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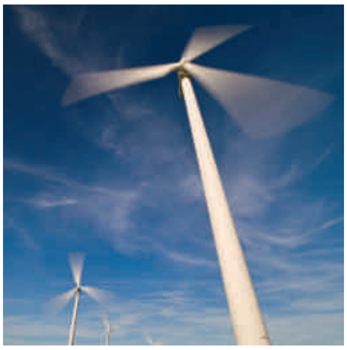
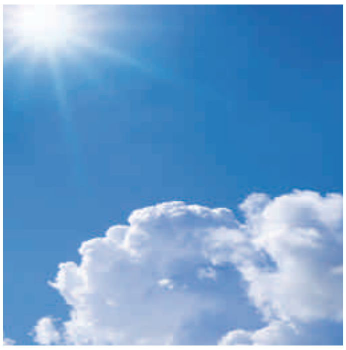
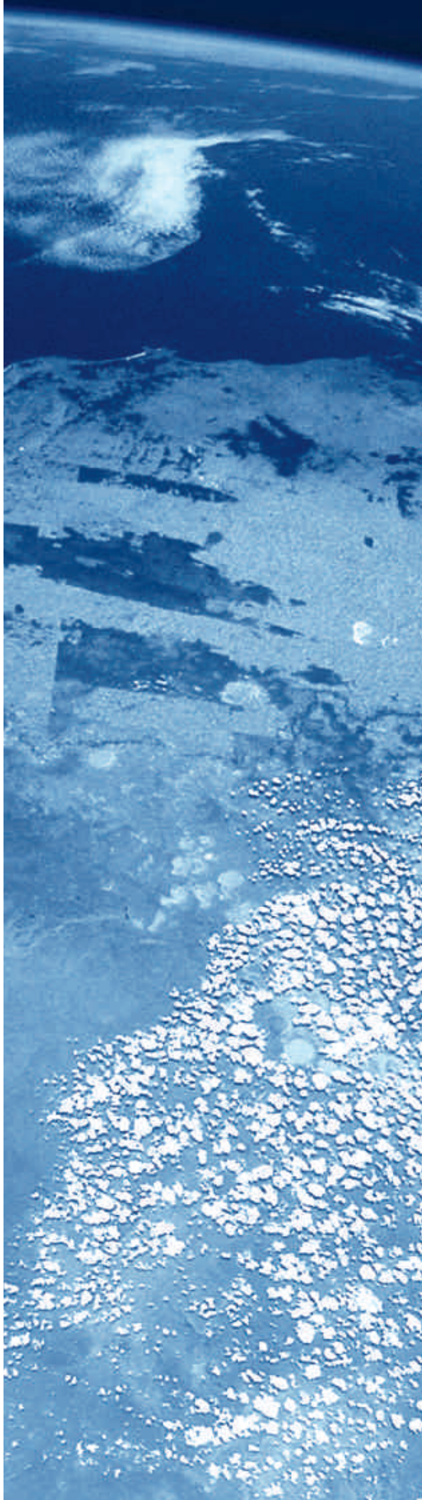
# Green Investing

## Towards a Clean Energy Infrastructure







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**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
17th 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 and Global Leadership Fellow, World Economic Forum

### Expert Committee

**Morgan Bazilian**
Special Advisor on Energy and Climate Change, Department of Energy, Ireland

**Marcel Brenninkmeijer**
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**
Director, McKinsey Global Institute, McKinsey & Co.

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

**Wen Hsieh**
Partner, Kleiner Perkins Caufield & Byers

**Jeremy Kranz**
Vice President, GIC Special Investments

**Marc S. Lipschultz**
Partner 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

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

## Writer

**Alice Hohler**
New Energy Finance

## Editors

**Helena Hallden**
World Economic Forum

**Nancy Tranchet**
World Economic Forum

## Creative Design

**Kamal Kimaoui**
World Economic Forum

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# Preface

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

Anuradha Gurung
Associate Director, Investors Industries
Global Leadership Fellow
World Economic Forum

The World Economic Forum is proud to release this report as part of our Green Investing project. The Green Investing project, which was mandated by the Forum's Investors community at the World Economic Forum Annual Meeting in Davos 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.

The investment volumes required to avoid the catastrophic impact of climate change are substantial and success will largely depend on the successful mobilization of both the public and private sectors. This report highlights 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. Furthermore, the report aims to identify policy recommendations that could potentially enable the efficient deployment of further necessary private capital.

Over the past year we have witnessed a severe global financial crisis. As the effects of the financial crisis continue to unfold, the world faces serious challenges to both capital markets and the global economy. There is significant risk of a severe global recession that will affect many sectors, asset classes and regions in tandem.

It is in this context that the World Economic Forum is releasing this report. Its launch is timed to coincide with the World Economic Forum Annual Meeting 2009. Leaders from industry, government, civil society and other key sectors will have a unique and timely opportunity to actively shape the post-crisis world in a holistic and systematic manner. It is crucial that the environmental challenges are not left aside when focusing on stabilizing the global financial system and reviving global economic growth. Waiting for economic recovery, rather than taking decisive action now, will make the future climate challenge far greater. To this end, we hope that this report will stimulate informed dialogue among stakeholders on the opportunities that will emerge from a move towards a resilient and sustained low-carbon economy.

The Green Investing project is conducted in conjunction with the Forum's broader Copenhagen Climate Change Initiative which will bring together business leaders, government representatives and world-class experts to help catalyse a practical, focused public-private dialogue on climate change to complement the United Nations negotiation process.

Guidance was provided by an actively involved Committee of Experts which included:

- **Morgan Bazilian,** Special Advisor on Energy and Climate Change, Department of Energy, Ireland
- **Marcel Brenninkmeijer,** 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,** Director, McKinsey Global Institute, McKinsey & Co.
- **Kirsty Hamilton,** Associate Fellow, Renewable Energy Finance Project, Chatham House
- **Wen Hsieh,** Partner, Kleiner Perkins Caufield & Byers
- **Jeremy Kranz,** Vice President, GIC Special Investments
- **Marc S. Lipschultz,** Partner and Global Head of Energy and Infrastructure, Kohlberg, Kravis and Roberts and Co.
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- **Chris Mottershead,** Vice Principal, Research and Innovation King's College London
- **Eric Usher,** Head, Renewable Energy and Finance Unit, Energy Branch, DTIE United Nations Environment Programme

On behalf of the World Economic Forum, we wish to thank New Energy Finance, in particular Michael Liebreich, Chris Greenwood and Alice Hohler, and the members of the Expert Committee for supporting us in the creation of this report. We would like to acknowledge the P8 Group and Heidrick and Struggles' contribution to the project. 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.

Investors and policy-makers are facing an historic choice. 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. As the cost of clean energy technologies decreases and policy support is put in place, the shape of the eventual energy system is emerging. But 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.

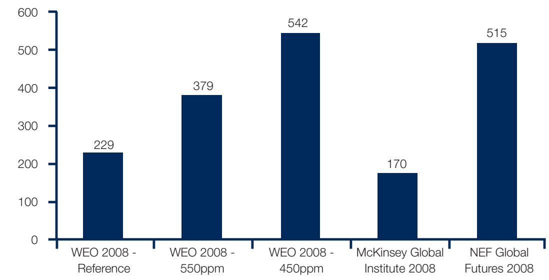
We are not going to rehearse the science of climate change in this paper. Suffice to say, the most recent data show carbon and temperature trajectories tracking the pessimistic edge of the scenarios considered by the Intergovernmental Panel on Climate Change (IPCC), the scientific body set up to advise policy-makers. To have a chance of limiting the average increase in global temperatures to 2°C, a level which an increasing number of experts already considers unsafe, the IPCC believes that we need to limit the concentration of greenhouse gases in the atmosphere to the equivalent of 450 parts per million of carbon dioxide equivalent by volume (450ppm $CO_2e$) by 2030. This means reducing $CO_2$ emissions by 60% from baseline levels by 2030.

Energy is responsible for more than 60% of the $CO_2$ emitted into the atmosphere each year. If we are to limit emissions to a level consistent with 450ppm $CO_2e$, what is required over the coming few decades is nothing less than a complete restructuring of our energy infrastructure – the fuels we use, how we generate and distribute electricity, how we power our transportation, the way we heat and cool our homes and offices, the way we run our factories[1]. And we have to achieve this without jeopardizing the global growth needed to pull the developing world out of poverty or destroying the accumulated capital formation that is needed to pay pensions and healthcare costs in the developed world.

**The Scale of Investment Required**

The sums involved in a shift to a low-carbon energy system are daunting and there are varying views regarding the exact amount of investment necessary. The Stern Review talks of a cost of 1% of global GDP to limit greenhouse gases to a concentration of 550ppm $CO_2e$ by 2050, equivalent to around US$ 500 billion a year currently (global GDP 2007 was US$ 54 trillion), although the longer the delay in taking decisive action, the higher the cost of mitigation. The International Energy Agency's World Energy Outlook (WEO) 2008 estimates around US$ 550 billion needs to be invested in renewable energy and energy efficiency alone each year between now and 2030 if we are to limit concentrations to 450ppm $CO_2e$, while New Energy Finance's Global Futures analysis points to an average annual investment of US$ 515 billion over an extended period (see Figure 1).

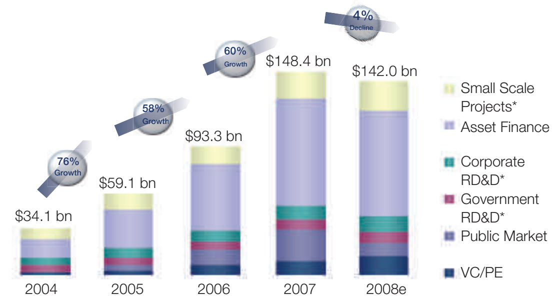
**Figure 1: Estimated Clean Energy Annual Investment to 2030, US$ billions**




Note: WEO 2008 covers investment in renewable energy generation and energy efficiency, with an assumption that half the additional power investment required under the 550ppm and 450ppm scenarios is in renewable energy; McKinsey covers only energy efficiency investment; New Energy Finance Global Futures covers investment in renewable energy and energy efficiency technologies only.

Source: IEA WEO 2008, McKinsey, New Energy Finance

**Figure 2: Total Global New Investment in Clean Energy, 2004-2008, US$ billions**




Note: Figures marked * are based on industry estimates from various sources; all others are extrapolated values based on disclosed deals from the New Energy Finance Industry Intelligence Database; figures are adjusted to remove double-counting

Source: New Energy Finance

The good news is that the process of transition and the associated surge in investment have already begun. Investment in clean energy – defined here as investment in renewable energy and energy efficiency technology, but excluding nuclear power and large hydro – increased

[1] For the purpose of this paper we will consider only investment in clean energy (defined here as investment in renewable energy and energy efficiency technology, but excluding nuclear power and large hydro) – although we accept that this forms only a subset of all "Green Investment" opportunities.

from US$ 33 billion to US$ 148 billion between 2004 and 2007 (see Figure 2), and now accounts for around 10% of global energy infrastructure spend. In electricity generation, the rapid expansion of sustainable energy has been even more striking, with 42GW of power generation capacity added in 2007, just under a quarter of the total 190GW of power generation capacity added worldwide.

### Eight Emerging Large-Scale Clean Energy Sectors

The four-year surge in investment activity in clean energy has spanned all sectors, all geographies and all asset classes. What has begun to emerge as a result is the overall shape of the new lower-carbon energy infrastructure. No one can describe with certainty what the world's energy system will look like in 2050. A substantial proportion of our energy will undoubtedly still be supplied by fossil fuels, but we can now be fairly certain that a future low-carbon energy system will include a meaningful contribution from the following eight renewable energy sources:

1. Onshore Wind
2. Offshore Wind
3. Solar Photovoltaic (PV)
4. Solar Thermal Electricity Generation (STEG)
5. Municipal Solid Waste-to-Energy (MSW)
6. Sugar-based Ethanol
7. Cellulosic and Next Generation Biofuels
8. Geothermal Power

Although these energy technologies – which constitute only a subset of the full range of opportunities – may not yet be fully cost competitive with fossil fuels, the economics of experience curves and oil and gas depletion are working powerfully to level the playing field. Renewable energy technologies are becoming cheaper as they reach scale and operating experience. This trend has been obscured recently by surging commodity prices and supply chain bottlenecks, but with new industrial capacity coming on-line we are about to see prices drop as they come back in line with costs now that we are moving into a buyer's market. Solar PV electricity costs may become comparable with daytime retail electricity prices in many sunny parts of the world in the next 12 to 36 months, even without subsidies. Wind is already cost competitive with natural gas-fired electricity generation in certain locations without subsidies.

Renewable energy is not generally subject to risks associated with fuel input costs. Increasing fuel prices by 20% increases the costs of generation by 16% for gas and 6% for coal while leaving renewable energy technologies practically untouched. The volatility of fuel prices alone should act to encourage utilities to build some proportion of renewable energy into their portfolios. And higher capital costs for many renewable energy technologies – and no fuel costs – mean that they will benefit more from reductions in effective interest rates than natural gas or coal. Indeed, in a world in which effective interest rates for energy projects drop 300 basis points, while fuel prices and carbon credit prices each rise by 20%, onshore wind becomes cheaper than natural gas, and geothermal and waste-to-energy not only beat natural gas, but are even cheaper than coal-based power.

Nuclear power is also set for a renaissance in many countries around the world. Nuclear's share of total electricity production has remained steady at around 16% since the 1980s. Its contribution is clearly set to grow over the medium to long term, although it will always be limited by issues of cost, storage, safety and public resistance. We do not consider it in detail in this paper.

### Key Enablers of a Shift to Clean Energy

The shift to a low-carbon energy system cannot be achieved simply through the addition of new sources of renewable energy. It will also be necessary to make wholesale changes in the way energy is distributed, stored and consumed. Again, the outlines of these changes, and the investment opportunities implied, can already be seen. We focus here on four areas:

1. **Energy Efficiency.** It has been frequently said that the cheapest source of energy is the energy never used. There are enormous opportunities for improving the efficiency of the world's energy infrastructure, both on the supply side and the demand side – and many of them could even produce returns above the cost of capital of major businesses. In a recent report, the McKinsey Global Institute estimated that there are US$ 170 billion of energy efficient investment opportunities that would produce an IRR of 17% or more.
2. **Smart Grid.** The world's electricity grids were designed to distribute power cheaply and reliably from large, centralized, predictable power stations. The grid of the future will have to cope with decentralized, fluctuating supply. It will also be expected to deliver a far more sophisticated range of services to help with demand-side energy management. Only a new and fully digitally-enabled grid architecture will be able to meet these needs, and the investment requirement is estimated by New Energy Finance at US$ 8.6 trillion (including US$ 6.8 trillion to repair and replace the existing transmission and distribution network).
3. **Energy Storage.** The need for energy storage is increasing – whether to power hybrid electric vehicles, to smooth out fluctuations in supply and demand, or to extend appliance functionality. The cost of storing 1MWh of electricity ranges from US$ 50 to US$ 180,

depending on the technology used. As power storage prices come down, it can increasingly be used to smooth the supply of power or to bridge the gap between peak and night-time electricity rates. Improved power storage is also required by ever more advanced mobile appliances and ubiquitous communications.

4. **Carbon Capture and Sequestration.** No discussion of the future energy infrastructure can be complete without considering Carbon Capture and Storage (CCS). Although there are no installations at scale yet, there are almost 200 projects at varying degrees of completion around the globe. With so many countries – including China and the US – overwhelmingly dependent on coal for their electricity, CCS needs to form part of the solution if we are to restrict $CO_2e$ concentrations to 450ppm.

### The Role of the Carbon Markets

Although it may sometimes not seem to be the case, we are moving inexorably towards a world in which every major economy puts a price on greenhouse gas emissions. Currently the most liquid markets are the European Union Greenhouse Gas Emission Trading Scheme (EU-ETS) and the global Kyoto compliance markets. Others are following in their footsteps in Australia, Japan, the US's Regional Greenhouse Gas Initiative (RGGI), California and the Western Climate Alliance. Then there is the voluntary market, rapidly taking shape and increasing in volume. These may soon be joined by a US Federal carbon market and a strengthened global scheme may emerge from the negotiations in Copenhagen in 2009.

What we are seeing is the emergence of a system of interlinked policy-led financial markets, similar to currency markets. A single price for carbon everywhere in the world is probably not achievable, but neither is it necessary. As each of these carbon markets grows in liquidity, its rules firm up and become well-understood, and it is linked to other markets via project-based and other mechanisms, arbitrage will reveal a global carbon price range – and it will be one that drives significant behavioural change.

Carbon prices alone, however, will not be high enough – at least for the next few decades – to prompt a large-scale roll-out of renewable energy, nor will they be sufficient to promote carbon capture and sequestration. Prices will be set for many years to come by cheaper sources of credit – energy efficiency and project-based mechanisms in the developing world. So a carbon price is an essential driver towards a lower carbon economy, but additional policy interventions will still be required.

