International Energy Agency

IEA Report for the Clean Energy Ministerial

TRANSFORMING GLOBAL MARKETS FOR CLEAN ENERGY PRODUCTS

Energy Efficient Equipment, Vehicles and Solar Photovoltaics

2010

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Executive summary

In 2010, many major economies can point to successful examples of domestic market transformation for clean energy products, resulting in a dramatic improvement in energy efficiency and cost reductions that allow technologies to enter a growing number of markets. Yet there remains potential for greater, global market transformation within the end-use energy efficiency, renewable energy and transport sectors in all countries. Achieving this potential will require application of good practices at the national level, as well as a step change in international co-operation to increase incentives, remove trade barriers, co-ordinate domestic policies, and harmonise technical codes and standards.

What is market transformation?

Market transformation refers to the process of increasing incentives or reducing market barriers to support the adoption of cost-effective, energy-efficient and clean energy products in a sustainable manner. Policies can transform markets sustainably by encouraging incentives and addressing barriers to the point at which clean or efficient products become normal practice in appropriate applications.

A market transformation initiative generally includes:

- **market analysis,** including identification of the particular barriers that are hindering the development, introduction, purchase and use of the targeted product;
- a **clear goal** (such as product sales or performance improvements), together with specific milestones that will need to be accomplished to achieve the goal;
- a set of **co-ordinated activities** that will achieve the desired objectives and systematically address each of the identified barriers;
- **periodic evaluations** designed to adjust policies and respond to actual market experiences; and
- a **plan for transitioning from market intervention** activities toward a largely self-sustaining market, *i.e.* an "exit strategy".

Market transformation initiatives simultaneously stimulate the development of new products and promote their market introduction by effectively changing consumer-purchasing practices so that targeted products become commonplace. Policies and activities are tailored to address the different stages of a product's market diffusion. For example, research and development (R&D) and technology procurement efforts are suitable in early stages to stimulate the introduction of new technologies. Rebates and targeted outreach to large purchasers (*e.g.* bulk purchases) can then strategically increase market penetration until the product achieves "niche" status. Consumer education, loans/rebates and promotional activities (*e.g.* labelling) help expand market share. Mandatory performance standards complete the transformation process by removing inefficient products from the market. Cost reductions occur through each stage of the product's market diffusion, which allows for an even faster deployment trajectory.

Well-designed efforts prompt key market actors — including manufacturers, retailers and installers — to change their behaviour, resulting in a much larger impact than approaches that focus strictly on consumers. Such efforts can also lay the groundwork for new minimum product performance standards that "lock in" the improved product. As market share increases, activities will evolve and costs will continue to decline. To continue market transformation, actors will need to fine-tune tactics (*e.g.* reduce the value of rebates) or shift activities to address the next generation of products. Yet market transformation does not end after product sales reach the targeted level of deployment. Policy makers can extend successful market transformation efforts to related products, using shared promotional and educational activities, rebates and government procurement.

For example, governments and the private sector could work together to "pull" super-efficient appliances into the market by co-operating on measures such as manufacturer incentives and support for R&D. At the same time, countries could "push" the most inefficient appliances out of the market by co-operating on measures such as global standards.

Promising areas for international collaboration

Expanded market transformation efforts have the potential to produce very large energy savings and product cost reductions. When market share of efficient products approaches 100%, savings can be significant. For example, the five areas of priority action in equipment energy efficiency outlined below could deliver around 1.3 gigatonnes (Gt) of carbon dioxide (CO_2) savings per year by 2030 (Klinckenberg *et al.,* 2009). For electric and/or plug-in hybrid vehicles (EV/PHEV), achieving sales targets of 50% of light-duty vehicle (LDV) sales by 2050 will save, in that year, around 1 billion tonnes (20 million barrels per day [mb/d]) of oil and almost 3 Gt CO_2 (IEA, 2010a). Continued market growth will enable solar photovoltaic power to achieve grid parity (*i.e.* competitiveness with retail electricity prices) in many countries by 2020 and earlier in countries having high solar irradiation and high retail electricity costs (IEA, 2010b).

This paper looks at three clean energy product categories: equipment energy efficiency; low-carbon transport, including high-efficiency vehicles and electric/plug-in hybrid electric vehicles (EV/PHEVs); and solar photovoltaic (PV) power. Each section identifies ways to enhance global co-operation among major economies through case studies and examples, and ends with specific suggestions for greater international collaboration on market transformation efforts. The paper also includes an annex with more detailed case studies on energy-efficient electric motors, televisions, external power supplies and compact fluorescent lights.

Promising areas for greater global co-operation on market transformation include:

- harmonised test procedures, standards and labelling for energy-efficient products (including appliances, lighting, televisions, and motors);
- co-ordinated standards and fiscal policies for fuel economy, together with common testing procedures;
- sharing of information and experiences around pilot projects for EVs/PHEVs, along with efforts to harmonise technical product standards;
- coherent policy support for solar PV, aligning fiscal support and incentive mechanisms where possible, in concert with increased collaboration on R&D.

Part 1: Fostering global market energy-efficient equipment transformation

Introduction

IEA analysis states clearly that increased action is needed to promote energy efficient equipment (IEA, 2009). Governments of major economies must continue to implement policies to promote energy-efficient equipment; manufacturers must continue to innovate. And both groups must act together to transform the market.

This section begins by describing successful examples of national and regional market transformation for energy-using equipment. In a world in which equipment is globally traded, market transformation to promote energy-efficient equipment must move beyond the national level. Global co-operation can yield significant benefits, and the major economies are in a unique position to show leadership in this field.

National examples suitable for global consideration[1]

Efforts to transform national markets for appliance and equipment began in the 1980s and 1990s. Assessment of successful projects in developed and developing countries provide useful lessons to countries attempting to expand markets for energy-efficient products. The examples below illustrate market transformation in different sectors.[2]

LED traffic lights in the United States: Traditionally, traffic signals have used incandescent lamps. But in the mid-1990s, signals using light-emitting diodes (LEDs) were developed. The LED signal lamps use only about 10% of the energy of comparable incandescent lights and have much longer life, reducing re-lamping costs and safety problems caused when lamps burn out. Barriers to LED market penetration included concerns about product visibility and quality, and high costs. The first two barriers were addressed by research and new specifications, including work by the Institute for Traffic Engineers, the state of California and the US Environmental Protection Agency's Energy Star programme. The high cost barrier was addressed by financial incentives provided by many electric utilities. As incentives drove higher sales, prices fell. Utility and state energy offices also reached out to state and local transportation officials responsible for traffic signal purchasing and installation, providing information to demonstrate energy and maintenance cost savings, procurement and bulk purchasing arrangements, and grant programmes for LED signal installations. The State of California adopted minimum efficiency standards for traffic signals in March 2003; a federal standard was adopted by the US Congress in 2005 (Nadel *et al.,* 2003).

Refrigerators in Thailand: In the early 1990s, the Electricity Generating Authority of Thailand (EGAT) operated a series of demand-side management (DSM) programmes, including a

[1] The term *global consideration* is used to highlight excellent examples of national market transformation that can be applied to similar national markets by government agencies. The term *global co-operation* is reserved for market transformation efforts that involve multiple governments in a collaborative project affecting a multinational marketplace.

[2] There are additional case studies in the annex.

refrigerator labelling programme, to reduce electric demand by more than 200 MW. EGAT built a refrigerator testing lab in Bangkok and established a voluntary labelling programme under which refrigerators were rated on a scale of 1 to 5 (5 being the most efficient) based on their energy efficiency. EGAT ran television advertisements explaining the advantages of 5-rated products for households and for the nation. Sales of 5-rated units climbed substantially, and manufacturers began to develop and market more 5-rated products. After 5-rated refrigerators made up more than 90% of product sales, the rating system was recalibrated to encourage further efficiency improvements.[3]

Condensing furnaces in North America: Condensing furnaces have thermal efficiencies of 90%, much higher than conventional furnaces. The higher efficiency results from increased heat reclamation from exhaust gases, which cool the gases to the point that they condense. The major barrier is the need to deal with acidic condensate, and the resulting installer training and higher costs. Market transformation efforts began in the US state of Wisconsin, which used its low-income weatherisation programme to train installers and provide free furnaces to low-income households. Natural gas utilities offered incentives, and the market share of condensing furnaces in Wisconsin rose over several years to about 85%.[4] Several other northern US states and Canadian provinces began similar efforts, and the federal Energy Star programme began to require a 90% efficiency rating to earn its label. In 2009, the US market share of condensing furnaces was about 40% (Amrane, 2010). In 2008/09, several states and provinces adopted minimum efficiency standards requiring new furnaces to be condensing. In 2009, furnace manufacturers and efficiency supporters negotiated a consensus agreement to require condensing furnaces in northern states; this recommendation is now being considered by the US Congress and the US Department of Energy.

Regional co-operation projects

Market transformation generally occurs "at home" and has only infrequently ventured beyond national borders. Government agencies and energy utilities tend to manage market transformation initiatives with a focus on domestic activities. Availability of incentive funds normally falls within national boundaries, and proponents are used to working within them. This trend is changing, as more major economies realise the benefits of more co-ordinated regional and international approaches. In the European Union, for example, national governments are working together on market transformation programmes — such as the Motor Challenge — that address common interests.[5] North America also has effective examples of regional co-operation, such as the Consortium for Energy Efficiency (CEE).

The Consortium for Energy Efficiency (CEE): CEE is a bi-national US/Canadian non-profit organisation that focuses on market transformation in North America. CEE's membership consists primarily of energy efficiency programme implementers, such as utilities and some state and provincial agencies. Together, its membership controls about USD 6 billion in annual funds for demand-side management (DSM). Members work together on common initiatives, often developing common specifications, approaches and materials for incentive and education programmes, which members can adapt for use within their jurisdictions. CEE began as a US

[3] See *http://eetd.lbl.gov/clasp*.

[4] *See www.energystar.gov/ia/partners/prod_development/revisions/downloads/ac_ashp/AmericanCouncilforanEnergyEfficientEconomy(ACEEE).pdf*

[5] See *http://re.jrc.ec.europa.eu/energyefficiency/motorchallenge/index.htm*.

organisation. But because the United States and Canada generally operate as a regional market (with the same manufacturers and similar lifestyles and consumer tastes), many Canadian utilities and agencies subsequently joined the CEE. This ensures that both countries' perspectives are reflected in projects for the common market.[6]

True market transformation most often requires the participation of government agencies. Their endorsement gives greater authority to a project than can be generated by opportunistic co-operation between experts or multinational companies alone. Independent experts (even when from different countries) agreeing to work together can achieve a great deal, but more can be achieved if they have government support.

Global co-operation between major economies on energy efficiency market transformation could overcome transnational market barrier constraints. The examples in this paper demonstrate that market transformation can occur beyond national borders, but they also show barriers that complicate transnational implementation. Effective global co-operation will require the dedication of resources and the designation of a venue/organisation to manage this co-operation. The International Partnership on Energy Efficiency Co-operation (IPEEC) is one candidate.[7]

Global co-operation projects for energy-efficient products

The global co-operation case studies discussed in this report provide examples of market transformation for energy-efficient products in the residential, commercial, industrial and transport sectors. Most of the projects began when actors in industry, energy efficiency advocates and governments identified and seized opportunities for co-operation.

Energy efficiency standards and policies

Standards and labelling policies offer one of the best prospects for global co-operation. Countries could also co-ordinate programme design as appropriate to send clear, performance-based signals or even to use synchronised financial incentives to encourage manufacturers to scale-up production of super-efficient devices.

Mandatory minimum (or average) energy performance requirements and comparative labels remain the two most common policy instruments used within national product policy strategies. As far back as in 2001, almost 40 countries operated 29 comparative and 24 endorsement labelling schemes (Harrington and Damnics*,* 2001). Today, most nations now have some form of end-use energy efficiency programme (IEA, 2009).

These policy instruments create dependable ways to distinguish between efficient and inefficient products. They require replicable ways to measure and classify products to deliver results and ensure that suppliers' claims are not open to question. The elements of a robust, defensible standard and/or labelling scheme are:

[6] For further information on CEE, see *www.cee1.org.*

[7] The IPEEC is a new high-level international forum to facilitate actions that yield high energy efficiency gains. IPEEC is leading international co-operation in several areas including capacity building, energy management and buildings networks, finance and indicators. See *http://ipeecshare.org*.

1. **Testing protocols**: reliable and repeatable test methods for measuring product energy performance (*e.g.* a test procedure for refrigerators that specifies the equipment to be used, describes the conditions and duration of a test, and provides instruction on the data to be collected during the test).
2. **Benchmarking requirements for comparative purposes**: ranking methodology of product energy performance (*e.g.* an algorithm describing an energy efficiency index for refrigerators based on energy consumption during a test, the size of the product and its functions [WEC, 2008]).
3. **Performance requirements**: classification of products into energy performance classes (*e.g.* the definition of seven energy efficiency classes in the EU energy label).
4. **Conformity claims**: a means of the supplier communicating to the marketplace that the product's energy performance complies with market rules (*e.g.* through the EU energy label or the US Energy Star label or through energy efficiency performance regulation).

Energy-efficiency standards are sets of procedures and regulations that prescribe the energy performance of manufactured products. Energy-efficiency labels are informative labels affixed to manufactured products that indicate a product's energy performance and efficiency in a way that allows for comparison between similar products or endorses the product's use.

Standards and labels are core elements of a national market transformation policy, and most other policy instruments include built-in measurement principles. Standards and labels, unlike many other market transformation policies, include all four of the steps listed above for classifying products.

- A **minimum or average energy performance standard** provides a classification of products in banned and allowed products (Step 3 in the above), based on a standardised test (Step 1) and algorithm (Step 2), and typically indicates that suppliers of products must indicate compliance with the standard when placing products on the market (Step 4).
- An **energy label** provides the market with an unambiguous identification of the energy performance of products (Step 4), based on a classification (Step 3), which is itself derived from the result of a standardised test (Step 1) and the calculation of a ranking order (Step 2).

The effectiveness of standards and labels relies on the unambiguous classification of product types. This classification, and the identification of product types, must be reliable. A product's energy performance classification can be verified. Such procedures rely on general market surveillance for aspects such as the unambiguous identification of product types and the enforcement of product bans (by standards). Without this, monitoring policies are less effective.

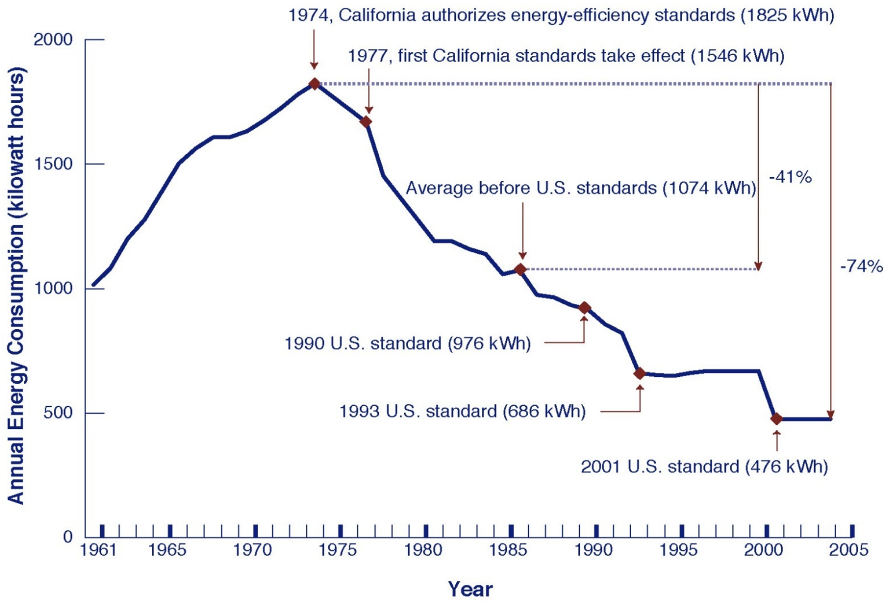
Perhaps the most dramatic example of the effectiveness of energy-efficiency standards and labels is the transformation of the refrigerator market in the United States. The average new refrigerator sold in the United States today uses, per year, only one-quarter of the electricity that would have been used by a refrigerator sold 30 years ago when standards and labels were first introduced. This dramatic drop in energy use has been achieved despite the increased size and added features of new models.[8]

Many other programmes in the developed world that target refrigerators have similar claims of improved efficiency (*e.g.* Australia, 2006; EuP, 2009). This success story needs to be tempered

[8] See *http://eetd.lbl.gov/clasp*.

by the reality that this product, among the most-traded consumer appliances in the world, is still subject to very different test methods in almost every regional market, including Europe, North America, Japan, China, Korea and Australia. Also, the product is still subject to a diverse range of regulatory performance requirements and test protocols.

Figure 1: US domestic refrigerator average efficiency improvement, 1960-2005



Source: Lawrence Berkley National Laboratory.

Several countries have implemented, or are exploring, incentive programmes for energy-efficient appliances. Co-ordinating incentives and aligning standards could create unprecedented economies of scale for these appliances.

Substantial energy savings

Global market transformation could yield very substantial energy savings and reductions in greenhouse gas emissions. Several global models already exist which attempt to estimate these benefits; they take into account average current efficiencies of products, new technologies, and expected market developments such as growth in product ownership. Analysis conducted by the Lawrence Berkeley National Laboratory (LBNL) for the Collaborative Labelling and Standards Program (CLASP) indicates that the savings potential is very large, as quantified in the table below, if all countries would move to comparable minimum performance levels for products (Klinckenberg *et al.,* 2009).

