International Energy Agency

IEA Report for the Clean Energy Ministerial

GLOBAL GAPS IN CLEAN ENERGY RD&D

Update and Recommendations for International Collaboration

2010

INTERNATIONAL ENERGY AGENCY

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- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
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Introduction

Achieving global energy security, climate change and access goals will require nothing short of an energy revolution. This implies several needs: major improvements in the full set of low-carbon energy technologies (LCETs), including energy efficiency in buildings, industry and transport; the near decarbonisation of the electricity sector through rapid acceleration in the use of renewable energy and of cleaner, higher efficiency coal combustion and carbon capture and storage (CCS); and the introduction of a new generation of advanced vehicles.

The IEA's *Energy Technology Perspectives 2010 (ETP 2010)* study shows very real signs that some of the necessary changes are starting to occur, in part due to recent implementation of "green" stimulus package funding for clean energy technologies (IEA, 2010a). However, this is just a start: sustaining and accelerating the transition will require unprecedented intervention by governments in developing policies that work with and influence energy and consumer markets. It will also require a significant expansion in the research, development and demonstration (RD&D)[1] of all available LCETs.[2]

This report seeks to inform decision makers seeking to prioritise RD&D investments in a time of financial uncertainty. It is an update of the December 2009 IEA report *Global Gaps in Clean Energy Research, Development and Demonstration,* which examined whether rates of LCET investment were sufficient to achieve shared global energy and environmental goals (IEA, 2009a).[3] It discusses the impact of the green stimulus spending announcements, and provides private sector perspectives on priorities for government RD&D spending. Finally, it includes a revised assessment of the gaps in public RD&D, together with suggestions for possible areas for expanded international collaboration on specific LCETs. The conclusion re-affirms the first *Global Gaps* study finding that governments and industry need to dramatically increase their spending on RD&D for LCETs.

This analysis may be characterised as an international discussion paper that identifies options for consideration by interested governments. It is recognised that all RD&D decisions will be made by individual countries, based on their own policy contexts, priorities and needs.

[1] "RD&D" as used in this document follows IEA definitions and includes applied research and experimental development, but excludes basic research unless it is clearly oriented towards the development of energy technologies. Demonstration projects are included, and are defined as projects intended to help prove technologies that are not yet commercial. IEA definitions exclude technology deployment activities. Where simply "R&D" is used, it indicates that data are available only for the research and development stages.

[2] For the purposes of this report, LCETs include the following: advanced vehicles (including vehicle efficiency, electric/hybrid vehicles, and fuel cell vehicles); bioenergy (including biofuels and biomass combustion for power and heat); carbon capture and storage (including storage and use of CO_2 from power plants, industrial processes and fuel transformation activities); cleaner, high efficiency coal combustion (for power and heat generation); energy efficiency (for commercial and residential buildings and industrial facilities); nuclear energy (nuclear fusion and fission); other renewable energy (geothermal, hydropower, ocean/marine/tidal energy and wind power); smart grids (transmission and distribution systems, end-use systems, distributed generation and information management); and solar energy (solar photovoltaic power, concentrating solar power and solar heating and cooling).

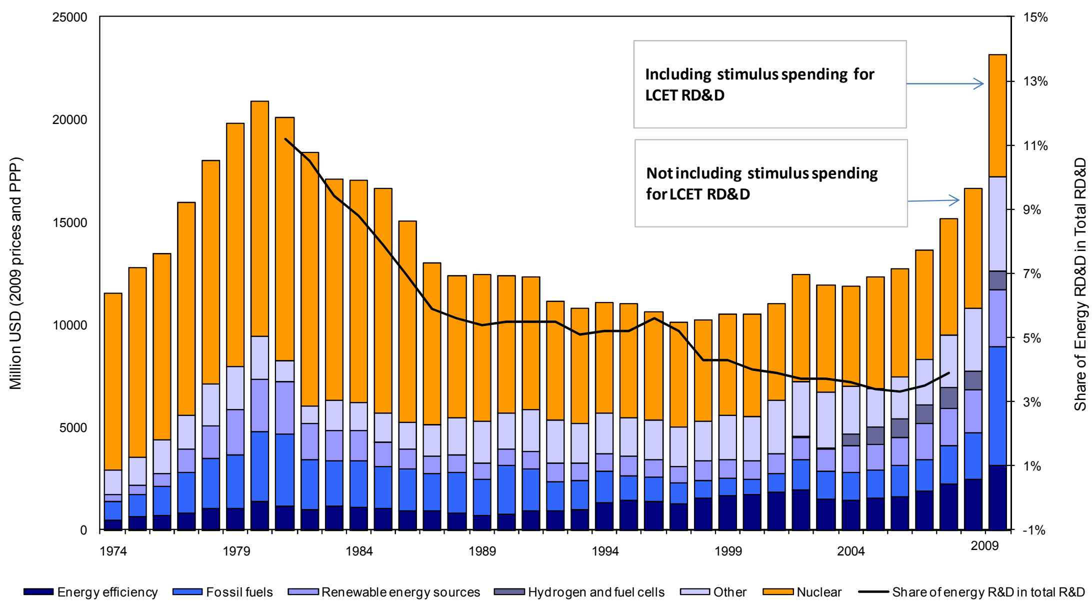
[3] Compared to the previous *Global* Gaps study, this paper includes an expanded set of country data (all IEA member countries plus data collected for the first study), as well as spending on additional technologies (nuclear energy and other renewable energy).

Public expenditure on energy RD&D

Government spending on clean energy RD&D continues to rise. As a result of the "green" stimulus packages during the past two years, 2009 saw a significant increase in IEA member country expenditures on clean energy RD&D. With the stimulus spending, annual IEA member country spending is about USD 23 billion; USD 16 billion without stimulus spending.[4] This stimulus-related increase nearly doubles IEA member country spending from 2008 levels, and exceeds the previous peak spending period in the early 1980s (Figure 1). However, as discussed below, this increase is not expected to be sustained in 2010.

Government RD&D budgets have steadily increased since 1997. However, with the exception of 2009, total public sector budgets for energy RD&D have declined in real terms over the last 35 years: pre-stimulus nominal levels in 2008 were only slightly above amounts budgeted in 1976. Moreover, the relative share of energy in total RD&D has declined significantly, from 12% in 1981 to 4% in 2008.

Figure 1: Government RD&D expenditure in IEA member countries, 1974-2009



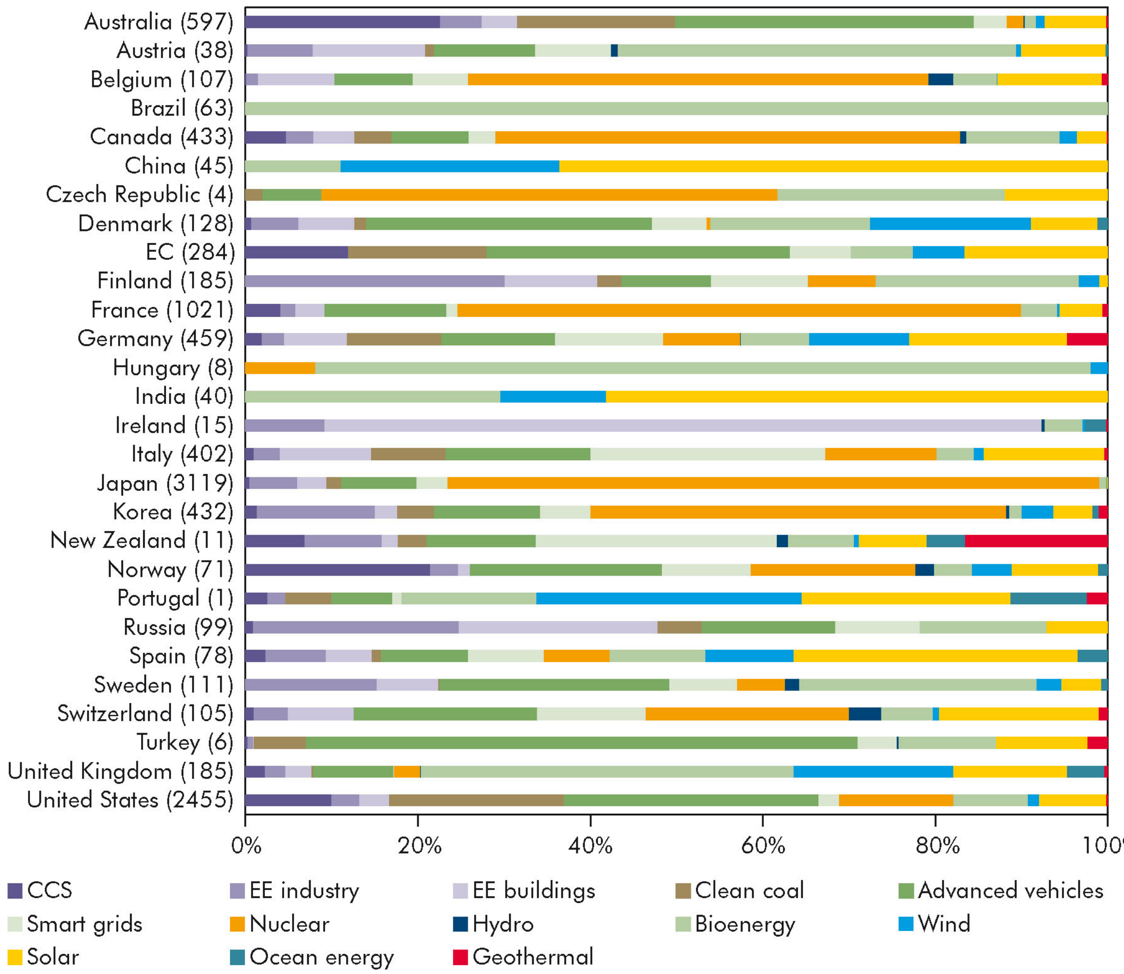
Note: PPP = purchasing power parity.
Source: IEA databases, 2010 cycle. RD&D budgets for the Czech Republic, Poland and Slovak Republic have not been included for lack of availability.

Countries spend very different amounts on RD&D for LCETs, and devote their investment to a wide range of technologies, depending on national circumstances (Figure 2). In 2008, the last year with detailed data, nuclear fission and fusion attracted around 40% of public RD&D spending (78% on traditional fission reactors). Government expenditure on fossil fuel research

[4] These amounts reflect the stimulus spending observed in 2009, including the US American Recovery and Reinvestment Act. These are one-time appropriations (although actual expenditures may go into future years). Some countries have not yet reported stimulus spending amounts dedicated to RD&D. These totals do not include spending amounts in other major economies such as China, Russia, Brazil and India.

experienced the largest drop in share from 1992 to 2006, although annual expenditure in this sector increased by 12% between 2006 and 2008 as a result of increased interest in CCS. There were also increases in annual budgets over this period for renewables (28%), energy efficiency (17%), and hydrogen and fuel cells (10%).

