executive briefing

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The Uncertain Middle

Innovation lessons for low carbon energy technology from demonstration projects and trials

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The Advanced Institute of Management Research (AIM) develops UK-based world-class management research. AIM seeks to identify ways to enhance the competitiveness of the UK economy and its infrastructure through research into management and organisational performance in both the private and public sectors.

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about AIM

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- Working in cooperation with leading international academics and specialists as well as UK policymakers and business leaders…
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- Disseminating ideas and shared learning through publications, reports, workshops and events…
- Fostering new ways of working more effectively with managers and policymakers…
- To enhance UK competitiveness and productivity.

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- Conduct research that will identify actions to enhance the UK's international competitiveness
- Raise the quality and international standing of UK research on management
- Expand the size and capacity of the active UK research base on management
- Engage with practitioners and other users of research within and beyond the UK as co-producers of knowledge about management

contents

AIM research themes

Current AIM research projects focus on:

UK productivity and performance for the 21st century.
How can UK policymakers evaluate and address concerns surrounding the UK's performance in relation to other countries?
National productivity has been the concern of economists, government policymakers, and corporate decision-makers for some time. Further research by scholars from a range of disciplines is bringing new voices to the debates about how the productivity gap can be measured, and what the UK can do to improve the effectiveness of UK industry and its supporting public services.

Sustaining innovation to achieve competitive advantage and high quality public services.
How can UK managers capture the benefits of innovation while meeting other demands of a competitive and social environment?
Innovation is a key source of competitive advantage and public value through new strategies, products, services and organisational processes. The UK has outstanding exemplars of innovative private and public sector organisations and is investing significantly in its science and skills base to underpin future innovative capacity.

Adapting promising practices to enhance performance across varied organisational contexts.
How can UK managers disseminate their experience whilst learning from others?
Improved management practices are identified as important for enhancing productivity and performance. The main focus is on how evidence behind good or promising practices can be systematically assessed, creatively adapted, successfully implemented and knowledge diffused to other organisations that will benefit.

introduction

Innovation transitions through public demonstration projects

Government intervention in support of innovation can take a number of forms, including public funding of R&D, public procurement, market subsidies and buyer incentives, regulatory change, improving skills, and strengthening the industry supply chain. An additional element of support is the funding of demonstration projects and trials.

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Publicly funded demonstration projects and trials are widely used to reduce some of the uncertainties and other development issues associated with new technologies. Faced with a combination of uncertain returns, considerable capital requirements, and lengthy periods of time before achieving a workable, competitive technology, companies may find it difficult to engage in prolonged experimentation on their own to resolve problems that occur as they move from the laboratory to commercial applications.

Driven by the need to develop low carbon energy technologies, publicly funded demonstration projects and trials (DTs) have been increasingly used to support innovation in the energy system. Since the 1970s they have been extensively used to overcome innovation uncertainties in renewable energy, through major programmes in the USA, European Union (EU) and Japan.

Despite the use of such programmes, however, relatively little is known about this uncertain middle phase in accelerating complex, large-system innovation – in particular, what companies actually gain, as distinct from what advocates and policymakers believe they should.

The purpose of this report is to improve our understanding of DTs in the innovation process, and provide lessons for future programmes from an analysis of DTs in solar photovoltaics (PV) and wind.

The value of wind DTs

Wind turbines have faced particular obstacles in gaining public acceptance because of their intrusion on the countryside, often in scenic areas. Planning restrictions have hampered adoption in many countries, including the UK, where there have also been Ministry of Defence objections to their interference with radar.

Consequently, simply gaining test sites in advance of commercial rollout was a problem. DTs thus played an important role in creating access to testing opportunities, through the sponsorship of government programmes that brought together coalitions of interests, including local authorities who controlled planning permissions and represented the community. This may help to explain the diffuse and protracted nature of EU wind DT programmes, as a way of creating a continuing supply of test sites.

Demonstration projects and trials in the UK and EU

Until now, the UK has lacked a coherent strategy towards DTs, while the EU and US have employed them with mixed success.

The publication of the *'Environmental Transformation Fund Strategy'* (BERR, 2008), however, promised 'to accelerate the commercialisation of low carbon energy and energy efficiency technologies in the UK, with a specific focus on the demonstration and deployment phases', acknowledges the lack of support for this in the past, and says that the ETF 'will add a new level of coherence' through a more interventionist approach 'in supporting large-scale demonstration and pre-commercial deployment'.

The UK now has a more complete set of institutions to support energy innovation than ever before, through basic research (the Research Councils), applied research (Energy Technology Institute and Technology Strategy Board), and pre-commercial development including demonstrations (ETF), with the Carbon Trust supporting activity through both latter phases, and a range of policy instruments supporting early deployment (see www.lowcarboninnovation.org.uk).

This welcome shaping of a more coherent policy landscape benefits from increased sophistication in thinking about innovation as an holistic process, including the widespread adoption of NASA's 'technology readiness levels' to define needed activity.

The UK has a number of DT projects and programmes planned and in progress, including wave and tidal, offshore wind, fuel cells, and micro-CHP. At the same time, the EC's 7th Framework Programme has major funding earmarked for DTs in low carbon energy to accelerate the development of fuel cells, hydrogen, and solar PV, with contracts currently being awarded.

The lessons from the AIM study should aid the design and use of DTs as instruments of public policy, identify how companies can make best use of them, and guide the coordination of policy incentives, regulatory measures and follow-on activities to maximise their impact.

The study and company sample

This report draws on a three-year project funded under AIM and ESRC's Targeted Innovation Initiative on the role of DTs in aiding innovation success in low carbon energy systems. Previously we have developed a comprehensive picture of the development of wind turbines, solar PV and fuel cells, drawing on our database of DT programmes in the EU, US and Japan.

The second stage of the research involved producing case studies of wind and solar PV companies that have engaged in DTs, to establish what learning and other kinds of benefit they have derived.

Drawing on interviews, company websites, contemporary interviews with founding entrepreneurs and technologists, commentaries on companies in the specialist press which follows developments in renewable energy, published evaluations of DT projects by governmental agencies, and our database records, we have developed generic lessons and case cameos to illustrate common learning benefits. Interviews with twelve experts on wind and PV, and with specialist organisations in Japan, provide further insights into the context of industry development and the value of DTs.

Because we are concerned here with the product and technology innovation process, our focus and data source is manufacturing companies. Their experiences as technology innovators provide a lens on what facilitated or blocked the development of a product for market, while as leading firms, participating in a large number of DTs, they give us a concerted view of the benefits.

However, this focus may neglect the wider social process on which successful innovation ultimately depends of getting 'buy in' from adopters and stakeholders. The energy utilities, as key adopters of new energy systems, have often been reluctant participants in DTs and wary of new technologies outside their model of a centralised energy system. Thus there is also a problem of the 'uncertain context' in which innovation takes place that affects awareness and acceptance. Policymakers tend not to build social and political considerations into DT programmes, although they have sought to overcome barriers by encouraging collaboration in both testing and market creation projects (and the EC's Intelligent Energy programme).

Rarely mentioned in company interviews, these issues are more apparent to expert observers and feature strongly in accounts of energy system innovation in Europe. The report highlights some examples. This must, nevertheless, be regarded as a critical general lesson for designing and managing non-technical DTs and overall programmes of activity.

what is a DT?

In broad terms, DTs do two things: they test technology, products, processes and systems (technical); and promote market diffusion and commercialisation (commercial). A third sub-set of these activities lies somewhere in between, with targeted projects on materials, components and subsystems demonstrating the potential for cost reductions to make applications competitive (economic). We refer to these as technical, economic and commercial DTs.

In practice, projects often have multiple objectives, while successive programmes typically shift through technical, economic and commercial goals, not in a simple linear fashion but through repeated cycles of development.

Another way of looking at DTs is in terms of how they are organised and staged. This highlights four types of learning intervention to advance the innovation process in its long 'uncertain middle' phase.

Four types of DT

1 Creating public awareness through one-off high profile demonstrations and competitions

A demonstrative project is a one-off, early stage project to show what a technology potentially can do and excite public interest. It has a particular place in the affections of US technologists and entrepreneurs. More than one PV firm, for example, mentioned 'the Solar Decathlon'[1] (a competition run by the US Department of Energy, in which universities designed and built a small solar-powered house on the Mall in Washington):

"This is one of the most fantastic and successful demonstration projects you are ever going to see, because you get university students and faculty working on it and it is exposed to millions of people. It accomplishes the two goals of educating students and faculty, and creating public awareness. We were a leader in residential rooftops at the time, so it really confirmed and supported our activities." (AstroPower)

Switzerland has also successfully used such projects to demonstrate solar energy in cars, planes and boats. Industry exhibitions, national and world 'expos' also provide a more regular opportunity to show off prototype ideas.

2 A programmatic demonstration to test, evaluate and characterise a technology for a particular application, often comparing different models and technologies

This has goals more closely allied to R&D than a field trial and for this reason is called 'demonstrative research' by the Japanese. The US PV-BONUS (1992-97) programme, for example, was intended to develop products for the building market by exploring design options to reduce application costs. However, to avoid political objections it was described as R&D. In the UK, the Carbon Trust's combined heat and power (CHP) trials (2004-07) evaluated a number of (non-wind/PV) technologies on efficiency and carbon saving criteria.

