenecks

New feedstocks should be compatible with existing processing infrastructure if next-generation biofuels are to be quickly and efficiently absorbed into the existing biofuels market. Specific blending mandates will help create demand, but production volumes must keep up. There are other logistical bottlenecks. Whether first- or next-generation, feedstocks are typically bulky and therefore expensive to transport long distances. Production to the right specification is also crucial.

Appendix 2 – Four Key Enablers

1. Smart Grid

Discussions about the smart grid have moved from the periphery of discussions about future energy supply to its heart. The smart grid is an essential part of any future energy scenario: the world's existing electricity grids simply cannot cope with the increasing diversity of energy sources, many from variable and decentralised renewable resources, and do not allow energy supply and demand to be managed efficiently. With global energy consumption set to triple between now and 2050, intelligent power management will be vital.

Today's grid is not interactive – energy flows from generator to consumer, with no corresponding flow of information about energy prices, demand patterns and so on in either direction. This data flow is essential if we are to manage our energy consumption more efficiently, make the most of energy from distributed sources such as roof-top PV, and tap into the power storage capabilities of domestic appliances and electric cars.

There are many questions about who will build the smart grid, who will pay for it and how long it will take to build. What kind of policy mix will motivate utilities to adopt smart grid technologies and solutions while stimulating innovation, economic efficiency and competition? Trillions of dollars will have to be invested in upgrading and repairing the current transmission and distribution network, and in incorporating interactive elements such as sensors and smart meters. How will consumers respond to the smart grid? Will they find it too complex or intrusive? How will personal data be protected? Will the myriad standards bodies in Europe and the US succeed in defining unified smart grid technology standards that are inter-operable, secure and future-proof? Who will regulate the smart grid?

Many of these questions remain unanswered – but there is concerted action to address them. In June 2009, New Energy Finance hosted the inaugural workshop for the Consortium on Digital Energy, which embodies the huge variety of stakeholders in a smart grid – including utilities, telecoms providers, carmakers, technology developers and regulators – and a diversity of views as to what the smart grid should look like. It also highlighted one of the main challenges to the smart grid becoming a reality; what kind of regulatory and policy mix will motivate utilities to adopt smart grid technologies and solutions while stimulating innovation, economic efficiency and competition? It looks likely that only regulation will drive this investment, but at the moment, most regulators remain in wait-and-see mode.

Smart Meters: Engaging the Consumer

Smart meters work. According to Finnish energy think tank VaasaETT, consumers can reduce their energy use by more than 10% once they are installed and used. According to a Brattle Group survey of pilot schemes in the US, Canada, Australia, and France, when combined with electricity price rises, smart meters allow residential customers to cut their electricity use at times of peak demand by 27-44%.

However, just installing a smart meter is not enough; consumers must want to use it, and must find it relatively easy to do so.

This gap is being filled by new small players like Good Energy Options, which makes a range of in-home displays to get the customer involved with their own consumption, and AlertMe, which has a range of home automation devices. Big players such as Microsoft and Google are also getting involved, offering web-based software to analyse consumption, for use in conjunction with a smart meter or independently.

More research is required to determine whether consumers will respond best to an in-home display, a web portal or simply a fridge magnet that glows red when electricity is most expensive, and blue when it's cheap – but customer engagement is being recognised as a key success factor in the smart grid and energy efficiency.

Source: New Energy Finance

Policy Status and Gaps

Government support is taking different forms. In the US, US$ 3.4 billion of stimulus funding in the form of grants were awarded in 2009 to 100 smart grid projects, designed to roll out a total of 18 million smart meters. According to the DOE, the total amount of private and public funds that will be invested in smart grid projects through this programme will be US$ 8.1 billion. The DoE had already granted US$ 7 billion to two federal-owned power administrations to build transmission that will eventually deliver renewable energy to the US's western states.

Meanwhile the EU has stipulated that 80% of European households should have smart meters by 2020, with 100% coverage by the year 2022. Finland is spearheading smart grid roll-out, with a new law requiring utilities to install smart meters in 80% of Finnish homes by the end of 2013. Sweden completed a near-100% roll-out during 2009, and other Scandinavian countries are taking a lead in smart meter installation. The United

Smart Meters: Engaging the Consumer

Lithium-ion batteries are widely used in computers and mobile phones, and have taken centre stage in electric vehicle development; but they could also be a solution for utility power storage in the future.

Lithium-ion batteries perform well on the metrics needed for power quality management applications, including cycle life, cost and power capacity. They are starting to be used for grid-scale power storage in the US and Chile. They currently cost around US$ 3 million/MW, but this could fall to around US$ 1 million/MW with scale.

Given the ever-broadening potential of lithium-ion batteries, sourcing lithium in sufficient quantities and at a reasonable price is vitally important. Chile, China and Bolivia have the world's largest lithium reserves.

However, a new technique developed in the US by Simbol Mining allows lithium to be extracted relatively cheaply, quickly and cleanly from the brine produced in geothermal power plants – extending both the reach and the quantity of lithium available for use in batteries.

There is also the potential for a healthy second-life market for used batteries from the electric car market, although it will be many years before this market has had time to develop fully.

Lithium-ion batteries are in competition with other technologies for grid-scale storage. These include pumped hydro, flow batteries, lead acid batteries, and batteries based on sodium sulphur and other advanced chemistries.

Kingdom is aiming for smart meters to be installed in every house by 2020. According to a recent report published by the United Kingdom's Department of Energy and Climate Change (Smarter Grids: The Opportunity), £8.6 billion will be spent on replacing 47 million gas and electricity meters, with an expected benefit of £14.6 billion over the next 20 years. DECC is providing a £6 million United Kingdom Smart Grid Demonstration Fund to encourage companies to continue developing smart technology such as energy storage.

Preliminary estimates indicate that by 2020, around 200 million smart meters could be operational in Europe and the US, meaning a rosy future for meter manufacturers such as Landis+Gyr (which is providing 150,000 Finnish consumers with smart meters), Itron, Silver Spring, GE and Echelon.

2. Power Storage

The ability to store energy efficiently will open up a wealth of opportunities for low-carbon technologies. Advanced batteries will provide power for electric vehicles and many other mobile applications, while utility-scale storage will allow fluctuations in electricity demand to be smoothed, generation to be managed to meet varying demand, and intermittent renewable generation to be accommodated.

Large-scale power storage has traditionally been in the form of pumped hydro, but technological advances will open up a vast new decentralised source of energy in the form of electric cars, whose power reserves can be tapped into during peak demand, and replenished when demand falls.

The most obvious form of energy storage is on the demand side is batteries, commonly used to power mobile, portable and remote devices from computers to cars. Electric vehicles are a Holy Grail for battery developers, although even the likely earlier take-off of plug-in hybrids offers a very substantial market.

Finding a solution for grid-scale power storage is becoming increasingly urgent for utilities. At grid scale, power storage has two main applications: energy management, where stored energy is used to provide additional supply when demand rises; and power quality management, where short sharp bursts of energy are used to stabilise the grid by smoothing out irregularities in supply or demand. Technology improvements and increased government support for advanced batteries, ultra-capacitors and other technologies could push the grid storage market from a projected US$ 1.5 billion market by 2012 to US$ 8.3 billion by 2016[5].

Developing advanced batteries is a priority for grid-scale energy management; dominant technologies include lead acid and sodium sulphur batteries (using conventional battery design, with chemicals stored inside the battery) and flow batteries (also known as reversible fuel cells, where the chemicals are outside the battery), most commonly using zinc bromide and vanadium redox. Sodium sulphur batteries are by far the most widely used battery for energy management: flow batteries are still very expensive, and the current generation of lead acid batteries, while much cheaper, are less robust and have a short life.

Technology Gaps & Bottlenecks

Battery technology developments currently being pursued include shortening recharging times, extending life, making portable batteries lighter and more compact and reducing cost.

On the power quality management side, flywheels and ultra-capacitors are relatively new technologies used to balance short-term grid fluctuations. Flywheels store power as kinetic energy, while ultra-capacitors store it as electrical energy. Flywheel technology has been proven at utility-scale, and commercialisation could halve its capital costs from US$ 1.5 million/MW currently to US$ 0.75 million/MW. Ultra-capacitors are a promising technology, but remain expensive and not yet proven at scale.

[5] NanoMarkets report: “Batteries and Ultra-Capacitors for the Smart Power Grid: Market Opportunities 2009-2016"

3. Advanced Transportation

Transport accounts for more than 27% of all final energy consumed (8,286 Mtoe), according to the International Energy Agency, and 23% of global CO_2 emissions. The transport sector is almost entirely reliant on oil to fuel it (94%). Oil accounts for 43% of global energy consumption, of which 61% is consumed in transport. The scale of the problem (and therefore the opportunity) has propelled advanced transport into the limelight. If only 10% of the global fleet were to consist of electric vehicles, this market will be worth US$ 300 billion in 2020 for the cars alone, with batteries an additional US$ 100 billion and the lifetime mileage worth an additional US$ 250 billion, according to the US Department of Transportation's Research and Innovative Technology Administration. Every major car manufacturer has an electrification programme and by 2012 there should be 119 types of electrically powered cars available globally, including 37 full EVs.[6]

There are multiple technologies looking to improve transportation efficiency: mass transit, biofuels, artificially-synthesized fuels, improvement to the internal combustion engine and fuel cells. The dominant technologies are plug-in vehicles - both plug-in hybrids (PHEVs) and full battery electric vehicles (BEVs). Non-pluggable hybrid vehicles (NPHEVs), such as the Toyota Prius, are near-term solutions that are easier to deploy than plug-ins, but they are not as efficient nor do they offer the impact of switching to a cleaner primary fuel. Even powered by old coal plants PHEV represent a 25% reduction in emissions.[7] The critical enabling technology for vehicle electrification has been lithium-ion batteries, giving electric cars minimum ranges of 100 miles and top speeds of at least 90mph.

Policy Status and Gaps

Electric vehicles are a nascent industry being accelerated by government support. The Boston Consulting Group has estimated that up to November 2009 governments had pledged over US$ 15 billion to support the electric vehicles ecosystem. Examples of this support include direct vehicle subsidies (e.g. US$ 7,500 in the US, 5,000 euros in France, 60,000 rmb in China), support for battery manufacturing (e.g. US$ 650m+ that A123 has received in grants, loan guarantees and state incentives in the US) and infrastructure (France has pledged 1.5 billion euros). This is all in addition to tax incentives. In Denmark, there is a 170% registration tax on gas-powered vehicles. In Israel the sales or value-added vehicle tax is lowered from 78% to 10% for electric vehicles. Any and all gas taxes can also be seen as support for EVs. The political wildcard is the introduction of regulatory emission/fuel economy standards. European and Japanese governments have proposed emissions standards with punitive financial penalties that car companies are unlikely to be able to meet without sizable EV penetration. If passed, and matched by US-based legislation, this legislation will ensure meaningful EV deployments by 2020.

Electric vehicles' role in a low-carbon future goes beyond pure transport – many experts see mass penetration of electric vehicles as the key for higher levels of renewable energy generation, and the most powerful driver for a smart grid. The amount of power realised from renewable sources fluctuates widely on a daily basis. This prevents renewables from participating in baseload power generation. Another impact of the variability in supply is

Electric Vehicles – A Cost Comparison

Gas Miles

According to the US Department of Transportation the average fuel economy in the US passenger car fleet is 22.5mpg. Gas prices around the globe tend to vary widely and can be put in the US$ 3–9 per gallon range and rising, given the 19% drop in global upstream oil investment (IEA). This results in a fuel cost per mile of 13 to 40 US$ cents, after the impact of government taxes or subsidies.

Electric Miles

The current technology for electric motors is highly developed for reliability, but less well-developed for power-to-weight and efficiency than the internal combustion engine. Current electric vehicles are getting 5 miles per kWh. Assuming a cost of 11 US$ cents per kWh that is equivalent to a fuel cost of 2.2 US$ cents per mile. However, the disparity in upfront costs for electric vehicles, with their expensive batteries, must also be included in the cost per mile. Batteries can be depreciated over their useful life (2500-4000 charge cycles on average taking just under nine years). This results in a depreciation cost of around 9 US$ cents per mile, for a total electric mile cost of around 11 US$ cents per mile.

