



# **Ensuring Green Growth in a Time of Economic Crisis: The Role of Energy Technology**

**International Energy Agency**



# Ensuring Green Growth in a Time of Economic Crisis: The Role of Energy Technology

## *Executive summary*

### Introduction

Despite the severity of the current financial and economic crisis, it cannot be allowed to distract us from addressing critical and strategic climate change and energy challenges. The energy sector produces 60% of global greenhouse gas emissions and so it must also be a key part of any strategy to reduce them. This paper describes the most promising low-carbon technologies, their current status and the policy framework that will be necessary to achieve their widespread deployment. It also highlights what immediate steps can be taken as part of a Clean Energy New Deal.

### An energy revolution is necessary and possible

Current trends in energy supply and use are patently unsustainable – economically, environmentally and socially. Without decisive action, energy-related emissions of CO<sub>2</sub> will more than double by 2050 and increased oil demand will heighten concerns over the security of supplies. We can and must change the path that we are now on, but this will take an energy revolution and low-carbon energy technologies will be at its heart.

Energy efficiency, many types of renewable energy, carbon capture and storage, nuclear power and new transport technologies will all require widespread deployment if we are to reach our greenhouse gas emission goals. Every major country and sector of the economy must be involved. The task is also urgent if we are to make sure that investment decisions taken now do not saddle us with sub-optimal technologies in the long run.

### Energy efficiency is the first step

Improvements in energy efficiency can deliver some of the largest and cheapest CO<sub>2</sub> reductions. Importantly in a time of financial crisis, they can also often be implemented quickly and bring more benefits for employment than any other category of energy technology. Investment in energy efficiency now will also delay the need for new supply capacity, giving more time for other, new low-carbon technologies to mature and so lowering the overall costs of deployment. Unfortunately, stubborn barriers exist to the deployment of many energy efficient technologies and so governments need to help remove or overcome them.

### A long-term integrated policy framework is needed

Developing and deploying low-carbon technologies will require an integrated policy framework. Many of the most promising technologies currently have higher costs than those they would replace and it is only through research, development, demonstration and deployment (RDD&D) that these costs can be lowered. An international and stable carbon price will need to form the cornerstone of

any successful policy in the longer term, but will not be sufficient by itself. It will need to be complemented by other policies and measures and by a significant increase in support for RDD&D. To be most effective, technology support policies need to evolve as a technology matures from the R&D stage to full commercialisation. However, financial support alone is not sufficient. Improvements in rules and regulations, especially those that are creating unintended barriers, must be promulgated at all levels of government.

Roadmaps that show what is needed to take technologies from their current status through to full commercialisation are a useful tool to help both government and private sector make the right choices. In response to a request from G8 leaders in Hokkaido, the IEA is leading efforts on roadmaps for the most important low-carbon technologies – on the demand side as well as the supply side, including renewable and fossil-fuel technologies. This will require concerted efforts involving all key stakeholders, including the private sector and developing countries.

#### Now is the perfect time to start

The economic stimulus packages now being adopted by many governments provide an excellent opportunity to ensure cleaner, more sustainable growth in the energy sector – both through immediate measures with impacts in the near term, and by influencing longer-term investment decisions. One of the most attractive options lies with refurbishing buildings. Renovating them to meet high energy efficiency standards and replacing outdated heating systems would cut energy use dramatically while creating jobs in manufacturing and building trades. Publicly-owned buildings could be the first target. The transportation sector also holds enormous potential for energy savings. Proposed government support for the auto industry could be designed to promote more fuel efficient vehicles, including through scrappage and buy-back schemes. Renewable energy can also play a role, with support through tax changes and targeted investments.

Such a Clean Energy New Deal is not a policy measure that substitutes for other, more long-term approaches. However, it could be the most promising and concrete way to take a determined first step to a sustainable future – from a security, environmental *and* affordability point of view.

## 1. The task ahead: an energy technology revolution

In recent months, global developments – namely, lower oil prices and the economic crisis – may have eclipsed the public's focus on critical energy and climate challenges. The current turmoil in markets is nothing short of critical. But IEA analysis highlights the importance of continuing to maintain focus on the medium- to long-term target of achieving a cleaner, more secure energy future. This longer-term objective requires both careful planning for the future as well as substantive action now.

The IEA has identified a clear need for substantial investment in all segments of the energy chain. But project delays and cancellations are becoming increasingly common. This creates the real risk that an energy supply crunch could choke off economic recovery as demand rebounds.<sup>1</sup> At the same time, G8 governments have recognised that a business-as-usual pathway for the global energy system is not sustainable.

Without additional policies, the IEA projects that primary energy demand will increase by an average of 1.6% per year over the next 25 years. Despite some changes to the fuel mix, CO<sub>2</sub> emissions in this reference scenario also increase by 1.6% per year. This means that by 2030 energy-related CO<sub>2</sub> emissions will have risen by 45% from their 2006 levels of 28 Gt.<sup>2</sup> Looking further ahead, without decisive action, energy-related CO<sub>2</sub> emissions could reach 62 Gt in 2050, resulting in an eventual global average temperature increase of up to 6°C.<sup>3</sup> Most of the increase is in non-OECD countries, but per capita emissions will remain higher within the OECD. This is unsustainable, not only from a climate change perspective, but also from a security of supply perspective – this reference scenario would imply a 25% increase in global oil demand by 2030.

However, these developments are far from inevitable. Low-carbon technologies that already exist or are in an advanced state of development can bring global CO<sub>2</sub> emissions back to current levels by 2050 (IEA ETP ACT scenario). Under this scenario, improvement of energy efficiency is a key first step, coupled with decarbonisation of the power sector in the longer term. Global emissions would need to peak between 2020 and 2030. Unfortunately, returning CO<sub>2</sub> emissions to current levels will almost certainly not be enough to prevent dangerous climate change. The IPCC has concluded that global CO<sub>2</sub> emissions must be reduced by 50% to 80% by 2050 if the long-term mean global temperature rise is to be limited to between 2 and 2.4°C. At the Heiligendamm Summit in 2007, G8 leaders agreed to seriously consider a global 50% CO<sub>2</sub> reduction target, and in the Hokkaido Summit in 2008 they announced their intention of seeking to share with all parties of the UNFCCC the vision of, and together with them to consider and adopt, the goal of at least a 50% reduction of global emissions by 2050. The Summit leaders added that this global challenge can only be met by a global response. They stressed that this will require both accelerating the deployment of existing technologies and the development and deployment of new low-carbon technologies. To examine

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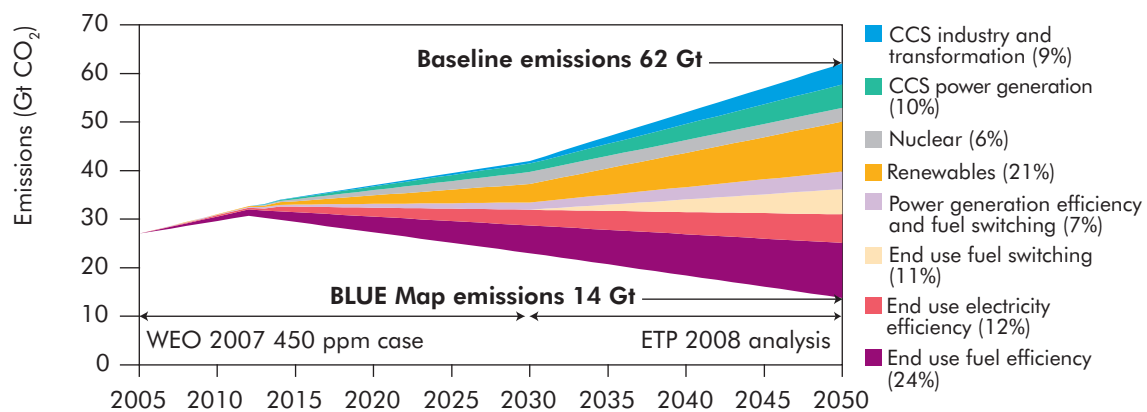
<sup>1</sup> The IEA will prepare background papers for the G8 Energy Ministers meeting on investment issues and climate policy.

