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ETP 2008: Technology Learning and Deployment

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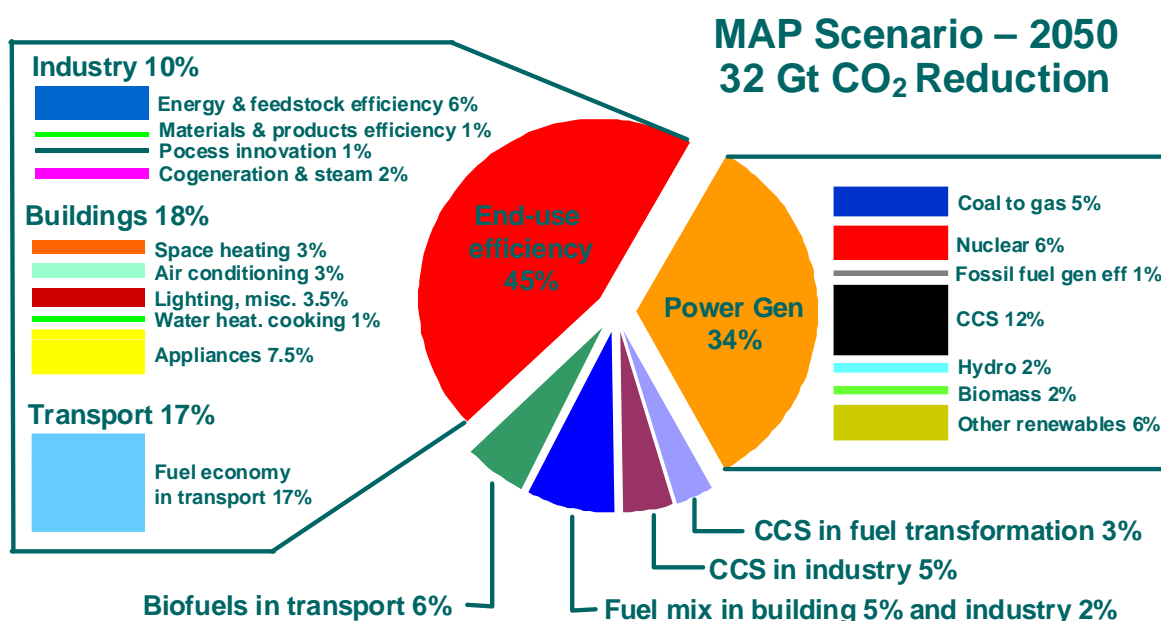
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Introduction

The IEA study *Energy Technology Perspectives 2006* (ETP 2006) demonstrates how energy technologies can contribute to a stabilization of CO₂ emissions at today's level by 2050. The results of the scenario analysis showed that no fundamental technology breakthroughs are needed. Technologies that are available today or that are under development today will suffice to meet the target. In this present analysis we focus on technology learning and deployment aimed at overcoming the "valley of death" faced by new technologies which have passed the RD&D phase, but still need to "buy down" high costs before they can enter the commercialisation phase.

The results of the ETP 2006 analysis shows that end-use energy efficiency and emission reduction in electricity production dominate total emissions reduction. Figure 1 shows the contribution of various technology categories to the emission reduction in the ACT Map scenario, in 2050, compared to the Baseline scenario. Forty five percent of the emission reduction is accounted for by end-use energy efficiency. Thirty four percent is accounted for by measures in power generation. CCS plays also an important role in the fuel transformation sector and in industry. Finally biofuels in transport account for 6% of the emissions reduction.

