

Technology-Forcing Standards for Energy Efficiency

Efficient Electrical End-Use Equipment (4E)
International Energy Agency

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The IEA Implementing Agreement on Efficient Electrical End-Use Equipment (4E)

4E is an International Energy Agency (IEA) Implementing Agreement established in 2008 to support governments to formulate effective policies that increase production and trade in efficient electrical end-use equipment.

Globally, electrical equipment is one of the largest and most rapidly expanding areas of energy consumption which poses considerable challenges in terms of economic development, environmental protection and energy security. As the international trade in appliances grows, many of the reputable multilateral organisations (for example the G8, APEC, IEA and IPEEC2) have highlighted the role of international cooperation and the exchange of information on energy efficiency as crucial in providing cost-effective solutions to climate change.

Thirteen countries have joined together to form 4E as a forum to cooperate on a mixture of technical and policy issues focused on increasing the efficiency of electrical equipment. But 4E is more than a forum for sharing information: it initiates projects designed to meet the policy needs of participants.

Participants find that pooling of resources is not only an efficient use of available funds, but results in outcomes which are far more comprehensive and authoritative.

The main collaborative research and development activities under 4E are undertaken within a series of Annexes, each of which has a particular project focus and agreed work plan. These currently comprise:

- **Mapping and Benchmarking**
- **Electric Motor Systems (EMSA)**
- **Standby Power**
- **Solid State Lighting (SSL)**

Current members of 4E are:

Australia, Austria, Canada, Denmark, France, Japan, Korea, Netherlands, Switzerland, South Africa, Sweden, UK and USA.

Further information on the 4E Implementing Agreement is available from: www.iea-4e.org

This report has been prepared for the 4E Executive Committee by:

Kevin Lane and Fiona Brocklehurst of Kevin Lane (Oxford) Ltd.

The project was overseen by:

John Cockburn, Office of Energy Efficiency, Natural Resources Canada, with the assistance of Mark Ellis, 4E Operating Agent.

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Hans-Paul Siderius, Agentschap NL, Netherlands

Mike Walker, DEFRA, UK

Peter Bennich, The Swedish Energy Agency

Robert van Buskirk, Department of Energy, United States of America

Shane Holt, Department of Climate Change and Energy Efficiency, Australia

Disclaimer

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4E Contact details

Mr Hans-Paul Siderius

Chair, 4E

NL Agency
P.O. Box 8242
NL-3503 RE
Utrecht
Netherlands

Tel: +31 88 602 26 09

e-mail: hans-paul.siderius@agentschapnl.nl

Mr Shane Holt

Vice-chair, 4E

Department of Climate Change and Energy Efficiency
GPO Box 854
Canberra, ACT 2601
Australia

Tel: +61 (2)6159 6882

e-mail: shane.holt@climatechange.gov.au

Mr Mark Ellis

Operating Agent, 4E

Mark Ellis & Associates
44 Albert St
Wagstaffe, NSW 2257
Australia

Tel: +61 (2)4360 2931

Mobile: +61 424 264 014

e-mail: mark@energyellis.com

Executive summary

Energy efficiency is considered essential to the continued economic and social development of nations. Where the current annual level of efficiency improvement is just over 1% pa, this needs to be of the order of 3-5% in order to significantly reduce energy use to meet current and future global commitments on greenhouse gas emissions (based on IPCC and IEA carbon and energy projections). Energy efficiency could deliver many of these savings at little or negative costs to society. However, owing to environmental externalities and other factors, not all cost-effective efficiency savings are being delivered. This is due to some relatively well known market failures.

To overcome these market failures, policy makers engage with the market in a number of regulatory ways. Technology-forcing standards is one approach to overcome market failures and help countries reach their climate change targets, and this is explored in this document.

Background

There is no universal definition for Technology-Forcing Standards (TFS), and the concept and terminology of TFS stems from the field of environmental regulation, specifically on the banning of particular processes or substances. Furthermore, there appears to be little existing theory on TFS in the field of energy efficiency, as it has mainly been confined to environmental regulation.

The term TFS is first observed in the development of catalytic converters in the early 1970s. Subsequent examples related to TFS have been found, ranging from car carbon efficiency (e.g. zero emission vehicles in California), the ban on ozone depleting substances, SO_x, and perhaps building regulations and even renewable obligations. The policy mechanisms have ranged from outright bans through to trading mechanisms which put a price on a pollutant (and in some cases include a 'get out' clause to temper the case where targets are set too stringently).

Working definition of TFS

In its strictest form, the definition for TFS is considered to be an energy performance standard which includes:

- Technology beyond what is currently available on the market today (or even technically achievable);
- May not be currently cost-effective;
- Requires innovation and broad diffusion to the market;
- And, importantly, must be delivered to the market via government signaling future regulation.

For the purpose of this report, to test the boundaries of such a policy approach, less rigorous definitions are considered.

Existing regulatory energy performance standards

Mandatory energy performance standards (which have an implication on the technology that can be employed) have been used for appliances in different ways, most notably:

- MEPS (in the USA, based on life cycle costs from engineering analysis applicable to the national market);
- MEPS (in the EU, initially weaker than the USA due to political processes necessary to secure passage, though now based on engineering analysis in a similar way to the USA, though with additional (non energy) considerations);
- MEPS (in Australia and New Zealand, where engineering analysis is eschewed in favour of aligning with the most stringent MEP already imposed elsewhere in the world, subject to economic appraisal);

- Top Runner (the Japanese dynamic standard-setting approach based on statistical analysis of the market, to establish the best available technology as the basis for a sales-weighted average for all suppliers in the future).

These approaches have been demonstrated to be very effective at improving the efficiency of products in those regional markets, both in terms of cost and at a quicker rate than through other policies such as rebates or improved information flows like labelling.

Developing TFS for appliances

For electrical equipment, faster innovation rates are possible, but developing and implementing strict TFS would be challenging, and would require strong political will to develop such new policy approaches. Whatever the policy mechanism used to deliver TFS, there are some generic benefits and reservations. The main benefits can be described as:

- Effectiveness (likely to bring forward significant technology change);
- Enabling (*de facto* requiring) investment in R&D and innovation of new technology;
- Providing long term regulatory certainty to industry to lower the risk associated with R&D.

The main reservations might be summarised as:

- The danger of required innovation rates may not being achieved, thereby forcing industry to invest in expensive and sub-optimal technologies;
- The risk that regulators do not enforce TFS thereby disadvantaging, through their inherently higher product development costs, those companies which have supported TFS and providing a marketing fillip for those companies which do not commission the required R&D;
- The risk that the political commitment to TFS may evaporate should sections of industry actively lobbying against targets and the policy itself.

There are occasions where such a (TFS) policy approach may be appropriate for a national, regional or even global market; specifically, when the following conditions are satisfied:

- There is a known pathway for efficiency improvement (e.g. for lighting and televisions products quantum dots and LED technology may be appropriate);
- TFS can be applied to a sufficiently large trading market/block to commit market players to change;
- Appropriate efficiency measurement metrics are in place or are sufficiently developed to provide confidence that robust measures will be established by the time the TFS standards comes into effect.

Mitigating actions for risks from TFS

There are some risks from employing TFS, and there are some actions that can be taken to mitigate these risks, which can be summarised as follows (grouped by risk factor):

- Targets are too stringent or not achievable at acceptable cost, which could be mitigated by:
 - Regular reviews of progress;
 - Supporting TFS with other policy measures (e.g. rebates, procurement, R&D tax breaks).
- Information asymmetry between regulator and industry, mitigated by:
 - Developing expertise (directly or through contractors);
 - Obtaining information from component suppliers;
 - Using international competition to provide information.

- Low industry access to capital for innovation and R&D, mitigated by:
 - Encouraging and supporting collaboration (to reduce costs);
 - Offering grants and tax breaks in support of R&D;
 - Providing policy confidence (no flip-flopping).
- No policy mandate for TFS, which could be mitigated by:
 - Providing evidence to policy makers where this could work;
 - Developing existing approaches (MEPS, Top Runner) to have more stringent targets.
- Leakage/reduced competitiveness, mitigated by:
 - Making regulation geographical coverage as wide as possible;
 - Reducing cost of innovation by supporting R&D.

TFS remains a possibility for collective action by multi-lateral gatherings of government officials charged with creating energy performance standards, though a number of preconditions would need to be met before it could be considered a main-stream option.

Recommendations

Based on the research undertaken for this report and discussion at the May 2012 Stockholm 4E meeting, the following three main recommendations are made:

1. In the context of the development of future energy performance standards, the concept of TFS is worthy of further work by governments to determine whether it constitutes a legitimate and useful public policy goal to drive international end-use energy efficiency cooperation. In this respect, 4E might entertain commissioning further work to better define and describe the concept as applied to end-use electrical energy efficiency equipment issues.
2. TFS should be considered within the context of existing energy performance standards in agreed international case studies by benchmarking it against past regulatory interventions for those products. For example, 4E could request its various product Annexes to create TFS targets for lighting, motors and network standby. 4E could work with other multilateral groups to encourage other suitable technology types to consider using TFS to establish stretch goals for the future.
3. The role of TFS, as a policy goal, should be debated by senior government officials to determine interest and possible support. To facilitate this, 4E and/or other multilateral groups could coordinate workshops to explore possible links between innovation and subsequent regulation, at gatherings under the auspices of the International Energy Agency, the Clean Energy Ministerial and the International Partnership on Energy Efficiency Cooperation.

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Glossary

Term	Meaning
4E	IEA Implementing Agreement on Efficient Electrical End-Use Equipment.
BAT	Best available technology. EuP studies defines 'BAT' as a technology already available on the market, or at least whose feasibility has already been demonstrated in minimising environmental impacts and is expected to be introduced within 1 to 3 years. It helps in defining medium-term ecodesign targets.
BNAT	Best not yet (or nearly) available technology. EuP suggests 'BNAT' refers to technology, which has the potential to lead to further (environmental) performance improvements, but is still under research and development and can be considered as a future option. It helps in identifying long-term ecodesign options.
ECS	Energy Conservation Standards, essentially MEPS by another name.
EuP	Energy-using product or 'EuP' means a product which is dependent on energy input to work as intended. In Europe these are covered by the Ecodesign Directive which sets performance levels.
Max Tech	Highest efficiency (theoretical), a term usually in US ECS rule-making research.
MEPS	Minimum energy performance standards.
MLLC	Minimum life cycle cost.
R&D	Research and development.
TFS	Technology-forcing standards.

1 Introduction and aim

Mater artium necessitas → Necessity is the mother of invention

1.1 Context and background (original scope of the project)

With respect to energy efficiency, the traditional approach to the transformation of markets for energy-using products typically involves the use of minimum energy performance standards to eliminate the worst performing products and a combination of comparative information and endorsement labelling to encourage consumers to purchase more efficient products. Often the latter are also deployed to support financial incentive programmes. Technology commercialisation programmes frequently accompany these to ensure the continuous introduction of new, more efficient products to the market.

This process can take a decade or more, during which time equipment which is less than optimally efficient, and which has a long product lifetime, is installed in the stock resulting in lost savings and foregone opportunities. Not only are inefficient technologies embedded in the stock but some have argued that innovations are not pursued with appropriate vigour because of the long times and investment horizons necessary to gain sufficient market share to offset technology development costs.

An alternative approach to market transformation could be focused more deliberately on approaches that accelerate the introduction of the most efficient technology. Most often this has involved support for basic research, product development and improvement, commercialisation, market promotion, etc.

At present there may be discernible technology performance targets that could be realised in a way that eliminates a number of these steps and accelerates the process. In some cases, using targets that are broader than traditional product category boundaries could also encourage shifts to new ways of meeting demands for energy services. To achieve these targets clear signals need to be given to markets that allow appropriate investment to take place more quickly. Mandatory standards that call up these performance standards may be a way to accomplish this.

1.2 Initial understanding of project

The rapid improvement in efficiency of energy-using products is currently hampered by a lack of long-term R&D to bring forward new technologies onto the market sufficiently early. Various policy methods exist to support such R&D, from classical research investment, to technology horizon scanning, through to more sophisticated approaches such as the UK's Forward Commitment Procurement (FCP, 2011, designed mainly for the public sector, which looks at purchasing from the outcome-based specification needed instead of purchasing for the immediate perceived need).

However, there are few examples of mandatory standards to promote very efficient technologies.

Technology-forcing standards is an approach whereby the specified standard cannot be met with existing technology, or at least not at an acceptable cost. One early example of such a policy approach is the 1970 U.S. Clean Air Act, which required a 90% reduction in tailpipe emissions from vehicles over a relatively short five year period. At the time of the policy being introduced such technology was not available; and by the end of the period catalytic converters had successfully been developed (even though at great cost). Some theoretical work on this has been done by academic researchers (e.g. Gerard and Lave, 2007) examining the impact of such standards, and this will be summarised in the literature review.

Such a policy approach is worth exploring for appliances, and has been previously touched upon. For example, the IPCC in its Fourth Assessment report listed this as a potential policy area for appliances:

“A product standard would, for example, be the requirement that refrigerators operate minimally at a specified level of efficiency, while a technology-forcing standard would involve setting the refrigerator efficiency requirement slightly beyond present-day technological feasibility but announcing that the efficiency requirement will not go into effect until a number of years following the announcement.”

The current project will explore the status of research and develop a sensible future plan for this topic, specifically the extent to which IEA 4E could make a worthwhile contribution in this area.

1.3 Structure of report

This report is structured as follows:

- Introduction (structure, aims, status);
- Literature review and discussion on a definition of TFS;
- Examples of technology-forcing standards;
- Types of technology-forcing standards for equipment;
- Potential targets for end-uses;
- Technical and public policy risks of such an approach;
- Alternative and complementary approaches;
- Discussion of other considerations (not listed in the seven tasks);
- Summary findings and provisional recommendations;
- References.

2 Literature review – TFS theoretical

A review of the literature reveals that there is not much theoretical analysis of “technology-forcing standards” in appliances or end-uses: the term is more often used in other areas of environmental regulation. Most of the theoretical discussion surrounds environmental regulation and alternative taxation-based approaches.

In the past, economists have argued that environmental regulation and competitiveness are antagonistic as regulation will always restrict competitiveness. However Porter *et al* (1995) argues that well-designed regulation could stimulate innovation and improve competitiveness. This concept has been widely discussed and a growing evidence base supports it.

Porter *et al* identified the key facets to good regulation as being:

- regulation must create the maximum opportunity for innovation, leaving the approach to innovation to industry and not the standard-setting agency;
- regulations should foster continuous improvement, rather than locking in any particular technology;
- the regulatory process should leave as little room as possible for uncertainty at every stage.

Others support this thesis suggesting that ‘TFS’ standards should be the only type of standards to be introduced, superseding taxation (see for example Hahn, 1989).

Looking at environmental regulation, some technology-forcing standards are already included. Generic approaches include regulations using “BAT” and related performance levels. The standards generally follow the ‘known’ most effective technology.

Best Available Technology (BAT)

Best available technology (BAT) is a term usually applied with regulations on limiting pollutant discharges with regard to the abatement strategy. Similar terms are best available techniques, best practicable means, and best practicable environmental option. The term constitutes a moving target on practices, since developing societal values and advancing techniques may change what is currently regarded as “reasonably achievable”, “best practicable” and “best available”. The EU and the USA consider the following.

- EU: Best available techniques not entailing excessive costs (BATNEEC), sometimes referred to as best available technology, was introduced with the 1984 Air Framework Directive (AFD) and applies to air pollution emissions from large industrial installations. Superseded by IPCC (see Sorrel, 2002);
- US: The Clean Air Act (1970) requires that certain facilities employ Best Available Control Technology to control emissions. This is an emission limitation based on the maximum degree of reduction of each pollutant subject to regulation under this Act emitted from or which results from any major emitting facility. The permitting authority determines this on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, through application of production processes and available methods, systems, and techniques, including fuel cleaning, clean fuels, or treatment or innovative fuel combustion techniques for control of each such pollutant.