[6] Deutsche Bank Nov 3, Electric Cars: Plugged in 2

[7] EPRI

that unexpectedly large yielding days produce power that gets wasted. Electric vehicles are a solution to this problem as they act as distributed large scale storage devices. Current utility scale storage solutions come in 2MW increments; 50,000 EVs would offer 1GW worth of storage, 500 times that amount. The benefits to the grid are that EVs provide load by levelling night-time electricity demand. However, at present the cost of a battery cycle for Lithium-ion batteries makes vehicle-to-grid prohibitively expensive. As we build towards meeting RPS standards there is a strong symbiotic economic argument for the parallel deployments of renewables and electric vehicles.

Technology Gaps & Bottlenecks

Widespread EV adoption faces three roadblocks that need to be addressed (i) infrastructure; (ii) psychological barriers/range extension; and (iii) availability and cost competitiveness of vehicles.

The infrastructure for gas powered cars has been built up over the past 100 years. Electric vehicles need plug-in infrastructure and a smart charging network that protects grid integrity through local load management. Pragmatically infrastructure will need to be inter-operable among regions and OEMs, as the alternative is impractical from a cost and functionality standpoint.

Over 80% of people travel less than 40 miles per day, well within the 100-mile range offered by today's EVs. The want for range tends to far exceed the need, and range extension is an issue common cited by EV opponents. As batteries improve and EVs become more prevalent this will subside, but in the near term it must be addressed. PHEVs are a form of range extension. The issue is that enabling gas extension limits the electricity range and benefits of EVs. An alternative is battery swapping, which has all of the EV benefits and can be done in less than sixty seconds but has a high infrastructure cost. A third is fast charge, which takes at least 15 minutes in charge time, can not be operated by the driver and places stress on the grid, as opposed to charging at the home or office.

The availability of electric vehicles is a bottleneck: there has been limited number of electric vehicles available and the ones that are on the road, like Tesla, are not for a mass audience. This will change with the Renault Fluence ZE in 2011, which will be mass produced and has commitments for 150,000 units. Electric vehicles have a perception issue on cost competitiveness. The cost for EV and gas powered is equivalent except for the battery. From a total cost of ownership perspective, EVs are cheaper as the lower cost per mile more than offsets the upfront costs of the battery.

Electric Vehicle Infrastructure – Better Place

Better Place's vision is to be an electric vehicles solutions provider that ensures that we can confidently drive an EV anytime, anywhere. Better Place is developing and deploying EV driver services, systems and infrastructure. Subscribers and guests will have access to a network of charge spots, switch stations and systems which optimise the driving experience and minimise environmental impact and cost.

Most cars will be charged at home, overnight, in some cases taking advantage of "time of use" metering to avoid mass simultaneous recharging leading to grid overload.

The vision is not without its challenges, notably is the high capital cost in the Catch 22 scenario where infrastructure needs to be built in advance of cars being on the road. Bespoke / proprietary batteries are also a potential barrier to battery exchange.

Nevertheless, Better Place is gaining momentum. In 2008, Israel became the first nation in the world to commit to an all-electric car infrastructure, followed by Denmark. Both have since begun installing Better Place charging stations.

In March 2008, DONG Energy, Denmark's largest power generator, signed an agreement with Better Place, under which DONG wind energy will be used to power Better Place cars.

The problem is that consumers currently disassociate acquisition costs from ongoing costs. Project Better Place, as well as building electric car infrastructure, is addressing this challenge by purchasing the batteries in place of consumers. They will help transform car purchases to a mobile phone model where the upfront cost is subsidised in exchange for a fixed term service agreement.

4. Carbon Capture & Storage (CCS)

In a world dependent on coal for its energy for the foreseeable future, technology that captures and stores the CO_2 emissions has an important role to play in the shift to a low-carbon energy future. Industrializing countries, notably China, have rich domestic coal reserves that will be used to support economic growth, especially as other energy resources elsewhere in the world diminish and fuel prices rise.

New Energy Finance expects demand for CCS to reach 160-240MtCO_2e/year by 2020, equivalent to the emissions from 26-44 coal-fired power stations or 8-12% of emission reductions under global emissions trading schemes. This is 7-11 times greater than current levels – but at current development rates, CCS will only be ready to inject 95MtCO_2e/yr in 2020, even assuming that the necessary funding (around US$ 80 billion) is made available.

CCS is an early-stage technology. While it can be profitable in some cases, for example when combined with enhanced oil recovery (EOR) or where a levy on CO_2 emissions is in place (such as in Norway), adding CCS to conventional power generation projects does not currently make economic sense. Using the technology available at the moment, CCS increases the plant's overall costs by as much as 85% and significantly reduces its overall efficiency because of the extra energy required to run the capture equipment.

CCS may be expensive, but so is the cost of not developing it. The IEA's recently released Technology Roadmap for Carbon Capture and Storage suggests that without CCS, overall costs to reduce emissions to 2005 levels by 2050 will increase by 70%. To achieve the necessary emission reductions, the IEA suggests that 100 projects should be developed globally by 2020 and over 3000 projects by 2050. This level of development would need additional investment of US$ 2.5-3 trillion between 2010 and 2050.

Before CCS can begin to fulfil even this potential, scaled-up demonstration projects must be built - and as yet, none have. New Energy Finance is currently tracking 238 projects in 27 countries, of which 42% are commercial, 29% pilot, 21% R&D/academic and 8% demonstration. Most of these are in the US, but 41 commercial-scale projects have been announced in the EU. The costs involved - US$ 1-2.5 billion for 100-300MW plants or US$ 57-91/tCO_2e avoided – are prohibitive in these tight economic times without any clear market incentives. The bottom line is that it is far more expensive to use CCS to deal with a tonne of CO_2 than it is to buy carbon credits on the ETS, even on the most aggressive price estimates.

Table 15. Carbon Capture & Storage – Economic Overview

Potential Scale	21.4 MtCO_2e injected in 2009, equivalent to CO_2 capture from 1.4GW generation. Demand could reach 160-240MtCO_2e/year by 2020
Market Readiness	The viability of CCS is entirely dependent on the existence of the carbon markets and CO_2 price
Project Returns	n/a

Source: New Energy Finance

Funding for the first demonstration plants must therefore come directly from governments if CCS is to scale the gaping "Valley of Death" currently lying between it and commercialisation.

Policy Status and Gaps

Key drivers for CCS include national and/or regional emissions standards; subsidies that help bridge the gap between the current cost of CCS and the time when it becomes economically viable; and carbon trading systems, which put a transparent value on CO_2 emissions and allow emitters to capitalise on reducing their CO_2 emissions.

Governments are making commitments to CCS projects. The G20 has a goal of 20 demonstration projects by 2020. The European Commission intends to facilitate construction of 10-12 demonstration projects, and the United Kingdom has said it will back four CCS demonstration plants, while mandating that all newly built coal plants demonstrate CCS technology on at least 300MW of their net capacity. The EU has so far committed just over 8 billion euros(US$ 11.9 billion) to CCS, funded by EU ETS' New Entrants Reserve, EU member states and the European Economic Recovery Plan. The US, Canada and Australia have also outlined plans to build large-scale projects. In June 2009, the US resuscitated the previously abandoned FutureGen project to build a 275MW CCS-equipped Integrated Gasification Combined Cycle (IGCC) plant. Under its clean energy stimulus plans, the US has pledged US$ 4 billion, Canada US$ 2.6 billion and Australia US$ 6.4 billion to CCS.

However, these commitments only close a small amount of the funding gap, estimated to be US$80 billion between now and 2020. This early-stage gap will probably be plugged by further direct government funding either in the form of grants or incentives combined with investment from those in the private sector who stand to benefit most from CCS (or lose most by not dealing with their CO_2 emissions), such as companies in the oil & gas and utility sectors.

Once the first demonstration projects have been built, other forms of financing will be needed. Later projects could be funded via levies on electricity or fossil fuel production (effectively a direct tax on those producing the CO_2 that CCS is designed to address), and ultimately CO_2 financing where market incentives (carbon credits) would attract private sector investment. Carbon prices are expected to rise to a suitable level to achieve this in Europe by 2020, and subsequently in other countries.

Technology Gaps & Bottlenecks

The big challenge for CCS is establishing its technical and economic feasibility. Once a stable carbon price is in place and CCS is viable on a large scale, the industry will take off. As the most expensive part of the CCS chain, carbon capture is a focus for research and development investment.

Technological improvements could reduce the cost of CCS by 50%, to US$ 30-60 per tonne of CO_2e in the medium to long term. However, the cost is likely to rise in the short term as capture technologies are scaled up for the first time and need optimization.

Within the overarching goal of cutting costs, technology is needed to understand the long-term behaviour of CO_2 in different subsurface geological environments. The goal of this research is to certify that CO_2 injected will be stored safely and securely over geologic time, and to ensure proper credit can be given to those that store, rather than emit, CO_2. Research on the storage of CO_2 is also designed to win public acceptance of CCS.

Identifying sites suitable for CO_2 storage, where injection points can be made, is a key bottleneck. Although there are enormous potential global reserves for CO_2 storage, the number of sites suitable as actual injection sites is considerably less.

Building a CCS infrastructure is another potential bottleneck. If a CCS industry is to take shape, it will be necessary to build thousands of kilometers of CO_2 pipeline to go from source to sink, or to connect to a CO_2 pipeline network. Some 90% of all installed CO_2 pipelines are in the US, although 81% of announced CCS projects are in other countries, highlighting the scope for investment in building CO_2 pipelines.

CCS Technologies

CCS technologies fall broadly into two categories; pre-combustion and post-combustion capture.

The main attraction of **pre-combustion capture** is that it first converts the fossil fuel feedstock to a gas, largely composed of CO_2 and H2, where the CO_2 can be captured quite easily, and water is the only by-product. Pre-combustion technology, largely referred to as IGCC (integrated gasification combined cycle), is favoured for several planned large-scale CCS demonstration projects, including FutureGen, due to the relative ease and low cost of capture. IGCC plants, however, suffer from high up-front capital costs and process complexity. Furthermore, they are mostly only suitable for new-build applications.

Post-combustion capture, on the other hand, can be retrofitted to many existing global fossil-fuelled power and industrial plants, reducing the capital cost of the CO_2 capture facility. The trade-off, however, is that since the concentration of CO_2 in the flue gas of existing power stations is only 13-15%, CO_2 capture is more expensive and energy-intensive than in IGCC. New Energy Finance is tracking approximately 200 research projects aimed at developing new technologies to improve capture efficiency and decrease the cost of post-combustion capture.

Drawing on the best of both pre-and post-combustion capture, **oxycombustion** is a third technology that is gaining ground and could be a game-changer. Here, the fossil feedstock is combusted in a pure O2 boiler. The extremely high temperature lends efficiency, while the combustion flue is 85% CO_2, making for easy capture. Oxycombustion can be used in new builds or repowering; its major challenge is decreasing the energy penalty and the cost of O2 purification.

Appendix 3 – Most Common Market Policy Mechanisms

Market mechanisms to encourage investment in generation capacity can be tailored to individual countries and electricity markets, with the lessons learnt in one market readily transferred to another.

Feed-in tariffs are probably the most widely-recognized clean energy market mechanism, and have successfully stimulated investment in several European markets. Renewable Portfolio Standards, which set out a minimum percentage of energy to be sourced from renewable generation, are also widely used. RPS structures boost investment in clean energy, although they are a blunter instrument than feed-in tariffs. Auctions, where long-term electricity supply contracts are offered to renewable generators in a competitive bidding process, are another mainstream energy market mechanism.

The interaction between market forces and policy and financing mechanisms must be carefully managed if the right effects are to be achieved.

Feed-In Tariffs

Feed-in tariffs stimulate investment in renewable energy generation by guaranteeing power prices of up to five times the average spot rate for electricity, depending on the technology used. Solar, for example, generally receives a higher rate than wind because it is more expensive. Feed-in tariff programmes usually run for 20-25 years and are indexed to inflation.

Financiers like feed-in tariffs because they allow clear cash flow forecasting on the back of a guaranteed floor price for electricity generated, while their stability and generosity are appreciated by the renewable energy industry. Feed-in tariffs are also relatively simple and scalable. They have put Germany and Spain second and third respectively in terms of installed wind capacity globally, and made Spain a world leader in installed PV capacity.