### Impact of the Current Financial Crisis

The road to a sustainable energy future is not without its speed bumps. Although total investment volume in 2008 declined only marginally over 2007, it was supported by a very strong first half. By the final quarter of the year, the volume of clean energy investment had dropped by over half from its peak at the end of 2007. Public market funding for clean energy businesses has decreased significantly, with valuations down by nearly 70% during the course of 2008. Venture capital and private equity investment held up reasonably well, but asset-based finance slowed markedly as the credit crunch ate into the availability of debt finance and the tax credits that have been driving the US wind boom.

The short-term challenge for the world's policy-makers is to maintain the extraordinary momentum of the clean energy industry in these difficult times. To do so, they must use all the tools at their disposal. An enormous monetary stimulus has already been applied through the drop in global interest rates.

On top of the monetary stimuli, policy-makers around the world are designing fiscal stimulus packages. As they do so, it is vital that every dollar should be made to multitask: it should support short term consumption and jobs, as well as building the long-term productive capacity of the economy, and at the same time moving us forward towards key long-term goals such as a sustainable energy system. Developing renewable energy technologies, rolling out a fully digital grid, properly insulating homes and offices, and educating a new generation of engineers, technicians and scientists should all be part of any fiscal stimulus programme.

### The Need for Smart Policy

Even after the current crisis subsides, there will be a need for smart policy to support the shift to a clean energy infrastructure. The industry needs a well-designed set of support mechanisms – one that is tailored to each geography, and to the technological maturity of each sector. Sectors nearing maturity and competitiveness with fossil fuels need rate support as they close the gap; technologies that work in the lab but are too risky to scale up need support and finance to bridge the "Valley of Death"; sectors with longer-term technological promise need research funds.

Once policy-makers make incentives for clean energy a key element of their response to the current financial crisis, there will still be a need for further action. An entire ecosystem of supporting technology and service providers will be fundamental to the growth of a healthy clean energy sector – and this is inextricably linked to the ability of entrepreneurs and companies to create new businesses. One of the reasons that Europe consistently lags venture investment in clean energy in the US by a factor of five to seven is that the **conditions for venture investment** in Europe are less well-developed. Governments should also create markets for clean energy through **public procurement**. With central, regional and local government accounting for 35-45% of economic activity in all of the world's largest economies, public sector purchasing can be a powerful force. Clean energy use should be mandated in public procurement, which would create guaranteed markets for leading innovators in transport, heat and electricity.

Finally, policy-makers should enforce **energy efficiency standards**. Utilities and energy-intensive industries will respond to carbon prices and other price signals, but many individuals and businesses will simply not do so. As a result, there will always be a role for regulation to mandate certain changes in behaviour, such as appliance efficiency and standby power limits, corporate average fuel economy (CAFE) standards and building codes. They must also address the asymmetry between energy providers, who want their customers to use as much energy as possible, and consumers, who on the whole would prefer to use less.

But whichever policies are adopted, the overarching requirement is for policy **stability** – the impact of policy uncertainty on cost of capital must be better understood – and **simplicity**, so that the industry is not burdened with unnecessary bureaucratic costs. Poorly-designed, overlapping, intermittent, contradictory or overly-generous policies do more harm than good. Similarly investors need to understand the scale and nature of the investment opportunity presented by the world's one-time shift to low-carbon energy.

## Conclusion

The need to shift to a low-carbon economy is stronger than ever. Clean energy technologies are becoming increasingly cost-competitive with fossil-based energy. A carbon price will eventually level the playing field, but in the meantime clean energy solutions require support from policy-makers.

Policy-makers need to build frameworks which enable corporations and investors to make good returns by squeezing carbon out of the world's economy. And investors need to understand the scale and nature of the investment opportunity presented by the world's one-time shift to low-carbon energy.

2009 is a critical year to bring these players together and start the transition toward a clean world energy infrastructure. The official UN negotiations will work on developing the overall framework for a follow on to the Kyoto Protocol by December of 2009. To complement and support this process, a platform should be created that connects policy makers (of the major economies in particular) with major investors and global energy corporations. A discussion, involving all these key players, can then take place during 2009 on how best to design the enablers identified in this report, in order to make the transition happen: a coalition of public-private expertise that designs the clean energy motor to drive the new framework forward.

# 2. Scale of the Challenge

A transformation in the world's energy infrastructure is required between now and 2030. The most recent data show $CO_2$ emissions and temperature trajectories tracking the pessimistic edge of the scenarios considered by the IPCC. To have a chance of limiting the average increase in global temperatures to 2°C, a level which an increasing number of experts already considers unsafe, we have to limit the concentration of greenhouse gases in the atmosphere to the equivalent of 450 parts per million of carbon dioxide by volume (450ppm $CO_2e$) – compared to 385ppm currently and 280ppm before the industrial revolution. Energy – principally electricity generation and transport fuels – accounts for more than 60% of the $CO_2$ emitted into the atmosphere each year. If we are to avoid the worst effects of climate change, therefore, we need to shift within the space of a few decades to a low-carbon energy infrastructure.

**Figure 3. International Energy Agency World Energy Outlook 2008 – Highlights**

The International Energy Agency's World Energy Outlook (WEO) 2008, published in November 2008, contains the most recent set of $CO_2$ forecasts. It is also a baseline used by many companies and institutions.

The key messages are as follows:

- The Reference scenario (equivalent to the status quo: no new policies supporting renewable energy) is compared to two scenarios: 550ppm and 450ppm $CO_2e$ levels in the atmosphere. 450ppm is widely considered to be the maximum $CO_2$ concentration level required to avoid the worst effects of global warming by restricting temperature rises to 2°C. Both follow similar paths to an emissions plateau in 2020, after which the 450ppm assumes stronger and broader policy action.
- 77% of the emissions reductions (relative to the Reference scenario) will come from renewable energy and energy efficiency, with the balance from nuclear power and Carbon Capture and Sequestration (not considered a viable alternative in 2007).
- Energy demand in OECD countries under the Reference scenario will grow more slowly than predicted in 2007 (but faster for non-OECD countries) because of lower expected GDP growth combined with higher oil prices suppressing demand in developed countries.
- Renewable energy plays a larger role than in previous editions of the WEO, especially wind and solar power. Forecast renewable energy production in 2030, and consequently investments, was revised upwards from 2007 even in the base case Reference scenario.
- The 450ppm scenario depends on increasing spending on R&D now in order to develop the necessary advanced technologies
- Higher oil prices in the long-run (2030 estimate up from US$ 62/barrel in 2007 to US$ 122 in real 2008 terms), on the basis that lack of investment in existing fields will constrain supply and lead to a long-run rising oil price. This is positive for renewable energy, as it lowers the point at which renewable energy becomes competitive with conventional energy.

Source: IEA WEO 2008

The scale of investment required has been estimated by various different institutions, including the Stern Review, the International Energy Agency (IEA), the US's Energy Information Administration (EIA), McKinsey Global Institute and New Energy Finance. Their estimates of required investment vary considerably, not least because they use different definitions of the solution space, but all agree on one thing: that the sums involved are very substantial – trillions of dollars between now and 2030. In the long term, of course, the cost of doing nothing is even higher; the Stern Review estimated that inaction – adapting passively to climate change rather than acting now to mitigate it – will cost at least US$ 2.5 trillion, and will expose it to risks which are hard to quantify.

In 2005, the baseline year for most forecasts, energy-related $CO_2$ emissions accounted for 27,000 mega tonnes (Mt). By 2030, the IEA's latest baseline "Reference" scenario has emissions of 40,000Mt – an increase of just under 50%. This increase is not inevitable, however, particularly if action is taken quickly. The IEA has also published a "450ppm" scenario, in which $CO_2$ emissions are just 25,700Mt in 2030, a decrease of 5% from the 2005 figure (see Figure 3).

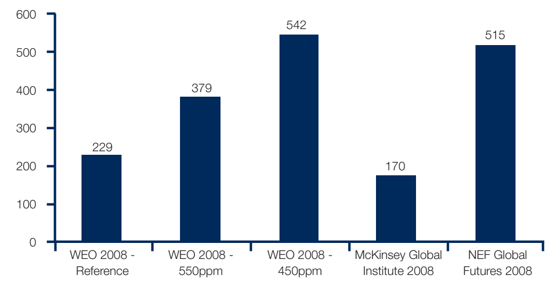
Estimates bold enough to look forward to 2050 are even more divergent. In its Energy Technology Perspectives scenarios – which include potential impacts of new technologies, the IEA has looked at a "Blue" scenario – in which just 14,000Mt are emitted by 2050 (half of 2005 $CO_2$ levels), compared with 62,000Mt in the Reference scenario.

These $CO_2$ emission reductions will be achieved by a combination of renewable energy and nuclear power, with energy efficiency playing a major role at all stages of the supply chain. Carbon capture and storage (CCS) contributes to almost every mitigation scenario.

Importantly, however, all the scenarios other than the business-as-usual Reference scenario, envisage a far higher proportion of renewable energy in the energy mix by 2030. Renewable energy accounts for as much as 46% of electricity generation in the more carbon-constrained scenarios, compared to 18% currently, and up to 23% of total primary energy demand (which includes transportation, heating etc). It is now widely accepted that renewable energy will provide a considerable contribution to the future energy mix. The questions now relate to the proportion of mainstream energy demand which will be met by renewable sources and, vitally, how much will the transition cost (see Figure 4).

The IEA's baseline Reference scenario sees cumulative energy investment of US$ 26.3 trillion between now and 2030. This includes cumulative renewable energy investment of US$ 5.5 trillion, of which US$ 3.3 trillion is for electricity generation – equivalent to US$ 229 billion a year for renewable energy, 60% of it for electricity generation. But this will result in an energy system which still contributes to 40,000Mt of global $CO_2$ emissions by 2030.

**Figure 4: Annual Investment Required to 2030, US$ billions**




Note: WEO 2008 covers investment in renewable energy generation and energy efficiency, with a New Energy Finance assumption that half the additional power investment required under the 550ppm and 450ppm scenarios is in renewable energy; McKinsey covers only energy efficiency investment; New Energy Finance Global Futures covers investment in renewable energy and energy efficiency technologies only.

Source: IEA WEO 2008, McKinsey, New Energy Finance

Even higher investment is needed to reduce emissions further. To reach emissions consistent with 550ppm $CO_2e$, additional investment of US$ 1.2 trillion is needed in generating capacity, and US$ 3 trillion in energy efficiency, nearly half of it in transport. To limit greenhouse gases to 450ppm $CO_2e$ an additional US$ 3.6 trillion of generating capacity and significantly higher energy efficiency investment (US$ 5.7 trillion) is required from 2020 onwards.

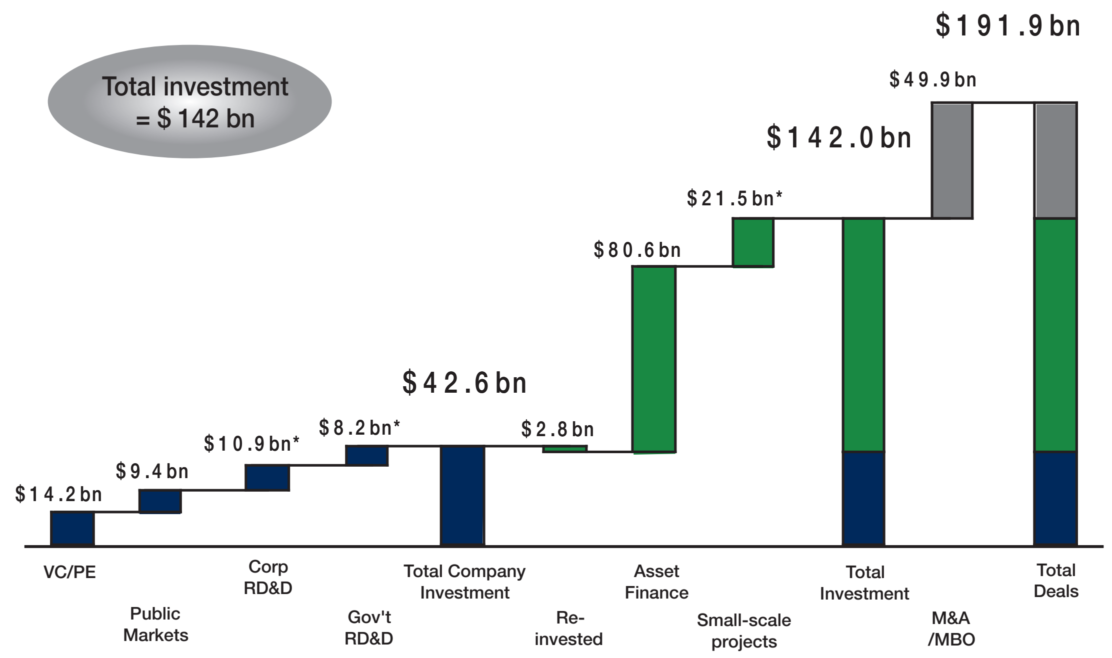
The role of energy efficiency in reducing energy demand cannot be underestimated. A recent McKinsey Global Institute report – How the World Should Invest in Energy Efficiency – estimates that energy efficiency alone could halve the projected growth in energy demand, delivering half the $CO_2$ emission cuts necessary for a 450ppm $CO_2e$ outcome by 2030. This would involve exploiting US$ 170 billion of investment opportunities in energy efficiency that would produce an IRR of 17% or more. Not only does this compare favourably to the most obvious comparator, the IEA's 450ppm scenario, which requires additional annual investment in energy efficiency of US$ 238 billion, but the investment would only need to be made between 2009 and 2020, a mere 12 years, half the time horizon of most other forecasts, including those from the IEA.

# 3. Current Volume of Investment

The process of transition to a clean energy infrastructure has already begun, with a surge in investment from US$ 33 billion in 2004 to around US$ 150 billion in 2008. Investment in clean energy – defined here as investment in renewable energy and energy efficiency technology, but excluding nuclear power and large hydro – increased from US$ 33 billion to US$ 148 billion between 2004 and 2007 (see Figure 2), and now accounts for around 10% of global energy infrastructure spend. In electricity generation, the rapid expansion of sustainable energy has been even more striking, with 42GW of power generation capacity added in 2007, just under a quarter of the total 190GW of power generation capacity added worldwide.

Annual investment in renewable energy generation capacity is expected to top US$ 100 billion in 2008 – according to New Energy Finance's figures – and was growing at nearly 50% per year until the global financial crisis bit in the second half of the year. Prior to the crisis, New Energy Finance forecast investment in clean energy (including new energy efficiency technologies) would reach US$ 450 billion annually by 2012, rising to more than US$ 600 billion from 2020 (and probably even higher), indicating that the capital markets – at least before the credit crunch – were certainly capable of meeting the International Energy Agency's figures of US$ 380-540 billion required each year between 2008 and 2030.

**Figure 5. Clean Energy Investment Types and Flows, 2008, US$ billions**




New Energy Finance tracks deals across the financing continuum, from R&D funding and venture capital for technology and early-stage companies through to public market financing for projects and mature companies. Figures are adjusted to remove double counting. Investment categories used in this report are defined as follows:
Venture capital and private equity: all money invested by venture capital and private equity funds in the equity of companies developing renewable energy technology. Similar investment in companies setting up generating capacity through Special Purpose Vehicles is counted in the asset financing figure.
Public markets: all money invested in the equity of publicly quoted companies developing renewable energy technology and clean power generation. Investment in companies setting up generating capacity is included in the asset financing figure.
Asset financing: all money invested in renewable energy generation projects, whether from internal company balance sheets, from debt finance, or from equity finance. Excludes refinancings and short term construction loans.
Mergers and acquisitions: the value of existing equity purchased by new corporate buyers in companies developing renewable technology or operating renewable energy projects.

Source: New Energy Finance

The four-year surge from 2004-2007 in investment activity spanned all sectors, all geographies and all asset classes, and as a result the clean energy financing spectrum is well-developed, from very early stage investment in emerging technologies, right through to large established companies raising money on the public markets.

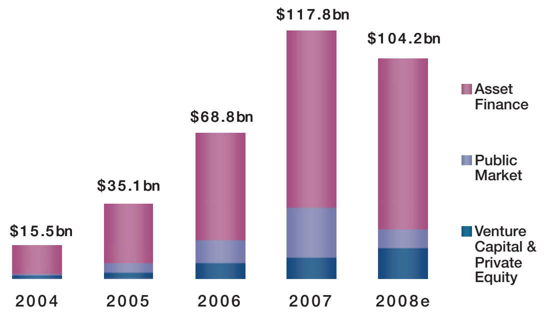
In 2008, new investment in clean energy is estimated to have reached US$ 142 billion worldwide (see Figure 5), down slightly from US$ 148 billion in 2007, but up nearly fivefold from US$ 33.4 billion in 2004. While the global financial crisis has slowed this growth, money is still flowing into clean energy. While the 2008 total is down only slightly from 2007, a strong start may disguise a much weaker second half of the year.

Of the 2008 investment, approximately 80%, or US$ 104 billion, was provided by third-party investors, such as Venture Capitalists, Private Equity providers, Asset Managers, Banks etc., to companies developing new technologies, manufacturing production equipment, and building new generation capacity across a range of clean energy sectors (see Figure 6). Most investment is in asset finance – building new renewable energy power generation projects and biofuels processing capacity – which is estimated at US$ 81 billion in 2008. Billions of dollars have been flowing in via the world's public markets, with US$ 23.4 billion raised in 2007, but only US$ 9.5 billion in 2008, as a consequence of the global financial crisis.