Figure 1: Emission reduction in the ACT Map scenario, 2050



Source: IEA estimates

The main technology focus in this paper will be on power generation technologies, but CCS in industry, biofuels and fuel cell vehicles are also included in the analysis. The following technologies are included in our deployment analysis:

Power Generation

Integrated gasification combined cycle (IGCC)

CO₂ capture and storage (CCS)

Onshore Wind

Offshore Wind

Solar PV
Solar Thermal
Geothermal
Biomass integrated gasifier/combined cycle BIG/CC (BIG/CC)
Tidal
Nuclear generation III
Nuclear generation IV

Transport

Fuel cell vehicles
Grain ethanol
Lignocellulosic ethanol
Fischer Tropsch -biodiesel

Industry

CO₂ capture and storage for blast furnaces
CO₂ capture and storage for cement kilns
CO₂ capture and storage for black liquor gasifiers

Technology learning

Most new energy technologies initially have higher costs than the incumbent technologies. Costs can be reduced by further R&D and usually fall, sometimes significantly, as a result of the “technology learning” effect. The process of technology learning – in which production costs decrease and technical performance increases as cumulative installed capacity rises – can make new technologies available at lower costs (Boston Consulting Group 1968, OECD/IEA, 2000). In fact the cost of new technologies may drop below the cost of existing technologies. If this is the case, the switch to the new technologies will reduce the energy cost in the long term. However market forces do not value such long term uncertain benefits highly. This is a major reason why government intervention could be warranted.

The prospect that a given technology will be produced and sold on the market can stimulate private industry R&D (“learning-by-searching”) and improvements in the manufacturing process (“learning-by-doing”). Feedback from the market may suggest avenues for improving a technology, reducing its costs or tailoring some of its features to consumers’ needs (“learning-by-using”). These benefits are only reaped when technology is actually put in the market. The rate of technology improvement is therefore usually a function of the rate of technology adoption.

Technology learning is a key issue for energy R&D and energy investment decisions in emerging new technologies. Experience curves help clarify the potential benefits of deployment programmes and provide policy analysts with a tool to explore technology and policy options which can support the transformation of energy systems. This discussion paper aims to address a number of important questions that will be discussed at the 11-12 June 2007, Technology Learning and Deployment workshop.

Important questions to be answered are:

- What is deployment?
- How important is deployment?
- How learning curves can be used to estimate deployment costs?
- How fast can technology deployment expand?
- When to move from RD&D to deployment, and what is the right balance between RD&D and deployment expenditures?
- What is the role of government, and what is the role of industry?

- What are the benefits of international cooperation on technology deployment?
- How can effective deployment policies be designed to promote technology uptake?

1 What is deployment?

Deployment is the term used for the technology stage between research, development and demonstration (RD&D) and market uptake. The technology is not yet economic, compared to the established technologies, except for certain niche markets. Production takes place on a small industrial scale. Technology learning based on mass production (economies of scale) and series of small product improvements result in cost reductions. Production is rapidly expanding during this production stage.

Figure 2: Stages in Technology Development

R&D: ↓ Demonstration ↓ Deployment ↓ Competitive	<p>Technologies in need of R&D to overcome technical barriers and to reduce costs. The outcome is still uncertain, especially in the early stages of development.</p> <p>Demonstration of the technology. Often government funding is needed to finance part or all of the costs of the demonstration.</p> <p>Successful technical operation, but in need of support to overcome cost barriers. With increasing deployment learning-by-doing effects will result in gradually decreasing costs.</p> <p>Technology is cost competitive in some or all markets, but some technologies may require sustained incentives to value CO₂ emission reduction or other benefits.</p>
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Source: IEA

2 How important is deployment?

As Figure 2 illustrates, a new energy technology will typically go through several stages to overcome technical and cost barriers before it becomes cost-competitive. Even if a technology is technically proven after the R&D and demonstration stage, costs may still be too high for the market to take up the technology. This is often referred to as the “valley of death” that new technologies face on the way to full commercialisation. Programmes aimed at taking the technology through the deployment phase can require considerably more resources than the RD&D phase. In some cases prolonging the R&D phase to reduce the market entry cost for the technology may lead to reduced overall costs, as long as the increased R&D expenses are lower than the reduction in deployment costs. Although the costs of the technologies will be reduced by R&D and learning, some technologies, like CO₂ capture and storage, can only be cost competitive if credit is given for the CO₂ emissions reductions.