Such BAT driven standards have the benefit of being relatively easy to set once the technology has been proven (and the policy framework is in place). However, aspects of reasonable cost and political lobbying can cloud the development of targets.

A detailed study by Gerard and Lave (2007) suggest that regulation (especially TFS) is better than 'letting the market decide'. It also notes the difficulty in developing or enforcing appropriate TFS due to information asymmetry between government and industry. "Firms might be able to exploit this asymmetry by deliberately missing the standard – hiding their innovative capabilities, under-investing in R&D, and claiming that the standards cannot be met. If industry participants argue that meeting a standard is impossible, and regulators have no foundation to contradict them, then it is unlikely that regulators will be able to enforce the standards" (Gerard and Lave, 2007, page 4). There are several ways to address this:

- Develop expertise directly or through (independent) contractors;
- Use competition (within region or foreign vs. domestic) to encourage firms to provide information;
- Obtain information from component suppliers who are looking to expand their market for an innovative technology.

If spending on R&D and innovation is the key to successful TFS then there are some reports on the role that regulators can play. For example Kemp (2004, chapter 3) has a useful discussion on the roles of regulators versus the supply (industry) side in supporting and forcing innovation.

In addition to TFS being used for technological innovation, Kemp also suggests an alternative approach: "innovation waivers" whereby industry can extend the deadline to meet an environmental standard by offering to develop an innovative solution, which would offer greater costs savings from a superior technology. In principle this is a very attractive approach both for innovators and regulators. However Kemp reports that the experience to date in the USA has been poor owing to the short time (with fixed deadline) allowed for the development and the poor administration of the programme. Similarly, Hahn (1989) provides a discussion on US experience on 'Innovation waivers' and tradeable permits.

Other findings from the literature review include:

- Some efficiency improvements occur (and manufacturers will seek to innovate) where they (coincidentally) reduce costs and improve the quality of their products. This is often seen, for example, in the consumer electronics sector, though regulation may provide extra stimulus to go further and/or quicker;
- There is a well known lack of current information amongst government regulators;
- The threat of regulation may be more effective than actual regulation.

Kemp suggests that TFS should only be used:

- When environmental risks are large and acute;
- There is consensus on technology solutions or trajectory;
- Solutions can be developed at a low enough cost.

If this route chosen, policy makers need to take care of:

- Strictness;
- Differentiation;
- Timing;
- Administration;
- Flexibility;
- Enforcement.

The main benefits can be described as:

- Effective (bring forward technology);
- Providing certainty;

- Enabling (requiring) investment in R&D and innovation of new technology.

The main disadvantages can be described as:

- Risk in forcing industry to invest in overly expensive and sub-optimal technologies;
- There is low credibility (if regulators ‘over-egg’ the performance levels which cannot be known with certainty in advance). Consequences of low credibility could include a lack of industry action and engagement, or even active lobbying against targets and policy.

In 2007, Nentjes *et al* noted critically that TFS were used relatively rarely. Technology **following** standards, such as those using BATNEEC are much more common and presented a model as to why that might be so. They took the case of regulation (as against a trade or incentives scheme) and modelled how a regulator might balance the extra uncertainty and time required against the potential greater resulting emission reduction of a TFS and against the shorter time and greater certainty (but potentially lower emissions cut) of a technology following standard. They looked at two cases: where cost considerations are binding (a maximum cost for industry is set) and non-binding (less restriction). In the latter case, if the regulator is prepared to allow for time and for some risk TFS will be attractive. The scope for TFS in the former case is very restricted. They comment that “it appears that the conditions [for a TFS to be attractive] are hardly ever present in practice. The three examples of technology-forcing policies presented in their introductory section might even not have been tried if the regulator had not underestimated the amount of time that would be involved in meeting the minimum technological requirements and the inherent uncertainties.” They acknowledge that they do not consider the supplying technology market or the use of alternative policy instruments alongside the regulation in their analysis, both of which might make TFS more attractive.

Such approaches are usually considered for environmental pollution, and are relatively well established. However, for energy-using appliances, this is less so, and there are two main approaches to standards which may ‘force’ some form of technological development. They include:

- Engineering approaches to determine cost-effective MEPS standards;
- Dynamic statistical revisions of targets based on best on market (Top Runner).

As further background to these types of appliance standards, analysis in the USA and especially US MEPS are usually based on an analysis of life cycle costs and examine engineering options to improve efficiency. The efficiency options examined include a cost component. The highest efficiency level that could be achieved is termed ‘Max Tech’ in US studies. There are a few known issues with such MEPS approaches and target levels implemented:

- They usually overestimate the actual costs – as shown by a recent Defra-funded study (Defra, 2011a);
- Such studies tend to underestimate the rate of improvement that is possible since innovation can usually go further;
- These, coupled with lobbying, mean that existing MEPS are not as ambitious as they could be.

As a result of these limitations some are pushing for stricter MEPS standards (e.g. <http://www.coolproducts.eu/>), which could be considered a move towards TFS.

These MEPS and related policy approaches, though not strictly technology-forcing standards, are reviewed in a later section (Section 4).

3 How to define technology-forcing standards for appliances

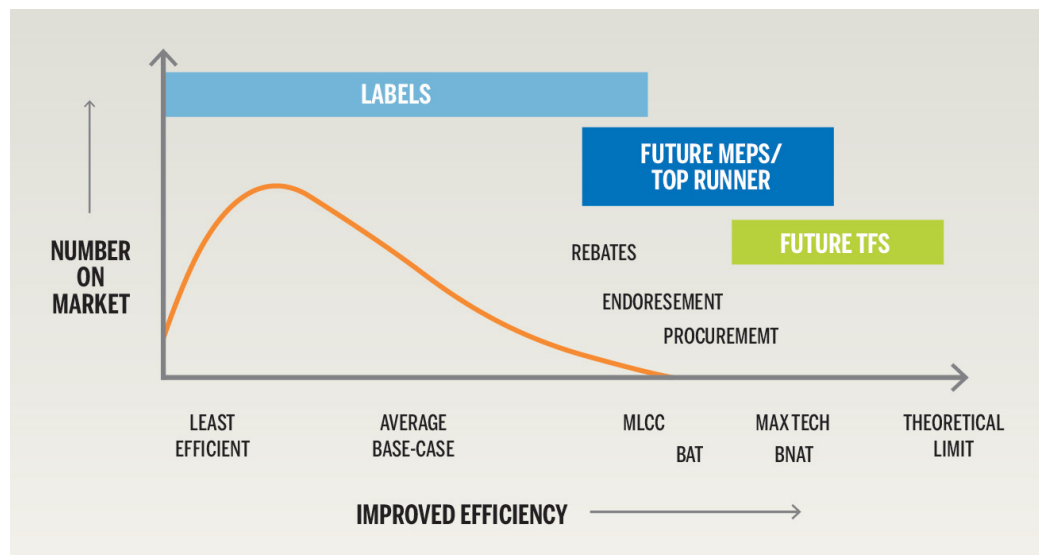
Usually in product or energy-using equipment policy, practitioners are targeting efficiency under a certain measurement standard, ideally international and repeatable and representative of actual use and impact by consumers. The main policy tools used by decision makers around the world include:

- Comparative labelling, such as the EU A-G scheme, or the Chinese 1-5 label;
- Endorsement labelling, such the Energy Star programme, where the most efficient products (say top 20% of the market) may display the label;
- Financial incentives or rebates, which can be based on the labels;
- Procurement programmes, such as government contracts based on Energy Star;
- Minimum energy performance standards (MEPS) to remove the least efficient products from the market;
- Top Runner scheme – a requirement for the market average to reach a defined efficiency standard based on the previous current best on the market.

The entire process of moving the market towards more efficient products using these tools in a coordinated and timely way can be termed market transformation.

The market transformation approach typically is shown visually, as shown in Figure 1 below. The y-axis shows the number of products on the market, with different policy measures that may be in place. The x-axis shows the increasing efficiency of products on the market and lists some efficiency points sometimes referred to by analysts and decision makers. The likely location of technology-forcing standards (TFS) (for future products to reach) is also included on the efficiency ‘spectrum’, towards the very efficient end of the scale to the right.

Figure 1: Efficiency spectrum and policy measure targets



Importantly, the above picture is not a static one: there is a dynamic process. There are different approaches to implementing measures, coupled with different timing.

The points located on the curve are essentially efficiency levels, which can be determined by technical analysts. The efficiency performance levels for the different policy measures are set by policy makers or regulators, usually by making use of the technical analysis.

The main analytic tool used in the USA and Europe is engineering analysis of efficiency design options. The expected costs and energy savings of the design options are used to determine consumer life cycle cost curves (purchase cost + running costs + maintenance costs). Increased efficiency is assumed to come at increased product cost to include the additional design option. At some point during increasing the efficiency (with ever greater consumer purchase costs) it is no longer worthwhile overall (financially based on these engineering estimates) to improve the efficiency. This point is known as the minimum life cycle cost, and has been used to set MEPS levels (as mandatory regulations). This is further explored in Section 9.

Going beyond the MLCC level is possible, though will likely require additional costs. “Max Tech” has been used by the USA (Desroches and Garbesi, 2011) and others to show their best estimate, which may be beyond the best available on the market: “Max Tech” designs combine all existing best practices into single appliances or pieces of equipment. Few existing analyses of products actually do so.

Other approaches can be used to set the target performance levels. The Japanese Top Runner uses statistical averages to set future target levels. This has the bonus of not requiring expensive engineering analysis.

One way of thinking about the challenges of setting a TFS is to show how various existing initiatives are located on an efficiency spectrum (the x-axis in Figure 1). For example, voluntary labels may target BAT performance levels, whilst procurement or engineering analyses require or describe the BNAT performance level. A theoretical minimum energy input for delivered services would be at the lowest end of the scale. One proposal is to have TFS target levels somewhere between the BNAT performance level and the theoretical minimum. Alternatively, the target could be between the BAT and BNAT or around the BNAT level; which has the advantage of a known technology path, though the product design or cost may still be unknown.

For TFS we are looking at the far right of the curve (the very efficient end), and how to bring forward more efficient products. Usually, once products have made it to market (under the main part of the curve itself), there are well-established mechanisms to increase the uptake (e.g. through incentives and market information); and eventually make these the minimum performance standard. However, well-implemented TFS may also remove (or reduce, or at least change) the need for some of these established approaches.

In response to a stimulus to improve products whether through regulation or otherwise, an expected course of action by suppliers is usually:

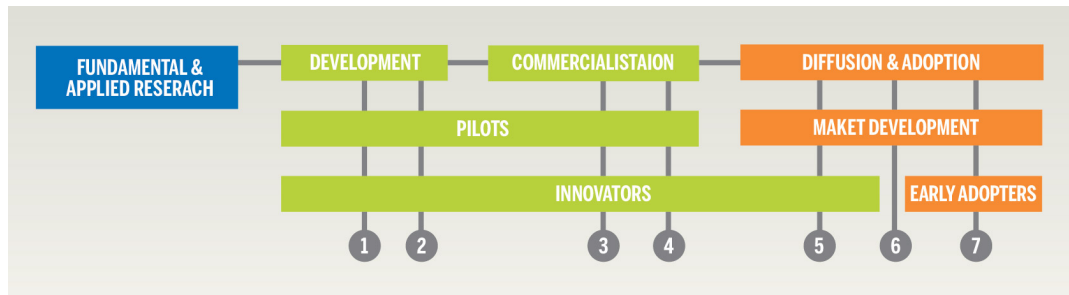
- Diffusion of existing technology;
- Incremental changes (e.g. extra insulation for fridges);
- Product reformulation (e.g. have two compressors in a fridge-freezer);
- Product or component substitution (e.g. LCD for CRT televisions);
- Development of new products (e.g. LED and OLED backlighting televisions).

For the current project we are mostly interested in how to stimulate and bring forward the last stage listed, though some of the other actions may also bring forward valuable efficiency improvements.

In terms of TFS, interpreted as MEPS beyond current known technology levels, a well studied example is car pipe emissions standards in the USA (Gerard and Lave, 2007), where catalytic converters were developed as the technical solution to particulate emissions in a very short period of time, through substantially increased investment in research and development.

Ultimately, TFS are trying to bring forward **innovation** by the suppliers. Understanding of innovation is a subject in itself, and there are multiple phases of innovation process within a company (Figure 2), though the aim of TFS should be to increase manufacturer/supply chain spend on innovation to deliver more efficient products at some point in the future.

Figure 2: Innovation phases (example)



Source: Klinckenberg (2011, personal communication).

There are already some policy measures to address innovation. However, well-constructed and effective TFS could potentially bypass, at least to some extent, the need for such measures. Stimulating innovation (not necessarily for energy-using equipment) is currently done via multiple policy tools, including:

- Subsidies;
- Taxes;
- Tradeable permits;
- Covenants (industry or voluntary agreements);
- Tax breaks for appliances (for industry, not consumers).

Recent studies provide evidence that environmental taxation can also spur innovation (OECD 2010, EEA 2012). Examples of other 'less forcing' approaches, which include performance levels beyond current technology, include:

- Procurement rules, e.g. UK's Forward Commitment Procurement (designed mainly for the public sector, which looks at purchasing from the outcome-based specification needed instead of purchasing for the immediate perceived need) (FCP, 2011);
- Energy Plus (2003, see section 7.5 for more details), a development of an earlier procurement style project, where manufacturers competed to develop the most efficient refrigerator (EEI=0.2 was the winner). In the USA a similar 'golden carrot' competition was used for refrigeration and washing machines;
- Swedish procurement in 1990s;
- SEAD (under CEM) competition (on TVs and motors).

There are other measures which focus on Best Available Technology, such as Topten (for further information see Bush *et al*, 2011), though again these are voluntary in nature.

Since these are voluntary and less forcing in nature the impact on the market may be small and less certain. They certainly need other measures to deliver widespread diffusion into the market.

However, some of the targets listed or achieved will be useful as benchmarks for MEPS or TFS. For example technology procurement programmes have historically been useful in understanding performance possibilities around the BAT and BNAT performance levels. This rarely leads to commercialisation and a rapid change in the market, unless followed up by other measures. Thus, it could be argued that procurement (and similar approaches) is a good tool to

help determine performance targets, with MEPS and similar ensuring that these products gain a mass market share.

It is worth noting that if the market is rapidly transformed from 'average' products to the future MEPS level or TFS style products, without additional policy support in between, (e.g. rebates and additional margins from products labeled as more efficient) there will be a different and noticeable impact on firms. The voluntary sales from higher efficiency products are where firms tend to maximise their margins with premium products being awarded benefits. A TFS could arguably change that and commoditise efficiency for the entire market. This would be good for energy efficiency (since there will be cheaper very efficient products, with no premium being charged for efficiency), however, potentially at the detriment of profit for firms. Clearly, firms would have to seek other aspects and features of their products to charge a premium.

Thus, for the purpose of this paper, technology-forcing standards could be defined as follows:

PROPOSED definition of technology-forcing standards:

- Efficiency performance levels (or technology) that are currently:
 - not on the market at present;
 - too costly at present to be widespread.
- Which require:
 - innovation; or
 - broad diffusion.
- Importantly, delivered via regulation.

3.1 Wider definition of products and considering energy services

There may be an opportunity to deliver higher standards if products and their classifications are not defined so rigorously as at present. For this, there are at least two aspects worth pursuing:

- Take existing product policy to classify products into product types, technologies or classifications, which means less-stringent targets are included for some product types. For example, 42 types of refrigerator combinations are described in the recent regulatory standards in the USA. So that it is possible for a side-by-side refrigerator-freezer to use noticeably more energy than top-bottom mounted fridge-freezers (which both have the same adjustable volume), reducing these to fewer models could increase efficiency though potentially also reducing customer choice (or in the case of labelling, making clear to the consumer the energy costs of their choices);
- Defining a wider service rather than a product specific service and set an energy limit for delivering that service while being flexible as to how that service is delivered. This is done in some industry sectors already, e.g. lighting for specific tasks (per area), or for industry agreements in terms of energy/output (e.g. kWh/dozen eggs in UK climate change agreements). For the residential sector, an obvious service example includes space heating, where there are multiple ways of improving the efficiency of the heating system. Historically, the efficiency of a boiler was determined at full load operation, which has pushed manufacturers to supply boilers which operate well at that load (reaching a condensing mode). However, in most residential situations the boiler rarely needs to operate at full mode. So there may be more effective ways of improving system efficiency.