Wind is the most mature clean energy technology and accounted for more than a third of capacity investment (see Figure 7) – more than either nuclear or hydroelectric power. A total of 21GW of new wind capacity was added worldwide in 2007 – amounting to half of all new renewable energy capacity and over 11% of all new power generation capacity. In March 2008 the industry passed the milestone of 100GW installed capacity (for comparison, the United Kingdom has approximately 80GW of installed power generation capacity from all sources). An estimated 25GW of new capacity was added in 2008.

Solar energy is the fastest-growing sector. The development of large-scale solar projects propelled the sector into the limelight in 2007, when it attracted US$ 17.7 billion in project financing, nearly a quarter of all new investment – up 250% on the previous year. Solar is also the leading sector for venture capital investment, as investors back such emerging technologies as thin film (which uses less silicon and other non-silicon materials) and Solar Thermal Electricity Generation (STEG), whereby

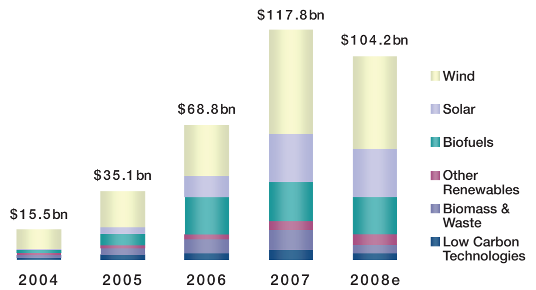
**Figure 6. Clean Energy Investment by Asset Class, 2004-2008e, US$ billions**




Note: Totals are extrapolated values based on disclosed deals from the New Energy Finance Industry Intelligence Database. They exclude R&D and Small Projects.

Source: New Energy Finance

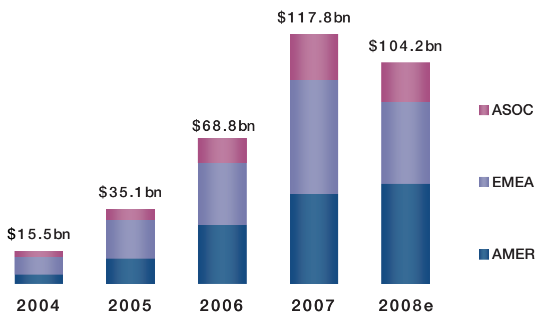
**Figure 7. Clean Energy Investment by Sector, 2004-2008e, US$ billions**




Note: Totals are extrapolated values based on disclosed deals from the New Energy Finance Industry Intelligence Database. They exclude R&D and Small Projects. Other Renewalbes includes geothermal and mini-hydro; Low Carbon Technologies includes energy efficiency, fuel cells, power storage.

Source: New Energy Finance

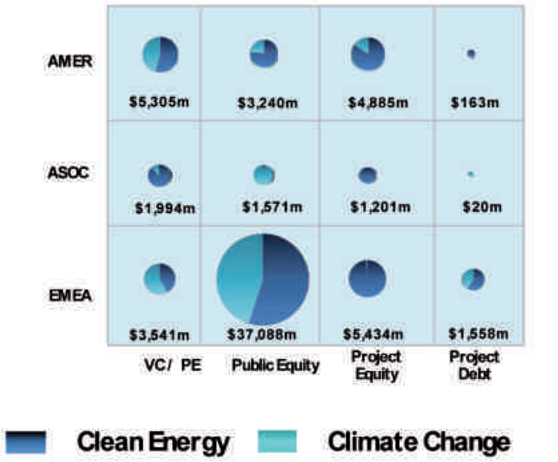
**Figure 8. Clean Energy Investment by Geography, 2004-2008e, US$ billions**




Note: Totals are extrapolated values based on disclosed deals from the New Energy Finance Industry Intelligence Database. They do not include R&D or Small Projects, which is why the total in this chart is lower than the headline total new investment shown in other charts. ASOC = Asia Oceania region; EMEA = Europe Middle East Africa region; AMER = Americas region.

Source: New Energy Finance

**Figure 9. Clean Energy and Climate Change Funds by Region, 2008**




Note: Data as of October 2008; Data refers to total assets managed

Source: New Energy Finance

the heat of the sun is concentrated with mirrors to produce steam and drive a conventional turbine. Total solar investment in 2008 is estimated at US$ 26 billion, a 10% increase on 2007.

The past few years have seen an explosion of interest in clean energy by venture investors, attracted by the size of the markets that will be created. New Energy Finance has identified over 1,500 separate venture and private equity groups, all searching for the clean energy equivalent of Cisco, Dell, Amazon or Google. Indeed, Google itself is one of the searchers, with a strong commitment to clean energy.

It remains to be seen how many of these venture players will retain their interest after the energy price crashes. Having said that, venture and private equity investment in the sector has continued throughout the financial crisis, with an estimated US$ 14 billion of new investment (excluding buyouts) in 2008. As well as the solar sector, investors have been looking for winners among the next generation of technologies, from cellulosic and algae-based biofuels – which bypass the conflict between food and fuel – through to energy storage and digital energy management. Companies working on energy efficiency have been attracting record investment, especially from earlier-stage investors. The period 2003 to 2005 saw a flurry of venture activity in the hydrogen and fuel cell sector.

Investment in clean energy has not only increased over the past few years, but has also diversified geographically (see Figure 8). As recently as five years ago, clean energy meant wind, mostly in Denmark, Germany and Spain. Since then renewable capacity rollout has shifted away from Europe and towards China and the US. Developing (non-OECD) countries attracted 23% (US$ 26 billion) of asset financing in 2007, compared to just 13% (US$ 1.8 billion) in 2004, although the bulk of this went to the fast-growing economies of China, India and Brazil. India and China in particular are determined to become clean energy powerhouses. By 2007, investment in clean generation capacity in China – excluding large hydro projects such as the Three Gorges dam – had soared to US$ 10.8 billion.

Finally, the past few years have seen another trend of significance in the financing of clean energy – the provision of investment vehicles for those not able or willing to make their own direct investments. In 2004, there were only 10 quoted equity funds targeting the sector, almost all of them run by specialist companies such as Triodos, Sustainable Asset Management and Impax. By the end of 2007, the lay investor had the option of more than 30 funds, several managed by high-street names such as Deutsche Bank, ABN Amro, HSBC or Barclays. By October 2008 these funds had over US$ 42 billion in assets under management (see Figure 9). A number of Exchange Traded Funds had also been launched, including the Powershares Global Clean Energy Fund, which tracks the WilderHill New Energy Global Innovation Index (NEX) and soon grew to have over US$ 200m in assets under management.

# 4. Investment Performance

Over the past few years, prior to the recent turmoil in the global financial markets, investors made good returns from clean energy investments at all stages of the value chain. While the exceptional gains of the past few years may have declined during 2008, the sector as a whole has fared better than any major benchmark over the past five years.

### 4.1 Public Markets

The WilderHill New Energy Global Innovation Index (ticker symbol NEX) tracks the performance of around 90 leading clean energy companies, spanning different sectors, geographies and business models.

Over the period from the beginning of 2003 to the end of 2007, the NEX rose from its index value of 100 to a peak of 549.08, a compound annual growth rate of over 40%. 2007 was a particularly high-octane year, logging an increase of 57.9%, and the index defied gravity for the first three quarters of 2008, before succumbing to the credit crisis and ending the year at 178 (see Figure 10).

Back-testing suggests a fairly close correlation existed between the NEX and NASDAQ between 2000 and 2003, when many renewable energy stocks were seen as technology plays. However, this changed as clean energy came into its own as an investment sector against a background of higher energy prices, environmental and geopolitical concerns. Now the NEX correlates most closely with the oil price (see Figure 11). As the oil price has fallen in recent months, so has the NEX, although December 2008 saw further falls in oil prices along with a recovery in the NEX.

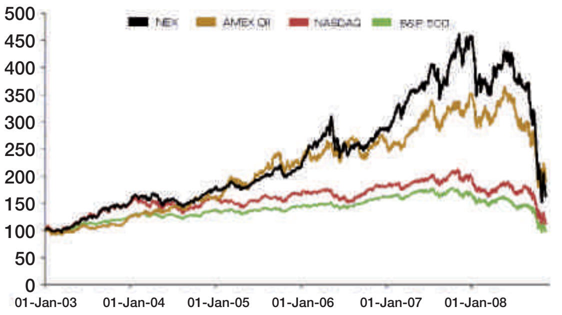
Indeed, although historically clean energy stocks have been more volatile than those from other sectors, their returns have been consistently higher, making them an attractive investment proposition on a risk-adjusted basis despite their recent history (see Figure 12). Even after its tumultuous 2008, the NEX remained up 75% on six years ago – an annual return of 9.8%, unmatched by any of the major stock market indices.

### 4.2 Venture Capital and Private Equity

On the venture capital and private equity side, some spectacular returns were achieved during the period 2004 to 2007.

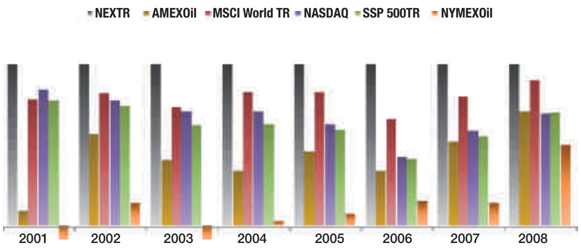
For private equity players, one of the most successful strategies during this period was to identify clean energy companies which had been struggling to commercialize their products or services during the period of low energy prices, but which were now experiencing soaring demand. Allianz Private Equity and Apax Partners shared

**Figure 10. Performance of NEX vs Major Indices, 2003 to 2008**




Source: New Energy Finance, Bloomberg

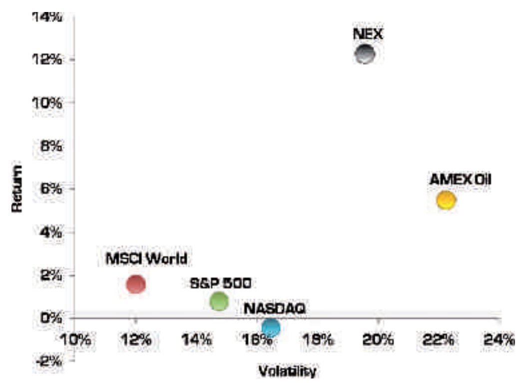
**Figure 11. Correlation of NEX to Indices and Oil, 2003 to 2008**




Note: Correlation measures how close the relationship between the NEX and other indices is. The higher the correlation, the closer the relationship. Negative correlation indicates a contrary relationship (when one goes up, the other goes down).
Correlation at 2 December 2008. Nymex Oil refers to oil futures; Amex Oil is an oil company index

Source: New Energy Finance

**Figure 12. NEX vs. AMEX Oil, NASDAQ and S&P 500, Sep 2005 – Sep 2008**




Note: Returns are over 3 years, annualized so they represent the compound annual return. Volatility is averaged over the same 3 year period.

Source: New Energy Finance

the private equity deal of the year in 2006. They bought Hansen Transmissions, a leading provider of gearboxes for wind turbines for € 132m, and 22 months later they were able to sell it for € 465m to India's Suzlon Energy, then the world's most valuable turbine manufacturer, recording an IRR of 101% on their investment. Other very successful deals of this nature included an investment made by Goldman Sachs in Zilkha Renewables (later renamed Horizon Wind Energy), which they were subsequently able to sell to Energias de Portugal at a substantially increased value.

Meanwhile in venture capital, investors in clean technologies in Europe and the US were on track to achieve excellent returns on their investments up to mid-2008, according to the third annual European Clean Energy Venture Returns Analysis (ECEVRA), completed by New Energy Finance in collaboration with the European Energy Venture Fair.

The study, which is based on confidential returns by investors at the end of H1 2008, covered 302 clean technology portfolio companies, representing € 1.77 billion of venture capital invested in clean technology since 1997. Of these, 26 have so far resulted in public listing and 32 have been exited or partially exited via trade sale. The success rate to date has been reasonably high with a pooled gross IRR (at the portfolio company level, not the fund level) of over 60%, based on the limited number of exits and with only 23 companies being liquidated or written off at the time of the study,. These exceptional returns, were driven by the outstanding success of a small number of early investments in the solar sector – Q-Cells and REC in particular. Without these, the pooled return was closer to 14%. As of mid-2008 there had been relatively few down-rounds (subsequent venture rounds at reduced valuations), but it is a very young sample with relatively few exits to date.

Of course these returns relate to an extraordinary period in history – combining a period of extreme interest in all things green with historically cheap access to debt. There is no doubt that the next few years will be much harder for venture and private equity investors in clean energy. Any downturn in venture capital will not, however, be confined to the clean energy sector. According to quarterly analysis by Thomson Reuters and the National Venture Capital Association (NVCA) of nearly 2,000 US investors, venture capital performance dropped sharply in the second quarter of 2008, although venture capital returns still exceeded public market indices (S&P and NASDAQ). Venture exits in general have also fallen sharply. The first three quarters of 2008 saw only six IPOs of venture-backed companies, representing the lowest volume for the first three quarters of the year since 1977. Meanwhile for those venture capital and private equity investors who have raised their funds but kept their powder dry, this looks like a good point in a notoriously cyclical asset class to be making investments.

### 4.3 Asset Finance

The bulk of new investment in the clean energy sector (approximately 80%) is in asset finance – to fund the building of wind farms, geothermal power plants, biofuels refineries and the like. A large number of different financing structures have been used: fairly standard project finance structures may account for the bulk of deals, but utilities have funded much new capacity on their balance sheets. In the US, tax equity tends to take the place of debt; lease finance, export finance and multilateral agencies such as development banks also play a major role.

Typical project equity returns range from the very low – perhaps where investors are driven by regulatory or charitable requirements – to extremely attractive. Early wind projects in Italy, for instance, were able to generate equity returns of 20-30% because of high electricity and Green Certificate prices, allied with good wind resources. However, returns were later pushed down as there were fewer sites to choose from. Indeed this trend has been replicated in all major wind markets, with later projects often located in lower wind speed areas, providing their investors with lower returns. This has encouraged investors to seek new markets to hit target returns, including Latin America (especially Chile) and Eastern Europe (particularly Poland, Romania and most recently Bulgaria). It has also meant that utilities, whose target rate of return is lower than that of private equity investors, have become the leading proponents of greenfield wind farms.

Equity investors in clean energy assets are typically divided between three camps: the developer who identifies the clean energy resource and puts the project together; equity sponsors who help to fund the project through the construction phase but aim to sell the completed asset; and those primarily investing in operating assets, who wish to avoid development risks, specializing instead in the management of existing assets. Naturally there is cross-over between these classes of investor, where developers have sufficient capital to do without equity sponsors and retain their portfolio of developed wind-farms, but as capital has become more constrained this is becoming the exception, rather than the norm.

The very rapid recent pace of growth in the wind industry (25% compound annual growth in installation activity) has afforded plentiful opportunities for financial investors. Equity sponsors of projects under development are exposed to significant development, financing, turbine supply, and interest rate risks. They have, however, succeeded in achieving strong returns. Good projects by strong developers are able to sustain higher effective interest rates and lower leverage, and so have remained financeable throughout 2008.
Yields from existing wind projects vary depending on local tariffs and/or tax incentives, the wind regime, maintenance costs, and financing structure. Ultimately returns to investors purchasing operating wind assets will depend on the entry price. With a significant number of portfolios being put on the market by distressed sellers, and the promise of cheaper debt in coming years, 2009 looks like it may be a good year for bargain-hunters.

Meanwhile in the solar sector, the cost of electricity from photovoltaic cells is due to plummet in 2009. The second issue of the quarterly New Energy Finance Solar Silicon and Wafer Price Index, which was published in December 2008, forecasts average silicon contract prices falling by over 30% during 2009. With thin-film PV module manufacturing costs approaching the US$ 1/Watt mark, crystalline silicon-based PV will come under severe competition for larger projects, resulting in margins shrinking throughout the silicon value chain, and substantially lower prices for consumer.

New Energy Finance analysis, based on the historic cost experience curve, suggests that current silicon-based solar module prices of US$ 4/Watt could drop to US$ 2.60/Watt by the end of 2009, a reduction of 35%, before leading manufacturers started making losses on marginal sales. For a ground-mounted plant in a region with good insolation, and based on a 6% real cost of capital, this could translate into an unsubsidized generation cost of US$ 0.17/kWh for crystalline silicon – competitive with daytime peak retail electricity prices in many parts of the world, but not yet with wholesale prices.