[1] 'Decathlon' refers to the houses being tested and evaluated on ten criteria.

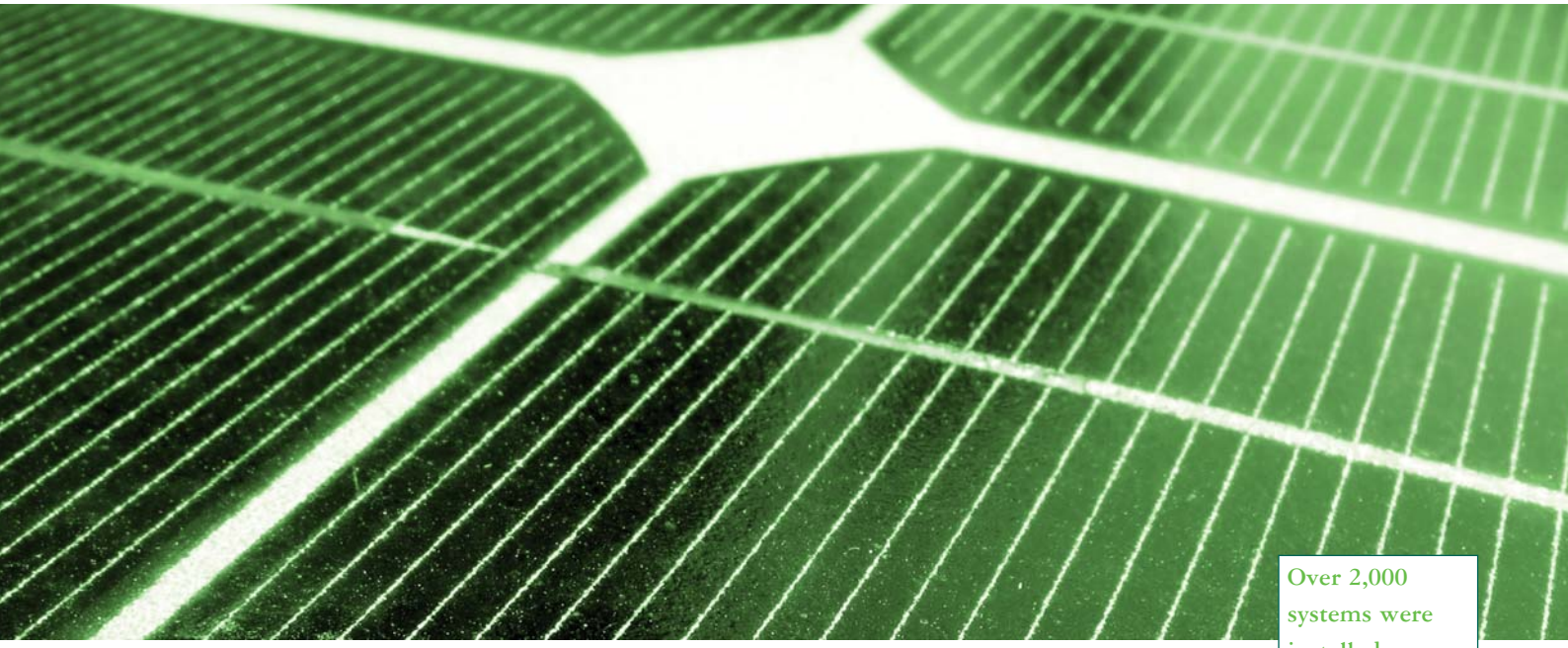
3 Programmatic field trials and tests to improve performance and reduce costs before commercial rollout

The German 1000 Roofs Solar Power Programme (1991-95) was described as a 'demonstration cum market formation programme' to develop installation know-how. Over 2,000 systems were installed on private residences and extensively monitored, leading to the establishment of EU standards for grid connection in the next phase of large-scale rollout.

4 Permanent testing and demonstration facilities (test centres)

A test centre provides an offline learning facility, which can support manufacturers in a wide range of ways, from initial experience to product certification. In the UK, the Building Research Establishment (BRE) in 2008 had six demonstration homes erected by different homebuilders to Code Level 5 (very low carbon) or Code Level 6 (zero carbon). Contractors gained experience in building these homes and having them subjected to BRE tests and certification.

The first and last of these demonstration projects and tests are easily overlooked, because they do not have the visibility of bureaucratically organised programmes (such as the EC Framework Programmes) and their impact is difficult to gauge.



Over 2,000 systems were installed on private residences and extensively monitored…

Test centres, in particular, lack the visibility of field programmes, although they can perform some of the same functions more cost-effectively than testing in the field and provide a distinctive service at other times throughout the whole innovation process. Permanent test centres have contributed importantly to PV development in Japan and the US, and to wind turbine development in Denmark, US and Japan.

Each activity performs a different role within the development cycle, and it is important that companies and policymakers are clear about these.

Exhibit 1: Lessons from the US TEAM-UP Programme

The US TEAM-UP end-of-programme review of 35 PV projects from 1995 to 2000 distinguished demonstrative projects (for image building and public relations) from commercial projects (to build plant with a real commercial purpose): 'Each of these goals requires significantly different types of project.'

Companies undertaking a demonstrative project and looking to build their image as green or environmentally friendly should:

- create a project that will give maximum exposure at minimum cost
- choose a reliable, low-maintenance PV system
- select a site that is highly visible
- select a system that is visually appealing
- and, even more important than spending money on the systems themselves, allocate funds to an education and public relations campaign

Organisations that are more interested in the commercial energy generated than image building, on the other hand, should:

- select large systems, because these are more cost-effective (enabling volume purchase discounts, reduced labour expense, less frequent troubleshooting)
- choose a system that is replicable in order to minimise the cost of future installations through standardisation and accumulated learning
- ensure systems are properly monitored for functioning and performance

lessons for policymakers and companies from DTs

From the cases, we have developed a number of core lessons described under one of five headings. The first three headings emphasise integration, coordination and iteration of activity – in other words a long-term holistic approach to innovation, neglect of any part of which may spell failure. The last two stress the importance of learning from DTs, including learning from project failures so these can be redressed and step changes achieved.

A A coordinated programme to develop technology, product and manufacturing

B From technology to market

C Back-to-front DTs

D Subsidy versus learning

E Capturing and spreading learning

Many of the lessons will be familiar to those with close experience of DTs. However, among these are issues that are too readily overlooked, or where important nuances are missed. This includes the importance of an iterative approach. Appendix 3 provides a summary checklist.

Early stage DTs focus on the technical aspects of development.

A DTs need to be part of a coordinated programme of activity and policies to develop technology, product and manufacturing

Early stage DTs focus on the technical aspects of development. At this point in the development cycle, the contributions of R&D, DTs and test centres overlap. The boundaries between these are often blurred. Large firms often engage simultaneously and sequentially in public programmes of separately funded RD&D. For example, BP Solar, one of the world leaders in PV engaged in 39 EU DT projects, plus 20 R&D-related over a 15-year period, while its US acquisition Solarex was involved in successive US programmes (PVUSA (1987-91), PVMaT (1991-96), PV Bonus (1992-97), SMUD Pioneer (1995-2000), and TEAM-UP (1995-2000).

Lesson 1: Technology and product development benefit from combined funding from R&D grants, DTs, and performance validation by test centres

Like Solarex, the US firm Sunpower and its 2006 acquisition Powerlight benefited from extensive US grants over many years to develop products for the building market through PV-Bonus and TEAM-UP. In addition, they used grants for validation testing, including National Renewable Energy Laboratory (NREL) monitoring of installed PV efficiencies to support their product claims. This kind of testing was vital at a time when verification was difficult because of cost and inadequate methodologies – a typical problem in early stage technical development.

1a Formal monitoring by research laboratories and testing centres, using nationally approved testing protocols and methodologies, is crucial for early commercialisation and accessing finance

The combined effect of R&D, DTs and the development of standards is to support innovation's requirement for long-term commitment by opening up sources of finance: *"Understanding and quantifying the structural loads [in wind turbines] was a breakthrough that probably covered a 10-year span. This was the gate we needed to pass through to substantially scale up machine size, overall the greatest contributor to the reduction in cost of electricity. By defining appropriate levels of structural loads, the International Design Standards firmed up, which in turn broadened wind project financing sources."* (James Dehlsen, founder of Zond and Clipper Windpower, 2007)

Laboratories such as NREL, the European JRC Solar Test Installation, ECN in the Netherlands, Riso in Denmark, and the Rokko facility in Japan have played a key role in establishing reference standards. The UK has lacked central facilities of this kind in key areas, but is now better served, through the Science and Technology Facilities Council-Rutherford Appleton Laboratory (STFC-RAL), the New and Renewable Energy Centre (NaREC), the European Marine Energy Centre (EMEC) in Scotland, and the proposed Centre for Carbon Metrology.

Lesson 2: Coordinated action is necessary to address wider energy system issues

The technology readiness levels (TRL) framework distinguishes between component testing (levels 4-5) and full system testing (levels 6-8). An important aspect of this for new energy technologies is their impact when connected to national and regional grids. Japan's Central Research Institute of the Electric Power Industry (CRIEPI) and Rokko have been important in addressing these wider system issues through combined R&D, DTs and testing in a country where the grid is less robust.