The momentum behind feed-in tariffs continues to build. During 2009, many countries introduced (or announced) feed-in tariffs, including China, Greece, Finland, South Africa, several Indian states and parts of Australia. In October 2009, Ontario introduced a generous feed-in programme under which renewable developers can sign 20 year power purchase agreements with the province for CAD 103-820/MWh, combined with a fast-track permitting process.

However, feed-in tariffs are not without their downsides. One is their cost – someone has to pick up the bill if handsome benefits are to go to equity investors (who have been earning returns of up to 20% in Spain), project developers and manufacturers.

Spain introduced feed-in tariffs for solar photovoltaics in 2003, on the back of its established feed-in tariffs for wind, which propelled it into third place worldwide for installed wind capacity. In 2008, 3GW of PV was installed in Spain, more than was installed worldwide in 2007, rapidly approaching the national installation cap of 4GW set by the Spanish government at the programme's outset.

In February 2009, Spain renewed its feed-in tariff for a further three years, but cut to 32-34 eurocents/kWh from 45 eurocents/kWh, declining each quarter and with a national cap of 500MW per year, increasing only slowly. There followed a damaging period of uncertainty as politicians dithered over whether to renew the tariff in a less generous form or cut it altogether.

The total cost of renewable capacity installed under the feed-in tariff programme to date – 3.3GW of photovoltaics, 5.5GW of wind and a small amount of biomass and solar thermal generation – will be 53 billion euros over the 25-year life of the tariffs, or 39.9 billion euros net of the avoided cost of alternative sources of power. This liability, equivalent to 13% of the country's cumulative national debt of 423 billion euros in June 2009, will be funded by Spanish taxpayers – and will rise as projects are added under the renewed feed-in regime.

In liberalised electricity markets, the additional cost is passed through to consumers. In Germany, feed-in tariffs for wind (9.3GW), solar (4.8GW) and biomass (2.7GW) projects built between 2004 and 2008 will cost electricity consumers 122.3 billion euros between 2008 and 2030, equivalent to 55.7 billion euros more than the cost of generating electricity from cheaper sources and adding 0.6 eurocent/kWh to each electricity bill. These are the costs of the feed-in tariffs to date, but as renewable capacity increases, so will the liabilities associated with them.

Auctions

Auctions have been used in various countries to encourage specific forms of clean generation capacity to be built. The process can be used in conjunction with other incentives, such as tax breaks and/or government grants. Auctions have several advantages: for example, governments can specify that winning bidders must source a certain proportion of their components from domestic manufacturers, boosting the local economy. Another advantage is that the competitive process allows market forces to determine electricity pricing, even though governments may choose to tip the playing field using other mechanisms. However, auctions tend to work best where the state plays an active and almost autocratic role in electricity supply, rather than in deregulated markets, such as those in some advanced developing countries.

China used a competitive auction system for wind between 2003 and 2007, in which developers bid for projects on the basis of long-term tariffs. Following criticism that competitive bidding was damaging the country's wind industry, the process was refined so that the lowest bidder did not necessarily win, if it might put the project's success at risk; towards the end of the process, bids closest to the average were generally successful. China has now reverted to a feed-in tariff for wind, and will introduce one for solar too, but auctions gave it a long period of price discovery, which will allow it to pitch its feed-in tariffs at a sensible level. The new tariffs are higher than most winning national concession bids, but are at the same level as the non-concession projects approved in 2007 and 2008.

Brazil is moving in the opposite direction to China, expanding its auction programme for power generation projects and biodiesel supply. In 2007, Brazil ran a one-off auction for renewable energy which attracted bids from nine wind farms, 54 small hydro projects and 24 biomass projects – but all the contracts were taken up by cheaper biomass and small hydro projects. Now, following strong interest from wind developers, the government has announced that it will hold one or two wind-only auctions a year, the first of which is due to take place in December 2009. In July, energy regulator EPE reported that 441 projects representing 13.3GW of installed capacity had registered to take part in the wind tender. It is unclear how much capacity will be contracted, although expectations are that power purchase agreements worth between 800MW and 1.2GW will be available.

California has recently proposed a "reverse auction" feed-in tariff, designed to reduce the ability of developers to make windfall profits by selling the electricity they produce at artificially high rates. In August 2009, the California Public Utilities Commission suggested letting developers bid on contracts to install green energy projects. A solar company that offers to sell electricity to one of California's three big utilities at a rate lower than its competitors would win a power purchase agreement. The scheme could be operational in 2010, if it meets with no serious opposition.

Renewable Portfolio Standards (RPS) / Green Certificates

The aim of Renewable Portfolio Standards (RPS) is to accelerate the integration of renewable energy by requiring electricity supply companies to source a specific percentage of their power from renewable sources. Currently, many RPS regimes are voluntary rather than mandatory.

Renewable Portfolio Standards have been adopted in the United Kingdom, Italy and Belgium as well as in 29 US states (collectively accounting for over half the electricity sales in the US) and the District of Columbia. A further six US states have non-binding goals for the adoption of renewable energy. President Obama has made a national RPS a cornerstone of his energy strategy, advocating that 25% of electricity be generated from renewable sources by 2025.

RPS policies seem to have been successful in encouraging new renewable development in certain parts of the US. Between 1998 and 2007, an estimated 8,900MW of new non-hydro renewable capacity was built in states with RPS policies. However, it is impossible to prove that RPS policies were the only driving factor, and RPS instruments have been most successful where they have been used alongside the federal Production Tax Credit (PTC). When the PTC has been withdrawn, RPS structures alone have not always managed to maintain the same level of renewable capacity addition.

RPS regimes work hand-in-hand with green certificates, which are earned by certified renewable energy generators for each MWh of clean power they produce. Electricity companies can buy green certificates to fulfil their obligations under the RPS, as it is not always practical for them to buy clean energy directly from a renewable source, because of availability, grid connections, and so on. Green certificates have a variety of different names; for example, Renewable Energy Certificates (RECs) in the US, and Renewable Obligation Certificates (ROCs) in the United Kingdom.

The main advantage of the RPS is that it is a market-based system, so it allows competitive forces to promote the most efficient forms of renewable generation rather than picking technologies. It paves the way for market-ready (or nearly commercial) renewable technologies to break into the electricity market and from there achieve economies of scale and efficiency improvements more quickly than otherwise. It also introduces competition between renewable generators, favouring those that can produce electricity most cheaply.

On the downside, though, many Renewable Portfolio Standards are not yet mandatory, so electricity suppliers are not penalized for failing to meet the targeted proportion of renewable energy. RPS policies are therefore rarely enough on their own to maintain significant investment in clean energy, and are best used in combination with finance mechanisms such as tax credits.

WORLD ECONOMIC FORUM
COMMITTED TO IMPROVING THE STATE OF THE WORLD

References

Boston Consulting Group, Batteries for Electric Cars: Challenges, Opportunities, and the Outlook to 2020
www.bcg.com/expertise_impact/Industries/Automotive/PublicationDetails.aspx?id=tcm:12-36622

Brattle Group, A National Assessment of Demand Response Potential, June 2009
www.brattle.com/Publications/ReportsPresentations.asp?PublicationID=1050

Database of State Incentives for Renewables and Efficiency
www.dsireusa.org

Greening our Built World
www.islandpress.com/bookstore/details.php?prod_id=1970

International Clean Technology Venture Returns Analysis (ICTRA)
https://cleantechnologyreturns.com/

International Energy Agency, Key World Energy Statistics 2009
www.iea.org/textbase/nppdf/free/2009/key_stats_2009.pdf

International Energy Agency, World Energy Outlook 2009
www.iea.org/WEO/2009.asp

McKinsey & Company, Unlocking Energy Efficiency in the US Economy, July 2009
www.mckinsey.com/clientservice/electricpowernaturalgas/US_energy_efficiency/

United Kingdom Department of Energy and Climate Change, Smarter Grids: the Opportunity
www.decc.gov.United Kingdom/en/content/cms/what_we_do/United Kingdom_supply/network/smart_grid/smart_grid.aspx

UNEP, Catalysing Low-Carbon Growth in Developing Economies
www.unep.org/PDF/PressReleases/Public_financing_mechanisms_report.pdf

UNEP, Public Finance Mechanisms to Mobilise Investment in Climate Change Mitigation
www.sefalliance.org/fileadmin/media/sefalliance/docs/Resources/UNEP_Public_Finance_Report.pdf

US Department of Energy, The Smart Grid: an Introduction
www.oe.energy.gov/DocumentsandMedia/DOE_SG_Book_Single_Pages.pdf

VaasaEtt Report on Household Response to Dynamic Pricing of Electricity 2009
www.vaasaett.com/wp-content/uploads/2009/03/smart-meters-and-smart-pricing-_02-28-09_.pdf

World Bank, World Development Report 2010: Development and Climate Change
http://siteresources.worldbank.org/INTWDR2010/Resources/5287678-1226014527953/WDR10-Full-Text.pdf

World Economic Forum, Green Investing: Towards a Clean Energy Infrastructure
www.weforum.org/pdf/climate/Green.pdf

World Economic Forum, Low Carbon Task Force Report
http://www.weforum.org/documents/gov/Environment/TF%20Low%20Carbon%20Prosperity%20Recommendations.pdf

World Meteorological Organization: 2000-2009, The Warmest Decade, December 2009
http://www.wmo.int/pages/mediacentre/press_releases/pr_869_en.html

For your notes

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

The World Economic Forum is an independent international organization committed to improving the state of the world by engaging leaders in partnerships to shape global, regional and industry agendas.

Incorporated as a foundation in 1971, and based in Geneva, Switzerland, the World Economic Forum is impartial and not-for-profit; it is tied to no political, partisan or national interests. (www.weforum.org)

Is It Better To Burn or Bury Waste for Clean Electricity Generation?

P. Ozge Kaplan, Joseph DeCarolis, and Susan Thorneloe

Environ. Sci. Technol., **Article ASAP** • DOI: 10.1021/es802395e • Publication Date (Web): 10 February 2009

Is It Better To Burn or Bury Waste for Clean Electricity Generation?

P. OZGE KAPLAN,*,† JOSEPH DECAROLIS,‡ AND SUSAN THORNELOE§

National Risk Management Research Laboratory, United States Environmental Protection Agency (U.S. EPA), Research Triangle Park, North Carolina 27711, and Department of Civil Engineering, North Carolina State University, Raleigh, North Carolina 27695

Received August 26, 2008. Revised manuscript received December 13, 2008. Accepted December 30, 2008.

The use of municipal solid waste (MSW) to generate electricity through landfill-gas-to-energy (LFGTE) and waste-to-energy (WTE) projects represents roughly 14% of U.S. nonhydro renewable electricity generation. Although various aspects of LFGTE and WTE have been analyzed in the literature, this paper is the first to present a comprehensive set of life-cycle emission factors per unit of electricity generated for these energy recovery options. In addition, sensitivity analysis is conducted on key inputs (e.g., efficiency of the WTE plant, landfill gas management schedules, oxidation rate, and waste composition) to quantify the variability in the resultant life-cycle emissions estimates. While methane from landfills results from the anaerobic breakdown of biogenic materials, the energy derived from WTE results from the combustion of both biogenic and fossil materials. The greenhouse gas emissions for WTE ranges from 0.4 to 1.5 $MTCO_2e$/MWh, whereas the most agressive LFGTE scenerio results in 2.3 $MTCO_2e$/MWh. WTE also produces lower NO_x emissions than LFGTE, whereas SO_x emissions depend on the specific configurations of WTE and LFGTE.

Introduction

In response to increasing public concern over air pollution and climate change, the use of renewable energy for electricity generation has grown steadily over the past few decades. Between 2002 and 2006, U.S. renewable electricity generation—as a percent of total generation—grew an average of 5% annually (*1*), while total electricity supply grew by only 1% on average (*2*). Support mechanisms contributing to the growth of renewables in the United States include corporate partnership programs, investment tax credits, renewable portfolio standards, and green power markets. These mechanisms provide electric utilities, investment firms, corporations, governments, and private citizens with a variety of ways to support renewable energy development. With several competing renewable alternatives, investment and purchasing decisions should be informed, at least in part, by rigorous life-cycle assessment (LCA).