**Figure 13. Investment and Energy Poverty**

According to the UN, over 2 billion people lack access to modern fuels and 1.6 billion lack access to electricity. Renewable energy can play a major role in addressing energy poverty, but the traditional finance sector is ill-equipped to finance their deployment.
A wide range of renewable energy technologies offer promise in providing energy services to the poor in the developing world – including micro-digesters to produce gas for cooking and heating, solar water heaters and cookers, advanced biomass combustion, and of course distributed electricity generation from photovoltaic and other sources. Indeed, where no grid or fuel distribution infrastructure has yet been built, these solutions will often be cheaper than traditional fossil-based sources of energy. However, their provision will require the investment of hundreds of billions of dollars over the coming decades. Traditionally, governments, development agencies and multilateral lenders such as the World Bank, Asian Development Bank, and the EBRD have provided finance focusing on large-scale projects. Effectively remedying energy poverty will require a very large number of small projects, requiring microfinance approaches that are beyond the capabilities of most mainstream investors. In addition, local entrepreneurs often need substantial support in developing technologies and business models to deliver solutions.
A number of organizations are working on innovative ways of using microfinance to provide clean energy in developing countries. An in-depth discussion of these financial pioneers is beyond the scope of this report, but they include the following:
- Acumen Fund www.acumenfund.org
- D-Light Design www.dlightdesign.com
- E+Co www.eandco.net
- GEXSI www.gexsi.org
- Global Village Energy Partnership www.gvep.org
- Grameen Shakti Bank www.gshakti.org
- Green Microfinance www.greenmicrofinance.org
- Solar Electric Light Fund www.self.org

A survey of a further selection of providers has been undertaken by the SEEP Network and can be found here: http://www.seepnetwork.org

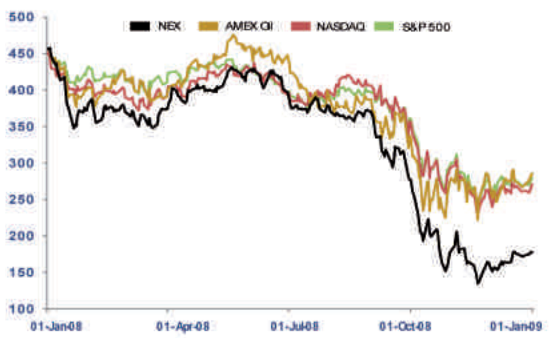
Source: IEA WEO 2008

# 5. Impact of the Global Financial Crisis

The global financial crisis of 2008, and the recession that is following in its wake, represents a serious threat to the clean energy sector. Short-term energy and carbon prices have fallen, making clean energy less competitive in immediate financial terms. At the same time risk has been re-priced, and finance is much harder to come by. The crisis may, however, also represent something of opportunity: as policy-makers take decisive action to refuel their economies, they are at least talking about ensuring the resulting fiscal and monetary stimuli benefit the clean energy sector. Beyond that, it remains to be seen whether the crisis will shake policy-makers' determination to shift to low-carbon energy and force embattled voters to take painful action to limit greenhouse gas emissions.

Clean energy investment held up well during the early phase of the credit crunch, as did the valuations of publicly-quoted clean energy companies, only to be very hard hit during the closing months of 2008.

**Figure 14. Performance of NEX vs Major Indices, 2008**




Note: Index Values as of 31 December 2008; AMEX Oil, NASDAQ and S&P 500 rebased to 455.19 on 31 Dec 2007

Source: New Energy Finance, Bloomberg

The NEX index defied gravity for the first three quarters of 2008, trading mainly in the 350 to 450 range. The final quarter of 2008, however, saw the index collapse, touching a low of 135.15 in late November, a level not seen since September 2003 – before the ratification of the Kyoto Protocol, before Hurricane Katrina and President Bush's statement that the US was "addicted" to oil, before the publication of the Stern Review, before the premiere of the Inconvenient Truth.
Since that low, however, the NEX index has bounced back, ending the year at a slightly more respectable 178 – perhaps in recognition that the sector's sell-off had been overdone, perhaps as opportunistic investors began to pick up bargains, and perhaps on hope that the election of President Obama would create a floor through which the sector would not fall (see Figure 14).

There are three reasons why the sector was hit so hard. First, with energy prices collapsing by 70%, the sector was bound to suffer – these are, after all energy stocks. Second, investors were getting rid of stocks with any sort of technology or execution risk, in favour of longer-established businesses. Third, in an era of sharply constrained credit, investors penalized companies with high capital requirements – even the more established, asset-based clean energy companies, which bear no technology risk, being high-growth are capital-hungry.

The collapse in valuations of clean energy companies effectively shut the door to further fund-raising in the public markets. New financings – IPOs, secondary offerings and convertible issues – dropped by 60%

**Table 1. Global Clean Energy Investment, 2007-2008: US$ billion**

| Asset Class | 2007 | 2008e | Change |
|---|---|---|---|
| Venture Capital/Private Equity | US$ 9.8 billion | US$ 14.2 billion | 45% |
| Public Markets | US$ 23.4 billion | US$ 9.4 billion | -60% (minus) |
| Asset Finance | US$ 84.5 billion | US$ 80.6 billion | -5% (minus) |
| **Total** | **US$ 117.7 billion** | **US$ 104.2 billion** | **11%** |

Note: 2008 estimates are New Energy Finance preview figures, published in October 2008

Source: New Energy Finance

between 2007 and 2008 to US$ 9.4 billion (see Table 1), mainly because of turbulent market conditions and lower valuations. 2007's total was boosted by Iberenova's US$ 6.6 billion IPO, the fourth largest in the world in any sector.

Venture capital and private equity to a certain extent stepped in where the public markets stepped out during 2008. New investment – i.e. excluding buyouts – is estimated to have reached US$ 14.2 billion in 2008, 45% higher than a year earlier. Venture capitalists, those that have already raised funds and now need to put them to work, have continued to invest, particularly in the solar and digital power sectors. In the wake of decreased leverage, there is evidence that some private equity players have preferred to invest expansion capital with modest leverage rather than return money to their limited partners. Meanwhile, anecdote suggests that valuations have come down, though not quite to the extent of public market valuations, making this a good time to invest for those that have funds available.

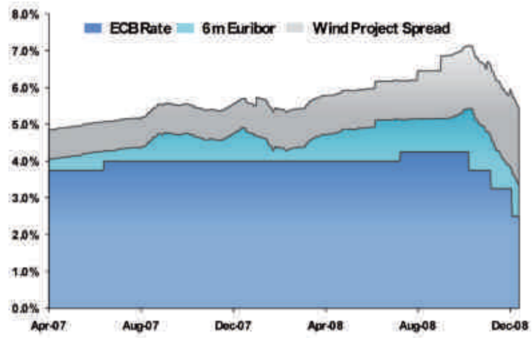
The most serious impact of the credit crunch has been felt in asset finance. New build investment volumes fell steadily throughout 2008, from a peak of US$ 26.7 billion in Q4 2007. They are forecast to total US$ 80.6 billion in 2008, a fall of only 5% on the year before, but the true scale of the drop in investment is masked by investment in the first half which was much higher than in the same period in 2007. By the final quarter of the year, investment volume was down over 30% on the peak. Not only has it become harder for clean energy project developers to access capital, but borrowing costs have risen sharply. Even though underlying central bank interest rates have fallen around the world, interbank lending rates have risen and project debt spreads have widened: in the European wind industry, for example, borrowing margins have more than doubled from 80 basis points over Euribor in the second half of 2007 to 170 basis points in 2008 (see Figure 15).

Even during the darkest weeks of October and November 2008, investment deals continued to close, including a rights issue by Brazilian bioethanol leader Cosan, which raised US$ 412m, and Chinese wind turbine manufacturer Dongfang Electric Corporation, which raised US$ 195m in a secondary offering. In addition, over 80 VC and PE deals were completed in Q4 2008.

A repeat of the collapse in investment in clean energy which followed in the wake of previous spikes in energy prices in the 1970s and 1980s, therefore, does not look likely. For one thing, there is a web of policy in place around the world which supports a mandated level of activity far in excess of previous levels. Secondly, no serious commentator expects oil prices to revert to the US$ 25 per barrel median price (in 2008 money) which prevailed throughout the 1990s. Growing demand for oil – much of it fuelled by the rising middle classes in China and India – is demanding the exploitation of ever more expensive sources of supply – deeper offshore fields, shale oils and tar sands – driving up the cost of marginal production.

There is no question that the short-term priority for the world's policy-makers is to do whatever is necessary to prevent the effects of the financial crisis turning from a recession to a depression. The good news for clean energy investors is that supporting the sector is seen by the leaders of many of the world's major economies as consistent with achieving this goal. As they address the urgent problems and then the longer-term structural weaknesses of their economies, the clean energy sector stands to benefit as follows:

**Figure 15. Debt spread chart for 200MW European area wind farm, 2007-2008**




Note: Data as of 13 December 2008

Source: New Energy Finance, Bloomberg

1. **Monetary stimulus.** An enormous monetary stimulus has already been applied in every major economy of the world – central bank rates have dropped to levels not seen for half a century. At the time of writing, this wall of cheap debt has not yet worked its way through the system, as banks steward their capital in fear of the levels of defaults which will emerge as the recession bites. However, at some point a flood of cheap money will begin to flow, and when it does, clean energy infrastructure – safe projects with reliable yields – will be among the first to benefit. Renewable energy projects generally have higher up-front costs but lower

or no fuel costs, making them more than averagely sensitive to periods of higher interest rates or credit risk aversion – and more than averagely responsive as interest rates fall.

2. **Fiscal stimulus.** Around the world debate is raging, not about whether fiscal stimulus is needed, but how much and what sort. Policy-makers are trying to ensure that any fiscal stimulus multitasks by supporting short term consumption and jobs and building the long-term productive capacity of the economy, as well as moving us along in achieving our long-term goal of a sustainable energy system. The development of clean energy technologies, rolling out a fully digital grid, properly insulating homes and offices, and educating a new generation of engineers, technicians and scientists meet all of these criteria and could be part of many fiscal stimulus programmes.

3. **Deficit reduction.** Policy-makers are likely to look for sources of tax which are not only substantial, but at the same time encourage the move towards a low-carbon economy. And that means the likely dismantling of any fiscal support for fossil fuels – fuel subsidies, research grants, exploration concession waivers, investment tax holidays, accelerated depreciation, export guarantees and soft loans. Then we could see increasing energy taxes, a dramatic reduction of fuel subsidies in the developing world, and either a carbon taxes or cap-and-trade schemes with auctioning of permits.

The position of US president-elect Barack Obama is of particular interest in this context. During his campaign, he stated that "there is no better potential driver that pervades all aspects of our economy than a new energy economy ... that's going to be my No. 1 priority when I get into office." As well as supporting the extension to the Production Tax Credits and Investment Tax Credits, so instrumental in the development of the US wind and solar sectors, he has indicated his support for a federal Renewable Portfolio Standard (the minimum proportion of renewable power in the electricity mix) of 25% by 2020. He has also committed to spending US$ 150 billion on clean energy over the next 10 years.

Since his election, President-Elect Obama has galvanized the world's carbon negotiators by restating his commitment to provide leadership on the issue of greenhouse gas emissions. By the time this report appears, President Obama's inauguration will have taken place, and he may have outlined both the nature of the fiscal stimulus that will be applied to the US economy in 2009, and his policy towards clean energy.

In summary, while the global financial crisis has certainly brought the clean energy sector down to earth with a bump, the fundamental drivers – climate change, energy security, fossil fuel prices and scarcity – remain strong. With continued government support through the current financial crisis, the sector will likely see a return to its long term growth trend in the near future.

# 6. Eight Key Renewable Energy Sectors

No-one can predict with any certainty what the energy mix will look like in 2030, let alone 2050. Fossil fuel generation will undoubtedly still be a substantial part of the equation. However, it is clear that any future low-carbon energy infrastructure will have to include a significant proportion of energy generated from renewable sources – most scenarios showing the proportion of primary energy having to reach 40-50% by 2050. Some of the leading technology contenders are emerging and, in some cases have begun to build significant experience.

In this section, we highlight eight renewable energy technologies which look particularly promising in terms of two factors: abatement potential and current state of competitiveness. In the next section we will look at some of the other technologies – principally around the digital/smart grid, energy efficiency, power storage and carbon capture and sequestration – which will be required if low carbon energy is to fulfil its full potential within the future energy mix.

1. **Onshore Wind**. The most mature of the renewable energy sectors, the onshore wind industry saw 21GW built in 2007, bringing installed capacity to over 100GW. In Germany, Spain and Denmark wind power now supplies 3%, 11% and 19% respectively of total electricity production during the course of the year, and in Denmark up to 43% of the country's electricity demand at times of peak wind supply. Electricity from onshore wind can be generated at prices of 9-13 c/kWh, making it only 32% more expensive than natural gas CCGT, even in the absence of a carbon price.

2. **Offshore Wind.** When the best sites for onshore wind have been snapped up, the next place to look for large quantities of renewable energy 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 than onshore, farms can be built at scales impossible on land, and the availability of space is almost unlimited if deep waters are mastered. At present, the cost of electricity from offshore wind is high – around 16-21 c/kWh – but this will come down rapidly as more project experience is gained.

3. **Solar Photovoltaic Power.** Photovoltaic (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 commercializing thin film technology, with investment volume growing to US$ 50 billion in 2007-2008. Although there has been a bottleneck in the production of solar-grade silicon, new capacity is coming on line and costs are set to drop rapidly from US$ 4/W to US$ 2.60/W by the end of 2009, making unsubsidized solar PV generation costs comparable with daytime peak retail electricity prices in many sunny parts of the world.

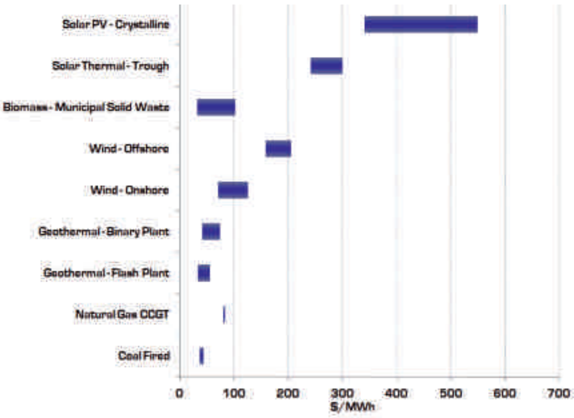
4. **Solar Thermal Electricity Generation.** While PV is ideal for smaller projects and integrated into buildings, the technology of choice for big solar plants in the world's deserts looks set to be Solar Thermal Electricity Generation (STEG): concentrating the heat of the sun to generate steam, which can be used in conventional and highly efficient turbines. There are relatively few projects up and running yet, but with costs already in the 24-30 c/kWh range, this technology is shaping up to be a part of the solution in the sunniest parts of the world.

5. **Municipal Solid Waste-to-Energy (MSW).** The use of municipal solid waste to generate energy is increasing, led by the EU countries. Waste has traditionally been deposited in landfill sites, a practice which is becoming increasingly expensive and constrained by shortage of sites. Landfill also creates methane, a powerful greenhouse gas. Waste that cannot be recycled, however, can be used to generate electricity by a variety of technologies at costs starting at 3 to 10 c/kWh. Government support for the development of MSW plants is increasing, for example through the Private Finance Initiative (PFI) in the United Kingdom. The US MSW sector is also seeing a resurgence, with specialist operators planning to build several new plants.

6. **Sugar-based Ethanol.** The period 2004-2006 saw US investment in biofuels soar, with investors pouring US$ 9.2 billion into the sector. But most of this flowed into corn-based ethanol, which is more expensive to produce than sugar-based ethanol, subject to volatile prices and controversial because its feedstock is a food staple around the world. By contrast, Brazilian sugar cane-based ethanol is competitive with oil at US$ 40 per barrel; it grows well in many southern hemisphere countries (and far from the Amazon); and there is no shortage of land to increase production substantially without jeopardizing food production.

7. **Cellulosic and Next Generation Biofuels.** The argument over food vs fuel is an emotive one. In most regions, there is sufficient land to increase biofuels production from the current 1% of transport fuel to 3% or even 5% without impacting on food availability (as long as we can quickly return to increasing annual agricultural productivity). But after that the only way to

**Figure 16. Clean Energy and Traditional Technologies – Range of Levelized Costs of Energy, December 2008, US$/MWh**




Note: Levelized Cost of Energy (LCOE) allows different energy generation technologies to be compared, taking into account their cost of production and generation efficiency. Figures indicate the required range of generation price for each clean energy technology to be competitive. Levelized costs exclude any subsidies. LCOE analysis assumes an internal hurdle/return rate of 10%, which is used to derive generation costs. Base case assumptions: interest rate = 2.5%; Fuel price (2009): Coal = US$ 115.29/tonne, Natural Gas = US$ 11.49/MMBtu; Carbon price (2009) = US$ 28.11/tonne.

Source: New Energy Finance

increase production of biofuels will be to source feedstock that does not compete with food. Luckily, the cost of producing biofuels from agricultural waste through cellulosic conversion and algae is coming down rapidly, and the future fuel system is likely to include a proportion of fuels from these sources. Future technologies could include artificial photosynthesis and synthetic genomics.

8. **Geothermal.** Geothermal power is particularly attractive as a renewable energy source because it can be used as predictable base-load power in a way that wind and solar power cannot be. Until now, geothermal power has been used only in limited regions, but a raft of new approaches has helped make it economically viable across a wider area. In addition, all countries can exploit geothermal resources for ground source heat pumps or district heating, if not for large-scale electricity generation.