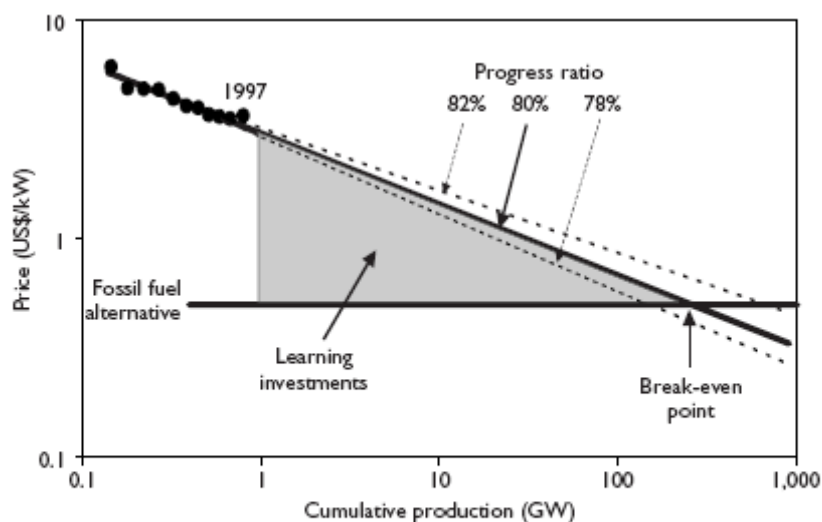
According to New Energy Finance, global expenditures on clean energy deployment (renewable energy, biofuels, low-carbon technology and the carbon markets) have more than doubled from \$27.5 billion in 2004 to \$70.9 billion in 2006 (New Energy Finance 2007). Current expenditure on deployment of clean energy technologies is just under nine times the government RD&D expenditure for energy which is approximately \$8 billion. On the other hand the annual commercial energy investments for the supply side alone for a baseline scenario amount to \$750 billion to one trillion per year for the period till 2030 (IEA 2003).

Demand side energy investments estimates depend highly on system boundaries, but add substantial additional cost. Therefore there is approximately an order of magnitude difference between RD&D and deployment cost, and an order of magnitude between deployment and commercial investments.

3 How can learning curves be used to estimated deployment costs?

Deployment cost can be derived based on technology learning curves. These learning curves show a constant reduction of the investment cost for each doubling of the installed capacity. Figure 3 demonstrates how this relationship can be used to estimate the learning investment (or deployment costs) necessary for a technology to arrive at the cost of the alternative fossil technology or “break-even” point. Learning curves are useful tools to help estimate deployment costs for new technologies, but the accuracy of the results is uncertain as learning rates are uncertain.

Figure 3: Learning curve for making Photovoltaics break-even



Break-even point and learning investments for photovoltaic modules with a progress ratio of 80%. The shaded area indicates the remaining learning investments to reach the break-even point. The figure also shows changes in the break-even point for progress ratios of 78% and 82%.

Source: IEA 2000

Note: 1 minus the progress ratio is equal to the learning rate.

Literature sources show that learning curves have been validated for a wide range of energy technologies over many orders of magnitude of installed capacity, see e.g. (IEA 2000, McDonald and Schratzenholzer 2001, Neij 2003, Junginger 2005...). Past experience shows that learning rates are not always constant as technology characteristics change or as technologies mature. In the case of nuclear energy, increased security needs for new power plants have resulted in cost escalation, and the projected cost reduction has not occurred.

A review of the current literature on learning curves for energy technology has raised a number of issues on how learning rates should be applied. The common use of price versus cost data due to the confidentiality and therefore lack of available cost based data has resulted in uncertain learning rates. The wide difference in learning rates shown in Table 1 for wind technologies, which vary from 8 to 32% raises the issue of which system boundaries should be used for learning rates.