In 2005, a total of 245 million tons of MSW was generated in the United States, with 166 million tons discarded to landfills (*3*). Despite the increase in recycling and composting rates, the quantity of waste disposed to landfills is still significant and expected to increase. How to best manage the discarded portion of the waste remains an important consideration, particularly given the electricity generation options. Although less prominent than solar and wind, the use of municipal solid waste (MSW) to generate electricity represents roughly 14% of U.S. nonhydro renewable electricity generation (*1*). In this paper we compare two options for generating electricity from MSW. One method, referred to as landfill-gas-to-energy (LFGTE), involves the collection of landfill gas (LFG) (50% CH_4 and 50% CO_2), which is generated through the anaerobic decomposition of MSW in landfills. The collected LFG is then combusted in an engine or a turbine to generate electricity. A second method, referred to as waste-to-energy (WTE) involves the direct combustion of MSW, where the resultant steam is used to run a turbine and electric generator.

Clean Air Act (CAA) regulations require capture and control of LFG from large landfills by installing a gas collection system within 5 years of waste placement (*4*). The gas collection system is expanded to newer areas of the landfill as more waste is buried. Not all LFG is collected due to delays in gas collection from initial waste placement and leaks in the header pipes, extraction wells, and cover material. Collected gas can be either flared or utilized for energy recovery. As of 2005, there were 427 landfills out of 1654 municipal landfills in the United States with LFGTE projects for a total capacity of 1260 MW. It is difficult to quantify emissions with a high degree of certainty since emissions result from biological processes that can be difficult to predict, occur over multiple decades, and are distributed over a relatively large area covered by the landfill.

CAA regulations require that all WTE facilities have the latest in air pollution control equipment (*5*). Performance data including annual stack tests and continuous emission monitoring are available for all 87 WTE plants operating in 25 states. Since the early development of this technology, there have been major improvements in stack gas emissions controls for both criteria and metal emissions. The performance data indicate that actual emissions are less than regulatory requirements. Mass burn is the most common and established technology in use, though various MSW combustion technologies are described in ref *6*. All WTE facilities in the United States recover heat from the combustion process to run a steam turbine and electricity generator.

Policy-makers appear hesitant to support new WTE through new incentives and regulation. Of the 30 states that have state-wide renewable portfolio standards, all include landfill gas as an eligible resource, but only 19 include waste-to-energy (*7*). While subjective judgments almost certainly play a role in the preference for LFGTE over WTE, there is a legitimate concern about the renewability of waste-to-energy. While the production of methane in landfills is the result of the anaerobic breakdown of biogenic materials, a significant fraction of the energy derived from WTE results from combusting fossil-fuel-derived materials, such as plastics. Countering this effect, however, is significant methane leakage—ranging from 60% to 85%—from landfills (*8*). Since methane has a global warming potential of 21 times that of CO_2, the CO_2e emissions from LFGTE may be larger than those from WTE despite the difference in biogenic composition.

Although WTE and LFGTE are widely deployed and analyzed in the literature (*9*–*13*), side-by-side comparison of the life-cycle inventory (LCI) emission estimates on a mass

* Corresponding author phone: (919) 541-5069; fax: (919) 541-7885; e-mail: kaplan.ozge@epa.gov.

† On Oak Ridge Institute for Research and Education postdoctoral fellowship with U.S. EPA.

‡ North Carolina State University.

§ U.S. EPA.

10.1021/es802395e CCC: $40.75

per unit energy basis is unavailable. LCI-based methods have been used to evaluate and compare solid waste management (SWM) unit operations and systems holistically to quantify either the environmental impacts or energy use associated with SWM options in the broad context of MSW management (*14–16*).

The purpose of this paper is to present a comprehensive set of life-cycle emission factors—per unit of electricity generated—for LFGTE and WTE. In addition, these emission factors are referenced to baseline scenarios without energy recovery to enable comparison of the emissions of LFGTE and WTE to those of other energy sources. While the methodology presented here is applicable to any country, this analysis is based on U.S. waste composition, handling, and disposal, with which the authors are most familiar. In addition, parametric sensitivity analysis is applied to key input parameters to draw robust conclusions regarding the emissions from LFGTE and WTE. The resultant emission factors provide critical data that can inform the development of renewable energy policies as well as purchasing and investment decisions for renewable energy projects in the prevailing marketplace.

Modeling Framework

The LFGTE and WTE emission factors are based on the composition and quantity of MSW discarded in the United States in 2005 (Table S1 of Supporting Information (SI)). We excluded the estimated quantity and composition of recycled and composted waste.

The emission factors are generated using the life-cycle-based process models for WTE (*17*) and LF/LFGTE (*18*) embedded in the municipal solid waste decision support tool (MSW-DST). The MSW-DST was developed through a competed cooperative agreement between EPA's Office of Research and Development and RTI International (*19–22*). The research team included North Carolina State University, which had a major role in the development of the LCI database, process, and cost models as well as the prototype MSW-DST. While a summary is provided here, Table S2 (SI) provides a comprehensive set of references for those interested in particular model details. The MSW-DST includes a number of process models that represent the operation of each SWM unit and all associated processes for collection, sorting, processing, transport, and disposal of waste. In addition, there are process models to account for the emissions associated with the production and consumption of gasoline and electricity. The objective of each process model is to relate the quantity and composition of waste entering a process to the cost and LCI of emissions for that process. The LCI emissions are calculated on the basis of a combination of default LCI data and user-input data to enable the user to model a site-specific system. For example, in the landfill process model, one key exogenous input is the efficiency of the LFG collection system. The functional unit in each process model is 1 ton of MSW set out for collection. The MSW includes the nonhazardous solid waste generated in residential, commercial, institutional, and industrial sectors (*3*).

Each process model can track 32 life-cycle parameters, including energy consumption, CO_2, CO, NO_x, SO_x, total greenhouse gases (CO_2e), particulate matter (PM), CH_4, water pollutants, and solid wastes. CO_2 emissions are represented in two forms: fossil and biogenic. CO_2 released from anthropogenic activities such as burning fossil fuels or fossil-fuel-derived products (e.g., plastics) for electricity generation and transportation are categorized as CO_2-fossil. Likewise, CO_2 released during natural processes such as the decay of paper in landfills is categorized as CO_2-biogenic.

The management of MSW will always result in additional emissions due to collection, transportation, and separation of waste. However, for this analysis, the configuration of the SWM system up through the delivery of the waste to either a landfill or WTE facility is assumed to be same.

TABLE 1. Inputs to the Landfill Process Model

	LFG collection system efficiency [a] (%)	oxidation rate (%)
during venting	0	15
during first year of gas collection	50	15
during second year of gas collection	70	15
during third year and on of gas collection	80	15

[a] We assumed efficiency of the collection system based on the year of the operation and the ranges stated in U.S. EPA's AP-42 (*8*).

Electricity Grids. While LFGTE and WTE provide emissions reductions relative to landfill scenarios without energy recovery, the generation of electricity from these sources also displaces conventional generating units on the electricity grid. The process models in MSW-DST can calculate total electricity generated and apply an offset analysis on the grid mix of fuels specific to each of the North American Electric Reliability Council (NERC) regions, an average national grid mix, or a user-defined grid mix. Because our focus is on the emissions differences between WTE and LFGTE technologies, the emissions factors reported here exclude the displaced grid emissions.

For reference purposes, emission factors for conventional electricity-generating technologies are reported along with the emission factors for WTE and LFGTE (*23*). These emission factors on a per megawatt hour basis include both the operating emissions from power plants with postcombustion air pollution control equipment and precombustion emissions due to extraction, processing, and transportation of fuel. The background LCI data are collected on a unit mass of fuel (*23*); when converted on a per unit of electricity generated basis, the magnitude of resultant emissions depends on the efficiency of the power plant. A sensitivity analysis was conducted on plant efficiencies to provide ranges for emission factors.

Estimating Emission Factors for Landfill Gas-to-Energy. The total LCI emissions from landfills are the summation of the emissions resulting from (1) the site preparation, operation, and postclosure operation of a landfill, (2) the decay of the waste under anaerobic conditions, (3) the equipment utilized during landfill operations and landfill gas management operations, (4) the production of diesel required to operate the vehicles at the site, and (5) the treatment of leachate (*18*). The production of LFG was calculated using a first-order decay equation for a given time horizon of 100 years and the empirical methane yield from each individual waste component (*18, 24*). Other model inputs include the quantity and the composition of waste disposed (Table S1, SI), LFG collection efficiency (Table 1), annual LFG management schedule (Figure 1), oxidation rate (Table 1), emission factors for combustion byproduct from LFG control devices (Table S3, SI), and emission factors for equipment used on site during the site preparation and operation of a landfill. While there are hundreds of inputs to the process models, we have modified and conducted sensitivity analysis on the input parameters that will affect the emission factors most significantly.

The emission factors are calculated under the following scenario assumptions: (1) A regional landfill subject to CAA is considered. (2) A single cell in the regional landfill is modeled. (3) Waste is initially placed in the new cell in year 0. (4) The landfill already has an LFG collection network in place. (5) An internal combustion engine (ICE) is utilized to generate electricity. (6) The offline time that is required for

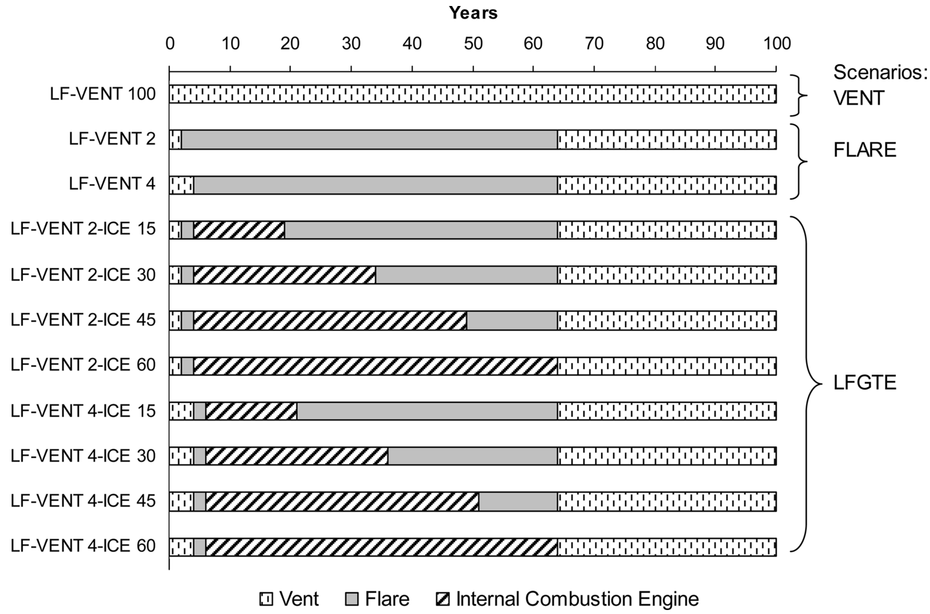


FIGURE 1. Annual landfill gas management schedule assumed for alternative scenarios.

the routine maintenance of the ICE is not considered. (7) The LFG control devices are assumed to have a lifetime of 15 years. (8) The LFG will be collected and controlled until year 65. This assumption is based on a typical landfill with an average operating lifetime of 20 years in which LFG production decreases significantly after about 60 years from initial waste placement. This is based on the use of a first-order decay equation utilizing empirical data from about 50 U.S. LFG collection systems.

The timing of LFG-related operations has significant variation and uncertainty that will influence the total emissions from landfills as well as the emission factors per unit of electricity generated. To capture these uncertainties and variation, several different management schemes were tested. Figure 1 presents the different cases considered for LFGTE projects. Each case differs according to the management timeline of the LFG. For instance, LF-VENT 2-ICE 15 corresponds to no controls on LFG for the first two years, after which the LFG is collected and flared in the third and fourth years. From year 5 until year 19, for a period of 15 years, the LFG is processed through an ICE to generate electricity, after which the collected gas is flared until year 65. Finally from year 65 on, the LFG is released to the atmosphere without controls.