Lesson 3: Development of manufacturing processes and scale-up benefit from R&D grants and DTs

There is often specific provision for manufacturing development in programmes in the US, Japan and EU, since standard production techniques are an essential accompaniment of opening up markets and increasing sales. AstroPower's commercialisation of its Silicon Film process was helped through continuing influxes of know-how and cash from no fewer than 87 NREL and other DOE and federal grants over a period of nine years, including several projects under PVMaT (1991-96) to improve manufacturing processes. *"A DT forces the company to scale up, as a lot of these are installations in applications for which no manufacturing exists."* (AstroPower)

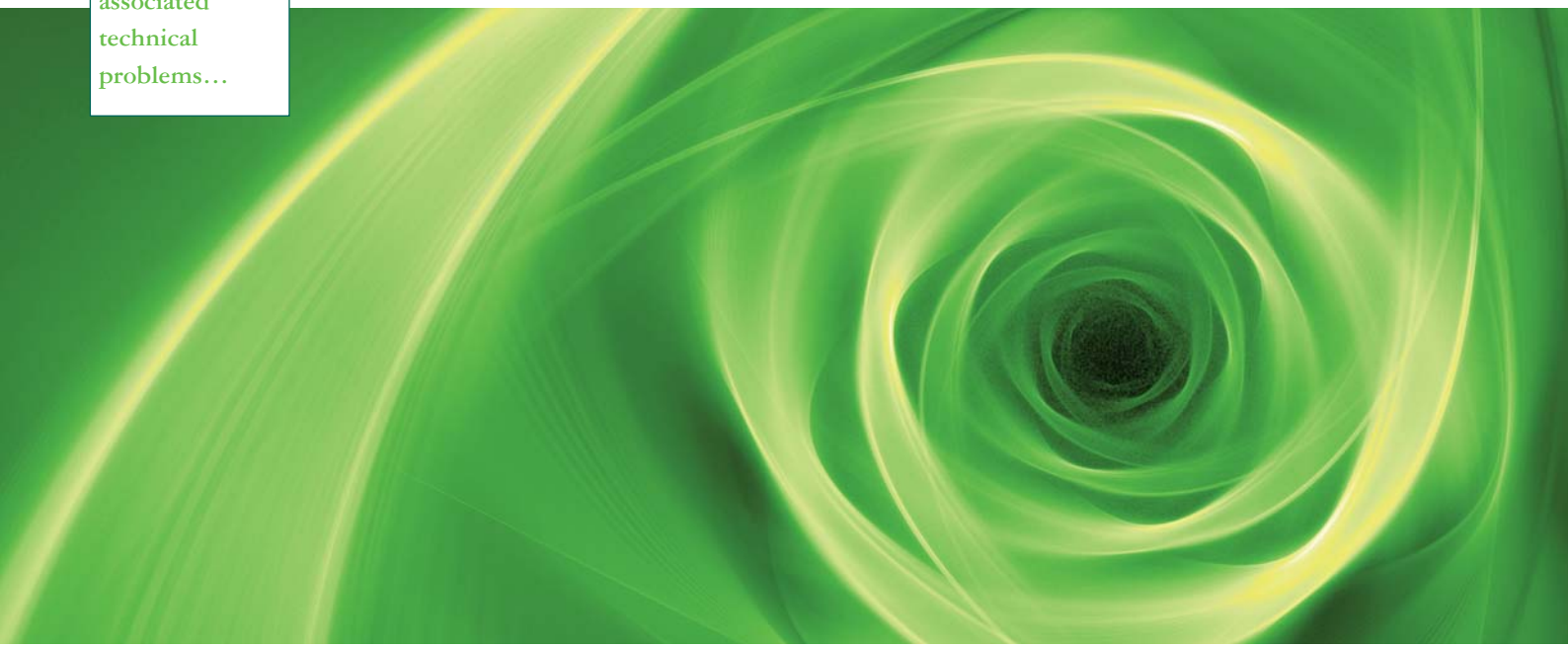
Lesson 4: Before embarking on market development, technology and product need to be adequately tested and developed

Firms should not enter DTs with technically unproven technology. In effect, this means DTs validate prior R&D and take a working prototype to the next stage of scaling up. The wide scope of EC programmes and the tendency to group everything under 'RD&D' helps the interplay between developing applications and ongoing R&D, but means that clarity of project goals and overall management become especially important and that lessons from DTs need to be fed back to R&D.

4a DT programmes need to be timely and not promote a technology before it is ready, thereby encouraging firms to jump the gun

Problems arise when firms use market development programmes before they have fully explored associated technical problems…

Problems arise when firms use market development programmes before they have fully explored associated technical problems, or use them for ongoing technical development. As the Solar Electric Power Association, TEAM-UP Final Reports, 2001 observed: *"Don't publicise a product or contract to deliver it until the product is available for purchase."*



Most firms will use DTs to fund their product development if they can, whether or not it is appropriate, and large firms are adept at this: *"I used to work in big company R&D and I know that the most attractive thing for them is to win government grants to pay for their R&D, rather than pay for it by themselves."* (Schott Solar)

And, as a corollary of 4a,

4b DT programmes need to apply rigorous selection criteria and avoid approving projects just to achieve their quota and funding target

Lesson 5: Technology development may be better funded through R&D programmes to avoid DTs that are tied in with market goals

The logical progression is to begin with programmes that test and advance the technology, then to explore market applications…

R&D programmes – especially those focused on developing manufacturing for production – can often achieve their aims more effectively than DTs, because they are conducted away from the pressure of customers and make it easier to pursue persistent, iterative efforts towards target goals.

R&D grants also provide better protection for intellectual property than DTs, whose goals invariably include disseminating knowledge. However, State (EU) funding rules may delay the progression from R&D to DTs unnecessarily.

B From technology to market

Lesson 1: Coordinated activity implies a natural sequence from technology to market development, backed by market support

The logical progression is to begin with programmes that test and advance the technology, then to explore market applications, develop manufacturing to assist scale-up and reduce product costs, and finally promote take-off through subsidies and incentives in selected markets.

Even early programmes to test and improve technology, though, involve applications of different kinds and scale, and thus provide an initial market test. This highlights the requirement for multiple, parallel development paths involving technology, market, company, and regulation.

The US approach to solar photovoltaics followed this pattern. But, in contrast to the Japanese and German rooftop programmes, no targeted programme of subsidies followed to stimulate market take-off. In part, this was because the Germans and Japanese made an early commitment to rooftop applications, which the US did not, and in part because of inconsistency in US federal subsidies and support for renewables. This has long been a cause of complaint among US renewable firms and advocates: *"The SMUD rooftop programme (1995-2000) was successful, but it needed to be followed up and this did not happen in the US. Japan and Germany did what had to be done but the US did not."* (Schott Solar)

As is now almost universally recognised, DTs need to be followed up with appropriate market creation incentives, to complement technology-push with market-pull.

1a A stop-start approach to public subsidies that relies on the stimulus from DTs and R&D projects has a negative effect on overall commercialisation

As Donald Osborn, SMUD's Solar Program Director put it: *"Demonstration and R&D projects alone do not accelerate the commercialisation of new technologies. In fact, large, one-time purchases tend to dry up supply, and thereby increase prices, without stimulating the increase in production capacity necessary for manufacturing cost reductions. Furthermore, manufacturers do not rely upon short-term subsidies, mandated purchases, or set-asides in making investment decisions because these programs create false markets. A combination of aggressive price reductions and commitments for substantial and sustained capacity acquisition is required for full commercialisation of these technologies."*

Other forms of public subsidy – such as the Non-Fossil Fuel Obligation in the case of UK wind power – can similarly create a stop-start environment.

Lesson 2: DTs should provide a series of structured steps for developing product and entering markets

2a Exploratory projects precede market-focus

The first step is to explore applications, before promoting take-off. Company attitudes to market focus crystallize as a technology matures, and with hindsight can be rather unforgiving to projects that lack a clear market focus.

"Demonstration projects which are based on wild ideas do not make any sense, particularly if just regarded as an opportunity to get equipment out of the factory and into some sort of market situation. The key message is that we need to fund demonstration projects that involve equipment that relates to a realistic market. In other words we need commercialisation demos, rather than show-and-tell demonstration projects. Underlying this must be the realisation that we want this market to happen." (ex-Solarex)

This contrasts with the enthusiasm of US companies for the Solar Decathlon 'show and tell' project. The US TEAM-UP evaluation also took a different view, in recognising the distinctive character of PR demonstrative projects. The UK is perhaps insufficiently willing to fund speculative projects at the DT stage that might open up and shape markets.

2b By making products visible, even at the prototype stage, DTs can open up early markets

Market opportunities can be a by-product of technical tests, however. While the immediate driver for wind firms to participate in DTs was to get sites to test prototypes, they also provided an entry point for follow-on sales.

During the 1990s, for example, NEG Micon supplied demonstration wind turbines to a number of sites in Japan. This not only earned sales revenue – some £200m – but established NEG Micon in Japan, enabling it to develop a partnership with a company now owned by Toyota, which in turn provided the bridgehead to the New Zealand market when it merged with Vestas.