**Table 2. Sensitivity of Power Costs to Changes in Inputs**

| | Base case power generation cost (US$/MWh) and (comparative ranking) | Interest rate -300 bp (% change) | Fuel prices +20% (% change) | Carbon prices +20% (% change) | Potential cost in low interest, high fuel and carbon cost scenario this excludes any impact of scale or experience curve! (US$/MWh) and (revised comparative ranking) |
|---|---|---|---|---|---|
| Coal Fired | 40.6 (1) | -7.1% | +6% | +45% | 58.1 (4) |
| Natural Gas CCGT | 82.0 (5) | -1.3% | +16% | +14% | 104.8 (6) |
| Geothermal – Flash Plant | 44.3 (2) | -4.6% | - | - | 42.3 (1) |
| Geothermal – Binary Plant | 58.0 (3) | -5.1% | - | - | 55.0 (3) |
| Wind – Onshore | 108.2 (6) | -10.4% | - | - | 88.8 (5) |
| Wind – Offshore | 181.8 (7) | -5.5% | - | - | 171.8 (7) |
| Biomass – Municipal Solid Waste | 67.5 (4) | -12.1% | - | - | 54.8 (2) |
| Solar Thermal – Trough | 270.9 (8) | -7.7% | - | - | 249.9 (8) |
| Solar PV – Crystalline | 445.7 (9) | -8.1% | - | - | 409.5 (9) |

Note: Levelized Cost of Energy (LCOE) allows different energy generation technologies to be compared, taking into account their cost of production and generation efficiency. Levelized costs exclude subsidies. LCOE analysis assumes an internal hurdle/return rate of 10%, which is used to derive generation costs. LCOE analysis assumes an internal hurdle/return rate of 10%, which is used to derive generation costs. Base case assumptions: interest rate = 2.5%; Fuel price (2009): Coal = US$ 115.29/tonne; Natural Gas = US$ 11.49/MMBtu; Carbon price (2009) = US$ 28.11/tonne

Source: New Energy Finance

## Table 3. Summary Table of Target Sectors

| | Installed Capacity Worldwide, 2008 | Relative Scale by 2030 | Market Readiness/ Levelized Cost of Energy | Technology Gaps | Potential Bottlenecks | Policy Requirement |
|---|---|---|---|---|---|---|
| **1. Onshore wind** | 103.5GW | More than 1,000GW | US$ 89-126/MWh | • Existing technology adequate, drive train improvements required to increase reliability and decrease costs<br>• Ever-larger turbines<br>• Power storage (to reduce impact of intermittency) | • Short term: capital availability<br>• Longer term: bearing, gearbox and blade supply chain<br>• Weakness of electricity grid<br>• Slowness of planning applications | • Stable implementation of existing policies<br>• Modest rate support in the form of Renewable Portfolio Standard, Feed-in Tariff or Green Certificates<br>• Accelerated planning processes<br>• Incentives/regulation to require integration and remove grid bottlenecks |
| **2. Offshore wind** | 1.5GW | 100GWs | US$ 158-205/MWh | • Reliability of offshore turbines still a key concern<br>• New dedicated marinized technology at larger scale being rolled out over next 5 years | • Turbine supply resulting from low margins on sale compared to onshore turbines | • Continued, stable support in Germany and the United Kingdom<br>• Attractive tax treatment of RD&D<br>• Incentives/funding for grid development<br>• Accelerated planning processes |
| **3. Solar PV** | 13.3GW | 10GWs | Currently extremely uneconomical<br>(US$ 341-549/ MWh) but with potential to halve in next 2 years | • Continued scale-up of entire crystalline silicon supply chain; process engineering to reduce costs<br>• Mass manufacture of scalable, high-efficiency thin film on flexible substrates<br>• Jump to next generation of super-efficient cells | • Capital<br>• Access to transmission grid<br>• Refined silicon, formerly bottleneck about to go into oversupply | • Substantial support, long-term but declining over time, in the form of investment tax credits<br>• Mandatory net metering by utilities<br>• Attractive tax treatment of R&D<br>• Public research funds |
| **4. Solar thermal** | 438MW | 10GWs | Uneconomical<br>(US$ 241-299/ MWh) with some reduction potential | • Proof of concept for most up-and-coming technologies | • Availability of steam turbines<br>• Links to transmission grid<br>• Permitting | • Rate support in the form of Renewable Portfolio Standard, Feed-in Tariff or Green Certificates<br>• Clear direction on permitting for large projects which cannot currently get planning permission in the US<br>• Attractive tax treatment of RD&D |
| **5. Sugar-based ethanol** | 70 billion litres per annum | 250+ billion litres per annum | Competitive with oil at around US$ 45 per barrel | • Mass adoption of efficient cogeneration equipment<br>• Ability to use efficiently all cane residues<br>• Biotechnology for longer term/geographical viability: transgenic cane<br>• Adoption of flexible fuel vehicles in different countries<br>• Transfer of technology to different sugar-producing countries | • Import tariffs/corn ethanol subsidies<br>• Lack of hedging instruments/no liquid futures market or long term contracts<br>• Logistics to keep costs low and increase export capability: transport, storage and port facilities<br>• Price of oil below US$ 50 for external market | • Definition of sustainability criteria and international standards<br>• End of import tariffs in EU, US, Japan<br>• Adoption of blend targets<br>• Brazil: legislation to allow for use of transgenic cane |
| **6. Cellulosic and Next generation biofuels** | 10 million litres per annum | 100+ billion litres per annum | n/a | • Selection or development of economically optimal feedstocks<br>• Lower process cost using enzymes, bacteria and fungi<br>• Development of algae-based biofuels | • Producing of feedstock to quantity and quality required<br>• Cost of feedstock collection/delivery to refineries<br>• Ability of existing infrastructure to cope with next generation biofuels volume | • Capital support from governments for demonstration-scale projects<br>• Blending subsidies to ensure demand – especially during periods of low oil prices<br>• Incentives for farmers to produce energy crops<br>• Attractive tax treatment of RD&D |
| **7. Geothermal** | 10GW | 10GWs | US$ 33-74/MWh | • Enhanced Geothermal Systems (EGS) using hot dry rocks<br>• Improving resource exploration technology<br>• Smaller plug-and-play modules for low-grade resource power conversion | • Drilling rig availability<br>• Power plant construction delays<br>• Permitting delays | • Rate support in the form of Renewable Portfolio Standard, Feed-in Tariff or Green Certificates<br>• Country goals specific for geothermal<br>• Accelerated planning process |
| **8. Carbon Capture and Storage** | 18 $MtCO_2e$ injected in 2008, equivalent to $CO_2$ capture from 1.4GW generation | Very substantial | Currently over US$ 100 per tonne of CO2, but with potential to halve costs | • Reducing parasitic cost of capture to nearer thermodynamic limit<br>• Understanding of long-term stability of $CO_2$ in subsurface geological environments<br>• Developing technologies to monitor and remediate possible leakage | • Identification and permitting of points of injection and plants suitable for capture<br>• Pipeline construction | • Clarity on emissions targets<br>• Clarification of environmental legislation<br>• Inclusion of captured CO2 in carbon trading systems<br>• Capital support towards cost of pilot projects |

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

Source: New Energy Finance

Further details of each of these leading sectors is included in Appendix I, and summarized in Table 3. The relative scale, technology gaps, potential bottlenecks and policy requirements for each sector are outlined.
It is important to emphasize that these are by no means the only clean energy sectors of promise. There are many other emerging technologies – a wide range of biomass-based power generation approaches, wave and tidal power, ground source heat pumps, ocean thermal and osmotic power – each of which has substantial potential and its fervent admirers.

Nuclear power is also set for a renaissance in many countries around the world. Nuclear energy's share of total electricity production has remained steady at around 16% since the 1980s, when 218 reactors were built around the world. However, nuclear power will clearly be part of any future energy system, although its contribution will be limited by issues of cost, storage, safety and public resistance. We do not consider it in detail in this paper.

Although the eight key technologies highlighted here are not yet fully cost competitive on a levelized basis, i.e. without subsidies (see Figure 16), the economics of experience curves and fossil fuel depletion are working powerfully to level the playing field. Renewable energy is becoming cheaper as technologies increase in scale and operating experience. This trend has been obscured recently by surging commodity prices and supply chain bottlenecks, but with new industrial capacity coming on-line we are about to see falls in the cost of clean energy.

It should be noted that any comparison of levelized costs of different energy sources is a minefield:

- What cost should one use for each energy source? There is no single point number which can be used: costs vary by the nature of the resource, the distance to the source of demand, the age and efficiency of the local infrastructure.
- What is the levelized cost of competing technologies? Fossil-based energy has undoubtedly benefited from substantial public investment globally in the past, but in pure economic terms that should be treated as a sunk cost; any subsidies to the fossil fuel sector, however, must be taken into account. But what about the enormous contribution to national treasuries generated through fossil fuel taxes?
- What assumptions should be made about future prices of fossil fuels? And interest rates? Renewable energy, with most of its costs up-front, may win in a high-fuel-cost, low-interest-rate scenario, but not otherwise (see Table 2. ). It is worth pondering in this context the impact of the current extreme monetary stimulus, coupled with the drop in oil and gas investment we are seeing around the world.
- How should one measure and attribute the "externality costs" of fossil-based energy? Burning fossil fuels has negative impact on public health and the environment – principally in terms of climate change – which are not borne by the energy sector. Over time, these externalities look set to be increasingly priced in to investment decisions, as shown by the abandonment of plans for scores of new coal-fired power stations in the US (e.g. the TXU transaction). We will look at the question of the role of carbon markets in spurring a shift to clean energy in Section 8.

As discussed above, the exact levelized cost of energy is contingent on an array of macroeconomic variables that can be difficult to forecast. Inputs such as prevailing interest rates, fuel prices and the market price of carbon can have large impacts on the final cost calculus. Table 2 shows a few examples of sensitivity analysis for these key variables. Electricity generation from renewable energy very often has little to no variable cost, instead front-loading the vast bulk of the lifetime cost in the upfront capital expenditures (capex). As opposed to natural gas generation, where the bulk of the lifetime cost is embedded in the variable fuel costs, capex-heavy generation is very dependent on the price of financing. In our low interest scenario, with a 300 basis point net drop in interest rates, solar PV and onshore wind fall by 8.1% and 10.4% respectively, while natural gas falls by only 1.3%. Capital costs for coal-fired plants have risen substantially over the last few years, making it also quite responsive to interest rate fluctuations. The fuel price and carbon price analysis show that natural gas has a significant advantage in a high carbon environment due to its relatively low emissions while coal cost rises precipitously by 45%.

The low interest, high carbon, and high fuel price scenario shows the plausibility of onshore wind, geothermal and biomass becoming competitive with fossil fuels unsubsidized and without significant cost reductions. In fact in many markets renewable energy is already becoming economically viable. While our global baseline average for natural gas sits at US$ 82/MWh, the high volatility of gas prices has lead many market operators to calculate a risk-adjusted cost of US$ 100-110/MWh, bringing onshore wind into the fray. In particularly sunny climates, solar PV and solar thermal correlate very well with demand peaks and already find themselves close to parity with peak power prices. While our best case scenario still leaves many forms of renewable energy generation with a sizeable gap to competing with fossil fuels, their rapid descent down the experience may push them into the energy mix faster than most expected.

The shift to a low-carbon energy system will not be achieved simply through the addition of new sources of clean energy. It will also be necessary to make wholesale changes in the way energy is distributed, stored and consumed.

The cheapest and easiest way to reduce $CO_2$ emissions – particularly in the short term – will be through improving energy efficiency. Renewable energy, while plentiful and increasingly cheap, generally has the twin disadvantages of being intermittent, and not co-located with the source of demand. Investment will be required in power storage and in energy distribution systems, principally the grid. Finally, given the abundance and security of coal supplies, it is essential that we unlock the potential of carbon capture and sequestration (CCS) technology.

### 7.1 Energy Efficiency

Energy efficiency can make a significant contribution towards closing the gap between energy demand and supply. It has frequently been said that the cheapest source of energy is the energy never used. There are enormous opportunities for improving the efficiency of the world's energy infrastructure, both on the supply and on the demand side – and many of them could even produce returns above the cost of capital of any major business.

A McKinsey Global Institute report published in July 2008 – How the World Should Invest in Energy Efficiency – argues that targeting cost-effective opportunities in energy productivity could halve the growth in energy demand and cut emissions of greenhouse gases, while generating attractive returns for investors. Boosting energy efficiency will help stretch energy resources and slow down the increase in carbon emissions. It will also create opportunities for businesses and consumers to invest US$ 170 billion a year from now until 2020, at an attractive 17% average internal rate of return.

However, there are several barriers blocking investment in and adoption of energy efficiency technologies. Market and policy barriers include a general lack of consumer education, fuel subsidies that encourage (or at best fail to discourage) inefficient energy use, and an asymmetry of benefit that leaves landlords and tenants resistant to energy efficiency because they believe that the other side stands to gain more.

A further challenge is the fact the most energy efficient opportunities are in developing countries – McKinsey's analysis suggests that two-thirds of the US$ 170 billion required investment would go to developing economies, where it would be more efficiently used as the cost of abating a unit of energy is around 35% lower than in developed countries (because here, energy savings are more marginal and therefore expensive). But in developing countries, investment is harder to come by and there is a sense of "It's our turn now", which can make them particularly resistant to pressure from countries that have already enjoyed their industrial revolutions.

In terms of sector, most energy efficiency opportunities lie in the industrial sector (49%), followed by residential (23%), transport (15%) and commercial (13%). Many of these efficiencies could be realized quite easily and cost-effectively. For example, much of the potential for industrial energy efficiency is in emerging markets, such as China, where the cost of realizing them is on average 33% lower than in the US, and as much as 50% less in some other countries. Buildings can be even made energy positive, meaning they produce more energy than they consume by using integrate solar PV (roof, facade, window), chromic glass, heat-exchangers/pumps, smart devices, and smarter architectural building designs. In the residential sector, nearly 80% of the investment would be directed at just one area – installing more efficient heating and cooling systems in existing and new homes.

However, it should also be noted that the experience from countries such as Denmark and Japan has shown that exploiting energy efficiency opportunities requires sustained public policy support over an extended period. One particular barrier to achieving step change improvements in energy efficiency world is the nature of utility regulation in the developed world: as long as utilities are able to earn more – even after any penalties or fines – for selling more gas or electricity – they will have little real incentive to help their clients reduce energy demand. So you have the paradoxical situation whereby utilities, with the lowest cost of capital of any companies, raise money to build power stations to meet additional demand from clients who can easily make energy savings with extremely short payback periods. This is a problem that can, and must, be solved by a combination of changes to utility regulatory frameworks, combined with a revitalization of the Energy Service Company (ESCO) model, whereby third parties (including utilities) underwrite the capital cost of energy-saving improvements, and share in the resulting cash savings.

### 7.2 Smart Grid

As well as using what energy we generate more efficiently, we need to streamline power generated from a far more diverse range of sources than currently – and this will require substantial investment in electricity networks around the world. The world's electricity grids were designed to distribute power cheaply and reliably from large centralized power stations to broadly distributed demand. The grid of the future will have to cope with decentralized, fluctuating supply. They will also be expected to deliver a far more sophisticated range of services to help with demand-side energy management. Only a new and fully digitally-enabled grid architecture will be able to meet these needs, and the investment requirement is estimated by New Energy Finance at US$ 10 trillion, (including US$ 6.8 trillion to repair and replace the existing transmission and distribution network). "Smart grid" technology will allow intermittent power from renewable sources such as wind and solar, as well as distributed generation, to be integrated into the grid alongside baseload power from conventional sources and nuclear energy. Sophisticated software to manage (and ideally match) electricity supply and demand in the most efficient way possible will ensure that power is delivered where and when it is needed.

Further downstream, there are a variety of technologies that aim to optimize energy supply and demand networks. Metering technologies can be used to monitor energy use in homes and offices, or individual energy-using devices. Metering data can incentivize owners to cut down on energy use, while a utility can use the information to help optimize their energy use. Smart grid technology developers create a real-time feedback loop between customers and suppliers allowing them to optimize their energy consumption during peak power events.

### 7.3 Power Storage

Power storage will be another key feature of the energy supply of the future. Across the energy system the need for energy storage is increasing, whether to power hybrid and electric vehicles, to smooth out fluctuations in supply and demand, balance intermittent renewables, or to extend appliance functionality. All application areas will provide investment opportunities in the coming years as the need for low cost, lightweight, high energy density technologies intensifies.

The hybrid vehicles of today use nickel metal hydride (NiMH) batteries. Next generation vehicles such as plug-in hybrids (PHEVs) or full electric vehicles (EVs) will most likely use lithium ion batteries. A number of start-up companies in the US and Europe are working on developing new low cost solutions. However, the battery alone will not determine the success of an EV and therefore design of the vehicle itself is of the utmost importance. As with batteries many new venture backed companies are developing new vehicles. Of course, the large automakers are working hard to develop technology of their own, however it is an area that most of left undeveloped for some time.