To quantify the emissions benefit from LFGTE and WTE, landfill emissions occurring in the absence of an energy recovery unit can serve as a useful comparison. Thus, three baseline scenarios without electricity generation were defined for comparison to the energy recovery scenarios: LF-VENT 100 (LFG is uncontrolled for the entire lifetime of the LF), LF-VENT 2 (LFG is uncontrolled for the first two years, and then the LFG is collected and flared until year 65), LF-VENT 4 (LFG is uncontrolled for the first four years, and then the LFG is collected and flared until year 65). Since emissions are normalized by the amount of electricity generated (MW h) to obtain the emission rates, an estimate of hypothetical electricity generation for the baseline scenarios must be defined. The average electricity generation from a subset of the energy recovery scenarios is used to calculate the baseline emission rates. For example, emission factors [g/(MW h)] for LF-VENT 2 are based on the average of electricity generated in LF-VENT 2-ICE 15, LF-VENT 2-ICE 30, LF-VENT 2-ICE 45, and LF-VENT 2-ICE 60. Additional sensitivity analysis was conducted on oxidation rates where scenarios were tested for a range of 10−35%.

Estimating Emission Factors for Waste-to-Energy. The total LCI emissions are the summation of the emissions associated with (1) the combustion of waste (i.e., the stack gas (accounting for controls)), (2) the production and use of limestone in the control technologies (i.e., scrubbers), and (3) the disposal of ash in a landfill (*17*).

Emissions associated with the manufacture of equipment such as turbines and boilers for the WTE facility are found to be insignificant (<5% of the overall LCI burdens) and, as a result, were excluded from this analysis (*25*). In addition, WTE facilities have the capability to recover ferrous material from the incoming waste stream and also from bottom ash with up to a 90% recovery rate. The recovered metal displaces the virgin ferrous material used in the manufacturing of steel. The emission offsets from this activity could be significant depending on the amount of ferrous material recovered. Total LCI emissions for WTE were presented without the ferrous offsets; however, sensitivity analysis was conducted to investigate the significance.

In the United States, federal regulations set limits on the maximum allowable concentration of criteria pollutants and some metals from MSW combustors (*5*). The LCI model calculates the controlled stack emissions using either the average concentration values at current WTE facilities based on field data or mass emission limits based on regulatory requirements as upper bound constraints. Two sets of concentration values (Table S4, SI) are used in calculations to report two sets of emission factors for WTE (i.e., WTE-Reg and WTE-Avg). The emission factors for WTE-Reg were based on the regulatory concentration limits (*5*), whereas the emission factors for WTE-Avg were based on the average concentrations at current WTE facilities.

The CO_2 emissions were calculated using basic carbon stoichiometry given the quantity, moisture, and ultimate analysis of individual waste items in the waste stream. The LCI model outputs the total megawatt hour of electricity production and emissions that are generated per unit mass of each waste item. The amount of electricity output is a function of the quantity, energy, and moisture content of the individual waste items in the stream (Table S1, Supporting Information), and the system efficiency. A lifetime of 20 years and a system efficiency of 19% [18000 Btu/(kW h)] were assumed for the WTE scenarios. For each pollutant, the following equation was computed:

$$LCI\_WTE_i = \sum_j \{(LCI\_Stack_{ij} + LCI\_Limestone_{ij} + LCI\_Ash_{ij}) \times Mass_j\} / Elec \quad \text{for all } i \quad (1)$$

where LCI_WTE_i is the LCI emission factor for pollutant i [g/(MW h)], LCI_Stack_{ij} is the controlled stack gas emissions for pollutant i (g/ton of waste item j), $LCI\_Limestone_{ij}$ is the allocated emissions of pollutant i from the production and use of limestone in the scrubbers (g/ton of waste item j), LCI_Ash_{ij} is the allocated emissions of pollutant i from the disposal of ash (g/ton of waste item j), $Mass_j$ is the amount of each waste item j processed in the facility (ton), and Elec is the total electricity generated from MSW processed in the facility (MW h). In addition, the sensitivity of emission factors to the system efficiency, the fossil and biogenic fractions of MSW, and the remanufacturing offsets from steel recovery was quantified.

Results and Discussion

The LCI emissions resulting from the generation of 1 MW h of electricity through LFGTE and WTE as well as coal, natural gas, oil, and nuclear power (for comparative purposes) were calculated. The sensitivity of emission factors to various inputs was analyzed and is reported. Figures 2−4 summarize the emission factors for total CO_2e, SO_x, and NO_x, respectively.

Landfills are a major source of CH_4 emissions, whereas WTE, coal, natural gas, and oil are major sources of CO_2-fossil emissions (Table S5, SI). The magnitude of CH_4 emissions strongly depends on when the LFG collection system is installed and how long the ICE is used. For example, LF-VENT 2-ICE 60 has the least methane emissions among LFGTE alternatives because the ICE is operated the longest (Table S5, SI). CO_2e emissions from landfills were significantly higher than the emissions for other alternatives because of the relatively high methane emissions (Figure 2, Table S5).

The use of LFG control during operation, closure, and postclosure of the landfill as well as the treatment of leachate contributes to the SO_x emissions from landfills. SO_x emissions from WTE facilities occur during the combustion process and are controlled via wet or dry scrubbers. Overall, the SO_x emissions resulting from the LFGTE and WTE alternatives are approximately 10 times lower than the SO_x emissions resulting from coal- and oil-fired power plants with flue gas controls (Figure 3). The SO_x emissions for WTE ranged from 140 to 730 g/(MW h), and for LFGTE they ranged from 430 to 900 g/(MW h) (Table 2, Table S5). In a coal-fired power plant, average SO_x emissions were 6900 g/(MW h) (Table S6 and S7, SI). Another important observation is that the majority of the SO_x emissions from natural gas are attributed to processing of natural gas rather than the combustion of the natural gas for electricity-generating purposes.

The NO_x emissions for WTE alternatives ranged from 810 to 1800 g/(MW h), and for LFGTE they ranged from 2100 to 3000 g/(MW h) (Figure 4, Table 2, Table S5). In a coal-fired power plant, average NO_x emissions are 3700 g/(MW h) (Tables S6 and S7, Supporting Information). The emission factors for other criteria pollutants were also calculated. Besides CO and HCl emissions, the emission factors for all LFGTE and WTE cases are lower than those for the coal-fired generators (Tables S5−S8, SI).

While we have provided a detailed, side-by-side comparison of life-cycle emissions from LFGTE and WTE, there is an important remaining question about scale: How big an impact can energy recovery from MSW make if all of the discarded MSW (166 million tons/year) is utilized? Hypothetically, if 166 million tons of MSW is discarded in regional landfills, energy recovery on average of ∼10 TW h or ∼65 (kW h)/ton of MSW of electricity can be generated, whereas a WTE facility can generate on average ∼100 TW h or ∼600 (kW h)/ton of MSW of electricity with the same amount of MSW (Table 3). WTE can generate an order of magnitude more electricity than LFGTE given the same amount of waste. LFGTE projects would result in significantly lower electricity generation because only the biodegradable portion of the MSW contributes to LFG generation, and there are significant inefficiencies in the gas collection system that affect the quantity and quality of the LFG.

Moreover, if all MSW (excluding the recycled and composted portion) is utilized for electricity generation, the WTE alternative could have a generation capacity of 14000 MW, which could potentially replace ∼4.5% of the 313000 MW of current coal-fired generation capacity (*26*).

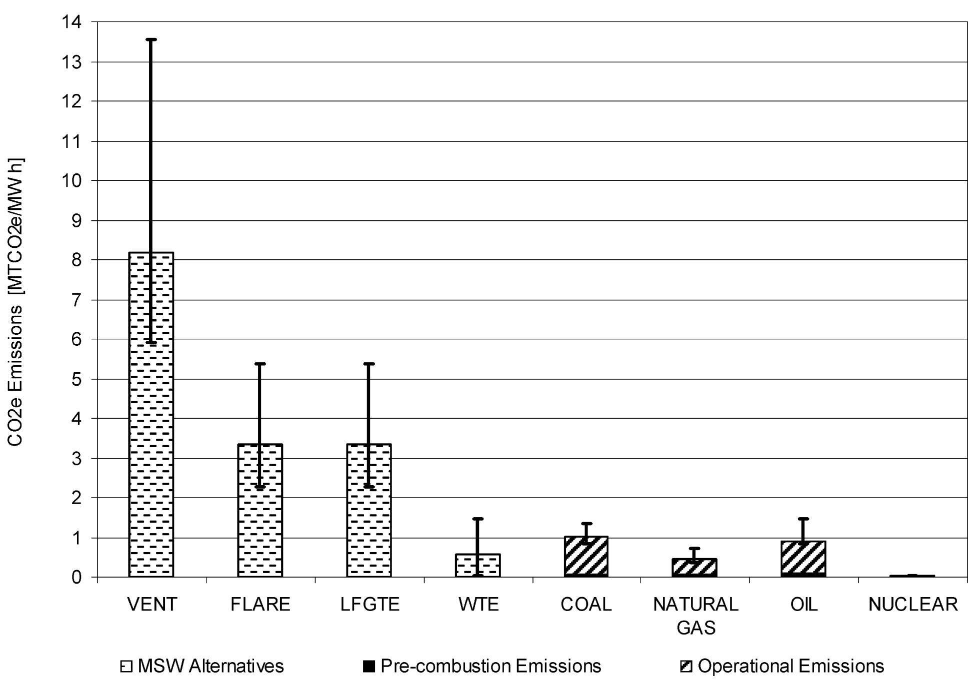


FIGURE 2. Comparison of carbon dioxide equivalents for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5−S8, Supporting Information, include the full data set).

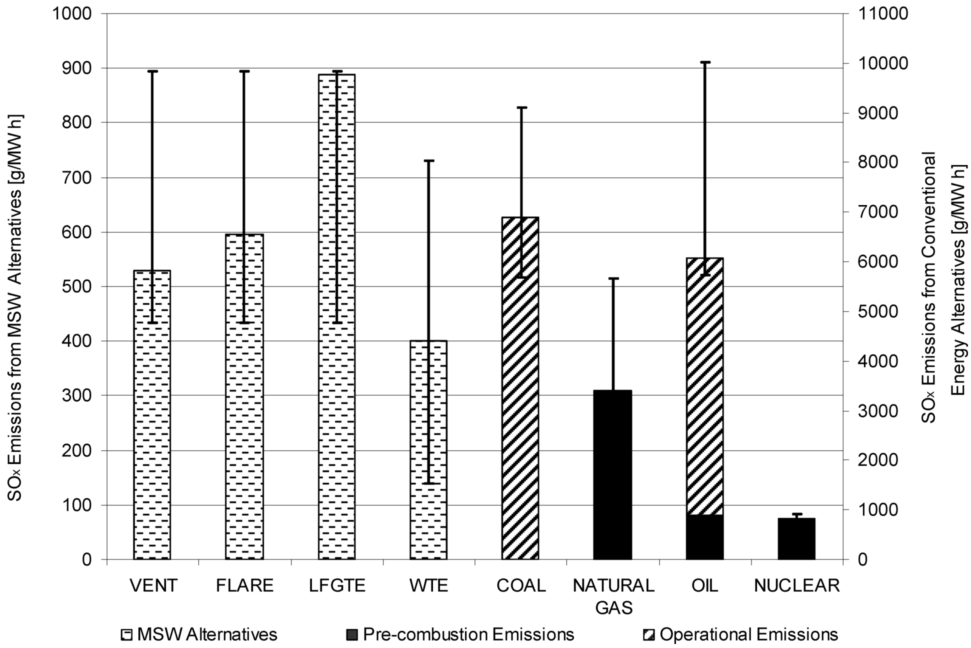


FIGURE 3. Comparison of sulfur oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5−S8, Supporting Information, include the full data set).