Table 1: Energy-efficient appliance emission mitigation potential, Mt CO_2 (cumulative, compared to 2007 baseline)

	2020	**2030**
Domestic cold	128	303
Domestic wet	32	63
Televisions	134	251
Domestic lighting	125	292
Consumer electronics	79	192
Domestic cooking electricity	15	30
Domestic boiler electricity	53	108
Domestic water heating electricity	12	137
Domestic air-conditioning	11	74
Domestic boilers, fuel	43	110
Domestic water heating, fuel	7	21
Total	**639**	**1581**

Source: Klinckenberg *et al.,* 2009.

Resource savings

A global co-operation approach has resourcing advantages compared with time-intensive national approaches, in which each individual government develops its own unique scheme without leveraging other governments' analyses and experiences. The case studies summarised below (and expanded in Annex A) resulted in global market transformations that achieved important benefits with relatively little financial and human resources. Annex A includes four case studies that showcase the capacity for global co-operation between governments in a range of energy-efficient products, including:

- **Industrial motors:** electric motor systems account for nearly half of worldwide electricity use and have large energy savings potential. Testing, voluntary labelling, education and consumer and vendor incentive efforts began in Canada in 1998. Minimum efficiency performance standards followed in Canada and the United States in the mid-1990s, and have now been adopted in many major economies. While there was consideration of overseas developments in many countries, international co-ordination was mostly informal and occurred without high-level political endorsement. As a result, the spread of higher standards from one country to another was delayed (for example, European standards did not become effective until 2009). The International Electrochemical Commission adoption (in 2008) of a new specification unifying the many regional standards provides a common foundation for future international co-ordination efforts.
- **Televisions:** in 2000, television energy use began to increase significantly due to the introduction of new large-screen technologies. In 2005, experts recognised the need to develop an internationally accepted energy-use test procedure covering all television display technologies. Today, three national regulatory and one voluntary scheme have adopted a common efficiency test protocol. Although the use of common protocols enables

easier comparison of these requirements, subsequent performance requirements have not been well-coordinated.

- **External power supplies (EPS):** external power supplies are used for many electronic devices and are fundamental to modern lifestyles. Unfortunately, they are often very inefficient; in many cases, about half of the electricity that flows through these devices is consumed by the power supply itself. Recognising the international nature of the power supply market, the United States, China and Australia began in 2003 to develop a harmonised test protocol, marking protocol and ranking system, which has subsequently been adopted in many countries. In Europe, the EU Code of Conduct based on this system is expected to slow the growth of EPS energy consumption by about 30%.
- **Compact fluorescent lamps (CFLs):** though first introduced in the 1970s and offering about 75% energy savings over incandescent lights, CFLs struggled for two decades with uneven quality and inconsistent test methods, performance specifications, and compliance and verification schemes. Since the 1990s, CFLs have become a global success story, as governments grew the CFL market through educational campaigns, bulk procurement and other incentives coupled with performance criteria. In 2009, over 4 billion CFLs were manufactured worldwide; uptake is expected to continue to grow, facilitated by the phase-out of incandescent lamps in many countries, along with an international test methodology, performance specifications, test facility benchmarking and compliance mechanisms developed by the Compact Fluorescent Lighting Initiative. International experience with CFLs yields several valuable lessons regarding quality assurance and market transformation that may prove particularly salient for the emerging market for solid-state lighting.

The television case study shows how experts (tasked and funded by a small number of motivated major economies) can deliver a test method suitable for global alignment. The governments involved were able to avoid multiple regulatory debates that result in different stringency levels in the three regional markets discussed. They were also able to preserve their sovereign right to determine the best set of cost-effective activities for their own national jurisdiction.

International trade considerations and the existence of global markets create new market barriers when each country independently implements its own energy-efficient product policies and standards. Mass-manufactured products often do not differ much across countries, irrespective of national efficiency schemes. The Compact Fluorescent Lighting (CFL) Initiative found 32 different schemes addressing efficiency globally, even though 80% of CFLs are produced in mainland China and 10% manufactured in Chinese Taipei (CFLI, 2008). New national efficiency schemes should therefore take account of existing efforts so the market transformation strategy works effectively within an increasingly global market for energy-efficient products.

The World Trade Organisation (WTO) recognises the capacity of national schemes to become unintentional trade barriers and has developed reporting mechanisms to avoid this outcome. The reporting requirements are intended to ensure that national programme managers are familiar with relevant overseas schemes. National schemes based on international principles like harmonised test methods and aligned performance levels do not attract WTO scrutiny. Governments are still able to justify efficiency variations based on environmental and climatic grounds for their national schemes. The WTO rules aim to lessen the risk of national variations being caused by a lack of awareness about similar schemes.

Options and priorities for global co-operation

Future global co-operation could take several practical forms including major economies taking action on one or more of the products discussed below. Additionally, financial incentives offer significant prospects for global co-operation. For example, governments could encourage utilities to treat energy efficiency programmes on a similar scale to new generation capacity. Similarly, major economies and utilities could explore incentive options for financing accelerated deployment of early-stage, energy-efficient products to bring down costs, remove barriers and catalyse private investment. One option is to agree on a co-ordinated set of incentives for manufacturers of internationally traded high-efficiency appliances. Countries could also explore developing common educational materials or co-ordinating financial incentives to maximise their impact and reduce programme costs. Co-operation should involve, where applicable, international agencies such as the International Electrotechnical Commission (IEC), the International Organisation for Standards (ISO) and the IEA. These international organisations can assist by highlighting emerging priority areas for further co-operation.

Major economies can take a leadership role in promoting global co-operation to achieve energy-efficient equipment in several areas, including:

1. **Domestic cold appliances:** energy demand for cold appliances is projected to more than double between 2005 and 2030, with more than half the increase in China and South Asia. Refrigerators are essentially the same globally, but there are design differences by region (the most notable being frost-free versus direct cooling). Elements of system design (such as internal temperature balance) are likely driven by test standard requirements. Potential exists for global harmonisation of test standards, but so do several barriers; the most significant being the development of a new, globally relevant methodology that takes into account climate and consumer usage.
2. **Domestic lighting**: energy demand for domestic lighting is projected to double between 2005 and 2030, with broadly similar increases in every region of the world. Lighting products are globally manufactured and traded, with very small regional differences. Minimum performance standards already exist in almost all major economies. International collaboration should focus on aligning test standards and minimum performance standards for LEDs and developing standards for ballasts and CFLs.
3. **Televisions**: energy demand for televisions is projected to quadruple between 2005 and 2030, with large increases in all regions, especially Sub-Saharan Africa and South Asia. While televisions tend towards the same technology globally, there has been a major transformation in the market over the past five years from CRT technology to flat screens (mostly LCD and some plasma). A rapid increase in screen size in most markets has led to increased energy consumption. Subsequently, it has been necessary to develop a new global test standard. There is also a lack of regulation for televisions; this needs to be addressed.
4. **Electric motors**: energy demand for electric motor systems is projected to double between 2005 and 2030, with similar increases in all regions. A globally harmonised test method is available, but older test methods are still widely used. Future work should focus on systematically phasing out older test methods. Minimum performance standards are also in place in most major economies; these may need to be reviewed.
5. **Air conditioners**: residential air conditioners are an increasing source of electricity demand, with demand projected to increase by a factor of six between 2005 and 2030. Air conditioners present a threat to electricity supply security in days of extreme weather.

Sharing experiences of predicting and managing rapid increases in air-conditioning demand will lead to improved decision making and more effective demand-side management. There are existing test protocols and certification schemes that could be modified to cover residential and commercial air conditioners for all climate zones.

6. **Network standby power**: standby power has been an issue of concern for more than a decade. A range of policies have been developed to address the issue of excessive standby power demand. However, products are becoming increasingly complex; many have now dramatically increased functionality, both in "on" modes (primary function active) and "low power" modes (only secondary functions or no functions are active). The range of products now connected to networks is growing rapidly, with a proliferation of wired and wireless technologies to connect products. Co-ordinated policies are needed to address this growing global problem of standby power demand.

The following table outlines the tasks required to address each area of action outlined above.

Table 2: Energy efficiency global market transformation tasks

	Work task
1. **Domestic cold appliances**	
	• Initial focus on assisting the development of a new global test procedure • Provide assistance to countries adopting suitable minimum performance standards for cold products • Provide assistance for countries with existing labelling and standards programmes to migrate to the new global test method
2. **Domestic lighting**	
	• Globally align test standards and minimum performance standards for LEDs • Develop suitable standards for ballasts and CFLs, and improved application of non-energy quality aspects of lighting
3. **Televisions**	
	• Discuss and align global minimum performance standard and labelling initiatives for televisions, now that the global test method is finalised
4. **Electric motors**	
	• Align minimum performance requirements and label categories, based on the new test standard • Focus on programmes that relate to system design and performance (upstream and downstream of the installed motor)

5. **Air conditioners**	
	• Harmonise domestic air conditioner standards using the established ISO test method focusing on seasonal energy efficiency rating schemes • Consider aligning the North American and European certification schemes for commercial air conditioners
6. **Network standby power**	
	• Build on existing standby power efforts to cover appliances when connected to the internet and other communication systems • Ensure IEC standards are effective for measuring and controlling network-connected appliances

Part 2: Clean energy vehicles: market transformation options

Introduction

As shown in the recently published IEA *Energy Technology Perspectives 2010 (ETP 2010)* (IEA, 2010), a business-as-usual approach to transport between 2007 and 2050 will result in roughly a doubling of both fuel use – to about 4 000 million tonnes of oil equivalent (Mtoe). On a well-to-wheels basis, this will correspond with a doubling of CO_2 emissions to about 16 gigatonnes of CO_2-equivalent (Gt CO_2-eq). The ETP Baseline Scenario is driven primarily by increases in passenger light-duty vehicles (LDVs), freight trucking and aviation. It assumes no significant uptake of advanced vehicles or propulsion systems such as electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs) or hydrogen fuel cell vehicles. It also assumes no tightening of fuel economy standards beyond those policies already in place.

It is possible to reverse this trend and reduce fossil fuel use and transport-based CO_2 emissions well below today's levels by 2050, primarily by shifting to more efficient vehicles and to advanced technology vehicles with new propulsion systems and fuels. A 50% cut in energy use per kilometre is possible in most countries, even for conventional internal combustion engines (ICE) on gasoline vehicles.

Other transformations and transitions can also advance sustainable transport. One option is shifting fuel use to those types of biofuels that provide low net greenhouse gas emissions without damaging ecosystems or threatening food security. Another important transformation is implementing more sustainable configurations of cities and transport systems (IEA, 2010).

Fuel economy represents an area in which key transformations have already begun but must continue over the next 20 years to reach sustainability targets. Uptake of EVs/PHEVs is just beginning but will be critical to these aims.

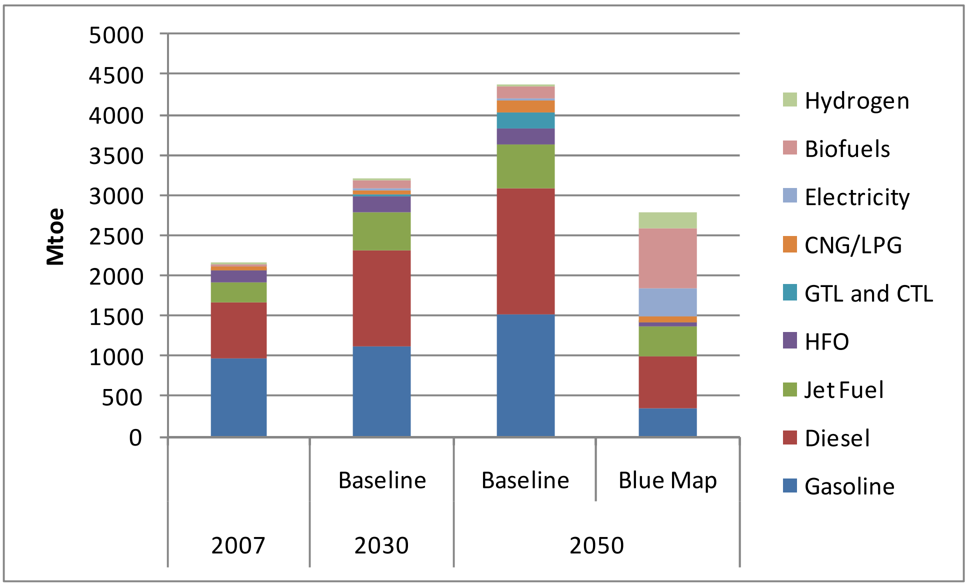
Major economies are well positioned to lead these transformations provided that they take aggressive, consistent actions. Greater international co-ordination and joint planning of infrastructure and market development are vital.

ETP 2010 low-carbon transport scenarios

In the ETP BLUE Map Scenario, total transport fuel use rises much more slowly than in the other scenarios, reaching about 30% above 2007 levels by 2050. Very low-carbon fuels such as biofuels, electricity and hydrogen provide about half of all transport fuel use in that year. This results in about 1 500 Mtoe of fossil fuel use and just over 6 Gt CO_2-eq emissions in 2050, nearly 10 Gt (60%) below the Baseline Scenario and nearly 20% below 2005 levels. The BLUE Map achieves this outcome for transport through rapid deployment and mass adoption of new technologies and fuels, and through the implementation of strong policies to support these changes. Fuel economy improvements and the adoption of PHEVs (battery electric and plug-in hybrids) also play critical roles. The Baseline and BLUE Map energy use results are shown in

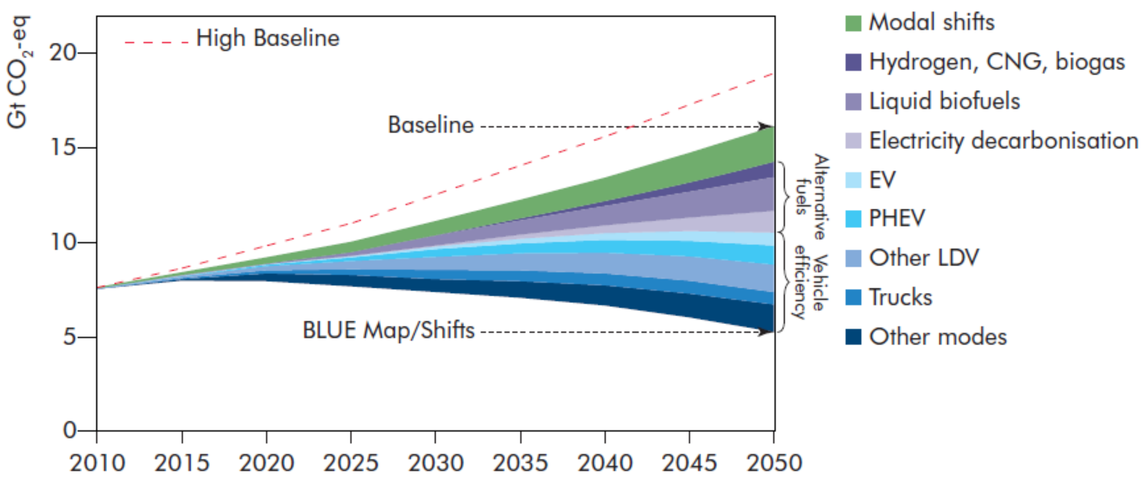
Figure 2; the share of greenhouse gas reductions from these and other sources is shown in Figure 3.

Figure 2: IEA transport energy use in *ETP 2010* scenarios



Note: By 2050 in the BLUE Map Scenario, electricity, hydrogen and biofuels have low life-cycle emissions.

Figure 3: Transport greenhouse gas reductions by source



Note: This figure includes CO_2 reductions from modal shifts included in the related BLUE Shifts Scenario, a supplementary scenario to BLUE Map, as described in *ETP 2010*.

The ETP BLUE Map Scenario explores measures to cut oil use, including an ongoing tightening of standards to reach a 50% reduction in LDV stock-average fuel intensity between 2005 and 2050 (and by 2030 for new vehicles). Fuel economy improvements across all vehicle types (including ships and aircraft) account for more than half of the total oil savings in BLUE Map, *i.e.* half of the 2.5 billion tonnes of oil (50 mb/d) saved in 2050. Vehicle efficiency also plays a key role in reducing the cost of oil in BLUE Map to USD 70/barrel in 2050 compared to the projected USD 120/barrel in the Baseline Scenario (IEA, 2010).

Fuel economy improvements

Vehicle fuel economy can be substantially improved over the next 20 years and beyond. The Global Fuel Economy Initiative (GFEI), for example, targets a global 50% reduction in new car fuel intensity compared to 2005 levels by 2030, based on an assessment of technical potential (GFEI, 2009).

Even though manufacturers have adopted many new technologies, very little progress on fuel economy was made throughout the world in the past two decades (especially in the late 1980s and throughout the 1990s). Instead, the new technologies were used to maintain existing fuel economy levels while allowing for increases in vehicle size, weight and power. Fuel economy standards in the United States rapidly ramped up between 1978 and 1985 – showing that it was possible to achieve rapid improvements in fuel economy. These standards, however, have not changed significantly in the past 25 years.

In contrast, significant changes and new strategies to promote fuel economy have occurred since the mid-1990s in both Europe and Japan.

In the **European Union** in the late 1990s, the three major European auto manufacturing groups (ACEA, JAMA and KAMA) made voluntary commitments to achieve a 25% improvement in fuel economy between 1995 and 2008 (IEA, 2009). Steady progress over several years allowed European manufacturers to hit their interim targets, but the pace of improvement needed to reach the 2008 target began falling behind after 2003. Dieselisation of the vehicle fleet, which accounted for a large share of the initial fuel economy improvements, had reached high levels in many European countries, creating a need for new strategies and technology approaches. But manufacturers did not adopt these quickly enough and trends toward larger, heavier vehicles continued to offset much of the technology uptake.