2c DTs validate the market for an application and force refinements in the application

In general, DTs do not identify markets and applications, they validate the application. To get value from a DT, a company must already have done work on the target market.

'It really is about validating the market application, because if you find something in the demonstration project that does not meet the customer's needs, you have to go for a rethink. There are two aspects to this learning – the final specification of the product, and the precise nature of the customer need. DTs force the company to finish its design all the way through to the end user." (AstroPower)

This requires a customer that will interact with you. The learning that results is often unexpected (see Exhibit 2). Finding out what people actually want to do with a product can drive rapid technology change, as the proliferation of the mobile phone demonstrates.

Exhibit 2: Learning what customers want

In PVUSA, AstroPower submitted products to technical testing by utilities at three test stations: *"The utility was much more interested in the cosmetics than expected, even though the installation could not be seen. Some of the modules had blemishes on them and had to be replaced. This was not technically important but it was customer important."*

Solarex had similar experiences: *"Demonstration projects are extremely valuable as they enable you to find out things. The sorts of thing we discovered were understanding what the customer really wants and the importance of having a product that is very robust.*

We also learned that engineers find it difficult to comprehend customer reactions. Too often, the reaction is one of hostility and that the reason equipment doesn't work must be the way it has been used. In reality, the equipment has to be bullet proof when it goes out at the door."

2d A key objective of market-oriented DTs is to generate certificated performance data

Firms stress the importance of DTs in providing long-term data that demonstrates product performance, reliability, ease of maintenance and installation. They will often supply discounted product to companies and academic institutions to get this. The marketing function sees such data as essential in overcoming obstacles in domestic and international markets.

Firms stress the importance of DTs in providing long-term data that demonstrates product performance, reliability, ease of maintenance and installation.

Performance statistics from DTs, systematically collected and published, serve both participating firms and the industry at large, enabling firms to gain insurance cover and offer supportable performance warranties. This requires, however, that the manufacturer retains some operational control and can collect valid data, that government as funding agency stipulates this, and/or that the project partners share a common goal. Otherwise, the collection of relevant data tends to be patchy. It is even better if third party agencies conduct independent verification and accreditation.

2e The value of projects and the quality of data required varies according to the type of firm

A technology developer has different requirements from a systems integrator. A system integrator typically has less interest in data capture, will focus on providing know how, and probably source from multiple firms. It will be active in managing projects, work with utility companies, and be more likely to deal directly with government departments. Similarly, the type of involvement and what constitutes useful learning will vary for other firms in the supply chain.

- Small technology developers should be careful what kind of projects they participate in.

  SMEs are liable to get involved in any available project that might benefit them, and are therefore likely to be disappointed more often. They also need to be careful about how much of their scarce human and physical capital gets tied up in a project.

- Government funding and managing agencies should ensure SMEs have realistic expectations, and in multi-partner projects define roles very clearly.

  The trend for large multi-partner DTs in EU Framework Programmes risks the loss of informal knowledge sharing from the close team-working found in smaller projects, since firms tend to be protective of knowledge that affects intellectual property.

- The demands of project management need to be commensurate with the value to firms.

  Many Japanese firms complain of NEDO's conservatism in commissioning projects and its reporting and auditing requirements. International projects tend to involve extensive paperwork, which is irksome and makes participation questionable.

2f Going to market means developing partners – while early DTs develop a firm's own learning, later DTs build distribution and supply chains

Having developed its expertise and product, a firm needs committed customers and distributors to enter a real market. Building relationships is essential for market-realisation (Exhibit 3). Firms will benefit from DTs that encourage this.

For example, by bringing together manufacturers and utility companies the TEAM-UP (1994-2000) programme created market-oriented entrepreneurial activities in the US PV industry for the first time. Multi-year funding, which a single procurement could not have accomplished, was also a critical factor in testing what worked.

2g Incentives to consumers to participate in DTs create satisfied customers and product champions

Incentives can be important for persuading ordinary consumers to participate in pre-commercial trials. Japan and Germany (and SMUD in California) have used various incentives in this way in their PV rooftop programmes, which involved putting equipment on people's homes and monitoring it. This applies even more to fuel cells, where modification to an existing power source and facilities may be necessary.

Having developed its expertise and product, a firm needs committed customers and distributors to enter a real market.

The objective is to create satisfied customers who will create good publicity. Continuing financial benefits from measures such as feed-in tariffs add to the feel good factor. This highlights the importance of coordinating market creation measures with DTs.

2h Projects that are closer to market should engage the marketing department, but not become divorced from company R&D

The transition from technology development to trials that pave the way for a large-scale rollout implies a shift in internal organisational focus. At Sharp, field trials become the province of marketing, as marketing depends on having certificated performance data to support sales. Field trials also involve working with a range of parties from gatekeepers (retailers, distributors, etc) through to end-users down-stream. The marketing department will either already have such relationships, or it will have to create them.

Market-oriented projects may still generate research issues, though. Companies need to be alert to these so they can be solved in-house, without necessarily relying on public R&D to resolve them. In these ways, the DT programme should be rooted in the company business plan, from design, through evaluation and further R&D, to market exploitation.

Lesson 3: DT programmes for market development may still need to be backed by continuing access to public R&D

While companies need to maintain their R&D as they open up markets, policymakers should also back DT programmes with continuing public R&D. One of the lessons of the failed US Million Solar Roofs (MSR) programme was that *"MSR should have influenced R&D, and R&D should have influenced MSR plans."* (Strahs and Tombari, 2006)

The Solar America Initiative is designed to avoid the same mistakes, by combining technology and market development with a new wave of innovation and demonstration projects directed at a wide range of stakeholders, and backed by substantial R&D and venture capital. In fuel cells, the SECA programme to advance solid oxide fuel cells uses a similar structure of projects backed by direct recourse to designated universities and national laboratories to solve fundamental materials and scientific problems that might arise.

Exhibit 3: Partnering to go to market

AstroPower's focus in PVUSA (1987-91) was to develop its own expertise; by the time of TEAM-UP (1995-2000) it was looking for markets.

Five projects with retail partners for its residential system provided the stimulus for sales and marketing initiatives through 2000-04, leading to long-term relationships with retailers and house-builders in the US and Europe.

"PVUSA to TEAM-UP was a good transition. TEAM-UP funding was critical to getting management excited. Without this, few systems would have been sold. TEAM-UP created a learning environment for residential systems. From this we learned to favour the larger systems that have reduced transaction costs per kilowatt. TEAM-UP funding was also the catalyst for the creation of state-based buy-downs." (AstroPower)

Lesson 4: Firms need to participate externally in standard setting and regulatory bodies to influence the environment for commercialisation

In wind, solar PV and fuel cells, managers from pioneering firms take on the role of champions within industry associations and lobby to be consulted on policy, regulations and standards. Firms benefit from assigning senior managers to committees concerned with these wider system issues. Nevertheless, this use of senior management time has a substantial opportunity cost, especially for SMEs.

C Back-to-front DTs

Lesson 1: DTs for market development should follow as well as precede DTs for technical development, reflecting the iterative and recursive nature of innovation

Coordinated activity implies a natural, logical sequence from technology testing to market development. Unfortunately, this notion, which has prevailed with regard to DTs since the 1970s, is contradicted by changing perceptions of the innovation process. A more recursive view is justified by the iterative nature of innovation, and reflects what has actually happened in European support for PV.

Until the early 1990s, EU-funded DTs supported market development in remote off-grid locations, which at the time were widely perceived as the most suitable market for PV. When Germany and Switzerland promoted rooftop systems, however, the focus shifted to technical DTs to support entry to more challenging, grid-connected markets. The technical aspect of projects, although never entirely absent from the early projects to develop markets (to prove an application in a new setting), became more dominant.

Lesson 2: Targeting 'low end' markets first to generate revenue and learning, through government-subsidised sales and DTs for market development, may subsequently enable firms to pursue 'high end' markets, with the support of technically focused DTs

In the early stages of a new technology, markets are uncertain. Firms may therefore try unfashionable markets, either from choice or force of circumstance, helped by an open bidding process for DT projects to target these markets.

Clayton Christensen's theory of disruptive innovation suggests that new firms, faced with competing products based on mature incumbent technologies – as in electricity generation – will initially target low-end markets out of the mainstream that have simpler requirements.

In the language of innovation theory, this gives these firms a protected space in which to try new things. Once they have achieved a basic design, low cost production, technical/market experience and, crucially, high reliability – a key factor for isolated communities – they are in a position to tackle more demanding markets in developed economies with a greater chance of success.

Exhibit 4: From low-end to high-end markets, through DTs focused first on market development and then on technical improvement

In common with other PV firms in the 1980s and 1990s, the Spanish firm Isofotón initially focused on off-grid applications. In the absence of a domestic market in Spain, and its subsequent collapse in 1989, they were drawn towards rural electrification projects in developing countries, where they had the advantage of language and culture, which the then leading German firms lacked.

During this period in the 1990s, Isofotón was supported by the Spanish Development Agency, governments of developing countries, NGOs with subsidies for commercial projects, and by 15 EU-funded DT projects for rural/remote uses and water purification in Spain and France.