Industrial electric motors are a clear case where product standards (MEPS) are insufficient to deliver all the cost-effective and technical potential energy savings. MEPS on motor enable

relatively simple regulatory 'wins', though larger savings are now possible from improving the systems where electric motors are purely components and sub-components. It is possible to regulate some of these motors which are embedded in larger products themselves, such as pumps and fans. However, more challenging are the larger systems with multiple components and sub-components.

At this point it is worth noting that MEPS and any proposed TFS should be based on a defined performance metric. This metric is usually defined in terms of performance rather than declaring which technology to use to meet standards. In addition, there should not be different performance levels for different technology types of product. Thus, technology winners are not chosen by policy makers, only the performance target to reach. If the target is made more generic or the scope is relaxed there may be opportunities for more flexible approaches and lower cost approaches for complying with performance targets.

Some of these are considered further in Defra, 2011c.

4 Recent applications of technology-forcing standards and lessons learnt

As an extension to the literature review, this section aims to identify and assess some recent applications of technology-forcing standards. For each example a brief description of approaches discovered and their major benefits and disadvantages will be described. As such this section may suggest some useful lessons for development of TFS for appliances.

Although the precise definition of TFS may be sufficiently clear, we are looking at the margins of what is possible in terms of ambitious performance standards, so this section will err on the side of including 'standards' that may not necessarily be true technology-forcing standards. Examples examined in this section are listed below:

1. US Energy Conservation Standards;
2. EU MEPS (Ecodesign);
3. Japan Top Runner;
4. Renewable (portfolio) targets;
5. UK Climate Change Agreements;
6. Phasing out incandescent lamps ;
7. Ozone depleting ban (Montreal Protocol);
8. Clean Air Act (1970) – tailpipe emissions;
9. Zero emission vehicles (California);
10. SOx Emission reduction;
11. England zero carbon new build homes.

4.1 US Energy Conservation Standards

Energy conservation standards (ECS) or minimum energy performance standards (MEPS) have a long and successful history of use in the USA (since NAEETC 1987), following their initial development and deployment in the State of California. In this case, the efficiency standards apply to the sale of all new energy-use products on the market, and are mandatory in nature, which means that all products must comply or face sanction.

The target levels for each product are developed in individual rule-makings, which are rigorously undertaken. The target levels themselves are based on economic optimums from the consumers' perspective, based on very detailed engineering analyses. The technology options are based on proven designs, even if they are not yet on the market, or all the different combinations of options have been used to that point.

Importantly, the targets can go beyond the current best on the current market, and this has occurred for several products (e.g. for the 2001 refrigerator standard).

Other observations and lessons:

- recent ECS rulings have included the effects of learning (economies of scale) in the reduction of future purchase costs. Though these are in the NIA models, not the LCC target models, so importantly do not have an impact on the target levels themselves;
- recent ECS rulings have included the societal cost of carbon in the NIA models;
- there appears to have been a small backtrack in 2011 on the target levels – going to MLCC to consumer, not the equivalent LCC (or maximum cost-effective savings) which had also been included in some earlier rulings;
- the MLCC ECS levels are likely to be short of the TFS levels proposed in the earlier definition;

- an important component of the US analytical framework is Max Tech, and is pertinent to TFS. A recent Max Tech analysis by LBNL (Desroches and Garbesi, 2011) suggests 200 Quads of energy could be saved if Max Tech levels were implemented.

The main benefit of this approach is that it is a ‘no regrets’ approach: the improvements in efficiency that are demanded by the regulation should not incur additional costs to consumers on average. The main disadvantage of this approach is the cost of undertaking such a detailed analysis for each product, and the review period and process of updating the standards since there is no automatic update or revision process.

4.2 EU Minimum Energy Performance Standards (Ecodesign directive)

Similar to the USA, the EU has developed minimum energy performance standards for a range of energy-using products. The legal vehicle is a framework directive at the European level (Ecodesign directive 2009/125/EC), which allows for implementing measures which are translated into appropriate national Member States regulatory instruments.

Prior to the EuP (or Ecodesign Directive), the EU had a cumbersome mechanism, and the two main MEPS measures (refrigerators and boilers) only removed the worst from the market and could not really be considered technology-forcing. This was a result of the policy-making process which allowed political negotiation or lobbying to have a large impact.

The New EuP standards (Ecodesign) are more ambitious and intend to deliver cost-effective technology change, and may be technology-forcing in that it may propose levels that are not currently on the market.

The EuP directive is part of Integrated Product Policy where:

- The policy levels are decided by a regulatory committee which considers views from a consultation forum into account. The underlying evidence and analysis is based on research projects or ‘lots’ which are contracted out by the European Commission;
- The analytical approach to target efficiency levels are similar to the US ECS, which are based on detailed engineering analyses (though smaller budget and consequently less detailed);
- Non-energy aspects are included in the Ecodesign methodology (VHK, 2005);
- A Best Available Technology (BAT) analysis is included, which is useful to show the currently known best technology;
- A BNAT should also be included in the analysis.

The intention and ambition of the EU programme is laudable; however a review of EUP implementation levels was undertaken by a campaign ‘cool products for a cool planet’ (CoolProducts, 2010) which suggested the implementing measures under EuP had not been sufficiently ambitious. They suggested that even Tier 2 levels of TV, domestic refrigerators and unidirectional lighting (except for lamps) standards were unnecessarily unambitious. The proposed levels for boilers and water heaters were also considered to be unnecessarily unambitious. They conclude that “The implementation of the Ecodesign Directive should more prominently and aggressively promote energy efficiency by requesting from manufacturers to put on the market products that are at least close to the most cost-effective solutions at the time of the entry into force of the measures. And the middle and long term requirements could be based on the level of the best available technologies of today”.

A formal EC-funded methodology and evaluation review is currently underway by CSES. Their final report has just been published (CSES, 2012). In terms of assessing the impact of measures implemented thus far, they have not added much, citing a lack of available data.

4.3 Japan's Top Runner

The Top Runner approach is an alternative (to the US and EU) approach to setting performance standards. A summary of the programme is:

- Starting in 1998, this is a different approach to improve efficiency of products, with over 20 products regulated from passenger cars, gas appliances, refrigerator/freezers, vending machines through to electric toilet seats;
- It is a dynamic approach where the leading products, plus some allowance for further likely improvement, become the targets for a future corporate fleet average. The fleet average targets are set some years ahead (average about 5-6 years but this varies by product);
- Manufacturers and importers have to report annually on all models being sold, though the smallest companies do not have to meet targets but have to report on them;
- Manufacturers and importers are required to co-operate with the standard setting process;
- Compliance is by 'name and shame'.

In terms of the impact of this scheme, there are some reports available by the various responsible committees (e.g. Energy Efficiency Standards Subcommittee, Advisory Committee for Natural Resources and Energy), for the different end-uses, all of which are available at http://www.eccj.or.jp/top_runner/index.html

There are very few detailed evaluations in the public domain; however an evaluation of Japan's Top Runner by Kimura (2010) suggested that the Top Runner approach:

- Is useful as it avoids the issue of poor updating of MEP standards (as was the case in Japan in the 1980s), so could be quicker;
- Is flexible, as standards can be set higher than the market leaders (during the setting phase) if technical analysis reveals this is possible. (e.g. this was done for AC equipment);
- Is flexible as it has been extended to include labelling aspects and retailer certification and supports other policies;
- Is not technology neutral, as there are different standards for different technologies (e.g. CRT is a different level than LCD), so this would not drive innovation within a technology group classification;
- Is effective, as a high compliance rate is reported, and no 'naming and shaming' undertaken;
- Has impact across the range and especially at the low end as it is cheaper to remove very inefficient models than improve efficient ones (shown for AC);
- Contains a risk of non-cost-effective models being developed or required (though regulation has a light touch to avoid this, ECCJ, 2008, p17);
- Is difficult for analysts to project the future of products (e.g. fluorescent lighting and TVs where target were easily met only two years after they were set, well ahead of the target date);
- Provided energy reductions in line or better than estimated, though detailed evaluation would have to extract the impact of other measures and factors;
- Is applied to the Japanese market, which is dominated by a limited number of domestic producers (which all have a high technology competency, so there is no risk of exclusion with higher targets).

In a separate review, Nordqvist (2006) for AID-EE also notes:

- There is a lack of information on costs or a full assessment of the effect in terms of energy savings. There are only estimates which limits the ability to do a full assessment;
- “A decisive success factor for the Top Runner programme in Japan is stakeholders’ – in particular industry’s – willingness and capability to co-operate extensively with the regulator and each other, devoting considerable time and resources in the process”;
- Only energy in use considered. There is no assessment of product effectiveness or of other impacts e.g. lifecycle analysis;
- There is a risk of challenge from WTO but this has not occurred. Mitigating factors may be that the Japanese regulator invites the World Trade Organization to review and comment on committee results, and importers’ organisations (when applicable) are given the opportunity to take part in the work of a Top Runner standard setting committee;
- No manufacturer uses the ‘fleet average’ aspect. All manufacturers remove all models from the market which do not achieve the standard, so it acts like a MEPS standard (so far);
- “Negotiations over standards are conducted, as much as possible, with individual manufacturers as participating stakeholders, rather than with branch organisations. The reason for this is the assumption that branch representatives, in these cases, would tend to defend the interests of the least good performer”;
- Lists success and fail factors.

One perceived disadvantage is that firms may not be so forthcoming with innovations if products they develop are to become the future standard level. This is a risk, but interestingly this does not seem to have happened in the Japanese case so far (from evidence available).

4.4 Renewable energy (portfolio) standards

Although not true technology-forcing standards these are considered, as renewable energy portfolio standards (RPS) have brought forward an expansion and commercialisation of renewable energy technology, which would otherwise not have happened – or at least more slowly.

An example of an RPS is the UK renewable obligation, which requires energy retailers to source a certain proportion of their supply from renewable sources. This proportion is set to increase in time (by around 1% per annum). These renewable sources are more expensive than convention sources (such as fossil fuels) or in some cases undeveloped technologies such as off-shore wind-farms.

In the UK, there is a clause to allow an energy retailer to buy-out their obligation (penalty) if a target cannot be met, which is fed back to those who do meet the target as a bonus. This is a useful mechanism which supports ‘good behaviour’.

A similar approach is used in many US states (some prior to the UK), and other regions (e.g. China). The obligation may also be placed on different parts of the supply chain.

Lessons learnt:

- Care needs to be taken that industry does not concentrate on short-term winners, e.g. large subsidies to develop the wind industry at the expense of other longer term options. In the UK this resulted in the introduction of technology banding, whilst in some US states the obligations is ‘carved out’ for some technologies.

4.5 UK climate change agreements (CCA)

The policy aim is for Energy Intensive industry to significantly reduce their energy use and carbon emissions. The scheme, which started in 2000, is based on industry sectors represented by trade associations which agree ever lower targets for energy use/emission reduction which have to be met in alternate years. Some targets are absolute, some relative (energy used/output). A discount in the Climate Change Levy (CCL) provides an incentive to join. More recently a further incentive has been provided by the exemption from being in the Carbon Reduction Commitment if more than a certain proportion of energy use is included in CCA.

A further overview and summary of the scheme is as follows:

- There is an enormous range of companies represented within the scheme from small and medium sized enterprises to sites which are part of multi-national organisations such as Tata Steel. The sectors also range enormously from those with hundreds of mostly small members to some with one or two large companies. The scope for companies to respond to targets, in terms of access to capital and to technological expertise, also varies enormously;
- To date, if a sector overall has passed all units (sites) within it, then it is deemed to have passed¹. It is proposed that this is changed in the revised scheme. If the sector fails a milestone target then the agreement is voided and the CCL reduction is cancelled;
- If a site is not likely to meet their targets through performance in the past they have to be able to meet them by purchasing UK ETS allowances. Allowances on the scheme have traded at low prices but most sites have met their targets directly whenever possible;
- Trading is one of a number of risk management tools available to sites, particularly at the start of the scheme. These have gradually been reduced over the course of the scheme;
- The issue of 'relative' versus 'absolute' is a relevant one (the 'currency' used). Defra (then the Department of Energy and Climate change, DECC) pushed for *absolute*- in order to achieve carbon emission targets. The Department for Business Innovation and Skills (BIS) pushed for *relative* in order not to restrict market growth or reduce competitiveness of UK industry, and ended up with both;
- Targets can also be expressed in carbon emissions² (with scope for reductions via fuel switching in principle although this has been used very little in practice) and in energy;
- Targets for sectors are reviewed about every five years (i.e. there have been two to date and targets are to be reviewed as part of the extension of the scheme beyond 2012);
- The cost of the scheme has only been assessed *ex-ante* in impact assessments. It is expected that the net cost to industry is positive. Some responses are 'no cost' (behavioural) and the perception is that new measures are installed which have pay backs of two years or less³ even without the FLL discount. The administrative cost is relatively low;
- It is recognised by DECC that the targets set have not been challenging and their contribution to innovation in energy reduction has been minimal. Both in sector target reviews and when setting targets for new entrants, DECC have suffered from information asymmetry – both in terms of the energy savings technically available to each industry/site and to the affordability of these measures to industry/site (compounded by the fact that there are so many different sectors requiring a huge

¹ Most sector associations have insisted that all members pass to avoid the risk of the sector agreement being voided.

² The carbon emission rates for different fuels are standardised and have been fixed since the beginning of the scheme so there is no 'windfall' reduction for sites with carbon targets for the reduction in carbon content of electricity.

³ Which most suites insist is the most long term investment for which they can get funding.

range of expertise to address). When negotiating sector agreements, dealing with the trade associations means that information is only presented on the lowest common denominator – information on the sites that have chosen to be more innovative is very difficult to come by. Component suppliers, who may offer innovative solutions, are not involved in the dialogue. And as the scheme is UK-only there is no opportunity for foreign competitors to intervene if they have relevant information;

- The proliferation of metrics used within sectors has restricted the use of benchmarking, which is one contribution to addressing the information asymmetry⁴.

Lessons learnt:

- Trade associations protect the weakest members so are unlikely to agree stretching targets;
- Information asymmetry between government and industry is hard to address when many different processes and sectors are involved (and even worse when there is no common metric within sectors);
- Information asymmetry leads to unambitious targets and low achievement of savings relative to the potential.

4.6 Phasing out of low-efficiency incandescent lamps

For over a century incandescent general service lamps (GLS) have been the main form of residential lighting. These types of lamps are now very cheap to manufacture (essentially a commodity) and provide a good quality light, though are inherently energy inefficient with known alternative technologies. As such, various regions around the world have phased out, or are in the process of phasing out, sales of these technologies.

Usually this is undertaken by setting a performance requirement for lamps above the efficiency threshold for incandescent (e.g. 12 lumen/Watt) through MEPS (rather than a specific technology ban), and this allows manufacturers to reach the levels in a flexible manner.

Other observations include:

- Although this policy development was not strictly technology-forcing, it did result in significant investment in the technological development of lamps, though some of the response in the short term has mainly been to develop halogen incandescent look-a-likes (which are not near current optimal energy performance levels, though they do have other desirable characteristics);
- GLS lamps are low value products. Industry is interested in selling higher value lamps, so are generally in favour of the phase-out;
- There is clear scope for much stricter longer-term TFS since LEDS are known to have the capacity for much higher energy efficiency.