Analysis of learning rates for wind, indicate that learning rates for wind based on electricity production costs better reflect potential cost reductions as improvements in efficiency and lower O&M costs are reflected in lower electricity costs and do not necessarily translate into lower investment costs for wind turbines or wind farms (Neij 2003). If we accept that the appropriate system boundary will differ from one technology to another, what distortions can be expected when these different learning rates are used to estimate deployment costs for a group of technologies. Additional analysis and further data collection is required to examine the right system boundaries to be used when applying learning curves.

Table 1: Estimated learning rates for various energy technologies

Technology	Source	Country / Region	Period	Learning Rate (%)	Performance measure
Nuclear	Kouvaritakis 2000	OECD	1975-1993	5.8	Electricity Prod. Cost (\$/kWh)
Onshore Wind	Neij 1999	Denmark	1982-1997	8	Price of Wind Turbine(\$/kW)
	Durstewitz 1999	Germany	1990-1998	8	Price of Wind Turbine(\$/kW)
	IEA 2000	US	1985-1994	32	Electricity Prod. Cost (\$/kWh)
	IEA 2000	EU	1980-1995	18	Electricity Prod. Cost (\$/kWh)
	Kouvaritakis et al 2000	OECD	1981-1995	17	Price of Wind Turbine(\$/kW)
Offshore Wind	Isles 2006	8 EU countries	1991-2006	3	Installation Cost of Wind Farms (\$/kW)
PV	Harmon 2000	Global	1968-1998	20	Price PV module (\$/Wpeak)
	IEA 2000	EU	1976-1996	21	Price PV module (\$/Wpeak)
	Williams (2002)	Global	1976-2002	20	Price PV module (\$/Wpeak)
	ECN 2004	EU	1976-2001	20-23	Price PV module (\$/Wpeak)
	ECN 2004	Germany	1992-2001	22	Price of balance of system costs
Biomass	IEA 2000	EU	1980-1995	15	Electricity Prod. Cost (\$/kWh)
CHP	Junginger 2005	Sweden	1990-2002	9	Electricity Prod. Cost (\$/kWh)
CCS	Rubin et al 2006	Global	na	3-5	Electricity Prod. Cost (\$/kWh)

Source: McDonald and Schratzenholzer 2001, Williams 2002, Junginger 2005, Rubin 2006, and Isles 2006

Deployment cost estimates are very sensitive to assumed learning rates. An overly conservative learning rate may lead to a technology being dropped, while an unjustified high learning rate could lead to unrealistic expectations on potential cost reductions and a misallocation of limited deployment investments. An increase of 1% from 18% to 19% would reduce the required learning investment in PV from just over \$ 600 billion to just over \$ 500 billion as the cumulative capacity needed to enter the competitive stage would drop from approximately 500 GW to 400 GW.

Recent analysis on learning rates for offshore wind farms actually show learning curves rising as the price based data used in this analysis shows the market pricing in the higher risk associated with offshore versus onshore wind farms (Isles 2006). As more offshore wind is deployed the market is expected to become more competitive and learning rates for offshore wind farms are expected to fall.

Material costs can also have an impact on learning rates as currently seen in PV and wind, where learning rates are expected to show a temporary increase as the shortage of silicon, steel and gear boxes have pushed up PV and wind turbine costs. In the case of PV, the current silicon shortage has led to increased R&D in thin film technologies as significantly less silicon is required. If this technology becomes proven it is anticipated that significantly less learning investments will be needed to bring PV to the competitive phase (Williams 2002). One could argue that this is technology transition and does not invalidate the use of learning curves. However it suggests that the learning curve approach must be combined with sound technology definition and deployment policy advice must consider the notion of new breakthrough technologies.