This support helped Isofotón's development of systems in third world markets, as well as for Spain's own arid areas. As a result, Isofotón became the leader in marketing solar power to the developing world, until Spain's strategy of boosting its own use of solar in 2004 caused it to shift its focus to the domestic market.

The subsequent shift in market focus was accompanied by two things.

First, Isofotón benefited from the stimulus to the grid-connected European PV market from Germany's 100,000 Roofs programme (1999-2003). Isofotón gained 15 percent of this market to become the world's seventh largest producer of solar cells. Spain's feed-in tariff introduced in 1994 added a further boost.

Secondly, the European DTs in which Isofotón participated changed significantly, from being almost all to do with market development before 2000 (21 out of 23) to almost all technical thereafter (15 out of 17). Explicit technical objectives to improve cell efficiency, manufacturing and costs reflected the general shift in EU Research Development and Demonstration (RD&D), and the worldwide effort to improve efficiencies through new materials and concepts in second generation PV.

In all these post-2000 DTs, Isofotón was the lead or partner, showing both its strategy to upgrade its technology to address the more demanding market of grid-connected PV in Europe and its desire to keep a close hold of the resulting IP.

This shift in product-markets and DTs follows the pattern predicted by disruptive innovation, and is quite contrary to what conventional wisdom on DTs would suggest. To exploit low-end markets, early DTs must focus on market development to test suitable products; while later DTs need to focus on technical development and the economics of product and technology to penetrate high-end markets.

2a Low-end markets may still remain highly attractive

Low-end markets can be highly attractive, with continuing opportunities in developing countries for low-cost deployment of renewables. Off-grid markets for large-scale PV, according to the International Energy Agency (IEA), have potentially better long-term prospects than grid-connected rooftop and building-integrated PV. Thus, DT programmes, insofar as they are needed to support continuing development, should not become locked in to single market opportunities.

2b Low-end new markets means innovating in business models

Opening up markets in developing countries, not only means developing an appropriate system to couple PV to water pumps and desalination, but also devising models for project finance and servicing.

Thus, organisational and business model innovations are often a necessary accompaniment to technical innovation. Selling PV to India and China shows this process continuing. However, while developing countries without their own indigenous industry are a natural soft market, they are likely to be wide open for emerging producers in other newly emerging, low cost economies such as China.

Lesson 3: DTs facilitate a probe and learn process to find viable markets

Shifting from low-end to high-end markets also involves a probe and learn process, as firms experiment with versions of their technology in new markets and applications. European DTs in PV supported the probe and learn process by enabling firms such as Isofotón to customise their products to different markets.

Lesson 4: Innovation advances unevenly and further rounds of technical, economic and market DTs may be warranted

While the low-end, high-end pattern is a particular case, technology in general does not progress in a straight line. Ideas are abandoned and then revived when component and material technologies on which those ideas depend have progressed sufficiently enough to support the original idea; or conditions change and make it economic; or wider design changes occur to support it.

So, discarded failed technology may return when the timing is better and other problems solved. Policy and funding should be ready to revisit failed experiments through new rounds of DTs.

> To maintain the momentum of advance, DTs need to sustain and support different options, including second and third generation technologies and variants.

Lesson 5: DT programmes need to be iterative to support versions of technology at different stages of development

Competing versions of a technology, based on different materials, for example, can also develop in sequence or in parallel, with no dominant design emerging in either the short- or even long-term. To maintain the momentum of advance, DTs need to sustain and support different options, including second and third generation technologies and variants. The scope for testing these is greater and cheaper, however, through retrofits to earlier models in commercial use.

Parallel funding of R&D and field-testing in PV and wind remains a feature in Japan, however, where there is a focus on next generation concepts and systems.

D Subsidy versus learning

Lesson 1: DTs provide early revenues to support new firms

Early-stage DTs provide revenues that can be vital for the survival of small new firms before markets have formed. Many interviewees have suggested that one role for DTs in the early days was simply to keep the PV industry afloat, and this was certainly the case in wind. Estimates of the market share contributed by DTs are hard to come by, but were probably 15-20% in PV, and even higher for firms such as Isofotón that lacked a domestic market.

DTs provide a subsidised quasi-market and income to sustain firms' commitment, although there are strong critics of this use of public money. The irony is that direct subsidies are quite freely advocated for helping lift-off at the early commercial stage, yet hidden subsidies are anathema at the pre-commercial stage. In Japan, DTs are used as a deliberate form of subsidy when near to market because they are easier to implement.

Managing the tapering down and phasing out of subsidies to balance market support with the need for continuing innovation, however, is a continuing challenge. Most countries have got this wrong at various times. It is a moot point whether DTs are any more of a blunt instrument in this respect than more formal subsidies.

1a DT-driven quasi-markets can only be temporary and without technical reliability simply lead firms into a cul-de-sac, the end result of which is market withdrawal

Under pressure to achieve sales during early product development, firms make often fatal mistakes exploiting DTs as a market subsidy: *"We had just built an expensive factory, so it was essential to get some product out of the door and inevitably we took some shortcuts. Our approach to the demonstration projects was very opportunistic. We knew that we needed to get product out. But this is no way to fund an industry, relying on a market of last resort…*

> Whatever else DTs may contribute, one thing they must do is produce learning.

"One of the consequences was that in order to achieve sales, a lot of product went to BP service station canopies – in other words it was an internal company market. The residential market take-up was nothing like as fast or as extensive as had been anticipated. This was compounded by the fact that a lot of customers were enthusiasts who were disappointed with the results. So we did not get market take-off." (ex-Solarex)

Lesson 2: DTs must contribute to learning

Whatever else DTs may contribute, one thing they must do is produce learning. The contribution to technical learning should be obvious enough to avoid proliferation of ineffectual projects (although there are inevitably examples of countries duplicating research). The learning contribution to market development, however, is often less clear and thus more likely to function as a subsidy.

EU programmes are full of similar projects to stimulate national markets (and/or further social goals), involving the same set of participating large companies. The question, then, is how far that learning is captured by single companies or shared.

2a DTs produce different learning for different stakeholders, with the hope that the one will reinforce and complement the other

Manufacturers often have the keenest interest in learning from DTs and are the most vociferous lobbyists for publicly funded DTs. However, as analysis of lead partners in PV and wind shows, they often act merely as suppliers, with user-operators (utilities and ESCOs) and regional authorities as the principals, although national patterns vary considerably. If the utilities are not wholly committed, as in most countries they have not always been, they can end up controlling and restricting the pace of adoption.

Committed user-operators, however, can be highly instrumental in diffusion by using DTs in which they participate as reference sites for installations elsewhere. This must be the hope in the EU funding extensive projects in wind and PV with regions and utilities.

2b DTs can educate reluctant partners

Since new energy technologies lie outside the experience of the incumbent electricity utilities firms, DTs that create collaboration can help educate them. The TEAM-UP review claimed one important achievement was to educate participating utilities on the benefits of distributed generation and managing peak demand. On the other hand, Japan's continued testing of grid connection can be seen as the electrical utilities trying to frustrate progress of technologies that pose a commercial threat to them.

Exhibit 5: What a DT to foster learning might look like

"The role of a publicly funded demonstration project is to help resolve uncertainty in order to get confidence and investment. So it is either early stage technology development, or where the technology is a solution looking for a problem. The value of a demonstration project is to open everybody's eyes to the potential of something.

"Given that EU targets for 2020 are demanding and the PV industry has been averaging 40% compound growth, I think all sorts of cracks will start to appear. Working out what those cracks might be, by doing some kind of demonstration project, could be a very good thing. The demonstration project that consists of just a whizz-bang building covered with PV doesn't demonstrate anything that we didn't know in the 1960s.

"Our company is in the business of integrating PV with buildings, so some kind of demonstration project that helps the construction industry accelerate its understanding of the methods needed to manage PV in buildings would be an excellent topic. The intention would be to open up the eyes of the construction industry to what the future is going to look like.

"Another example might be to consider a trial that draws on the experience of ground-mounted solar farms in the desert areas of California and Spain. A demonstration project to figure out what is the meaning of a solar farm in the United Kingdom might have merit. In a crowded island like the United Kingdom, could we have some land that is set aside in some way for something that is less inflammatory than a wind farm?

"My point is that the demonstration trial is only valid at the very early stage of a particular application. In the example of the construction industry, the development of solar PV for that particular application is at a very early stage as far as the construction industry is concerned. So it counts as an early stage demonstration." (Solar Century)

2c Those that retain some ownership in projects will learn most

The US firm, Zond, which began as a project developer for wind farms, was able to make the transition to a manufacturer in its own right because it recognised the value of one important dictum – retain ownership in projects in order to capture new learning: *"Particularly in the early years, we retained a piece of the ownership of many of our projects. In retrospect, I think that was probably the reason we survived when other companies fell by the wayside. The income from our projects not only supplied operating capital that allowed us to make it through the tough times, it also gave us an owner's view of projects which made us more aware of the impacts of unscheduled maintenance costs and the importance of good customer service."* (James Dehlsen, 2007)

2d Failure is an essential and inevitable part of learning

Without the possibility of failure – and actual failures within a programme – there may be only limited learning. This is very hard for governments to accept.