Figure 2: Total energy RD&D for LCETs by country (million 2008 USD)



Note: Amounts in parentheses at left are total expenditures in million 2008 USD. Spending amounts for Australia, Canada, Germany, Russia and the United States are 2009 estimates based on country submissions. The table includes all of those IEA member countries and other major economies for which data are available. No data are available for Greece, Luxembourg, the Netherlands, Poland and the Slovak Republic. Nuclear includes only nuclear fission spending.
Source: IEA, 2010a.

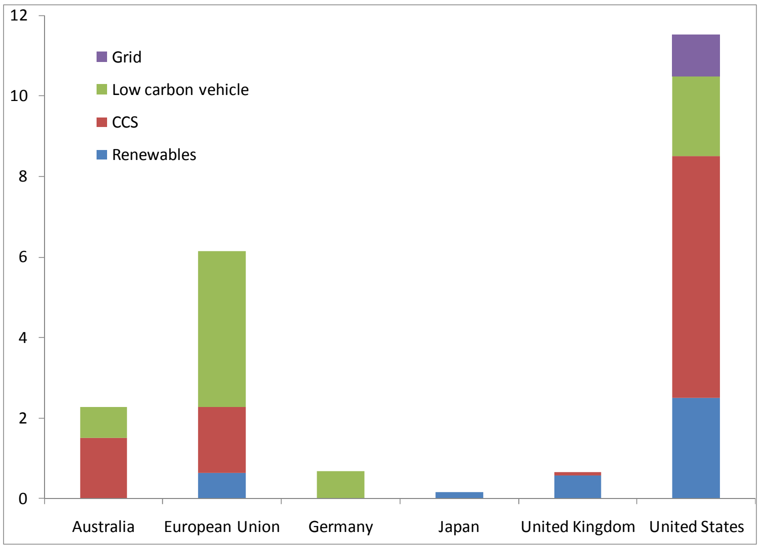
National energy RD&D expenditures vary significantly as a function of gross domestic product (GDP) per capita and CO_2 emissions. On a per-capita basis, Finland, Japan and Australia spend the highest proportion (between 0.07% and 0.08% of GDP in 2008) of all IEA countries for which information is available. Overall average expenditure on energy RD&D in IEA countries is about 0.03% of GDP. In terms of levels of low-carbon RD&D investment compared to CO_2 emissions, Switzerland, France and Finland spend most, closely followed by Japan, Denmark and Sweden.

Government stimulus commitments to clean energy RD&D

During 2008-09, several major economies announced stimulus measures designed to improve their economic situation: many of these plans included investment in LCET research, development, demonstration and deployment (RDD&D) (OECD, 2009a). At the end of 2009, major economies had allocated more than USD 520 billion to clean energy technologies, including energy efficiency retrofits for buildings, high-speed railways, smart grids and renewable energy (HSBC, 2010). Of this total, approximately USD 23 billion is for RD&D for LCETs (Figure 3). The United States has the largest amount (USD 12 billion) of RD&D in its stimulus packages, followed by the European Union (USD 6 billion). Some countries with major LCET stimulus spending — such as South Korea and China — are not included in Figure 3 because publicly available spending data did not specifically identify RD&D activities.

It is widely believed that the stimulus packages are a one-time increase in funds and new commitments to RD&D for LCETs may be ending. No major announcements were made in the first half of 2010. Further, as of end 2009, only USD 82 billion of the total funding committed through stimulus packages had been delivered. In May 2010, only 21% of promised stimulus spending had reached the energy sector (BNEF, 2010a). This is due in part to the challenges governments face in rapidly increasing administrative capacity to award funds in an effective manner – *i.e.* with sufficient evaluation and monitoring to ensure that funds are directed towards the best programmes (IEA, 2009b).

Figure 3: Green stimulus spending by leading countries on low-carbon technology RD&D



Source: HSBC, 2010.

Stimulus spending has had a measurable effect on improving market investment in LCETs. In the renewable energy sector, for example, the Global Wind Energy Council estimates that wind turbine installations reached over 37 GW in 2009, up 38% from 2008.[5] This was largely driven by

[5] See *www.gwec.net/index.php?id=13.*

China, which accounted for 35% of the new installations, making China the largest region for wind installations for the first time. The United States also saw 10 GW of new wind power in 2009 (Sandalow, 2010). Other renewable technologies also experienced modest growth as compared to the expected decline in investment due to the financial crisis. In the United States, the Department of Energy stimulus spending has been matched nearly 1:1 by private investment (Sandalow, 2010).

Whether this sudden push for LCETs can be sustained over the medium to longer term is uncertain. These one-time increases need to be managed to ensure a smooth transition and steady growth for LCETs. This requires a strategic, comprehensive approach that combines public funds to advance RD&D with a suite of policy tools to catalyse private sector investment.

Catalysing private finance and technology innovation by industry

Providing larger amounts of publicly funded RD&D is one way to advance LCET development. While IEA member countries and other major economies have made a collective commitment to double RD&D spending for LCETs, this is insufficient to achieve global energy goals (IEA, 2009a). As a result, governments need to rely on industry to become an active partner in accelerating energy technology research and deployment. This creates additional challenges in that low-carbon industries are often too fragmented to fund significant research (*e.g.* in the buildings sector), deployment timeframes are long and capital needs large, and the investment risk is too great for any one business to sustain. Additionally, regulatory uncertainties, and competitive and financial market pressure, make it difficult for the private sector to increase investment in RD&D for LCETs. Finally, as a result of the financial crisis, business investment in RD&D for LCETs is being re-oriented towards short-term, low-risk innovations while longer-term, high-risk projects are being cut (OECD, 2009b).

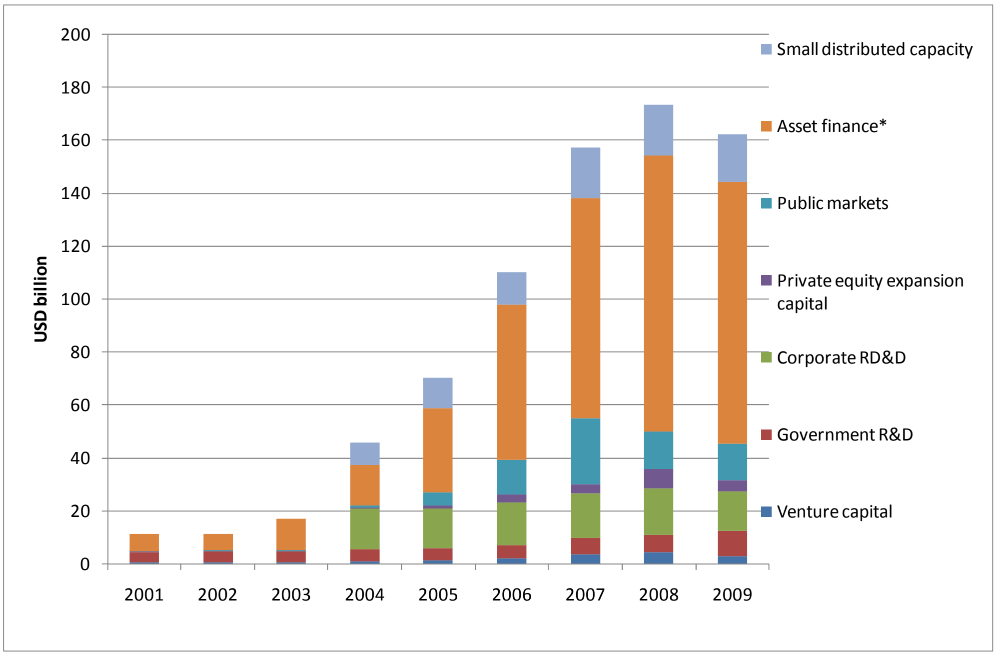
Industry investment in clean energy RD&D is difficult to determine on a global basis. In the United States, energy sector RD&D funding is very low in comparison to other sectors such as pharmaceutical (invest 20% of revenues in RD&D), information technology (15%) and semiconductors (16%). By contrast, energy firms invest only 0.23% of revenues in RD&D (National Science Board, 2010). The European Commission estimates that industry accounts for 69% of total European RD&D investments in non-nuclear priority LCETs (EC JRC, 2009). Much of the private sector innovation is not carried out by traditional energy companies. In the European Union, industries with elevated investment in RD&D for LCETs include equipment suppliers, chemicals, energy components or those that operate exclusively in one technology area (*e.g.* wind turbine manufacturers) (EC JRC 2009).

Governments must increase their efforts to understand the needs of, and engage with, the private sector. In addition to the “technology push” approach of directly funding LCETs through public spending, many countries use policies and incentives to promote greater private investment as a means of “pulling” LCETs into the marketplace. Strategies that link RD&D efforts with mass-market deployment schemes have proven to be the most effective in accelerating technology progress. Such approaches send clear signals to the market, which can help to attract additional investment and promote innovation. This fosters technology efficiency and economies of scale, thereby reducing investment costs along the learning curve. Successful policy approaches include:

- **Fiscal incentives** including reduced taxes on biofuels (United Kingdom and United States) and a wind energy production tax credit (United States).
- **Mandated blending requirements of biofuels** with petroleum-based fuels (Brazil and European Union).
- **Capital grants for demonstration projects and programmes** including clean coal (United States) and solar photovoltaic (PV) (United States, Germany and Japan).
- **Feed-in tariffs** for wind, PV, and other renewables (Germany), and wind and solar schemes (Spain).
- **Quota-based schemes** such as renewable portfolio standards (several US states) and vehicle fleet efficiency standards (California).
- **Tradable quotas** such as the Renewables Obligation and Renewable Transport Fuels Obligation (United Kingdom).
- **Tenders for tranches of output** such as the former Non-Fossil Fuel Obligation (United Kingdom).
- **Direct subsidies and government procurement** including hydropower (Sweden) and nuclear power (France).

Public and private RD&D spending accounts for only about 20% of the total LCET investment that has recently occurred (Figure 4). Therefore, it is important for governments to have a better understanding of how private finance markets operate, so that they can design effective policy measures to attract that funding.