In 2005, the European Union concluded that the voluntary system was not likely to reach its targets and moved to adopt a mandatory system. This system, finalised in 2007, uses a linear function to relate required fuel economy levels to vehicle weight, with heavier vehicles facing a less stringent requirement. The system uses units of CO_2 emissions per kilometre as the metric. Based on the European Union's expected future sales mix of passenger LDVs, the requirement is consistent with achieving 135 g/km by 2015, compared to 154 g/km in 2008.

Japan adopted an approach called "Top Runner" (Box 1), which resulted in strong fuel economy improvements over the past 15 years (Figure 4).

Adoption these approaches has placed Japan and Europe at the forefront of fuel economy improvements. As their standards are in place through 2015, they will continue to have significantly more efficient vehicles than most other countries and regions – and indeed to continue improving on advances already achieved.

Box 1: Japan's Top Runner Programme

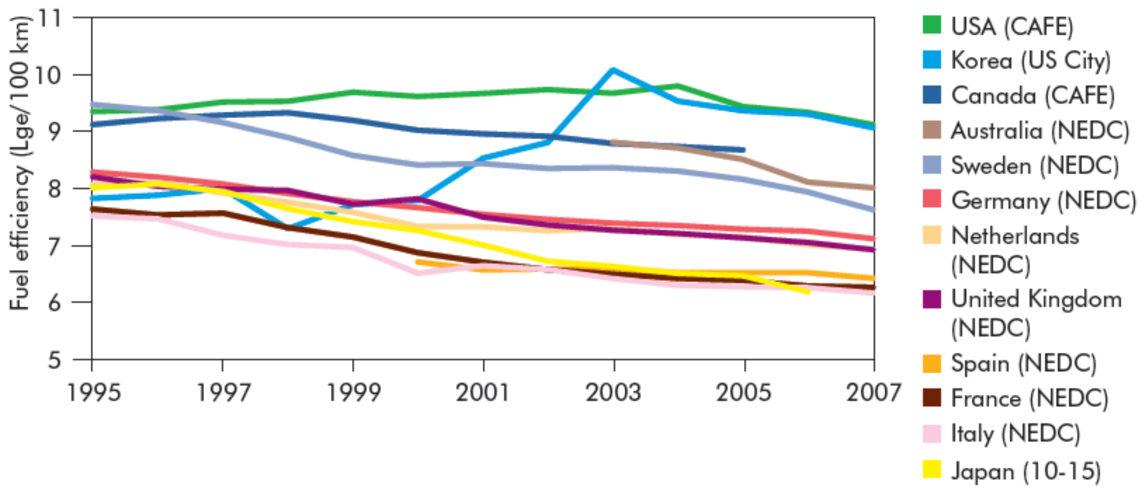
The Japanese government set its fuel efficiency targets in 1999 by reference to the best-performing vehicles in the national market, the "Top Runners." Initially, standards were limited to gasoline- and diesel-powered LDVs, and were effective until 2010. Subsequent standards were introduced for other vehicle types, such as LPG vehicles (2003) and for trucks (2006), with penalties taking effect in 2010 and 2015, respectively. Japan's truck standards are the first in the world to cover this type of vehicle. The resulting system of regulation covers virtually all types of road vehicles in the country (MLIT, 2007).

In 2007, the government published updated Top Runner fuel efficiency standards for LDVs to reach in 2015. Target levels are based on the most fuel-efficient vehicles in each of 16 different weight classes, and are used to set targets that an average of all cars sold by a manufacturer within a given weight class must meet.

Recent trends and targets

The Japanese and European initiatives clearly changed the course of fuel economy trends in their countries and have helped give impetus to other nations (Figure 4). Within the past four years, the United States, Canada, Korea and China have adopted or significantly tightened LDV fuel economy regulations, putting OECD countries back on track towards the GFEI 50% reduction target, which was endorsed by countries of the Major Economies Forum (MEF, 2009).

Figure 4: New light-duty vehicle fuel economy trends in selected countries



Notes: US City, CAFE, NEDC and 10-15 are acronyms refering to different test cycles that are not directly comparable.
Source: IEA Mobility Model database.

In the **United States**, the Obama Administration recently finalised a rulemaking on fuel economy standard for new cars and light-trucks, which is expected to increase miles per gallon (MPG) by about 25% to 35.5 MPG by model year 2016. This puts the United States on an aggressive fuel intensity improvement track (*e.g.* litres (L)/100km), equal to or even exceeding the pace set by other OECD countries, though starting from a higher fuel intensity level. The Administration estimates that this will save the equivalent of 1.8 billion barrels of oil. It has also launched a process to develop efficiency standards for heavy-duty vehicles (freight trucks), which no other country except Japan has implemented to date.

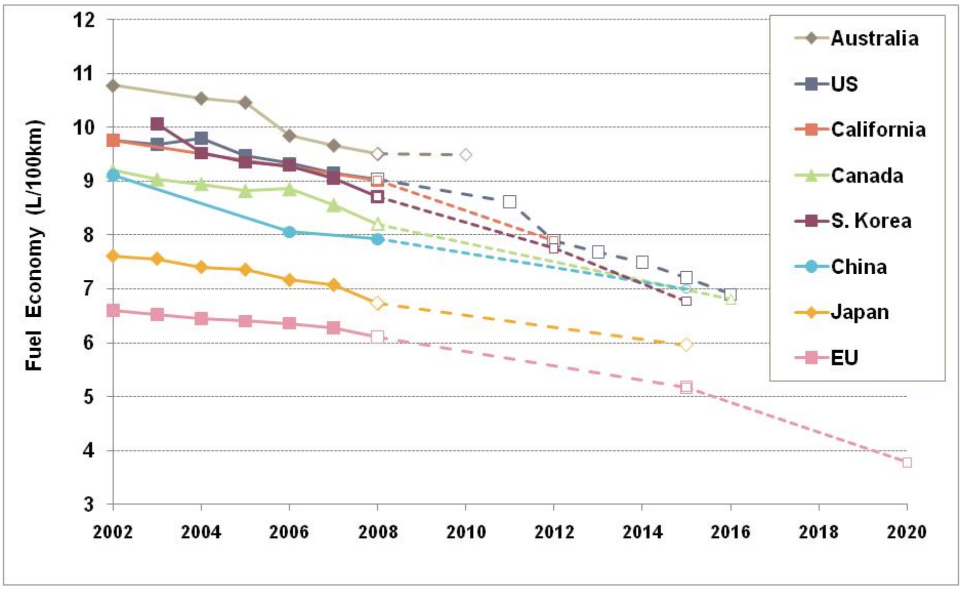
China imposed fuel economy standards in 2005 on LDVs, using a system that sets a minimum fuel economy for each weight class. The 2005 standards affected few vehicles because the targets for smaller vehicles were set above 8 L/100 km for automatic transmission vehicles and at over 11 L/100 km for 1 500 kg curb-weight vehicles. The standards for 2008 were tightened by 1 L/100 km for the lightest vehicles and by almost 2 L/100 km for heavier vehicles. Standards will be made more stringent in 2012. The Chinese government has taken two steps to curb the trend toward larger and more powerful vehicles. First, it imposed more stringent fuel economy standards for heavier vehicles than for lighter vehicles. Second, it lowered the tax rate (from 3% to 1%) on vehicles with engines smaller than 1.6 L displacement while increasing taxes (from 15% to 25%) on vehicles with engines over 3 L.

Adopting and tightening fuel economy standards the world's two largest car markets – the United States and China – will save billions of barrels of oil and billions of tonnes of CO_2 over the next 20 years. Recent cost/benefit studies conducted by the IEA and others show that in all countries adopting standards, drivers will benefit from substantial fuel cost savings, which will likely pay for most or all of the costs of the improved technology (IEA, 2009 and 2010; Bandivadekar *et al.,* 2008).

Figure 5 shows a market transformation in progress – a new direction for fuel economy and a path toward much more efficient vehicles, in contrast to the stagnation that prevailed in recent decades. The fuel economy standards shown in Figure 5 will save around 2 mb/d of oil in 2020 and a total of 3 billion barrels between 2010 and 2020. Further, fuel economy in OECD countries is now on track towards the GFEI target of a 50% reduction in new car fuel intensity by 2030, which the IEA considers a key part of achieving a low-carbon future for transport. However, in order to reach this target and maximise oil savings and CO_2 reduction, four key actions are necessary:

- OECD countries must continue to tighten fuel economy standards, and must complement the targets with tax policies to spur demand for more efficient vehicles.
- Beyond China, more non-OECD countries must begin to adopt bold fuel economy policies. Large markets such as India and Brazil would benefit from adopting standards; smaller markets and vehicle-importing countries may find it more appropriate to introduce tax incentives based on metrics such as fuel economy or CO_2 emission.
- All countries must work to ensure that actual on-road fuel efficiency improvements match those in tested fuel economy across the entire stock of vehicles. Key measures include promoting eco-driving, reducing traffic congestion and revising test procedures to more closely reflect real-world driving conditions.
- Standards and other efficiency measures are also needed for trucks, which account for up to half of road fuel use in some countries. To date, only Japan has developed fuel economy standards for trucks, though such standards are under development in the United States and the European Union.

Figure 5: Average fuel economy trends through 2008 by region, with enacted or proposed targets through 2020



Note: Fuel economy figures reflect each country's own test procedures. Solid lines show historical patterns; dashed lines show enacted standards; and dotted lines show proposed standards.
Source: ICCT, 2010.

Even as these first targets are being achieved, steps must be taken simultaneously to promote adoption of more advanced vehicle propulsion systems and fuels, in order to ensure even greater progress in cutting fuel intensity and CO_2 emissions, particularly after 2020. The next section covers this second market transformation.

Electric vehicles and plug-in hybrid vehicles

In light of the ETP Baseline Scenario projection, in which fuel use doubles worldwide by 2050, even a 50% reduction in the energy intensity of cars will only keep fuel use and CO_2 emissions roughly constant. Outright reductions in CO_2 will require turning to new fuels and new vehicle propulsion systems. Among these, perhaps the most promising technology over the next 20 to 40 years will be electric and/or plug-in electric vehicles (EVs/PHEVs).

Electric vehicles (EVs) will provide three important benefits: zero vehicle emissions of any kind; the possibility to run on an energy source that produces almost zero greenhouse gases; and continued efficiency gains compared to ICE vehicles. For example, highly efficient gasoline vehicles (probably hybridised) may achieve around 4 L/100 km of fuel economy (60 MPG); running on electricity and electric motors, currently available EVs can achieve 2 L/100 km of gasoline equivalent.

Plug-in hybrid vehicles (PHEVS) offer a compromise between pure EV and ICE vehicles, incorporating both systems. These vehicles are more complex than EVs and are likely to be somewhat less efficient, but they preserve the long driving range offered by ICEs and also offer the flexibility to use either electricity or liquid fuels.

Box 2: France's plan to launch EVs

In October 2009, the French government committed USD 2.2 billion (EUR 1.5 billion) to a 10-year plan to help put 2 million PHEVs on the road by 2020. The funds will help pay for:

- manufacturer and buyer subsidies, including purchase "bonuses" of up to EUR 5 000 to support consumers buying EVs;
- a nationwide network of more than 4 million EV charging stations, with 1 million by 2015; and
- funding for battery manufacturing and industrial research.

The plan also includes regulatory measures, such as requiring all new apartment developments in the country to install charging stations, beginning in 2012. It will also call for public and private tenders for fleets of EVs to generate demand, with a target for these fleets to account for 100 000 EVs by 2015.

The two major French car manufacturers, Renault and PSA Peugeot Citroën, have pledged to begin selling EVs in France by 2012.

The government has named an EV co-ordinator to liaise between ministries, and to work closely with cities, electric utilities, vehicle manufacturers and other stakeholders to co-ordinate all aspects of EV development.

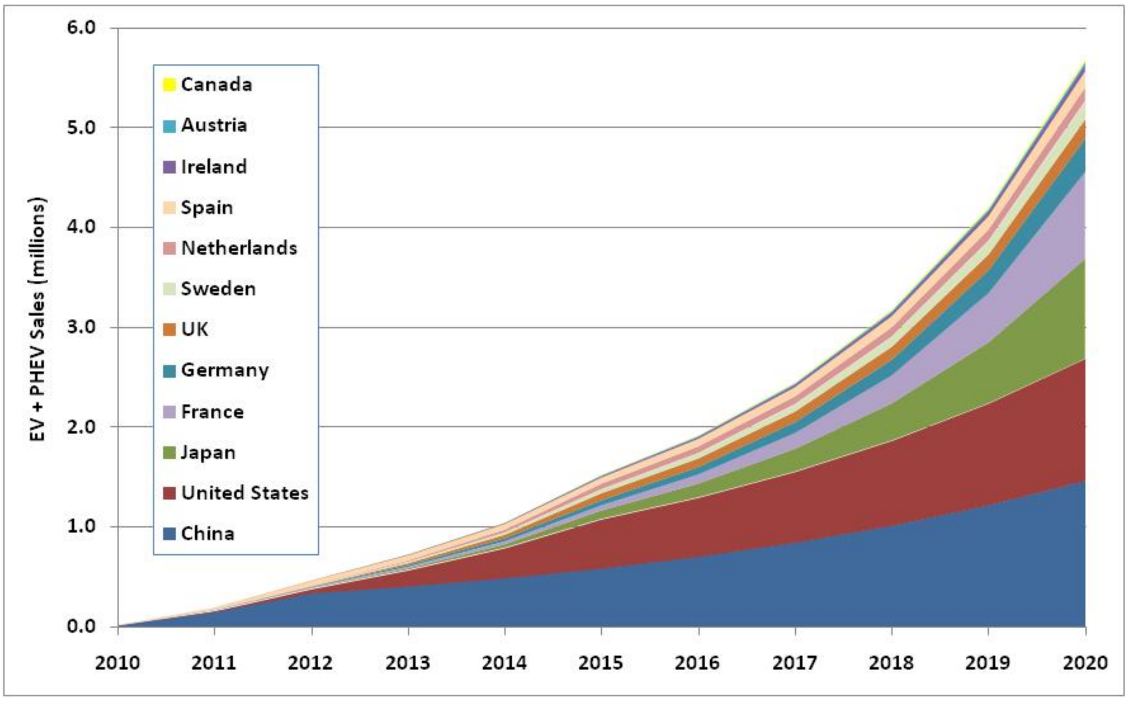
Source: French Ministry of Ecology press release, 1 October 2009, and news reports.

It will take considerable time and strong policies to bring EVs/PHEVs into the mainstream market, which is why efforts must begin now. Even with very aggressive increases in vehicle production and sales, it will likely be 10 years before these vehicles begin to approach a significant share of total sales within the OECD, and perhaps 20 years before they become a significant share of global vehicle stocks. This time frame provides a good opportunity to develop, implement and optimise many of the key technologies and systems that will support EVs/PHEVs in moving toward larger scales over the coming 5 to 10 years.

In 2009, the IEA published the *IEA Technology Roadmap: Electric and Plug-in Hybrid Electric Vehicles*, which charts a course for countries around the world to collectively adopt EVs/PHEVs, and ramp up sales on a path consistent with the ETP BLUE Map Scenario. By 2050, this roadmap envisions EVs/PHEVs reaching sales of over 100 million per year, or over 50% of total LDV vehicle sales globally. To meet this target, sales will need to be on the order of 30 million per year by 2030, and probably at least 5 million by 2020. Even this level will be quite challenging to reach, since it will require more than a doubling of EV/PHEV production each year over the next 10 years. In contrast, starting from 10 000 vehicles with a more modest 10% annual growth rate, it would require 65 years just to reach sales of 5 million.

The benefit of jump-starting EV/PHEV sales can be seen in terms of accumulating vehicle stocks and oil savings. Reaching sales of 5 million by 2020 results in about 20 million EV/PHEVs on the road on that year, with a relatively modest oil savings of 0.4 mb/d (one billion barrels saved over the decade). But with continued growth, by 2030 the numbers increase tenfold, reaching about 200 million EV/PHEVs on the road and around 3 mb/d of oil saved in that year. By 2050, over 1 billion EV/PHEVs on the road can save over 15 mb/d of oil. Reaching the target of 5 million sales over the next 10 years is the key to transforming the market in a way that enables much greater EV/PHEV deployment and more significant emission reduction impacts during the following decade and beyond. Therefore, reaching the target of 5 million also implies taking short-term large-scale action to establish needed infrastructure and reduce costs.

Figure 6: Projected EV/PHEV annual sales to 2020 based on announced country targets



Note: Compiled in June 2010, based on government announcements and news reports. For targets set and achieved before 2020 (*e.g.* China's target is for end of 2011), a 20% annual sales growth is assumed thereafter.

To achieve these ambitious targets, several actions will need to be pursued in the next 5 to 10 years:

By 2010-2012:

- limited production of most new EV/PHEV models, many as part of demonstration projects in key cities
- co-ordinated investments in private and public recharging infrastructure
- determination and harmonisation of key codes and standards
- substantial vehicle purchase incentives

By 2012-2015:

- application to programmes and policies of lessons learned during 2010-12
- introduction of more optimised vehicle designs and batteries that have benefited from experience and interim research
- increase in production runs toward commercial scale (tens of thousands per year for some models)
- continued purchase incentives
- application of some smart-grid concepts, such as differential metering and time-of-day pricing for recharging

By 2015-2020:

- rapid increases in EV/PHEV production, reaching 100 000+ per year for many models (*e.g.* sales of 5 million per year by 2020 could be achieved through sales of 100 000 units for 50 different models)
- as battery costs decline, a commensurate decline in vehicle purchase incentives and other government support

Together, these three phases lay out a process for rapid market transformation. Most major economies appear to be taking appropriate steps to initiate this market transformation; over the coming years, they must continue to update their policies and follow through on commitments.