Table 2: Undiscounted deployment investments

	Cumulative capacity at 2005	Current inv. Cost [\$]	Learning rate [%]	Estimated break-even date	Total deployment cost [\$]
Onshore wind	44.1 GW	\$ 935 / kW	7	2025-2030	\$311 bn
Offshore wind	3.7 GW	\$ 1570 / kW	9	2030-2035	\$202 bn
PV	2.9 GW	\$ 4.5 / W	18	2040-2045	\$604 bn
Solar Thermal	1.6 GW	\$ 2.3 / W	5	?	?
BIG/CC	0 GW	\$ 2500 / kW (2010E)	5	?	?
Geothermal	21 GW	\$ 1600 / kW	5	?	?
Tidal	1.0 GW	\$2900 / kW	5	?	?
IGCC	1 GW	\$ 1800 / kW	3	2030-2035	\$ 410 bn
CCS	0 GW	\$ 750 / kW (2010E)	3	Post 2050	\$ 400 bn +
Nuclear III	1 GW	\$ 2600 / kW	3	2025	\$ 890 bn
Nuclear IV	0 GW	\$ 2500 / kW (2030E)	5	Post 2050	\$ 400 bn +
Fuel Cell Vehicles	0	\$ 570 / kW	15	Post 2050	\$ 6000 bn +
Grain ethanol		\$ 0.75 / litre	8	2015	\$ 17 bn
Lignocellulosic ethanol	0	\$ 1 / litre (2020 E)	2	2030	\$ 60 bn
FT-biodiesel	0	\$ 1 / litre (2010 E)	5	2050	\$ 55 bn
CCS blast furnace	0	\$ 50 / t CO2 (2030E)	5	?	?
CCS cement kilns	0	\$ 75 / t CO2 (2030E)	5	?	?
CCS black liquor IGCC	0	\$ 1500 / kW (2030E)	5	2050	\$ 30 bn

Source: IEA estimates

It should be noted that the deployment investments shown in Table 2 are undiscounted. If these investments are discounted, they are considerably lower. However the slower the technology develops, the lower the value of future benefits once the technology becomes cost effective. In an extreme case, the initial cost may exceed the long-term discounted benefits.

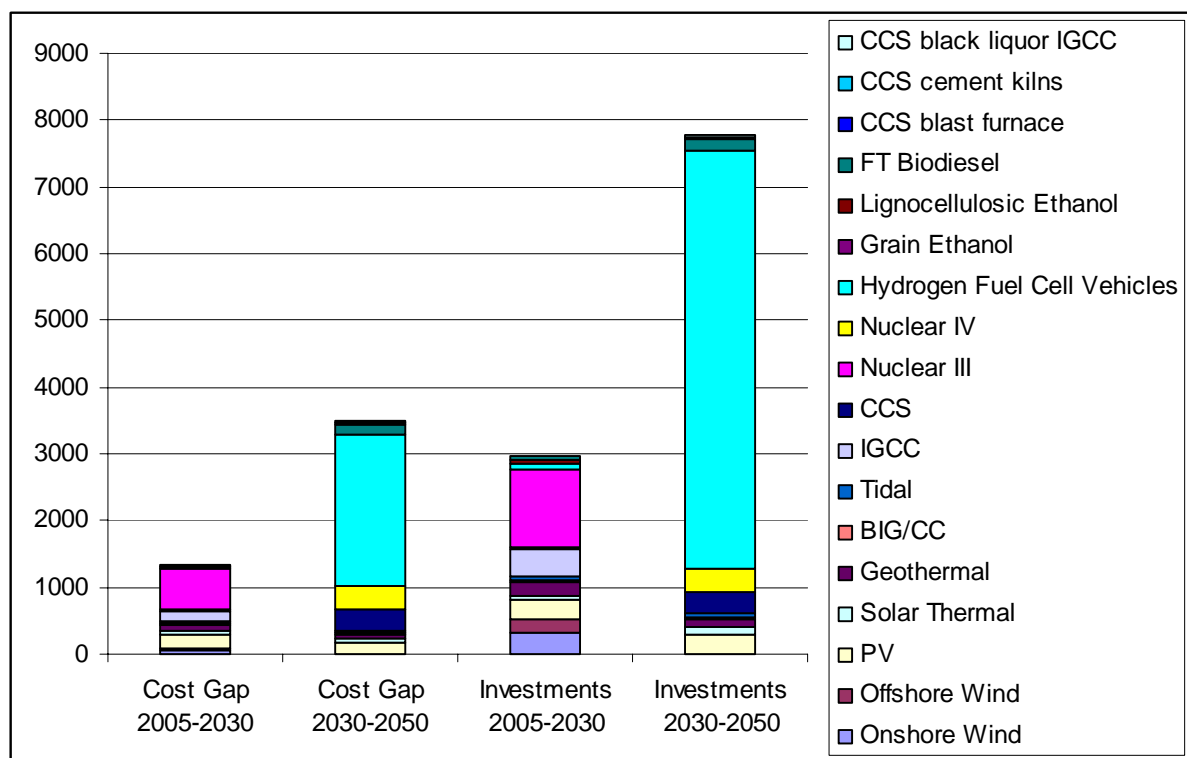
Total deployment investments from 2005-2050 for the listed technologies are estimated at \$ 10.5 trillion¹. This figure is likely to be on the low side as a number of the technologies such as CCS and BIG/CC will likely need additional incentives or at least a 25\$ / t CO₂ price