<sup>2</sup> IEA (2008), *World Energy Outlook 2008*.

<sup>3</sup> IEA (2008), *Energy Technology Perspectives 2008*. These projections for CO<sub>2</sub> are consistent with emissions of all six greenhouse gases covered by the Kyoto Protocol reaching 80-90GtCO<sub>2</sub> equivalent by 2050.

what this would mean in practice, the IEA has also developed the so-called BLUE Map scenario, which targets a CO<sub>2</sub> emissions reduction of 50% from current levels by 2050.<sup>4</sup> The analysis for this scenario shows that such a target will require nothing less than an energy technology revolution, with very rapid development and deployment of a wide range of existing and new low-carbon technologies. This change will be difficult, but it is possible if implementation starts now (see Figure 1).

**Figure 1: Technologies for reducing energy related CO<sub>2</sub> emissions**



Source: IEA (2008), *Energy Technology Perspectives 2008*.

**Key point: Energy efficiency, carbon capture and storage, renewables and fuel switching are all needed**

The key aspects of this energy technology revolution can be characterised by the following four elements in the BLUE scenario:

- **Improved energy efficiency** – the biggest share of the total emissions reduction (36%) will come from an increase in energy efficiency. The annual improvement in global final energy intensity will increase from 1.6% to 2.5%. This will require a *doubling* of the energy efficiency improvement, from 0.9% per year in the Baseline scenario to 1.7% per year in the BLUE scenario. It will take huge efforts to achieve this, but this is more a question of good policies and organisation than of additional costs. Overall, the increased energy efficiency will also give net financial benefits. It has to be the cornerstone of any sustainability strategy.
- **Increased deployment of renewable energy** – the second biggest share (21% of the overall reduction of emissions) is due to a massive further deployment of renewable energy technologies. By 2050, almost half of total electricity generation under the BLUE scenario is from renewable energy sources, up from 18% today. Wind, solar PV, CSP, biomass and hydro, in particular, will all have an important role to play. For instance, the BLUE scenario envisages an average of 56 GW of onshore wind being built every year between 2010 and 2050, while over the same period the average installation rate of PV panels is 215 million m<sup>2</sup> per year.

<sup>4</sup> IEA (2008), *Energy Technology Perspectives 2008*.

- **Widespread introduction of carbon capture and storage** – the third largest share (19%) of emissions reductions comes from the rapid and widespread introduction of carbon capture and storage (CCS), both in power generation and industry. Due in part to the long life of boilers and power generating equipment, which are often privately held, it will not be economically practicable to completely phase out fossil fuel use for power generation and heavy industry over the next 50 years. Therefore, CCS (both retrofitted to existing facilities and incorporated as part of new plants) will be vitally important to reduce CO<sub>2</sub> emissions. G8 leaders have supported the call by the IEA for twenty large-scale demonstration plants to be operational by 2020. Then, to achieve these emissions reductions, between 2020 and 2050 the rate of deployment would need to increase to an average of 45 CCS coal-fired plants and 25 CCS gas-fired plants of 500 MW being built every year.
- **Continued fuel switching** – a major part of the emissions reductions is an increase in the share of nuclear. This would require 32 nuclear plants of 1 000 MW to be built each year from 2005 to 2050. In addition, extensive fuel switching in industry from coal to low-carbon fuels, such as natural gas, has to be implemented. In later years, second-generation biofuels will become increasingly important in transportation.

It is important to note that *all* options are needed. It is not either CCS or renewables, nor nuclear or energy efficiency, but all of them together. Nor can the changes be restricted to electricity generation; fundamental changes are also needed in industry, transport and buildings. Indeed, these changes might be even more difficult or expensive than changes in the power sector, but they are just as necessary. This is a general statement of course; in the IEA scenarios a least-cost approach has been chosen. Some countries might exercise some options more than others. But as a *global* approach – and the approach must be global – all of them will be needed to the extent shown above.

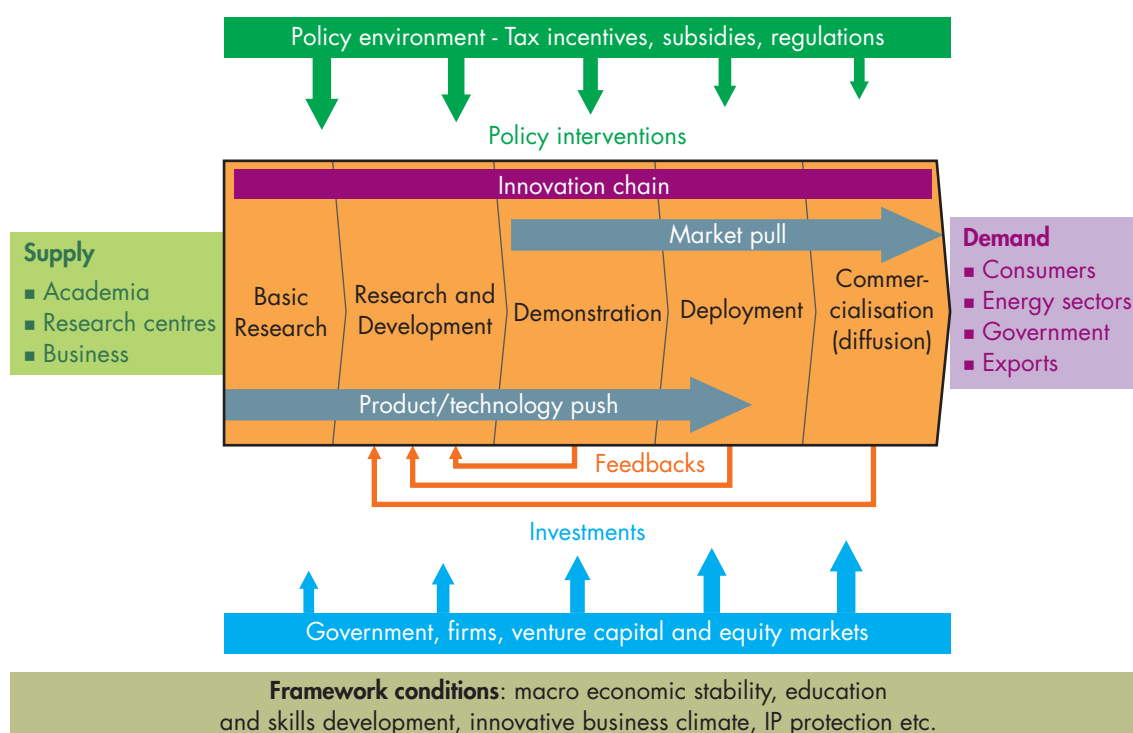
The remainder of this background paper is structured as follows. The second section explains the need to use both “push” and “pull” policies. Next, the third section looks at the state of play of the most important clean energy technologies in milestone years. Section 4 looks at the investments and integrated policy approach that are needed. Sections 5 and 6 then describe the impact of the current economic crisis on clean energy and some of the measures being taken in response, and finally Section 7 will underline further opportunities to use the current situation to invest actively in clean energy.

## 2. Policies to develop and deploy low-carbon technologies

Many low-carbon technologies currently have higher costs than the incumbents. It is only through technology learning from research, development, demonstration and deployment (RDD&D) that these costs can be reduced and the technologies become economic. Thus most new technologies will require, at some stage, both the “push” of research, development and demonstration (RD&D) and then later the “pull” of market deployment (Figure 2). Often, and particularly when a rapid transition is required, both the push and pull have to be organised or supported by governments.