Lessons learnt:

- Industry agreement makes it easier;
- It could be argued that sub-optimal development occurred by development of halogen incandescent look-a-likes, which could have been invested in higher efficiency lighting. That said, the first steps of savings were very cost-effective.

⁴ There is an analogy in products – where a ‘frost free’ fridge freezer with the same volume and energy use as a non ‘frost free’ can get a different energy efficiency label rating.

4.7 Banning of Ozone-depleting substances

The Montreal Protocol is widely considered as the most successful environmental protection agreement. The Protocol sets out a mandatory timetable for the phase-out of ozone-depleting substances. This timetable has been reviewed regularly, with phase-out dates accelerated in accordance with scientific understanding and technological advances. The treaty was signed in 1997 but strengthened through five amendments: London 1990, Copenhagen 1992, Vienna 1995, Montreal 1997 and Beijing 1999 - which have brought forward phase-out schedules and added new ozone-depleting substances to the list of substances controlled.⁵

The number of signatories to the treaty has increased over time and in September 2009 East Timor ratified it, making it universally supported and making it the first international environmental treaty to achieve complete ratification. This also eliminated the risk of 'leakage' which is a constant concern of current carbon treaties. The treaty has proved its success both in reducing emissions and in its effect on the ozone layer, the recent evidence for which was presented by the UNEP (2010) and Mäder *et al* (2010).

The Montreal Protocol sets binding progressive phase-out obligations for developed and developing countries with developing countries allowed more time to respond. Developing countries have also benefited from support from a Multilateral Fund set up to implement the phase out of ODS, created in 1992. Funds are used, for example, to finance the conversion of existing manufacturing processes, train personnel, pay royalties and patent rights on new technologies, and establish national Ozone Offices. To date more than US\$2.3 billion has been approved to support more than 6000 projects and activities in 148 developing countries.

The success of the treaty was not obvious initially. When an agreement was first proposed, there was strong resistance from industry. Sunstein (2007) describes how the intense media attention and voluntary public response (dramatically reducing their use of aerosol sprays), together with growing scientific evidence of ozone depletion brought a change in attitude of industry and Government in the USA (who were responsible for 50% of emissions). He states that when safe alternatives to CFCs were developed, some manufacturers, such as DuPont, pledged to phase out CFCs and supported an international treaty. Miller (1990) takes a less positive view of the US industry response. He states that manufacturers were aware of substitutes to CFCs as far back as 1980, initially asserting that these were not feasible but as regulation threatened in 1986, said that they were possible with supportive government action. Miller also relates the effect of regulation on estimates of the cost of compliance: in 1989, once a worldwide interest in phasing out all CFCs was clear, the US EPA estimated that the cost of this was less than their initial estimate of the cost of 50% phase-out. DeCanio (2009) also notes that the *ex-ante* estimates of cost were higher than *ex-post* because of unexpected and unpredictable technological progress, learning-by-doing, and economies of scale.

Miller stresses the importance of the public-private partnership in the achievements of the Montreal Protocol. This point, i.e. engaging the private sector effectively, is also made by Heaton *et al* (2006) and Parson (2002). Heaton refers to two collaborations to test alternatives to CFCs: AFEAS (Alternative Fluorocarbons Environmental Acceptability Study)⁶ and PAFT (Programme for Alternative Fluorocarbon Toxicity Testing)⁷. There was Government involvement (from the USA, EU and Japan) but the core was a collaboration involving all 17 major industry players, who pooled resources rather than each carrying out their own environmental and toxicity testing programmes. This enabled a much faster and more cost-effective introduction of CFC alternatives than would have taken place otherwise.

⁵ Text taken from <http://www.environment.gov.au/atmosphere/ozone/legislation/montp.html>

⁶ For more information, see <http://www.afeas.org/>

⁷ A summary of PAFT's work is at http://www.mexichemfluor.com/europe/download/M_PAFT.pdf

Parson⁸ focuses on the importance of the Technology and Economics Assessment Panels (TEAPs). These were set up, in some haste, at the time of the signing of the protocol. Parson claims that due to the speed in setting up “they had a lot of freedom. They were permitted to choose participants, carry out their work, and prepare reports to the parties with little political oversight--independence that greatly enhanced their effectiveness.” Initially they excluded the private sector but this was changed in 1990. They organised into separate work groups for each type of ozone-depleting chemical, and they evaluated the potential of specific technologies and operational changes that might reduce chemical use in specific applications. Participants came from industry but also from academia, government, and NGOs, operating with antitrust protection. Companies offered their experts’ time because they saw a number of benefits to themselves through their collaboration. The intense involvement of the private sector avoided the information imbalance that restricts the ambition of standards-setting in many regulations.

Conclusions

The regulation did cause technology-forcing. Alternatives to CFCs in most applications were developed and commercialised, which would not have happened purely through voluntary action.

Lessons learnt:

- Strong public engagement and scientific evidence of need for action enabled widespread international agreement with strong targets;
- Regulation set the goal but did not specify the solutions, which developed in response;
- Frequent reviews of the targets meant that they were kept ambitious and feasible. Decisions could be based on current evidence. The strong involvement of the private sector acting collaboratively with each other and with Government (via AFEAS, PAFT and TEAPs) was important (maybe even crucial) to increasing the speed and reducing the cost of response, ensuring research did not go down ‘blind alleys’ or get held up by IP issues;
- The differences in requirements for developed and developing countries and financial support from of the multilateral fund enabled the involvement of the latter. This parallels to different tiers of requirements for SSL in IEA 4E annex;
- The cost of compliance was significantly lower than initially anticipated.

4.8 Clean Air Act (1970)

The Clean Air Act was explicit in its performance target and the implementation process. Congress required a 90% reduction in tailpipe emissions (HC and CO by 1975 and NO_x in 1976), with a high sanction/fine per car sold that did not meet the requirement. The implementation was done by EPA, which had little flexibility owing to the nature of the regulations. The act is considered a success, though it should be noted that these standards were not fully met until 1993 (almost 20 years late) with difficulties meeting the levels, and legal challenges by the industry to try to delay implementation.

Gerard and Lave (2007) compare the results of the 1970 Clean Air Act (administered by the EPA) against the US Secretary of Transport’s 1969 decision to force manufacturers to introduce air bags (administered by NHTSA). Even though one standard relates to emissions and the other to safety, the timing, costs and technical complexities were the same, though the outcome was quite different.

⁸ The benefits of this approach are also described by Andersen (1997) and Milford *et al* (2008).

Table 1: Comparison of catalytic converters and airbag introduction

Variable affecting TFS	Clean Air Act 1970 (catalytic)	DoT 1969 airbag mandate
Technology cost	\$200-250	\$235 (GM)
Asymmetric information	EPA erases advantage	GM reveals information
Regulatory mandate	Legislative (congress)	Regulatory (agency)
Raise rivals' costs		Yes
Non-compliance	EPA 'winks' at Chrysler	?
Liability concerns	recalls	Yes

Source: Gerard and Lave (2007)

Lessons learnt:

- Strong regulatory (EPA) worked better than a voluntary approach (NHTSA);
- The congressional mandate supplied considerable credibility to the regulatory agency (EPA in this case);
- Getting information on the technology required can erase the problem of asymmetric information. Any asymmetry can mean a delay or reduction in performance levels. Though in the comparison this was not a decisive factor;
- Political and regulatory factors of the implementation process were decisive in this case;
- Competition can drive manufacturers to develop technology early, either by reducing cost (competitive advantage) or technology suppliers providing information insights to regulators;
- A get out clause is needed if the target is nearly reached, though some pragmatic flexibility is necessary;
- The adversarial nature of TFS means courts may be involved.

4.9 Zero emission vehicles in California

The California Air Resources Board (CARB) first adopted the zero emission vehicle regulation in 1990 as part of the low emission vehicle regulation. Manufacturers are required to produce a fraction of their sales as ZEV or ZEV-enabling products. The 2012 amendment requires that 15% of sales by 2025 need to be ZEV or PHEVS.

This is an interesting policy measure as it was very challenging for industry to achieve, and some consider overly-so. There have been various analyses of this policy: Collants and Sperling (2008) describe The California Zero Emission Vehicle (ZEV) rule, adopted in 1990, as “arguably one of the most daring and controversial air quality policies ever adopted.” This paper also addresses how such policy came about and survived. Two quotes from the paper have been extracted directly, as they directly address two important questions for the current study.

Policy analysis:

(1) Why did the regulatory agency choose a mandate as the policy instrument? Our analysis shows that the central factor was distrust. CARB felt that no other policy mechanism could extract the best effort out of car companies to develop and commercialize BEVs. As one interviewee described, mandates were a more common and accepted part of the policy/political language before Newton Gingrich and the 1994 “Republican Revolution.” Under current circumstances, a policy like the ZEV mandate would have little chance to enter the language of any regulatory proposal, let alone be adopted. To understand the mandate, it is thus important to first understand the policy attitudes at that time.

Another factor explaining the choice of a rule based approach was CARB's simplified characterization of previous regulatory experiences. Technology-forcing, command-and-control regulations had been effective in bringing catalytic converters to market. Their thinking was: Why not for ZEVs also? CARB did not fully appreciate the differences in cost, market acceptance, and technological challenge.

(2) How did such a radically innovative policy idea survive the adoption process? The answer resides in the complex convergence of a set of factors and events. Our analysis shows that the mandate survived because it was a very small fragment of the much larger and very important Low Emission Vehicles and Clean Fuels program. The LEV proposal included challenging emission requirements for automakers with earlier compliance deadlines, and pressing alternative fuel requirements for oil companies. The program also allowed for biennial reviews, meaning the car and oil companies could fight the ZEV battle later.

They could focus on more pressing issues such as the ULEV emission standards and methanol fuel requirements, which affected many more vehicles and much more fuel sooner in time.

Another very important factor that eased opposition to the ZEV mandate was General Motors's alleged intention to produce a zero emission vehicle. It encouraged CARB staff to proceed with the rule, and defused claims by GM and other automakers that the technology was not feasible.

The convergence of the three streams, the creation of a window of opportunity, and the lead of a policy entrepreneur were, according to our analysis, necessary, though not sufficient conditions for the ZEV mandate to happen. A number of factors not contemplated by Multiple Streams, including embedding a requirement on radical innovation in a broader regulation, were essential for the mandate to reach implementation. The implications of such additional factors for policy adoption may have been unplanned but, because they are replicable, provide useful lessons for future policy processes.

Source: Direct quote from Collants and Sperling (2008)

4.10 USA SO_x emissions reduction via cap and trade scheme

Initially in the US (from 1970 onwards) SO_x emissions from electricity generating plants were controlled by regulation with maximum levels set for existing plants and new, more stringent, performance standards set for new builds. From 1978 onwards these required the fitting of capital-intensive flue gas desulphurisation plants (or scrubbers for short). In 1990 the Clean Air Act moved away from regulation to a cap and trade system, setting a cap on aggregate emissions and allowing a trade in marketable permits or allowances. The final goal was to halve the emission from the 1980 levels. Initially in 1995 the 110 most polluting power plants were included, followed by all fossil fuel plants greater than 25MW capacity in 2000.

SQW (2007) quote the results as a reduction of SO_x emissions between 1990 and 2001 of 32%, and with assessments showing that this was greater than would have been expected under a no action case. Assessments by Carlson *et al* (2000) and Ellerman *et al* (2000) (as reported by SQW) both found substantial cost savings relative to a regulatory approach and while the allowance price has fluctuated, it averaged at US\$170 per tonne in phase II which was much lower than the EPA *ex-ante* estimate of marginal abatement cost. However Burtraw *et al* (2009) attribute at least some of the cost decrease to the reduced cost of low sulphur coal and natural gas, not to the trading mechanism itself or any resulting technological innovation. Although they also note that under a regulation which required scrubber installations⁹ the cost advantages of these would not have been accessible.

SQW report that the biggest criticism of the scheme was the cap, which had been set by Congress with no provision for revision. It is claimed that the scheme generated process innovation (Burtraw, 2000 and 2004, quoted in SQW) whilst recognising that little patentable innovation in abatement technologies was generated. Two process innovations were: increased

blending of fuel (high and low sulphur coal) and scrubbers operated without backups (which reduced capital costs).

Taylor *et al* (2005a) make a strong case that regulation, not trading schemes, is the mother of invention. They take the case of SO₂ control in the USA and make recommendations on policy approach using data on: policies proposed/ applied, public R&D funding, patent filings, conference/research collaboration, and cost and effectiveness of scrubbing units. They conclude SO_x trading had little effect; and that sufficiently stringent regulation (or the threat of it) which is not committed to a particular technology, and is reviewed appropriately, works best. The key aspects of policy should be:

1. It should be technologically flexible.
2. It should maximise the number of likely innovators engaged in improving the technology. (This argues against emissions trading programs since, as Driesen (2003) points out, such instruments provide equal measure of under-compliance as over-compliance incentives, inducing less innovation than a performance-based standard in which everyone had an incentive to comply).
3. It should be stringent enough that it can take advantage of the old adage that “Necessity is the mother of invention.” Regulatory stringency, as illustrated in the SO₂ case, is tied to increased collaboration within the research community across organisational types.

Taylor *et al* (2005b) adds more detail and, in analysis of patent activity, found that the effect of demand ‘pull’ (legislation/regulation) was much greater than the technology ‘push’ (government R&D funding). “The implication of this is that an “RD&D and wait” environmental policy—one that invests in RD&D and otherwise does not require environmental performance until environmental technologies have matured—is likely to find environmental improvements either a long time in coming or dependent on the innovative activities of other nations.”

Conclusions

The introduction of SO_x cap and trade in the USA did introduce process innovation which reduced costs relative to those anticipated, but at least some of this reduction was a windfall from the reduced cost of low sulphur coal and natural gas. From the literature it is difficult to judge the level of stringency of the cap, although the degree of banking in phase I suggests that the cap in this phase was too low. While opinions differ, SO_x trading does not make an unequivocal case for a trading system being more cost effective or generating more innovation than regulation.

Lessons learnt:

- If regulation (or a trading cap in this case) is used, it should be technology-neutral, should be flexible and have the capacity to be adjusted in response to the developing situation/new evidence;
- Process innovation can be as important as technology innovation.

4.11 English Building Regulations – zero carbon by 2016

Building regulations place requirements on builders of new homes, and also some retrospective work of homes.

- Since 1965 building regulations have been used by the British Government to reduce energy (as well as other requirements)¹⁰;
- England has had multiple iterations of building regulations, with recent increased frequency, and with increased emphasis on energy (e.g. 1986, 1991, 2002, 2006, 2010/11);

¹⁰ Scotland and Northern Ireland have had separate regulations for some time – Wales since 2011

- A zero carbon standard was agreed for 2016. Specifically, for any new build houses, the carbon emitted during a typical year should be balanced by renewable energy. This standard was considered very challenging (the UK being the first country in the world to set such a standard). The final details have yet to be pinned down, so cannot be determined an unequivocal success just yet;
- These are forcing standards that are beyond what was previously considered good or even best practice in the UK, and incur some costs, at least initially. So they will drive the building industry;
- Recent changes in ambition:
 - In the 2011 budget, the chancellor made 'zero carbon' have a less stringent definition, down to level 5 (on the Code for Sustainable Homes). To attain a level 5, a home must only be 'zero carbon' in its emissions from fixed heating and lighting. For a level 6, the home must also be carbon neutral in its emissions from fixed heating and lighting as well as home appliances (this involved a requirement of renewable energy sources such as solar panels to offset the energy requirements of home appliances);
 - The Code for Sustainable Homes rated from 1 (slightly more efficient than then current in 2006) through to 6 (zero carbon). The aim was to go to level 6.
- The EU is also currently grappling with the issue of what 'zero carbon means' under the Energy Performance of Buildings Directive.