Ensuring EVs/PHEVs are cost-competitive

For at least the next 5 to 10 years, the cost of EVs/PHEVs will likely be substantially higher than that of similar-sized ICE vehicles. Dramatic cost reductions for batteries will be needed to achieve full commercialisation of these vehicles, though for PHEVs, the cost of the hybrid system is also a significant factor. The IEA estimates that in the near term, batteries are likely to cost in the range of USD 600 per kilowatt-hour (kWh) to USD 800/kWh even at large volume. This means that for a 30 kWh EV/PHEV (typical to provide a range of 150 km), the batteries alone will cost USD 18 000 to USD 24 000 per vehicle. Through ongoing RD&D, deployment and learning by doing, this cost is expected to drop, with a target of USD 300/kWh (or less) around 2015 to 2020. This will help bring EV/PHEV battery costs down to less than USD 10 000 per vehicle.

The energy cost savings associated with EVs/PHEVs is likely to be in the range of USD 3 000 to USD 5 000 per vehicle; along with savings from removing the ICE system, this may pay for most of the battery costs over the vehicle life. In the near term, lifetime fuel cost savings will not come close to covering the higher costs of EV/PHEVs.

Several studies suggest that the target of USD 300/kWh will be attainable, but only if large-scale production (*e.g.* 100 000 units per year) can be achieved and cumulative production attains a much higher level. Increased production and learning is precisely what brought down the cost of small appliance lithium-ion (Li) batteries over the past 10 years.

Increased sales and production will, in turn, require incentives to attract sufficient buyers. The amount needed to spur demand is unclear, since few EVs/PHEVs have as yet reached the market. But if one assumes that consumers will not pay a net life-cycle cost premium for EVs/PHEVs, the market incentives in the near term may need to be on the order of USD 7 500 to USD 10 000 per car. This could be set on the basis of performance rather than technology, such as for vehicles with very low greenhouse gas emissions. Several countries are adopting this type of approach; while it appears sensible, policies must be carefully managed to avoid excessive costs. The subsidy will need to be reduced as battery and EV/PHEV costs drop, with a full phase-out of subsidies perhaps by 2020 as production volumes rise rapidly.

Over the next 10 years, the ETP BLUE Map Scenario includes worldwide sales of EVs/PHEVs that total about 10 million on a cumulative basis. At an average subsidy level of USD 5000 per car (reflecting a phase-down over time), this would cost USD 50 billion over 10 years across several countries. Despite seeming large, this amount is less than 1% of the USD 10 trillion or more that the world will spend on new LDVs over the next 10 years.

Co-ordination of infrastructure development

Specific actions will be needed over the next 5 to 10 years to ensure that recharging infrastructure is developed alongside the market uptake of EVs/PHEVs. These include:

- Ensuring that charging stations are available at reasonable cost for residential locations for EV/PHEV owners, and providing public recharging options for urban dwellers who do not have home recharging possibilities. This also involves co-ordination of investments in public and private retail recharging stations and, in some cases, direct provision of this infrastructure (especially in areas with a fairly high density of EVs/PHEVs).
- Co-ordinating the ramp up in EV/PHEV sales with recharging availability through collaboration by national governments, manufacturers and other stakeholders, and working closely with key cities.
- Ensuring common systems and standards for charging, at least within each country and preferably across regions. It will be critical to decide how and when to roll out fast-charging stations, which will provide important benefits but will be expensive and have potentially adverse impacts on electricity generation profiles. Managing the introduction of smart metering and vehicle-to-grid services will also be a critical area for co-ordination.
- Providing other types of support, such as information to the public, funding for RD&D projects, etc.

Table 3: Comparison of EV/PHEV-related policies in several countries

Country	Sales target	Fiscal incentives	Other comments
China	Production of 500 000 cars by end of 2011	Up to USD 8 800 per vehicle	Incentives available in 12 Chinese cities
France	Up to 2 million stock by 2020; 50 000 purchase order for government fleets	USD 6 300 (EUR 5 000) tax credit per vehicle	Total funding of USD 1.9 billion (EUR 1.5 billion) includes funding for four million recharging points by 2020, battery production
Japan	About 1 million sales by 2020 (based on 20% share of LDV sales target)	Up to USD 14 000 (JPY 1.3 million) per vehicle	Fiscal incentives can change frequently
Germany	1 million total stock by 2020	No direct incentives at this time	USD 350 million (EUR 285 million) for infrastructure development and battery R&D
Spain	250 000 sales by 2014	Up to USD 7 500 (EUR 6 000) per vehicle	Primary focus on Madrid, Barcelona, Seville
United Kingdom	1.5 million stock by 2020	Up to USD 7 500 (GBP 5 000) per vehicle	Total funding of USD 375 million (GBP 250 million) for low-carbon transport
United States	1 million total stock by 2015	Up to USD 7 500 per vehicle	US DOE providing R&D funding and grants of over USD 2 billion

Source: Government announcements and news reports.

Strong support is beginning in some countries (Table 3), but in the coming years it will be critical that major economies pay close attention to each of these aspects, while also working closely with other stakeholders trying to make progress in each area. Key stakeholders include city governments (which clearly play a critical role in co-ordinating developments in their cities), electric utilities, third-party providers of various goods and services, and automobile and parts (such as batteries) manufacturers. National governments are the focal point for ensuring co-ordination of all actors and activities.

Options and priorities for global co-operation

Across governments, considerable co-ordination efforts will also be needed over the next 5 to 10 years. The most important areas include:

Sharing R&D results and learning from demonstration projects and full-scale deployment. Each country will experience successes and failures in their efforts to ramp up EV/PHEV use and will learn important lessons that can benefit other countries. If all countries learn together, progress will be faster and more consistent around the world.

Co-ordination of planning and target setting. Governments have begun announcing sales and production targets, which create expectations on the part of vehicle and battery manufacturers, as well as international service providers. Each government needs to understand how their plans relate to those of other countries, and avoid any potential shortages or "choke points" that could result from lack of planning. One example is Lithium resources, which should be adequate to supply the needed Li-ion batteries over the next 10 to 20 years but may become scarce during periods when the global growth in demand outstrips growth in supply. Careful co-ordination and planning can hopefully avert this and other market distortions.

There is, accordingly, a strong need for greater international co-ordination and joint planning of infrastructure and market development. Tracking progress, sharing information and identifying successes (as well as failures) in a structured, ongoing fashion will become increasingly important over the next few years.

Major economies can play an important role in co-ordinating activities within their own borders and in terms of fostering international communication and co-ordination. More specifically:

For fuel economy, more efforts are needed to co-ordinate standards setting. Efforts to standardise fuel economy testing procedures would be helpful, as would making these test procedures more closely approximate actual on-road driving conditions. By moving toward more consistent approaches, the policies are likely to have a larger combined impact on manufacturer decisions about the types of vehicles to produce. This will also reduce the cost for manufacturers to meet the various policy requirements and targets.

Governments can also collaborate to develop programmes to encourage improved on-road fuel economy, including eco-driving education and traffic management systems such as those that support road-user charging.

For EVs/PHEVs, the co-ordination functions outlined above are important for countries with large markets for personal vehicles. Sharing information and findings from RD&D projects will be a key activity, as will co-ordination in R&D and in setting relevant codes and standards. Finally, governments should communicate all policies, plans and targets, as well as track progress using various agreed indicators. Global co-ordination initiatives will provide valuable opportunities to advance the dialogue and move forward.[9]

[9] See IEA's 2010 report for the Clean Energy Ministerial *Global Gaps in Clean Energy RD&D: Updates and Recommendations for International Collaboration* for more information on specific advanced vehicles opportunities.

Part 3: Transforming electricity generation through solar photovoltaics

Introduction

Photovoltaic (PV) devices allow the direct conversion of sunlight into electricity. PV is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions. At present, PV provides only around 0.1% of total global electricity generation; the costs of electricity from PV are still relatively high for most applications. However, recent dramatic cost reductions and effective supporting policies have led to rapid expansion in capacity. In its recent *IEA Technology Roadmap: Solar Photovoltaic Energy*, the IEA has projected that PV could provide as much as 5% of global electricity consumption in 2030, rising to 11% in 2050 (IEA, 2010a).

Achieving the market transformation necessary to support this level of PV electricity supply will require concerted and sustained policy support. But such efforts will also deliver associated environmental, economic and societal benefits. Effective and efficient incentive schemes must be sustained to help to increase installed capacity and stimulate the experiential learning that can drive down costs, thereby creating a virtuous cycle and bridging the gap to PV competitiveness. Financial incentives need to be complemented by measures to remove other barriers that may delay or restrict PV deployment as higher levels of penetration are achieved, *e.g.* constraints associated with grid compatibility. In addition, a long-term focus on technology development and improved co-ordination among national energy RD&D activities are needed to advance all types of PV technologies, including commercially available systems, and emerging and novel technologies.

ETP PV solar scenarios

According to the BLUE Map Scenario described in the IEA's *Energy Technology Perspectives 2010* (*ETP 2010)*, by 2050, solar power would provide 16% of annual global electricity production, including 7% from PV; the balance would come from concentrated solar power (CSP) (IEA, 2010b). In the Blue High Renewables (HiRen) variant, the share for renewables electricity is set at 75% in 2050, with solar power becoming the largest source of electricity generation, at 25% of supply equally split between PV and CSP. This scenario is broadly consistent with the results in the recent IEA Technology Roadmaps on PV and CSP, which indicate that PV and CSP could each provide around 11% of electricity supply by 2050 (IEA, 2010a; IEA, 2010c).

Overview of market opportunities for PV

Technology and status

PV systems directly convert solar energy into electricity. The basic building block of a PV system is the PV cell, a semi-conductor device that converts solar energy into direct-current (DC) electricity. PV cells are interconnected to form a PV module, typically ranging from 50 Watts (W) to 200 W. These PV modules are combined with a set of additional application-dependent system components (*e.g.* inverters, batteries, electrical components and mounting systems) to form a PV system. PV systems are highly modular and can be linked together to provide power ranging from a few watts to tens of megawatts (MW). Importantly, the individual components can be mass-produced. As the level of deployment rises, the scale of production plants for modules and other components can expand, which will help to reduce production costs.

A portfolio of PV technology options is being developed, with various options at different levels of maturity. Commercial PV modules may be divided into two broad categories: wafer-based crystalline silicon systems and thin films. Several newer technologies are emerging, including advanced thin films and organic solar cells, concentrating photovoltaics (CPV) and other novel concepts with significant potential for increased performance and reduced costs.

Box 3: PV technologies: an overview

Crystalline silicon (c-Si) modules represent 85% to 90% of the global annual market. They are divided into two main categories: *i)* single crystalline (sc-Si) and *ii)* multi-crystalline (mc-Si).

Thin films currently account for 10% to 15% of global PV module sales. They are subdivided into three main families: *i)* amorphous (a-Si) and micromorph silicon (a-Si/μc-Si); *ii)* Cadmium-Telluride (CdTe); and *iii)* Copper-Indium-Diselenide (CIS) and Copper-Indium-Gallium-Diselenide (CIGS).

Emerging technologies encompass advanced thin films and organic cells; the latter are about to enter the market via niche applications.

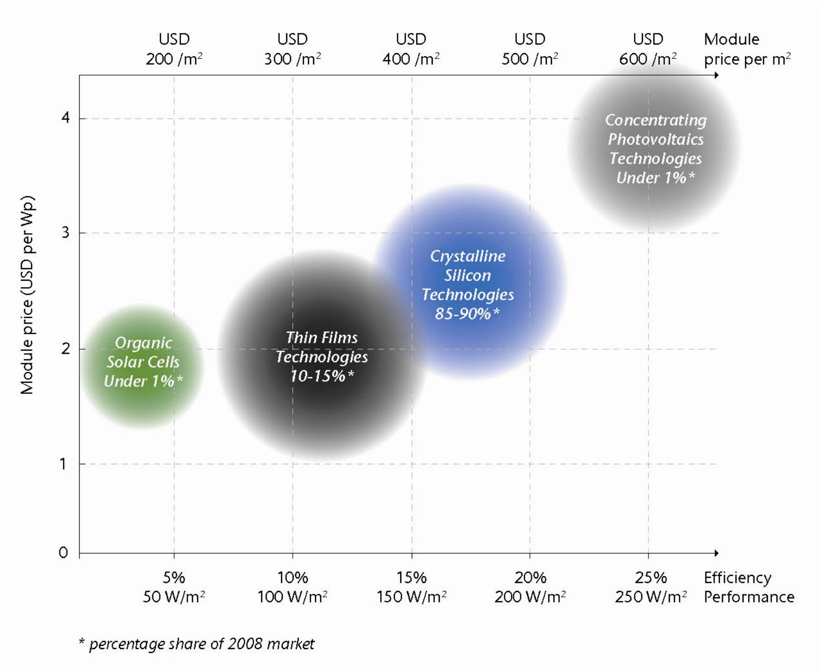
Concentrating PV technologies (CPV) use an optical concentrator system that focuses solar radiation onto a small high-efficiency cell. CPV technology is currently being tested in pilot applications.

Novel PV concepts aim to achieve ultra-high efficiency solar cells via advanced materials and new conversion concepts and processes. They are currently the subject of basic research.

Note: Detailed information on technologies can also be found on the website of the IEA Implementing Agreement for a Co-operative Programme on Photovoltaic Power Systems: *www.iea-pvps.org*.

The large variety of potential PV applications will allow a range of technologies to be present in the market, from low-cost, lower-efficiency technologies to high-cost, higher-efficiency technologies. Due to their lower conversion efficiency, the lower per-watt cost associated with the manufacture of some module technologies (*e.g.* thin films) is partially offset by the higher area-related system costs (for mounting and the required land) (Figure 7).

Figure 7: Overview of the cost and performance of different PV technologies



Note: All values refer to 2008.
Source: IEA, 2010a.

Sectors

PV technologies are suitable for four end-use sectors, each with distinct markets:

- **Residential systems** (up to 20 kW) on individual buildings/dwellings.
- **Commercial systems** (up to 1 MW) for commercial buildings, schools, hospitals and retail.
- **Utility-scale systems** (starting at 1 MW) mounted on buildings or directly on the ground.
- **Off-grid applications** (varying sizes) for various applications.

The various applications have different system costs and compete at different price levels. Until the mid-1990s, most systems were stand-alone, off-grid applications such as telecommunications units, remote communities and rural electricity supply. The number of grid-connected systems has since increased rapidly due to incentive schemes introduced in many countries; most grid-connected systems are installed as building-integrated systems (BIPV). More recently, ground-mounted large-scale installations (with generation capacity in the tens of megawatts) have gained a considerable market share. Off-grid PV systems now constitute less than 10% of the total PV market, but remain important in remote areas and in developing countries that lack electricity infrastructure.

Costs and prices

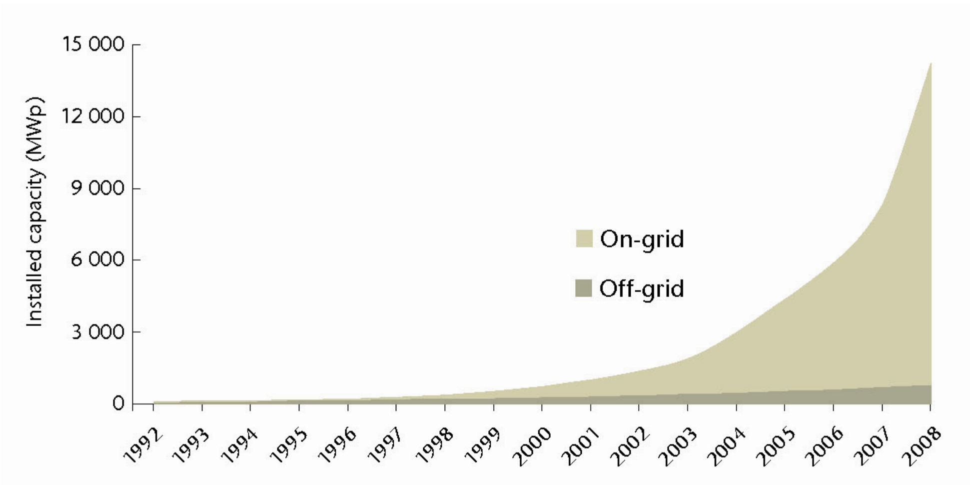
In 2008, typical turn-key prices for PV in leading market countries ranged from USD 4 000/kW for utility-scale, multi-megawatt applications to USD 6 000/kW for small-scale applications in the residential sector. The range of prices in IEA countries is larger, depending on local market maturity and circumstances.

Associated levelised electricity generation costs from PV systems depend heavily on two factors: the amount of yearly sunlight irradiation (and associated capacity factor) and the interest/discount rate. PV systems do not have moving parts, so operating and maintenance (O&M) costs are relatively low, estimated at around 1% of capital investment per year. Assuming an interest rate of 10%, the PV electricity generation costs in 2008 for utility-scale applications ranged from USD 240/MWh in locations with very high irradiation and a high capacity factor (2 000 kWh/kW, for a 23% capacity factor) to USD 480/MWh in sites with moderate or low irradiation (1 000 kWh/kW, a 11% capacity factor). The corresponding generation costs for residential PV systems ranged from USD 360/MWh to USD 720/MWh, depending on the relevant incident solar energy. While these residential system costs are very high, it should be noted that residential PV systems provide electricity at the distribution grid level. This allows them to compete with electricity grid retail prices rather than wholesale prices; grid prices can also be very high in several OECD countries.