Some of the technologies needed for the BLUE scenario are not yet available for deployment (e.g. third generation, ultra-high efficiency or ultra-low cost PV devices and fourth generation nuclear power). Many others require further refinement and cost reductions before they can be fully commercialised (e.g. CCS and offshore wind). A huge effort of RD&D will therefore be needed for both groups. However, public energy RD&D spending today, at some USD 10-11 billion per year, is in real terms about half the level it was 25 years ago. Governments have made commitments to increase public RD&D and some countries indeed increased investment, but overall goals have not yet been fully realised. Private sector RD&D in energy technology exceeds public investment, at USD 40-60 billion per year (but only partly related to clean energy). At the moment it is difficult to set a particular target, but it is clear that a major acceleration in RD&D effort is needed, as well as more international co-operation and a higher effectiveness of the investment.<sup>5</sup> The call by the European Commission to double public RD&D by 2012 and again by 2020 is indicative of the effort that will be required (see also Section 4).

**Figure 2: Policy environment for developing and deploying technologies**



Source: IEA (2008), *Energy Technology Perspectives 2008* (adopted and modified from Grubb, 2004 and Foxon, 2003).

**Key point:** Both technology push and market pull is often necessary to develop and deploy technologies

<sup>5</sup> Estimates of total investment needed in clean energy give the same picture. According to New Energy Finance, clean energy investments (in renewables, excluding large-scale hydro, and efficiency) increased in 2004-07 from USD 33 to 148 billion. The IEA has computed that some USD 380-540 billion is needed each year between 2008 and 2030. Again, this would imply approximately a threefold increase compared to recent levels.

Other technologies, such as onshore wind, biomass, third generation nuclear power, hybrid vehicles and many energy efficiency technologies are already commercially available but their diffusion remains dependent on policy measures. In *World Energy Outlook 2008*, the IEA developed an overarching policy framework that, combined with greater effort on R&D, might enable a strategic long-term approach. This framework consists of the following three elements:

- Cap-and-trade systems in industry and power generation in OECD countries and possibly other major economies.
- International sectoral agreements in OECD countries and other major economies.
- National policies and measures in the buildings sector and more generally in developing countries.

Without a cap-and-trade system, it seems unlikely that a common international CO<sub>2</sub> price will come into being on a wide scale. A CO<sub>2</sub> price is seen by many as the main pull factor for new clean technologies, especially when uncertainty of prices can be reduced.<sup>6</sup> Some technologies will diffuse faster with a CO<sub>2</sub> price; others – like CCS – will never enter the commercial stage without such a price or massive public support.<sup>7</sup> However, one cannot expect a global CO<sub>2</sub> price to emerge immediately and therefore international agreements in those sectors that are suitable for such an approach – *i.e.*, that are characterised by a limited number of major actors, exposure to global competition, and a significant share of global emissions – might be an important aspect of the package and stimulate diffusion of new technologies. For those sectors in which international trade does not play an important role – like buildings – and in countries not yet able to participate in the foregoing approaches, national policies and measures are both feasible and necessary.

Finally, it is necessary that all countries have access to technologies that enable them to build the most efficient new power plants and industrial facilities and install energy efficient equipment. Much of the development of this technology is currently being undertaken within the OECD countries, but most of its deployment will need to be elsewhere. As example of a network which can help in technology development deployment is the IEA Implementing Agreements (in which both member and non-member countries work and co-operate), which provide a framework for joint research projects, discussion of specific technology issues and information exchange.<sup>8</sup>

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<sup>6</sup> Some commentators have suggested that a cap-and-trade system might benefit from price floors and caps to provide more certainty for investors.

<sup>7</sup> There is a fair amount of model-based literature on the effect of energy prices on energy innovation (so-called induced innovation), but the empirical evidence is scarce. The general view is that higher energy prices and strong climate policy induce additional technological change. However, the effect may be smaller than expected if the current investment in RD&D is too small to achieve the developments necessary for a rapid and substantial reduction of CO<sub>2</sub> emissions. RD&D is needed that both makes existing low-carbon technologies cheaper and produces new technologies that can replace carbon-intense technologies in the future. On the other hand, RD&D without CO<sub>2</sub> prices cannot be expected to have much effect (see W.D. Nordhaus in A. Grubler [2002], *Modeling Induced Innovation in Climate Change Policy*, Washington).

<sup>8</sup> IEA (2007), *Energy Technologies at the Cutting Edge*.

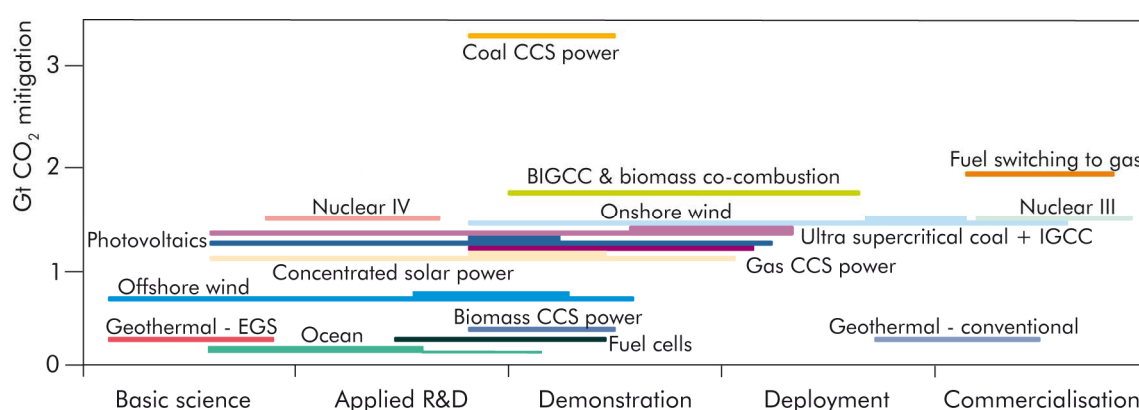


### 3. Current status and prospects of important low-carbon technologies

*Energy Technology Perspectives 2008* (ETP) presented an assessment of the current situation and prospects of the most important low-carbon technologies. A summary is shown in Table 1, together with relevant milestones in 2030 and 2050. Figure 3 gives an overview of the status of important clean technologies in power generation. The higher a technology in the figure, the greater the role it is expected to play in the energy revolution. Technologies further to the right reflect those on the road towards commercialisation. Comparable figures are available for industry and transport.<sup>9</sup> In the transport case, new technologies enabling higher energy efficiency are already in the deployment stage. Electric vehicles, cellulosic ethanol and advanced biodiesel, fuel cell vehicles, more efficient aircraft and freight shipping are all in the demonstration and early deployment stages. Table 1 may be summarised as follows:

- Some technologies, like third generation nuclear and wind, are already commercially available but their diffusion depends on policy measures (for wind a number of support mechanisms are in place in different countries, while for nuclear power the general policy approach relies more on the eventual introduction of a CO<sub>2</sub> price and resolution of waste issues).
- Many technologies are available in a demonstration phase (CCS, concentrated solar power, second generation biofuels) and will develop rapidly with suitable policies (RD&D incentives, CO<sub>2</sub> price, standards). Without such policies, they will not become competitive in the coming decades.
- A third group of technologies includes those commercially available, but too expensive to diffuse without strong policies (offshore wind, solar PV). Technological (*e.g.* batteries for electric vehicles), economic (high costs and/or market failures) and non-economic (spatial planning, grids and meters) hurdles may also have to be overcome. If this can be achieved, it is possible that they might become fully competitive before 2030. In the case of solar PV it makes sense not to compare costs with power market prices but with the higher retail prices. In that case strong policies might make also solar PV competitive before 2030.

**Figure 3: Technology development and CO<sub>2</sub> mitigation for power generation**



Source: IEA (2008), *Energy Technology Perspectives 2008*.