¹ The estimated deployment figures are based on learning rates for capital costs.

before they are competitive. Learning alone are not enough to make these technologies competitive unless the reduction in CO₂ emissions is credited with a price of at least \$ 25 / t CO₂. Deployment investments for the 2005-2030 period are estimated to be less than \$ 3 trillion and the largest portion of these investments are expected to be for nuclear, IGCC, wind and PV technologies. During the 2030-2050 period, total deployment investments are estimated at \$ 7.8 trillion, 80% of which are accounted for by hydrogen fuel cell vehicles. This high share of a single demand side technology shows the importance of the whole demand side for energy technology deployment cost analysis.

According to a report prepared by New Energy Finance and to be released soon by UNEP, the total deployment in clean energy technologies (includes renewable energy, biofuels, low-carbon technology, and the carbon markets) for 2006 was \$ 71 billion, 40% less than the \$ 110 billion estimated annual deployment investments needed between 2005-2030. If we exclude investments in nuclear power which make up a large portion of deployment costs from 2005-2030, annual required investments in deployment fall to \$ 73 billion per year, in line with reported investments in 2006.

Figure 3: Estimated Deployment Investments and Cost Gap based on ACT Map



Source: IEA estimates

Note: figures are not discounted

If we consider the cost gap, the total *additional* cost for technologies under ACT Map from 2005-2030 is \$ 1.3 trillion or \$ 54 billion per year. The cost gap is defined as the total investment cost necessary to make these technologies competitive minus the investment cost of the alternative fossil technology necessary to meet the same output. Total additional costs for 2005-2050 are \$ 4.6 trillion. If a \$25 / ton CO₂ price was also factored into this analysis these learning costs could be reduced even further.

In this analysis we have applied learning rates to technologies which are still at the RD&D phase which is very uncertain as the evolution of investment costs in unproven technologies can be difficult to predict. As the learning curves for nuclear have shown, unexpected

measures, externalities or market changes could result in a significant increase in costs that lie outside of a given learning curve boundary system. On the other hand, the analysis does not include other external benefits such as reduced local air pollution or increased supply security.

It should also be noted that the cost are underestimated because this approach assumes 100% success. In practice, technology development is a very uncertain process. For example in the field of car technologies, many options have been tried in the past three decades, while only very few have survived. Therefore the linear technology learning model underestimates the cost of failure. It is estimated that this may double the deployment cost. Still, \$ 110 billion a year is not significantly different from the level of current deployment investments.

The fact that established technologies show consistently a lower learning rate than emerging technologies cast significant doubt on the reliability of using learning rates to project future cost reductions. A better understanding of the factors that drive future cost reductions is needed in order to reduce the uncertainty of using learning rates based on historical cost data to estimate future deployment costs.