Technologies for bulk storage vary between traditional methods, such as pumped hydro and compressed air energy storage (CAES), to novel methods such as advanced batteries. For high power density applications, such as balancing short-term grid fluctuations, flywheels and ultracapacitors are beginning to be explored. Both pumped hydro and CAES require specific geographical and geological formations such as rivers that can be dammed or salt caverns, respectively. Therefore, batteries may be a more versatile next generation technology. In particular, sodium sulphur batteries or flow batteries such as vanadium redox have begun to be implemented for peak power load levelling and storage of intermittent wind energy. The cost of grid scale bulk storage for 1MWh of electricity ranges from US$ 40 to US$ 180, depending on the technology used.

Intermittent renewable energies such as wind will benefit greatly from power storage. Such functionality would provide enhanced reliability, balance frequency fluctuations from turbines and potentially allow for price arbitraging – selling wind generated off-peak during peak, high demand and high price electricity periods. However, battery technologies are still too expensive for price arbitraging. Prices will need to fall to US$ 50/MWh to prove economically feasible. New Energy Finance estimates that the current cost of utilizing battery technologies ranges from US$ 180/MWh for sodium sulphur batteries to US$ 114MWh for vanadium redox batteries. Several venture backed companies claim to be developing technologies that would provide significantly lower US$/MWh costs.

### 7.4 Carbon Capture and Storage

A major component to all models outlining potential solutions to climate change, carbon capture and storage (CCS) involves removing $CO_2$ from processes that utilize fossil fuels for power or industrial applications, then trapping it in subsurface geologic formations or using the gas for other purposes. As CCS is the predominant means by which the concept of clean coal is to come to fruition, and since coal-fired power generation accounts for 41% of global emissions, the potential for CCS deployment is enormous. However, up to now, CCS has experienced difficulties in gaining widespread use due to technical issues, but mostly because of insufficient legislative incentives, incomplete regulatory frameworks, and lack of public acceptance.

At present, government incentives are vastly insufficient to meet the high cost of capture and storage, which currently totals approximately US$ 115 per tonne $CO_2$ saved (and US$ 100 per tonne $CO_2$ saved for capture-only). By 2020 however, the market will be able to support extensive CCS deployment in the EU, Australia, US and Canada, although CCS, induced by trading programmes alone, will not exceed 275 million tonnes $CO_2$e injected per year. This number is a vast increase from the current yearly injection rate of 18 million tones $CO_2$e, but still only accounts for a reduction of roughly 1% of global emissions and is equivalent to the emissions from just 41 coal-fired power stations. Clearly, government mandates are needed to increase CCS as a means of carbon mitigation. Post 2020, the continuous lowering of emission targets will make CCS the essential abatement option for many countries and together with carbon trading will therefore ensure its further deployment.

The current push in CCS research and development is two fold; implementation of demonstration projects and improving $CO_2$ capture techniques. For CCS to become a widespread commercial option, the entire process from capture to storage and monitoring must be demonstrated on a utility scale. This has not yet happened, but several such projects are in planning, totalling over US$ 53 billion, and many smaller ones are currently underway. A major obstacle to the construction of large-scale demonstrations is cost, which is expected to decrease by more than half the current price, to US$ 30-60 per tonne $CO_2$ saved, as capture technology improves. There are currently over 190 capture technology demonstration projects underway worldwide.

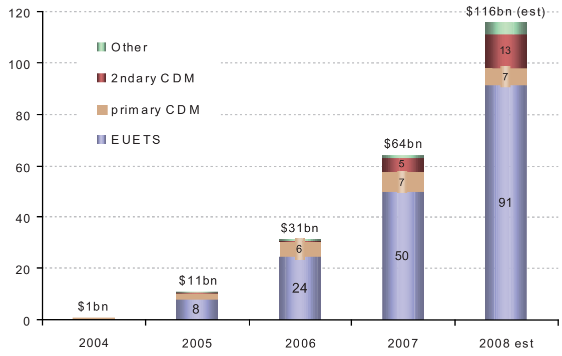
Besides working out the technical and economic details of CCS, demonstration projects will serve to provide information necessary to establish effective regulatory frameworks. Several countries have completed drafts of such frameworks.

As carbon prices are unlikely to exceed US$ 50 per tonne in the short term, CCS demonstration projects, utility scale and smaller, will be completed only with strong assistance from the public sector, and will be coupled with revenue-generating activities such as enhanced oil recovery. However, post 2020, as carbon prices rise and the cost of capture decreases, CCS will become more and more a part of global emissions reductions.

We are moving inexorably towards a world in which greenhouse gas emissions will have a cost. Over the next two decades this will transform the economics not only of the energy sector, but of all energy-intensive industries. However, carbon pricing alone will not be sufficient to spur a shift to clean energy in the short to medium term. But over the longer term carbon prices will be an increasingly important driver of investment in clean energy.

Despite the turmoil in the world's financial markets, 2008 was another year of record growth in the carbon markets. Transaction value in the global carbon market grew 81% over the first nine months of 2008, reaching a total value of US$ 87 billion and is likely to exceed US$ 100 billion by the end of the year (see Figure 17).

**Figure 17. Global Carbon Credit Trading Volume, 2004-2008, US$ billions**




Source: UNFCCC data, New Carbon Finance analysis

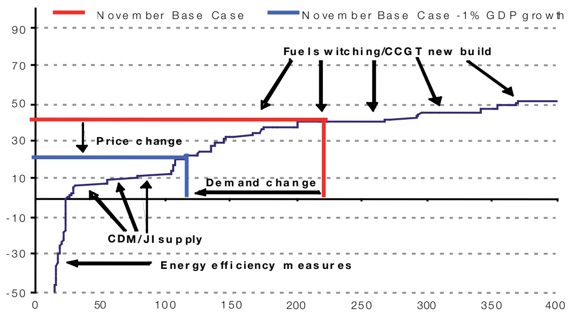
### How Carbon Markets Work

Carbon markets do not trade carbon in the way that copper markets trade copper, or oil markets trade oil. What changes hands is the right to emit a certain volume of $CO_2$ or an equivalent amount of another greenhouse gas.

The intention is first to put a price on emissions that have until now been cost-free, and second to allow trade in permits, so that those who can most easily reduce emissions have the greatest incentive to do so. There are other ways of spurring emission reductions: governments can simply mandate them, perhaps demanding the use of energy-efficient technologies – but this brings all the risks of centralized control and picking technology winners. A carbon tax is the other solution often mooted. While simple to collect, it fixes the price of emissions but not their volume, which one can then only hope will be reduced according to plan.

Cap-and-trade, in principle (i.e. before allowing the trading of project-based credits from outside the capped region or industries), fixes the volume of emissions and then lets the market find the appropriate price level. In the short term, this may be driven by the usual factors – sentiment, liquidity, news-flow, momentum and so on – but in the long term, prices are driven by the number of credits created, the expected demand from industry, and the ease of closing any shortfall between supply and demand, using technology and investment available during the relevant commitment period (see Figure 18).

**Figure 18. Drivers of Carbon Price – Supply, Demand and Abatement**




Note: Supply of credits is decided by regulations governing each particular cap and trade scheme and commitment period. Demand for credits comes from the relevant regulated industries. Any shortfall can be met by a range of abatement approaches or project-based credits from the developing world. These are exploited in ascending order of cost according to the abatement curve for that scheme and time period. The clearing price is decided by the marginal abatement technology required to meet any shortfall.

Source: New Carbon Finance

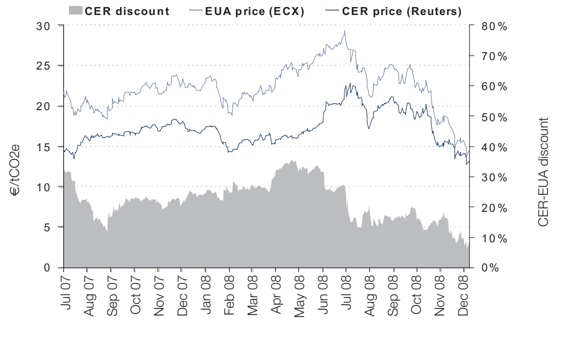
### EU-ETS and Global Kyoto Compliance Markets

Currently the most liquid markets are the European Union Greenhouse Gas Emission Trading Scheme (EU-ETS) and the global Kyoto compliance market.

The EU-ETS, which started its second phase in 2008, covers some 45% of Europe's total greenhouse gas emissions. It has dominated carbon credit trading to date, accounting for 79% of transactions by value. Despite some downward movement in price towards the end of 2008 as a result of the global economic downturn, the average settlement price of European Union Emissions Allowances (EUAs) closed the year at around US$ 25 per tonne (see Figure 19).

The Kyoto compliance market arose because signatory governments in the developed world can purchase credits from emissions-reducing projects to contribute towards their reduction commitments. These can either

**Figure 19. EU-ETS Price History: Phase II EUA and CER prices, July 2007-December 2008, €/tonne $CO_2e$**




Source: ECX, New Carbon Finance (volumes are from ECX and BlueNext only)

be generated in the developing world under the Clean Development Mechanism (CDM), or in developed

countries under the Joint Implementation Mechanism (JI). CDM credits, known as Certified Emission Reductions (CERs), accounted for 17% by value of carbon trading transactions under the EU ETS in 2008.

In order to qualify, each CDM project has to be registered with the UN. The process was initially hampered by bureaucratic delays, but there are now some 4,000 projects in the registration pipeline, which New Carbon Finance expects to yield some 1.5 billion CERs by 2012. This figure rises to more than 1.8 billion tonnes when an estimate for projects that have yet to enter the pipeline is included. Early CDM projects earned returns of hundreds of millions of dollars for modest investment by targeting industrial gases with greenhouse gas effects thousands of times more powerful than $CO_2$. Since then, however, the CDM has catalysed the investment of many billions of dollars in clean energy in developing countries.

By the end of 2008, 59% of all CDM projects were based on renewable energy or energy efficiency, although their modest size means they account for only 37% of CERs; this 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 we estimate that the CDM will have stimulated the flow of roughly US$ 15 billion from developed to developing projects for investment in low carbon projects in developing countries.

### Other Emerging Carbon Markets

Where the EU ETS and the Kyoto Compliance Markets have led, others are now following. The Australian Carbon Pollution Reduction Scheme is scheduled to start

**Figure 20. Existing Multinational Initiatives Promoting Investment in Clean Energy**

Several organizations and projects have been set up to share information and encourage investment in renewable energy, energy efficiency and the carbon markets. These include:

- Basel Agency for Sustainable Energy www.energy-base.org
- Carbon Disclosure Project www.cdproject.net
- CERES www.ceres.org
- Clean Energy Investment Working Group www.cleaninvestment.org/
- Energy Efficiency 21 www.ee-21.net
- European Energy Venture Forum www.europeanenergyventurefair.com
- Institutional Investors Group on Climate Change www.iigcc.org
- Investor Network on Climate Risk www.incr.com
- London Accord www.london-accord.co.uk
- Renewable Energy and Energy Efficiency Partnership www.reeep.org
- Sustainable Energy Finance Alliance www.sefalliance.org
- UNEP Sustainable Energy Finance Initiative www.sefi.unep.org

Source: New Energy Finance

operation in 2010. Japan is trialling a voluntary ETS after years of negotiation between government and powerful utilities and industry groups.

The US, which could – some would say should – be the deepest carbon credit market in the world, has been somewhat left behind, but is now making rapid progress. The Regional Greenhouse Gas Initiative is up and running, albeit with modest carbon reduction ambitions. California and the Western Climate Alliance are working on state-level or regional plans. Then there is the voluntary market, rapidly taking shape and increasing in volume. And President-Elect Obama has clearly stated his support for a federal cap-and-trade scheme.
The emerging mosaic of carbon markets may look chaotic, but what we are seeing is the emergence of a system of interlinked, policy-led financial markets, similar to today's currency markets.

## Potential Future Developments

Perhaps the biggest problem the carbon market presents to investors – other than its sheer complexity – is its apparently uncertain future. The Kyoto Protocol in its current form lasts only until 2012. Two processes are under way, working to develop a successor regime: one involving those nations that have ratified Kyoto, and a second, the so-called Bali roadmap, which includes the US.

The December 2008 Poznan negotiating session, which took place after the US election but before the Inauguration of President Obama, produced little of substance, although this was not surprising. Issues debated included the adoption of emissions targets for large developing countries (India and China) – although this was firmly rejected, the structure of the CDM, the inclusion of credits from avoided deforestation and carbon capture and sequestration and, of course, the potential commitment by the US. President Obama has signified that such a commitment will be forthcoming under his leadership, and the world is holding its breath to see what comes out of negotiations in Copenhagen in December 2009. This is seen as the last chance if there is to be a solution in place before the current Kyoto arrangements expire in 2012, although missing that deadline does not mean the process is dead, so an extension is possible, if not probable.

Whatever happens in Copenhagen, the future of the EU ETS and CDM is secure. The EU has shown a strong commitment to climate goals in general – most recently passing the climate package which sets out its target of reducing emissions by 20% by 2020, and by 30% if other nations join in – and to the EU ETS in particular. It will also continue allow CDM credits to be used in lieu of local carbon reductions. New Carbon Finance's central forecast for the price of credits in Phase II of the EU ETS is for an increase from the current US$ 21 per tonne to US$ 40 per tonne in 2012. Beyond 2012 prices will continue to rise as carbon caps bite more deeply in the run-up to 2020 and beyond, and easy sources of credits are exhausted.

## Summary: Carbon Markets – Necessary but not Sufficient

In summary, the long-term outlook for carbon remains bullish as momentum towards a network of national and regional schemes remains strong. However, it will be some time – possibly decades – before carbon credits alone provide an economic rationale for the large-scale roll-out of renewable energy, for the deployment of the key enabling technologies for such large-scale roll-out, or for commercial carbon capture and sequestration projects. If these goals are to be achieved, a broader range of policy tools is required.

# 9. Longer-Term Policy Requirements

Any shift to a low-carbon energy infrastructure will need to be supported by a range of policy tools: there will be no one-size-fits-all solution. A carbon price, while helpful, will not be sufficient to spur the deployment of renewable energy or carbon capture and sequestration for the foreseeable future. And even if policy-makers make incentives for clean energy a key element of their response to the current financial crisis, there will still be a need for further action. The industry needs a rational set of support mechanisms, tailored to each geography and sector.

While a carbon price is the logical foundation of any policy regime for clean energy, as we have seen, it cannot on its own spur the development of a healthy clean energy industry. It might drive a switch by utilities from coal to natural gas, boost energy efficiency and discourage deforestation, but it cannot stimulate the uptake of a variety of clean energy technologies at different stages of maturity. Nor can it catalyse the deployment of the key enabling technologies that will be required, including the digital grid and carbon capture and sequestration.

These goals will only be achieved by support tailored to the stage of commercialization of the sector in question:

- **Almost Commercial.** Sectors nearing maturity and competitiveness with fossil fuels need rate support only for a limited period to help them close the gap. Once a clean energy technology is within 20% of the cost of fossil energy, it should be able to stand on its own two feet, with utilities choosing to deploy it as a way of hedging against feedstock volatility (as demonstrated by the late Dr Shimon Awerbuch). But until this tipping point is reached, the goal should be to support renewable technologies during a finite period while suppliers drive their costs down.
- **Ready to Scale.** Technologies that work in the lab but are too risky to scale up need support and finance to bridge the "Valley of Death", which they must pass through in order to reach commercialization. Until the first full-scale plants are built, it is impossible to eliminate technology risk – which debt providers will not take. Yet equity providers will not make adequate returns without an element of debt funding. Specialist funds could help break this inherent circularity. Technologies currently falling into this "Valley of Death" might include marine power, next generation biofuels, large networks of plug-in hybrids and advanced geothermal, even very large-scale offshore wind turbines and solar thermal chimneys. Major public funds could be created to smooth the transition of these technologies across the Valley of Death. These should be sufficiently large to pool the risk of multiple technologies and projects; they should leverage the skill of private equity providers and insurance companies; and they should take only the final tranche of unavoidable technology risk.
- **Blue Sky.** Sectors with longer-term technological promise need research funds. Venture capital investment in clean energy technologies has exploded since 2005, but it is remarkable how small the total investment is – US$ 4 billion worldwide out of total clean energy industry investment of US$ 142 billion in 2008 (just 3%) – reflecting a shortage of "outside the box" ideas. There needs to be far higher investment in universities, national labs and other publicly-funded research into the fundamentals of energy technology. With the path to market for energy technology often taking 10 to 15 years, commercial players tend to under-invest in blue sky research – a gap that could be plugged by public funds.

But simply supporting chosen sectors will not be enough to develop and deploy new renewable energy technologies. An entire ecosystem of supporting technology and service providers will be fundamental to the growth of a healthy clean energy sector – and this is inextricably linked to the ability of entrepreneurs and companies to create new businesses. One of the reasons that Europe consistently lags venture investment in clean energy in the US by a factor of five to seven is that the **conditions for venture investment** in Europe are less well-developed.

Governments should also lead by example, creating markets for clean energy through **public procurement.** With central, regional and local government accounting for 35-45% of economic activity in all of the world's largest economies, public sector purchasing can be a powerful force. Clean energy use should be mandated in public procurement, which would create guaranteed markets for leading innovators in transport, heat and electricity.