Market growth

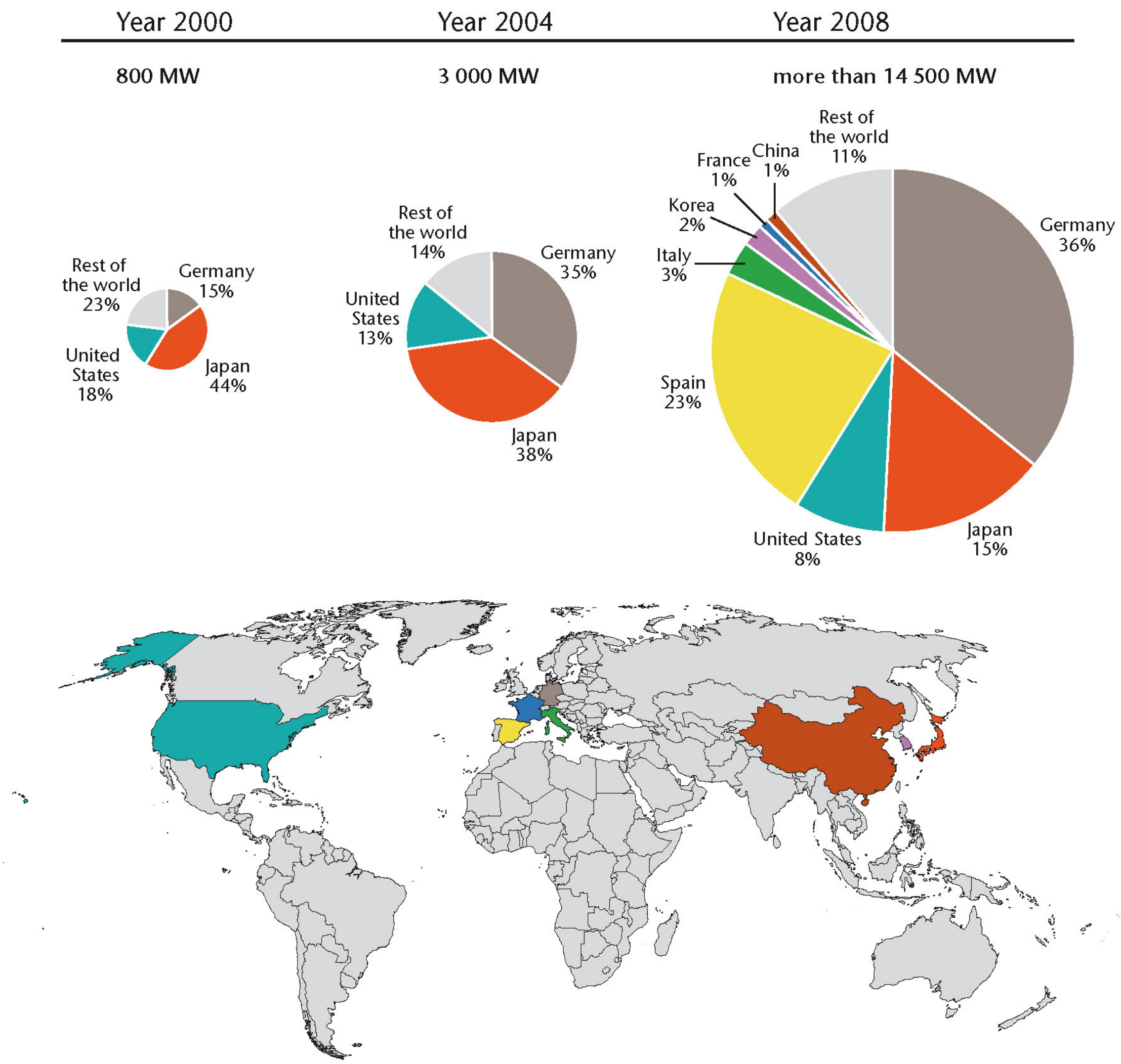
PV continues to be the fastest-growing power technology in the world. The global PV market has experienced a vibrant annual growth rate of 40% for more than a decade; cumulative installed PV power capacity has grown from 0.1 GW in 1992 to 14 GW in 2008. Annual worldwide installed new capacity increased to almost 6 GW in 2008 (Figure 8).

Figure 8: Global cumulative installed capacity of PV, 1992-2008



Source: IEA, 2010a.

Figure 9: Solar PV capacities in leading countries



Source: IEA, 2010a.

According to preliminary data from the PV industry, new additions in 2009 totalled more than 7.2 GW, bringing the total cumulative capacity installed up to almost 22 GW at the end of 2009. In addition to this exponential growth, the other important signal for market transformation is the geographical spread of PV. Until 2006, PV was concentrated in three countries: Germany, Japan and the United States. Other countries now play an increasing role, including Spain, Italy and the Czech Republic (Figure 9).

Although domestic use of PV remains relatively limited, China is the world's largest PV manufacturer. The geographical expansion of the PV market has been driven by the implementation of strong support policies in an increasing number of countries including Australia, France, Greece, India, Korea, Portugal, Thailand and the United Kingdom.

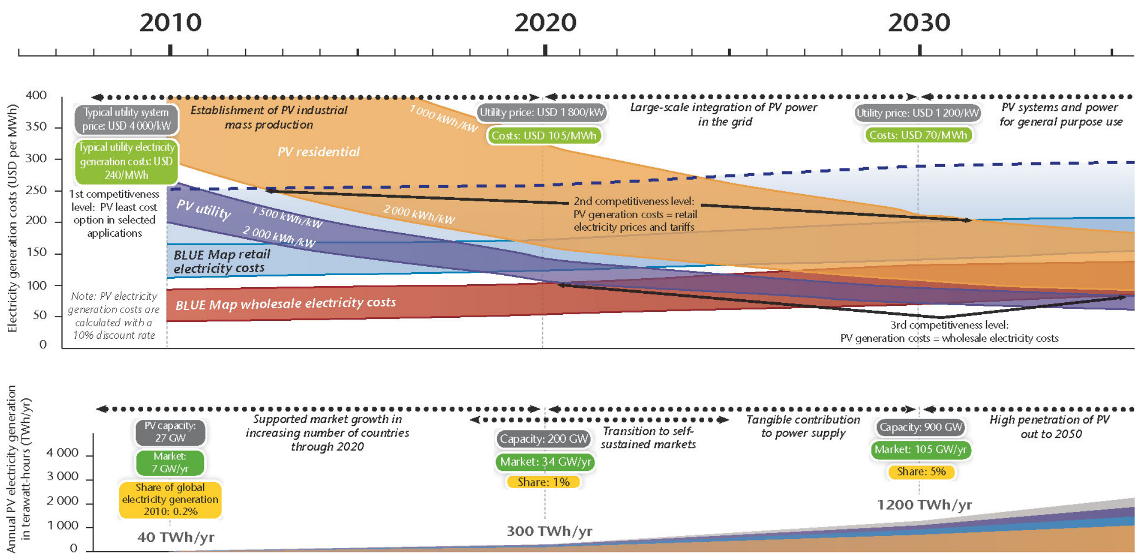
IEA projections for potential growth in PV

The recently published *IEA Technology Roadmap: Solar Photovoltaic* concludes that future market growth could be higher than anticipated in earlier studies, based on recent market growth rates (Figure 8) and associated cost reductions. The global PV market more than doubled between 2007 and 2008, while system prices fell 40% between 2008 and 2009. This acceleration in the deployment of PV has been triggered by the adoption of PV incentive schemes in several countries.

The roadmap assumes an average annual market growth rate of 17% in the next decade, leading to a global cumulative installed PV power capacity of 200 GW by 2020. This growth will be facilitated in part by policy incentives (such as feed-in tariffs) that support the deployment and decrease overall costs of PV. It should be noted that this capacity value is significantly lower than industry goals. For example, the European Strategic Energy Technology (SET) Plan[10] projects 400 GW installed in Europe by 2020, and an indicative target of 700 GW by 2030.

With such policy support, this roadmap envisions that PV will achieve grid parity (*i.e.* competitiveness with electricity grid retail prices) in many countries by 2020. Parity is expected to be first achieved in countries and regions with high solar irradiation and high retail electricity costs, such as in Italy and California (Figure 10).

Figure 10: PV market deployment and competitiveness levels



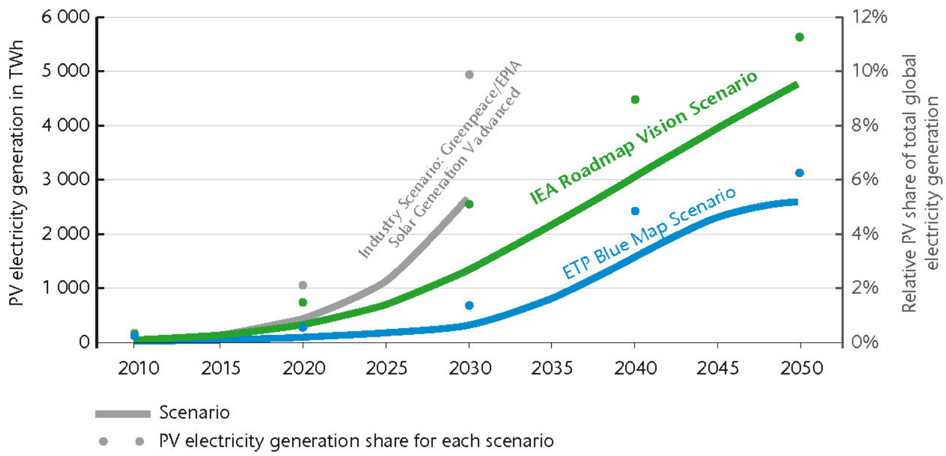
Source: IEA, 2010a.

The roadmap assumes the continuation of an evolving, favourable and balanced policy framework for technology development and market deployment in many countries over the longer term. Accelerated deployment and market growth will, in turn, prompt further cost reductions from economies of scale, significantly improving the relative competitiveness of PV by 2020 and spurring additional market growth. From 2020 to 2030, an average annual market growth rate of 11% is assumed, bringing global cumulative installed PV capacity to about 900 GW by 2030. At this time, the annual market volume of new installed capacity would be

[10] See http://europa.eu/legislation_summaries/energy/european_energy_policy/l27079_en.htm.

over 100 GW/yr. The total cumulative installed PV capacity is predicted to reach 2 000 GW by 2040 and 3 000 GW by 2050, generating 4500 TWh/yr – approximately 11% of expected global electricity supply (Figure 11).

Figure 11: Global PV power generation and relative share of total electricity generation



Note: The share of total electricity generation is calculated with the projected world electricity generation of the ETP BLUE Map Scenario (42 300 TWh in 2050).
Source: IEA, 2010a.

PV as a key market transformation area

Deploying PV requires strong, consistent and balanced policy support. The five main areas of policy intervention include:

- creating a policy framework for market deployment, including tailored incentive schemes to accelerate market competitiveness and remove barriers to deployment;
- ensuring grid access for PV- generated electricity and developing smart grids to optimise the integration of distributed generation systems;
- fostering market facilitation and transformation by establishing standards and developing novel financing models, and through supporting training and education;
- supporting continuing technology development and sustained R&D efforts to advance the cost and efficiency improvements outlined above;
- improving international collaboration to allow for accelerated learning and knowledge transfer to emerging and developing countries.

Policy frameworks

In order to justify the high capital investments for PV installations and manufacturing plants, potential users and industry require clear and long-term signals that markets will develop and that adequate returns on investments can be reasonably assured. To effectively stimulate such markets, major economies should establish long-term PV targets and commit to predictable financial incentive schemes that facilitate market introduction and deployment until costs decrease and grid parity is achieved. These should be complemented by appropriate framework conditions such as access to grids and incentives such as feed-in-tariffs, feed-in-premiums, tradable certificate schemes, portfolio standards, fiscal incentives or investment subsidies.

To ensure efficient use of funds, these programme support schemes must be designed specifically to the characteristics and relative costs of PV (rather than being technology-neutral). The levels of support should be reviewed in a transparent way and with a clear timetable, with the aim of reducing support levels steadily over time to foster innovation and cost reduction in PV technology, and to avoid over-rewarding investors. In order to manage this process effectively, governments and regulators must be well informed and participate actively in market development for PV products. As PV reaches grid parity, economic incentive schemes will be able to evolve towards a market-enabling framework based on net metering and priority access to the grid.

Providing economic support alone, however, is not enough. Non-economic barriers can significantly hamper the effectiveness of support policies. Administrative hurdles such as planning delays and restrictions, lack of co-ordination between different authorities, and long lead times in obtaining authorisations and connection to the grid are key barriers for PV deployment. Governments should address administrative barriers by ensuring coherence and co-ordination among different authorities, and by implementing time-effective and streamlined administrative authorisation procedures for PV systems.

Grid access and smart-grid development

Given its variable, non-dispatchable nature in distributed applications, PV presents new challenges for grid integration. In most areas of the world, PV currently represents less than 1% of electricity generation and can be absorbed by existing grids without any problems. With a larger number of PV systems in place, grid accessibility and integration will become increasingly challenging. In fact, if not properly addressed in the short term, grid integration problems may prevent PV from achieving its maximum potential. Better grid planning and management can unlock opportunities for PV to meet existing electricity demand. Because both solar energy supply and electricity demand are highest during the summer, PV can reduce critical summer load peaks in some regions, thereby lowering the need for high-cost peak generation capacity and for new transmission and distribution investments.

To accommodate an increasing share of variable PV, transmission and distribution systems will need to become more flexible, which requires new ways of thinking about how electricity is generated and distributed. Flexibility can be increased through both market and transmission optimisation measures. Market measures include broadening markets to smooth overall variability and implementing demand response measures that better match demand with supply. Transmission optimisation measures include improved interconnection and adoption of advanced transmission and management technologies, including smart grids, metering and enhanced energy storage.

Smart grids can provide many benefits to both end-users and generators. Importantly, they can facilitate PV deployment by making it possible to monitor and manage the bi-directional transport of electricity in a way that accommodates the variable, non-dispatchable nature of PV. Using digital technology, smart grids will enable the control of conventional generation along with demand-side management that responds to the variable generation of PV. They also support seamless implementation of storage technology that can act as a load in times of excess generation relative to demand and as an electricity generation source when demand is greater. Smart grids can also process real-time meteorological data to predict PV system output, enabling it to be managed more like dispatchable generation.

The generation profile of PV can be combined with system design aspects of smart grids as new electricity grids are built and existing grids are maintained. PV produces most of its electricity during the summer, reasonably aligning with the seasonal daily peak demand for electricity. The ability of smart grids to monitor and manage electricity flow at nodes will allow for more accurate system sizing and needs assessment. This could reduce system costs in implementation and postpone investment in system upgrades, allowing for better utilisation of current electricity system infrastructure. Advanced metering infrastructure – part of smart grid deployment – will also allow PV system operators (both small and large scale) to better understand system operational characteristics. This will ensure proper maintenance and provide operators with the ability to optimise electricity production.

Market facilitation and transformation

To facilitate the realisation of the ambitious goals indicated above, several other measures are required, including:

- establishing internationally accepted standards and codes for PV products and components to foster greater consumer adoption;
- identifying new financing and business models for end-users and rural electrification to catalyse grid investments and storage solutions for the full-scale integration of PV;
- supporting training, education and awareness for a skilled workforce along the PV value chain.

Internationally accepted standards and codes

Standards, codes and certificates help create confidence in PV products and facilitate their integration into new markets. Standards not only provide safety and quality assurance but also improve the competitiveness of the PV industry by avoiding administrative hurdles and facilitating more widespread adoption. This reduces unit costs. Standards, codes and certificates are needed in several areas: for performance, energy rating and safety standards for PV modules and building elements; for grid interconnection; for quality assurance guidelines along the value chain; and for the re-use and recycling of PV components. The development of an internationally agreed set of codes and standards will permit increased deployment of a variety of PV technologies and lead to the adoption of improved technologies as they become available.

Identifying new financing and business models

PV systems require considerable up-front investments, but once installed are inexpensive to operate. High initial investment costs are an important barrier for residential and small commercial customers, and for off-grid applications. Investment barriers require innovative but uncomplicated financing approaches, including the development of PV market and business models aimed at end-user service and efficiency. One option that shows promise is the development of energy service companies (ESCOs) that own the system and provide an energy service to the end-user for a periodic fee. The user is not responsible for the maintenance of the system and never becomes the owner. Major economies should explore providing financial incentives to PV ESCOs for on-grid and off-grid applications.

The high cost of capital and limited access to funds exacerbates the investment cost challenge in the developing world. To overcome encourage widespread use of PV in rural and remote communities, new implementation models for financing and operating PV systems are needed. Several financing mechanisms are available:[11]

- **Direct (cash) sales:** the end-user immediately becomes the owner of the system.
- **Credit sales:** the end-user obtains a credit from the PV supplier or from a third-party institution (possibly through micro-credit initiatives). Depending on arrangements, the end-user ultimately becomes the owner and the PV system can be used as collateral against the loan.
- **Hire (lease) or lease-purchase and a fee-for-service model:** the PV supplier/dealer or a financial intermediary leases the PV system to the end-user. At the end of the lease period, ownership may or may not be transferred to the end-user.
- **Fee for service:** as in an ESCO, the end-user purchases the energy service, but the supplier retains ownership of the system.

Major economies can also address the investment cost challenge by creating a market framework and/or mechanisms that foster investments in innovative grid and storage technologies. Time-dependent electricity tariffs (higher at peak load in summer), capacity value markets and ancillary PV markets have all shown promise, and merit further exploration and adoption as appropriate.

Enhancing training, education and awareness for a skilled workforce

Efforts are needed to increase the number of qualified workers for a growing solar industry along the full value chain and the lifecycle of PV product development, from research to system installation and maintenance. A well-trained workforce is necessary to ensure technology development, quality installations, cost reductions and consumer confidence in the reliability of solar installations.

Workforce development activities should focus on building the capacity of educational institutions to respond to increased demand for high-quality training for solar installers. Major economies are also encouraged to provide training and education to create a skilled PV workforce along the full value chain. This involves developing outreach programmes that target specific professional groups, such as local government planners, architects and home builders.