**Key point: Power generation technologies are at very different stages of development**

<sup>9</sup> IEA (2008), *Energy Technology Perspectives 2008*.

<b>Table 1: Technology timelines in baseline and sustainable (BLUE) scenarios</b>				
<b>Technology</b>	<b>Now</b>	<b>2015</b>	<b>2030</b>	<b>2050</b>
CCS in power	CCS is the largest single option for reducing emissions and is needed because of the large available coal reserves and due to the impossibility to decarbonise parts of industrial emissions by other means. Twenty demonstration plants are needed in the short term. A facilitating regulatory framework and carbon prices, emission standards or other incentives are needed to make it commercially viable after 2020. Both technology and policy issues have to be solved. Various industry applications have to be developed. This option is getting much attention recently. 2050 BLUE shares: OECD countries 34%, non-OECD 66%			
Baseline	Small demos.		10 demos.	Only EOR.
BLUE	Capture; some transport and storage with EOR.	10 demos. Transport infra available.	20 full-scale demos by 2020 12% power by 2030	30% power
Nuclear	Generation 3+ is commercially available and plants are being built. Generation 4 would reduce costs, diminish nuclear waste and further enhance safety. System design and prototype to be expected in BLUE by 2030 and commercial deployment by 2040-50. 2050 BLUE shares: OECD countries 49%, non-OECD 51%			
Baseline gener. 3+	Available			160 GW
Baseline gener. 4	No development of Gen IV			
BLUE gener. 3+	Available		200 GW	935 GW
BLUE gener. 4			Prototype	285 GW
Wind	Strongest growing renewable source in absolute terms: 40% of new installed power capacity in Europe in 2000-07, 25% of new power production and 40% of new power plant installation in US in 2007. At several sites onshore, wind already competitive, but offshore still expensive. With stable, predictable policy support and internalisation of external costs, onshore wind might be fully competitive before 2020. Offshore still needs strong technology improvement. Non-economic hurdles (spatial planning, grid connection) often more important than financial incentives. 2050 BLUE shares: OECD 43%, non-OECD 57%			
Baseline Onshore	>100 GW			400 GW, in general competitive.
Baseline Offshore	<10 wind parks.			Not competitive.
BLUE Onshore		2020 competitive.	2025 900 GW	>2000 GW.
BLUE Offshore			Competitive.	>2000 GW.
Solar PV	Strong technology development needed: reduced material intensity, cost reduction, increased efficiency and lifetime of films, new types of devices. Both silicon and alternative feedstock production needed. Strong competition between different approaches. Specific attention to off-grid application in developing countries needed. 2050 BLUE shares: OECD countries 54%, non-OECD 46%.			
Baseline	<5 GW	Marginal growth.	<60 GW.	Remains commercially uncompetitive.
BLUE		Rapid growth. Strong competition between technologies.	2025 competitive with retail prices; >150 GW in 2030.	1150 GW

Concentrating Solar Power	Renewed attention recently. Both incremental improvements by scaling up and big leaps (towers with air receivers) necessary. Heat storage increases value of electricity produced. Many opportunities in low-density, sunny regions need low-cost long-range transmission systems. 2050 BLUE shares; OECD countries 37%, non-OECD 63%.			
Baseline	<1 GW	Scaling up of 1 <sup>st</sup> generation technologies	<10 GW	Remains commercially uncompetitive.
BLUE		New technologies, fast scaling up.	250 GW - competitive.	630 GW
Efficiency in buildings and appliances, efficiency in transport	Different technologies and approaches; limit standby power to 1 Watt, tighten standards (television, other applications) or develop and make them mandatory (electronic devices, computers). Building codes may be improved with end goal of energy passive houses, which also will increase the share of heat pumps. Best practices in lighting may be further improved. By means of tightened standards in transport 50% efficiency improvement for new cars in 2020 and for all stock in 2030 feasible. 2050 BLUE shares: OECD 47%, non-OECD 53%. Technologies already commercial; deployment depends on mandatory standards, CO <sub>2</sub> prices, support policies.			
Second-generation biofuels	Both lingo-cellulosic ethanol and Fischer-Tropsch “biomass-to-liquids” are reaching the demonstration and next the deployment phase. Various technologies are now tested at small scales. After successful commercial introduction rapid gain in fuel sales might be expected, but land availability will be a constraint in some countries. BLUE 2050 shares: OECD countries 46%, non-OECD 54%.			
Baseline	Demonstration plants available, but most		2030: cost reduction to USD 0.6 per litre.	After 2040: rapid gain.
BLUE	activities in R&D stage.	2020: cost reduction to USD 0.6 per litre.	After 2030: rapid gain.	
Electric and plug-in vehicles	At least 1 mln. hybrids are expected to be available in 2010/11. Accelerated RD&D necessary to reduce battery costs; improved life span and charging time and other issues are also important. Infrastructure and business models for electric vehicles now being developed and a 2020 aim of 10% of all cars is mentioned for some smaller countries. 2050 BLUE shares OECD countries 49%, non-OECD 51%.			
Baseline	Plug-in expected in 2010;		Further RD&D	Minimal deployment.
BLUE	EV in demonstration stage.	Plug-in trials.	2025 – 1 million plug-ins, start pure electric.	High market penetration plug-ins; share EV increases.
CCS in industry	See text above. BLUE 2050 shares: OECD countries 47%, non-OECD 53%			
Baseline	Not available, only R&D.		3 demos.	Limited use.
BLUE		15 demos in 2015-30; transport infrastructure.		Majority of iron, cement, ammonia, chemical pulp equipped with CCS.

#### 4. An integrated policy approach: which investments are needed? How can the medium and long term be combined?

An important question is the extent to which a policy orientation focusing on the medium term (up to 2020) might conflict with the necessity to achieve the real transition before 2050. It is clear that an integrated approach is needed so as to avoid any conflicts. Such an approach will need to consider the whole timeline to 2050 and examine how the different existing and emerging technologies fit within the overall transition, thus ensuring a smooth progression towards a clean energy future.

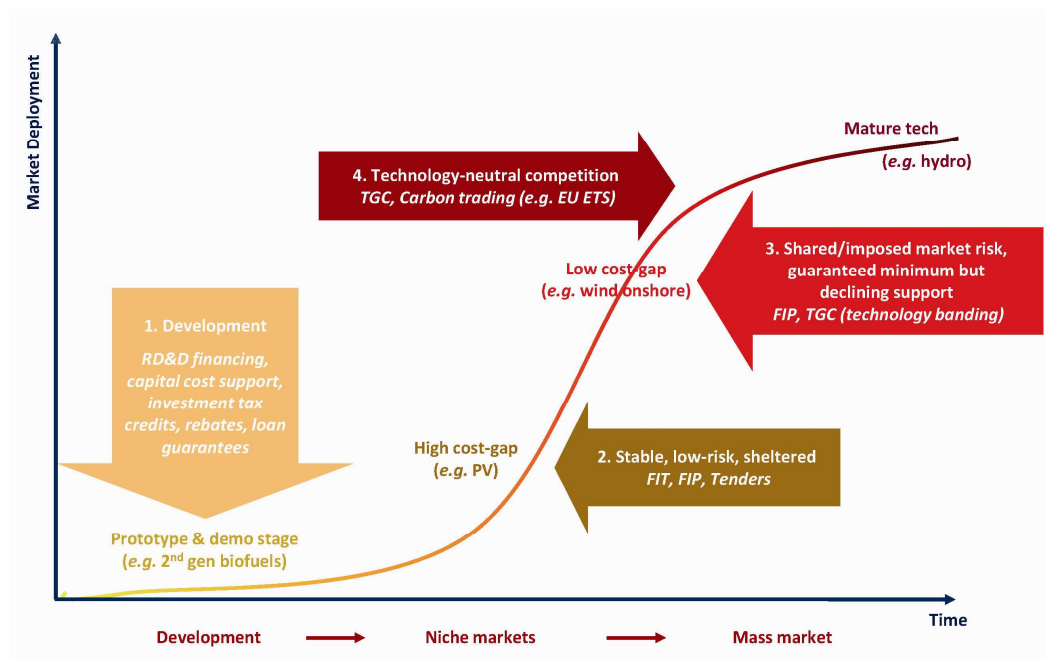
The first priority should be the implementation of “low-hanging fruit” technologies that need to overcome a variety of barriers but will reap financial benefits – mainly energy efficiency, such as better insulation in buildings, clean combined heat and power and efficient lights and appliances, but also renewable energy technologies close to market competitiveness. In particular, a short-term focus on improved energy efficiency might “buy time” that is needed to decrease costs of emerging technologies through initial deployment and make novel technologies available through RD&D. Since improved energy efficiency often reduces overall costs, it can also have positive impacts on the economy (see Section 6). Last year, the G8 endorsed 25 IEA recommendations to increase energy efficiency, and the IEA will report to the G8 Summit in La Maddalena in July 2009 on the progress of implementation. It is also expected that the G8 and G5 ministers will endorse an International Partnership for Energy Efficiency Cooperation (IPEEC) and a Sustainable Buildings Network (SBN) – essential first steps to start a real global effort. Energy efficiency indicators, such as those developed by the IEA, are also needed to track overall progress and identify where new or enhanced policy intervention is required.