Finally, policy-makers should enforce **energy efficiency standards.** Utilities and energy-intensive industries will respond to carbon prices and other price signals, but many individuals and businesses will simply not do so. As a result, there will always be a role for regulation to mandate certain changes in behaviour, such as appliance efficiency and standby power limits, corporate average fuel economy (CAFE) standards and building codes. They must also address the asymmetry between energy providers, who want their customers to use as much energy as possible, and consumers, who on the whole would prefer to use less.

But whichever policies are adopted, the overarching requirement is for policy stability – the impact of policy uncertainty on cost of capital must be better understood – and simplicity, so that the industry is not burdened with unnecessary bureaucratic costs.

# Appendix - Target Sector Summaries

## 1. Onshore Wind

The most mature of the renewable energy sectors, the onshore wind industry saw 21GW built in 2007, bringing installed capacity to over 100GW. In Germany, Spain and Denmark wind power now supplies 3%, 11% and 19% respectively of total electricity production during the course of the year, and in Denmark up to 43% of the country's electricity demand at times of peak wind supply. Electricity from onshore wind can be generated at prices of 9-13 c/kWh, making it only 32% more expensive than natural gas CCGT, even in the absence of a carbon price. The Global Wind Energy Council forecasts that the global wind market will grow by over 155% to reach 240GW of total installed capacity by 2012.

Onshore wind can compete with conventional generation without subsidy, where wind speeds are high enough. However, 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 Germany and the US.

### Policy Status and Gaps

The wind industry has benefited from broadly supportive legislation, particularly in Europe and India which until recently has been home to the world's largest installed wind generation capacities, but now increasingly in North America and China. However, the industry needs a stable policy environment and reinforcement/renewal of existing policies if it is to continue to thrive. Political incentives to increase investment in the electricity grid will also boost the wind sector (along with all clean energy generation technologies).

### 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. The industry has been built on three-bladed upwind turbines whose design was popularized and commercialized by Danish companies in the late 1990s. 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:

- Operations and maintenance, where marked improvements in existing asset management techniques are being pioneered through scale and closer inventory and technical team management
- Innovative technologies, either to reduce the cost of generation and the sector's exposure to volatile commodities (steel/copper)
- Supporting infrastructure for wind farms both in resource forecasting (high technology required) and grid expansion (mainly capital rather than technology required)

### Potential Bottlenecks

Raising finance will remain a bottleneck in the short term, as it will for all energy projects. This is not only to do with less capital being available to finance onshore wind, but also because margins have broadened. Financing projects at a cost that makes economic sense will also be a challenge.

In the longer term, blade and turbine supply may constrain onshore wind development. Planning permission remains an issue, particularly in the most heavily populated and mature European markets, such as the United Kingdom.

**Table 4. Onshore Wind – Economic Overview**

| | |
|---|---|
| **Potential Scale** | Greater than 1,000GW, of which only 100GW has been exploited. |
| **Market Readiness** | LCOE = US$ 89- 126/MWh |
| **Project Returns** | 10-20% depending on market and resources |

Source: New Energy Finance

**Table 5. Top five wind markets by capacity, 2007**

| Market | Capacity (GW) |
|---|---|
| **Germany** | 22.7 |
| **United States** | 16.9 |
| | 15.1 |
| **India** | 8.3 |
| **China** | 5.9 |

Source: New Energy Finance, GWEC

## 2. Offshore Wind

When the best sites for onshore wind have been snapped up, the next place to look for large quantities of renewable energy 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. At present, the cost of electricity from offshore wind is high – more than 16 c/kWh, but these will come down rapidly as more project experience is gained.

Offshore wind is relatively unexploited compared to onshore wind, but is coming into its own as the onshore market becomes saturated, particularly in densely populated areas such as Europe. However, offshore wind faces some logistical and design challenges, including the high cost of grid connection from offshore sites, higher wear and tear, and more difficult operation and maintenance.

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 21). Other markets such as Belgium (0.8GW granted concession), Netherlands (150-200MW under construction), Denmark and Sweden will also provide demand for turbines and installation vessels.

The United Kingdom government has placed a growing emphasis on offshore wind to meet its long term renewable targets and as a hedge against rising gas imports. However, impatience with government procedure has led some industry participants to forge ahead with their own support plans for prototype turbines. For example, the Crown Estate, which owns more than half the United Kingdom's foreshore, tidal riverbeds and seabed rights, has committed to buy Clipper Windpower's first offshore wind turbine.

In the US high profile and contentious debate over the Cape Wind Project near Cape Cod has marred debate and to some extent distracted from the quality resources off the coast of major load centres where high electricity prices are common such as Virginia, Rhode Island, and New York.

### Policy Status and Gaps

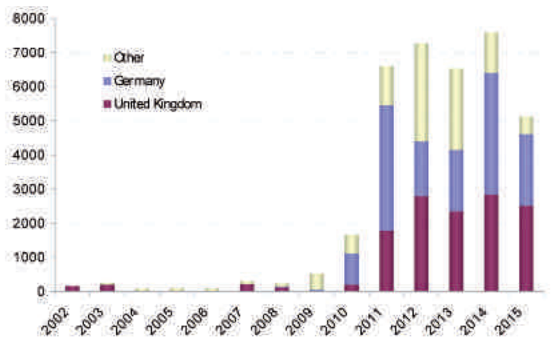
Offshore wind's long lead times, substantial capital spending (US$ 300m+) and long term operating risk

**Table 6. Offshore Wind – Economic overview**

| | |
|---|---|
| **Potential Scale** | 100GWs |
| **Market Readiness** | LCOE = US$ 158-205/MWhProject |
| **Returns** | Marginal |

Source: New Energy Finance

**Figure 21. Current and planned offshore wind projects by expected commissioning date (MW)**




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

mean that investors (primarily oil, gas and utilities) have made cautious but significant moves in the sector. The United Kingdom and Germany are emerging as key markets, defined by steadily increasing policy support in the form of planning guidelines, feed-in tariffs and green "top-up" certificates. Elsewhere in Europe patchwork support is spurring some growth in Denmark, Sweden, Netherlands and Belgium, but higher than expected costs and capital spending uncertainty remains a challenge.

### Technology Gaps

Offshore wind faces a substantially different and far harsher environment to onshore wind, with the result that early marinized versions of onshore turbines installed offshore suffered high profile and costly reliability issues. Significant work by Siemens, Vestas Repower and others have resolved many of the reliability issues by strengthening and improving components and insulating internal mechanisms from salt laden sea air.

This has come at a cost though with considerable compromises made on weight and upfront costs. Reducing the weight of the nacelle (at the top of the tower) either through removing or replacing electrical components, gearboxes or blades are still being actively pursued by numerous companies and it is likely that innovations around turbines and foundations will improve the economics of offshore wind – as long as a stable demand environment is generated by governments.

### Potential Bottlenecks

Offshore turbines have lower profit margins than onshore turbines; as long as onshore development continues to be healthy, turbine manufacturers will focus on producing onshore turbines, creating a potential bottleneck for offshore turbines.

## 3. Solar – Photovoltaic (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 commercializing thin film technology, with investment volume growing to US$ 50 billion in 2007-2008 (see Figure 22). Although there has been a bottleneck in the production of solar-grade silicon, new capacity is coming on line and costs are set to drop rapidly from US$ 4/W to US$ 2.60/W by the end of 2009, making unsubsidized solar PV generation costs comparable with daytime peak retail electricity prices of approximately 17 c/kWh in many sunny parts of the world.

PV has also flourished under generous incentive regimes in Germany and then Spain, encouraging high profile IPOs from silicon, wafer, cell and module manufacturers. These companies' values have soared because a severe shortage of silicon has driven up their products' price and ensured strong order books.

Other companies have capitalized on the silicon shortage by developing technologies that use less silicon in their solar modules, or that use other materials altogether. Although the global PV market has traditionally been dominated by crystalline silicon modules, New Energy Finance expects that thin-film modules (silicon and non-silicon based) will account for 18% of solar panels produced in 2008, up from 14% in 2007. Thin-film modules are cheaper to produce than conventional silicon modules, because they use less silicon and benefit from a more integrated manufacturing process.

Installed PV generation capacity worldwide is 13.3GW, a fraction of installed wind capacity. This is because solar is the most expensive renewable energy source in nearly all applications. While it is the best option in a few niches, such as grid-isolated telecommunications towers and calculators, these markets are tiny. The growth markets are for grid-connected power plants supported by generous incentives. PV will eventually become cost-competitive in some mainstream retail markets, and this will unlock substantial additional demand, but this is unlikely to happen for several years.

### Policy Status and Gaps

Incentives are by far the most significant driver of the PV market, in the form of feed-in tariffs and/or tax credits. Where these have been provided, as in Japan, Germany, Spain, and California, PV has thrived. Conversely, where subsidies are being capped or phased out, as they were in Japan and more recently have been in Spain, installation falls away.

PV also requires mandatory net metering, as homeowners need easy two-way access to the grid to benefit from owning distributed generation.

### Technology Gaps

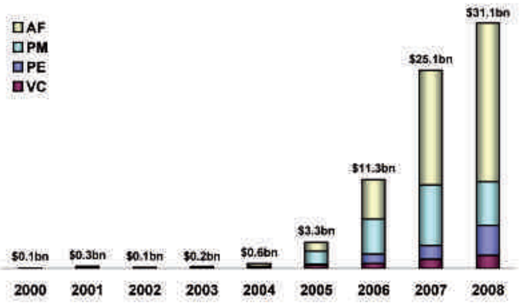
Mass manufacture of thin-film modules and reduction of cost for crystalline silicon modules are the key challenges for the solar industry. The next few years will be crucial, but if PV delivers on its near-term promises it will be cost-

**Table 7. Solar PV – Economic Overview**

| | |
|---|---|
| **Potential Scale** | 13.3GW currently installed<br>Potential capacity limited only by economics |
| **Market Readiness** | LCOE = US$ 341-549/MWh<br>Currently extremely uneconomical but with potential to halve in next 2 years |
| **Project Returns** | Heavily dependent on incentive regime |

Source: New Energy Finance

**Figure 22. Investment in solar (nearly all PV), 2000-2008: US$ million**




Source: New Energy Finance

effective in many more niches and will need much less subsidy than at present.

### Potential Bottlenecks

Over the next two years, oversupply of modules appears inevitable and the price is likely to fall to the marginal cost of production, representing a 40% fall for crystalline silicon modules. Shortage of affordable capital (the economics of PV are extremely sensitive to interest rates because nearly all the cost is upfront), caps to incentive regimes, customer inertia and permitting and transmission bottlenecks are therefore the main limits to the growth.

## 4. Solar Thermal Electricity Generation (STEG)

While PV is ideal for building-integrated and smaller projects, the technology of choice for big solar plants in the world's deserts looks set to be thermal: concentrating the heat of the sun to generate steam, which can be used in conventional and highly efficient turbines. There are relatively few projects up and running yet, but with costs of 24-30 c/kWh, this technology is shaping up to be a part of the solution in the sunniest parts of the world.

Solar Thermal Electricity Generation (STEG) – also known as Concentrated Solar Power (CSP) – comes in many different designs, the most mature being parabolic trough, but new ideas including tower and heliostat, Fresnel linear reflectors and parabolic dishes have been developed. All work on the same principle, of using mirrors to concentrate the sun's heat to produce steam that drives a turbine.
There is very little installed STEG capacity worldwide; just 438MW, although a further 131MW is due to be commissioned in Spain by the end of 2008. There is a large pipeline of STEG projects, mostly in Spain and the US but also several backed by government tenders in the Middle East and development bank funding in North Africa and Mexico (see Figure 23).

North Africa has excellent theoretical STEG potential – it has very high insolation, is eligible for funding from international development agencies and could be connected to Italy (and then to the rest of Europe) via a short submarine transmission cable. However, the region lacks the political support and grid connection to get the industry off the ground. In spite of this, some STEG plants are being developed, but most are add-ons to existing combined cycle gas turbine plants rather than stand-alone installations. In Morocco, for example, construction has started on the Ain-Beni-Mathar project, a 470MW combined cycle gas plant with a 20MW STEG component, funded by the National Electricity Office, the African Development Bank and the Global Environment Fund.

The first operational STEG plant was the Luz parabolic trough plant in the Mojave Desert, California. This was built in the late 1980s and early 1990s, and although the developer was forced into bankruptcy, it has been operating ever since.

### Policy Status and Gaps

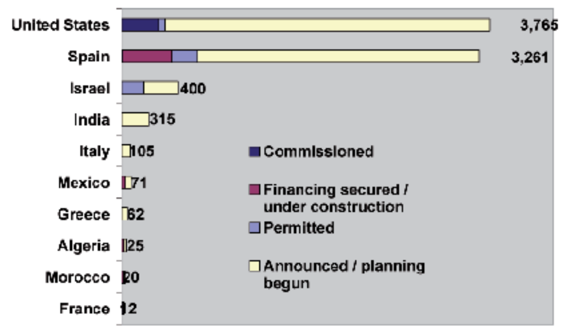
Like PV, STEG is highly subsidy-dependent, and there are only two near-term markets: Spain and the US. Spain's future after 2011 is uncertain, because once 425MW of STEG is installed, there will be a window of 12-24 months for further projects to be commissioned under the current regime. In the US, the eight-year Investment Tax Credit and utility willingness to contract for STEG to meet Renewable Portfolio Standards give the industry certainty. In other markets, progress on government tenders and development projects is slow.

**Table 8. Solar Thermal - Economic Overview**

| | |
|---|---|
| **Potential Scale** | 438MW currently<br>Scale limited only by space and grid connection has been exploited. |
| **Market Readiness** | LCOE = US$ 241-299/MWh<br>Uneconomic |
| **Project Returns** | n/a |

Source: New Energy Finance

**Figure 23. STEG pipeline by country and status, 2008, MW**




Source: New Energy Finance

### Technology Gaps

While parabolic trough is essentially a mature technology, and turbine design is unlikely to see any breakthroughs, new STEG collector designs have the potential to improve PV's economics when their technology is proven. Funding for the first large-scale plants, however, will be difficult as they will involve technology risks.

### Potential Bottlenecks

In Spain, there are no bottlenecks for those with projects in the pipeline. In the US, permitting and transmission access will keep most planned projects on the drawing board for at least a year, and once those are overcome, it may not be easy to raise the necessary capital.

## 5. Sugar-based Ethanol

The period 2004-2006 saw US investment in biofuels soar, with investors pouring US$ 9.2 billion into the sector (see Figure 24). But most of this flowed into corn-based ethanol, which is more expensive to produce than sugar-based ethanol, subject to volatile prices and controversial because its feedstock is a food as well as a fuel. Many investors regretted their haste. By contrast, Brazilian sugar cane-based ethanol is competitive with oil at US$ 40 per barrel; it grows well in many southern hemisphere countries (and far from the Amazon); and there is no shortage of land to increase production substantially without jeopardizing food production in the region.

Sugar cane is the most cost-efficient and environmentally friendly feedstock for ethanol production with 70-90% fewer $CO_2$ emissions than gasoline, but it can only be grown under specific climate and soil conditions in southern hemisphere countries. Brazilian sugar cane ethanol is competitive with petrol at US$ 40 a barrel, but ethanol from other feedstocks, such as maize, is not economic without subsidy. The US ethanol market in particular has suffered as corn prices have soared since 2006, making production uneconomic in many cases and forcing producers to scale back their expansion plans. Corn ethanol also suffers from the food-fuel controversy, as well as relatively unimpressive emissions reductions (up to 30%).

Global ethanol production capacity is 70 billion litres per annum (Lpa). Brazil and the US are the two largest ethanol producers in the world, producing respectively 27 billion Lpa and 35 billion Lpa.

### Policy Status and Gaps

Most countries seeking to promote ethanol use do so by imposing a minimum blending requirement, although the well-established markets of Brazil and the US have discretionary blending. Ethanol can be used in ordinary vehicles in a blend of up to 25% without engine conversion, making widespread adoption a viable prospect.

Policy is a key driver of ethanol markets, both domestically and internationally. Ethanol benefits from blending mandates and local subsidies; but the operation of a global market is inhibited by widespread import tariffs that put Brazilian ethanol in particular at a disadvantage to locally produced ethanol in the US and other countries. France, however, recently announced that it would reduce and eventually cut its subsidies to domestic ethanol producers by 2012, and other countries may follow its lead.

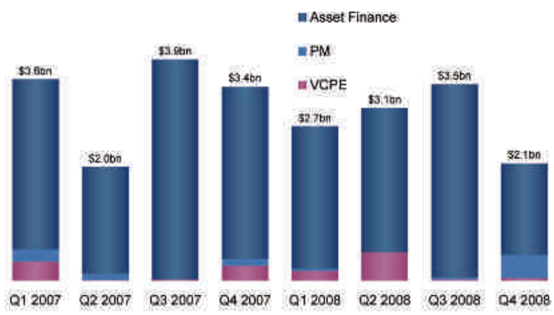
Ending import tariffs and defining international standards would also boost the international ethanol market, avoiding market distortions and allowing for free trade and long term international trade contracts. Brazil, which understandably lobbies for the removal of import tariffs,

**Table 9. Sugar-based Ethanol – Economic Overview**

| | |
|---|---|
| **Potential Scale** | 70 billion Lpa commissioned production capacity Global production estimated to reach 255 billion Lpa by 2030 |
| **Market Readiness** | Brazilian sugar ethanol is market-ready i.e. competitive in its own right with oil at US$ 40/barrel |
| **Project Returns** | n/a |

Source: New Energy Finance

**Figure 24. Investment in Sugar/Maize Ethanol, US$ million**




Source: New Energy Finance

has some support from the US, Sweden and international trade organizations.