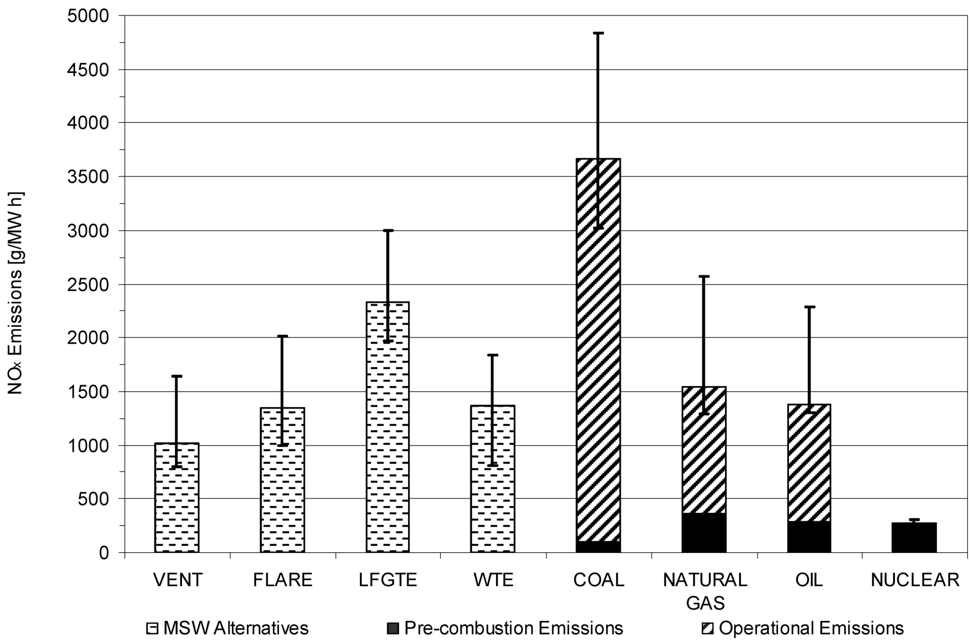


FIGURE 4. Comparison of nitrogen oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5−S8, Supporting Information, include the full data set).

A significant portion of this capacity could be achieved through centralized facilities where waste is transported from greater distances. The transportation of waste could result in additional environmental burdens, and there are clearly limitations in accessing all discarded MSW in the nation. Wanichpongpan studied the LFGTE option for Thailand and found that large centralized landfills with energy recovery performed much better in terms of cost and GHG emissions than small, localized landfills despite the increased burdens associated with transportation (*13*). To quantify these burdens for the United States, emission factors were also calculated for long hauling of the waste via freight or rail. Table S9 (SI) summarizes the emission factors for transporting 1 ton of MSW to a facility by heavy-duty trucks and rail.

Sensitivity analysis was also conducted on key inputs. With incremental improvements, WTE facilities could achieve efficiencies that are closer to those of conventional power plants. Thus, the system efficiency was varied from 15% to 30%, and Table 2 summarizes the resulting LCI emissions. The variation in efficiencies results in a range of 470−930 kW h of electricity/ton of MSW, while with the default heat rate; only 600 (kW h)/ton of MSW can be generated. The efficiency also affects the emission factors; for example, CO_2-fossil emissions vary from 0.36 to 0.71 Mg/(MW h).

The emission savings associated with ferrous recovery decreased the CO_2e emissions of the WTE-Reg case from 0.56 to 0.49 $MTCO_2e$/(MW h). Significant reductions were observed for CO and PM emissions (Table 2).

TABLE 2. Sensitivity of Emission Factors for WTE to Plant Efficiency, Waste Composition, and Remanufacturing Benefits of Steel Recovery

	baseline factors		Sensitivity on: system efficiency	Sensitivity on: waste composition		Sensitivity on: steel recovery	
Input Parameters Varied[a]							
heat rate [Btu/(kW h)]	18000	18000	*[11000, 23000]*	18000	18000	18000	18000
efficiency (%)	19	19	*[15, 30]*	19	19	19	19
composition	default	default	default	*all biogenic*	*all fossil*	default	default
stack gas limits	reg	avg	*reg/avg*	reg	reg	*reg*	*avg*
steel recovery	excludes	excludes	excludes	excludes	excludes	*includes*	*includes*
Results: Criteria Pollutants							
CO [g/(MW h)]	790	790	[500,1000]	740	880	−110	−110
NO_x [g/(MW h)]	1300	1500	[810, 1800]	1200	1400	1200	1400
SO_x [g/(MW h)]	578	221	[140, 730]	550	620	450	90
PM [g/(MW h)]	181	60	[38, 230]	180	190	−190	−310
Results: Greenhouse Gases							
CO_2-biogenic [Mg/(MW h)]	0.91	0.91	[0.58, 1.2]	1.5	0.03	0.91	0.91
CO_2-fossil [Mg/(MW h)]	0.56	0.56	[0.36, 0.71]	0.02	1.5	0.49	0.49
CH_4 [Mg/(MW h)]	1.3E−05	1.3E−05	[8.1E−06, 1.6E−05]	1.6E−05	7.9E−06	−5.0E−05	−5.0E−05
CO_2e [$MTCO_2e$/(MW h)]	0.56	0.56	[0.36, 0.71]	0.02	1.45	0.49	0.49
Results: Electricity Generation							
TW h [b]	98	98	[78, 160]	61	37	98	98
(kW h)/ton	590	590	[470, 930]	470	970	590	590
GW [c]	12	12	[9.7, 20]	7.6	4.7	12	12

[a] For each sensitivity analysis scenario, the input parameters in italics were modified and resultant emission factors were calculated and are reported. [b] The values represent the TWh of electricity that could be generated from all MSW disposed into landfills. [c] 1 TWh/8000 h = TW; a capacity factor of approximately 0.91 was utilized.

TABLE 3. Comparison of Total Power Generated

	total electricity generated from 166 million tons of MSW, TW h	total power [a], GW	electricity generated from 1 ton of MSW, (kW h)/ton
waste-to-energy	78−160	9.7−19	470−930
landfill-gas-to-energy	7−14	0.85−1.8	41−84

[a] 1 TW h/8000 h = TW; a capacity factor of approximately 0.91 was utilized.

The composition of MSW also has an effect on the emission factors. One of the controversial aspects of WTE is the fossil-based content of MSW, which contributes to the combustion emissions. The average composition of MSW as discarded by weight was calculated to be 77% biogenic- and 23% fossil-based (Table S1, SI). The sensitivity of emission factors to the biogenic- vs fossil-based waste fraction was also determined. Two compositions (one with 100% biogenic-based waste and another with 100% fossil-based waste) were used to generate the emission factors (Table 2). The CO_2e emissions from WTE increased from 0.56 $MTCO_2e$/(MW h) (WTE-Reg) to 1.5 $MTCO_2e$/(MW h) when the 100% fossil-based composition was used (Table 2, Figure 2). However, the CO_2e emissions from WTE based on 100% fossil-based waste were still lower than the most aggressive LFGTE scenario (i.e., LF-VENT 2-ICE 60) whose CO_2e emissions were 2.3 $MTCO_2e$/(MW h).

The landfill emission factors include the decay of MSW over 100 years, whereas emissions from WTE and conventional electricity-generating technologies are instantaneous. The operation and decomposition of waste in landfills continue even beyond the monitoring phases for an indefinite period of time. Reliably quantifying the landfill gas collection efficiency is difficult due to the ever-changing nature of landfills, number of decades that emissions are generated, and changes over time in landfill design and operation including waste quantity and composition. Landfills are an area source, which makes emissions more difficult to monitor. In a recent release of updated emission factors for landfill gas emissions, data were available for less than 5% of active municipal landfills (*27*). Across the United States, there are major differences in how landfills are designed and operated, which further complicates the development of reliable emission factors. This is why a range of alternative scenarios are evaluated with plausible yet optimistic assumptions for LFG control. For WTE facilities, there is less variability in the design and operation. In addition, the U.S. EPA has data for all the operating WTE facilities as a result of CAA requirements for annual stack testing of pollutants of concern, including dioxin/furan, Cd, Pb, Hg, PM, and HCl. In addition, data are available for SO_2, NO_x, and CO from continuous emissions monitoring. As a result, the quality and availability of data for WTE versus LFGTE results in a greater degree of certainty for estimating emission factors for WTE facilities.

The methane potential of biogenic waste components such as paper, food, and yard waste is measured under optimum anaerobic decay conditions in a laboratory study (*24*), whose other observations reveal that some portion of the carbon in the waste does not biodegrade and thus this quantity gets sequestered in landfills (*28*). However, there is still a debate on how to account for any biogenic "sequestered" carbon. Issues include the choice of appropriate time frame for sequestration and who should be entitled to potential sequestration credits. While important, this analysis does not assign any credits for carbon sequestered in landfills.

Despite increased recycling efforts, U.S. population growth will ensure that the portion of MSW discarded in landfills will remain significant and growing. Discarded MSW is a viable energy source for electricity generation in a carbon-constrained world. One notable difference between LFGTE and WTE is that the latter is capable of producing an order of magnitude more electricity from the same mass of waste. In addition, as demonstrated in this paper, there are significant differences in emissions on a mass per unit energy basis from LFGTE and WTE. On the basis of the assumptions in this paper, WTE appears to be a better option than LFGTE. If the goal is greenhouse gas reduction, then WTE should be considered as an option under U.S. renewable energy policies. In addition, all LFTGE scenarios tested had on the average higher NO_x, SO_x, and PM emissions than WTE. However, HCl emissions from WTE are significantly higher than the LFGTE scenarios.

Supporting Information Available

MSW composition, physical and chemical characteristics of waste items, detailed LCI tables and sensitivity results, and emission factors for long haul of MSW. This material is available free of charge via the Internet at http://pubs.acs.org.

Literature Cited

(1) Energy Information Administration. Renewable Energy Consumption and Electricity Preliminary 2006 Statistics. www.eia.doe.gov/cneaf/solar.renewables/page/prelim_trends/rea_prereport.html (accessed Aug 26, 2008).

(2) Energy Information Administration. Annual Energy Review 2006. www.eia.doe.gov/emeu/aer/elect.html (accessed Aug 26, 2008).

(3) U.S. Environmental Protection Agency. *Municipal Solid Waste in the United States: 2005 Facts and Figures*; EPA/530/R06/011; U.S. EPA: Washington, DC, 2006.

(4) Federal plan requirements for municipal solid waste landfills that commenced construction prior to May 30, 1991 and have not been modified or reconstructed since May 30, 1991; final rule. *Fed. Regist.* **1999**, *64* (215).

(5) Standards of performance for new stationary sources and emission guidelines for existing sources: Large municipal waste combustors; final rule. *Fed. Regist.* **2006**, *71* (90).

(6) Ruth, L. A. Energy from municipal solid waste: A comparison with coal combustion technology. *Prog. Energy Combust. Sci.* **1998**, *24*, 545–564.

(7) Database of State Incentives for Renewable Energy. Rules, Regulations, & Policies for Renewable Energy. http://www.dsireusa.org/summarytables/reg1.cfm?&CurrentPageID=7&EE=0&RE=1 (accessed Aug 26, 2008).

(8) U.S. Environmental Protection Agency. AP-42 Fifth Edition. Compilation of Air Pollutant Emission Factors. http://www.epa.gov/ttn/chief/ap42/ch02/index.html (accessed Aug 26, 2008).

(9) Cheng, H. F.; Zhang, Y. G.; Meng, A. H.; Li, Q. H. Municipal solid waste fueled power generation in China: A case study of waste-to-energy in Changchun City. *Environ. Sci. Technol.* **2007**, *41*, 7509–7515.

(10) Eriksson, O.; Finnveden, G.; Ekvall, T.; Bjorklund, A. Life cycle assessment of fuels for district heating: A comparison of waste incineration, biomass- and natural gas combustion. *Energy Policy* **2007**, *35*, 1346–1362.

(11) Jaramillo, P.; Matthews, H. S. Landfill-gas-to-energy projects: Analysis of net private and social benefits. *Environ. Sci. Technol.* **2005**, *39*, 7365–7373.

(12) Themelis, N. J.; Ulloa, P. A. Methane generation in landfills. *Renewable Energy* **2007**, *32*, 1243–1257.

(13) Wanichpongpan, W.; Gheewala, S. H. Life cycle assessment as a decision support tool for landfill gas-to energy projects. *J. Cleaner Prod.* **2007**, *15*, 1819–1826.