For all technologies, at whatever stage of maturity, global roadmaps need to be developed that present a holistic vision for the development and deployment of that technology. These roadmaps will include: a vision of specific technology targets to be achieved by a specific date; critical RDD&D activities and milestones to achieve these targets; identification of which barriers (including legal, financial, market) have to be overcome; assessment of what policies are required to support development and deployment; recommendation of how to share responsibilities among partners (governments, industry, etc.); and a proposal of which criteria will be used for evaluation. A roadmap only has a meaning if all crucial partners agree on the main elements to effectively start its implementation. By drafting such roadmaps in advance, one can largely overcome the danger that activities in the short run do not contribute effectively to those needed in the long run. In 2009, roadmaps will be presented by the IEA for solar PV, wind, electric/hybrid vehicles, CCS, nuclear energy and the cement industry. Further roadmaps will be completed in time for the G8 meeting in Canada in 2010 at which time the IEA has been asked by the G8 to report on the progress made by this approach (see annex for a description of the roadmap process).

In terms of policy support, facilitating the deployment of these clean technologies will require an evolution of current markets to a system in which externalities have a monetary cost and adequate infrastructure is available. Experience to date suggests that policy frameworks that combine different technology-specific support schemes as a function of technology maturity are best at successfully and efficiently fostering a smooth transition of clean energy technologies towards mass market integration (Figure 4). Less mature,

high-cost technologies, such as solar PV or large CCS demonstration plants, need predictable, technology-specific incentives.<sup>10</sup> Economic modelling also suggests that a carbon price can have sizeable effects on RD&D and technology deployment. For instance, a recent study searching for an “optimal world carbon price” to stabilise long-run CO<sub>2</sub> concentration at 450 ppm estimated this price would induce a four-fold increase in RD&D and deployment expenditure on renewable energy by 2050, compared with the baseline scenario. However, a general increase of RD&D is not enough to effectively reduce costs of climate mitigation (and security of supply). Only major technological breakthroughs – especially beyond the electricity sector – could significantly reduce future mitigation costs. Further along the learning curve, as both technology and markets mature, it is recommended to move towards more market-oriented mechanisms. For example, feed-in premium<sup>11</sup> or an obligation to install a certain portion of renewable technologies or to implement energy efficiency with some “technology banding”, might be needed.<sup>12</sup> The more competitive a technology becomes, the less specific and costly the incentives need to be.

**Figure 4: Fostering clean energy transition towards mass market integration**



**Legend:** FIT = feed-in tariff; FIP = feed-in premium; TGC = tradable green certificate; EU ETS = European Union Emission Trading Scheme

**Source:** Adapted from IEA (2008), *Deploying Renewables: Principles for Effective Policies*.

**Key point:** Support policies need to be tailored to the maturity of the technology

<sup>10</sup> The essence of an integrated policy approach is that this technology needs investment and has to be *organised*. The benefits of that organisation are the highest of all separate elements of a cost-efficient climate policy (see W.D. Nordhaus [2008], *A Question of Balance*, Yale University Press).

<sup>11</sup> A feed-in premium is a bonus paid to renewable energy producers in addition to the electricity market price. An important difference between a fixed feed-in tariff and the premium payment is that the latter introduces competition between producers in the electricity market.

<sup>12</sup> IEA (2008), *Deploying Renewables: Principles for Effective Policies*.

Once the technology is close to competitiveness, specific support systems can be phased out altogether and – assuming an appropriate carbon price has been implemented – clean energy technologies will compete on a level playing field with other ones. For onshore wind, this situation may already exist in some regions: with a CO<sub>2</sub> price of USD 30 per tonne CO<sub>2</sub>, wind onshore could be less expensive in parts of Europe compared with coal or gas-powered generation. Solar PV does not compete on the wholesale electricity market, but is mainly delivered to the distribution grid where it is more attractive due to the higher prices paid by small consumers. Consequently, it could reach grid parity by 2015 in important European residential markets and with high insolation coinciding with high peak demand this grid parity might be reached before 2015.

In recent years, several major economies have implemented combination policy frameworks for renewables, increasingly applying market principles as technology maturity and deployment increase. Spain applies a feed-in premium with cap and floor prices for wind onshore, while the United Kingdom and Italy have recently introduced technology banding in their tradable green certificate systems, which in both cases co-exists with feed-in tariffs. China's support for renewable energy also reflects a combination of different incentives tailored to the maturity of different technologies, such as generation-based tenders for wind onshore standing alongside feed-in tariffs for solar PV.

In terms of costs to society, applying an integrated approach in a combination policy framework is not only an effective but also a cost-efficient solution to bringing renewable energy technology to market integration. It allows the exploitation of the “low-hanging fruit” of abundant clean energy technologies which are closest to market competitiveness while preserving and implementing the long-term strategic vision of providing cost-effective options for a low-carbon future. Analysis performed at the European Union level supports this conclusion.<sup>13</sup> Modelling results indicate that – while in the short term, technology neutral support may incur lower costs to society, as this “low-hanging fruit” can still be tapped – in the medium to long term, technology-specific incentives lead to lower *per unit* as well as *total* costs for consumers. This is due to the cost savings involved in using carefully designed and implemented support mechanisms to defer the deployment of currently less mature technologies until they are ripe. .