"If nothing in a prototype goes wrong, you have not learned as much as you should have done. If there were no failures at all, you have probably not been ambitious enough. This is all part of the art of prototyping, and therefore a useful aspect of a demonstration project." (Solar Century)

On the other hand, there may be good reasons for avoiding palpable failures that can lead to widespread loss of confidence in a technology, especially with DTs aimed at bringing a technology and product to market.

If a DT means exposure to potential customers, no company will want it to fail. For example, turbines that failed, even of other manufacturers, were felt to have set back market entry into some countries, such as Brazil, for years.

2e Performance monitoring is essential for learning and should be costed in to projects

An essential part of any project is monitoring performance, and doing so over a sufficiently long time scale, since reliability is a typical concern with a new technology. This requires the manufacturer to retain some operational control in order to collect valid data, which in turn requires that this be costed in, otherwise it may not be done effectively or even happen at all. Equally, there should be provision for independent third party verification and public reporting of results.

2f Projects should include provision to solve teething troubles promptly

Preventing damage from adverse publicity when equipment encounters teething troubles means making provision for maintenance and trouble-shooting, and having skilled technicians available to respond. This also needs to be allowed for in project budgets. Companies need to resist the temptation just to bury bad news, but do something about it in order to learn.

Lesson 3: Reporting results is an important aspect of all demonstration projects to ensure learning takes place

The open reporting of results from DTs varies considerably, but can be onerous. For technical trials, however, it needs to be sufficiently detailed to provide statistical tests of significance. Companies in both Europe and Japan have concerns about the reporting overhead, with many believing the major benefit is know-how that is not shared, rather than published technical data. Indeed, Japanese firms admit to keeping back useful information and not bidding for funds where the lessons could be commercially beneficial to others.

The US appears far better than other countries in reporting – from publicising demonstrative projects to excite interest, reporting the results of technical tests and conducting evaluation reviews, to publishing test centre results.

In Japan, NEDO-funded trials require companies to collect operating data on a daily basis, provide an annual report, and assist in publicising results. Evaluation, moreover, is conducted at pre-project, interim, post-project and follow-up stages – the first three against targets, the last on economic and social impact.

For technical trials, however, it needs to be sufficiently detailed to provide statistical tests of significance.

The evaluations of WEGA I and II on wind turbines are rare examples of detailed analysis in EC projects. However, companies found the reporting protocols for these were too detailed and impossible to fulfil.

E Capturing and spreading learning

Lesson 1: To catalyse momentum, DTs need to have goals beyond the strategic interests of individual companies

The goal of public DTs should be to catalyse the development of a technology, develop an industry base, and stimulate production and diffusion of socially useful products – to set the ball rolling.

While lead companies play a necessary and vital role, the overall goal ought not to be subsumed to their particular interests.

The problem is that calls for public DTs are often structured in a way that encourages companies, or narrow groups of collaborators, to pursue their own focus limiting the impact to their own strategic goals.

Programmes benefit from company input in their specification and design, but there is a risk they are then captured by special interests (the FP7 Fuel Cells and Hydrogen JTI has already been criticised for this). On the other hand, the conflict between generically focused projects and companies' pursuit of their own competitive advantage poses problems for designing, managing and ultimately funding DTs.

Lesson 2: Lead markets stimulate local manufacturers and investment in local production facilities, and attract foreign manufacturers to do the same – DTs thus foster national advantage

Technology development, industry development and market diffusion are closely related (Exhibit 6). Governments have increasingly sought to achieve these synergies in successive eras of new technology, from wind, through PV, to fuel cells. The US, Japan and Germany have all become more nationalistic in managing DT programmes, and the TSB and Carbon Trust have begun to define energy innovation for the UK in similar fashion.

To fulfil all three goals, however, requires a concerted use of technology-push and market-pull measures. From 1980-99, the UK was by far the biggest beneficiary from EU wind projects, but failed to develop a wind turbine industry or, until recently, achieve any significant deployment.

In PV, BP Solar and Shell Solar prospered, despite the lack of a UK DT programme to support development and a domestic market. But though established multinationals can overcome such disadvantages by locating production in buoyant overseas markets, a domestically-based industry will nevertheless fail to emerge or will be small, shallow, fragmented and short-lived.

In the longer-term, it puts even the large players at a disadvantage and leads, as we have seen, to their divesting renewable businesses perceived as non-core to more locally grounded firms. This becomes a critical issue with the flight of manufacturing to China.

Exhibit 6: Local markets stimulate industry growth

"It is a well known phenomenon in many industries that local market conditions have a significant influence on industry growth. This is also true with PV.

"Looking back, we all remember not only the US having the biggest yearly market, but also the remarkable – even for today's standards – 6 MW Carissa Plains project in the early 1980s. As a consequence, two of the biggest companies – Arco Solar [now part of Solarworld] and Solarex [now BP Solar] – had their production in the US.

"The enormous market growth in Japan in the mid 1990s was accompanied by a similar industry growth. Sharp is today the market leader in solar cell production and Kyocera, Mitsubishi and Sanyo are among the first ten global producers.

"With the feed-in law in Germany, which differentiated the renewable technologies, the PV market grew in only four years by tenfold, with the consequence of heavy investments in production capacities – RWE Schott Solar, SolarWorld, Q-Cells and Shell Solar among those with highest investments." (Hofmann et al, 2004)

This was, of course, before the rise of Chinese manufacture, with its hold on silicon production for PV.

2a Government funding of DTs can encourage private finance

Government funding of DTs, especially nearer market, is a signal that it is committed to adoption, and thus can encourage private investment. Such signals (credentialing) are easier to interpret in more corporatist states like Japan. This has become more important with the increased scale of investment required (for example, in wind) and the growth of venture capital provision. Whether it is because governmental signals via investment in DTs are too weak, or because UK firms are loath to invest, this remains an area of national weakness.

2b Governments use DTs to develop the industrial structure for low carbon technologies with varying degrees of effectiveness

NEDO has explicit goals to strengthen Japan's industrial structure by means of RD&D, and uses DTs for national advantage in the programme to export expertise in grid control systems. Although classed as aid, this provides test opportunities to Japanese firms and market entry. The EC has supported many projects in PV with similar effect.

While the consortium structure of EC projects develops the supply chain in principle, more often this is a wished-for rather than proven benefit. The UK Technology Strategy Board's 2009 carbon abatement technologies and fuel cells and hydrogen technologies programmes are at last beginning to place emphasis on supply chain development.

2c DTs are likely to be more effective in enabling learning to permeate down the supply chain, than in promoting technology exchange between partners

Firms often resist partnering to remain in control of their intellectual property, which may be exposed by collaboration – although, in fact, it is often firms least experienced in collaboration that are most wary of it, to their own detriment.

"Gamesa rarely partner with other companies because it is difficult to maintain a good relationship… there will always be disagreements. Additionally, if you are all competing in the same markets, then how can you gain competitive advantage? This is one of the problems of EU funded projects, which insist on collaborations." (Gamesa)

In DTs with a technical focus, large manufacturers are very careful to be the lead partner to retain control of significant intellectual property. This poses a risk to SMEs who may therefore avoid participating.

For these reasons, learning may disseminate more effectively through and strengthen the supply chain, although even this may not be straightforward (Exhibit 7).

2d To develop industrial structure DTs need to have sufficient scale and duration

The objectives of a pre-commercial DT include showing that costs can be lowered to market competitive levels and preparing the industry to respond to large-scale commercial rollout.

There are too many instances – the Californian wind rush; the Non-Fossil Fuel Obligation on UK wind – of using market creation subsidies without the national industry being prepared and instead inducing boom and bust. A DT of sufficient scale and timeliness lowers costs by providing production volumes, and therefore helps to create a labour force with standardised skills for installation – an essential aspect of a supply chain.

Exhibit 7: Learning through the supply chain

The US firm, Zond (now part of GE), began as a project developer for wind farms during the 1980s wind rush in California, sourcing wind turbines from a number of manufacturers and installing them for the electricity utilities. The then small Danish company, Vestas, offered suitably rugged designs for the local terrain, and Zond ordered 150 V-15 turbines and increasingly large numbers throughout the 1980s, culminating in 1985 with an order for 1,100.

When the ending of investment tax credits led to the drying up of orders from the utilities, Zond fell back on re-engineering virtually every aspect of the wind projects it had built to improve productivity and revenue. This gave Zond immense insights into how to reduce costs through improved design and upscaling, with the result that they embarked on developing their own machine.

"We were confident we had something to offer in machine design, because we had solid experience in turbine installation, operation, maintenance, re-engineering and parts fabrication on over 2000 turbines." (James Dehlsen, 2007b)

In 1993, Zond was awarded grant support to develop its own turbine by NREL/DOE, and began work on the 550 KW Z40. Further 'enlightened DOE/NREL support' enabled demonstration of the technology with several key utilities, resulting in a successful marketable product and for the past ten years a leading role in the industry.

Lesson 3: Failure to provide continuing, long-term support to domestic markets is likely to result in a loss of technology and learning from DTs and its transfer to other companies and countries through acquisition

The failure of the US PV market to take off in the 1990s meant firms lost their considerable lead in production, and became vulnerable to acquisition by European multinationals which enjoyed more buoyant, subsidised, local markets. Inconsistent and volatile incentives and subsidies also caused the US to lose much of its wind turbine industry. Complex industry consolidation and the resulting transfer of learning from DTs and R&D is a feature of emergent technologies, including those in energy (Exhibit 8).