(14) Eriksson, O.; Carlsson Reich, M.; Frostell, B.; Bjorklund, A.; Assefa, G.; Sundqvist, J. O.; Granath, J.; Baky, A.; Thyselius, L. Municipal solid waste management from a systems perspective. *J. Cleaner Prod.* **2005**, *13*, 241–252.

(15) Kaplan, P. O.; Ranjithan, S. R.; Barlaz, M. A. Use of life-cycle analysis to support solid waste management planning for Delaware. *Environ. Sci. Technol.*, in press.

(16) Thorneloe, S. A.; Weitz, K.; Jambeck, J. Application of the U.S. decision support tool for materials and waste management. *Waste Manage.* **2007**, *27*, 1006–1020.

(17) Harrison, K. W.; Dumas, R. D.; Barlaz, M. A.; Nishtala, S. R. A life-cycle inventory model of municipal solid waste combustion. *J. Air Waste Manage. Assoc.* **2000**, *50*, 993–1003.

(18) Camobreco, V.; Ham, R.; Barlaz, M.; Repa, E.; Felker, M.; Rousseau, C.; Rathle, J. Life-cycle inventory of a modern municipal solid waste landfill. *Waste Manage. Res.* **1999**, 394–408.

(19) Harrison, K. W.; Dumas, R. D.; Solano, E.; Barlaz, M. A.; Brill, E. D.; Ranjithan, S. R. A decision support system for development of alternative solid waste management strategies with life-cycle considerations. *ASCE J. Comput. Civ. Eng.* **2001**, *15*, 44–58.

(20) Kaplan, P. O.; Barlaz, M. A.; Ranjithan, S. R. Life-cycle-based solid waste management under uncertainty. *J. Ind. Ecol.* **2004**, *8*, 155–172.

(21) Solano, E.; Ranjithan, S.; Barlaz, M. A.; Brill, E. D. Life cycle-based solid waste management—1. Model development. *J. Environ. Eng.* **2002**, *128*, 981–992.

(22) RTI International. Municipal Solid Waste Decision Support Tool. https://webdstmsw.rti.org/ (accessed Aug 26, 2008).

(23) National Renewable Energy Laboratory. U.S. Life-Cycle Inventory Database. http://www.nrel.gov/lci/about.html (accessed Aug 26, 2008).

(24) Eleazer, W. E.; Odle, W. S.; Wang, Y. S.; Barlaz, M. A. Biodegradability of municipal solid waste components in laboratory-scale landfills. *Environ. Sci. Technol.* **1997**, *31* (3), 911–917.

(25) Environment Agency. *Life Cycle Inventory Development for Waste Management Operations: Incineration*; R&D Project Record P1/392/6; Environment Agency: Bristol, U.K., 2000.

(26) U.S. Department of Energy. *Electric Power Annual 2005*; DOE/EIA-0348(2005); U.S. DOE: Washington, DC, 2006.

(27) U.S. Environmental Protection Agency. *Background Information Document for Updating AP42 Section 2.4 Municipal Solid Waste Landfills*; EPA/600/R-08-116; U.S. EPA: Washington, DC; http://www.epa.gov/ttn/chief/ap42/ch02/draft/db02s04.pdf.

(28) Barlaz, M. A. Carbon storage during biodegradation of municipal solid waste components in laboratory-scale landfills. *Global Biogeochem. Cycles* **1998**, *12*, 373–380.

ES802395E

EEA Briefing 2008 01

ISSN 1830-2246

Better management of municipal waste will reduce greenhouse gas emissions

- The amount of municipal waste is expected to grow by 25 % from 2005 to 2020.
- Increased recovery of waste, and diverting waste away from landfill play a key role in tackling the environmental impacts of increasing waste volumes.
- As recycling and incineration with energy recovery are increasingly used, net greenhouse gas emissions from municipal waste management are expected to drop considerably by 2020.
- Limiting or avoiding growth in waste volumes would further reduce greenhouse gas emissions from the waste sector and deliver other benefits to society and the environment.

Growing waste volumes

On average, each European citizen generated 460 kg municipal waste in 1995. This amount rose to 520 kg per person in 2004, and a further increase to 680 kg per person is projected by 2020. In total, this corresponds to an increase of almost 50 % in 25 years. This projected continuing increase in waste volumes is primarily due to an assumed sustained growth in private final consumption (i.e. an average growth in the EU-15 and EU-12 respectively of 2 % and 4 % per year by 2020 (EC, 2006)) and a continuation of current trends in consumption patterns.

However, as shown in Figure 1, there are significant differences between EU-15 ([1]) and EU-12 ([2]) Member States. While an EU-15 citizen generated 570 kg on average in 2004, the figure was only 335 kg for an EU-12 citizen. Nevertheless, as EU-12 economies further develop and consumption patterns evolve, waste volumes are likely to increase over the next 15 years and approach current EU-15 levels. Looking forward, municipal waste volumes within the EU-15 and EU-12 are expected to grow by 22 % and 50 % by 2020, respectively. Over the entire period, more than 80 % of the total municipal waste is generated in the EU-15.

If we were simply to spread all EU municipal waste generated in 2020 (i.e. about 340 million tonnes) on the ground, it would cover an area the size of Luxembourg 30 cm thick or Malta 2.5 m thick!

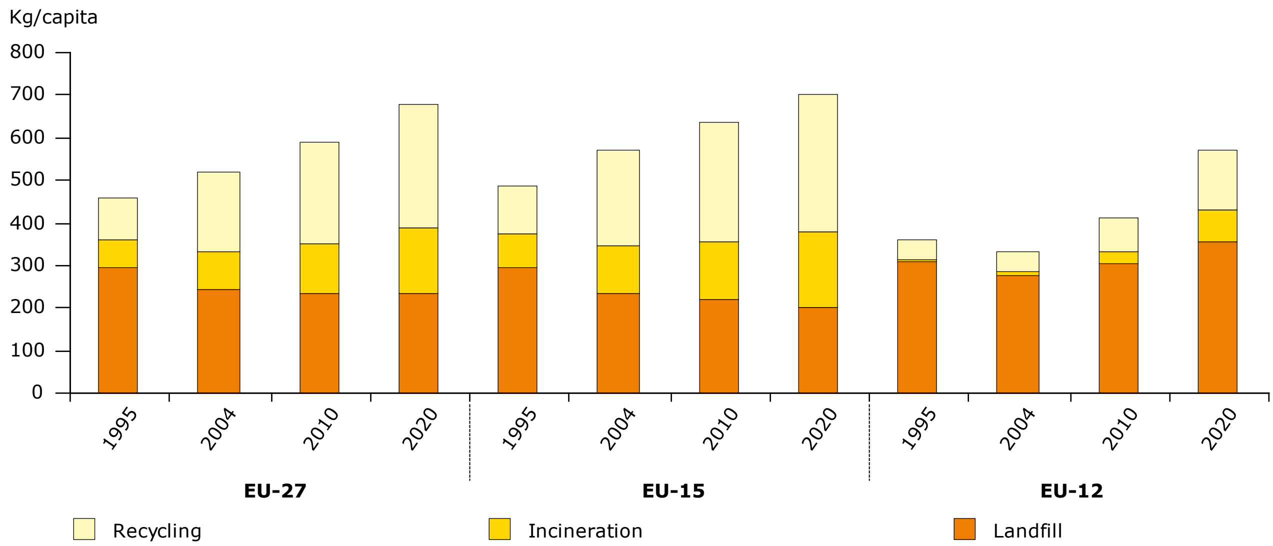
These results indicate that efforts to prevent the generation of waste should be significantly reinforced, if the aim of the Sixth Environment Action Programme of a significant reduction in volumes of waste is to be achieved.

Increasing recovery and diversion of waste from landfill

Historically, disposal by landfilling has been the predominant treatment method for municipal waste, but over the last two decades considerable reductions in landfilling have taken place. In 2004, 47 % of total EU municipal waste was landfilled

([1]) Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the United Kingdom.
([2]) Bulgaria, Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovenia and the Slovak Republic.

Figure 1 Generation and management of municipal waste in Europe *(per capita)*



Source: Eurostat and ETC/RWM.

(see Figure 1). This is expected to decrease further to around 35 % by 2020. Recycling and other material-recovery operations are expected to increase from the current level of 36 % to around 42 % by 2020. Finally incineration was used for 17 % of municipal waste in 2004 and is likely to increase to about 25 % by 2020.

These past and expected trends are in part the result of dedicated policies which aim to increase the recycling and recovery of packaging waste (e.g. 1994 Packaging Directive) and to divert biodegradable municipal waste away from landfill (e.g. 1999 Landfill Directive). Overall, a further reduction of the quantity of municipal waste going to landfill is projected, which reflects the efforts made at national and European levels to achieve, among other things, the objectives set in the Sixth Environment Action Programme.

An EEA publication (2007) illustrates patterns in Member States approaches to waste management, particularly in the context of the Landfill Directive.

Falling net greenhouse gas emissions from municipal waste management

In 2005, greenhouse gas emissions from waste management represented about 2 % of the total emissions in the European Union.

Emissions of methane, one of the six greenhouse gases controlled by the Kyoto Protocol, are especially linked to agriculture (particularly cattle) and landfill operations. The EU Landfill Directive can therefore help in achieving EU targets on greenhouse gas emissions reductions, for example through methane recovery and diversion of biodegradable municipal waste from landfill. Another interface between waste management and climate change policies is the consumption of energy (giving rise to greenhouse gas emissions) in the collection, treatment and manufacturing use of waste.

Net emissions of greenhouse gases from the management of municipal waste are projected to decline from a peak of around 55 million tonnes CO_2-equivalents per year in the late 1980s to 10 million tonnes CO_2-equivalents by 2020 (Figure 2).

This is due to two separate developments. On the one hand, waste quantities that enter management facilities are projected to continue to grow as waste generation *per capita* increases and waste collection is further improved. This pushes direct emissions of greenhouse gases from the waste management sector up. Landfilling represents 60 % of the total in 2020, and recycling and incineration about 20 % each.

On the other hand, recycling and incineration will be increasingly used. This represents savings (or avoided greenhouse gas emissions) that offset direct emissions. Recycling contributes 75 % of total avoided emissions by 2020 and incineration almost 25 %.

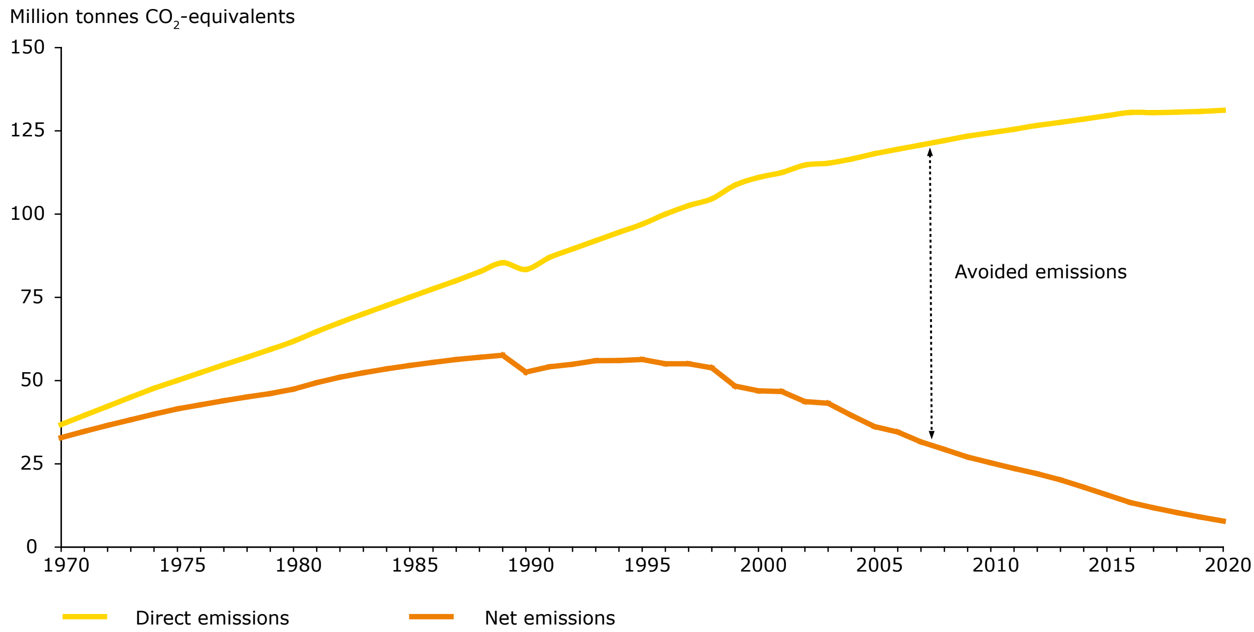
Overall, therefore, the projections show that better management of municipal waste will reduce greenhouse gas emissions in Europe, decoupling environmental pressures from economic growth as called for in the Sixth Environment Action Programme. Furthermore, with an expected further development of recycling and waste being increasingly used as a resource, the projections point towards achieving the long-term goal of becoming a recycling society as stated in the Thematic Strategy on Prevention and Recycling.