At the same time, in order to make the energy technology revolution happen, it is important for governments to also provide strong and coherent RD&D support, within and across technology families. Based on the deployment analysis from ETP 2008, it is estimated that RDD&D<sup>14</sup> investment needs under the BLUE scenario are USD 14-15 trillion between 2005 and 2050. Deployment costs<sup>15</sup>

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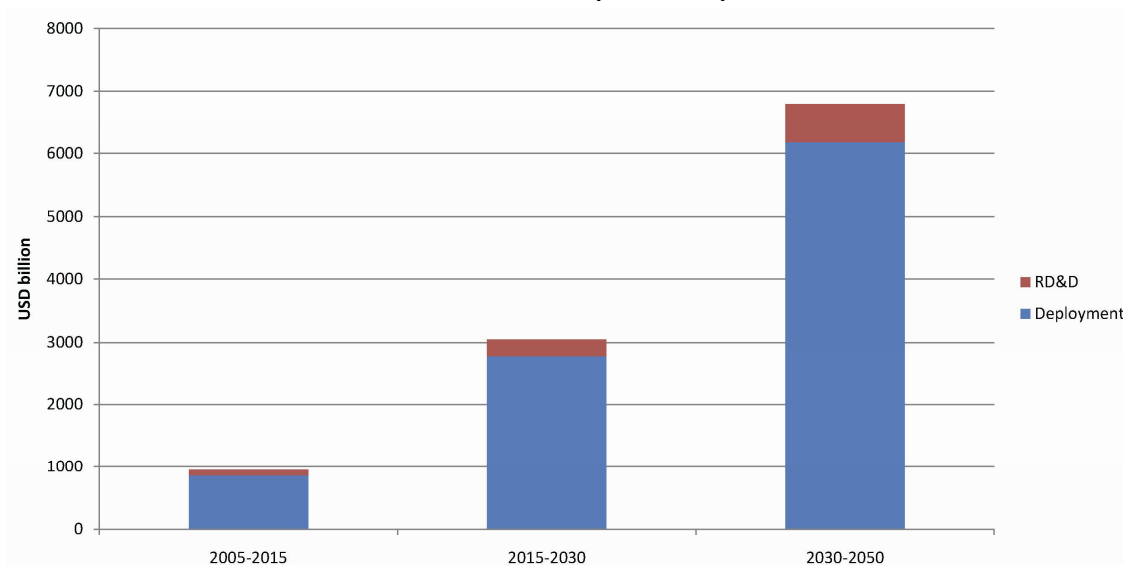
<sup>13</sup> Ragwitz, M., A. Held, G. Resch, T. Faber, R. Haas, C. Huber, R. Coenraads, M. Voogt, G. Reece, P.E. Morthorst, S. Grenaa Jensen, I. Konstantinaviciute and B. Heyder (2007), *OPTRES – Assessment and Optimisation of Renewable Energy Support Measures in the European Electricity Market*, Final Report of the project as conducted by a consortium led by Fraunhofer Institute Systems and Innovation Research for the European Commission, DGTREN, Intelligent Energy for Europe - Programme (Contract No. EIE/04/073/S07.38567), Fraunhofer Institute Systems and Innovation Research, Karlsruhe.

<sup>14</sup> There is not sufficient data for an accurate estimation of RD&D needs, so for the purposes of this analysis we assumed that RD&D investments are 10% of deployment needs.

<sup>15</sup> Deployment costs are the total amount that must be invested in cumulative capacity of a new technology up to the point where its unit costs (*e.g.* expressed in p/kWh for an electricity generating technology) reduce sufficiently that they reach

are assumed to represent the bulk of these investments at an estimated USD 13 trillion and RD&D needs are estimated at USD 1-1.5 trillion. In the short to medium term, an estimated USD 1 trillion is needed by 2015, while an additional USD 3 trillion is needed from 2015-2030 and the remaining 10 trillion will be required for the 2030-2050 period.

**Figure 5: Investments in research, development, demonstration and deployment, 2005-50**  
**BLUE Scenario (2005 USD)**



*Note:* Does not include investment needs for the deployment of Electric Vehicles which we estimate to be an additional USD 3.0-3.5 trillion. RD&D investments are estimated at an additional USD 300 billion.

*Source:* IEA estimates.

**Key point:** *Deployment accounts for the largest share of RDD&D costs– mostly needed from 2030-2050*

Investments in demand-side technologies, especially in transport, represent the largest share of these investment needs and account for an estimated USD 10 trillion of the total required RDD&D investments. RDD&D investment needs for the power sector are estimated at USD 3.5 trillion, of which USD 0.5 trillion is needed by 2015. The largest share of USD 2 trillion is needed from 2015-2030 and this will fall by half to USD 1 trillion from 2030-2050. Approximately two-thirds of all RDD&D investment needs from 2015-2030 are attributed to the power sector, while over half of all RDD&D needs from 2030-2050 will be accounted for in transport. RDD&D investments in the buildings sector is very small at just USD 0.5 trillion and almost all is needed in the early years.

An equitable sharing of the risks and costs will be important for the success of scaling up investments in RDD&D. This is true whether it relates to balancing the interests and needs of

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those of the incumbent technology (break-even point). This is therefore equal to the sum of the costs of the incumbent technology (which would have been incurred anyway), plus the additional investment costs (learning investments) required while the new technology becomes competitive.



producers and consumers, governments and the private sector or developed and developing countries. However, given the size of the investments needed, it seems clear that simply scaling up existing mechanisms and approaches will not work; novel solutions will be needed.<sup>16</sup> In particular, limited public resources mean that the extent to which governments are able to act as a catalyst rather than simply the fuel for developing new technologies may be crucial, giving particular prominence to the role of public-private partnerships.

One further question that is worth asking is whether an increase of RD&D might actually decrease the *overall* investment costs (in general deployment costs are a magnitude more than total RD&D). Different technologies provide different examples and some even point in opposing directions in answering this question. No solid answer is available. The cost of scaling up technology will always be the highest in the innovation chain. One always will need ongoing RD&D throughout all phases to ensure efficient deployment and continuing availability of next-generation technologies. However, it could be argued that a higher share of RD&D in the overall investment mix might lead to lower deployment costs and a better return on total investment. Unfortunately, greater investment in technology does not necessarily significantly decrease the costs of climate policy or of increased energy security; market imperfections and other non-economic barriers can impede deployment of energy efficiency more than costs per se. For example, tenants may not invest in energy efficiency in their homes because it is expensive, but because they are not allowed by owners of the houses to do so. On the other hand, new breakthrough and backstop technologies may reduce costs of climate policy or security of supply considerably, perhaps by as much as 50%.<sup>17</sup> In sum, an integrated approach of more RD&D, roadmaps and international co-operation is most likely to bear fruit. A final argument for such an approach is that lock-in situations – in which much is invested in deploying technology packages that quickly come to a dead end – might be prevented.

## 5. Impact of the current crisis

The current economic and financial crisis has an impact on clean energy in several ways:

- Short-term CO<sub>2</sub> ambitions are becoming easier to attain. Global GDP growth has likely fallen from 5% per year in 2004-07 to some 0.5% in 2009 and might still be significantly less than the long-term average in 2010. It is too early to speculate on economic growth in 2011, but deep financial crises in the past have often had a lingering effect. Therefore, the economic slowdown will likely make it easier for many nations to attain Kyoto targets, as can be seen by the huge drop in CO<sub>2</sub> prices in the European Emission Trading scheme since October 2008. It also can have beneficial second-order effects. In one European country, car leasing companies have started to scrutinise costs more closely, resulting in 15% less fuel consumption. However, this short-term benefit will be offset as generally lower economic

<sup>16</sup> The question of financing is discussed in more detail in a companion paper: World Bank (2009), *Financing Technology to Support Low-carbon and Climate-resilient Growth*.

<sup>17</sup> OECD (2009), Economics Department Working Paper No. 664.



growth leads to less investment in new energy technologies and slower energy efficiency improvements.

- Investments in the energy sector have decreased: both in a general way because of the economic crisis and the associated lower demand for new products, but also in a specific way because of low energy prices and the lower expected profitability of energy supply and efficiency options. In recent years wind energy in the United States and Europe was the second-fastest growing source of power generation after natural gas. Additional global wind capacity in 2008 grew by 29%, relatively more than in the past decade, and in absolute terms it equalled the growth of 2006 and 2007 together, or that of the entire 2001-2005 period. All renewables still saw an impressive global increase in capital investment in 2008, but with a major slowdown at the end of the year. The consultancy Emerging Energy Research expects a worldwide increase in wind capacity of 14% in 2009, less than half the annual growth recorded in the recent past. It might take European wind turbine companies until 2012 to install the production capacity they had previously planned for 2010. A.T. Kearney, the global management consulting firm, expects that investments in European power generation will be one-third less than required to meet adequate security of supply standards. Investments in renewables could fall even more, as they require relatively more initial loan capital than thermal plants even though they have no fuel input costs. Many clean energy companies rely relatively heavily on debt financing, which either has become much harder to find or more expensive due to higher risk premiums. Only half of the large investment groups that actively financed wind power in the United States in 2008 remained active in early 2009. Without government intervention, zero growth in investment in clean energy companies in 2009 might be likely. In developing countries, like India and Brazil, the ethanol industry is being hard hit as well and Russian grid companies have announced they will need backing from the state.
- The performance of clean energy companies, which had been flying high on the back of soaring energy prices in 2007 and 2008, fell back in autumn 2008. A representative index that tracks the performance of clean energy stocks worldwide plunged almost 70% between January and November 2008. In the period November 2008 until March 2009 no substantial gains were achieved.<sup>18</sup> The general feeling in the clean energy industry is that 2009 will be a very difficult year, but as energy security and climate problems remain, longer-term prospects remain bright – for those companies which survive the downturn.