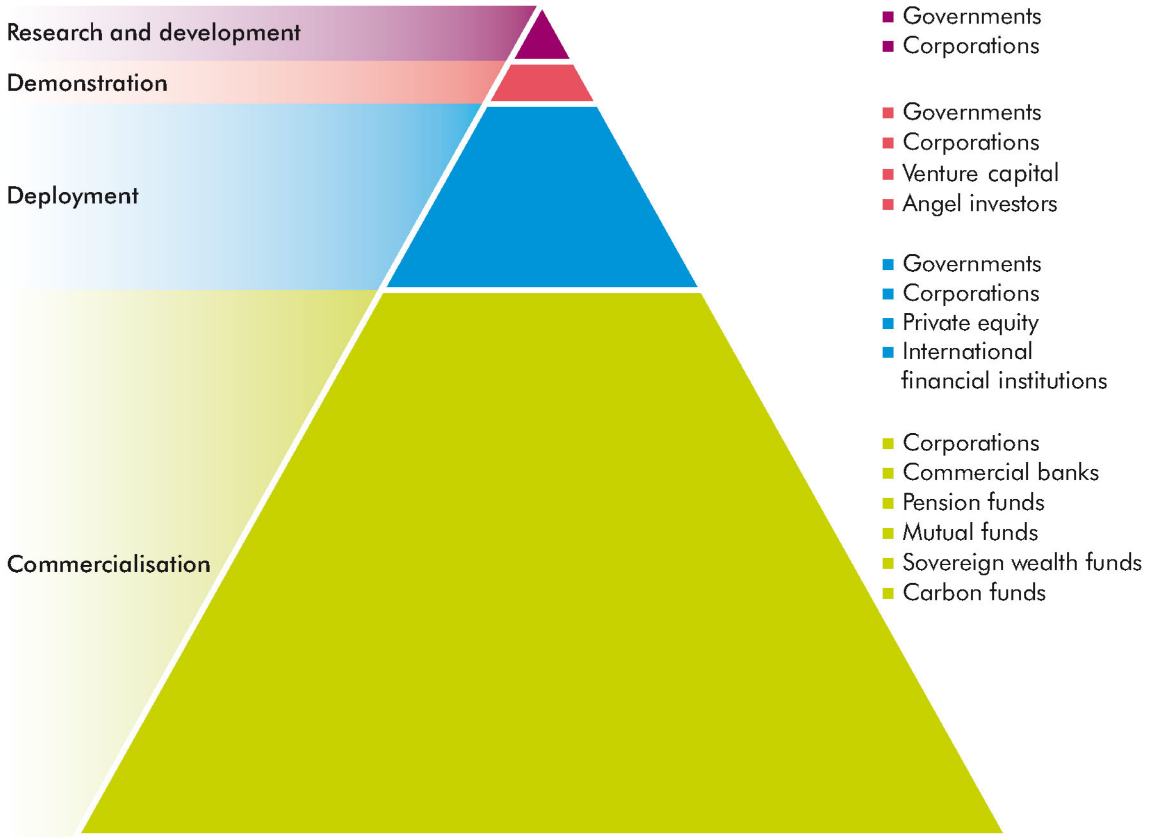
Figure 4: Public and private investments in LCETs, 2001-09



* Asset finance excludes amount re-invested in equity. Estimates for corporate RD&D and investments in small-scale projects are not available for 2001, 2002 and 2003.
Source: BNEF, 2010b.

A key consideration is that funding approaches need to be tailored to the different stages of technology development. Government funding is most relevant for early stage technology development, while private finance tends to assume a larger share of later-stage technology deployment and commercialisation. The scale of investment requirements for the various stages – namely research, development, demonstration, deployment and commercialisation – is roughly captured by the area represented in the pyramid (Figure 5).[6]

Figure 5: Government RD&D spending catalyses a much greater total investment



Source: IEA, 2010a.

For technologies such as CCS, smart grids and electric vehicles, which require significant investment in large-scale demonstration and related infrastructure, the critical period before commercial scaling carries high financial risks and requires sufficient regulatory frameworks. Targeted public funding designed to leverage private sector finance can help to offset the greatest risks for such technologies. Offering these funds through competitive tendering can help ensure the benefits are directed toward the most efficiently run projects.

Policy stability and policy instruments

Frequent changes in LCET policy support raise investor risk.[7] Governments need to take steps to ensure policy predictability and stability so that investors can confidently finance a larger

[6] The actual share of investment needed at each stage differs significantly from one technology to another, but investment generally needs to increase as technology advances from R&D to demonstration, deployment and commercialisation.

[7] See "Spain pressed over solar tariff cuts," *Financial Times (24 June 2010).*

portion of required investments over longer payback periods. For example, current carbon prices are too low or unpredictable to attract the scale of the investment needed in new technologies. Governments need to take measures to establish higher and more certain carbon prices to reduce uncertainty from the carbon markets and make investment more attractive.

Several different initiatives, such as the Institutional Investor Group on Climate Change, the Investor Network on Climate Risk[8] and the Finance Initiative launched by the United Nation Environment Programme,[9] promote the importance of climate change within the investment community. These initiatives are encouraging, but more active engagement between governments, industry and the financial community is needed. Governments and industry should target the financial community with efforts to increase education and raise awareness of climate change issues. They should also promote low-carbon investment opportunities to the public and private pension funds, and help educate fund managers on the strategic rationale for investment in LCETs. Many existing funds are not set up to invest in the types of financial instruments most commonly used to fund low-carbon technologies. For example, many funds can only invest in the public equity market; they are restricted from making direct investments or investing in the sort of debt instruments that provide significant funding for LCETs.

Tax measures, including modified capital gains taxes, tax credits, tax exemptions or lower rates of tax for reinvestment in LCETs could help stimulate investment. In the United States, the tax credit scheme for low-carbon technologies has been the most effective instrument to increase financial flows to the sector. It has allowed many financial institutions with large tax liabilities to make large equity investments in projects at significantly lower required returns. The Chinese government recently announced (in specific provinces) a new purchase tax credit, valued at USD 7 320 (CNY 50 000), to purchasers of electric vehicles.[10] This sort of direct subsidy could be combined with loan softening programmes that enable banks to pass on the benefit to consumers by lowering leasing rates or through other innovative financing mechanisms.

Various public finance mechanisms have been successful in promoting investments in energy efficiency and renewable energy technology development and deployment (Table 1). These mechanisms can leverage commercial financing by a factor of 5 to 15 (UNEP SEFI, 2008).

Table 1: Public finance mechanisms to support investment in clean technologies

Mechanisms	Description
Credit lines	Local commercial financial institutions (CFI) to provide senior and mezzanine debt to projects
Guarantees	Share with local CFIs the commercial credit risks of lending to projects and companies
Debt financing	Financing of projects by entities other than CFIs
Private equity (PE) funds	Investing risk capital in companies and projects
Venture capital (VC) funds	Investing risk capital in technology innovations

[8] See *www.incr.com.*
[9] See *www.unepfi.org.*
[10] The areas of focus are Shanghai, Shenzhen, Hangzhou, Hefei and Changchun. See *http://blogs.edmunds.com/greencaradvisor/2010/06/china-announces-plan-to-subsidize-evs-and-plug-in-hybrids-in-five-major-cities.html.*

Carbon finance	Facilities that monetise the advanced sale of emission reductions to finance project investment costs
Grants and contingent grants	Share project development costs
Loan softening programmes	Mobilise domestic sources of capital
Inducement prices	Mobilise domestic sources of capital
Technical assistance	Build the capacity of all actors along the financing chain
Tax credits	Target the different phases of technology maturity; care must be taken to avoid favouring specific technologies over others
Loan guarantees	Reduce risks that impede private investment
Public concessionary loans or equity	Provide long-term leverage at low costs, especially for large-scale infrastructure projects
Government procurement	Incentivise deployment and commercialisation via public sector projects

Source: Adapted from UNEP SEFI, 2008.

Private-public partnerships

One innovative solution now being tested is the creation of new public-private institutions that pool funds for a variety of LCET investments. This might include: infrastructure projects (*e.g.* offshore wind transmission and distribution, CO_2 storage pipelines, electric vehicle recharging stations); initial capital or guarantees as part of a consortium to fund major investments in renewable energy or bundled energy efficiency retrofits; and loans, equity or venture capital to companies seeking to bring demonstrated LCETs to full commercialisation.

In 2010, the UK government announced its intention to invest up to USD 1.5 billion (GBP 1 billion) from the sale of infrastructure assets to create a commercial Green Investment Bank, with the expectation that the private sector would at least match this commitment (UK GIBC, 2010). The Bank addresses market failures and investment barriers for LCETs and their related infrastructure by providing equity co-investment, creating "green" bonds to access capital held by institutional investors and providing insurance products. The Bank will also play an important role in co-ordinating and providing coherence among the variety of existing government LCET funds and initiatives. The US Congress is considering a similar proposal for a Clean Energy Deployment Administration.

Angel investors and venture capital

Depending on the technology, the pathway from the laboratory to commercial product can be a challenging phase of development. Angel investors and venture capital firms can play an important role in identifying technologies with the greatest commercial potential, but competition for funding can be intense. Some governments have initiated programmes to target this critical phase. The United Kingdom's Carbon Trust provides targeted support by leading industry collaborations and investing in early stage low-carbon companies to help business commercialise low-carbon technologies (Carbon Trust, 2009). Another example of ways to bridge this gap is the US government's recent creation of the

Advanced Research Projects Agency-Energy (ARPA-E) to fund technologies, including those that are not sufficiently advanced to attract venture capital investment.

Assessment of low-carbon RD&D gaps

Global investment in LCETs needs to increase substantially to achieve the energy revolution necessary to address the challenges of climate change and energy security. The shortfall between the current USD 10 billion in annual public RD&D spending and the investment needed is estimated at USD 40 billion to USD 90 billion. Half of this investment gap is expected to come from public sources (Table 2). Therefore, achieving global energy and climate change ambitions (as outlined in the *ETP 2010* BLUE Map scenario) will require a twofold to fivefold increase in public RD&D spending.[11]

These results are similar to the previous IEA *Global Gaps* study, which estimated that public sector RD&D spending for LCETs needs to be three to six times the current levels (IEA, 2009a). Increasing public investment in LCETs offers proven productivity and economic growth benefits, and is an important strategy for governments seeking to emerge from the financial crisis with a sustained green growth strategy (see box).

Public RD&D is a good investment

A sustained public increase in RD&D spending is an important strategy to help governments to emerge from the financial crisis while also laying the foundation for green growth. Past public RD&D investments in LCETs have led to large improvements in the performance of specific energy technologies, energy sectors and to national economies. Public energy RD&D spending offers many benefits, including economic development, productivity growth, accelerated technology learning rates and more rapid development of patents. The effect of government RD&D on productivity is significant and positive, and outweighs the cost (OECD, 2001).