Support for the local market, however, becomes problematic once the level of local content starts to decline. If an emerging low carbon technology has failed to establish a foothold, it rapidly becomes a lost cause as it begins to mature, and the economic benefit from public funding, whether in DTs or subsidies, becomes questionable – unless, of course, the interest of carbon mitigation over-rules all other considerations.

3a Transfer of market learning from DTs via acquisition is less certain

Acquisition also buys markets. Since 2001, Schott Solar has acquired both the technology and markets of ASE Americas, Ascension Technology and Applied Power Corporation, all heavily involved in the US TEAM-UP programme to develop a PV market. One aspect of this process, however, is the discarding of unpromising markets as emerging dominant firms consolidate their focus, as indeed Schott has done. There is thus an inevitable obsolescence in the pay-off and learning from market focused DTs.

Exhibit 8: Learning transfer through industry consolidation

Although the German firm, Schott (now trading as Schott Solar), only got involved in PV in 2001, through the acquisition of the US firm, Applied Power, it has emerged as one of the largest and strongest PV firms through a series of further acquisitions and mergers.

In the process, it has acquired technology and learning from a host of US and EU RD&D projects. This includes the manufacturing process on which much of the crystalline silicon PV industry is now based, known as edge-defined film-fed growth (EFG). This process, which drastically cuts the use of silicon in PV wafers, was first developed in the 1970s by Mobil Tyco Solar Energy in the US.

conclusion

In this report we have sought to show the benefits that companies gain from DTs in innovating and commercialising new energy technologies. Such an analysis has rarely, if ever, been attempted. Evaluation is more typically concerned with the perspective of the funding agency – have programmes or projects achieved their goals? – rather than a 'what lessons can we take from them', approach.

Public evaluation of European programmes in PV typifies this shortcoming, with its focus on individual case studies. This falls well short of systematic evaluation, while also exposing the disparate character of Framework Programmes. As a result, it raises questions over whether such projects can lead to widespread adoption, whatever the scientific knowledge resulting, and casts doubt on one of the central objectives of the EC – to use its programmes to encourage the sharing of experience amongst organisations in the EU Member States, and ensure that lessons are learned as quickly and efficiently as possible.

This report, in contrast, seeks to identify lessons for the design, ordering and conduct of DTs in relation to the overall innovation process through the different forms DTs take, by:

- Emphasising the interplay between R&D and DTs in developing technology, product and manufacturing, along with the important role of offline test centres as a cost-efficient and complementary resource.
- Arguing for a coordinated, sequential approach, and the need for a structured approach to take technology and product to market in a series of smooth transitions.
- Stressing the iterative and recursive nature of innovation in which technically-focused DTs and R&D often follow the opening up of markets, as high-end opportunities succeed low-end less sophisticated ones, second and third generation technologies come on stream, and failed technology is revived.
- Arguing that learning should be paramount, which means effective reporting as well as suitably challenging goals, while recognising that DTs also perform a legitimate subsidy role by creating early quasi-markets.
- Stressing the importance of capturing and spreading learning to catalyse and strengthen national industry and develop national markets. The justification of publicly funded DTs is the public good. If the innovation process is not managed holistically, the benefits from DTs and R&D will inevitably pass overseas and the public expense will have been in vain.

Understanding the impact of DTs on innovation is vital to the design and use of DTs as instruments of public policy, and to the coordination of policy incentives, regulatory measures and follow-on activities to maximise their impact. With a range of new programmes seeking to drive the development of low carbon technologies to mitigate climate change, this has particular relevance at the present time.

appendix 1

Leading PV DT and Related Programmes in EU (plus Germany and Switzerland), Japan and US

Dates	Germany/ Switzerland (SW)	EU	Japan	US
1975-79		PV Demonstration (1979-83)	TEPCO R&D (1979-97)	DoE Flat-plate solar array (1975-85) DoE NASA Federal Photovoltaic Utilization Program (1976-84) Federal Photovoltaic Utilization Program (1979-81)
1980-84	Utility Companies (1983)	Pilot Plant (1980-83)	NEDO Demonstrations (1980-82)	DoE Large Systems (1980) DoE Residential (1980) DoE large grid-connected (1981) SCE Carissa Plains (1982-85) SMUD Rancho Seco (1984)
1985-89	SW Megawatt (1987) REN – NRW (1988)			PVUSA (1987-91) Western Area Power (1989-92)
1990-94	1,000 Roofs (1990-95) SW Energie (1991-99) Sonne in der Schule (1994)	Thermie 1 (1990-94) Alterner 1 (1993-97)	NEDO Field Test for Public Facilities (1992-97) Residential PV System Monitor (1994-96) Rokko Test Centre (1994)	PVMaT (1991-96-2001) SMUD PV Pioneer I (1993-99) PV Bonus (1992-97) SMUD Grid Support (1993-99) DoD PV (1994) TEAM-UP Large Systems (1994-2000)
1995-99	100,000 Roofs (1999-2003) 300 Parishes (1999-2001)	Thermie 2/Joule-Thermie (1995-98) Altener 2 (1998-2000) Framework Programme 5 (1998-2002)	ECO-school (1997-2003) Residential PV System (1997-2000) Local Efforts (1997-2004) Industrial Use (1998-2002)	TEAM-UP Residential (1995-2000) Million Solar Roofs Initiative (1997-2010)
2000-06	Flagship Solar Roofs (2004-06)	Framework Programme 6 (2003-2006) Intelligent Energy (2003-2006)	Residential PV System (2001-04) Grid-connected PV (2002-07) NEDO MegaSolar (2006-10)	SMUD PV Pioneer II (2000-) Solar America Initiative (2007-1015)

appendix 2

Leading Wind DT Programmes in the EU, Japan and US

Dates	EU				US			Japan		
			No of projects	No of turbines		No of projects	No of turbines		No of projects	No of turbines
1970-79	ENALT 1C		3	5	MOD-O	1	1		0	0
					Federal Prog 2	1	13			
		Germany/ Denmark/ Netherlands	2	3	MOD-OA	1	4			
					MOD-1	1	1			
					Misc	1	1			
1980-84	ENALT 2C		54	72	MOD-2	1	3	Various	2	2
					NASA/DOI System	1	2			
					Verification					
			7	12	Misc	3	32			
1985-89	ENNONUC 3C		14	20	MOD-5B	1	1	Various	5	5
	ENDEMO C		82	151	Bushland test-bed					
					Misc					
		Germany/ Denmark/ Netherlands	3	7						
1990-94	Thermie 1		49	190	Altamont Pass	1	22	Various	22	42
					Misc	3	4			
1995-99	Thermie C		44	120	Turbine Verification	1	48	Various	60	94
					Next Generation	1	2			
2000-04	Mega-Wind		1	1				Various	6	6
	Explore-Wind		1	2						
Total			**260**	**583**		**19**	**136**		**95**	**149**

appendix 3: a checklist of lessons for DTs

A DTs need to be part of a coordinated programme of activity and policies to develop technology, product and manufacturing

Lesson 1: Product development benefits from combined funding from R&D grants, DTs, and performance validation by test centres

1a Formal monitoring by research laboratories and testing centres using nationally approved testing protocols and methodologies is crucial for early commercialisation and accessing finance

Lesson 2: Coordinated action is necessary to address wider energy system issues

Lesson 3: Development of manufacturing processes and scale-up benefit similarly from R&D grants and DTs

Lesson 4: Before embarking on market development, technology and product need to be sufficiently tested and developed

4a DT programmes need to be timely and not promote a technology before it is ready, thereby encouraging firms to jump the gun

4b DT programmes need to apply rigorous selection criteria and avoid approving projects just to achieve their quota and funding target

Lesson 5: Technology development may be better funded through R&D programmes to avoid DTs overlain with market goals

B From technology to market

Lesson 1: Coordinated activity implies a natural sequence from technology to market development, backed by market support

1a A stop-start approach to public subsidies that relies on the stimulus from DTs and R&D projects has a negative effect on overall commercialisation

Lesson 2: DTs should provide a series of structured steps for developing product and entering markets

2a 'Exploratory' projects precede 'market-focus'

2d A key objective of market-oriented DTs is to generate certificated performance data

2e The value of projects and the quality of data required varies according to the type of firm

- Small 'technology developers' should be careful what kind of projects they participate in
- Government funding and managing agencies should ensure SMEs have realistic expectations, and in multi-partner projects define roles very clearly
- The demands of project management need to be commensurate with the value to firms

2f Going to market means developing partners. While early DTs develop a firm's own learning, later DTs build distribution and supply chains

2g Incentives to consumers to participate in DTs create satisfied customers and product 'champions'

2h Projects that are closer to market should engage the marketing department, but not become divorced from company R&D

Lesson 3: DT programmes for market development may still need to be backed by continuing access to public R&D

Lesson 4: Firms need to participate externally in standard setting and regulatory bodies to influence the environment for commercialisation