4 How fast can technology deployment expand?

This question is of importance because it determines the rate at which new technology can impact the market. A recent IEA study *Tackling Investment Challenges in Power Generation* (2007) indicates that most IEA countries are entering a new investment cycle in power generation. This represents an important opportunity to deploy cleaner and more efficient power generation technologies. The investment decisions taken over the next decade will lock in CO₂ emissions for the next 40 – 50 years.

According to the *World Energy Outlook 2006* (WEO 2006) OECD countries will need to add 466 GW of new power generation by 2015 which represents 20% of existing capacity. Improved energy efficiency could reduce this figure, but as many of these power plants are nearing the end of their operation life, large investments are need to replace much of the existing capacity. The WEO 2006 estimates that 200 GW will need to be replaced by 2015 and a third of existing capacity or 872 GW will need to be replaced by 2030.

The deployment of new technologies in niche markets warrants further analysis as significant benefits (cost savings) exists when deployment can be focused on niche markets. These markets often provide high growth rates and require less learning investments as the cost of the alternative technology is also higher. For example, Poconi (2003) found that the break even price for PV in southern Italy was 4€ / Wp versus an average 1 € / Wp for utility owned systems.

5 When to move from RD&D to deployment, and what is the right balance between RD&D and deployment expenditures?

Energy technology policy can be split into two fields: government funded RD&D programmes to develop new technologies; and deployment measures aimed at introducing new technologies which are not yet competitive into the market (Wene 2007). Government funded RD&D provides incentive for industry to invest in RD&D (Watanabe 1995).

The relationship between expenditures in RD&D and deployment are not clear. Historically expenditures in RD&D appear to one order of magnitude larger than expenditures in deployment. It is unclear whether this is the correct balance. Can additional investments in R&D reduce total deployment costs?

In the PV industry, the high cost of silicon has led to an increase in both government and industry R&D expenditures to advance thin film technologies which are expected to radically reduce the cost of PVs and hence the total deployment costs for making PVs competitive.

6 What is the role of government, and what is the role of industry?

While governments play an important role in stimulating deployment, the costs of the programmes are often borne by the private sector. For example, governments may establish codes or minimum standards that require the market to invest in certain technologies, often at a higher initial cost for the market but which will result in the reduced cost of the technologies as the deployment increases. The expectation of large future markets stimulated by deployment programmes may also have the important benefit of activating additional R&D by private industry. With a market in sight, industry will step up their efforts, set research priorities and find ways to cut costs.

7 What are the benefits of international cooperation on technology deployment?

The benefits of technology learning are typically shared on a global level. This emphasises the need for international collaboration on technology development and deployment. In many cases, deployment costs can be lowered through international collaboration. In the case of wind, the most cost effective sites in each country would be developed first and the aggregated impact would reduce the overall cost of reaching the required deployment level to buy down a given technology. If deployment was left to just one country or a few countries less economical sites would be required, driving up the total deployment costs.

Much of the deployment in clean energy technologies is expected to take place in OECD countries, but as investments in power generation are locked in for 40-50 years there is also a need to promote the deployment of cleaner technologies in non-OECD countries. Technology transfer from OECD to non-OECD countries would help to not only promote the up-take of cleaner technologies in non-OECD countries, but could also speed up the deployment phase as manufacturing costs are generally lower in non-OECD countries.

8 How can effective deployment policies be designed to promote technology uptake?

The answer to this question is at present unclear. Additional analysis is required to evaluate existing deployment programmes. What is clear is that governments should not pick technology winners and that this is best left to the private sector. It is the role of industry to bring technologies to market, but governments can implement deployment policies aimed at promoting cleaner energy technologies that would otherwise not be adopted by the market. These policies should be targeted at over-coming barriers to market up take of new and improved energy technologies (Sagar and van der Zwaan 2006)

Deployment policies should be designed to benefit those technologies which can most cost effectively support policy objectives on environment and security. An analysis of the effectiveness of various deployment policies such as feed-in tariffs, green certificates or fixed and voluntary targets are beyond the scope of this paper, but further analysis may be undertaken in ETP 2008.

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