The impact of the crisis on more specific energy ambitions is less clear:

- In terms of renewable energy, most targets are framed as a share of energy demand. Both investments in renewables and overall energy demand will decrease because of the crisis and the net effect is uncertain. The exact formulation of policy instruments will be important. Some countries have an obligation for energy companies to meet a certain

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<sup>18</sup> Wilderhill New Energy Global Innovation Index (NEX). The increase of NEX in the past years was double that of NASDAQ or Standard & Poor share indices, but its decrease in autumn 2008 also much more substantial. Since October 2008 the NEX volatility has remained relatively large.

target. Other countries have feed-in tariffs that guarantee a certain price. In both cases, the production of renewable energy might still increase in line with policy ambitions. As most renewable energy is produced in the same region where it is used, in principle this might improve security of supply.

- In many countries, the electricity grid has become an impediment to increasing shares of renewables; on the other hand, more renewables are a major argument to invest in “smart grids”. This has two aspects. New high-voltage lines are needed to connect wind and large-scale solar production with consuming areas and the volatility of wind generation demands more flexible grid systems. Second, power delivery systems are being combined with an information system that allows the utility and its customers to constantly monitor and adjust electricity use. The latter might lead to electricity savings of at least 5%. In most countries grid tariffs are regulated. The investments forthcoming are implied by the tariffs as formulated by an independent regulator. Unfortunately, the practices of regulators rarely take credit-crunch problems into account.<sup>19</sup> Where networks are owned by private companies the credit crisis might curtail additional investment even when regulated tariffs allow for it. The effect of the crisis on regulated state-owned companies is expected to be marginal, however, assuming their budgets remain intact.
- Progress in transport envisages growth in hybrid cars and plug-in vehicles. Owing to collapsed car sales and oil prices, the profitability of these innovative concepts has diminished. However, car manufacturers have long-term planning horizons and investments that started some years ago will lead to new hybrid and plug-in models in 2009-11. Although the economic crisis may have slowed momentum towards greener cars, it has not stopped it. Manufacturers are already co-operating with electricity utilities to build charging stations and study ways to integrate cars with the power grids in Israel, Denmark and Portugal. Nonetheless, the longer energy prices and demand for cars remain low, the slower investments will come in the next planning cycle.

## 6. The recovery package: a Clean Energy New Deal

A long-term approach needs to be taken towards energy security and the climate. Stability and predictability in regulatory behaviour and policy interventions enable and encourage investment. Is it possible to combine this long-term orientation with a much needed policy approach to tackle the economic crisis? At first sight, a combination has many advantages. Investments in greater efficiency, renewables or smart grids will tackle unemployment and create new jobs, while providing energy that will eventually be needed for a sustained economic expansion. However, we have to look more carefully. Measures to battle the economic crisis and boost the economy should be “timely, targeted and temporary”, according to Lawrence Summers, Director of the US National Economic Council.<sup>20</sup> Timely means they need to have effect in the short-term: 2009 and 2010. Many green investments with long-term planning procedures will not meet this criterion. Targeted might

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<sup>19</sup> Risks are increasing and this is not taken into account in multi-annual approaches by regulators. Furthermore, equity risk is currently being placed upon the debt.

<sup>20</sup> Lawrence Summers, “Why America must have a fiscal stimulus”, Op-Ed, *Financial Times*, January 6, 2008.

not be a problem in this case. However, temporary might be an impediment. Some economic incentives could require many years to achieve their desired results, as in the case of European feed-in tariffs for renewables that guarantee prices for ten years or more. Nonetheless, tremendous opportunities still exist. If drafted carefully, economic stimulus packages provide an excellent opportunity to ensure greener and more sustainable growth in the energy sector. Most countries can simply choose to improve and extend *existing* programmes and instruments in order to be able to invest quickly.

- **Renewable energy:** An example is the organisation of tax changes and targeted investments in the United States. To help renewable energy projects find financing in today's difficult market conditions, recent legislation will allow such investments in place in 2009 and 2010 to temporarily claim a 30% investment tax credit instead of the production credit that is normally payable over a ten-year period. The US will invest very considerably in electricity grids, as will France. In France utilities have been invited to submit plans for additional investment that could be implemented in the near future. Improving the quality and resilience of electricity and gas networks are excellent examples of win-win approaches. Australia has brought forward AUD 500 million in its Renewable Energy Fund. Chinese state-owned companies will accelerate development of wind power. However, it is important that the additional money is targeted at the real problems in specific countries. If spatial planning is the effective hurdle to investment in wind energy, more money only makes the policy approach more expensive but does not deliver more wind turbines. Most countries are very much aware of the necessity to start solving the most pressing issues, including the NIMBY ("Not in my backyard!") phenomenon.
- **Buildings:** Often the very best option, as for example proposed by the European Commission, is a temporary additional stimulus to increase energy efficiency in existing buildings.<sup>21</sup> Owing to market imperfections, the energy efficiency of existing buildings remains considerably less than optimal. Retrofitting them to increase their efficiency will quickly provide jobs for workers in the building trades and manufacturing and decrease energy bills almost as rapidly. The United States has extended and increased tax credits for commercial buildings, builders of energy efficient homes and manufacturers of energy efficient appliances. It provided USD 4.5 billion for construction, repair and alteration to federal buildings that impact on energy efficiency and conservation. More generally, the biggest single item of its USD 80 billion Recovery and Reinvestment package will be invested in energy efficiency. The United Kingdom has allocated GBP 100 million to insulate low-income houses and boosted funding to residential energy saving programmes.
- **Transport:** An example is the Italian measure to give a bonus to people scrapping a car at least ten years old and replacing it with a new vehicle with low-carbon dioxide emissions (in the Italian case less than 130 g/km for diesel and 140 g/km for gasoline cars). France has also offered reduced interest loans with a maximum term of two years until the end of 2010 to

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<sup>21</sup> Confronted with a list of possible options to tackle the economic crisis with green measures, 81% of participants at an important European energy conference preferred building renovations.

encourage green production. Germany and other European countries have also introduced a vehicle buy-back programme for drivers who buy new cleaner cars. The United States has introduced a new tax credit for plug-in hybrid vehicles and electric charging stations and hopes to have one million plug-in hybrids on the road by 2015. Several countries are investing in urban transport or railways.

- **Funding:** Europe decided to channel a big part of its package through the European Investment Bank, which expects a private-sector multiplier of six to one for its clean energy investment in both 2009 and 2010. The United States is considering a national Infrastructure Reinvestment Bank.
- **Training:** Important also is the increased funding to worker training programmes in the United States and other countries, part of which will be dedicated to training in the renewable and energy efficiency industries.

According to a recent estimate by HSBC, the bank, South Korea has invested the highest portion – 81% of its total recovery package – in clean energy (renewables, energy efficiency, CCS and public transport). China, France, Germany and the US also rank high with respectively 38%, 21%, 13% and 12% of their total packages focused on clean energy.<sup>22</sup> Analysis by the IEA of committed and planned investments in member countries indicates that close to USD 128 billion are earmarked for energy efficiency alone.