Lessons learnt:

- Since early regulation, there has been a focus on energy service rather than on specifying technology or elements (e.g. requirement of 10mm of insulation). Industry has been allowed to decide on the way to achieve any target levels, rather than policy being prescriptive and 'picking winners';
- Frequent revisions of the regulations means industry is expecting the ratcheting effect. This can be beneficial in terms of industry preparing for change, but can also mean industry putting brakes on these revisions;
- It requires strong regulation and government to see through ambitious changes.

4.12 Other forcing regulations

There are other technology-forcing regulations which could be examined, and these include:

- Banning of phosphates from washing detergents;
- Banning of PCBs in chemical industry regulations.

4.13 Summary of lessons learnt from examples

The lessons learnt from these examples can be grouped as follows:

1. Flexibility is important:

- Care needs to be taken that industry does not concentrate on short-term winners e.g. for large subsidies to develop the wind industry. In the UK this led to the introduction of technology banding. In some US states the obligations (Renewable Portfolio Standards) are 'carved out' for some technologies;
- Regulation sets the goal but does not specify the solutions, which develop in response (Montreal Protocol);
- The differences in requirements for developed and developing countries and financial support from the multilateral fund enabled the involvement of the latter. This parallels to different tiers of requirements for SSL in IEA 4E annex (Montreal Protocol);
- Frequent review of targets meant that they were kept ambitious and feasible - decisions could be based on current evidence. The strong involvement of the

private sector acting collaboratively with each other and with Government (via AFEAS, PAFT and TEAPs) was important (maybe even crucial) to increasing the speed and reducing the cost of response, ensuring research did not go down 'blind alleys' or get held up by IP issues (Montreal Protocol);

- A get-out clause is needed if a target is nearly reached. Some pragmatic flexibility is sensible (US Clean Air Act);
- If regulation (or a trading cap) is used it should be technology neutral, should be flexible and have the capacity to be adjusted in response to the developing situation/new evidence (USA SO_x trading);
- Process innovation can be as important as technology innovation (USA SO_x trading);
- There is a focus on energy service rather than a specific technology or element. That is, let the industry decide on the way to achieve any target levels rather than being prescriptive and 'picking winners' (England zero carbon homes);
- Frequent revision means industry is expecting the ratcheting effect. This can be beneficial in terms of industry preparing for change, but can also mean industry putting brakes on these revisions (England zero carbon homes).

2. Strong regulation/public support necessary:

- Strong public engagement and scientific evidence of need for action enabled widespread international agreement with strong targets (Montreal);
- Strong regulatory approach (EPA) worked better than a voluntary approach (NHTSA) (US Clean Air Act);
- The congressional mandate supplied considerable credibility to the regulatory agency (EPA in this case) (US Clean Air Act);
- Political and regulatory factors of the implementation process were decisive in this case (US Clean Air Act);
- It requires strong regulation and government to see through ambitious changes. (England zero carbon homes).

3. Degree/nature of industry co-operation is key:

- Trade associations protect the weakest members so are unlikely to agree stretching targets (UK CCAs);
- Information asymmetry between government and industry is hard to address when many different processes and sectors are involved (and even worse when there is no common metric within sectors, UK CCAs);
- Information asymmetry leads to unambitious targets and low achievement of savings relative to the potential (UK CCAs);
- Industry agreement makes strong action easier (inefficient lamp phase-out);
- Getting information on technology required can erase the problem of asymmetric information. Asymmetry can mean a delay or reduction in performance levels, though this was not a decisive factor (US Clean Air Act);
- Competition can drive manufacturers to develop technology early – either by reducing cost (competitive advantage) or technology suppliers providing information insights to regulators (US Clean Air Act).

4. Other

- The cost of compliance was significantly lower than initially anticipated (Montreal);
- The adversarial nature of TFS means courts are involved (US Clean Air Act).

5 Types of technology-forcing for appliances and equipment

This section will try to suggest the type of technology-forcing standards that are likely to be most effective in stimulating energy efficiency in appliances and equipment. This may be different for different types of appliances and other factors, such as the structure of the industry.

Historically, for appliances and equipment, the main types of technology-forcing standards (in the broadest sense of the term) include the following:

- Mandatory energy performance standards based on engineering analyses;
- Fleet average efficiency performance standards (most have been industry agreements);
- Japanese Top Runner.

MEPS/ECS are now widely used: globally over 100 products are regulated in such a way. They are usually based on an engineering examination of the life cycle cost to the consumer (LCC), where:

$$LCC = \text{purchase cost} + \text{operating cost} + \text{maintenance cost}$$

The minimum of this curve is usually used to determine the point at which to set the MEPS/ECS standard. To undertake such engineering analysis properly is expensive (in the order of US\$1million upwards, and more for more complex products), though the cost is usually covered by reduced running costs. It requires government/regulators to pay for this analysis and the benefits are for consumers, society and the environment.

These have proved to be very effective (e.g. a detailed evaluation by Lane and Harrington, 2011, shows significant reductions in energy by successive rounds of MEPS on refrigerators in Australia).

In some cases an engineering analysis does not show any cost-effective improvements beyond what is already on the market. In this situation, the Japanese Top Runner can be useful in setting more stringent standards.

Regardless of the standard approach (whether engineering-based MEPS or a Top Runner style), there are other factors that should be considered:

- A focus on services, rather than technology:
 - Heating boiler at full load;
 - Standards are split by technology type, e.g. refrigerator (42 types in US).
- A removal of correction factors.

Importantly, any technology-forcing standard should be technology neutral so that the supply chain can truly innovate. This approach is generally recognised, however there are many cases where this does not happen. Different standards can apply to different types of products. Examples include:

- Prior to the Ecodesign regulations, the EU treated vented and condensing tumble dryers differently, where one is given a 10% allowance on the energy label;
- The US top loading and front loading washing machines have different standards;
- US rulings have different standards for its 42 different types of the same product (refrigerators);
- Australia has different standards for fridge-freezers with different configurations (side-by-side versus top mounted freezers);

- The Japanese Top Runner Programme sets different performance levels for different technology levels.

If stronger target levels are to be set, longer lead times may be required. Increasing the lead times to the effective dates of policies is a risk, specifically:

- If the target is easily met, then there may be lost revision time;
- Or too stringently, and the industry does not try to reach the target.

In these cases, there may need to be some review mid-way through the period.

Additional flexibility may be afforded to the supply chain by means of using fleet averages, rather than targets that every product must reach. This is a feature in the Japanese Top Runner Programme (though not yet used, as to date all products have reached the target). Including this feature will indeed make it easier (greater flexibility) for suppliers though mean a greater challenge for the regulator to check if targets are being met. A strict standard for every product means a regulator needs to find only one non-compliant product to prove a standard has not been met.

Other wider approaches could be considered, though this is outside the scope of this current analysis. A complementary approach to standards on a product or company level is to include a trading mechanism. This may be difficult to introduce at a product level, though such aspects are being considered (such as white certificates used for energy efficiency obligations). Even wider would be to make use of emissions caps at the person or household level through schemes such as personal carbon allowances. Similarly, there could be carbon caps at the energy supplier level. Of course caps do exist at the national level (at least in principle, and even 'legally binding' at the UNFCCC level), though there is a potential disconnect between these targets and actions by actors improving the efficiency of appliances. It appears that only at the regulation stage is the cost of carbon included in assessments.

Other factors to consider:

- Speed of technology change;
- Potential savings;
- Likely costs;
- Use of correction factors or technology bins in product regulation.

Current MEPS in the EU may not be reaching their potential. One option is to use the current regulatory structure (policy vehicle) and have stricter requirements. That is, to move towards Max Tech performance (or BNAT) levels, and make cost less of a decisive factor. This would be a step towards true technology-forcing.

A further enhancement would be a requirement to have quicker review periods for updating the performance levels. However, there is a cost incurred for the update process, so a balance needs to be struck between the extra cost and additional benefit gained.

6 Identify relevant end-uses for TFS standards

This task is challenging because TFS can conceptually be applied to all energy end-use applications, or energy services. In this task we have identified several types of product where TFS may be more appropriate in the near term.

Before a particular end-use (delivered by an appliance or equipment) can be considered for TFS (or even stringent MEPS), certain criteria need to be assessed and fulfilled. The main conditions that need to be met include:

- Appropriate testing protocols and experienced facilities are made available;
- At least one technology pathway is known;
- The potential for increased cost risk is low.

Appropriate testing standards required

A prerequisite for TFS and other product policies is a testing method that is satisfactory. Usually, this means that the test is reproducible and representative and not technology-specific. These standards need to be sufficiently robust and future proof so that there are no exclusions and issues of definitions and scope after a period of time, say 5-10 years. Without this, it is difficult to set any legally binding targets. This is more challenging as the testing standards need to be appropriate for high efficiency products or services, which may be used in a different manner.

'Dynamic' products with known future technology

Where there is a known technology that could be delivered and applied relatively cheaply (but is not currently being used in a particular end-use), then these could be candidates for stricter standards. An obvious example is lighting, where expected developments in LEDs could mean much higher efficacy lamps at low costs. Providing standards at this stage may trigger research and development, which may give some firms a competitive advantage, especially those who can develop these technologies at a lower cost. Similarly televisions and monitors may also be significantly improved with developments, such as more efficient back-lighting.

Established products where risk of high new technology cost is low

There are some established products where a known technology is expected to be a little beyond cost-optimal based on currently known costs. Where the costs for the new technology are not that much, then a technology-forcing standard may be considered appropriate. This would then allow innovative companies to develop at lower costs and gain a competitive advantage.

System approaches which contain products

There are some products which sit within systems, where it can be more effective to optimise the system than focusing effort on the equipment alone. Examples include:

- Building regulations, which already include end-use requirements, rather than specific technologies (or standards on specific elements);
- Industry agreements on processes.

For these systems it is more challenging to make requirements using product policy; though examples do exist, e.g. for heating systems and standardised production processes. However, the regulation may be more effective if done on a wider basis; for example, the assessment of performance of a new building, or the annual emissions of the entire house, or person, or process.

Using these criteria it is possible to make an initial assessment of which products would be suitable for TFS. In essence any product which is currently covered by a MEP or Japanese Top Runner would be eligible to be considered for a more stringent TFS.

4E Research Overview of Technology-Forcing Standards for Energy Efficiency

Using these requirements it is possible to generate a *TFS-suitability assessment* table - Table 2.

Table 2: End-use TFS-suitability assessment table (example)

	Test standards	Known future technology	Cost risk low	TFS relevant	Comment
Lighting	Needs development, LED.	YES	YES	YES	After testing standards in place
Television	Yes. Though features may complicate.	Yes	?	Yes?	
Clothes washers	Usually specify temps	No?	?	No?	Lower temp and detergents more savings
Refrigeration	Yes	yes	Yes	Yes	
Small scale AC	Yes	Yes	Yes	Yes	
Heating		Yes?	Yes	Yes	

From this very simple analysis, it should be apparent that regulators and government agency staff could examine the use of TFS for a variety of electrical energy end-uses. There are some products which warrant further investigation as near-term targets, which include:

- Refrigeration;
- Small-scale air conditioners;
- Lighting;
- Television;
- Heating.

The 4E Implementing Agreement has several Annexes on lighting, motors and standby that could be explored using the TFS concept, when developing options for future global co-operation. The Super Efficient Appliance Deployment initiative also has a number of collaborations (e.g. for televisions and computers), while the Asia Pacific Economic Cooperation has partnered with air conditioning industry interests in the past to address efficiency issues. The 4E Implementing Agreement could explore interest from these other gatherings of government officials in the TFS approach as a means to foster international endeavour and avoid duplication of resourcing.

7 Potential target performance levels

With a government policy emphasis on the energy efficiency of products over the last 20-30 years, a noticeable improvement in the average efficiency of products sold is readily apparent for many appliances. So how far can efficiency take us? Some economists have suggested that there are some immediate technological limits to efficiency improvements. Whilst there are some physical limits to the advances that can be achieved in energy efficiency for some end-uses, it would appear that we are still far from reaching them. This issue is examined in Laitner's "How Far Energy Efficiency: Practical Limits or Policy Choices?" (Laitner, 2004) where he provides a rebuke to economists who suggest technology limits. Interestingly, and perhaps mischievously, Siderius (2011) has even suggested that future targets could be set at zero or near zero.

These statements of ambition, however, will flounder without detailed assessments in the context of individual product types. Within that context, on how TFS could work, this section will examine and suggest some potential target performance levels, either at the product or energy service level, along with relevant timeframes.

Proposing an ambitious potential future efficiency level is a challenging task. In general any energy efficiency potential (the TFS target) usually increases with:

- Increasing energy prices;
- Economies of scale;
- New technologies becoming available (through innovation).

There are a few existing pieces of research that could be used to try to infer future levels, such as engineering analysis, technology road maps, and results of literature reviews. For example, the following provide some evidence for potential target levels and time frames to delivery:

- The IEA Energy Technology Perspectives (ETP) roadmaps;
- EUP research studies examine technology options (especially Task 6 on technical options and BAT, and Task 7 on combining technical options);
- US ECS levels (especially the highest TSLs, and Max Tech levels);
- Desroche and Garbesi (2011) provide a list of Max Tech levels for different products;
- Latest Japanese Top Runner reports, summaries of which are available at http://www.eccj.or.jp/top_runner/index.html.

The above provides some sources for potential targets and timescales for end-uses. A few of these are used to develop proposed TFS target levels for some end-uses.

7.1 Lighting

It is expected that Solid State Lighting (SSL) is the technology with the potential to provide light of satisfactory quality with the greatest energy efficiency. For example Navigant (2010) predict that the highest efficacy from the non-SSL lamp producing 'white light' (i.e. excluding high and low pressure sodium), from a T5 fluorescent tube to be in 2030 to be 99.8lm/W, (a 5% improvement from 2010). In contrast the EU EcoDesign studies, (VITO, 2007; 2008) identified that around 300 lumens/Watt is the theoretical limit, whilst the US DOE (2011) give the theoretical limit as 350-450lm/W.

The draft 'tier 3' (i.e. current Best Available Technology) specifications for efficacy circulated by the IEA 4E SSL Annex (2011) are shown below.

Table 3: Current best available technology - SSL

Type	Efficacy in lm/W
Omnidirectional	> 80
Directional	> 60
Downlight	>70
Linear replacement	>120

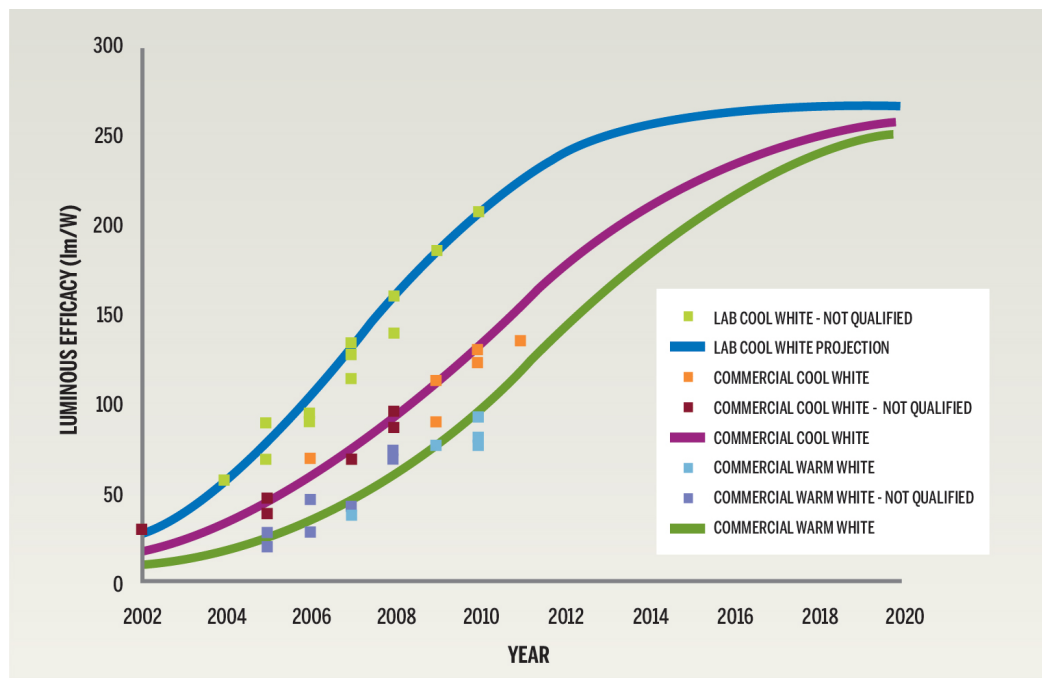
Source: IEA 4E SSL Annex (2011)

This suggests that for the same application the SSL BAT alternative has already surpassed the ‘conventional’ alternative (the T5 linear fluorescent tube).