Technology development

Increased and sustained RD&D efforts are needed over the long term in three main areas: to accelerate cost reductions and facilitate the transfer to industry of current mainstream technologies; to develop and improve mid-term cell and system technologies; and to design and bring novel concepts to industrialisation. Significant RD&D is also needed at the system level,

[11] See IEA Photovoltaic Power Systems Implementing Agreement, Task 9, at www.iea-pvps.org.

specifically in terms of improving the product requirements for building integration and minimising the environmental impacts related to very large-scale deployment of PV systems.

The main short-term (S), mid-term (M) and long-term (L) RD&D priorities for PV are to:

- improve the technical performance and cost efficiency of solar cells, modules and system components, for both existing and new solar cell technologies (S-L);
- improve manufacturability of components and systems for industry-scale production with substantial mass production and cost reduction potential (including manufacturing plant demonstration) by utilising economies of scale and scope (S);
- design PV as a building material and architectural element that meets the technical, functional and aesthetical requirements as well as cost targets (S-M);
- develop emerging technologies and novel concepts with potentially significant performance and/or cost advantages (M-L);
- apply life-cycle assessments and optimise the environmental impact of PV systems (M-L);
- develop and implement recycling solutions for various PV technologies (S-M).

RD&D expenditures for PV have been increasing in recent years, but IEA analysis suggests that it remains inadequate. RD&D expenditures in solar energy would need to increase by a factor of 2 to 4 relative to 2008 levels in order to achieve the BLUE Map 2050 goals of reducing global CO_2 emissions by 50%.

In the short term, increasing public funding for RD&D is crucial to accelerate PV technology development and deployment, and to create a more favourable environment for private RD&D. At their October 2009 meeting, IEA ministers recognised the need for more public-sector investment in PV technologies, with the goal of doubling investment by 2015. In the longer term, involvement of the private sector and implementation of public-private partnerships will be key to achieving the required RD&D funding levels.

Options and priorities for global co-operation

As more countries introduce incentive schemes designed to transform the PV market, cumulative capacity will increase more rapidly and accelerate progress along the experience/cost curve. This will shorten the time until the technologies become cost-competitive. By reducing costs, these policies will also make PV more accessible to developing countries, which can provide some of the major potential opportunities for PV deployment. Global co-operation opportunities exist in identifying and sharing best practices in policies supporting PV, co-ordinating incentive schemes and RD&D priorities, and providing financing for PV deployment in developing countries.

As countries accumulate experience with PV market transformation policies, this experience should be used to identify best practices and inform future policy decisions. The IEA's *Global Renewable Energy Markets and Policies Programme* is a useful resource for reviewing experience on policy development and deployment, and for identifying elements of best practice.

International co-operation on PV market transformation policy, at least at the regional level, could reduce market distortions by presenting a coherent system of incentives for PV developers and suppliers. Greater co-ordination is needed between national PV energy RD&D actors across the globe to ensure that important issues are addressed according to areas of national expertise while also taking advantage of existing RD&D activities and infrastructure. Long-term harmonisation of PV energy research agendas is also needed, as is the establishment of international testing facilities for materials and system components. One example of international PV energy technology collaboration is the IEA Implementing Agreement for a Co-operative Programme on Photovoltaic Power Systems (PVPS).

Vast PV resources exist in many countries where deployment has not yet begun to approach its potential. Many emerging economies – notably China and India – are becoming important global players in PV, both in terms of installed capacity and manufacturing. China now accounts for more than 15% share of global PV cell production. However, fast economic growth, limited energy supply and abundant conventional resources prompt countries such as China and India to look first to conventional energy supply. Without sufficient incentives and capacity to do otherwise, these countries are likely to follow a carbon-intensive development path. OECD governments are encouraged to assist developing economies in the early deployment of renewable energy – for example, through the exchange of best practices in PV technology, system integration, support mechanisms, environmental protection and the dismantling of deployment barriers.

Multilateral development banks are an important source of financing for joint development efforts. Financing facilities can be designed on a case-by-case basis to support differing needs. Since 1993, the World Bank (WB) and the Global Environmental Facility (GEF) have supported projects to improve commercial markets and financing for renewable energy technologies in developing countries. In China, from 1999 to 2007, the WB and GEF provided USD 40 million in grants and loans to fund market surveys, key capital investments, and the development of product standards and certification. This effort played an important role in supporting the sale of PV systems to approximately 400 000 rural households and institutions during the eight-year period. It also helped make China the world's top producer of solar equipment and components.

Bilateral development banks are another important source of development finance. The German state-owned Kreditanstalt fur Wiederaufbau Bank (KfW) invested USD 340 million (EUR 230 million) in renewable energy projects in developing economies in 2008. The Asian Development Bank (ADB) recently announced an Asian Solar Energy Initiative, which aims to provide USD 2.5 billion over the next few years to encourage development and deployment of solar technologies in Asia. Targeted projects such as these should be expanded to cover additional countries and regions with strong solar potential.

The IEA concludes and recommends the following:

- PV is an established, low-carbon power generation option. The costs of PV systems have declined dramatically, and this trend is likely to continue as the market grows and technology continues to advance. The IEA has projected that PV could provide as much as 5% of global electricity consumption in 2030, rising to 11% in 2050.
- Market development and costs reduction require ongoing and concerted policy support. In particular, sustained, effective and efficient incentive schemes need to be continued to stimulate increases in capacity and drive down costs, to the point where PV is competitive.
- These support measures need to be complemented by actions to remove barriers that may slow or restrict deployment as PV achieves higher levels of market penetration.
- Ensuring grid access and facilitating the development and deployment of smart grids will be key steps in facilitating large-scale deployment.

- A long-term focus on technology development is needed to advance all types of PV, including commercially available systems and emerging and novel technologies.
- Major economies can help accelerate progress along the experience curve by working together, sharing best practices in policy development and implementation, and taking measures to stimulate the market.
- Individual countries could also:
  - extend and improve co-ordination between national PV energy RD&D activities;
  - provide assistance to developing economies in the early deployment of renewable energy, through the exchange of best practices for PV technology, system integration, support mechanisms, environmental protection and the dismantling of deployment barriers; and
  - encourage the early deployment of technologies in the developing world with favourable solar situations by extending the use of funds from the multilateral banks and other international funding bodies.

Annex A: Case studies on global market transformation for energy efficiency

Case study 1: electric motors

Electric motors convert electricity to mechanical energy to undertake innumerable types of work. Motor driven systems are widely reported as using more than 40% of all global electrical energy. The savings potential for standards on motors alone is significant, but a far greater amount (as much as 20% to 30%) of electricity could be saved through global specifications for driven device standards as well as motor system optimisation.

Market transformation efforts for motors began in Canada in 1988 and spread gradually to other countries over the next two decades. These original efforts included testing, databases of product efficiency, high-efficiency specifications, educating motor purchasers and financial incentives, which effectively established many of these policies tools within end-use equipment programmes.

Minimum efficiency performance standards began in Canada and the United States in 1995 and 1997 respectively and have been adopted in quite a few major countries subsequently (especially in recent years). While there was extensive national consideration of overseas developments in many countries, international co-ordination was mostly informal and occurred without widespread high-level political endorsement. As a result, it probably took longer for the higher standards to spread from one country to another (for example, European standards did not become effective until 2009).

In 2008, the International Electrotechnical Commission adopted an efficiency specification that unifies the many national standard schemes. Under this scheme, new technology developments like a new super efficient class of motor, IE4 level, will be settled providing a sound foundation for future international efforts and national regulation. With accelerating engagement by developing and developed countries, this product type is a prime candidate for enhanced global co-operation.

Key lessons

Individual countries informally following the lead of Canada and the United States gradually improved the efficiency of motors being sold on their markets. Yet since this co-operation was informal, it probably took longer for the higher efficiency products to spread from one country to another. The International Electrotechnical Commission (IEC) decision to develop a new specification unifying the many regional standards now provides a common foundation for future international and national efforts. Such a foundation will make it easier for countries to adopt new internationally aligned standards as they are adopting an international specification, and to benefit from the achievements of the pioneering nations. This international specification includes several performance tiers, so individual nations can choose the level that best meets their needs and capabilities while remaining within the global scheme.

The opportunity

Electric motors account for nearly half of worldwide electricity use, including about 70% of electricity used in the industrial sector (Nadel *et al.,* 2002). Efficient motors can convert more than 95% of the energy in the electricity into useful work, with the remainder lost, primarily as heat but inefficient motors can lose up to 50% of the energy. Motor efficiency can be dependent on output and size – it is easier for larger motors to achieve higher efficiencies. Higher efficiencies however are also achieved with motor design including higher quality steel cores, improved quality and quantities of windings, superior bearings, better fans, and related technological improvements. However, improving motor efficiency costs money for better quality materials and for improved design and production processes. More efficient motors tend to be somewhat larger than less efficient motors with the same output, and they have a slightly higher speed, often requiring resizing of pulleys and other drive system components. These latter issues can be dealt with, but do require more thought than simply replacing an old inefficient motor with a new inefficient motor.

Electric motors are a mature technology. Before the 1973 energy crisis, motor manufacturers generally paid only limited attention to motor efficiency, as customers wanted compact and inexpensive motors. Following the subsequent increase in energy prices, manufacturers responded by developing higher efficiency products. Today, in most international markets, there are commonly three efficiency classes for motors – standard efficiency, high-efficiency and premium efficiency. In developing countries, older motor designs with sub-standard efficiency are still often available. In 2008, the International Electrotechnical Commission (IEC) finalised a standard defining these three classes with less efficient motors left outside the rating scheme. The classes are labelled IE1 (standard), IE2 (high) and IE3 (premium), with minimum efficiency levels specified for each motor output level. These different classes are summarised in Table A1 for four-pole motors, the most common type. To facilitate efficiency comparisons, the energy savings, on a percentage basis, for upgrading from IE1 to each of the higher classes is also reported in the table.

Overall, energy savings from using more efficient motors can range from about 1-12%, depending on motor output and efficiency class. While the percentages do not appear especially high, the energy savings can be enormous since motors often run for 4 000 hours per year or more, and since there are so many motors in use in the world (for example, a forthcoming study for IEA estimates that there are about 193 million motors with an output of 0.75 kW or more in use in the European Union plus eleven other major economies (United States, China, India, Brazil, etc.) (Waide, 2010).

Table A1: Nominal minimum efficiencies for electric motors in Europe (50Hz) per IEC Standard 60034-30

Rated output power (kW)	Minimum nominal efficiency, 50 Hz 4-pole motors			% energy savings relative to IE1	
	IE1	IE2	IE3	IE2	IE3
0.75	72.1	79.6	82.5	9.4	12.6
1.1	75.0	81.4	84.1	7.9	10.8
1.5	77.2	82.8	85.3	6.8	9.5
2.2	79.7	84.3	86.7	5.5	8.1
3	81.5	85.5	87.7	4.7	7.1
4	83.1	86.6	88.6	4.0	6.2
5.5	84.7	87.7	89.6	3.4	5.5
7.5	86.0	88.7	90.4	3.0	4.9
11	87.6	89.8	91.4	2.4	4.2
15	88.7	90.6	92.1	2.1	3.7
18.5	89.3	91.2	92.6	2.1	3.6
22	89.9	91.6	93.0	1.9	3.3
30	90.7	92.3	93.6	1.7	3.1
37	91.2	92.7	93.9	1.6	2.9
45	91.7	93.1	94.2	1.5	2.7
55	92.1	93.5	94.6	1.5	2.6
75	92.7	94.0	95.0	1.4	2.4
90	93.0	94.2	95.2	1.3	2.3
110	93.3	94.5	95.4	1.3	2.2
132	93.5	94.7	95.6	1.3	2.2
160	93.8	94.9	95.8	1.2	2.1
200 up to 375	94.0	95.1	96.0	1.2	2.1

Market transformation efforts

Given the large energy savings available from efficient motors, market transformation efforts for this product type were one of the first efforts of many nations. They began in the United

States and Canada in the 1980s and have spread to Australia, Europe, China and continue to this day in these and other countries.

North America. The first Canadian effort consisted of four components: 1) educational efforts to provide customers and dealers with information on high efficiency motors – their economics and availability; 2) customer incentives to pay part of the incremental cost of high efficiency motors; 3) vendor incentives to encourage vendors to routinely stock and promote high efficiency motors; and 4) support for efforts to enact national minimum efficiency standards. As a result of the first three components, high efficiency motors had gained a 70% share of the new motor market in 1993, up from approximately 5 percent in 1987. In 1992/93, the utility reduced the incentives by just over 10% but market penetration held since by then dealers routinely stocked (and many customers routinely requested) high efficiency motors. Provincial efficiency standards were subsequently introduced and B.C. Hydro phased out their promotional activities (Nadel, 1996). Following this model, similar efforts in Ontario, Canada and several US states achieved similar market transformation impacts.

An important underpinning of these efforts was the adoption of a test procedure, CSA 390/IEEE 112 Method B, that included all motor inefficiencies and therefore allowed a fair comparison of motors. The market transformation efforts used this foundation to begin widespread testing of motors for efficiency, comparison of test laboratories to improve replicability of test results across laboratories, and compilation of several databases listing motors from multiple manufacturers, including their efficiency. The testing allowed motors to be compared to one another. The databases were useful for setting specification levels for high efficiency motors, for establishing incentive levels, for manufacturers to know how their products compared to specification levels and their competitors, and for motor purchasers to be able to compare products.

In the United States, as market share for high-efficiency motors rose, several states considered adopting minimum efficiency standards. Ultimately motor manufacturers and energy efficiency supporters negotiated a consensus agreement that called for US-wide minimum efficiency standards to take effect in 1997, with the standards based on a high-efficiency motor specification developed by the National Electrical Manufacturers Association (NEMA). The US Congress enacted this standard in 1992, and it covers approximately 65% of sales of 1-200 horsepower (.76-149 kW) motors (certain specialised motors are excluded), (Nadel *et al.,* 2002). Shortly thereafter, the Canadian government adopted essentially the same standard, effective 1995. And following the signing of the North American Free Trade Agreement in 1994, Mexico adopted the same standard, effective in 2003.

Following the effective date of their high-efficiency standard in 1997, multiple US utilities and states developed a new "Premium Efficiency" specification, based on the best products on the US market, and began to promote this specification through education efforts as well as incentives. Market share for premium motors rose to approximately 20%. At this point, motor manufacturers approached efficiency supporters about increasing the US minimum to premium efficiency levels. Agreement was reached and the US Congress passed the new standard in 2007, effective late 2010. This agreement and law also included provisions to require high (but not premium) efficiency levels for 200-500 horsepower motors (149-373 kW) and for some of the specialised motors excluded from the original US standard (Elliott, 2007). Canada is in the process of adopting the same standard effective 2011 (NRCan, 2010). Mexico has also begun to revise their standards.

Australia and New Zealand. Australia started developing motor standards in the late 1990s. This was a joint federal/state effort under the leadership of the Australian Greenhouse Office. Originally work focused on developing standards that would eliminate 40% of products with the lowest efficiency from the market. However, the European voluntary Eff2 values were published around the same time and because the Eff2 value was very similar to the draft Australian 40^{th} percentile values, Australia decided to use Eff2 for their mandatory standard and Eff1 for their voluntary "high efficiency" standard. This decision to modify the original performance proposal was made on the grounds of facilitating trade and international alignment (Marker, 2003). New Zealand began considering standards as far back as in 1994, but later concluded an agreement with Australia to generally co-ordinate on standards activities. All standards committees now have both Australian and New Zealand Government appointees, and the two countries fully co-ordinate standards including the same test methods, standard levels, and mutual recognition of test results. The first electric motor Australian and New Zealand standards took effect in 2001 (Cogan, 1997 and 2003).

In 2002, Australian and New Zealand government officials decided that further improvements could be made, as the 2001 levels were substantially behind those of the United States and Canada, and began the process of developing a new standard. Both countries had adopted a policy of matching the best standard in effect elsewhere in the world, subject to the maintenance of competition in local markets, a positive cost benefit exercise and the production of a satisfactory regulatory impact statement (covering the economics of the new standards and the ability of manufacturers to meet the standard – Marker, 2003). The new standard was finalised in 2005 and took effect in 2006. It mandated standards based on the 2001 high efficiency values and included a new set of high-efficiency values, somewhat similar to the US premium efficiency levels (AS/NZS 1359.5.2005).

Europe. Meanwhile, in Europe, progress with high efficiency motors was slow, hampered by differences between countries and disagreements on appropriate test procedures. Europe generally used a test procedure that did not measure all motor losses. This was a less-expensive test procedure to implement, but meant that motor efficiency was harder to compare in a fair manner, since some losses were not measured, advantaging motors with high losses. After many years of discussion, European motor manufacturers set up a voluntary programme under which motors would be labelled in three efficiency classes (from most efficient Eff 1 to least efficient Eff 3), with Eff 1 motors roughly comparable to high efficiency motors in North America, and Eff 2 motors similar to standard efficiency motors in North America. Some governments and some manufacturers actively promoted use of higher efficiency motors using this scheme, but these sporadic efforts did not achieve the same sort of transformation as occurred in North America. As of 2005, approximately 9% of motors sold in the European Union were Eff 1 (CEMEP, 2008).

In about 2005, given the limited progress to date, the European Commission began pushing for further steps to improve motor efficiency, noting how Europe was lagging behind North America, Australia and several other countries. Several steps were taken, including agreeing on modifications to the motor test procedure to better measure motor losses or use default values for motor losses that were higher than actual losses for most motors. These changes allowed motor testing to be better harmonised with international procedures. In addition, the new IEC specification for IE1, IE2 and IE3 motors was developed, again, with an eye toward international harmonisation. Notably, these new performance levels were marginally less stringent that the voluntary scheme operated in Europe previously. With this accommodation, manufacturers agreed to adopt minimum motor efficiency standards and IE2 became a mandatory standard effective 2009.