An important aspect of any stimulus package is its immediate impact on jobs. Interestingly, clean energy technology seems to be very positive in this respect. The experience in California has shown that the first 1.4% of annual efficiency gains produced about 181 000 additional jobs while an additional 1% yielded an estimated 268 000 more.<sup>23</sup> A study by the Center for American Progress estimated the impact of a USD 100 billion package on the labour market by using input-output analyses based upon the lower-end estimates of earlier IMF studies. It calculated that direct effects (e.g., construction workers), indirect effects (e.g., wind turbine manufacturing) and induced effects (lower energy bills generate opportunities for alternative spending) would create in a total two million jobs. It also calculated that a clean energy package would induce *more* jobs than alternatives like general tax cuts or incentives for conventional energy production, due to its relative labour intensity, relatively high local and national impact and a lower share of high wages in the package.<sup>24</sup> That corresponds with an IMF study indicating that the short-run fiscal multiplier (a measure of the effect of government expenditure or tax reductions on the national economy) is in the range from 0.6 to 1.4 for clean energy, while for tax cuts, the multiplier is in the range from 0.3 to 0.8. In general, one might expect some 30 000 jobs for every billion dollars invested in OECD countries and somewhat more in countries with lower average wage costs.

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<sup>22</sup> *Les Echos*, 26 February 2009; HSBC (2009), *The Green Rebound*.

<sup>23</sup> Next 10 and University of California, *Energy efficiency, Innovation and Job creation in California*, October 2008.

<sup>24</sup> Center for American Progress, *Green Recovery*, September 2008.

To some extent the high job creation rate reflects the fact that renewables are not yet cost-effective. Not being least cost means that this option uses more inputs – in terms of capital and labour – for a given amount of output. But for job creation in the short run, this is an advantage.

Table 2 below attempts to rank the different approaches.

**Table 2: Estimated effectiveness of clean energy options in contributing to economic recovery**

	Job Intensity	Long-Term Cost Reduction	CO <sub>2</sub> Reduction	Security of Supply
Building Refurbishment	high	moderate	high	moderate
Switch to Cleaner Cars	moderate	moderate	moderate	high
Wind, Solar	high	high	moderate	moderate
Smart Metering	high	high	low	moderate
Battery Development	moderate	high	high	high
Clean Energy R&D	moderate	high	moderate	moderate
CCS	low	moderate	high	moderate

Impact: ■ high ■ moderate ■ low

Source: Petersen Institute for International Economics (2009), *A Green Global Recovery?*; London School of Economics (2009), *An Outline of the Case for a "Green" Stimulus*; IEA analysis.

**Key point: Energy efficiency, smart-metering and renewables create most jobs in the short term**

Energy efficiency, smart metering and renewable energy are all relatively job intensive. CCS is much less so, as it is very capital intensive. Building refurbishment can start relatively quickly, as can programmes to exchange old cars for new. Again, CCS and more research take time to bear fruit. The question of time-limitedness (not shown in the table) is about the same. Renewables and research options have the best prospect of cost reduction in the future. Except for an infrastructure measure like smart meters, all options contribute strongly to CO<sub>2</sub> reduction. Renewables and CCS do somewhat less in regions that already have a CO<sub>2</sub> cap: more clean power will enable other emitters (mainly industry) to pollute more. Reduction of transport fuels contributes more to security of supply as transport is heavily dependent on oil, whereas power already has alternatives like nuclear. In all cases, the overall ranking of clean energy options is very favourable, also in comparison with other options like road construction (which creates jobs but scores moderate to low in all other aspects). A recovery package based on such elements might aptly be named "A Clean Energy New Deal".

## 7. Focusing on long-term goals

A Clean Energy New Deal will only fully realise its mutually beneficial effects – tackling the economic crisis and contributing to a sustainable future - when it is imbedded in a strategic long-term approach. A bonus for scrapping old cars will lead to cleaner transport only if the new car is more energy efficient than the old one – and tough, mandatory standards might be necessary to ensure that this is the case. A tax reduction on all new appliances is a missed opportunity to favour more energy efficient models.

A successful long-term approach would likely include several key elements. It would begin by emphasising strong support for improvements in energy efficiency and the introduction of a carbon price in such a way that long-term uncertainties are reduced. It would also include substantial government funding for demonstration projects of technologies almost ripe for commercialisation along with significant increases in research, development, demonstration and deployment (RDD&D) funding for new technologies. In comparison with recent RDD&D budgets, a doubling of the order of magnitude may be appropriate. However, if this is implemented in a careful way and if international co-operation is improved (*e.g.* by using technology roadmaps), public money for later deployment could be decreased. Deep CO<sub>2</sub> cuts will be costly in any country, but cleverly designed green recovery packages can reduce costs everywhere.

The Clean Energy New Deal is not a policy measure that substitutes for other, more long-term approaches. It must comprise measures that would have been taken, later or in a different way, without the economic crisis. Indeed, it should focus on those measures that will foster the necessary investments for energy supply to meet demand in the next economic upturn. Low energy prices are temporary and recent developments have shown that supplies cannot always be assumed secure. From this perspective the Clean Energy New Deal might be the most promising and certain way to take a determined first step to a sustainable future – from a security, environmental *and* affordability point of view.

## ANNEX: IEA Technology Roadmaps

Issue: there is a pressing need to accelerate the development of advanced energy technologies. This challenge was acknowledged by the leaders from G8 countries, in their meeting in July 2008 in Hokkaido, Japan where they declared the wish to have the IEA prepare roadmaps to advance innovative energy technologies.

*“We will **establish an international initiative with the support of the IEA** to develop roadmaps for innovative technologies and cooperate upon existing and new partnerships, including carbon capture and storage (CCS) and advanced energy technologies. Reaffirming our Heiligendamm commitment to urgently develop, deploy and foster clean energy technologies, we recognise and encourage a wide range of policy instruments such as transparent regulatory frameworks, economic and fiscal incentives, and public/private partnerships to foster private sector investments in new technologies....”*

Overview: to achieve this goal, the IEA has designed a process for developing technology roadmaps. The overall aim is to reach a 50% emission reduction by 2050 by advancing global development and uptake of key technologies. The IEA will lead this process through the development of energy technology roadmaps under international guidance and in close consultation with industry. These roadmaps will enable governments, industry and financial partners to identify the steps needed and implement measures that will accelerate technology development and uptake.

Process: this process starts with defining a clear definition and elements needed for each roadmap. Accordingly the IEA has defined its global technology roadmap as: “... a dynamic set of technical, policy, legal, financial, market and organisational requirements identified by the stakeholders involved in its development. The effort shall lead to improved and enhanced sharing and collaboration of all related technology-specific RDD&D information among participants. The goal is to accelerate the overall RDD&D process in order to deliver an earlier uptake of the specific technology into the marketplace.”

Each roadmap will identify the major barriers, opportunities, and policy measures for each group of stakeholders (policy makers, industry and financial partners) to accelerate RDD&D efforts for specific clean technologies at both the national and international level. IEA roadmaps will be developed with countries, industry and existing international partnerships. Our approach will start with existing technology roadmaps as the vehicle for further developing a process aimed at accelerating international collaboration/cooperation and public-private partnerships for clean energy technologies. A possible long-term outcome would be creation of an IEA monitoring and review process of further development of key technologies based on these roadmaps.

We start the process by inviting 10-15 experts from **government and industry** for a series of two-day “brain-storming” session for each of the technologies to develop a draft roadmap. These roadmaps are then shared with the broader community of technology experts, governments, and industry as a way of starting the process. We also are planning a series of workshops in 2009 with the financial community to assist the IEA in defining financial barriers and opportunities for these technology roadmaps.