The EU Topten site¹¹ has LED products listed for LEDs but the authors consider that the IEA 4E Annex draft specifications are a better indication of current BAT. Top Runner has current standards for CFLs and fluorescent tubes but not for SSL (LEDs).

The latest US DOE projections of increase in efficacy to 2020 are shown below.

Figure 3: White light LED package efficacy targets: laboratory and commercial



Source: US DOE (2011), Figure 5.4

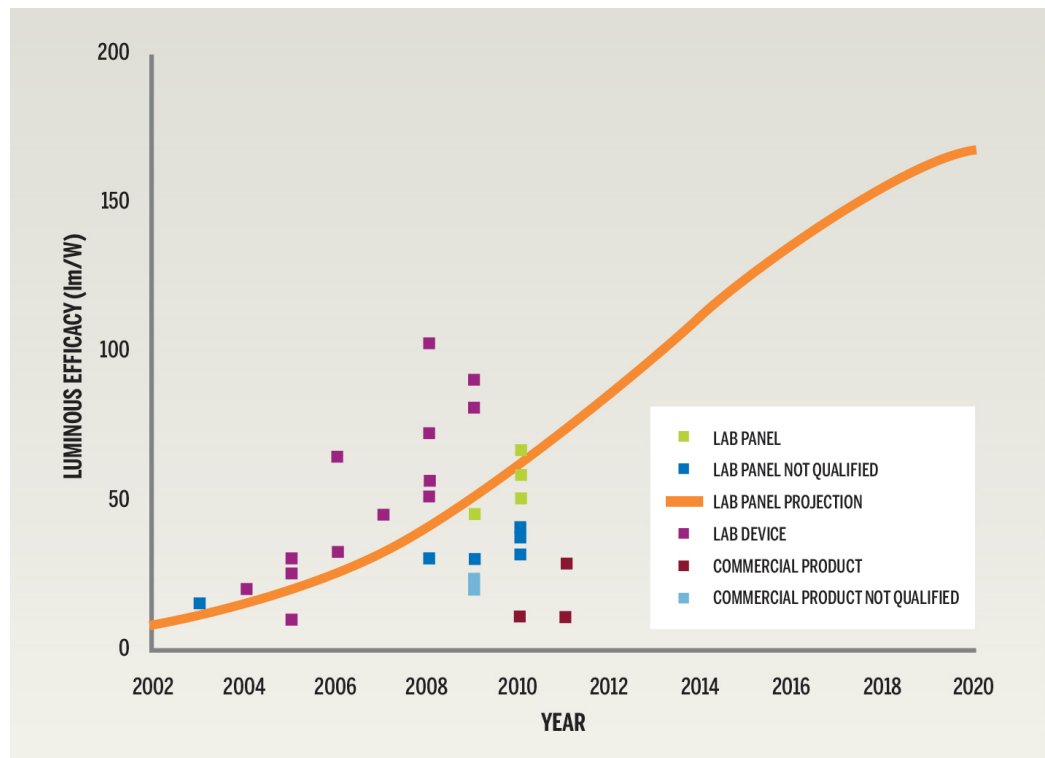
Notes:

1. Cool white: CRI 70-80; CCT 4746-7040 K
2. Warm white: CRI 80-90; CCT 2580-3710 K
3. Current density: 35 A/cm²
4. These results are at 25°C package temperature, not steady state operating temperature. Thermal sensitivity will reduce efficacies by 24% or so in normal operation, depending on luminaire thermal management.

The equivalent graph for white light OLEDs is shown below:

¹¹ <http://www.topten.eu/>. Neither the USA nor Chinese sites currently (December 2011) have lamp information.

Figure 4: White light OLED panel efficacy projections



ECEEE (2010) noted that the improvement in LED performance was faster than that expected in the eco-design studies published in 2009. Defra (2011b) reviewed a number of sources and projected a lamp efficacy of 263lm/W in 2020 (increase in EE on current of 43%) and 290 lm/W in 2030 (increase of EE to current of 48%). All these efficacies are for white sources which have colour rendering (or colour temperature) at least as good as conventional lamps and better than CFLs and fluorescents.

There are also a number of other criteria which need to be met for high consumer acceptance, high usability, low environmental impact, low impact on the electricity supply network and therefore contribute to a successful switch from 'conventional' sources. For example, the following factors are included for directional lighting (list mostly taken from IEA 4E SSL spec, though not in any order of importance):

- Lag start time;
- Dimmer compatibility;
- Flicker index;
- Photobiological hazard class;
- Glare luminance;
- Centre beam luminous intensity;
- Colour spatial uniformity;
- Harmonic distortion;
- Power factor;
- Recyclability;
- Colour maintenance;
- Lamp lifetime.

When setting standards for SSL these factors will need to be considered alongside increasing efficacy in order for effective market transformation.

Finally, light delivery is about more than just lamp efficacy. The very different form of SSL sources, both LEDs and OLEDs, means that there has to be innovation in light delivery (such as luminaire design). For example US DOE (2011) gives a projected OLED panel efficacy in 2020 of 168lm/W but a luminaire efficiency of 148lm/W. Good design in luminaire will be crucial to realise the full advantage of the increase in lamp efficiency, particularly as, unlike for incandescent lamps, the lamp for SSLs is expected to last as long as the luminaire/fitting. It will be important to stimulate innovation in luminaire as well as lamp design.

Conclusion

With a defined technology path for innovation there is plenty of scope for increasing the energy efficiency of lighting. The innovation needs to take into consideration the delivery of light (luminaires) and other consumer and environmental issues, as well as energy efficiency, to be fully effective.

7.2 Televisions

The efficiency of televisions has improved dramatically over the last few years, especially with the move away from CRT technology and a transition towards LCD flat-screen technology. The efficiency gain from improved backlighting (from CCFLs to LED) has driven much of this improvement of flat panel technology.

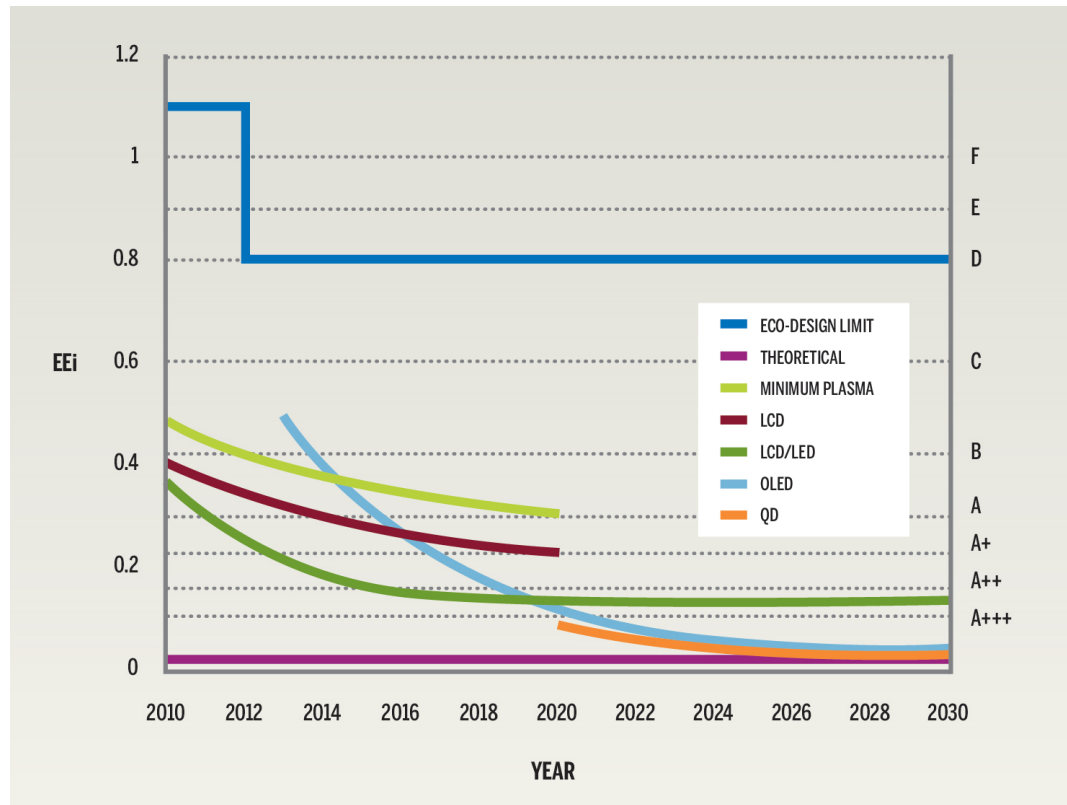
Historically, different testing procedures made it difficult to benchmark products internationally. However, this is increasingly possible with transition to the IEC test method. Still, an issue is how to show efficiency. The ratio of power/screen-area is the usual metric, though this metric tends to favour larger televisions. The EU uses an efficiency index (EEI) to overcome this, whilst Australia has a similar approach.

Useful data sources on performance levels and design options can be found at:

- EuP task 7 on design options (Fraunhofer, 2007a);
- Latest Japanese Top Runner at http://www.eccj.or.jp/top_runner/pdf/tr_tv_jul.2009.pdf;
- 4E M&B of televisions.

Future technology will be mainly driven by improvements in backlighting, and this is well captured by a recent analysis for Defra (2011b), which provided a likely projection of television efficiency as delivered by different technology types. See Figure 5 which also shows the recent Ecodesign MEPS level.

Figure 5: Projection of television technology (European Energy Efficiency Index, EEI)



Source: Defra (2011b)

Conclusion

The Defra (2011b) analysis shows that it is difficult to put effective MEPS in place for the case where technology is evolving quickly and where the regulator has poor access to knowledge. This has been grappled with by EU, US/California and Australian regulators. Setting a long-term target could prove difficult with a product evolving so quickly. However, there are apparently significant savings opportunities using LED and OLED technologies. In the longer term quantum dots (QD) may provide even further opportunities.

Other aspects may also need to be considered. Even if the products perform well under current standard IEC tests, they may well be being used differently by consumers in the home, e.g. the 3D mode may consume significantly more power in this mode than in the recent standard (IEC) testing method.

7.3 Heating products (boilers)

Setting mandatory efficiency requirements for heating products is a non-trivial task, as is evidenced by the protracted decision to implement Eco-design requirements for boilers at the EU level (the preparatory study - Kemna *et al*, 2007- reported on this five years ago and there is still no implementation measure in place).

Historically, the performance requirements for boilers were based on full operating loads, which are easy to test and provide benchmarking comparisons. However, using such conditions may not be the best approach to identify where the most amount of savings are available, since such operating loads are increasingly not realistic of actual equipment usage in the home and many boilers are reaching their efficiency limit (above 90% at full-load).

The specification of very stringent standards may have some impact on combo uses that can be perverse, e.g. by specifying a heating condensing requirement one may forsake some broader system impacts and opportunities from waste heat (this likely just requires careful drafting of the scope of the standard). Similarly, in well-insulated homes, traditional boilers may be ineffective, as they will rarely need to be running at full load. Combined systems with heat pumps may provide better alternatives, though other components of the heating systems may need to be addressed (e.g. the UK has small radiators which operate at a high temperature – a more effective system would be lower grade heat spread over a wider area, such as underfloor heating).

Additionally, from the perspective of the overall heating system, there are usually more savings from improving the fabric of the building. By examining the entire system there are options to switch to low carbon sources (if the aim is to reduce carbon emissions rather than energy *per se*). Improvement to the heat-generating equipment alone is not the only route to improving system efficiency (noting that the technology and policy options will be different for new buildings versus those needed for existing buildings). A recent IEA report (IEA, 2011) suggested key technologies are available today; though strong policy drivers (along with US\$3.5bn in research and development) are needed to deliver the changes required.

Thus, at a broader level performance requirements could be placed on the whole house. Indeed, ambitious performance targets have already been set at zero-carbon in the UK.

Conclusion

The efficiency measurement metric is an important issue. It cannot simply be a test measurement on the boiler at full operating load; since there are other types of heating products (e.g. heat pumps and solar thermal); and even for boilers this not a reflection of how high-efficiency products are used in homes. Importantly, there are still significant reductions in energy that can be made through more efficient heating systems, thus any metrics will need to account for systems and not just products. The technology pathway is also unclear, and is complicated by the focus of some governments on reducing carbon emissions, not just energy, and introducing fuel-switching as a longer term option. However, there are some options on technology pathways, e.g. as proposed by IEA (2011).

7.4 Small scale air conditioners

This section covers only ‘room’ or ‘residential’ AC not central AC or very large units. Note, there is no consistent definition of this in terms of type or capacity/power: in the EU this is 12kW or less; in the USA it is defined as ‘room’.

Comparisons of performance in different regions are complicated by different test methodologies and different definitions. Seasonal Energy Efficiency ratio (SEER) (or equivalent) has been used as a metric, as this is more reflective of use (taking account of the fact that most of the time, in most climates, units are not operating at full power), rather than EER (which only measures efficiency at full power). However different definitions of SEER complicate comparisons. Apart from a CLASP study (CLASP, 2012), no attempt has been made to ‘normalise’ the values from different regions in this section.

A further complication is that some AC is also used for heating and in some regions the cooling and heating efficiency are combined in a single metric. (The performance of heat pumps is covered in the previous heating sub-section). Finally the proportion of energy use in AC, and hence the priority in these regions, varies enormously by region depending on the climate.

Current or near future BAT have been identified in a number of sources:

- In Japan, the Top Runner (2008) standards were set for various type and sizes of AC, including domestic, expressed as APF: Annual Performance Factor, defined as (heat removed in cooling + heat added in heating/total energy consumption). Targets for

domestic AC were set for 2010 for non-duct and wall-hung categories and 2012 for the rest. The highest target was an APF of 5.5 (for wall-hung or non-duct AC with cooling capacity of between 4-5kW);

- In the USA, the Max Tech (equivalent to BAT) value in the Energy Conservation Standards Final Rule (US ECS, 2011) is expressed in terms of CEER (Combined Energy Efficiency Ratio), with units Btu/Wh, calculated as the capacity times active mode hours (equal to 750) divided by the sum of active mode annual energy use and inactive mode. There are 16 categories of AC in the rule (with sub-categories) and the CEER quotes vary from 9.80 to 11.96;
- In the EU (EC, 2011a), the energy labelling directive sets the threshold for the A category (the maximum initially) at a SEER of 5.1 (N.B. not for single or multi-ducted AC). The threshold for the highest category A+++ which is to be effective in 2019, is a SEER of at least 8.50. SEER is defined to take into account European seasonal conditions (defined in an annex);
- Michel *et al* (2011) tested a high efficiency Chinese model split wall-mounted AC using different measurement standards (Chinese, present and future European and US). They found that using the Chinese measurement standard its performance was a SEER of 6.21; using the current EU standard it was (N.B. EER not SEER) 4.9; using the draft new EU standard it was 8.56; using the US standard it was 7.86. This suggested that the current Chinese BAT is lower than that in the EU as there are equivalent products with EER (using old EU standards) of 5.63. This also suggested that using the proposed new standard several models are already available in the EU which would reach the A+++ label category threshold immediately;
- IEA 4E M&B (2011) looked at EER data, as SEER was only available from two countries. It is therefore only of limited use in comparing the other values found above. Also the data are up to 2009 so it is rather out of date when looking at BAT.