While it is difficult to make detailed evaluations of the returns from energy RD&D, studies have found positive results. For example, the European Union estimates an internal rate of return on investment of 15% from the period 2010-30 for its Strategic Energy Technology (SET) Plan RD&D investments (EC JRC, forthcoming 2010). In the United States, the Department of Energy found that its investment of USD 17.5 billion (present value) between 1978 and 2000 – primarily in RD&D for energy efficiency and fossil energy – provided a yield of USD 41 billion (Gallagher, Holdren and Sagar, 2006). Accelerated patent activity is another indicator of the success of public RD&D funding. The OECD found that a 10% increase in public expenditures on RD&D for fuel efficiency improvements in transport resulted in a 1.8% increase in high-value patents for hybrid vehicle technologies and a 0.7% increase for electric vehicles. Other LCETs also show statistically significant increases (OECD, 2010).*

*Based on an analysis of 17 IEA countries over 25 years; "high-value" patents are those with multiple claim filings. For related work, see: www.oecd.org/environment/innovation.

[11] Private LCET spending amounts are not well-documented; 2008 RD&D investment is estimated to be over USD 10 billion (BNEF, 2010c).

Table 2: Estimated global gaps in public low-carbon energy RD&D

	Annual investment in RD&D needed to achieve the BLUE Map scenario outcomes in 2050	Annual public RD&D spending	Estimated annual RD&D spending gap
	(USD million)[1]	(USD million)[2]	(USD million)
Advanced vehicles (includes EVs, PHEVs + FCVs; energy efficiency in transport)	22 500 – 45 000	1 860	20 640 – 43 140
Bioenergy (biomass combustion and biofuels)	1 500 – 3 000	740	760 – 2 260
CCS (power generation, industry, fuel transformation)	9 000 – 18 000	540	8 460 – 17 460
Energy efficiency (industry)[3]	5 000 – 10 000	530	4 470 – 9 470
Higher-efficiency coal (IGCC + USCSC)[4]	1 300 – 2 600	850	450 – 1 750
Nuclear fission	1 500 – 3 000	4 030	0[5]
Smart grids	5 600 - 11 200	530	5 070 – 10 670
Solar energy (PV + CSP + solar heating)	1 800 – 3 600	680	1 120 – 2 920
Wind energy	1 800 – 3 600	240	1 560 – 3 360
Total across technologies	**50 000 – 100 000**	**10 000**	**40 000 – 90 000**

[1] RD&D investment needs derived using 10% to 20% of average deployment costs for BLUE Map scenario and adjusted by a factor of 90% to reflect country coverage.
[2] IEA 2007 data with the following exceptions: Australia (2009-2010 estimated); Canada (2009 estimated); France (2007 revised via direct submission; Germany (2009 estimated); USA (2009 estimated). The non-member country data were taken from IEA (2009e). When necessary, spending calculated using 2008 exchange rates.
[3] Estimates for buildings energy efficiency RD&D needs were not available.
[4] Integrated gasification combined cycle and ultra-supercritical steam cycle.
[5] The gap for nuclear fission is assumed to be zero excluding any additional RD&D for Gen IV technologies. Therefore the sum of the estimates for the gap by technology do not sum to the total.
Note: Table includes all countries for which the IEA has spending data, including IEA member countries and data collected from other major economies for the first *Global Gaps* study.
Source: IEA, 2010a.

Closing the gap: collaboration opportunities by technology area

Following the 15th Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) (Copenhagen, December 2009), governments are looking for mechanisms by which to translate dialogue into action in order to enhance energy technology development and deployment. Attaining these goals will require increased co-operation among industries, businesses and government to advance energy technology research. Such multilateral and international collaboration provides many benefits. Even so, examples of existing and planned technology collaboration initiatives must be closely co-ordinated to ensure maximum effectiveness (see box).

The benefits of increased multilateral energy technology co-operation*

Industry and business partners
- Linking research, technology and policy requirements
- Accelerating research results and regulated intellectual property rights issues
- Information sharing, knowledge transfer and networking to raise credibility
- Access to large, emerging country markets and governments
- Harmonised benchmarking and standards
- Shared resources and risks leading to greater potential project scale
- Understanding government energy technology policy needs and input to priority setting

Governments and research institutions
- Understanding corporate near-term needs and investment conditions
- Deploying LCETs at an accelerated pace and scale
- Sharing resources and risks
- Harmonising technical standards and intellectual property issues
- Strengthening national and local research capabilities
- Strengthening linkages with like-minded organisations and avoiding gaps and overlaps
- Increasing project scale

These benefits are already being realised in several cross-cutting technology initiatives, including those described below.

The 41 **Multilateral Technology Initiatives (Implementing Agreements)** supported by the IEA are a flexible and effective framework for IEA member and non-member countries, businesses, industries, international organisations and non-governmental organisations (NGOs) to research breakthrough technologies, bridge existing research gaps, build pilot plants and carry out demonstration or deployment programmes. The IAs encourage technology-related activities that support energy security, economic growth and environmental protection. All of the IEA Implementing Agreements manage joint research programmes; countries and private organisations can participate in projects of specific interest. (*www.iea.org/techno/index.asp.*)

The **European Union's Strategic Energy Technology Plan (SET Plan)** comprises measures related to planning, implementation, resources and international collaboration in the field of energy technology, with the aim of accelerating the development and deployment of cost-effective LCETs. The SET Plan objectives are to bring new energy technologies to the market by 2020 while investing in longer term (to 2050) R&D, and to put European industry in a lead position worldwide while transitioning to a low-carbon economy by 2050. Priority technologies include: electricity grids, wind, solar energy (PV and concentrating solar power [CSP]), bioenergy, CCS and nuclear fission. The Plan also includes a new Smart Cities initiative, focused on energy efficiency in European cities. The SET Plan is complemented by technology-specific platforms and industrial initiatives that engage the private sector. (*http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm.*)

The **Asia-Pacific Partnership on Clean Development and Climate (APP)** includes Australia, Canada, China, India, Japan, Korea and the United States. These countries are working together to accelerate development and deployment of clean energy technologies. The APP focuses its efforts through Task Forces, which incorporate a public-private partnership model that brings together industry leaders and stakeholders with governments from the partner countries. The APP facilitates technology and best practices transfer through discrete projects and defined areas of co-operation. There are eight public-private Task Forces, including five that focus on energy-intensive sectors (Aluminum; Buildings and Appliances; Cement; Coal Mining; and Steel) and three that cover energy supply sectors (Cleaner Fossil Energy; Power Generation and Transmission; and Renewable Energy and Distributed Generation).

Proposed new multilateral technology collaboration initiatives include the **IEA's Low-Carbon Technology Platform**, the **UNFCCC's Technology Mechanism**, and the **Major Economies Forum Global Partnership**.

* In addition to these multilateral initiatives, there are many other arrangements such as: bilateral agreements between research institutes, academic exchanges, and industry-led collaborations with academic groups.

Public funds will play a critical role in several technology areas, including funding for high-risk, non-competitive basic research that does not attract investors. Advanced vehicles, biofuels and renewable energy technologies have a particularly strong need for expanded basic science research to deliver the breakthroughs required to achieve long-term cost competitiveness goals. Mechanisms of support are also needed for small LCET innovators that require seed funding because their primary assets (patents or ideas) are intangible and difficult to value.

The discussion below assesses funding gaps for individual technologies, followed by a review of countries that are taking the lead in each area through RD&D and policy frameworks, existing multilateral collaborative activities for the technology, and suggestions for future expansion.

Advanced vehicles

RD&D investments: < USD 2 billion	Global gap: USD 20 billion to USD 40 billion

Advanced vehicle RD&D, including electric vehicles, vehicle efficiency measures, and hydrogen/fuel cell vehicles, has the largest gap of all LCETs between current public spending and estimated needs. Currently, less than USD 2 billion is spent annually; it is assumed that 10 to 20 times this amount is needed to achieve global climate and energy targets. The United States is the leading spender, though Japan and France recently increased their investments significantly. The main focus is on vehicle efficiency RD&D, which includes several technologies and approaches such as lightweight materials, advanced thermal combustion engine (ICE)-based power trains and onboard diagnostics. This category makes up the largest share of advanced vehicles public funding. It is unclear what amount of the reported spending includes infrastructure investments such as developing systems to recharge EV/PHEVs.

The *IEA Technology Roadmap: Electric and Plug-in Hybrid Vehicles* (IEA, 2009c) includes recommendations for RD&D priorities. According to the Roadmap, expanded basic research for advanced vehicles is needed to produce new nano-materials for batteries and for use in vehicle construction to improve efficiency. Due to the long lag before commercialisation, basic research for advanced vehicles will continue to be a priority for publicly funded research. Battery cost reduction is also critical to achieve EV break-even cost with ICEs, and can be achieved via large battery production scales and learning. In the next two to three years, battery technology performance needs to be verified via publicly funded in-use testing, after which companies may be able to quickly advance to competitive mass production.

Companies are focusing their research efforts on improving production processes for the current generation of advanced vehicles. They may need government support in helping to adopt the complex production systems that will be required by new vehicle technologies. Large-scale deployment of advanced vehicle technologies will largely be funded by vehicle manufacturers, with support from the public sector in targeted roll-outs and combined public-private educational campaigns to ensure critical mass and public support.

Recommendations for advancing international action

International collaboration in advanced vehicles could be expanded, for example, through a framework that accelerates RD&D investment and helps policy makers develop strategies and adopt targets and principles. There is also the need to develop an international collaborative activity focused on sharing experiences and lessons learned from early EV/PHEV pilot-scale efforts. Existing international efforts, such as those highlighted below, provide a basis for expanding activities.

Advanced vehicles: International initiatives underway

The **Advanced Vehicle Leadership Forum (AVLF)** is a new global effort that will bring together governments, cities, auto manufacturers, electric utilities and other stakeholders to systematically share information and planning on global EV/PHEV development. Among other things, the AVLF will address technical standards and practices; assess current and potential domestic and international joint RD&D efforts (particularly multi-country demonstration projects); and explore opportunities to initiate public, private, and public-private R&D collaborations in the near term.

The **Global Fuel Economy Initiative** works to achieve a 50% reduction in global fuel economy by 2050 by promoting research, discussion and action to improve fuel economy worldwide, with a focus on raising awareness and capacity building. (*www.50by50campaign.org.*)

The **Implementing Agreement for Co-operation on Hybrid and Electric Vehicle Technologies and Programmes (HEV IA)** recently released a study that provides practical advice for deployment. The study found that developing closer partnerships between automakers and power utilities was essential, particularly to better target consumer education. The study also found that the cost of public recharging infrastructures far outweighed the cost of deployment. The 14 member countries of the HEV IA are also examining electric cycles, electrochemical systems, fuel cells for vehicles, and heavy-duty hybrid vehicles. (*www.ieahev.org.*)

The **Implementing Agreement for a Programme of Research, Development and Demonstration on Advanced Fuel Cells (AFC IA)** encompasses mobile and stationary applications of polymer electrolyte, molten carbonate and solid oxide fuel cells. Current projects include measurement and monitoring techniques, exchange of information on cell, stack and system performance, collaboration on the development of new procedures and models, and information sharing on application requirements. Nineteen countries participate, including Mexico. (*www.ieafuelcell.com*.)