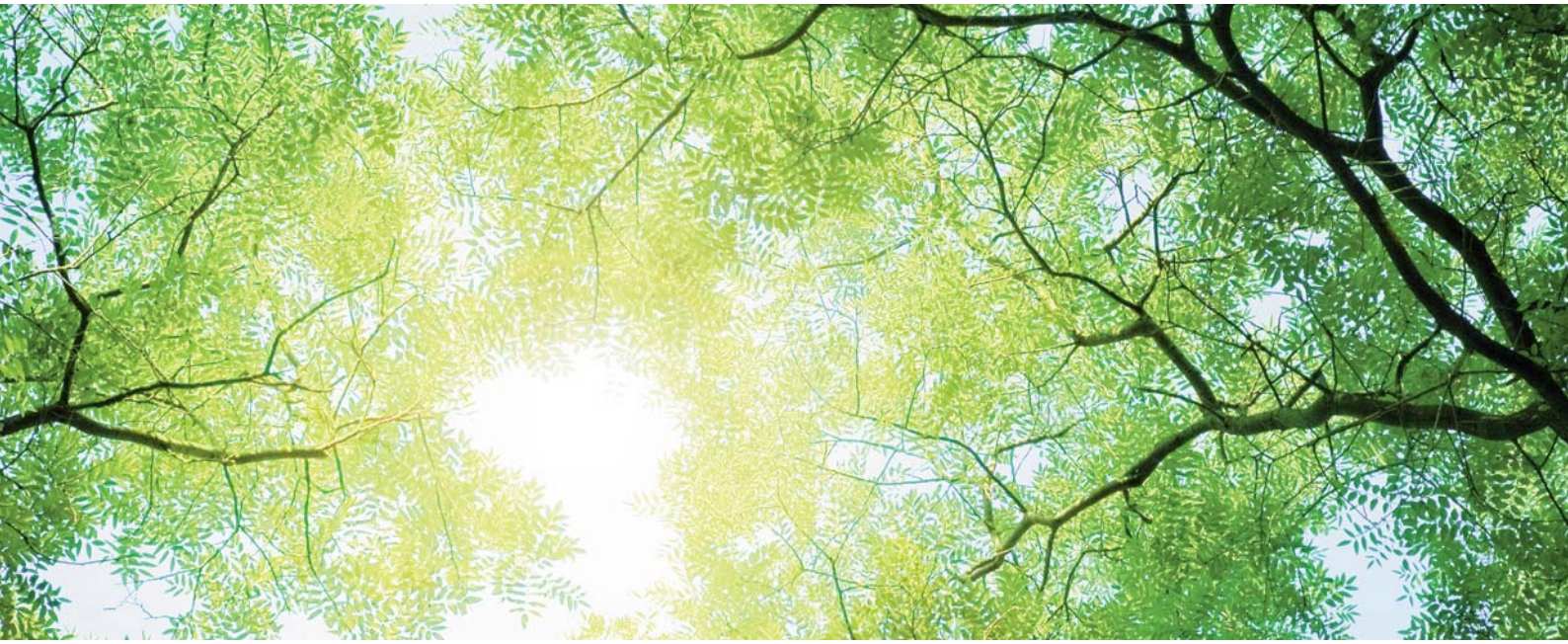
C Back-to-front DTs

Lesson 1: DTs for market development are often followed, not merely preceded, by DTs for technical development, reflecting the iterative and recursive nature of innovation

Lesson 2: Targeting 'low end' markets first to generate revenue and learning, through government-subsidised sales and DTs for market development, may enable firms subsequently to pursue 'high end' markets, with the support of technically focused DTs

2a 'Low end' markets may still remain highly attractive

2b 'Low end' new markets also mean innovating in business models



Lesson 3: DTs facilitate a process of 'probe and learn' to find viable markets

Lesson 4: Innovation proceeds unevenly and further rounds of technical, economic and market DTs may be warranted

Lesson 5: DT programmes need to be iterative to support versions of technology at different stages of development

D Subsidy versus learning

Lesson 1: DTs provide early revenues to support new firms

1a DT-driven quasi-markets can only be temporary and without technical reliability simply lead firms into a cul-de-sac, the end result of which is market withdrawal

Lesson 2: DTs must contribute to learning

2a DTs produce different learning for different stakeholders, with the hope that the one will reinforce and complement the other

2b DTs can educate reluctant partners

2c Those that retain some ownership in projects will learn most

2d Failure is an essential part of learning

2e Performance monitoring is essential for learning and should be costed in to projects

2f Projects should include provision to solve teething troubles promptly

Lesson 3: Reporting results is an important aspect of all demonstration projects to ensure learning takes place

E Capturing and spreading learning

Lesson 1: To catalyse momentum, DTs need to have goals beyond the strategic interests of individual companies

Lesson 2: Lead markets stimulate local manufacturers and investment in local production facilities, and attract foreign manufacturers to do the same. DTs thus foster national advantage

2a Government funding of DTs can encourage private finance

2b Governments vary in their use of DTs and effectiveness in developing the industrial structure for low carbon technologies

2c DTs are likely to be more effective in enabling learning to permeate down the supply chain than in promoting technology exchange between partners

2d DTs to develop industrial structure need to have sufficient scale

Lesson 3: Failure to provide continuing, long-term support to domestic markets is likely to result in loss of technology and learning from DTs and its transfer to other companies and countries through acquisition

3a Transfer of market learning from DTs via acquisition is less certain

appendix 4

A Short History of Wind Power

Modern wind energy dates from the 1970s, when the 1973 oil crisis spurred interest in alternative fuel sources. The US, Denmark, Germany, Netherlands, Sweden and UK began to invest in wind R&D, focusing with the notable exception of Denmark on large wind turbines.

Efforts to apply aeronautics knowledge to turbine design failed, however, and it was Denmark, with its simpler engineering approach that was the first to develop effective, smaller machines. The close association of the emerging industry in Denmark with user groups also helped gain acceptance and adoption, aided by substantial and sustained government support. In due course, the 3-bladed Danish Gedser model became the dominant industry design worldwide.

In the thirty years since, aided substantially by research programmes and DTs, the industry has achieved increasing upscaling of turbines, to the point where the largest onshore models are now in the 5-7MW range. From 1981-85, the industry benefited significantly from investment subsidies in California (the Californian wind rush).

Timely and consistent policies of government support helped Danish firms through subsequent periods of difficulty, leading to the domination of world production by firms such as Vestas, and a leading position in adoption. By 2006, wind turbines supplied around 1.5% of energy demand in IEA member countries, with Germany, Spain and the US accounting for around 60% of world capacity and leading firms. This is projected to increase massively towards 2020, especially with the shift to offshore wind farms in Western Europe.

National and in-company R&D has been overshadowed since the late-1980s by EU DT programmes. Projects have been widely distributed across EU member states, with the UK hosting the largest number. Since 2005, on the back of the early operational experience and commercial scale-up, there has been an increasing focus on raising turbine performance and lowering costs by revisiting the science of rotor blade design and materials, with computer-based modelling and wind tunnel testing displacing field-based DTs to a degree. Retro-fitting existing turbines is also a widespread option.

A Short History of Solar PV

Modern photovoltaic (PV) technology was invented in the 1950s at Bell Laboratories. Its first important application was to power satellites, until, like wind, the first oil crisis in 1973 spurred attempts to commercialise it for terrestrial use. The 1980s were a period of experimentation to improve the technology and reduce costs. The core costs of the PV module reduced sevenfold from 1980-2001 as a result of continued R&D.

The initial focus was on large off-grid applications in the US, where solar PV benefited from high levels of sunlight. At the end of the 1980s, however, the first experiments with roof-mounted, grid-connected PV took place in Switzerland and Germany. In 1994, Japan embarked on a large-scale roof programme, which resulted in some 165,000 installations in the following five years and propelled Japan into the lead position in installed capacity. Eventually, in 1999, Germany committed to its own large roofs programme, following lobbying from its major PV producers, Siemens and ASE, and the election of a new government committed to renewable energy.

Backed by a revitalised and more generous feed-in tariff, which obliged utility companies to take electricity from renewable sources at an advantageous price from producers (i.e. households generating their own electricity from rooftop PV), this enabled Germany to leapfrog Japan by 2004 as the leading adopter and manufacturer. As with wind, the US's early lead was dissipated by the absence of concerted policies to promote PV (California excepted), and its lead manufacturers were acquired by European firms.

Early on, the PV industry settled on mono-crystalline silicon to convert sunlight, partly because of its efficiency in doing so, but also because the semi-conductor industry could transfer its expertise into manufacturing PV wafers for cells. Japanese firms like Sharp and Kyocera were thus well placed to capitalise on Japan's rooftop programme. The two rooftop programmes thereby helped establish rooftop mono-crystalline PV as an early dominant design.

PV, however, remained uncompetitive without subsidy (and still is), especially when system and installation costs are taken into account. Thin-film (amorphous) silicon PV is therefore attractive because it greatly reduces PV manufacturing costs, and enables PV to be integrated into a building, offsetting other construction costs, although with a lower conversion efficiency.

Since the mid-1990s, EU DTs have played an increasing role testing and promoting new materials to support rooftop PV and Building Integrated PV (BIPV) and to reduce costs. These continue, with RD&D programmes developing third and fourth generation PV technologies with much greater efficiencies. Meanwhile, large-scale PV arrays, both grid-connected and off grid, are being proposed in the world's sunbelt, while first generation silicon-based PV manufacture moves increasingly to China.

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