The best long-term performance was examined in the EU Ecodesign study (Armines, 2008). This was reviewed recently (Defra, 2011b). This report took a current (2011) BAT SEER (presumably in European conditions) of 6.0 and projected an increase (using 'conventional' refrigerant) of 8.5 in 2020 (EE increase of 29%) and 10 in 2030 (EE increase of 40%). It noted that this was still some way short of theoretical max due to Carnot cycle of a SEER of 14.

Energy efficiency is not the only significant environmental issue for AC; the other is the choice of refrigerant. The switch of refrigerant from ozone-depleting CFCs to those which are ozone 'friendly' (generally R410a) is largely complete in developed countries (see IEA 4E M&B, 2011) and has clear environmental advantages. However, ozone-friendly refrigerants used so far have a high global warming potential (GWP, e.g. for R410a of 1300). There is a case to be made for offsetting lower energy efficiency for the use of a refrigerant with low GWP (below 150), such as Hydrofluoro-Olefines (HFO), propane or CO₂ and thus results overall in lower global warming emissions (in regions where electricity generation is not carbon free). This approach was adopted for the EU MEPS (a 10% reduction of the required efficiency levels for low GWP refrigerants, EU MEPS EC (2011b)).

Conclusion

There is scope for the improvement in energy efficiency of small AC, although the use of different measurement methodologies and range of metrics in different regions makes the scope less clear. If an international approach to TFS was used this would have to be addressed. AC also has a significant environmental impact via the refrigerant used and there is scope for environmental gains from switching to refrigerants with lower global warming potential provided that energy efficiency and safety are not compromised. It has not been possible to investigate this trade-off in detail in this review.

7.5 Refrigerators

A general point (from IEA 4E M&B, 2010) is that efficiency increases with volume, as larger units typically have a lower volume-to-surface area ratio which inherently makes the units more efficient per litre per kWh energy input, but energy use overall increases with volume. This needs to be taken into account when setting standards (and is done in the EU, USA, and Australia).

Comparisons of the performance of refrigerators in different regions are complicated by different test methodologies; some of which reflect the different climatic conditions. Countries take into account many energy-using features in setting standards: for example in the EU, as well as climate class, allowances are made for frost-free (although this only applies to fridges with freezer sections) and whether units are built-in. In the USA these allowances for different features results in 18 categories of fridges and freezers in the MEPS, some of which have up to four sub-categories. All of this makes it difficult to compare performance across different regions. No attempt is made in this section to normalise the data from different regions (though the 4E Mapping and Benchmarking Annex has attempted such a comparison, and is currently doing a second iteration).

Current or near future BAT have been identified in a number of sources:

- In Japan, Top Runner (2006) standards were set for 2010 expressed as annual energy consumption in kWh, calculated using formula using a fixed amount and a ratio of the adjusted volume. The target was set to give a 21% increase in efficiency for refrigerators and fridge-freezers and 12.7% for freezers over this period;
- In the USA, the Max Tech (equivalent to BAT) in the Energy Conservation Standards Final Rule (US ECS, 2011a) is expressed as % energy use reduction relative to the performance standards set in the rule (which is expressed as maximum annual energy use in kWh with a fixed amount and a ratio of the adjusted volume). For refrigerators the range of energy reduction was 33-36%;
- In the EU, EC (2010), the energy labelling directive sets the threshold for the A+++ category (the maximum, effective in 2011) at an Energy Efficiency Index of 22%;
- In the EU, the Topten site¹² has listings for refrigerators. At 5/12/11 this gave the best freestanding refrigerator with freezer as having an EEI of 22% (single model), with the best fridge-freezers also around this level. The China Topten website divides appliances by volume. In the smallest category¹³ the best product had an EEI of 20.5%. The US Topten site rates only large refrigerators¹⁴, the best rated there as of 20/12/11 had an annual energy use of 364kWh;
- The European best performance is disappointing given that the winner of a competition (part of the Energy+ project¹⁵, 2E+ 2005) for the most efficient fridge-freezer in 2004 had an EEI of 19.8%, while also achieving good scores on other requirements (environmental impact of refrigerant and foaming agent; noise; clear (external) temperature displays, reasonable price, and user friendliness).

Several studies have looked at the prospects for future improvement:

- Studies at the start of the 1990s suggested a technical target level at EEI of 12% (Herring and Waide, 1993). In their analysis, this level required the use of vacuum panels. The Energy+ (fridge-freezer) winner only had one vacuum panel on the front of the freezer, whilst the 0.3 winners had no vacuum panels and used fairly conventional insulation. This suggests that improvements in other areas of

¹² http://www.topten.eu/english/household/refrigerator_freestanding/freestanding.html

¹³ <http://www.top10.cn/?page=total-volume-180l>

¹⁴ <http://www.toptenusa.org/Top-Ten-Refrigerators/Top-Ten-Large-Refrigerators>

¹⁵ This project is reviewed for lessons learnt – see box

performance were greater than previously thought and thus that the efficiency from currently identified technologies could give an EEI of lower than 12%;

- Top Runner (2006) identified a number of options for increasing energy efficiency which included switching from HFC-134a to R600a, a natural refrigerant (isobutane) with lower GWP(3 vs. 1300) although it has other disadvantages (it is combustible). No attempt was made to quantify the possible resulting efficiency gains from these changes;
- The EU Ecodesign preparatory study (ISIS, 2007) identified a number of possible technologies for BNAT but costs and energy savings were not quantified. The possibility of a switch to refrigerants with lower GWP was discussed but not in detail and emission effects were not quantified;
- Defra (2011b) used the ISIS study as a main source but also identified another technology – magnetic cooling, having considerable potential, with the added advantage of not requiring a refrigerant. For a refrigerator they identified the best current performance (2011) as an EEI of 23%, with improvement in 2020 being an EEI 15 (EE increase of 35%), and in 2030 an EEI 10% (EE increase of 57%).

The IEA 4E M&B study (IEA 4E M&B, 2010) found that increasing energy efficiency had reduced energy use per appliance, or offset it (i.e. no increase) despite the increase in average volume of products and the increase of energy intensive features (e.g. ice makers and frost-free). However there is a continuing tension between these aspects – energy efficiency as a metric, particularly where it is adjusted for additional features, may not be sufficient to continue to reducing energy use. One of the policy recommendations of the report is to consider consumption caps.

Also, as has already been mentioned, there is significant environmental impact associated with the choice of refrigerant. The impact depends on the degree of leakage in use and the degree of recovery of refrigerant on disposal. But, as for AC, the choice of refrigerant is an important aspect of the environmental impact.

CASE STUDY: Energy+ - driving innovation using procurement and competition

In the course of investigating BAT and BNAT for refrigerators, the Energy+ projects: 2E+ (2005) and Lablanca (2006), provide interesting examples. These projects were different in approach to Technology-Forcing Standards reviewed earlier, in that they used procurement as the main tool rather than a regulation or a trading mechanism. However the aim was the same: to facilitate the spreading of an energy-efficient technology in a market (in this case fridge/freezers on the European market) i.e. to increase diffusion of efficient technology. The projects set a performance standard to qualify for involvement in the scheme (EEI \leq 42% and a max annual energy consumption of 280kWh/year). The project was successful (by the end of process 21 manufacturers were involved and 866 models under 49 brands qualified, up from two in March 1999). This was in addition to the production of very efficient models as a result of the competitions, as described in the main text). Some of the lessons learnt are likely to be relevant to other examples so they are included in this report. They are:

- The project enabled R&D departments to convince marketing departments of manufacturers to release existing models.
- Industry had a prominent role in convincing retailers to accept new products.
- Local rebate schemes (Germany, Belgium, Netherlands, Switzerland) helped drive demand.

A more detailed list of 20 success and failure factors and 17 lessons learnt (some of which are particular to procurement projects rather than TFS in general) is in the 2E+ report.

Conclusion

There is scope for the improvement in energy efficiency of residential refrigerators although the use of different measurement methodologies and range of metrics between regions makes the scope less clear. If an international approach to TFS was used this would have to be addressed. The technology route to the highest efficiency is not clear. While vacuum panels have been identified as a way to major energy gains these have not been commercially adopted – MTP (2006) identifies some reasons why this may be the case. One source has identified the prospect of a genuinely innovative technology to increase efficiency: magnetic cooling. This appears to have been identified as a prospect in late 1990s (West Virginia University), and there was a flurry of news interest in 2009 (e.g. in *Science Daily*, 2009) in response to new UK research but this does not appear to be approaching commercialization yet.)

The increasing volume and number of energy-using features of refrigerators may mean an energy cap should be considered.

As for AC, refrigerators also have a significant environmental impact via the refrigerant used and this needs to be taken into account in setting standards.

TFS could have been applied to each of these end-use technologies when developing the suite of government interventions that might have been contemplated in those markets. For the future, TFS could be accepted as a legitimate option that should be examined in any context, although there is a range of factors that mitigate against this approach.

8 Technical and public policy risk

In this section, it is important to attempt to identify both the technical and public policy risks that may accompany this approach and suggest policy and programme approaches to mitigate these risks.

In trying to determine TFS standards for some specific end-uses, some risks have been identified. The major risks envisaged include:

1. Technical and policy– stringent targets are not ultimately achievable at acceptable cost (in which case the credibility of the TFS programme would be damaged, along with damage to the industry that tried to reach the levels, and damage to the credibility of politicians who introduced them, etc.).
2. Technical – asymmetry of information (industry tends to know more than regulators) means it is difficult to set stretching targets.
3. Technical – access to capital for innovation and R&D means targets are not achieved.
4. Policy – no mandate to require TFS; needing new legislation, which is time consuming and requires strong political support.
5. Policy - leakage issues – with associated risk of reduced competition due to spending on new processes/R&D.

Taking these in turn:

1. Targets are too stringent and not achievable at an acceptable cost

- One of the main risks is that delivering products to a high efficiency level may mean significantly higher purchase costs which are passed on to consumers. However there is increasing evidence that increased costs from engineering analysis are never as high after the MEPS are introduced than was originally thought (*a priori*). Indeed a recent study for Defra (2011a) showed that learning-by-doing can reduce costs (and in the Montreal protocol *ex-post* costs were lower than estimated *ex ante*). The US has already started to include these in their impact assessments, whilst the UK has done similar in its recent impact assessments of Ecodesign measures. However, in the US case these considerations were not included in the LCC analysis which set the MEPS levels. Similarly, the UK/EU did not include these in the target-setting process (only in determining greater national benefits);
- Generally speaking setting too-stringent targets or those which have too high costs has not been the case for the TFS (and related) examples reviewed. Even where the targets were thought to have been very stringent (e.g. the Montreal Protocol and tailpipe emission reduction) they have been met and at 'reasonable' cost (although not always in the manner expected e.g. for SO_x many of the savings were attributable to using low sulphur coal (process innovation) rather than increased installation of scrubbers (technology diffusion), or over the original timescale). An exception has been the California zero emissions car.

Mitigating actions:

- Get accurate information on the potential from innovation and the costs of achieving it– covered in the next risk (information asymmetry);
- Regular reviews of progress – used in Montreal, CCAs and Top Runner. This is not in itself a panacea – industry may deliberately 'drag their feet' knowing that a review is due and if they make poor progress then the targets may be softened. There is also an inherent tension between the certainty which is needed to justify investment by companies in innovation and the need to review to check that targets are reasonable;

- Innovation waivers – as discussed in the literature review, Section 2. Though in principle these are attractive, the reported experience to date is poor;
- Collaboration amongst industry increases the speed of change and reduces costs. This proved very effective in meeting the Montreal protocol targets;
- Provide incentives for companies to share their IPR for effective diffusion of new technology – reducing costs (and the need to ‘reinvent the wheel’);
- Support the TFS with other policies – procurement, subsidies, R&D grants or tax breaks, competitions etc;
- Where the targets are international and cover both developed and developing countries, allow developing countries more time to respond and providing financial support to help them meet them (as per the Montreal Protocol, and the Kyoto Protocol under the UNFCCC).

2. Information asymmetry makes it difficult to set stretching targets

- Several of the examples described in section 4 illustrate this, including CCAs and the EU MEPS process.

Mitigating actions:

- Develop expertise directly or through (independent) contractors;
- Obtain information from component suppliers who are looking to expand their market for an innovative technology;
- Use competition (within region or foreign vs. domestic) to encourage firms to provide information. As a corollary to this, conduct negotiations over standards as much as possible with individual manufacturers as participating stakeholders, rather than with branch organisations (trade associations etc.); branch representatives, in these cases, would tend to defend the interests of the least-good performer;
- Use a common metric (internationally). This makes benchmarking straightforward making it harder for industry to ‘muddy the water’ and easier for good practice to stand out.

3. Technical – access to capital for innovation and R&D

- This may be a particular issue for small companies and may reduce competition. Alternatively in some areas the innovation may be driven by small companies and/or the need for innovation may open up the market and increase innovation.¹⁶

Mitigating actions:

- Encourage and support collaborative research (as per 1st risk);
- Offer grants or tax breaks in support of R&D;
- Give confidence that the policy will be adhered to. Companies are unlikely to be able to access investment if there is doubt that the targets will be held to and therefore that they are necessary/beneficial (but see comments on 1st risk regarding the need for review).

4. Currently no mandate, new legislation required

- Creating new legislation is time-consuming (in the EU, for example it takes at least five years for a new directive to be implemented, and in the case of the first refrigerator MEP significantly longer). The more international in scope the agreement is, the longer the time is likely to be required to reach agreement. It also requires strong political support to carry through. Even when the measure is in place the

¹⁶ For a discussion of the effect of product regulation on competition see Office of Fair Trading (2008).

policy may be open to legal challenge by industry (the case for several US examples quoted above).

Mitigating actions:

- Provide evidence to policy makers that such an approach would be viable;
- Reinforce some existing approaches which come close to technology-forcing (such as MEPS and Top Runner), rather than developing new policy alternatives. Developing alternative TFS may provide marginal gains with an increased risk of non-delivery or delay;
- Harmonise the regulations in different countries rather than trying to reach an international agreement *per se*.

5. Leakage /reduced competitiveness to non-regulated regions

- If a stringent requirement is set in one country or region and not in another and requires considerable investment by manufacturers and/or results in a higher cost to consumers (who may themselves be manufacturers) then the manufacturing capability may move outside this region/country (i.e. leak), or the region/country may become less competitive. For energy-using products, where it is the performance in-use phase which is mostly regulated, it is the latter risk which is significant. However, sometimes more efficient technologies turn out to be more cost effective in terms of manufacturing and, more often, in terms of lifecycle; so this is not always a given negative. Also other regions/countries have the same environmental constraints and may adopt similar regulations in future, so this may give 'first mover' advantage¹⁷ to those who adopt early.

Mitigating actions:

- Make the coverage of the regulation as wide as possible – at least to cover those areas which are in direct competition (although clashes with 4, i.e. increased time delay);
- Reduce costs of innovation by supporting R&D investment and encouraging collaborative research.

¹⁷ Although the value of 'first mover advantage' is hotly debated, for example this is raised for example in the discussion on whether the EU should adopt more stringent climate mitigation measures than agreed to in international treaties.

9 Recommendations

Based on the research undertaken for this report and discussion at the May 2012 Stockholm 4E meeting, the following three main recommendations are made:

1. In the context of the development of future energy performance standards, the concept of TFS is worthy of further work by governments to determine whether it constitutes a legitimate and useful public policy goal to drive international end-use energy efficiency cooperation. In this respect, 4E might entertain commissioning further work to better define and describe the concept as applied to end-use electrical energy efficiency equipment issues.
2. TFS should be considered within the context of existing energy performance standards in agreed international case studies by benchmarking it against past regulatory interventions for those products. For example, 4E could request its various product Annexes to create TFS targets for lighting, motors and network standby. 4E could work with other multilateral groups to encourage other suitable technology types to consider using TFS to establish stretch goals for the future.
3. The role of TFS, as a policy goal, should be debated by senior government officials to determine interest and possible support. To facilitate this, 4E and/or other multilateral groups could coordinate workshops to explore possible links between innovation and subsequent regulation, at gatherings under the auspices of the International Energy Agency, the Clean Energy Ministerial and the International Partnership on Energy Efficiency Cooperation.