The **Implementing Agreement for a Programme of Research and Development on Advanced Materials for Transportation Applications (AMT IA)** co-operates internationally to share information on technologies to reduce surface friction and weight, for example through the use of magnesium alloys, low-cost carbon fibres, and nano-composites. There are currently five countries participating, including China. (*www.iea-ia-amt.org*.)

Bioenergy

RD&D investments: USD 740 million	Global gap: USD 760 million to USD 2.3 billion

The gap in RD&D on bioenergy, including biomass combustion for heat or power generation (or cogeneration) and biofuels production, is estimated to be among the smallest of all the LCETs. Current IEA data shows a total of USD 740 million annual spending, where the need is estimated to be between USD 760 million to USD 2.3 billion. While the United States and the United Kingdom are leaders in overall bioenergy RD&D, Brazil leads biofuels RD&D spending. Finland is, despite its small size, a world leader in biomass combustion RD&D efforts, followed by Canada, Germany and Switzerland.

The most important breakthrough for bioenergy is expected to come from the cost-effective conversion of cellulose-rich biomass (found in wood, grasses and agricultural residues) to usable energy. There are no commercially operating facilities today; the United States and European

Union RD&D are focused on making cellulosic biofuels technologies viable by improving efficiencies in processing and conversion. There is also a need to develop bioenergy cycles which are sustainable, along with methodologies and standards which can ensure long-term sustainable performance.

Corporate biofuels R&D investments in Europe add USD 341 million (EUR 269 million) based on a European Union assessment of 23 companies (EC JRC, 2009). There are no reliable data estimates for corporate RD&D investments in the rest of the world. The gap in second-generation biofuels RD&D data may be due, in part, to the fact that research into second-generation biofuels has only recently become a public priority. Therefore, these activities may not yet be fully reflected in the national RD&D budgets reported to the IEA.

Recommendations for advancing international action

The 2009 *Bioenergy Technology Action Plan* prepared for the Major Economies Forum on Energy and Climate Change identified the need to foster the establishment of international regional centres of excellence among bioenergy networks that connect researchers and industry. The Plan further recommended that countries jointly undertake demonstration projects in lingo-cellulosic biofuels and integrated food and energy systems (MEF, 2009). Some of this collaborative research is already underway (see box). However, to address the current gap, expanded international collaboration is needed, particularly in 2nd-generation biofuels research. The IEA is developing a biofuels roadmap that could provide a high-level network to share RD&D experiences and priorities, together with the Global Bioenergy Partnership and the Bioenergy Implementing Agreement.

Bioenergy: International initiatives underway

The primary focus of the **Implementing Agreement for a Programme of Research and Demonstration on Advanced Motor Fuels** (**AMF IA)** is to facilitate the market introduction of advanced motor fuels and related vehicle technologies in IEA member countries. The AMF IA provides a platform for fuel analyses and reporting, drawing on the expertise of its 16 Contracting Parties. In addition to a current project assessing the emissions from use of ethanol as a motor fuel, the AMF IA is also conducting research on biomass-derived diesel fuels, fuel and technology alternatives for buses, and particle emissions of two-stroke scooters. (*www.iea-amf.vtt.fi.com*.)

The **Implementing Agreement for a Programme of Research, Development and Demonstration on Bioenergy** (**Bioenergy IA)** has 22 Contracting Parties, including Brazil, Croatia and South Africa. The Bioenergy IA focuses on the full range of bioenergy RD&D, including biomass combustion and co-firing, feedstocks, sustainable production, biorefineries, liquid biofuels, biogas, pyrolysis and thermal gasification. A recent study reviewed technical challenges facing second-generation biofuels, evaluated their costs and examined current policies to support their development. A complementary study evaluated the gaps in current research for production of second-generation biofuels; it found the main research gaps to be catalysts and biocatalysts, feedstock preparation and processing, and systems integration. (*www.ieabioenergy.com*.)

The **Global Bioenergy Partnership (GBEP**) brings together bioenergy stakeholders to organise, co-ordinate and implement targeted international RD&D and commercial activities related to production, delivery, conversion and use of biomass for energy, with a focus on developing countries. The GBEP has made progress developing sustainability criteria, as well as indicators and a methodological framework for measuring greenhouse gas savings. Technology co-operation among governments on the co-ordinated development and implementation of national bioenergy technology action plans for RD&D represents a new focus area, which aims to ensure the co-ordination of international RD&D efforts and seeking opportunities for joint RD&D projects. (*www.globalbioenergy.org*.)

The **APEC Biofuels Task Force** helps Asia-Pacific Economic Cooperation member economies better understand the potential for biofuels to displace oil in transport. It focuses on joint analysis of key issues affecting the development of biofuels, such as resources, economics, infrastructure, vehicles, and trade opportunities. (*www.biofuels.apec.org/task_force.html*.)

The **European Union Biofuels Technology Platform** engages with biofuels stakeholders, research projects funded by the European Commission and global biofuels organisations in a range of activities relevant to the R&D&D of sustainable advanced biofuels in Europe. The platform produces a strategic research agenda, and conducts mapping of research and demonstration activities. (*www.biofuelstp.eu*.)

Carbon capture and storage

RD&D investments: USD 540 million	Global gap: USD 9 billion to USD 18 billion

RD&D spending for CCS is distributed across the different technologies for CO_2 capture, transport and storage. The gap for CCS spending is estimated to be USD 9 billion to USD 18 billion, due in large part to the magnitude of large-scale demonstration plants. Funding information is lacking due to the fact that CCS has only recently become a high priority for some countries, and recent increases in spending may not yet be reflected in reported spending. Further, RD&D amounts for CCS in some countries have historically been reported under the more general category of clean coal.

The United States, by far the largest spender, is followed by France, Australia, Canada and Norway. There is evidence that China has increased spending on CCS, but data are not available. Investment is split mainly between CO_2 storage and CO_2 capture, with a very small amount allocated to CO_2 transport. This reflects the consensus that CO_2 transport is an established practice that does not require significant technology advancement. Several countries have made high-profile announcements of large-scale CCS demonstration projects, but these amounts do not yet appear in the data.

The *IEA Technology Roadmap: Carbon Capture and Storage* identified RD&D priorities, including reducing the energy penalty associated with CO_2 capture, application of CO_2 capture at scale and with reduced capital costs, and optimisation of integration, particularly for retrofit applications to achieve CO_2 capture rates above 85% (IEA, 2009d). For CO_2 transport, there is a need to expand mapping and planning work to improve understanding of how CO_2 pipeline systems will evolve over time, based on knowledge of CO_2 sources and CO_2 storage sites. CO_2 storage RD&D needs include developing improved models to advance global understanding of the capacity and injectivity of deep saline formations and the efficacy of different geological media to achieve long-term secure storage. RD&D must also be expanded in areas such as capture of CO_2 from biomass combustion and novel uses of captured CO_2 (*e.g.* production of algae from CO_2 for biofuels). There has been very little focus on CO_2 capture at industrial facilities, which are expected to make up a significant portion of future CCS projects.

These priorities are being addressed through at least 80 large-scale CCS RD&D projects at various stages of development. Of the announced projects, only one (the Australian Gorgon project) is proceeding to construction (IEA/CSLF, 2010). The European Commission reported corporate investments for RD&D in CCS at USD 304 million (EUR 240 million) in 2007 (EC JRC, 2009); data were not available for private RD&D investments for CCS in other world regions.

Recommendations for advancing international action

Governments and industry should intensify collaboration to accelerate the pace of development for full-scale CCS demonstration. The European Union's Zero Emissions Platform and the Global CCS Institute are solid steps in that regard. Despite these platforms, major economies acknowledged at the 2008 G8 Summit in Japan an urgent need to dedicate funding and begin construction of at least 20 large-scale CCS projects before 2015. In parallel, research should be expanded into potentials for industrial CO_2 capture, biomass CO_2 capture, and productive use of captured CO_2. The IEA GHG IA is a logical forum for sharing knowledge and expertise in this area and should be expanded to include other countries with forecasted growth in fossil fuel use.

CCS: International initiatives underway

The **Carbon Sequestration Leadership Forum (CSLF)** is a multilateral effort designed to advance CCS as a viable greenhouse gas mitigation technology. The CSLF's Technical Group fosters RD&D for CCS projects reflecting its members' priorities, working with industry, government and academic experts. (*www.cslforum.org*.)

The **European Union Zero Emissions Programme (ZEP)** provides advice on technical, policy and commercial matters related to expansion of CCS to meet EU targets. The ZEP involves industry and other stakeholders on all technology issues, including recommendations for next-generation CCS technologies, taking into account experience gained from the EU CCS Demonstration Programme. *(www.zeroemissionsplatform.eu)*

The **Implementing Agreement for a Co-operative Programme on Technologies Relating to Greenhouse Gases Derived from Fossil Fuel Use (GHG IA)** has been a leading forum for global RD&D collaboration for CCS for several years. Recent studies have evaluated saline aquifer storage development, CO_2 capture in the cement industry, and global CO_2 storage capability in oil and gas fields. The GHG IA also operates several CCS research networks, including information sharing on CO_2 capture methods and on various aspects of CO_2 storage (risk assessment, well-bore integrity, monitoring, modelling and environmental impacts). (*www.ieagreen.org*.)

The **Global CCS Institute (Global CCS Institute)** was launched in 2009 by the Australian government as an international RDD&D centre for CCS. Its primary focus is on accelerating deployment through large-scale demonstration. Global CCS Institute activities include knowledge sharing, strategic analysis to fill gaps in knowledge and project funding and support. *(www.globalccsinstitute.com)*

Cleaner, high-efficiency coal technologies

RD&D investments: USD 850 million	Global gap: USD 450 million to USD 1.8 billion

Annual spending on clean coal is estimated at USD 850 million, with a gap of USD 450 million to USD 1.8 billion. Cleaner, high-efficiency coal includes several improvements to reduce pollutants to air, water and waste throughout the coal chain, *i.e.* mining, transport and utilisation. It covers the extensive work being undertaken globally on advanced combustion, gasification and liquefaction technologies that offer opportunities for improved efficiencies. As might be expected, countries with large coal resources have sizeable RD&D portfolios, with combustion improvements and integrated gasified combined cycle (IGCC) the leading research focus areas. China, Poland, India and Indonesia are reported to have significant clean coal RD&D programmes and industry (including utilities and equipment suppliers) is also investing in advanced coal technologies aimed at improving efficiency. At present, data are not available to verify funding levels by these countries or industry.