China. Meanwhile, China was making substantial progress on motor efficiency, drawing in particular from lessons learned from North America, Australia and Europe. The Chinese were making a major push on energy efficiency, including on updating energy efficiency standards.

Given the large amount of energy used by motors, particularly since approximately 70% of China's electricity was used in industry, they decided to set motor minimum efficiency performance standards. Ultimately, a 2-tier standard was set – an initial tier, effective 2008, at the European Eff 2 level, and a second tier, at the Eff 1 level, effective late 2010. After the initial level went into effect but before the adoption of the second level, the Chinese government has been working with Chinese manufacturers, helping them to design and produce motors that will meet the new standard. Furthermore, in 2009, as part of economic stimulus efforts, China implemented a programme to provide incentives to manufacturers for sales of motors that met the new standard, thereby increasing market share and easing the transition to the new standard. In addition to saving energy domestically, the Chinese were also interested in increasing motor exports motors, and realised that to do so in many developed countries, they would need to meet international efficiency levels.

Other economies. Other economies also took action and adopted standards including Brazil, Costa Rica, Israel, South Korea and Taiwan. The Brazilian standard is at the "high efficiency" level (CLASP, 2010).

Accomplishments

As discussed in the section above, enormous progress on motor efficiency has been made. Minimum efficiency standards for motors are in effect for many countries. Canada and the United States have worked together and now have standards equivalent to the IE3 level. Several countries are at IE2 including Australia, New Zealand, Mexico, the European Union, Brazil, South Korea, and, as of late 2010, China. The IEC is now developing a new IE4 specification, for even higher levels of efficiency.

Lessons learned

There are several key lessons learned from efforts to promote improved efficiency motors over the past two plus decades:

- Fair, complete, and comparable test procedures are needed to measure efficiency and permit product comparisons.
- Market share of improved efficiency products can be increased through education efforts, and the development of databases that permit product comparison, financial incentives to purchasers, and technical assistance efforts to help manufacturers develop higher efficiency products.
- Minimum efficiency standards are a critical step to fully transform markets, locking out inefficient products returning to the market.
- Once a market is transformed to one efficiency level (*e.g.* "high efficiency"), efforts can proceed to the next efficiency level (*e.g.* "premium efficiency").
- Countries can learn from each other, especially from the examples of Canada and the United States.
- International co-ordination cannot be made more effective if most activity remains centred on national bodies reflecting on overseas developments.
- Much greater levels of co-ordination could have been implemented through international bodies like the IEC, which would have saved resources within all stakeholder groups.

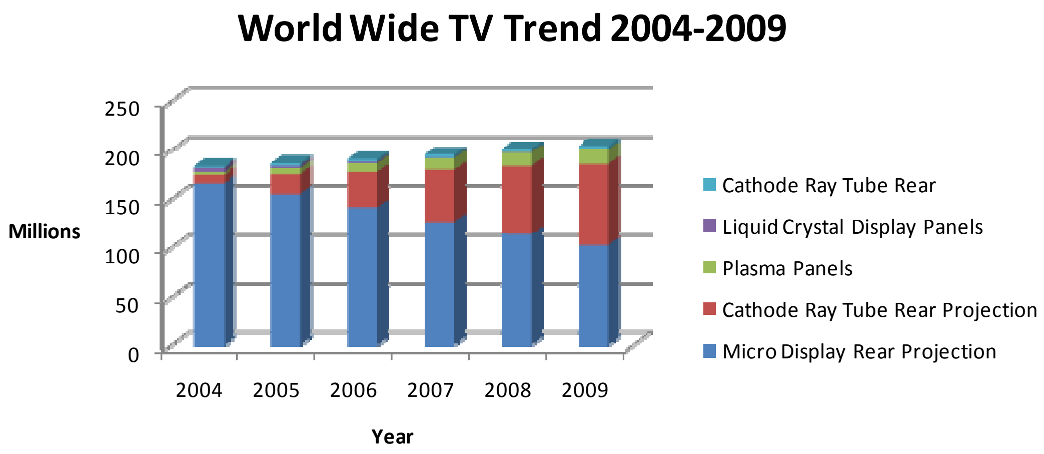
- The leadership ultimately shown by the IEC to task its motors committee with establishing global specifications for all motor efficiencies should make future international collaboration efforts easier.

Case study 2: televisions

Television was invented more than a century ago and gained popularity starting in the 1940s and 1950s. While the technology regularly improved, it was not until 2000 that energy use dramatically increased with the introduction of newer television technologies, which use much more energy due to larger screen sizes. Experts conclude that television energy consumption could increase by a factor of 10 by 2020 from a baseline of 2000, if left unchecked and unregulated.

The original cathode ray tube technology limited screen size to no larger than 80cm. Since 2000, newer display-device technologies, the most popular being Plasma and LCD, have allowed the development of larger screen sizes, now in excess of 350cm (four times as large as CRT). Experts claim the average screen size of televisions sold around the world increased from 60cm in 2004 to around 70cm in 2009 (but countries like Australia and the United States have an average size of 106cm).

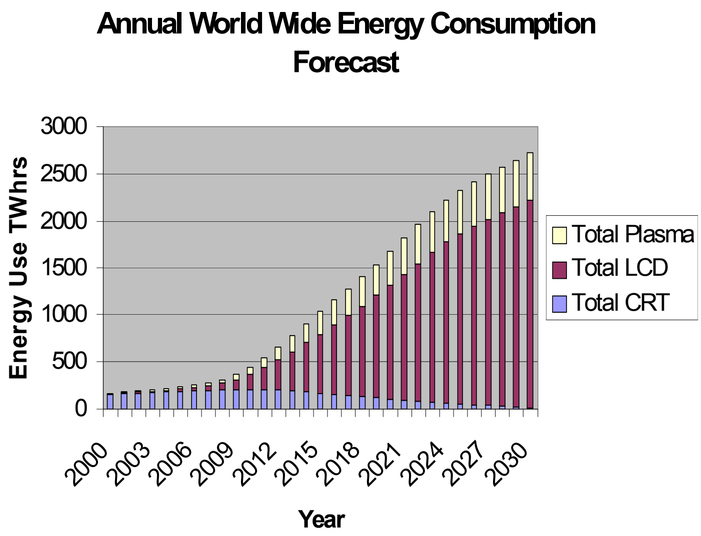
Figure A1: Worldwide annual television sales



Source: Jones, 2010.

Worldwide television energy consumption has doubled since 2000 from some 150 TWhrs in 2000 to around 300 TWhrs in 2009. With the increasing size of televisions and the market-driven phase out of CRTs, by 2020 the energy consumption could exceed 1 500 TWhrs and almost double again 10 years later.

Figure A2: Projected worldwide BAU energy use for televisions, without intervention



Source: Jones, 2010.

What was done?

The need to address television energy consumption was recognised by some regulators and industry experts by 2005. They identified the need for an internationally recognised energy-use test procedure, covering all available television display technologies fairly and accurately.

At that time, the IEC standard 62087 only covered CRT technology. By 2006, an IEC working group with representation from the United States, United Kingdom, Netherlands, Japan and Australia (and later also China) was tasked to develop a test procedure that would provide an energy consumption measurement that represented real world television use and was fair for all display technologies.

The experts were funded by governments and industry associations to model real world television viewing, particularly in regards to average picture brightness levels (APL), which, together with screen size, are the main contributing factors to television energy consumption. In a public review process taking several years, the group produced a 10-minute video loop that consisted of material not subject to copyright from all corners of the globe that matched the APL histogram. They also settled issues within the test method to the satisfaction of the global industry and regulatory agencies publishing the method as IEC 62087 Edition 2. A globally applicable test method appeared for the first time in late 2008.

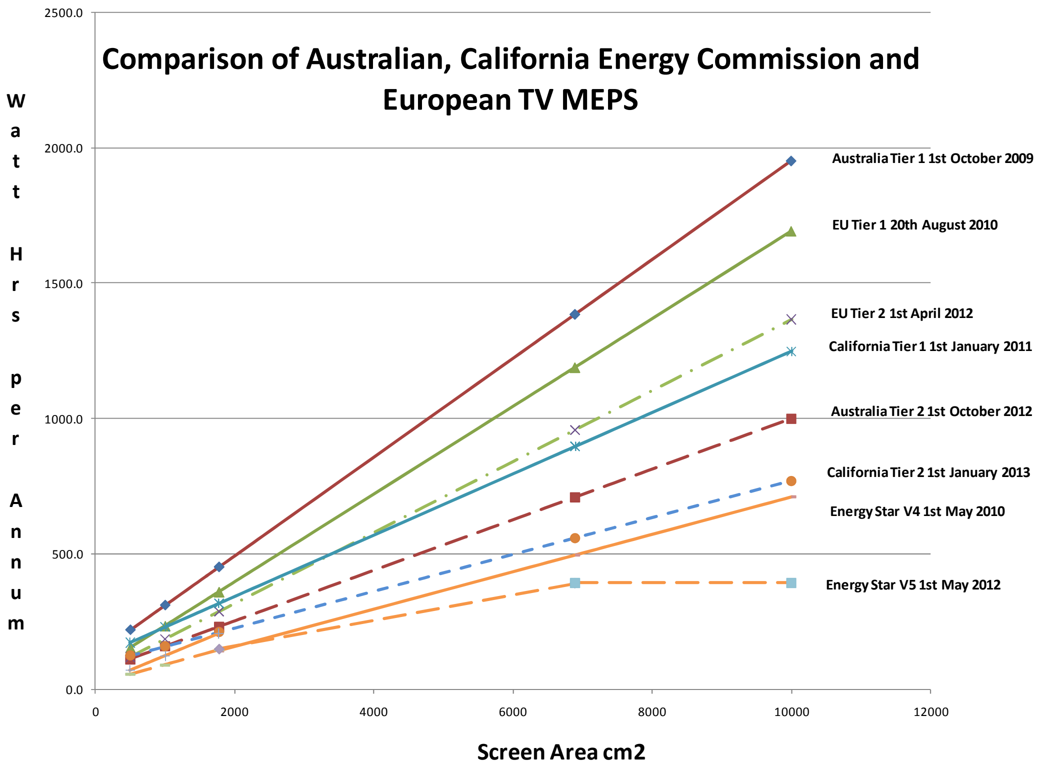
What resulted?

As of 2010, three regulated schemes and one voluntary scheme have adopted the test protocol to measure energy efficiency (Australia, California and Europe) as well as Energy Star. The performance requirements of the three regulatory schemes were settled in national debates (following established legal frameworks) and some dialogue between the parties negotiating performance requirements did occur.

The alignment that characterised the development of the test method, however, did not flow through to the suite of performance regulations adopted in the three jurisdictions. Regulators adopted a similar approach to defining energy performance metrics, consisting of the energy demand per square cm (or inch) of screen surface plus an fixed amount of energy per television, and followed a common format by establishing two performance levels to help phase in mandatory minimum performance levels. The regulations in the three locations, however, commenced at differing times, were set at differing stringencies and involved some different interpretations of the IEC test procedure.

Figure A3 shows that, currently, California's tier-2 requirements are the most stringent mandatory requirements, followed by the Australian and European Union requirements. US Energy Star new tier-5 requirements for its voluntary programme (not shown in the graph) are even more demanding and, interestingly, include an absolute cap on energy demand for large-size televisions.

Figure A3: Comparison between the Australian, European and Californian regulation



Source: Jones, 2010.

Lessons learned

The main lesson is that an internationally accepted test procedures for energy use is essential. Without the IEC test procedure for televisions, harmonisation of energy efficiency metrics in various economies, and to some extent requirements, as is starting to occur, would most likely have not emerged.

Secondly, for products with challenging and complex energy consumption characteristics, a well-coordinated and focused international group can overcome the challenges involved in developing a unified test procedure that can be applied globally.

Earlier involvement of Chinese government and industry experts could have avoided the larger differences between the test procedure as used in China and those in other economies. Although the procedure is somewhat everywhere, differences between the Chinese procedure and those in the United States, the European Union and Australia are more significant.

Availability of better market and sales data could have reduced the time needed to start work on the IEC test procedure. This, consequently, might have led to an earlier availability of a harmonised test procedure, allowing for the application of the procedure in advance of the development of performance requirements and full adoption in all MEPS developments.

The success of the television test procedure has led a group of experts to successfully petition the IEC to commence work on a new measurement method for set-top boxes, which should be published in late 2010 as Ed 3 of IEC 62087. In parallel to this work, the IEC has also established a working group investigating what other product energy test procedures are still deficient.

It is now possible to map television test results from various national and sub-national programmes which facilitate benchmarking of programme results, as in Figure A3. The benchmarking may encourage closer co-operation between regulatory agencies in setting future performance requirements for globally traded products.

Case study 3: external power supplies

External power supplies (EPS), also known as power adaptors, convert high voltage AC electricity available from wall sockets to the low voltage DC power used to power electronic products such as laptops, cordless/mobile phones, cameras, mobile music and communication devices. They are fundamental to modern consumer lifestyles.

Á worldwide estimate of EPS numbers is difficult. The US Environmental Protection Agency reports that there are 1.5 billion EPS in use in the United States alone, accounting for nearly 470 billion kWh/year or about 12% of the US annual electricity consumption. US government research also shows that approximately as much as half of the electricity that flows through an inefficient power supply is consumed by the power supply itself. The international trade in EPS as well as the range of efficiencies available have been key drivers of the move towards a single test procedure and policy harmonisation.

Historically, power supplies used traditional, magnetic transformers to convert power to a low voltage. Low quality transformers are plagued by high energy losses in this conversion process. These losses occur both in the conversion of power when the EPS is in use, and "no load" losses, occurring when the EPS is plugged in but not actually delivering power to an appliance. The energy efficiency of products can be improved by switching to better-quality transformers (*e.g.* better core steel, larger copper windings), or, as is now common, by switching to electronic, switch-mode transformers. Interestingly, the latter technology seems to have low losses as well as lower production costs compared to traditional power supplies – making this switch a very attractive option. Recently, the impact of power supplies on power quality has gained more attention because of distortions in the power grid.

International collaboration

In the absence of a robust measurement methodology, collaboration evolved in 2003 between the United States, China and Australia to develop a harmonised test method and marking protocol for EPS that has the potential to be adopted worldwide. The reference point for this work was the test method used by the US EPA in the development of the Energy Star programme (which itself was based on a test procedure suggested by ECOS, a consultancy, and EPRI, the technical laboratory for the US power industry). In parallel, a voluntary Code of Conduct on External Power Supplies (CoC) had been operating in the European Economic Community since 2000 with criteria broadly similar to those of Energy Star.

The three main outcomes were the following:

1. A test protocol developed during the collaboration has emerged over time. It sets out general test conditions and the measurement approach that should be used to determine efficiency of EPS at 25%, 50%, 75% and 100% of rated power output and under "no load" conditions. This method can be applied in any market (50 or 60 hertz, 110 or 220/230 volts) and has been adapted to allow national governments to support their country-specific voluntary or mandatory efficiency performance schemes. As a result, the US EPA has entered into agreements with several other governments to promote specific Energy Star qualified products, including EPS.[12] Participants were drawn from Australia, Canada, China, the European Union, the European Free Trade Association, Japan, New Zealand, Switzerland and Taiwan.
2. An international efficiency marking protocol has been established, providing a system to designate the efficiency performance of EPS. The international mark consists of a Roman numeral levels I to IV, with level I being the least stringent (least efficient) level, displayed on the EPS. In May 2008, the US EPA announced more stringent (level V) criteria to stimulate its market.
3. A 5-star rating system[13] is a voluntary rating system that covers the no-load charge of EPS up to 8W for mobile, handheld battery driven applications. Chargers sold by Nokia, Samsung, Sony Ericsson, Motorola and LG Electronics are covered. Chargers are rated from no stars for > 500 mW no-load power consumption to 5 stars for < 30 mW.

What has been achieved?

The test and marking protocols have delivered tangible direct and indirect benefits. Some examples are:

- Countries can opt into the international scheme for their voluntary or mandatory national regimes at a level that is commercially feasible, economically viable and nationally relevant.
- Manufacturers can optimise the design of their products globally, responding to the increasingly globally harmonised test procedure for EPS.
- In Europe, energy consumption due to EPS is expected to show net growth of 17 TWh between 2006 and 2020. Impact assessment calculations show that actions resulting from the EU Code of Conduct will counterbalance this growth with savings of up to of 5 TWh/year from 2010, equivalent to EUR 500 M.

[12] *http://www.energystar.gov/index.cfm?c=partners.intl_implementation.*
[13] *http://ec.europa.eu/environment/ipp/pdf/ipp_voluntary_agree_criteria.pdf.*

Country reports

The United States

Standards: The Energy Independence and Security Act 2007[14] is the first US federal law setting minimum energy performance standards for several energy-using products. The Act sets efficiency and standby requirements for EPS (Subtitle A, Sec 301). The EPS standard allows for no more than one-half watt in 'no load' mode and a minimum active mode efficiency that varies by output. The new standards were effective 1 July 2008. By 1 July 2011, DOE must conclude a rulemaking that would set new standard for power supplies not previously regulated and would update the standards legislated in 2007. Such new and revised standards would be effective 1 July 2013.[15]

The California Energy Commission has put in place standards for Class A EPS's that are federally regulated and for state regulated EPS.[16] The ECOS/EPRI test procedure has been adopted for this. External power supplies sold in California need only comply at 115Vac 60Hz and shall be marked with the performance mark with 115 beside the mark if they comply only at 115Vac. The Californian Energy Commission has put in place an "energy efficiency battery charger system test procedure".

Following the example of California, several other US States have recently developed appliance energy efficiency standards, including standards for "single-voltage external power supplies". States include Arizona, Massachusetts, New York, Oregon, Rhode Island, Vermont and Washington.