The projections used in this study assume that waste management capacity grows to match demand. However, if investment in new and improved management capacity does not keep up with the increasing waste quantities, net greenhouse gas emissions can be higher due to inefficient management.

Further benefits from limiting or avoiding growth in waste volumes

While the projections show that net emissions of greenhouse gases will fall despite increasing volumes of waste, action to limit or avoid the projected growth in waste volumes will further reduce net greenhouse gas emissions from the waste management sector. The collection and transport of waste, closely linked to waste volumes, is estimated to account for less than 5 % of the direct greenhouse gas

Figure 2 Trends and projections of greenhouse gas emissions from management of municipal waste in the European Union



Source: ETC/RWM.

TH-AM-08-001-EN-N
10.2800/18502

emissions of the waste sector, primarily due to the short distances over which municipal waste is usually transported. However, this figure represents 40 % of the net emissions in 2020.

Limiting waste volumes will also deliver other benefits such as reduced costs of waste management, and reduced air pollution (with particles and oxides of nitrogen) and noise related to the collection and transport of waste. The costs of waste management can otherwise increase significantly as volumes grow. The cost of collection and treatment of waste is particularly onerous, and generating waste is by definition a loss of resources.

In conclusion, Europe cannot become complacent with regard to the continuing growth in waste — reflecting our current unsustainable consumption and production patterns — as this in the long term may outweigh the improvements taking place in the waste management sector.

References

EC (2006), *European Energy and Transport — Trends to 2030 — update 2005*, European Communities, DG TREN, Luxembourg.

EEA (2007), *The road from landfilling to recycling: common destination, different routes*, European Environment Agency, Copenhagen.

EEA (2008), Supporting document to EEA Briefing 2008/01, *Better management of municipal waste will reduce greenhouse gas emissions*, European Environment Agency, Copenhagen. http://reports.eea.europa.eu/briefing_2008_1/en/Supporting_document_to_EEA_Briefing_2008-01.pdf.

European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99

Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

Publications Office
Publications.europa.eu

ISBN 978-92-9167-333-9

European Environment Agency

The New York Times

April 12, 2010

Europe Finds Clean Energy in Trash, but U.S. Lags

By ELISABETH ROSENTHAL

HORSHOLM, Denmark — The lawyers and engineers who dwell in an elegant enclave here are at peace with the hulking neighbor just over the back fence: a vast energy plant that burns thousands of tons of household garbage and industrial waste, round the clock.

Far cleaner than conventional incinerators, this new type of plant converts local trash into heat and electricity. Dozens of filters catch pollutants, from mercury to dioxin, that would have emerged from its smokestack only a decade ago.

In that time, such plants have become both the mainstay of garbage disposal and a crucial fuel source across Denmark, from wealthy exurbs like Horsholm to Copenhagen's downtown area. Their use has not only reduced the country's energy costs and reliance on oil and gas, but also benefited the environment, diminishing the use of landfills and cutting carbon dioxide emissions. The plants run so cleanly that many times more dioxin is now released from home fireplaces and backyard barbecues than from incineration.

With all these innovations, Denmark now regards garbage as a clean alternative fuel rather than a smelly, unsightly problem. And the incinerators, known as waste-to-energy plants, have acquired considerable cachet as communities like Horsholm vie to have them built.

Denmark now has 29 such plants, serving 98 municipalities in a country of 5.5 million people, and 10 more are planned or under construction. Across Europe, there are about 400 plants, with Denmark, Germany and the Netherlands leading the pack in expanding them and building new ones.

By contrast, no new waste-to-energy plants are being planned or built in the United States, the Environmental Protection Agency says — even though the federal government and 24 states now classify waste that is burned this way for energy as a renewable fuel, in many cases eligible for subsidies. There are only 87 trash-burning power plants in the United States, a country of more than 300 million people, and almost all were built at least 15 years ago.

Instead, distant landfills remain the end point for most of the nation's trash. New York City alone sends 10,500 tons of residential waste each day to landfills in places like Ohio and South Carolina.

"Europe has gotten out ahead with this newest technology," said Ian A. Bowles, a former Clinton administration official who is now the Massachusetts state secretary of energy.

Still, Mr. Bowles said that as America's current landfills topped out and pressure to reduce heat-trapping gases grew, Massachusetts and some other states were "actively considering" new waste-to-energy proposals; several existing plants are being expanded. He said he expected resistance all the same in a place where even a wind turbine sets off protests.

Why Americans Are Reluctant

Matt Hale, director of the Office of Resource Conservation and Recovery of the United States Environmental Protection Agency, said the reasons that waste-to-energy plants had not caught on nationally were the relative abundance of cheap landfills in a large country, opposition from state officials who feared the plants could undercut recycling programs and a "negative public perception." In the United States, individual states and municipalities generally decide what method to use to get rid of their waste.

Still, a 2009 study by the E.P.A. and North Carolina State University scientists came down strongly in favor of waste-to-energy plants over landfills as the most environmentally friendly destination for urban waste that cannot be recycled. Embracing the technology would not only reduce greenhouse gas emissions and local pollution, but also yield copious electricity, it said.

Yet powerful environmental groups have fought the concept passionately. “Incinerators are really the devil,” said Laura Haight, a senior environmental associate with the New York Public Interest Research Group.

Investing in garbage as a green resource is simply perverse when governments should be mandating recycling, she said. “Once you build a waste-to-energy plant, you then have to feed it. Our priority is pushing for zero waste.”

The group has vigorously opposed building a plant in New York City.

Even Mayor Michael R. Bloomberg, who has championed green initiatives and ranked Copenhagen’s waste-fueled heating on his list of environmental “best practices,” has shied away from proposing to get one built.

“It is not currently being pursued — not because of the technology, which has advanced, but because of the issue in selecting sites to build incinerators,” said Jason Post, the mayor’s deputy press secretary on environmental issues. “It’s a Nimby issue. It would take years of hearings and reviews.”

Nickolas J. Themelis, a professor of engineering at Columbia University and a waste-to-energy proponent, said America’s resistance to constructing the new plants was economically and environmentally “irresponsible.”

“It’s so irrational; I’ve almost given up with New York,” he said. “It’s like you’re in a village of Hottentots who look up and see an airplane — when everybody else is using airplanes — and they say, ‘No, we won’t do it, it’s too scary.’ ”

Acceptance in Denmark

Attitudes could hardly be more different in Denmark, where plants are placed in the communities they serve, no matter how affluent, so that the heat of burning garbage can be efficiently piped into homes.

Planners take pains to separate residential traffic from trucks delivering garbage, and some of the newest plants are encased in elaborate outer shells that resemble sculptures.

“New buyers are usually O.K. with the plant,” said Hans Rast, president of the homeowners’ association in Horsholm, who cut a distinguished figure in corduroy slacks and a V-neck sweater as he poured coffee in a living room of white couches and Oriental rugs.

“What they like is that they look out and see the forest,” he said. (The living rooms in this enclave of town houses face fields and trees, while the plant is roughly some 400 yards over a back fence that borders the homes’ carports). The lower heating costs don’t hurt, either. Eighty percent of Horsholm’s heat and 20 percent of its electricity come from burning trash.

Many countries that are expanding waste-to-energy capacity, like Denmark and Germany, typically also have the highest recycling rates; only the material that cannot be recycled is burned.

Waste-to-energy plants do involve large upfront expenditures, and tight credit can be a big deterrent. Harrisburg, Pa., has been flirting with bankruptcy because of a $300 million loan it took to reopen and refit an old public incinerator with the new technology.

But hauling trash is expensive, too. New York City paid $307 million last year to export more than four million tons of waste, mostly to landfills in distant states, Mr. Post said. Although the city is trying to move more of its trash by train or barge, much of it travels by truck, with heavy fuel emissions.

In 2009, a small portion of the city's trash was processed at two 1990-vintage waste-to-energy plants in Newark and Hempstead, N.Y., owned by a publicly traded company, Covanta. The city pays $65 a ton for the service — the cheapest available way for New York City to get rid of its trash. Sending garbage to landfills is more expensive: the city's costliest current method is to haul waste by rail to a landfill in Virginia.

While new, state-of-the-art landfills do collect the methane that emanates from rotting garbage to make electricity, they churn out roughly twice as much climate-warming gas as waste-to-energy plants do for the units of power they produce, the 2009 E.P.A. study found. Methane, the primary warming gas emitted by landfills, is about 20 times more potent than carbon dioxide, the gas released by burning garbage.

The study also concluded that waste-to-energy plants produced lower levels of pollutants than the best landfills did, but nine times the energy. Although new landfills are lined to prevent leaks of toxic substances and often capture methane, the process is highly inefficient, it noted.

Laws Spur New Technology

In Europe, environmental laws have hastened the development of waste-to-energy programs. The European Union severely restricts the creation of new landfill sites, and its nations already have binding commitments to reduce their carbon dioxide emissions by 2012 under the international pact known as the Kyoto Protocol, which was never ratified by the United States.

Garbage cannot easily be placed out of sight, out of mind in Europe's smaller, densely populated countries, as it so often is in the United States. Many of the 87 waste-to-energy plants in the United States are in densely populated areas like Long Island and Cape Cod.

While these plants are generally two decades old, many have been progressively retrofitted with new pollution filters, though few produce both heat and power like the newest Danish versions.

In Horsholm only 4 percent of waste now goes to landfills, and 1 percent (chemicals, paints and some electronic equipment) is consigned to "special disposal" in places like secure storage vaults in an abandoned salt mine in Germany. Sixty-one percent of the town's waste is recycled and 34 percent is incinerated at waste-to-energy plants.

From a pollution perspective, today's energy-generating incinerators have little in common with the smoke-belching models of the past. They have arrays of newly developed filters and scrubbers to capture the offending chemicals — hydrochloric acid, sulfur dioxide, nitrogen oxides, dioxins, furans and heavy metals — as well as small particulates.

Emissions from the plants in all categories have been reduced to just 10 to 20 percent of levels allowed under the European Union's strict environmental standards for air and water discharges.

At the end of the incineration process, the extracted acids, heavy metals and gypsum are sold for use in manufacturing or construction. Small amounts of highly concentrated toxic substances, forming a paste, are shipped to one of two warehouses for highly hazardous materials, in the Norwegian fjords and in a used salt mine in Germany.

"The hazardous elements are concentrated and handled with care rather than dispersed as they would be in a landfill," said Ivar Green-Paulsen, general manager of the Vestforbraending plant in Copenhagen, the country's largest.

In Denmark, local governments run trash collection as well as the incinerators and recycling centers, and laws and financial incentives ensure that recyclable materials are not burned. (In the United States most waste-to-energy plants are private ventures.) Communities may drop recyclable waste at recycling centers free of charge, but must pay to have garbage incinerated.

At Vestforbraending, trucks stop on scales for weighing and payment before dumping their contents. The trash is randomly searched for recyclable material, with heavy fines for offenders.

The homeowners' association in Horsholm has raised what its president, Mr. Rast, called "minor issues" with the plant, like a bright light on the chimney that shone into some bedrooms, and occasional truck noise. But mostly, he said, it is a respected silent neighbor, producing no noticeable odors.

The plant, owned by five adjacent communities, has even proved popular in a conservative region with Denmark's highest per-capita income. Morten Slotved, 40, Horsholm's mayor, is trying to expand it. "Constituents like it because it decreases heating costs and raises home values," he said with a smile. "I'd like another furnace."