Recommendations for advancing international action

Governments and industry should improve transparency and co-ordination between clean coal and CCS activities, as RD&D efforts to upgrade coal plants are often part of CCS projects. Also, given the significant coal resources available in large emerging economies, and the projected growth in coal use in these countries, there is a need to ensure cleaner processes are widely deployed.

Cleaner coal: International initiatives underway

The **Implementing Agreement for a Programme of Research, Development and Demonstration on Clean Coal Sciences** (**CCS IA),** operating on behalf of IEA member countries and external organisations, offering an authoritative source of reports, in-depth reviews and databases on the energy-efficient and environmentally sustainable use of coal (including co-firing coal with waste or biomass). Recently released reports cover topics such as: the capture of CO_2 with other air pollutants; co-gasification and indirect co-firing of coal and biomass; the performance and risks of advanced pulverised coal plants; and underground coal gasification. (*www.iea-coal.org.uk.*)

Energy efficiency in buildings and industry

RD&D investments: USD 530 million	Global gap: USD 4.5 billion to USD 9.5 billion

At present, there is no gap estimated for buildings energy efficiency RD&D, in part due to a lack of data on current R&D investment.[12] Several recently improved technologies (*e.g.* high-performance windows, reversible heat pumps) and practices (*e.g.* passive solar heating and daylighting) show potential for reducing energy consumption in new buildings by 80% or more compared to the existing stock. Although many of these technologies are available today, they are often more expensive than the default option and are not necessarily optimised for the widest range of applications, operations and climates.

Further R&D efforts are needed to improve buildings-related technologies, particularly their integration and system optimisation in different applications. The development of hybrid systems (*e.g.* combined solar-thermal heat pumps systems) could offer highly efficient systems with very low CO_2 emissions. A particular focus for the major economies the integration of buildings technologies into low-cost retrofits, as most of the savings potential is in the existing building stock.

Policies for "zero-energy" or "zero-carbon" buildings are an ambitious goal and need to be supported by significantly increased RD&D projects that integrate the full range of available technologies and best practices. This requires significant effort to adapt building designs and practises to local building norms and climates, individual technologies will benefit from global R&D effort, but their integration and demonstration must be country and even region specific.

[12] Many energy efficient buildings technologies are readily available at reasonable cost. Their adoption is slowed by the diversity of technologies, market barriers, lack of professional qualification and lack of consumer information.

Buildings sector companies are unlikely to fund costly, high-profile demonstrations; they feel the government should play a role in leading these exhibitions, and establish corresponding programmes of public outreach and education around behaviours and information management to maximise buildings energy efficiency.

Industrial energy efficiency is estimated to have a gap of USD 4.5 billion to USD 9.5 billion (current reported annual spending is USD 530 million). This large gap reflects the inclusion of several high-cost technologies and processes that reduce the carbon intensity of different industrial sectors,[13] fewer industrial energy efficiency improvements in major economies since 1990 (IEA, 2009e), and the need to re-design the production process to achieve emissions intensity goals in some emission-intensive sectors.

Energy efficiency in the buildings and industry sectors has captured growing levels of RD&D expenditures; while taking a smaller percentage of overall LCET research among IEA countries. Leading countries in energy efficiency spending include Japan (far ahead of other countries), followed by the United States, Finland, Korea, Australia, Italy and France. Japan, Finland and Korea spend a large share of their energy efficiency RD&D on industrial sector efforts.

Companies are most certainly contributing important resources to improving industrial energy efficiency, there is a lack of data on industry investments in RD&D. Industry participates in several collaborative initiatives to improve energy efficiency, including the Asia-Pacific Partnership (APP) Steel Task Force and other APP sectoral efforts. The results for the steel sector are indicative: while most of the sector's energy-savings technologies are cost effective, they are not widely used. The APP Steel Task Force has analysed and identified barriers to diffusion, including longer investment recovery periods and the lack of engineering capabilities in steel industries in developing nations. In addition, the internal rate of return (IRR) for steel production expansion tends to be much larger than the IRR for energy- efficiency improvements in most of the developing countries. As a result, scarce capital and engineering capacity are not allocated to energy efficiency.[14] These barriers are also found in other energy-intensive industries, including the chemicals, cement, and pulp and paper sectors.

Recommendations for advancing international action

The buildings sector would benefit from increased international collaboration. This is particularly true for specific buildings technologies, where advances can be easily shared. The need to develop tried and tested packages of technologies and building practices means that collaboration on demonstration programmes for net-zero and zero-carbon buildings are also important, but must be backed by strong country and regional programmes. International collaboration on "softer" areas of policy development will be vital to ensure that technologies perform as anticipated in delivering energy savings. The capacity of industry in terms of training and education for architects, equipment installers, building designers and operators must be increased to support policy goals. Expanding membership of the APP sectoral task forces to include developing countries with rapidly growing industrial sectors is also recommended.

[13] These include, among others: bio-products to replace fossil fuel feedstocks for manufacturing, chemicals, and materials; biorefineries; and capture and storage of non-combustion CO_2 sources (IEA, 2009f).
[14] See *www.app.gov/taskforces/steel/index.htm.*

Energy efficiency in buildings and industry: International initiatives underway

The IEA Implementing Agreements are important areas of existing collaboration in the buildings sector; those related to buildings include:

- **Implementing Agreement for a Programme of Research and Development on Energy Conservation in Buildings and Community Systems (ECBCS IA),** (*www.ecbcs.org*.)
- **Implementing Agreement for Co-operation on Technologies and Programmes for Demand-Side Management (DSM IA),** (www.ieadsm.org).
- **Implementing Agreement on District Heating and Cooling, including the Integration of Combined Heat and Power (DHC IA)**, (www.iea-dhc.org).
- **Implementing Agreement for a Co-operative Programme on Efficient Electrical End-Use Equipment (4E IA), (**www.iea-4e.org).
- **Implementing Agreement for a Programme of Research and Development on Energy Conservation through Energy Storage (ECES IA), (**www.energy-storage.org).
- **Implementing Agreement for a Programme of Research, Development, Demonstration and Promotion of Heat Pumping Technologies (Heat Pumps IA), (**www.heatpumpcentre.org)**.**
- **Implementing Agreement for a Programme to Develop and Test Solar Heating and Cooling Systems (SHC IA)** (www.iea-shc.org).

The **Implementing Agreement for Industrial Energy-related Technologies and Systems (IETS IA)** aims to accelerate research into cost-effective industrial technologies and system configurations. The IETS IA currently focuses on the energy-intensive process industries and technology areas, but is moving to expand research in other industrial sectors and to facilitate co-operation among industrial RD&D disciplines. There are currently 11 participants. Selected research projects include energy-efficient separations systems; energy-efficient drying and dewatering technologies; industry-based bio-refineries; and membrane technologies. (*www.iea-iets.org*.)

The **International Partnership for Energy Efficiency Co-operation (IPEEC)** was created in 2009 to identify areas of joint actions to maximise the impact and synergies of individual national actions. The IPEEC intends to enable joint R&D into key energy-efficient technologies, including application in developing countries. In addition, the IPEEC aims to exchange information on measures that can strengthen public-private co-operation to advance energy-efficient technology research, development, commercialisation and deployment. (*http://ipeecshare.org*.)

The **Sustainable Buildings Network (SBN)** was created in 2009 at the G8 Summit in Italy. A collaboration between major economies, the SBN is a network of networks managed by the Renewable Energy and Energy Efficiency Partnership (REEEP) that aims to identify policies to improve energy efficiency in buildings in different regions around the world. It also serves as a reference portal for information on energy efficient practices and use of renewable energy in buildings. During 2010-12, the SBN will focus on three topics: intelligent architecture in tropical regions, zero-energy buildings and policy packages for existing buildings. (*www.reeep.org/43.16674/sustainable-buildings-network-keeping-it-cool-intelligent-architecture-for-tropical-buildings.htm*.)

Nuclear energy

RD&D investments: USD 4 billion	Global gap: needs to be assessed

The gap in RD&D investment for nuclear fission energy must be assessed. There is a large amount of annual public nuclear spending – some USD 4 billion, of which 78% is spent on fission. Fission includes Generation IV plants, but no global assessment exists to identify these RD&D needs. Overall investment in nuclear fission is highest in Japan (55%), the United States (14%) and France (13%); investment in fusion is highest in the United States (41%), Germany (18%) and Japan (17%).

According to the *IEA Technology Roadmap: Nuclear Energy*, rapidly expanded nuclear fusion development is not expected to require major technological breakthroughs. Rather, the obstacles to more rapid nuclear expansion in the short to medium term are primarily policy-related, industrial and financial (IEA/NEA, 2010). Several technologies under development for next-generation nuclear systems offer the potential for improved sustainability, economics, proliferation resistance, safety and reliability. Some will be suited to a wider range of locations and potential new applications. Each involves a significant technological step, and will require full-scale demonstration before commercial deployment. Such systems could start to contribute to nuclear capacity before 2050.

The nuclear fission industry is a well-established, profitable and high-tech industrial sector that, as part of normal investments in improvements and everyday developments in current technology, already devotes considerable resources to RD&D on the nuclear fuel cycle, in general, and nuclear reactor technology, in particular. Analysis done for the EU SET Plan show that the European nuclear industry invests in RD&D in an almost equivalent amount to the public sector: USD 260 million (EUR 205 million) in industry RD&D on nuclear reactors, compared to USD 320 million (EUR 253 million) in public sector spending (EC JRC, 2009).[15] In contrast, little is known about industryl RD&D investment in nuclear fusion. The international fusion device, ITER, will need industry to design and build the pumps, processes, materials and components. The European procurement agency, Fusion for Energy, was established in April 2007 to work with industry in this regard (EC JRC, 2009).

Recommendations for advancing international action

Significant inter-governmental co-operation focuses on nuclear fusion RD&D. However, there are no similar efforts for fission. The *IEA Technology Roadmap: Nuclear Energy* recommends that the international community strengthen co-operation on institution building in countries planning new nuclear fission programmes. In countries without an existing nuclear fission industry, governments should provide support to domestic industry in developing capacities and expertise to participate effectively as sub-contractors and component suppliers in nuclear power plant projects both at home and abroad. This includes expanding nuclear fission RD&D capacities in these countries.