Voluntary label/test standard: The current ENERGY STAR specification (v2.0) came into effect in November 2008.[17] With respect to the International Efficiency Mark, any external power supply meeting the performance requirements for level V and above would qualify as ENERGY STAR (Version 2.0). Power supplies with performance levels of I-IV would not qualify under the Version 2.0 specification.

Test method:[18] The Test Method for Calculating the Energy Efficiency of Single-Voltage External AC-DC and AC-AC Power Supplies was developed by ECOS and EPRI in 2004, for the original purpose of use by the US EPA ENERGY STAR programme. The purpose of this test procedure is to establish a standardised method that can be used worldwide to measure the efficiency of single voltage external AC-DC and AC-AC power supplies across a full range of load conditions. Its intent is not to replace IEC 62301,[19] which focuses closely on the measurement of standby power, but to augment and extend it downward to the measurement of no load conditions and upward to the measurement of active mode conditions. Likewise, its intent is not to replace IEEE 1515-2000,[20] but to add specificity regarding loading conditions and reporting requirements.

[14] *http://www.govtrack.us/congress/bill.xpd?bill=h110-6.*
[15] *http://www.apec-esis.org/productsummary.php?country=The United_States&countryid=262&product=Power Supplies - External&ID=106.*
[16] *http://www.energy.ca.gov/2009publications/CEC-400-2009-013/CEC-400-2009-013.PDF.*
[17] *http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/eps_spec_v2.pdf.*
[18] *http://www.efficientpowersupplies.org/pages/External_Power_Supply_Efficiency_Test_Method_8-11-04.pdf.*
[19] Household electrical appliances – measurement of standby power.
[20] Recommended practice for electronic power subsystems: parameter definitions, test conditions, and test methods.

The ECOS/EPRI test procedure is used to determine if a model qualifies for ENERGY STAR. However ENERGY STAR has five further specific testing requirements.

Test standard:[21] The US DOE specifies the test procedure, in the CFR Part 430 Subpart B Appendices Z--Uniform Test Method for Measuring the Energy Consumption of External Power Supplies.

Canada

Regulation:[22] A review of potential regulation for EPS products is currently underway in Canada. The minimum energy performance standards (MEPS) are expected to be harmonised with the US Energy Independence & Security Act – 2007 (EISA) standards. The definition of EPS is harmonised with EISA, ENERGY STAR® European Union (EU), and Australia. There are some differences in the exclusions with EISA and ENERGY STAR.

Test standard: CSA-C381.1-08 is the test method for calculating the energy efficiency of single-voltage external ac-dc and ac-ac power supplies will be the reference test procedure for this product, as the Canadian government review MEPS. This test procedure is based on ENERGY STAR's Test Method for Calculating the Energy Efficiency of Single-Voltage External AC-DC and AC-AC Power Supplies.

Europe

Regulation: The first stage of the Eco-Design Regulation on External Power Supplies took effect in April 2010.[23] It sets two stages of mandatory requirements for EPS units, which specify both no-load condition power consumption and average active efficiency levels. In addition, certain information requirements are mandatory for manufacturers' technical documentation. A revision of the measure is expected no later than 2013.

Voluntary Code: The European voluntary code of conduct sets no load maximum power consumption and efficiency target for active mode. The ESCO/ESPRI test procedure has been adopted for measuring this. Version 4[24] is the most recent set of requirements, but the Code has been in place since 2005. Signatories of the Code of Conduct commit themselves to these targets, and to Design power supplies or component so as to minimise energy consumption of external power supplies. Those companies who are not responsible for the production of power supplies shall include the concept of minimisation of energy consumption in their purchasing procedures of power supplies. Signatories report annually to the EC on achievements.

Australia and New Zealand

Regulation:[25] Following collaboration between the United States, China and Australia to develop a harmonised test method and marking protocol for EPS, in 2004 work began on developing an Australian and New Zealand (ANZ) minimum efficiency performance standard

[21] *http://www.apec-esis.org/teststandard.php?no=1144.*
[22] *http://oee.nrcan.gc.ca/regulations/bulletin/ext-power-supplies-april2009.cfm?attr=0.*
[23] *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:287:0001:0010:EN:PDF.*
[24] *http://sunbird.jrc.it/energyefficiency/html/standby_initiative.htm.*
[25] *http://www.energyrating.gov.au/eps2.html.*

(MEPS). Between 2004 and 2007 technical reports, product profiles, draft standards and regulation impact assessments were developed. The final measure (AS/NZS 4665.2) was passed in 2007, and MEPS (Mark III) were introduced in December 2008 in Australia and December 2009 in New Zealand.

Energy performance requirements include the average efficiency (measured at 25%, 50%, 75% and 100% of rated output power) and consumption at no load. To meet MEPS, a power supply must meet or exceed the requirements for average efficiency, and meet or be lower than the no load thresholds, when tested according to AS/NZS 4665.1 at 230 V AC 50 Hz only. External power supplies with a nameplate input voltage of 240 V AC only shall be tested at 240 V AC.

The standard also defines minimum efficiency levels for "High Efficiency External Power Supplies" (Mark IV). Only products which meet the specified efficiency levels can apply this term to promotional or advertising materials.

Test standards:[26] Regulatory standards and test procedures for EPS are published by Standards Australia. AS/NZS 4665.1-2005, specifies the method of test to assess the energy performance of external power supplies, and the international system for marking the efficiency on the power supply. This test method is technically identical to the test method used by the US EPA in the Energy Star programme (and therefore based on the ECOS/EPRI test procedure). It describes the general test conditions, and the measurement approach for determination of efficiency at 25%, 50%, 75% and 100% of rated power output, and under no load conditions.

This Standard also describes the system for marking a power supply with a Roman numeral to indicate its overall energy performance. The requirements in AS/NZS 4665.2 are currently equivalent to numeral III. EPS may be dual marked if there is a difference between 230 VAC and 115 VAC performance.

Asia

In 2008, certification authority for energy-using products passed to the China Quality Certification Centre. The People's Republic of China has introduced a voluntary Energy Conservation Product Certification for Single Voltage External AC/DC and AC/AC Power Supplies. The ESCO/EPRI test procedure has been adopted for this.

The Republic of Korea runs a mandatory Energy Efficiency Label and Standard Programme, which has covered energy efficient adapters and chargers.[27] The programme is operated by the Korea Energy Management Co-operation (KEMCO[28]), delegated by the Ministry of Commerce, Industry and Energy. Under this programme, manufacturers (importers) are mandated to produce and sell energy efficient products from the outset. Where MEPS are violated, a fine of up to USD 16 000 can be charged.

Lessons learned/areas for further consideration

- Developing a test standard from first principles is time and resource consuming and difficult for government agencies to commit resources because of the uncertain time frame. The use

[26] *http://www.energyrating.gov.au/eps1.html.*
[27] *http://www.kemco.or.kr/nd_file/kemco_eng/MKE%20Notice%202009-158.pdf.*
[28] *www.kemco.or.kr.*

of an existing measurement method already honed by the rigors of the Energy Star scheme was the catalyst for this global co-operation. It provided the basis for governments to commit to examining this already agreed measurement protocol which could be settled by an international standards-setting body.

- Creating a set of meaningful performance levels that covered the field meant that the scheme had application anywhere in the world and was not tailored to just an industrialised or developing country paradigm. The categories of efficiency captured by the marking cover all possible EPS efficiencies. Participants found that a global marking scheme does not work if product efficiencies exist outside the marking scheme.
- Focussing collaboration on facilitating global EPS improvement was key. The US Energy Star programme's need to stimulate its market for technology improvements (creating an efficiency for class V) demonstrates why marking schemes cannot be fixed for all time by only catering for the best possible product available at the time of creating the scheme.
- It is sensible to plan for increases in stringency with performance levels that accommodate economic product development cycles (allowing time for manufacturers to redesign products) and a nation's capacity to pay.
- A systematic categorisation of products in various countries is needed, to support a global evaluation of the performance of EPS and the introduction of globally harmonised performance requirements. This would lower the cost of developing more efficient EPS, as the design costs can be spread over a larger market, and reduce compliance cost for industry.

Case study 4: compact fluorescent lamps

Compact fluorescent lamps were an early target of market transformation programmes in many countries. Early gains in market share in some developed countries were offset by slow adoption in others as lingering perceptions of poor product performance combined with other market barriers to hinder widespread use. Product availability was also limited until manufacturers ramped up production in the late-1990s and early-2000s.

Several market barriers were identified including: absence of a widely accepted, international test measuring CFL energy performance; limited facilities to test products and verify compliance; a wide range of efficiency performance seemingly not related to price or brand name; and the proliferation of inconsistent or poor-performing products. Many countries wasted resources in developing of their own performance specifications, test methods, compliance and verification procedures seemingly in competition with other schemes. Poor lifetime and light quality threatened to dissuade consumers from continuing to use CFLs. Global market transformation efforts, including the creation of a harmonised test method and a suite of performance tiers helped redefine manufacturing expectations and lay the groundwork for the broader phase-out of incandescent lamps in many countries.

The opportunity

Lighting is a major electric end-use, accounting for 2 650 TWh/yr of electricity – 19% of global electricity production in 2005. Throughout the world, incandescent lamps remain the most common source of lighting in the residential sector. These lamps account for 30% of global lighting electricity consumption with an average of 20 incandescent lamps per household in IEA member countries (IEA, 2006).

Incandescent lamps are extremely inefficient, converting only 5% of the energy they consume into visible light. More efficient alternatives represent one of the best opportunities for large-scale, cost-effective, and rapid reductions in global electricity consumption and greenhouse gas emissions but those alternatives faced the ubiquity of very cheap incandescent (even with poor energy performance and a short lifetime).

Compact fluorescent lamps (CFLs) were first introduced in the 1970s and still represent a viable, energy-efficient alternative to incandescent lamps used for general service lighting. CFLs produce approximately four times the light per watt of electricity compared to incandescent lamps (in other words, 75% energy savings) and should last six to ten times longer. The first generation of CFL technology had several drawbacks that limited their widespread adoption. As with all gas discharge lamps, CFLs require a ballast to operate. The development of self-ballasted, screw-based CFLs that could be readily installed in existing light fixtures was delayed limiting its initial appeal to a broad audience of consumers. Early CFLs were bulky and oddly shaped, making it difficult to use them in many existing light fixtures. They also exhibited flickering, long warm-up times, and colour shifts that led many consumers to abandon the technology after trials. These problems continued for some time, contributing to negative perceptions of the technology and aversion by many consumers.

By the mid-1990s, the major lighting manufacturers had addressed all these issues and were marketing high-quality CFLs in a range of sizes and shapes to fit most fixtures and sockets where incandescent lamps are typically used. But the maturing technology was attracting new manufacturers offering a new generation of poor-quality but low-cost CFLs. This continued the negative perception of many consumers. An improved infrastructure for CFL performance testing and compliance became a critical component in efforts to ensure consumer acceptance and viability of CFLs and deliver the tremendous energy savings opportunity they represent.

Market transformation efforts

CFLs were one of the earliest targets of market transformation activity. The significant energy savings, number of existing light sockets, frequency of lamp replacement, and relatively low cost compared to other energy-using products made CFLs extremely attractive as one of the cheapest and easiest opportunities for energy savings.

In 1990, market share for CFLs was well below 1% in IEA member countries where early production and promotion was focused (PNNL, 2006). Co-ordinated national promotional campaigns and bulk procurement efforts in Japan resulted in rapid and significant increases in CFL penetration. CFLs and linear fluorescent lamps accounted for 80% of residential lighting in Japan (PNNL, 2006). By the mid-1990s, European surveys showed that they were following that path but at a slower rate. Around 50% of households in many northern European countries, and 20% of households in the United Kingdom were using at least one CFL (Calwell *et al.,* 1999).

CFLs were slow to catch on in the United States. Throughout the 1990s, utilities and regional energy efficiency organisations focused on addressing the barriers to greater adoption of CFLs. Rebates, coupons, and bulk purchasing opportunities were provided to address high CFL prices. Marketing and educational campaigns were launched to improve consumer awareness and address consumer confusion about CFL selection and use. Retailers were targeted with incentives and training to encourage better stocking and promotion to increase the availability of CFLs in a wide range of retail outlets – including grocery stores where most consumers typically purchase incandescent lamps.

Despite these efforts, adoption of CFLs grew very slowly throughout the 1990s as consumer perceptions of poor lighting performance lingered and, in some cases, were reinforced by an increase in the number of low-cost, low-quality products entering the market from newer sources. In 1999, the US Department of Energy (DOE) released the first ENERGY STAR specification for screw-based CFL. In order to qualify for the endorsement label, products had to meet energy and performance criteria. The ENERGY STAR programme provided a common set of performance criteria and marketing platform and became the basis for market transformation activities in the United States.

As this century commenced, several factors served to drive a greater urgency for an accelerated market shift towards CFL and the recognition that only by concerted global action could effective market transformation occur. Growing concern about climate change and aggressive national commitments to reduce carbon emissions led many countries to redouble their efforts at capturing the energy savings available from CFLs. At the same time, the shift in manufacturing to China lead to another spate of high volume, inconsistent and poor quality CFLs from some suppliers threatening to reverse gains made with consumers by other Chinese quality suppliers (repeating the early CFL penetration experience in countries where CFLs were being introduced widely for the first time). The need for an international infrastructure for effective performance measurement, verification, and compliance became increasingly clear.

In 2005, the International CFL Harmonisation Initiative (CFLI) was launched as the result of an initial dialogue on the need for a harmonised test method and performance specifications for CFLs to improve product quality, reduce compliance costs, and increase industry capabilities. Eighty individuals representing 13 jurisdictions signed onto the initial communiqué outlining five key priority actions for the CFLI (CFLI 2005):

1. Testing methodology – development of an agreed test procedure for self-ballasted CFLs for submission to the International Electrotechnical Commission for publication as an international standard.
2. Performance specifications – the development of several performance specifications for self-ballasted CFLs of increasing stringency for use by government or private-sector bodies for regulatory or voluntary programmes.
3. International test facility product testing (proofing the scheme) – establishment of a product-testing programme to proof the test methodology developed under the CFLI, benchmark the performance of testing facilities around the world, and take steps to increase the capacity of testing facilities.
4. Compliance mechanisms – development of common procedures to demonstrate CFL compliance with reported performance level based on testing in accordance with the agreed test method.
5. Informing the international lighting community – development of transparent procedures to communicate the activities of the CFLI and to allow for the participation of all interested stakeholders.

Between 2005 and 2008, the CFLI convened a total of ten meetings to share progress and further co-ordinate activities within the priority areas identified to help lay the groundwork for an accelerated transformation of the global CFL market. This group of experts from industry, some governments and testing houses drove the creation of a global co-operation in just three years (after 30 years of ineffectual action). Specifics accomplishments for each task are detailed and related reports and resources are available on the initiative website (*http://apec.fivevision.com/www/cfl/index.php*).

Accomplishments

CFLs are a global co-operation success story. The global market for CFLs has grown exponentially over the past two decades. In 1990 worldwide sales of CFLs totalled 83 million (with the majority in the commercial sector), by 1997 global sales had grown to 356 million CFLs (PNNL, 2006). From 2005 to 2007, global production of CFLs increased by 70% with more than 3.7 billion lamps produced in 2007 (Waide, 2010). As of 2009, well over 4 billion CFLs were produced worldwide, with China accounting for more than 90% of global CFL production (as well as 30% of consumption) (Jeffcott, 2010).

Market penetration of CFLs has grown in all regions and continued growth is expected in light of mandatory requirements to phase-out incandescent lamps in the most common wattages and applications in jurisdictions around the world. Australia, Canada, the European Union, the United States, South Korea, the Philippines and many other countries have enacted regulations mandating the phase-out of general service incandescent lamps between 2009 and 2014. The specific performance requirements and scope of the regulations vary from country to country. CFLs are expected to fill the majority of light sockets where incandescent lamps were previously installed. Some countries have adopted minimum efficiency standards and/or mandatory performance specifications for CFLs to keep poor-quality lamps out of their markets. In countries without these requirements, ongoing efforts to identify and promote high-quality CFLs may be required. Some countries have announced aggressive subsidy programmes to phase-out these lamps.

Lessons learned

International experience with CFLs yields several valuable lessons for future market transformation efforts. These lessons may prove particularly salient for the emerging market for solid-state lighting.

- A single test method, accepted globally by stakeholders, can minimise the burden on manufacturers, governments, and others involved in product regulation or promotion.
- Alignment of performance specifications across the globe can provide clear guidance to manufacturers about expectations for product performance while maintaining flexibility for different jurisdictions to establish regulatory requirements or design voluntary recognition programmes suited to their market.
- A set of establish performance specifications which can be measured by qualified testing facilities have the advantage of holding suppliers accountable and offer a means to counter negative consumer experiences from poor-quality products. This is particularly important for new lighting technologies because end-users are very sensitive to lighting quality.
- Early adoption of common test standards and performance metrics can lower compliance costs and help to reduce product costs, leaving less room for low-quality products to gain a foothold or dampen consumer interest in the new technology.

- A transparent process open to input from all interested stakeholders will gain wider and quicker acceptance and is more likely to identify potential barriers or points of contention before final decisions are made (and while they can still be addressed).
- Minimum energy performance standards may be required to phase-out an inferior technology that is well-established due to low-cost, market structures, consumer habits and preferences.
- Consumer education is crucial especially on the most appropriate applications for the technology and providing accurate information on how the technology will function (including information about any limitations or differences in the technology relative to conventional alternatives). Sell, but don't oversell, non-energy benefits and other attributes of the new technology.
- Successful market transformation is built on relationships with manufacturers, retailers and other trade allies to leverage their expertise in developing customer-friendly programmes, advertising and education to build consumer awareness and interest.

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