Brazilian ethanol production would benefit from legislation to allow 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, increasing sugar cane ethanol productivity significantly.

Genetically modified sugar cane cannot be commercialized in countries like Brazil, but transgenic cane technology has nevertheless been developed by companies like Alellyx in Brazil (recently acquired by Monsanto for US$ 287m), and could boost sugar cane's productivity by 20%.

### Potential Bottlenecks

Falling oil price – and reduced crush spread – is the ethanol market's biggest challenge currently. With oil below US$ 40/barrel, even Brazilian ethanol ceases to be competitive overseas, although it remains in demand domestically.
Import tariffs and local subsidies also create a bottleneck for sugar-based ethanol. Once these are removed and a more level international playing field created, market mechanisms such as hedging instruments and a futures market will help build a transparent global ethanol market.

## 6. Cellulosic and Next Generation Biofuels

The argument over food vs fuel is an emotive one. In most regions, there is sufficient land to increase biofuel production from the current 1% of transport fuel to 3% or even 5% without impacting on food availability. But after that the only way to increase production of biofuels will be to source feedstock that does not compete with food. Luckily, the cost of producing biofuels from agricultural waste through cellulosic conversion and algae is coming down rapidly, and the future fuel system is likely to include a proportion of fuels from these sources.
As well as using byproducts of other crops, such as wheat straw, sugar cane leaves and forestry waste, crops are being grown specifically to produce biofuels, including jatropha (being trialled 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 – around 10 mLpa, compared to 69,900 mLpa of sugar-based ethanol – accounting for just 0.02% of global bioethanol production. However, this is expected to rise as new feedstocks are grown, technologies proven and scaled up, and the cost of production falls. Early-stage investment in second generation biofuels overtook first generation investment in the second and third quarters of 2008 (see Figure 25), although current economic conditions may reverse this trend in 2009.

### Policy Status and Gaps

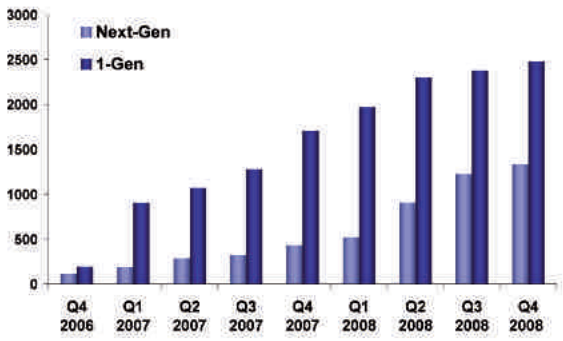
Policies supporting next generation biofuels are essentially the same as those relating to sugar-based ethanol (see above), including blending mandates, tax breaks, biofuel producers subsidies and feedstock

**Table 10. Next Generation Biofuels – Economic Overview**

| | |
|---|---|
| **Potential Scale** | 10 mLpa commissioned production capacity currently |
| **Market Readiness** | 5-7 years away from commercial production |
| **Project Returns** | n/a |

Source: New Energy Finance

**Figure 25. Venture Capital and Private Equity Investment in Biofuels – First Generation vs Next Generation, US$ million**




Source: New Energy Finance

cultivation subsidies. However, policy is starting to differentiate between first and next generation biofuels, in favour of the latter. In the US, for example, there is a mandate within the renewable fuel standard for a specific proportion of next generation biofuels.

In some countries, governments are giving farmers incentives to grow crops specifically for energy use, such as jatropha in India. Uptake has been poor, however, with farmers proving reluctant to run the risk of producing a crop whose yields are unproven, which may damage the soil and for which there is not yet an established market

The market needs capital support, in particular government funding for demonstration-scale projects to prove the technology is viable/scalable as well as encouraging farmers to invest in feedstock production. Financial incentives to encourage farmers to grow energy crops are also vital to overcome their initial caution.

Blending subsidies offering tax breaks to oil companies who blended next generation biofuels into their products, provided over a reasonably long time horizon (4-8 years) would also help reduce operating costs and give farmers, producers and developers an incentive to invest.

### Technology Gaps

Research and development is still focusing on which crops can be grown successfully on marginal land, and also which can be grown economically.

The key challenge for next generation biofuels is to lower production costs sufficiently to compete with conventional energy, and also with first generation biofuels, particularly sugar cane ethanol. Next generation biofuel production processes that fit easily and inexpensively into existing production capacity have the best chance of success.

### Potential Bottlenecks

As with sugar-based ethanol, a falling oil price is a threat to investment into the sector, even though blending mandates provide the industry with some support. Otherwise, logistics is potentially a bottleneck. Feedstock is typically bulky and therefore expensive to transport long distances. Making sure that feedstock is grown as near as practical to processors and produced to the right specification is crucial.

## 7. Geothermal

Geothermal power is particularly attractive as a renewable energy source because it can be used as predictable base-load power in a way that wind and solar power cannot be.

Geothermal taps the naturally-occurring heat stored in rock up to several miles below the surface of the earth. The extraction process is relatively simple in theory: a series of holes are drilled into the ground and the subterranean heat is captured by drawing to the surface the naturally occurring steam or hot fluid. The steam is then run through a turbine directly, or the hot geothermal fluid used to heat a separate working fluid that converts to a gas to turn the turbine. In both cases, the used geothermal fluid is injected back into the subsurface to aid in replenishing the resource.

Until now, geothermal power has been used only in limited regions, but a raft of new approaches has helped make it economically viable across a wider area. In addition, all countries can exploit geothermal resources for ground source heat pumps or district heating, if not for large-scale electricity generation. Notable production advances are taking place in the US, the Philippines, Indonesia, Iceland, New Zealand, Australia, Turkey, and Germany. Spurred in part by regulatory support, there is now a large geothermal development pipeline, especially in the US.

Global installed capacity at the end of 2007 was estimated to be 10GW (see Figure 26).

### Policy Status and Gaps

Renewable Portfolio Standards (RPS) help investors overcome the high up-front capital investment and financial risks of geothermal. Because geothermal is baseload power, it receives favourable pricing from utilities required to include renewables in their energy mixes. The large development pipeline in the US illustrates the positive effect of policy.

While tax credits, feed-in tariffs and national geothermal targets further spur geothermal investment, RPS is the key policy driver.

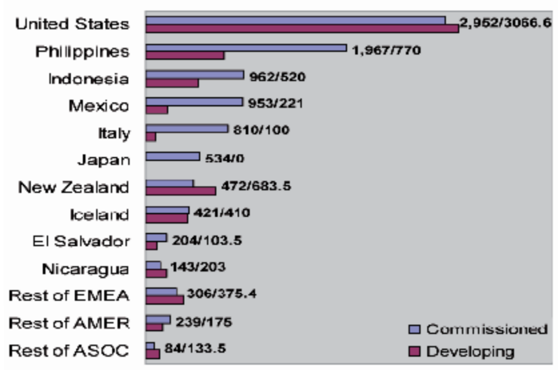
### Technology Gaps

Enhanced Geothermal Systems (EGS) extract heat by creating a subsurface fracture system into which water is injected. EGS “enhance” or create geothermal systems where natural fractures provide inadequate flow rates. The appeal of EGS is that poorly producing resources can be improved and non-productive ones made productive: if the technology is successful, geothermal electricity could be produced anywhere in the world. The resource potentials for EGS are vast – estimated at 517GW for just the US. The first pilot EGS plant came online in France in June 2008, but research is being carried out elsewhere, including Australia, where the world’s largest EGS (5-10GW) is being built.

| Table 11. Geothermal – Economic Overview | |
|---|---|
| **Potential Scale** | 10GW currently installed 24.5GW potential capacity by 2030 |
| **Market Readiness** | LCOE = US$ 33-74/MWh |
| **Project Returns** | n/a |

Source: New Energy Finance

**Figure 26. Global Commissioned and Developing Geothermal Capacity, Jan 2008: MW**




Note: Labels denote installed/developing capacity in MW

Source: New Energy Finance

Improvements in exploration technology would facilitate development of resources with no surface manifestations. In the US, for example, these resources are estimated to be 33GW. Better exploration technology would also improve the current drilling success rate in greenfield sites of just 20%, dramatically cutting development costs.

Smaller "plug-and-play" units are being developed to use resources that were previously uneconomical because of low flow rates, projects of 10-15MW. UTC is one of the leaders in this area.

### Potential Bottlenecks

As more companies become involved in developing geothermal projects, their fast growth risks eclipsing the available contractors and creating a construction bottleneck, increasing lead times and capital costs. Already there are long lead times (6-18 months) for drilling rigs – there is a shortage of specialist geothermal rigs (or ones that have been modified to cope with the more demanding geologies associated with geothermal). This is encouraging vertical integration (developers buying drilling companies) as well as developers and "drilling clubs" booking up rigs for long periods. There is also 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. Carbon Capture and Storage

No discussion of the future energy infrastructure would be complete without considering Carbon Capture and Storage. Although there are no installations at scale yet, almost 200 projects are at varying degrees of completion around the globe. With so many countries – including China and the US – dependent on coal-fired power, it is inevitable that CCS will form part of the solution to hitting $CO_2$ concentrations of 450ppm. In 2008, for the first time, the IEA's World Energy Outlook report included CSS as a technology that would be viable – and important – by 2020.

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 Norway), adding CSS to conventional power generation projects does not currently make economic sense (see Figure 27). 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. While it is accepted that CCS can reduce fossil fuel emissions, CCS's substantial cost has so far deterred large emitters from developing large-scale CCS projects. Instead investment has gone towards smaller scale projects that will serve as a springboard for development if a more stringent carbon reduction policy makes CCS economically viable.

18 million tones (Mt) $CO_2$e were injected in 2008, equivalent to the $CO_2$ emissions of 1,385MW of coal-fired generation (approximately 3 large coal-fired power plants)

### Policy Status and Gaps

Key drivers for CCS include national and/or regional emissions standards (restricting how much $CO_2$ and other greenhouse gases power generators and industries can emit); subsidies that help bridge the gap between the cost of installing and running CCS, and the time when it

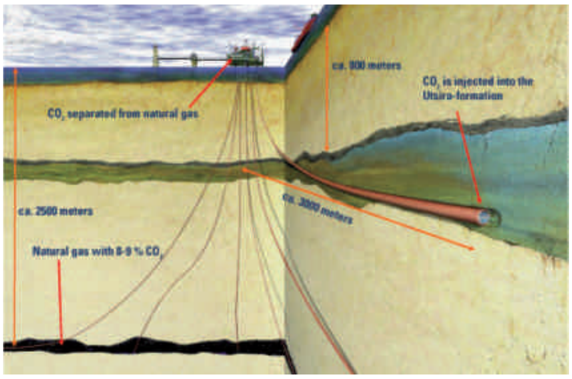
becomes economically viable (or imperative) to run the technology; and carbon trading systems, which put a transparent value on $CO_2$ emissions and allow emitters to capitalize on reducing their $CO_2$ emissions
The United Kingdom government has taken a lead in encouraging the construction of the first utility-scale project by setting up a contest whose prize is up to 100% of CCS retrofit to capture at least 90% of emissions on 300 MW of an existing coal-fired power plant. Bids have been submitted and are under review.

**Table 12. Carbon Capture and Storage – Economic Overview**

| | |
|---|---|
| **Potential Scale** | 18 Mt$CO_2$e injected in 2008, equivalent to $CO_2$ capture from 1.4GW generation |
| **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

**Figure 27. Global Commissioned and Developing Geothermal Capacity, Jan 2008: MW**




Source: Statoil

## Technology Gaps

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 – both in terms of $CO_2$ stored and the cost of doing so – the industry will take off. As the most expensive part of the CCS chain, carbon capture is a focus for research and development investment.

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, $CO_2$. $CO_2$ storage research is also designed to win public acceptance of CCS.

## Potential Bottlenecks

Identifying sites suitable for $CO_2$ storage, where injection points can be made, and also, at the other end, plants suitable for capture. 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, thousands of kilometres of $CO_2$ pipeline to go from source to sink, or connect to a $CO_2$ pipeline network, must be built. 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 $CO_2$ pipeline.

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**Appendices**

Global Wind Energy Council (GWEC) – wind industry statistics
Statoil – carbon capture and storage diagram

# About the Authors

## From New Energy Finance

**Michael Liebreich**
Michael Liebreich is Chairman and Chief Executive of New Energy Finance, the leading independent provider of information and research to investors in clean energy and the carbon markets. The company has a staff of 130 working out of 11 offices around the world, offering a range of services for senior decision-makers, including newsletters, data, subscription-based analysis and consultancy. Its New Carbon Finance division provides price forecasting, analytics and risk management services relating to all of the world's emerging carbon markets.

Michael serves as a Member of the World Economic Forum's Global Agenda Council on Alternative Energies, Advisory Board Member for the Energy and Climate Change working group of the Clinton Global Initiative (CGI) and Steering Group Member for a number of IEA RETD projects. Michael is a member of the Energy Leadership Forum of E+Co and an Advisory Board Member of the Wilderhill New Energy Global Innovation Index. He is on the Selection Committee for the 2009 Zayed Future Energy Prize and for the annual Euromoney and Ernst & Young Global Renewable Energy Awards. Prior to founding New Energy Finance in 2004 Michael helped to build over 25 companies as a venture capitalist, entrepreneur and executive, and spent five years with McKinsey and Company.

Michael earned his Masters in Engineering from Cambridge, winning the Ricardo Prize for Thermodynamics, and has an MBA from Harvard Business School. From 1986 to 1993 he was a member of the British Ski Team, competing in the World Cup and the 1992 Albertville Olympic Games. He is Chairman of the St Marks Hospital Foundation, a medical charity.

**Chris Greenwood**
Chris Greenwood is Head of Research at New Energy Finance, the leading independent provider of information and research to investors in clean energy and the carbon markets. Chris's responsibilities include managing New Energy Finance's research and analysis activities. This involves understanding the value chains and micro-economics of each clean energy sector, mapping organizations and investors, and analysing investment activity. Chris ensures that clients' needs are met through New Energy Finance's publications and analysis services.

Chris has 18 years of analysis, consulting and management experience from a number of roles within European energy companies, consultancy and IT services organizations. He holds a B.Eng (Hons) in Electrical Engineering from Imperial College, London.

# About the Authors

## From the World Economic Forum

**Max von Bismarck**
Max von Bismarck is Director and Head of Investors at the World Economic Forum. He leads an international team based in New York and Geneva which globally oversees all substantive activities and relationships of the World Economic Forum related to Private Equity, Venture Capital, Hedge Funds, Institutional Investors and Sovereign Funds.

Max currently champions projects concerning an emerging "New Financial Architecture", the "Globalization of Alternative Investments" and opportunities in "Green Investing". As an advisor to the Chairman he also led the process for the World Economic Forum 2005-2008 strategy development. Prior to joining the World Economic Forum Max helped to build 2 companies as an entrepreneur. He was a Co-Founder and Managing Director at Public One Strategy Consulting and Director Legal of the Oxford based technology company Mondus Limited. He studied Law and Modern History at St. John's College, Oxford University, and Humboldt Universität zu Berlin and holds an Executive Masters in Global Leadership (World Economic Forum in collaboration with Columbia University and INSEAD). Max was named a German-American Young Leader of the Atlantikbrücke in 2004 and a Global Leadership Fellow of the World Economic Forum in 2005. Max is a trustee of the World Economic Forum Retirement Plan.

**Anuradha Gurung**
Anuradha Gurung is Associate Director in the Investors Industries at the World Economic Forum, where she is also a Global Leadership Fellow. Anu is responsible for initiating, developing and managing projects that relate to Venture Capital, Private Equity, Hedge Funds, Institutional Investors and Sovereign Wealth Funds. These include the "Globalization of Alternative Investments" and "Green Investing" projects as well as a potential initiative on Infrastructure Investing. With Josh Lerner (Harvard Business School), Anu is co-editor of both volumes of the Globalization of Alternative Investments Working Papers: The Global Economic Impact of Private Equity Report.

Prior to joining the Forum, Anu was an Investment Banker in the Mergers and Acquisitions (M&A) team at UBS Warburg LLC (now UBS Investment Bank) and in the M&A and Financial Sponsor teams at Banc of America Securities, LLC. She was also a Research Analyst at Schneeweis Partners (now Alternative Investments Analytics, LLC), a research and consulting firm for hedge funds and other alternative investments. Anu was Phi Beta Kappa and graduated cum laude from Smith College with a BA in Economics (High Honours). She completed her Master of Public Policy degree from Duke University, where she was a James B. Duke Fellow and a Terry Sanford Scholar. Anu wrote the proposal for a mobile library system in rural Nepal, which was named one of the top five recipients of a World Bank Development Marketplace grant in 2003.

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