10 References

- 2E+ (2005), Procurement on very efficient white goods. Available at http://www.wupperinst.org/uploads/tx_wiprojekt/2Eplus_report.pdf
- Andersen SO (1997), Industry in the lead, Our Planet 9.2, Oct 1997, Ozone. Available at <http://www.ourplanet.com/imgversn/92/anderson.html>
- ARMINES, France (2008), Preparatory study on the environmental performance of residential room conditioning appliances (aircon and ventilation, ECODESIGN Lot 10). Draft report of Task 6. Available at http://www.eceee.org/Eco_design/products/airco_ventilation
- Burtraw D and Szambelan SJ (2009), U.S. Emissions Trading Markets for SO₂ and NO_x, Resources or the Future Discussion Paper. Available at <http://www.rff.org/documents/RFF-DP-09-40.pdf>
- Bush, E, Attali, S, Brunner, C, Dean, N, Arquit Niederberger, A, and Bo, H (2011), Topten: Global Project for the Most Energy Efficient Products. EADAL 2011, Copenhagen, Denmark. Available and accessed November 2011 at http://www.topten.info/uploads/File/037_Eric_Bush_final_Topten.pdf
- Collantes, G, and Sperling, D (2008), The origin of California's zero emission vehicle mandate. Transportation Research Part A 42, 1302–1313
- CoolProducts (2010), Energy savings in practice: potential and delivery of EU Ecodesign measures. December 2010. Coolproducts for a cool planet campaign, December 2010. Available at <http://www.coolproducts.eu/resources/documents/EnergySaving-in-Practice.pdf>
- CSES (2012) Evaluation of the Ecodesign Directive (2009/125/EC). Final report. 16 April 2012. Available at http://cses.co.uk/ecodesign_evaluation
- CLASP (2012), Cooling Benchmarking Study Compares Air Conditioner Efficiency in Major World Economies, 6 April 2012. Available at <http://www.clasponline.org/en/ResourcesTools/Resources/StandardsLabelingResourceLibrary/2012/Cooling-Benchmarking-Study>
- DeCanio, SJ (2009), Lessons from the Montreal Protocol for Climate Policy, Economics for Equity and Environment. Available at http://www.e3network.org/briefs/DeCanio_Lessons_from_Montreal.pdf
- Desroches, L-B and Garbesi, K (2011), Max Tech and Beyond: Maximizing Appliance and Equipment Efficiency by Design. Environmental Energy Technologies Division, LBNL, report LBNL-4998E. June 2011. Available at <http://efficiency.lbl.gov/drupal.files/ees/MTAB%20Final%20LBNL%20Report.pdf>
- Defra (2009), Saving Energy Through Better Products and Appliances. Available at <http://www.defra.gov.uk/publications/2011/06/16/pb13559-energy-products/>
- Defra (2011a), Impacts of Innovation on the Regulatory Costs of Energy-using Product Policy (SPMT09_045). Produced by Policy Studies Institute & BIO Intelligence Service, Available at http://randd.defra.gov.uk/Document.aspx?Document=EV0703_10122_FRP.pdf
- Defra (2011b), Long term energy performance for energy-using domestic and commercial appliances and products. Produced by AECOM for Defra, London, UK. Available and accessed 4 December 2011 at

<http://efficient-products.defra.gov.uk/cms/product-strategies/subsector/studies-to-inform-future-evidence#viewlist>

Defra (2011c), The practitioner's guide to product policy applied to systems. Produced by BRE for Defra, London, UK. Available and accessed 4 December 2011 at

<http://efficient-products.defra.gov.uk/cms/product-strategies/subsector/studies-to-inform-future-evidence#viewlist>

EC (2011a), Commission Delegated Regulation No 626/2011 of 4 May 2011, supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners. Available at <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:178:0001:0072:EN:PDF>

EC (2011b), Commission Regulation (EU) No¹⁸ .../..of ...implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans. Available at

http://www.eceee.org/Eco_design/products/airco_ventilation/draft_regulation_ecodesign_15_04_2011

ECEEE (Silver and Conway, 2010), Technology prospects for directional lamps, European ecodesign and labelling requirements for directional lamps. Available at

http://www.eceee.org/Eco_design/products/directional_lighting/technology_prospect_report

EEA (2012), Environmental tax reform in Europe: opportunities for eco-innovation. EEA Technical report, No 17/2011. Available at <http://www.eea.europa.eu/publications/environmental-tax-reform-opportunities>

FCP (2011), UK Forward Commitment Procurement. Available at

<http://www.bis.gov.uk/policies/innovation/procurement/forward-commitment>. Accessed November 2011.

Fraunhofer (2007a), EuP Preparatory Studies "televisions" (Lot 5). Final report on Task 7: Improvement potential. Version 2 August 2007, Fraunhofer IZM, Berlin, Germany

Available at http://www.ecotelevision.org/finalised_documents.php

Fraunhofer (2007b), EuP Preparatory Studies "televisions" (Lot 5). Final report on Task 8:

Scenario, policy, impact and sensitivity analysis. Version 6 August 2007, Fraunhofer IZM, Berlin, Germany. Available at: http://www.ecotelevision.org/finalised_documents.php

Gerard, D and Lave, L (2007), 'Experiments in technology forcing: comparing the regulatory processes of US automobile safety and emissions regulations', *Int. J. Technology, Policy and Management*, Vol. 7, No. 1, pp.1–14.

Hahn, R (1989), A primer on environmental policy design. New York: Harwood Academic Publishers.

Heaton A, Hodgson S, Overton T, and Powell R (2006), The challenge to develop CFC (chlorofluorocarbon) replacements: a problem based learning case study in green chemistry, *Chemistry Education Research and Practice*, 2006, 7 (4), 280-287

Available at http://www.rsc.org/images/Heaton%20paper_tcm18-66595.pdf

Herring, H and Waide, P (1993), Refrigerators, energy and climate: mandatory energy efficiency standards for domestic refrigeration units in the European Union: analysis of the draft EU directive and alternative proposals for a standard: main report; Greenpeace International

¹⁸ This is the title of the draft rule. The final rule with regulation numbers does not appear to be publicly available yet.

IEA (2011), Technology roadmap: Energy-efficient Buildings: Heating and Cooling Equipment. OECD/IEA, Paris, France. Available at http://www.iea.org/papers/2011/buildings_roadmap.pdf

IEA 4E M&B Annex (2010), Benchmarking document Domestic Cold Appliances: Freezers and Refrigerator/ Freezers Combinations. Available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=1>

IEA 4E M&B Annex (2011), Benchmarking Document Residential Air Conditioners. Available at <http://mappingandbenchmarking.iea-4e.org>

IEA 4E SSL Annex (2011), Draft performance tiers. Available at <http://ssl.iea-4e.org/>

IEA (2011), Technology roadmap: Energy-efficient Buildings: Heating and Cooling Equipment. OECD/IEA, Paris, France. Available at http://www.iea.org/papers/2011/buildings_roadmap.pdf

ISIS (2007), Lot 13: Domestic refrigerators & freezers. Preparatory studies for eco-design requirements of EuPs (Tender TREN/D1/40-2005). Final report, draft version. December 2007.

Jaffe, AB, Newell, RG, and Stavins, RN (1999), Energy-Efficient Technologies and Climate Change Policies: Issues and Evidence. Climate Issue Brief No. 19, Resources for the Future.

Kemna, R, van Elberg, M, Li, W, and van Holsteijn, R (2007), Preparatory study on Eco-design of Water Heaters: Task 7 report (Final): Policies, scenarios, impact & sensitivity analysis. VHK, Delft, 30 September 2007.

Kemp, R (2004), Technology and environmental policy: innovation effects of past policies and suggestions for improvement. MERIT, Maastricht University.

Kimura, O (2010), Japanese Top Runner Approach for energy efficiency standards. SERC discussion paper: SERC09035. Available at <http://www.climatepolicy.jp/thesis/pdf/09035dp.pdf>

Lablanca, N (2006), Evaluation of the Energy+ process. Within the framework fo the AID-EE project. Energy Intelligence for Europe programme, Contract number EIE-2003-114. eERG, Politecnico di Milano, Italy. Available at, and accessed November 2011: <http://www.aid-ee.org/documents/006EnergyplusEurope.PDF>

Laitner, John A. "Skip" (2004), How Far Energy Efficiency? Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings.

Lane, K, and Harrington, L (2010), Evaluation of energy efficiency policy measures for household refrigeration in Australia: an assessment of energy savings since 1986. E3 report no 2010/10. December 2010. Available at <http://www.energyrating.gov.au/resources/program-publications/?viewPublicationID=2150>

Mäder, J.A, Staehelin, J, Peter, T, *et al.* (2010), Evidence for the effectiveness of the Montreal Protocol to protect the ozone layer, *Atmospheric Chemistry and Physics*. 10:12161-12171. Available at http://www.atmos-chem-phys.net/title_and_author_search.html?title=Evidence+for+the+effectiveness+of+the+Montreal+Protocol+to+protect+the+ozone+layer

Michel, A, Bush, E, Nipkow, J, Brunner, C, and Bo, H (2011), Energy efficient room air conditioners – best available technology (BAT). EEDAL 2011, Copenhagen, Denmark. Available

and accessed November 2011:

http://www.topten.info/uploads/File/023_Anette_Michel_final_paper_S.pdf

Milford, L, Dutcher, D, and Barker, T (2008), Climate Technology Innovation - A New Global Strategy and Structure, Clean Energy group. Available at

<http://www.cleanegroup.org/assets/Uploads/2011-Files/Reports/CEG-MeridianNewGlobalStrategyStructureMay08.pdf>

Michel A, Bush E, Nipkow J, Brunner CU, and Bo H (2011), Energy efficient room air conditioners – best available technology (BAT), EEDAL May 2011. Available at

http://www.topten.info/uploads/File/023_Anette_Michel_final_paper_S.pdf

Miller, AS (1990), The development of substitute for Chlorofluorocarbons: Public-private co-operation and environmental policy, *Ambio* vol 19: no 6-7, available at

<http://www.jstor.org/pss/4313730> (first page only)

MTP (2006), IBNC16: Innovation Briefing Note: Vacuum insulated panels for refrigerated appliances. Available at

<http://efficientproducts.defra.gov.uk/spm/download/document/id/667>

Navigant (2010), Energy Savings Potential of Solid-State Lighting in General Illumination Applications 2010 to 2030. Available at

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_energy-savings-report_10-30.pdf

Nentjes, A, de Vries, FP, and Wiersma, D (2007), Technology-forcing through environmental regulation, *European Journal of Political Economy* 23 (2007) 903–916.

Nordqvist, J (2006), Evaluation of Japan's Top Runner Programme. Within the framework of the AID-EE Project. 3rd July 2006. Energy Intelligence for Europe programme, Contract number EIE-2003-114. Accessed 27 November and available at

<http://www.aid-ee.org/documents/018TopRunner-Japan.PDF>

Nordqvist, J, (2007), The Top Runner policy concept: Pass it down?, ECEEE

Available at

<http://lup.lub.lu.se/luur/download?func=downloadFile&recordId=620199&fileId=620584>

OECD (2010), Taxation, innovation and the environment, Organisation for Economic Co-operation and Development.

Office of Fair Trading (2008), The competition impact of environmental product standards. A report prepared by Frontier Economics for the Office of Fair Trading

Available at http://www.oft.gov.uk/shared_of/economic_research/oft1030.pdf

Parson, EA (2002), The Technology Assessment Approach to Climate Change, Issues in Science & Technology, Summer 2002. Available at

http://cses.washington.edu/cig/outreach/seminarfiles/.../Parson_IssuesST.doc

Porter, ME and van der Linde, C (1995), Toward a New Conception of the Environment-Competitiveness Relationship, *The Journal of Economic Perspectives*, Vol 9 no 4, pp97-118.

Available at <http://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.9.4.97>

Science Daily (2009), Environmentally-Friendly Cooling With Magnetic Refrigerators Coming Soon. Available from <http://www.sciencedaily.com/releases/2009/05/090515083822.htm>

Siderius, HP (2011), Zero energy appliance policies. EEDAL 2011, Copenhagen, Denmark.

Siderius, HP and Nakagami, H (2007), Top Runner in Europe? Inspiration from Japan for EU ecodesign implementing measures, ECEEE.

Available at: http://www.eceee.org/conference_proceedings/eceee/2007/Panel_6/6.024

Sorrel, S (2002), The Meaning of BATNEEC: Interpreting Excessive Costs in UK Industrial Pollution Regulation. *Journal of Environmental Policy & Planning*, 4, 2002, 23-40.

SQW Ltd (2007), Exploring the relationship between environmental regulation and competitiveness (phase 2), Annex : SO2 and NOx case study, for Defra. Available at <http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=14608&FromSearch=Y&Publisher=1&SearchText=SO2&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description>

Sunstein, CR (2007), Of Montreal And Kyoto: a Tale of two Protocols, Harvard Environmental Law Review, Vol 31. Available at

<http://www.climatechangeinsights.com/uploads/file/Of%20Montreal%20and%20Kyoto%281%29.pdf>

Taylor, M, Rubin, E, and Hounshell, D (2005a), Regulation as the Mother of Innovation: The Case of SO2 Control. *Law & Policy*, Vol. 27, No. 2, pp. 348-378, April 2005. Available at:

http://socrates.berkeley.edu/~scotch/science_policy/Taylor.pdf

Taylor, M, Rubin, E, and Hounshell, D (2005b), Technological Forecasting & Social Change 72 (2005) 697-718. Available at

<http://www.cmu.edu/epp/iecm/rubin/PDF%20files/2005/2005d%20Taylor%20et%20al,%20Tech%20Forecasting%20and%20Soc%20Chg%20%28Jul%29.pdf>

Top Runner (2006), Final Report by Electric refrigerator Evaluation Standard Subcommittee, Energy Efficiency Standards Subcommittee of the Advisory Committee for Natural Resources and Energy. Available at http://www.eccj.or.jp/top_runner/pdf/tr_re-freez_Jul.2006.pdf

Top Runner (2008), Final Report by Air Conditioner Evaluation Standard Subcommittee, Energy Efficiency Standards Subcommittee of the Advisory Committee for Natural Resources and Energy. Available at http://www.eccj.or.jp/top_runner/pdf/tr_air_conditioners_apr.2008.pdf

UNEP (2010), Scientific Assessment of Ozone Depletion: 2010, available at

http://ozone.unep.org/Assessment_Panels/SAP/ExecutiveSummary_SAP_2010.pdf

US DOE (2011), Solid State lighting R&D multi-year programme plan. Available at

<http://www1.eere.energy.gov/buildings/ssl/techroadmaps.html>

US ECS (2011), Room Air Conditioners Direct Final Rule. Available at

http://www1.eere.energy.gov/buildings/appliance_standards/residential/room_ac.html

US ECS (2011a), Residential Refrigerators, Refrigerator-Freezers, and Freezers Final Rule.

Available at

http://www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers.html

VHK (2005), EUP methodology. Available at:

http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/methodology/files/finalreport1_en.pdf

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VITO *et al* (2007), Lot 8: Office lighting – Final report. 2007/ETE/R/115. April 2007.

VITO, BIO, Energy Piano and Kreios (2008), Lot 19: Domestic lighting – Part 1 – Non-directional light sources. Task 8: Scenario – policy – impact and sensitivity analysis. October 2008.

West Virginia University, undated, Magnetic Refrigeration. Available at http://www.che.cemr.wvu.edu/publications/projects/prod_design/magnetic_refrigerator.pdf