Nuclear energy: International initiatives underway

The IEA has nine **Implementing Agreements** dedicated to different aspects of collaborative RD&D for nuclear fusion. To view their work programmes, see: *www.iea.org/techno/technologies/fusion.asp*.

The **International Thermonuclear Experimental Reactor (ITER)** is an international project to design – and build – an experimental fusion reactor that aims to produce up to 500 MW from fusion power. ITER enables an integrated fusion experiment and testing environment, but several key elements needed for power generation have yet to be developed before building a demonstration reactor (referred to as DEMO) that aims to produce electric power in the gigawatt range. These key elements for power generation are currently being researched in the national research facilities of the Contracting Parties to the IEA fusion Implementing Agreements under the guidance of the IEA Fusion Power Co-ordinating Committee, the fusion IAs have proven to be highly effective in facilitating advances in fusion energy research. (*www.iter.org*.)

[15] The same report estimated that for nuclear fission, industry invests 44% of the total RD&D budget in Europe.

Other renewables, including wind energy

RD&D investments: USD 240 million	Global gap: USD 1.6 billion to USD 3.4 billion

Other renewables include energy created from ocean, hydropower, geothermal and wind. Of these, only wind has an estimated gap.[16] Current spending on wind energy RD&D is USD 240 million, yet the gap is estimated to be USD 1.6 billion to USD 3.4 billion – despite the fact that wind energy receives by far the largest public RD&D investment. Other renewable energy sources take up sizeable portions of individual country RD&D budgets where there are large domestic resources. Hydropower is more than 50% of the other renewable budget in Germany, Belgium and Switzerland; New Zealand invests heavily in geothermal. Ocean, tidal and wave energy receives very small amounts of total global RD&D investment for renewable energy, but important research programmes and demonstration projects exist in France, Ireland, Portugal and the United Kingdom.

The gap for wind is driven largely by the need for improvements in offshore wind technologies. This includes: development of stronger, lighter materials to enable larger rotors and improved tensile strength; design of dedicated offshore wind turbines fundamentally redesigned for the offshore environment; advanced sub-surface structures; use of superconductor wires to reduce transmission losses; and development of advanced wind forecasting models (IEA, 2009g). Due to onshore wind's competitiveness in a growing number of markets, the public sector has successfully used "market pull" policy approaches such as feed-in tariffs and tax credits to encourage greater private sector investment in wind RD&D. Offshore wind still requires a significant RD&D push to achieve cost and performance targets, as outlined in the *IEA Technology Roadmap: Wind Energy*.

Recommendations for advancing international action

Greater co-ordination is needed among national approaches to wind energy RD&D. Increased collaboration would ensure that key aspects are addressed according to areas of national expertise, taking advantage of existing RD&D, testing activities and infrastructure. Long-term harmonisation of wind energy research agendas is also needed. The establishment of international testing facilities for components and turbines is of particular importance. The location of turbine and component-testing facilities will have important implications for domestic and international manufacturing. It is also imperative to expand capacity in wind energy RD&D in smaller developing countries with high wind resource potential. The exchange of best practice in wind technology, system integration, support mechanisms, environmental protection, approaches to mitigating water-stress, and the dismantling of deployment barriers are important areas of potential collaboration (IEA, 2009g).

[16] This is not to suggest there is no gap in RD&D for geothermal, ocean and hydropower. The *ETP 2010* BLUE Map scenario sees a strong rise in the use of geothermal resource in its 2050 scenario. This will require expanded RD&D to improve geothermal resource estimates, develop environmentally preferred extraction methods and improve direct use of geothermal energy.

The **Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Energy Systems (Wind IA)** is one example of international wind energy technology collaboration. The Wind IA includes national technology experts from over 20 countries, who together developed a coherent research programme in several important areas until 2013. Featured research topics include: integrating electricity produced from wind into power networks; offshore wind development; small wind turbine quality labelling; wind energy in cold climates; wind tunnel measurements; and improvement of aerodynamic models. (*www.ieawind.org*.)

In Europe, the **Wind Energy Technology Platform (TPWind)** builds collaboration among industry and public sector participants, and is also one of a range of different technology platforms established in partnership with the European Commission with cross-cutting activities. TPWind has developed a research agenda and market deployment strategy up to 2030, which provides a focus for EU and national financing initiatives, such as the multi-billion euro European Wind Initiative, established under the European Strategic Energy Technology plan. A German-Danish-Swedish Cooperation Agreement exists with specific focus on offshore wind energy RD&D. *(www.windplatform.eu)*

The **Global Wind Energy Council (GWEC)** is a wind industry trade association, providing a representative forum for the wind energy sector at the global level. Its focus is on policy analysis, trends and outreach to emerging markets. *(www.gwec.net)*

The **Implementing Agreement for a Co-operative Programme on Geothermal Energy Research and Technology** (**Geothermal IA)** aims to raise awareness about geothermal technology, geothermal resource potentials, environmental and social benefits, and the lack of demonstration plants through collaborative RD&D. Current research projects include efforts to investigate advanced geothermal drilling techniques, the direct use of geothermal energy and enhanced geothermal systems. (*www.iea-gia.org.*)

The **International Geothermal Partnership (IPGT)** brings together representatives from Australia, Iceland and the United States to accelerate the development of geothermal technology. IPGT provides a forum for government and industry leaders to co-ordinate efforts to develop new technologies and pursue projects. Partners share information on results and best practices to avoid blind alleys and limit unnecessary duplication. (*http://internationalgeothermal.org.*)

The **Implementing Agreement for a Co-operative Programme on Hydropower Technologies and Programmes (Hydropower IA)** aims to enhance the development of sustainable hydropower by carrying out research and programmes that disseminate balanced and objective information. Research entails the exchange of small hydro information and technology; policy and innovative technical applications; documentation of hydropower good practice; and integration of wind energy into hydropower systems (in partnership with the IEA Wind IA). (*www.ieahydro.org.*)

The **Implementing Agreement for a Co-operative Programme on Ocean Energy Systems** (**OES IA)** involves collaborative RD&D on ocean, wave and tidal current technologies, as well as ocean thermal energy conversion technologies and salinity power. Ongoing projects include monitoring efforts for ocean, wave, tidal, and current energy systems; development of recommended practices for evaluating ocean energy systems; and the grid connection and integration of ocean energy systems. (*www.iea-oceans.org.*)

The **International Renewable Energy Agency (IRENA)** is an intergovernmental organisation established in 2009 that today has over 140 country signatories. IRENA promotes increased adoption and sustainable use of all forms of renewable energy by facilitating access to information, including technical, economic and renewable resource potential data. The Agency also shares experiences on best practices and lessons learned regarding policy frameworks, capacity-building projects, available finance mechanisms and renewable energy-related energy efficiency measures. (*www.irena.org*.)

Smart grids

RD&D investments: USD 530 million	Global gap: USD 5 billion to USD 10 billion

Smart grids are a new category of low-carbon energy RD&D that combines investments in electricity generation, transmission, distribution and end-user infrastructure with energy storage and power conversion. There are a wide range of technologies and systems involved in a smart grid (*e.g.* improved component and system integration methods; enabling technologies such as superconducting wires and devices, storage technology, power conversion and communication technology; end-use interaction and communication; system and data security; and large-scale demonstration pilots). Smart grids also play an important role in facilitating integration of renewables and electric vehicles into electric networks.

The gap in public smart grid RD&D spending is estimated at USD 5 billion to USD 10 billion; currently USD 530 million is spent on this category. Three countries (Japan, Italy and the United States) lead the spending and investment in smart grids RD&D. However, this is a dynamic research area, and several other countries are increasing spending levels.

The private sector — including transmission and distribution system operators, electricity retailers, equipment suppliers, information technology companies, alternative service providers and aggregators — is known to be investing significantly in smart grid RD&D. In 2004, European Union electricity supply companies were reported to invest USD 2 billion in transmission and distribution alone. This amount has likely risen due to increased attention to smart grids (EC JRC, 2009). Overall, the European Commission Joint Research Centre estimates that industry provided more than 75% of total European Union smart grid RD&D investment in 2007 (EC JRC, 2009). Spending in 2010 for the US Electric Power Research Institute (EPRI) programme on Smart Distribution Applications and Technologies amounted to USD 4 million.[17] More information on amounts of private RD&D investment could reduce the size of the gap, but no data are available on regional corporate investment.

Recommendations for advancing international action

Increased spending on smart grids-related technologies, couple with its interdisciplinary nature, create a need for a common framework to define smart grids RD&D priority areas, technologies and opportunities for collaboration. The IEA has ten Implementing Agreements performing RD&D related to some aspect of smart grids (*e.g.* demand side management, electricity networks, high-temperature superconductors, hybrid and electric vehicles and renewables integration). Co-ordination of these and other IA work on smart grids is being carried out by the planned IEA *Technology Roadmap: Smart Grids*.

[17] See *www.smartgrid.epri.com/Demo.aspx*.

Smart grids: International initiatives underway

The **IEA Electricity Co-ordination Group** facilitates cross-sectoral efforts in the electricity sector by numerous Implementing Agreements. In the most recent meeting (April 2010), participants decided that co-ordination was needed for smart grids. This co-ordination has resulted in several joint initiatives amongst electricity-related Implementing Agreements, including some of the activities outlined below.

The **Implementing Agreement for Co-operation on Technologies and Programmes for Demand-Side Management (DSM IA)** focuses on electricity load shaping and load levelling. Load shaping enables the control of electricity demand in order to avoid inefficient and costly overload peaks. Load levelling is accomplished by storing excess electricity during periods of low demand, and through the implementation of energy efficiency. The work of the DSM IA is focused on the customer: relevant tasks include integration of DSM, energy efficiency, distributed generation and renewables, and micro-demand response and energy savings. (*www.ieadsm.org*.)

A key objective of the **Implementing Agreement on Electricity Networks Analysis, Research and Development (ENARD IA)** is to enhance awareness among policy makers of the importance of electricity networks in meeting energy policy objectives. ENARD IA develops new operating procedures, architectures, methodologies and technologies in a comprehensive and unbiased form to its four key stakeholders: governments, policy makers, power utilities and power engineering equipment producers. ENARD IA organised its activities in four annexes: work on information collation and dissemination; distributed generation system integration; infrastructure asset management; and transmission systems. (*www.iea-enard.org*.)

The **Implementing Agreement for a Programme of Research and Development on Energy Conservation through Energy Storage (ECES IA)** acknowledges that energy storage is a core function of a new electricity grid. Its objective is to develop advanced thermal and electrical energy storage. Its work includes promotion of standards, demonstration plants, in situ measurements and design tools. *(www.energy-storage.org)*

The **Implementing Agreement for a Co-operative Programme for Assessing the Impacts of High-Temperature (HTS IA)** is an R&D platform for high temperature superconductivity, a technology that can transport current with a very high power density and low losses. The HTS IA evaluates the impacts and benefits of HTS and identifies barriers. Select HTS IA RD&D projects include: alternating current losses and HTS, fault current limiters, simulating HTS using electromagnetic transient programmes, and superconducting motors. (*www.superconductivityiea.org*.)

Solar energy

RD&D investments: USD 680 million	Global gap: USD 1.1 billion to USD 2.9 billion

Solar energy public RD&D investments face a gap of USD 1.1 billion to USD 2.9 billion, with USD 680 million current annual spending. Of the three categories of solar energy RD&D (solar heating and cooling, CSP and PV), solar PV attracts the majority of public spending. The United States is by far the largest investor in solar energy RD&D across the three categories, followed by Italy, Germany, Korea and France. China and India are also reportedly increasing their solar energy RD&D investments, but spending data are not available.

The main RD&D priorities include improving efficiency for crystalline silicon PV technologies and automation of manufacturing to reduce costs as companies scale up production. For thin film PV, increased R&D is needed to improve device structure, large area deposition techniques, interconnection and manufacturing. Significant RD&D is also needed at system level, particularly for improving the product requirements for building integration and minimising the environmental impacts related to a very large-scale deployment of PV systems (IEA, 2010b). RD&D gaps for CSP include increasing system efficiency through higher process temperatures, reducing material consumption and automating operations (IEA, 2010c).

Development of compact seasonal heat storage is one of the most important priorities for solar heating and cooling; others include innovation in collector design, heat storage, cooling devices, and advanced materials. Industry is active in solar energy RD&D, but there is a lack of global data on spending amounts. In the European Union in 2007, private sector investments in solar PV totalled USD 230 million (EUR 221 million); corporate investments in CSP research were only USD 60 million (EUR 50 million) (EC JRC, 2009).

Recommendations for advancing international action

Several ongoing solar energy RD&D collaborative activities are underway. Expanded basic research is needed across all categories into novel materials that will provide breakthroughs in solar conversion efficiency in the longer term. For solar PV, a promising area for international collaboration includes improved integration into the electricity grid and enhanced storage technologies. Greater co-ordination is needed between national PV energy RD&D actors. Increased collaboration will ensure that important issues are addressed according to areas of national expertise, taking advantage of existing RD&D activities and infrastructure. Long-term harmonisation of PV energy research agendas is also needed, as is the establishment of international testing facilities for materials and system components.

Further, there is a need to work with solar resource-rich developing economies to foster the exchange of best practice in PV technology, system integration and to address barriers to demonstration and deployment. For CSP, public RD&D efforts have taken place mostly in Australia, Europe and the United States. China and Korea are building new programmes, as well as countries in the Middle East, including the United Arab Emirates through the Masdar clean energy programme. The IEA Implementing Agreements for solar energy technologies are also serving as active platforms for collaboration.

Solar energy: International initiatives underway

The **Implementing Agreement for a Co-operative Programme on Photovoltaic Power Systems (PVPS IA)** is one example of international PV energy technology collaboration. The PVPS IA includes technology experts from 23 countries developing a collaborative research programme concerning the cost reduction of PV power applications and the removal of technical and non-technical barriers to deployment. Current collaborative RD&D projects include: hybrid systems within microgrids; PV for developing countries; environmental health and safety; urban PV applications; and very large-scale PV systems. (*www.iea-pvps.org.*)

Since its inception in 1977, the **Implementing Agreement for Solar Power and Chemical Energy Systems (SolarPACES IA)** has been an effective vehicle for international collaboration on CSP. The SolarPACES IA START teams (Solar Thermal Analysis, Review and Training) have carried out missions to support the introduction of CSP to developing countries. By sending international teams of experts, independent technical advice was made available to interested countries, including Egypt, Jordan, Brazil and Mexico. In solar chemistry research, SolarPACES IA has succeeded in building up and supporting international interest in longer term RD&D. The current SolarPACES IA work programme includes tasks related to solar thermal electric systems, solar chemistry research and solar energy and water processes and applications. (*www.solarpaces.org.*)

The **Implementing Agreement for a Programme to Develop and Test Solar Heating and Cooling Systems (SHC IA)** conducts collaborative international research, development and testing of hardware, materials and design tools. Highlighted projects include: the potential for solar heat in industrial processes; housing renovation with solar and energy efficiency; compact thermal energy storage; polymeric materials for solar thermal applications; PV and thermal systems; solar air conditioning and refrigeration; solar energy and architecture; and net zero-energy solar buildings. (*www.iea-shc.org*.)

The **International Solar Energy Society (ISES)** is an UN accredited NGO which brings together industry, science and politics and aims to create international structures to facilitate co-operation. The ISES supports its members by, among other things, stimulating and encouraging fundamental and applied research in solar energy. (*www.ises.org.*)

Proposals for next steps

The IEA's *Energy Technology Perspectives 2008 (ETP 2008)* called for a clean energy revolution to address global energy security, energy access and environmental challenges. The recently released *ETP 2010* confirms that the transition has begun to a low-carbon economy. The past decade has seen an investment surge in clean energy technologies as governments made bold commitments to fund LCETs. The 2008-09 green stimulus spending announcements were welcome increases in public RD&D, but is seems they are largely one-time commitments. Further, some governments are backing away from their stimulus spending announcements, and industry is reducing its investments. This is particularly worrisome as clean energy technologies continue to cost more, on an unsubsidised basis, than traditional fossil-based technologies and it is unlikely that a global price on CO_2 will be settled in the near future. A great deal more must be done to bridge the gap between the estimated USD 10 billion in annual pre-stimulus spending and USD 40 billion to USD 90 billion needed to achieve sustainable energy goals.

What can governments do to create clear a pathway toward a true transition to the secure, widespread use of sustainable energy? The current crisis offers an opportunity to improve the efficiency of energy use, to move toward cleaner energy technologies, and to develop new green businesses and industries. Many governments have incorporated LCET support in their stimulus packages, and can build on this to improve their long-term potential for LCET innovation. After experiencing financial crisis in the 1990s, Finland and Korea took strategic decisions to increase funding for RD&D while cutting other public expenditures. Today, these countries are leaders in technology innovation in several LCET areas (OECD, 2009b).

Some promising signs are evident of continued budget support for clean energy. Several major economies recently announced budget proposals with large allocations for LCETs. Following from its June 2008 announcement of the National Action Plan on Climate Change, India established a National Clean Energy Fund for research and innovation, financed by a levy of USD 1.10 (INR 50) per tonne of coal produced or imported. With annual coal demand of 550 million tonnes in 2008-09, this fund is likely to reach USD 500 million annually (HSBC, 2010). As part of its Green New Deal strategy, Korea has formulated 17 new growth engines and provided support to associated research, including six LCET projects and the fusion industry, as well as basic research (OECD, 2009b). In the United States, significant stimulus funding has gone to science agencies such as the National Science Foundation (USD 3 billion, including basic research for LCETs) and the ARPA-E project mentioned previously. Chinese public funding for RD&D for LCETs has dramatically increased during the past decade (WRI, 2009). The EU stimulus plan calls on member states to improve the energy efficiency of the housing stock and public buildings, and to promote renewable energy and smart grids.

These efforts are a good start, but more is needed. Countries should take an intelligent, comprehensive approach that links technology investment with proven market-enabling policies. New approaches are needed to fund large-scale demonstrations and international collaboration. Finally, governments and industry should pursue expanded — but efficient — international collaboration.

Implement intelligent domestic energy policies

Non-financial measures to pull LCETs into the market — such as stricter energy efficiency requirements, regulatory frameworks for CCS, and development and planning of smart grid and EV/PHEV infrastructures — are equally important to implement. Governments can use limited public funds wisely by developing comprehensive, strategic energy strategies that effectively combine public investments with policies that catalyse corporate investment. RD&D funding efforts need to be tied to predictable, stable "market pull" strategies such as government procurement, loan guarantees and tax policies that mobilise private finance for later stages of technology deployment, thereby providing comprehensive support schemes. As new technologies move from demonstration to deployment, partnerships with large incumbent energy companies will help to raise the levels of funding required for firms to scale up. In the current tight financial markets, access to affordable capital may determine whether a firm will succeed or fail.

Create new public-private institutions to fund large-scale demonstration projects

Securing financing for demonstration-scale projects and related infrastructure is a key cross-cutting challenge for many LCETs, including CCS, energy efficiency in buildings and industry, offshore wind energy, smart grids and electric vehicles. Private investors are reluctant "go it alone" when funding large-scale demonstration projects. Infrastructure pilots also have an international collaboration dimension, in that many will be regional in nature and require cross-border co-operation on planning, funding and design. To address this need, governments should first perform regional strategic planning exercises to identify demonstration and infrastructure needs and investment amounts. They can then create new public-private institutions, such as the Green Investment Bank recently announced in the United Kingdom, that target this funding gap.

Accelerate cost reductions through expanded international RD&D

Government investment in clean energy RD&D is a public good that offers many domestic benefits, including improved national productivity, job creation, expanded exports and reduced local environmental impacts. Expanded international collaboration on RD&D offers additional benefits, including cost savings, accelerated learning, harmonisation of standards and approaches, and elimination of duplication. A key first step to help governments identify areas of potential overlap and address gaps in clean energy RD&D is to initiate a global effort to improve RD&D spending data reporting by the major economies. This study includes data from IEA member countries, but includes very little data from large emerging economies such as Brazil, China, India, Indonesia, Russia and South Africa. More must be done to collect RD&D priorities and spending data from these and other major economies. The private sector should also be engaged to report data, at least on a technology- or sector-specific basis. There is much to be gained from more detailed corporate investment on specific technology areas — this will enable more effective use of public RD&D to leverage private investment. An expanded dataset will also allow for an improved assessment of the return on investment for public sector RD&D in clean energy.

One proposal is to utilise the Major Economies Forum on Energy and Climate Change, together with the IEA's planned Low-Carbon Technology Platform, to conduct an expanded mapping of global RD&D investment in clean energy technologies. This effort would engage all major economies, as well as the private sector, to identify current and planned LCET investment in RD&D. This expanded dataset could then be used to close the spending gaps analysis included in this report. It would also enable focused, more effective international collaboration and extend the reach of limited government funds. The IEA Multilateral Technology Initiatives and other initiatives listed in this report offer a logical starting point, and should be engaged to identify the potential for up-scaling joint energy research on LCETs with the most promise. The IEA has begun this task and invites partners to join in this effort.

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